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Plastics and Metals: Competitors and Allies

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Materials for marine structures

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Introduction

The past two decades have seen the introduction and rapid growth of reinforced composites in several marine applications, of which the most spectacular has been the replacement of timber by glass reinforced plastic - GRP - for the hull construction of boats up to approximately 16 metres in length. More recently the trend has continued to include vessels up to 30 metres long, an area in which steel is fairly well established. Historically, steel is a comparative newcomer to shipbuilding which previously depended on, and was well served by timber. It is perhaps saddening to realise that the wholesale replacement of timber by metals in the 19th Century should be continued with renewed severity by plastics in the 20th Century.

In the Royal Navy both timber and metals have been replaced by plastics due, primarily, to their improved resistance to the many forms of degradation suffered by tradional materials when exposed to seawater. The properties of GRP are particularly attractive in that it does not rot or corrode, is not attacked by marine organisms, it can be readily formed into complex shapes, has high specific strength and is non-magnetic. Also, the raw materials are readily available and the craft skills required for fabrication are considerably less than for comparitive work in timber and metals.

Present applications include:

a. Ships boats and harbour service craft up to 20 metres in length.
b. Superstructures of submarines.
c. Sonar domes.
d. Flotation buoys.
e. Submarine battery cases.
f. Ballast system piping.
g. Protection of underwater fittings.

While development continues in many diverse materials and potential applications, the most important project currently in hand is the construction of a minesweeper hull in GRP to replace an existing hull of aluminium framing supporting a timber skin. The low magnetic requirements of the vessel preclude the use of metals for any sizeable part of the construction and this paper briefly describes some of the investigations which led to the start of construction in the latter part of 1970.

The minesweeper project has been referred to in papers by Henton (1), Cheetham (2) and Beale (3). The hull composes a monolithic structure approximately 45 metres long by 8,5 metres beam by 6 metres deep with a GRP weight of approximately 120 tonnes. Construction is carried out in a steel female mould (figure 1) into which the single skin and top hat frames are formed, while bulkheads and decks are prepared on adjacent moulds (figure 2) for installation at the appropriate times. The hull will occupy the mould for a period of 6 to 8 months and the completed vessel will be the largest GRP construction in the UK to date.

The selection of materials for the ship project has been largely dictated by service requirements, available production methods and the known limitations of composite materials. To a greater extent than with traditional materials, design, production and materials are intimately associated and factors such as the size of the laminate, the period required for laminating, building facilities, construction techniques etc necessarily influence the material selection.

Initial investigations indicated that:

a. Construction would be essentially manual lay up and therefore labour intensive.
b. Reliable post curing would not be practicable with the large moulds involved.
c. Knowledge was insufficiently advanced to permit economic sectionalised construction.

d. The size of the mould precluded orientation to obtain favourable down hand laminating conditions.
e. Control of the fibre volume fraction could be achieved only by mechanical resin dispensing in a high proportion of the laminate.

Apart from specialised moulding, spraying and winding processes, which are outside the scope of this paper, laminating involves the consolidation, ply by ply, of glass reinforcement impregnated with resin. The resulting laminate properties depend largely on fibre continuity, orientation and volume fraction. Production cost is mainly influenced by the type of glass reinforcement (figure 3) and by the labour required for consolidation, i.e. the number of plies.

Materials

For the ship project a coarse woven roving was selected as the most suitable reinforcement consistent with high strength, reasonable production costs and ready availability. Experiments were carried out to determine the most suitable weave pattern and fibre finish to provide satisfactory wet-out, long term wet strength and high heat distortion temperatures when combined with the selected resin matrix.

Selection of suitable resin offered a wide choice from existing epoxides and unsaturated polyesters. The requirement for room temperature laminating and resin cure indicated that little or no advantage would be obtained from the higher cost epoxides. Short term immersion tests with orthophtalic polyesters indicated highly desirable properties, but these were not sustained in longer term tests (figure 4). An isophtalic polyester was finally selected as most suitable for the following reasons:

a. Heat distortion temperatures 60° C +.
b. Strength loss due to long term immersion approximately 20%.
c. Complete cure is achieved despite the prolonged gel times essential in a large construction.
d. Ability to increase heat distortion temperature by local post cure of highly stressed structures exposed to high temperatures in service, e.g. weather deck, machinery spaces etc. (figure 5).
e. Low reactivity to allow primary bonding despite lengthy delays during construction.

The properties of the structural laminates are shown in Table I.

TABLE I

	Minimum Breaking Stress		Modulus (Stress/Strain)	
	psi [a]	MN/M^2 [b]	psi	MN/M^2
Tensile	33,000	228	2 x 10^6	13790
Compressive	27,000	186	2 x 10^6	13790
Bend (Flexural)	40,000	276	2 x 10^6	13790
Shear (Perpendicular)	16,000	110	0.5 x 10^6	3448
Shear (Interlaminar)	2,000	14	-	-
Specific Gravity	1.7			
Glass Percentage	50% by weight - 30% by volume			

a. psi = pounds per square inch

b. MN/M^2 = Meganewtons per square metre

Design

The low elastic modulus of GRP is a factor of extreme importance in the design of a hull which is, is effect, a girder subjected to alternating support between the centre and the extremities. The three basic problems are:

a. The low modulus will usually result in increased deflections if the design is based on stress. Such increased deflections, while possibly acceptable in the hull girder, could lead to unacceptable machinery alignment problems.

b. Careful attention must be paid to panel design to prevent buckling under combined compressive and side loading.

c. GRP does not re-distribute high stresses by local yielding and care is needed to avoid stress concentrations.

Pending sufficient service experience with GRP ship hulls, a minimum reserve factor of five is incorporated in the design calculations. Test programmes based on this factor indicate that a GRP ship has a life expectancy in excess of 20 years.
Sandwich construction consisting of a rigid, low density core with thin GRP skins is frequently advocated to minimise weight, although in a large vessel the cost and complexity may be less favourable than in small boats. Experiments using cores of flanged GRP webs, PVC foams, balsa wood, etc. indicated that GRP webs offered the best structural properties in a sandwich. A full scale hull section (figure 6) was constructed to investigate production aspects and to provide a test vehicle from which realistic design data would be obtained. The static and hydrostatic tests vindicated the design assumptions and the choice of materials forming the sandwich.

Unfortunately, the resistance to high shock forces resulting from nearby underwater explosions proved inadequate, and sandwich construction was therefore abandoned. Further tests on large panels indicated that the required shock resistance could be achieved by solid GRP laminates with metal fastenings to assist the bonded connections between stiffeners and panels. Single skin construction was therefore adopted for a second hull section (figure 7) which has proved wholly satisfactory.

PRODUCTION

a. Workshops

A well ventilated, heated, clean workshop is essential for GRP construction. Heating is required to ensure a minimum laminate temperature of approximately 15° C and ventilation is designed to limit the styrene content in the atmosphere to less than 100 ppm. The construction programme involves large areas (in excess of 200 square metres) of wet laminate exposed over long periods in each working day and it was therefore necessary to establish the rate of styrene emission, atmospheric concentration, and permissible air flow speed over the laminates to design a ventilation system providing the required working conditions, without removing the styrene in excess quantities, and thereby adversely affecting the laminate cure cycle and properties.

Heated storage is provided for the glass reinforcement to avoid moisture pick up. All preparation is carried out within the workshop. Resin mixing and distribution is controlled from a single source and cleaning fluids are retained in a specially provided enclosure divorced from the laminating areas.

Changing rooms and clean air recreation rooms are available for the operators, and access is arranged to minimise the ingress of dirt.

Space is provided for the training of personnel which, in the case of laminators, may take between one and three weeks. Each operator is required to demonstrate his proficiency by means of test laminates which are subject to close visual inspection and to physical tests.

The principal moulds are each provided with working platforms and a resin despensing machine impregnating the woven roving with a controlled mix and weight of resin ready for manual consolidation on the mould.

Stringent fire precautions are imposed at every stage and all electrical fittings are of approved flash proof designs.

b. Laminating

The structure of this first ship is formed from approximately 1 mm thick layers of 830 g/m^2 woven roving with approximately equal strength in both weft and warp directions. The woven glass, 1.2 metres wide, is laid transversely across the hull mould, the junctions between the plies being staggered to avoid weakness through the thickness of the finished laminate. Bulkheads and decks are made in large panels, stiffeners added and the panels roughly trimmed to shape.
Frames, stiffeners, machiners seats, etc. are laid up on low density polyurthane foam formers to form stable top hat sections. In regions subject to severe shock, the bond between the stiffeners and panel is supported by metal bolts inserted at intervals along the stiffener flanges.

Research and Development

The individual feasability studies indicated that knowledge would need to be extended in many areas including composite material properties, design and fabrication techniques. It was also realised that apparently trivial items could significantly affect large scale construction and that unrealistic test parameters could result in misleading design data. Much work remains to be done, but the results of the many individual evaluation programmes completed to date have provided the degree of confidence necessary to go ahead with the construction of the first ship. The following items are representative of the close association necessary between the specialists in materials, design and production.

1. Exotherm

Chemical reaction during the early stages of the resin cure cycle may result in a rapid rise in temperature and accelerated cure. The peak temperatures are a function of the volume of uncured resin available, and laminating rates require careful control to ensure that the subsequent increase in temperature is not harmful to the laminate. Apparently safe laminating rates may prove completely unacceptable in areas where the liquid resin volume is increased by local drainage from vertical surfaces (figure 8). For the ship project it is considered prudent to limit the number of "wet on wet" plies to a maximum of 12 in a 12 hour working period.

2. Delayed Lay Up

Delays during construction take one of two forms:
a. Routine while building up to the full laminate thickness.
b. Those occuring due to the phased installation of internal structure.
It has been established that satisfactory bond strengths are maintained over routine delays of seven days, and in fact, little or no degradation of bond strength is apparent up to 20 days if the surface is clean and free from contamination (figure 9). Despite the most stringent precautions, dirt and dust will inevitably accumulate on all surfaces, and for delays in excess of 7 days, a sacrificia "peel ply" is used to cover the exposed surface on completion of the initial stage of laminating. The "peel ply" is removed before the re-commencement of laminating, leaving a clean, well prepared surface requiring little or no further attention (figure 10). Should an unprogrammed delay occur, the traditional alternatives of surface abrasion or chemical priming are available, but the former introduces a great deal of dust which is difficult to remove, and the latter can be adversely affected by surface contamination. Both methods will no doubt be necessary for the preparation of small areas during fitting out, and suitable techniques and materials have been investigated to this end.

3. Joints

As previously mentioned, the ship hull is constructed as a single continuous laminate. Methods of joining have been necessarily evaluated in relation to decks (which would be unwieldy to manipulate as a single panel) and the repair of damage which may be experienced in service, for example, as a result of collision, grounding etc. Investigations show that many recommended joined forms, while satisfactory for lower strength chopped strand mat laminates, fall short of the requirements for woven roving laminates. The most satisfactory joint to match the strength of the parent laminate involves cutting back each ply to form a stepped edge and laminating to replace the deficient material. Either polyester or epoxide resin may be used to repair fully cured laminates, the choice being determined by the available conditions for laminating. Various joint forms have been evaluated to provide designers with a choice where strength matching is not an essential requirement (figure 11). The optimum joint configuration has been evaluated by large scale site application and subsequent explosion tests.

4. Structural Connections

Reference has been made to the "top hat" sections used for stiffening the hull. Both longitudinal and transverse stiffening is employed with a resulting requirement for satisfactory strength at framing intersections and connections of stiffeners to bulkheads, decks, hatch openings etc. Figure 12 illustrates a series of typical intersections subjected to static and fatigue testing at loads considerably in excess of the peak design requirements without significant damage. Similar intersections were also included in the test section which satisfactorily withstood severe shock forces.

5. Fire Hazards

GRP is formed from a combination of flammable resin with non-combustible glass reinforcement. The behaviour of the resulting laminate in a fire depends largely on the quantity of resin and type of reinforcement. Short random fibres, either in spray lay up or CSM provide little or no barrier to the flame attacking the more plentiful supply of resin. Glass woven reinforcement in the other hand, requires less resin and forms an effective fire resistant curtain over the laminate once the surface resin is burned off. While early tests indicated an undesirable reduction of properties - weathering and wet strength retention - associated with fire retardant resins, such resins can be utilised in the surface plies in high fire risk areas, or surface coatings of intumescent resin can be applied to upgrade the overall fire resistance.

The low K value (1.5) of GRP - steel about 3 and aluminium over 800 - is advantageous in reducing the risk of a fire spreading outside the individual compartment, which all too often results in a major conflagration. Comparative tests have shown that GRP is structurally superior to unprotected aluminium and reduces the hazards of the spread of fire from compartment to compartment.

Probably the most serious hazard is the emission of dense smoke at high temperatures, but this aspect applies to many materials necessarily fitted in ships irrespective of the hull material. The location of the source of fire is mostly the greatest difficulty.

6. Maintenance and Repair

The inherent resistance of GRP to sea water attack should lead to a substantial reduction in maintenance costs. The ship now under construction utilises clear resin mainly to assist quality control at this early stage and will therefore require painting for appearance and to prevent the emission of light during the hours of darkness. Also GRP is prone to marine fouling and will require periodical cleaning and treatment of the underwater portion with anti-fouling compounds. Suitable paints, methods of cleaning, surface preparation and coating have been the subject of a lengthy research programme. One problem encoutered was that the usual paint removers were far more effective on the resin than on the paints.

Minor repairs are easily and quickly made, using techniques developed for GRP boats. Reference has already been made to the complexity of major structural repairs.

Quality Control

The production of large test sections from which numerous test pieces were extracted has shown that little discrepancy exists between laboratory specimens and production, provided that the latter is subject to detailed planning and good quality control.
The quality control organisation required for construction in GRP differs appreciably from that required in metal. Instead of pre-chequed standard sections, requiring forming and assembly, the shipyard is supplied with rolls of glass reinforcement, barrels of resin and the associated curing agents. The structural material and the ship are then formed simultaneously and the whole operation is confined to one building. This arrangement can be advantageous as it is possible to establish short, precise lines of communications and thus minimise one of the more difficult problems associated with normal shipyard quality control.
The advantages of a compact building facility are somewhat offset, however, by the need to take prompt action, should an error arise in the GRP. The maximum quality control effort is essential during laminating, to ensure that any necessary remedial action is taken while the resin is in liquid form. Failure to detect a serious fault at this stage, could result in extensive repair, or rejection of a costly laminate when removed from its mould possibly months after the error was introduced.
Adequate quality control depends on trained personnel, realistic specifications, working procedures and programmes, and continuous vigilance.

Conclusion

This paper concerns the use of plastics to replace a composite of metal and timber in a project for which the wide scale use of metal could not be considered. Less stringent requirements could simplify construction and reduce costs, but present indications are that GRP is unlikely to become a serious contender for the main structure of large ship hulls where existing industry is already geared to production in metals.
The foreseeable growth in marine applications is likely to continue the existing trends of replacing metal components and providing highly erosion and corrosion resistant surfaces.
Research and development has shown most clearly that design and evaluation of plastic requires more accurate assessment of service conditions than is the case with metals, although this factor is somewhat offset by the reduced sensitivity to chemical attack.
Possibly the greatest need in relation to the future growth of reinforced plastics is the need for development of lower cost production methods, to take better advantage of the attractive properties and potential design flexibility.

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Responsibility for statements of facts made, and opinions expressed, rests solely with the author.

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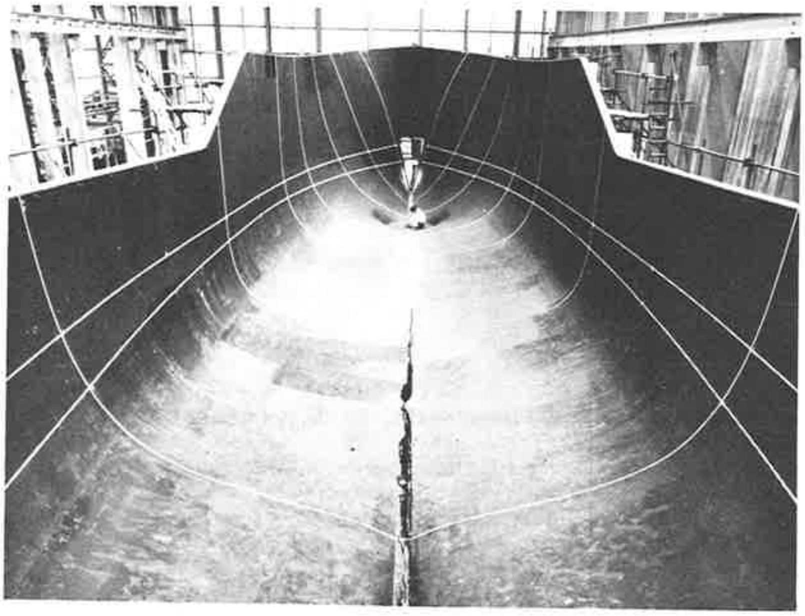


Figure 1

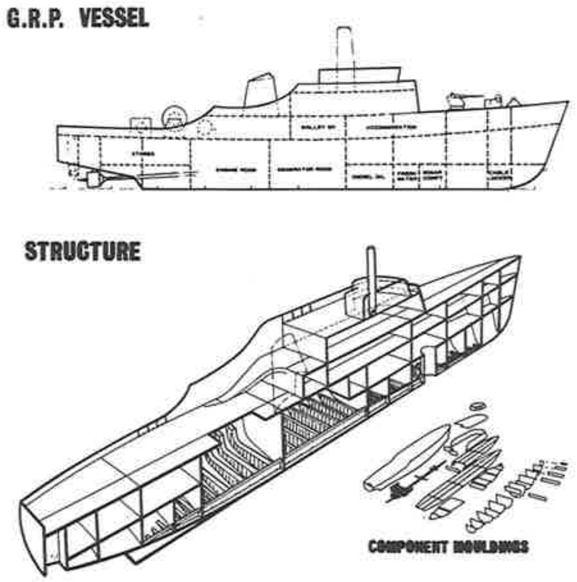


Figure 2

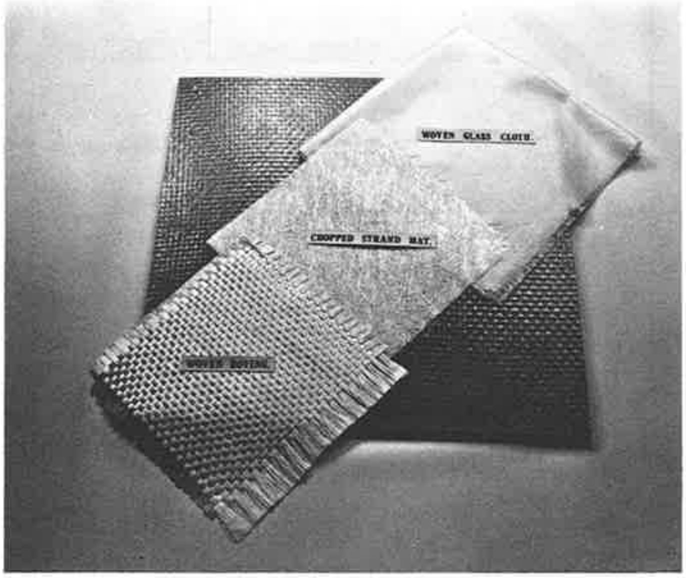


Figure 3

FIG 2

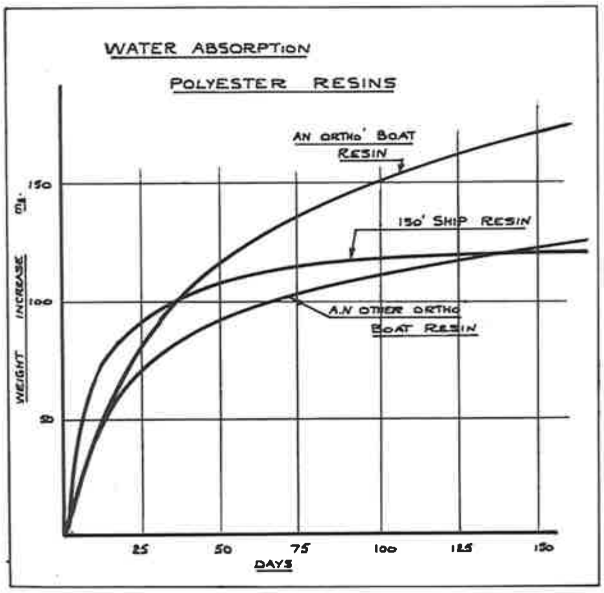


Figure 4

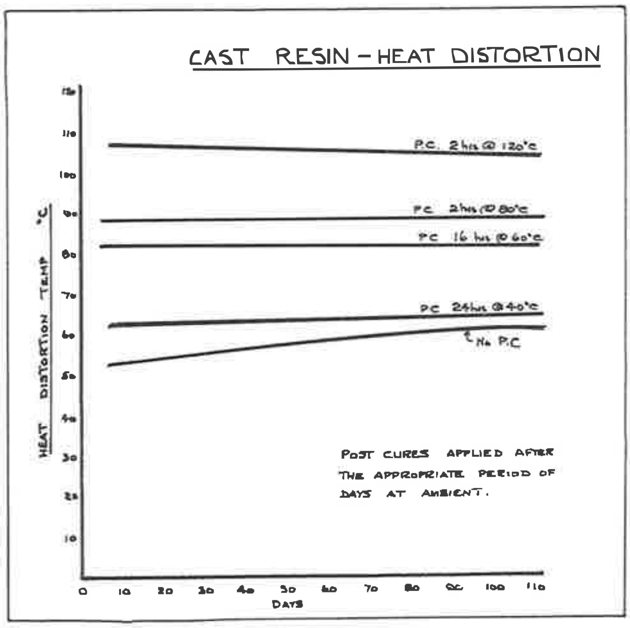


Figure 5

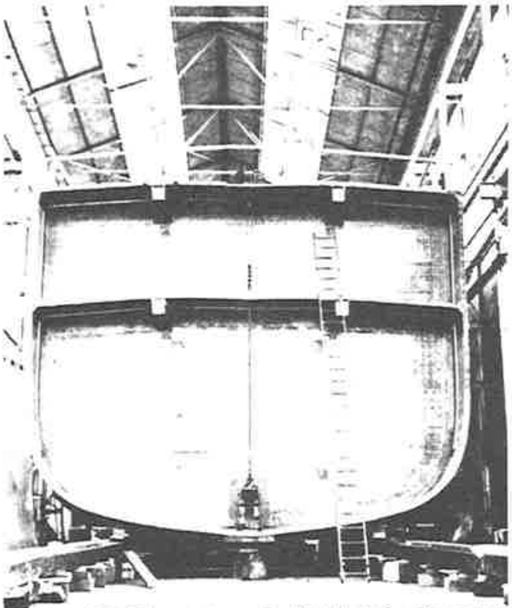


Figure 6

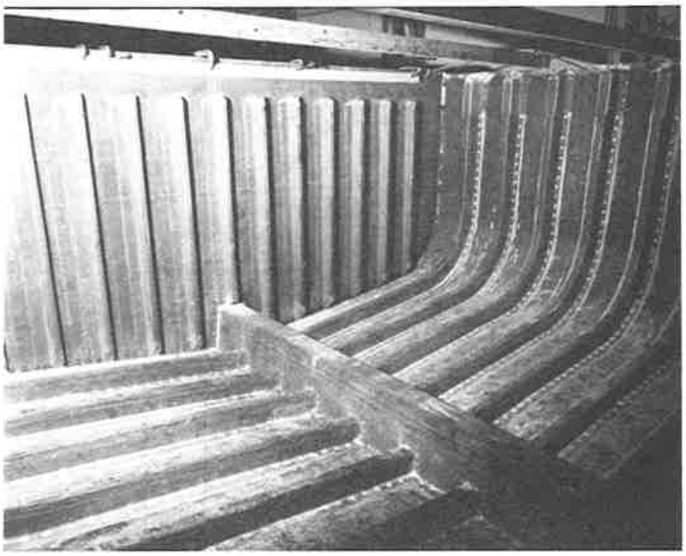


Figure 7

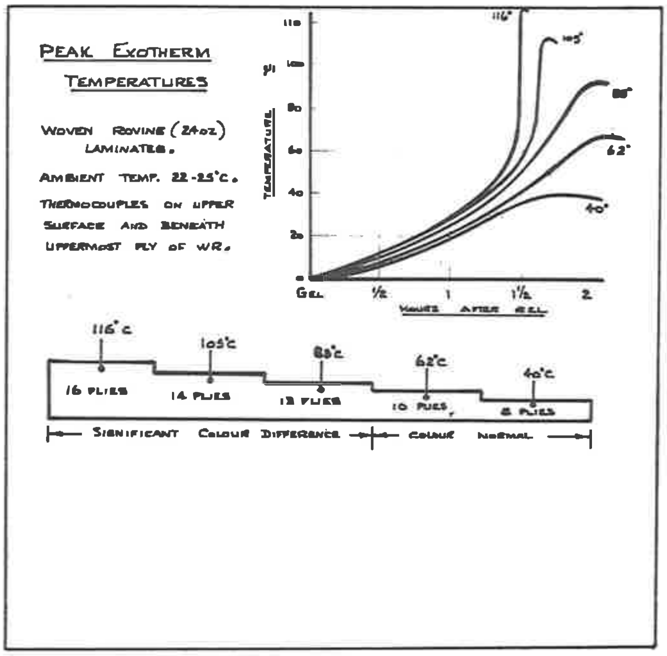


Figure 8

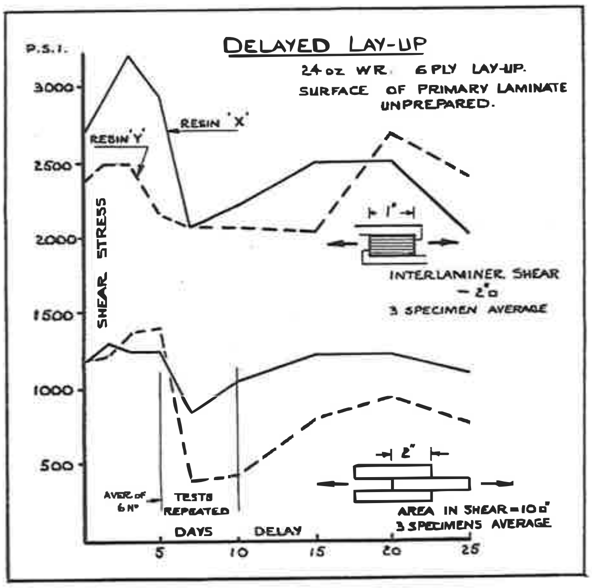


Figure 9

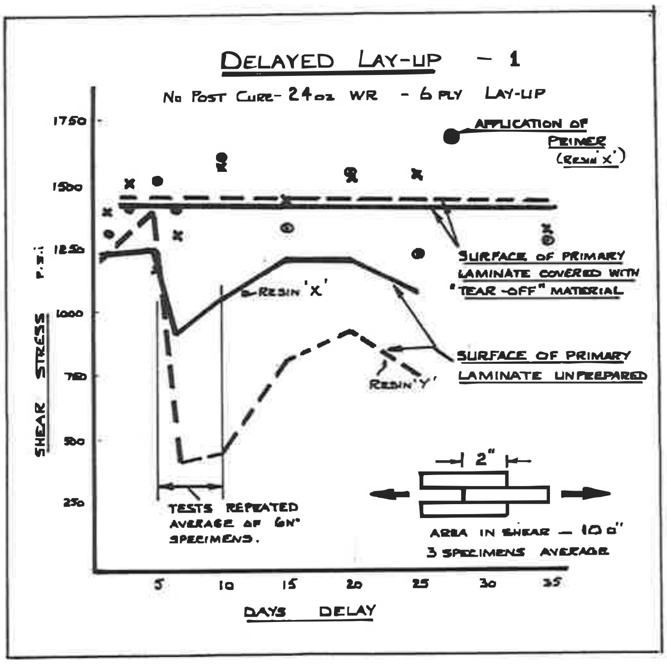


Figure 10

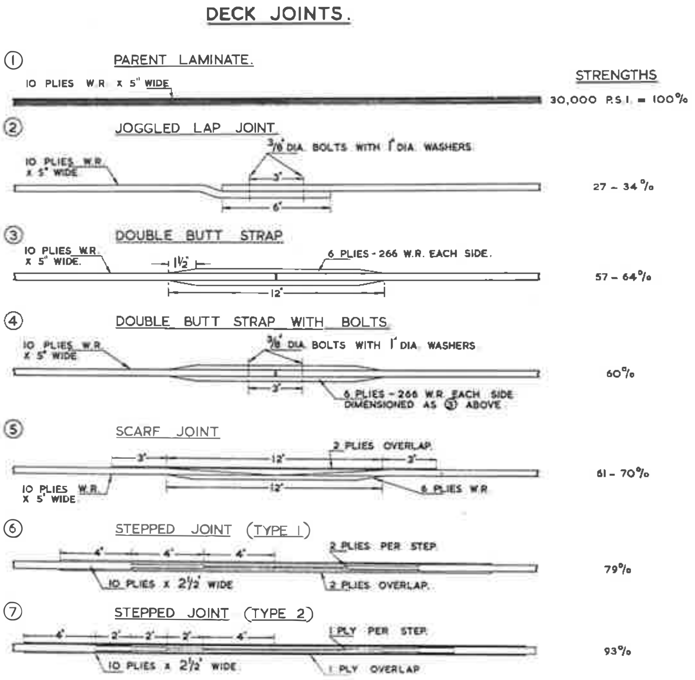
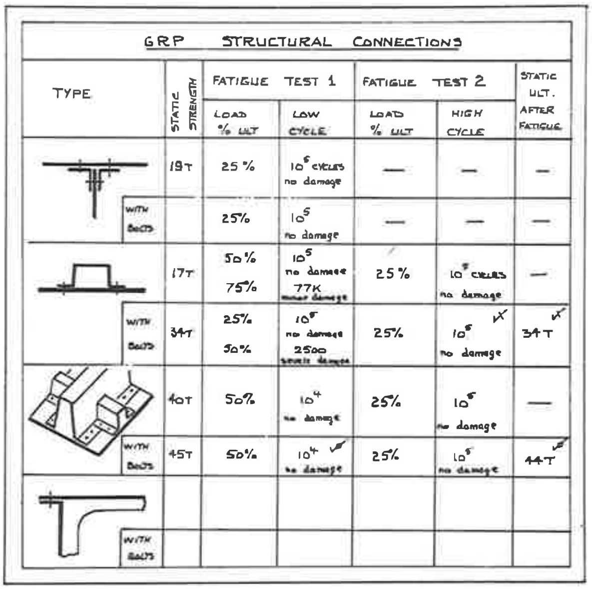


Figure 11



GRP STRUCTURAL CONNECTIONS

TYPE	STATIC STRENGTH	FATIGUE TEST 1		FATIGUE TEST 2		STATIC ULT. AFTER FATIGUE
		LOAD % ULT	LOW CYCLE	LOAD % ULT	HIGH CYCLE	
	19T	25 %	10^5 cycles no damage	—	—	—
WITH BOLTS		25%	10^5 no damage	—	—	—
	17T	50 % 75%	10^5 no damage 77K minor damage	25 %	10^7 cycles no damage	—
WITH BOLTS	34T	25% 50%	10^5 no damage 2500 severe damage	25%	10^5 ✓ no damage	34T ✓
	40T	50%	10^4 no damage	25%	10^5 no damage	—
WITH BOLTS	45T	50%	10^4 ✓ no damage	25%	10^5 no damage	44T ✓
WITH BOLTS						

Figure 12

DISCUSSION

Question

Could the speaker give us a comparison between the costs of a ship of, say 30 yards in length, built in reinforced plastic and built in timbe? Could the speaker tell us something about the size of the market for ships smaller than 30 yards in length as compared with ships bigger than that length?

Answer

I am not sure whether I am qualified to answer both questions.
The first question aims at ships that are the most 30 yards long, which is considerably less than the type of ship we have just discussed. For ships with a length of about 45 metres, the costs of construction in timber and in GRP seem to be comparable. Both are very costly forms of construction.
It is very difficult to state something about the size of the market, which was mentioned in the second question. For ships under 30 metres in length, there must be a large market in fishing vessels and work boats. As any international boat show will demonstrate, the point has been taken by shipbuilders for some time, especially with hulls up to 20 metres in length. But when you get between 20 and 30 metres in length, in my opinion the choice of material will be heavily influenced by the kind of facilities already available in the country that needs the boats. If the country already has a shipbuilding industry, they probably will choose metals. But if they don't have, the low investments needed to start a GRP industry, are certainly most attractive. I suspect that for this reason certain South-American countries are heavily engaged in building GRP boats in length's up to 30 metres. They have plenty of labour available and it does not need to be highly skilled. You only need a few experts to organize the programme, and a few technicians who handle the mould side.

Question

So shipbuilding with GRP is very suitable for underdeveloped countries?

Answer

Yes.

Question

It appears to me that your programme was extremely restrictive, as you have taken an existing class of ship and an existing design. Would it be an advantage if you could start from scratch and design specifically for GRP?

Answer

This is a very fair comment indeed. Our design is extremely restrictive, as we had to replace an existing structure. In my opinion it is essential to forget all your earlier concepts of ship construction when you start to use a new material like GRP. But this is, of course, a very difficult process of adaptation.

Question

Is it known how seawater attacks the GRP you have used? Is the resin itself attacked or does the water penetrate the interface between the glass fibres and the resin?

Answer

It seems that the attack is mostly between the fibres and the resin matrix.

Question

Is there deep bonding between the surface of the fibres and the resin matrix?

Answer

The information we have obtained to date indicates that we never obtain a 100 per cent. bond between the fibres and the resin. It is a patchy type of bond, and there always are a number of spaces available for water to penetrate when the laminate is loaded. Then there occurs a gradual break down as the water continues to penetrate the laminate.

Question

Did you investigate glas fibres with a specially prepared surface that ensures a good bond to the resin matrix?

Answer

Yes, it was a part of our evaluation programme to find the most satisfactory size on the glass. In fact, it took up a large part of our research programme and we have been able to limit severely the number of types of size that are acceptable for a particular resin.

Question

In your lecture you mentioned the sandwich construction, which you could not use because of the explosion problem. If this problem does not occur, would not be a sandwich construction be a lot cheaper than the construction you had to adopt?
My second question concerns the mechanism of failure of GRP as a consequence of the uptake of water by the laminate. Did you do fatigue tests under immersed conditions?

Answer

We feel that in small boats the production costs can be reduced substantially by the adoption of a sandwich construction. But for large hulls we are not wholly convinced of that. Decks, bulk heads and more or less flat panels might be produced economically as a sandwich. But a large hull, with its intricate shape, is a very different proposition. So for small boats the sandwich construction offers financial advantages, but it is an open question whether that is also true for large hulls.
As to your second question, we carried out a number of fatigue tests under immersion, e.g. immersion under load and immersion after having been loaded. The tests indicate that a laminate that has been loaded and immersed, will reach full saturation in about one year under atmospheric pressure. We can accelerate that by immersion at 1000 psi, and then we would reach full saturation after about 4 months. The results indicate that it is important to stay within your design parameters. When the laminate is wet and prestrained, it shows a drop in strength of about one order of magnitude after one million cycles. But if you start to load the laminate outside your design parameters, the drop of strength can become much greater than the amount mentioned.

Question

You mentioned that, in your opinion, GRP would not be used for large ships. But you also stated that some countries that enter the shipbuilding industry, find it advantageous to start with laminates, as construction with metals calls for high initial investments. Would not you expect that gradually construction with plastic will be extended to large ships, or are there fundamental reasons why this will not happen?

Answer

I think that there are fundamental reasons why this is not likely to take place. When you look at the GRP we are using and a traditional low alloy steel used in shipbuilding, GRP

has a weight advantage of a factor of something like four. But there is a disadvantage in tensile strength and in compressive strength, which for GRP are only about half as great as for steel. And the modulus is only one fifth of that of steel. Those are the approximate relationships.
A ship can be considered as a girder, and then the criterium for design is stiffness, not stress. If you introduce that in your computations, you will find that there is a limit to the size of the ship that can be built by using GRP alone, unassisted by some higher modulus material. You could combine plastics and metals, but then the first question you should ask is: Why? Metals are eminently suited to the construction of large ships, plastics are not.

Question

As you said in your lecture, the original design called for a metal frame, covered by a skin of timber. In that way you could take advantage of the good qualities of both materials. Why did not you do the same in this case? Was it not possible to replace the skin of timber by one of plastic?

Answer

There is a brief answer to that. The aluminium frame is completely unacceptable in a modern minesweeper, due to the magnetic signature that will develop. There are large rings and large sheets of metal, and these are unacceptable. They had to be accepted in the earlier vessels, which were designed or built a quarter of a century ago, because there was no alternative. Now there is, and we can reduce our magnetic signature quite significantly by taking out all metal framing.
Secondly I think that you will have problems with joining two so dissimilar materials. You would not only have problems with bonding, but also with the different coefficients of expansion. In shipbuilding, I do believe that it is impossible to combine plastics and metals in this way, as a hull will be highly stressed in practical circumstances. In lowly stressed constructions the combination may have good properties, but I do believe that this idea is a non-starter as far as ships are concerned.

Question

You mentioned the conventional mechanical strength tests. Have you done also dynamic testing, for example on sound absorption, shock absorption, vibration and shock propagation?

Answer

Yes, we did quite a lot of tests in these fields. Rather surprisingly, ships behave much the same, irrespective of the material they are built from, and GRP ships are no exception.

Question

In your studies on this very large project, you must have looked at all kinds of materials. But the stiffness problem, you mentioned, obviously prompts one to ask whether you could not incorporate a proportion of carbon fibre in the glass fibre mat. It may not be attractive today, but what about five or ten years from now? It is already known that a small proportion of carbon fibre can enhance stiffness to a considerable degree.

Answer

This is a good point, and we have indeed done research on the incorporation of carbon fibre in the laminate. But, firstly, I would like to point out that we have still a long way to go with glass reinforced plastics. We are using woven materials with an inbuilt crimp, and that influences the strength and properties of the laminate. At the moment we are limited by the type of materials available.

As to carbon fibres, we have already done a fair amount of research, and we have mixed glass and carbon in various ways. We have found that if we weave carbon into glass, we gain nothing; we only add to the cost of the laminate. If we use uni-directional filaments of carbon, we can get a substantial improvement in the properties of the laminate. The results of these investigations have been published.
As far as utilisation in the next decade is concerned, I think that the production processes will determine how far we go with the new materials. It is our ability to use them in various constructions, that will be important.

Would Prof. Dr. C.A. Verbraak give a last comment?

Yes, just a short comment on the problem of stiffness.
One has to go into elaborate and ingenious ways of design to solve this problem in the sizes of ships you are working on now. I wonder whether you are not actually promoting the application of steel in this way, because the same principles can be used for the application of extra high strength steelse for very large ships.

Answer

Well, we find that it'is very difficult to generate any interest in extra high strength steels for anything other than submersibles. But we obviously have a vested interest here, for if we could extend the market, we would find it much easier to get high strength steels for submarines. But of course, the same ideas go hand in hand: saving weight and producing a structure with high stiffness.

The Properties and Employment of Thick Plastic Coatings for Structural Elements

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Dortmund
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Demands for thick plastic coatings are increasing in all areas where steel is exposed to heavy corrosion. Thus, for example, the production of plastic-coated line pipe is steadily increasing. Again, coatings of this type are being used to an increasing degree in the civil engineering sector. The increasing aggressivity of water is playing a decisive role in this change in opinion.

It is very difficult to make generally applicable statements on the attack of brine, brackish water and fresh water on steel structures. This involves a great number of factors, which have not yet been determined in detail. It can safely be said that the simple electrochemical theory of oxygen corrosion cannot adequately explain the phenomena.

Turning to some empirical values on corrosion in sea water, some interesting information is disclosed by the Fig. 1 which depicts in principle the rusting of a sheet pile extracted in Bremerhaven after having been in use for a period of forty years. The average rusting at the main point of attack (about 0,5 m below MLTL = mean low tide level) is approx. 0,13 % per annum. This particularly heavy attack just below the MLTL is typical for many harbours, but is not always encountered.

For example, Fig. 2 shows the entirely different rusting profile of four test angles after 6 years of use in 4 German harbours. The heaviest attack in the zone of permanent immersion is always just below the MLTL, and in the Baltic Sea just under the MSL (= mean sea level), the Baltic having only a minor tidal rise.

However, in the greater majority of instances, maximum rusting losses just below the low tide or mean sea level amount to only 0,1 mm/year or less.

It is not very easy to interpret these findings. The explanation that the large areas in the alternating immersion zone act as a cathode in the presence of higher concentrations of oxygen and make the lower surface into a locally insulated, relatively small anode cannot give satisfaction.

Naturally, heavy incrustations form an obstacle to simple explanation of this corrosion, which is particularly heavy in some instances.

Barnacles and mussels do not present a primary hazard as regards steel corrosion. However, their metabolic products constitute a domicile for numerous bacteria, which probably reduce sulphate to hydrogen sulphide, and also form carbon dioxide and hydrogen. This causes heavily anaerobic conditions locally, which in turn prevent oxygen corrosion.

The effects of river water and of soils on iron corrosion are entirely different. It may be taken that rusting loss rates of = 0,01 % per year are generally encountered both in the air and in the underwater zone. For example, Fig. 3 shows a pile from a 100-KV-line mast which was extracted after 26 years; it exhibits an annual rusting loss rate of 0,006 to 0,012 mm. The rolled-in lettering is still clearly visible.

Substantially heavier corrosion rates have been established in certain cases, but all were connected with the outflow of very aggressive waste water in the near vicinity.

Taking into account increasing water pollution and at the same time the economic construction of steel structures, the question posed is: what can be done to ensure that corrosion damage will not substantially shorten the service life of the structure under even the worst possible conditions ?

A whole range of possibilities is open:

1. Thickening of the section, this solution should always be given consideration.

2. Cathodic protection, when the wall - depending on conditions - is charged with about 50 - 120 mA/m^2 in the initial stage until protective layers have been formed. Partial covering of the wall with organic protective coatings reduces the power requirement to only an insignificant extent. At the same time, possible effects on other cables must be considered. This solution is sometimes used to protect valuable facilities.

3. Passive protection: spray coating with zinc or aluminium and also hot-dip galvanizing have proved inefficient for underwater zones in both sea and fresh water, but are satisfactory for atmospheric environments.

Metallization followed by coating with tar epoxides for sea water and possibly bituminous coatings, applied hot or cold, for fresh water are good but expensive solutions.

To date, tar epoxide resins applied in layers about 0,3 mm thick have given good service, but experience is available only for a shorter time in sea water environments without metallization of the structural elements. The otherwise very good coatings on bituminous and coal-tar bases are completely destroyed by incrustations.

As the demand for a maintenance-free long-life coating for open sections with good mechanical resistance and offering protection against all corrosion attacks under water and in soils continued to grow, we investigated the possibilities of applying such thick plastic coatings at reasonable cost, and also the properties that can be attained.

With the exception of pipes, I can do no more than report on a development we have taken in hand and which in part has been brought to the industrial trial stage. However, the line of development under discussion is by no means in the final stage.

The term thick plastic coatings is to be understood as covering layers thicker than 1,5 mm.

The following selection of plastics is available:

1. Thermoplastics such as polyvinyl chloride, polyethylene (generally known as polyolefins)

2. Reactive plastics or elastomers such as polyurethane, epoxides, and unsaturated polyester.

Following solution of the difficult problem of adhesion to steel by using special application techniques and specially developed copolymerisate adhesives, polyethylene has definitely ousted polyvinyl chloride for coating applications that involve heavy stressing. Therefore the following discussion is limited to polyethylenes, especially as the application techniques for polyethylene and polyvinyl chloride are comparable. Polyethylene is either bonded to the steel or sinter-fused.

Present methods of applying polyolefins to steel on a bonded basis involve thermal treatment of the material by either sinter-fusing to powder or by melting an adhesive. If the adhesive method is selected, the polyethylene must be applied in the molten state, which is best done using an extruder. In the case of closed, almost axially symmetrical (not too complicated) sections or almost closed sections, a sheath can be drawn over the workpiece; the sheath fits smoothly to the workpiece after contracting, possibly using a partial vacuum. If the workpiece is axially symmetrical, polyethylene can also be wound on from a wide-slot nozzle. When using the sinter-fusing method for polyethylene powder, the demands on the geometry of the workpiece are not as high. However, it must be heated to rather high temperatures, and depending on wall thickness variations, differences in the coating thickness must be expected as resulting from the differences in heat capacity. Accordingly, sheathing with polyethylene always means that the workpiece must be temperature-resistant without its properties being affected up to the 350° C level. This also applies in principle to polyvinyl chloride.

Fig. 4 shows the scheme of the production line for extrusion coating of pipes with high-pressure polyethylene as carried out by us - and analogously by other manufacturs - on an industrial production scale.

Explanations to the numbers (Fig. 4):

1. roller table
2. grit blast facility to about 50 /um roughness
3. roller table
4. grating
5. roller table with coupling facility
6. pulk push device
7. inductionheating equipment to about 220° C for bonding agent
8. electrostatic application facility of bonding agent to 50 /um
9. continuous extrusion facility
10. 11. cooling device
12. roller table to release the pipes

Fig. 5 shows the electrostatic application of the bonding agent. The average coating thicknesses are about 50 /um. This distinguishes the Hoesch process from others. As the cohesive strength of the bonding agent is always lower than that of the polyethylene, efforts are made to restrict the thickness of the adhesive coatings to the minimum. Fig. 6 shows the continuous extrusion of the polyethylene sheath under a slight vacuum.

This process is used for pipes of 25 to about 330 mm. The coating thicknesses are between 0,6 and 4,5 mm. The speeds are limited partly by the extruder, reaching about 15 m with the smaller diameters and 4 m with the 330 mm pipes.

Fig. 7 shows the scheme of the sinter coating process with high pressure PE.

1. Grit blasting facility
2. Roller table
3. Roller table
4. Grating
5. Introduction facility for the burner
6. Coating facility for PE powder
7. Smoothing of polishing facility for PE surface
8. Transportation car to store

Larger pipes up to 1500 m are coated with sintered polyethylene in layers up to 2 - 5 mm thick.

Fig. 8 and 9 show the application facility. The required temperature of 350° C is built up using an internal lance. In contrast to the process just described, this is a discontinuous method. The application of PE powder lasts 8 - 25 min with a turning velocity of 10 - 15 per minute.

Axially assymmetrical sections used in sub-grade civil engineering work always involve considerable coating injuries. Consequently, considerations here are different to those of coating pipes with thermoplastics. For the required coating thickness of 1,5 mm, only solution-free systems can be used, even in the case of reaction resins.

Epoxides are not suitable at the present time because of their high costs, in spite of their very good properties. The unsaturated polyester systems have also failed to achieve popularity as coating materials for steel products.

Polyurethanes are a class of materials, which via polyaddition, produce from multi-function isocyanates with multi-function polyalcohols plastics ranging from brittle thermosetting plastics to synthetic rubber.

For moist environments, only polyols based on polyethers can be used, as the polyester-polyols incur great danger of hydrolysis.

The polyesterpolyols used can be extended using filler materials. In the cases under discussion, barium sulphate was used in ratios of up to 1 part polyol to 1 part of barium sulphate (by weight). This equals about 20 volume parts of barium sulphate. This filling also has a favourable effect on properties such as hardness and adhesion.

The real advantage of these reaction plastics, and especially of polyurethane, lies in the fact that they can be used in the cold state without thermal after-baking, and also in their very short reaction time. The multi-component spraying machine offers the most expedient processing method. Fig. 10 shows the spraying process using the example of pipe coating. In the main, this is a continuous and highly accurate metering facility for the two seperate components. These components are first mixed in a mixing heat, thoroughly stirred, and then sprayed using compressed air. As isocyanate readily reacts with water, which of course also contains an OH group, the compressed air must be dried to minor moisture contents by using a regenerable silicagel filter. By selecting special catalysts and thixotropicalizing agents, the reaction time can be controlled between seconds and minutes and, in addition, even vertical surfaces can be coated with a good finish without running of the plastic. This is demonstrated by Fig. 11, which shows the coating of a vertical sheet pile. The spraying process is limited purely by geometrical conditions. Substantially flat surfaces take a very good coating, as do axially symmetrical bodies with a reasonable diameter. Wherever possible, the value of 15° C should not be undershot during the coating procedures. The polyurethane coating needs about 1 - 2 hours following spraying to harden out to the extent needed for storage. As compared with coatings containing solvents, these solvent-free plastics permit very high production rates. For example, each machine can spray between 2 to 20 kg/min. With axially symmetrical bodies, a uniform coating is obtained by turning the item while maintaining a constant feed rate. Maximum feed rates of 7 m have been attained with 215 mm diameter pipes, each pass yielding a coating thickness of 0,8 - 1 mm.

In our experience, in the case of flat-surface coating thickness vary by about ± 15 % using the manual method. If the surface finish must be as smooth as possible, the spraying distance must be as great as possible. The material is then atomized, but material losses are also heavily increased.

At an optimum distance from the workpiece spraying losses are in the order of about only 10 %.

Completely hardened polyurethane elastomers have an extremely smooth and leatherlike skin. As final coating thicknesses of about 2 - 4 mm normally require several applications by casting or spraying, each successive coating must be applied at definite hardening intervals if bonding with the lower coatings is to be satisfactory.

Following the preliminary trials, 2000 m^2 of a sheet pile wall for the North-Sea harbour of Bensersiel were coated with polyurethane elastomers in the works. In view of the known minor degree of corrosion in the soil, only those parts of the piles as are exposed to water and to air were coated with polyurethane elastomers. Fig. 12 shows the coating of these sheet piles. Further standard piles were coated for the North-Sea port of Bremerhaven.

As the coating procedure demands certain temperature and air humidity conditions, it is advisable to carry out this operation under cover in the works.

However, repairs following welding or mechanical damage must be effected on site. Fig. 13 shows repair procedures of this type being carried out in the harbour of Bensersiel. As the repair areas were inevitably moist, a modified mis (prepolymer) had to be employed. Preparation was relatively easy. The coating was simply mechanically roughened to a slight degree and then swabbed with a towel.

A further interesting application is shown in Fig. 14 + 15. For bridge abutments, a permanent and maintenance-free coating is desirable more for appearance improvement than corrosion protection. However, if the coating is to be colourfast to light, the relatively inexpensive aromatic isocyanates may well have to be provided with a top coat of polyurethane containing a solvent. The durability of such coatings on these elastomers is very good.

Several hundred metres of pipe from 200 - 600 mm Ø have also been coated with polyurethane. However, as the initial costs of polyurethane are more than double those of the thermoplast polyethylene, further investigations into pipe coating have been discontinued, apart from special cases. Fig. 16 and 17 demonstrate the insulation of a pipe circumferential weld. The surface is first cleaned, and then a sleeve is applied consisting of a similar mix but with a rather different activation.

The mechanical properties of these polyurethane elastomer coatings are excellent. Fig. 18 shows the appearance of a polyurethane-coated pipe after it has been driven through a railway embankment.

The high mechanical strength makes these coatings highly insensitive to damage during transportation. Fig. 19 shows a comparison between sheet piles coated with tar epoxide and others coated with PUR elastomer; it can clearly be seen that the latter exhibit only very faint markings from the dunnage chocks, which did not lead to any damage.

The use of barium sulphate as a filler makes these coatings substantially fire-retarding. Fig. 20 shows how the pipes and coatings can be burned or thermally divided. Welding operations do not necessitate laborious removal of the plastic by mechanical means; it is simply burnt off. The residue is brushed away, and the surrounding area roughened. Damaged areas of the coating can easily be removed and then made good as described above. (Fig. 21) Burning does not generate aggressive fumes. However, there is a slight smell.

Physical and chemical properties of the coating materials

Fig. 22 shows several physical properties of the pure coating materials high-pressure polyethylene and filled polyurethane elastomer (sprayed). These permit certain qualitative statements to be made regarding the behaviour of the coating under various influences.

As indicated by Fig. 23, the modulus in torsion of the polyurethane elastomer clearly exhibits the formation of the glass and rubber elastic plateau with moderately steep incline as a function of the falling temperature.

In contrast, the modulus in torsion drops steadily with the temperature in the case of polyethylene, as to be expected. At lower temperatures, polyurethane is stiffer and approaches the glass state earlier which indicates its limitations for low-temperature applications, whereas polyethylene still shows no embrittlement down to - 60° C.

In contrast, polyurethane has rather better mechanical properties at higher temperatures as a result of the rubber state.

The properties were investigated on the following coatings (Fig. 24):

1. Pipe coating of extruded-sheath polyethylene on a floating adhesive
2. Pipe coating on sinter-fused polyethylene layer
3. Pipe coating of polyethylene wound layer on solid fusion adhesive of copolymerisate
4. Sprayed polyurethane coating in two layers without a bonding agent
5. Cast polyurethane coating in two layers with a bonding agent
6. Sprayed PUR coating in two layers with a bonding agent

The steel base was blasted to metallic cleanliness for each coating. Even though adhesion of the filled polyurethane to blasted surfaces is good, a cold-setting bonding agent was used following numerous observations and preliminary investigations.

With composite materials the main interest is centred not around the properties of the plastics, but the properties of the coating. In the systems as mentioned, the physical and the technological values used in part as quality designations in standards (for example TNO specification 13) and based on experience gathered with plastic-coated pipes buried in the ground were measured.

The following measurements were made:

Freedom from Pores

Measurement of the layer thickness distribution

Measurement of the Shore hardness

Measurement of layer formation in a cross-sectional specimen to determine porosity

Measurement of the identation depth of standard test pieces within a period of 24 h

Measurement of the specific impact energy in aacordance to impact loadings. Penetration of the hammer peen through the plastic is indicated by the closing of an electric circuit, when an audible signal is given

Measurement of the influence of water on coated pipe sections by recording the envelope resistance, as required under anodic loading of the pipe shell

Measurement of swelling of the coating.

Stressing of the coating under varying water vapour pressures and temperatures. As shown in Fig. 25 a coated pipe is immersed in water heated to 50° C while water with a temperature of 20° C flows through the pipe using the "sealed in" principle. The effects of 5 weeks of this treatment are investigated on the basis of appearance and also on the boundary layer metal-plastic following stripping of the coating.

Whereas these investigations are above all suited to the inspection of sound coatings on closed sections, further investigations are to be undertaken into the behaviour of these coatings as regards infiltration corrosion stemming from the ingress of aggressive media through injuries. This will no doubt always be the case when sheet piles are coated with plastics, as the coatings on locking edges and on the flat surfaces cannot withstand the driving operation without injury. In addition, the relatively more expensive coating will no doubt be reserved for only particularly endangered stretches in sea-water and fresh-water applications. The service life of such coatings will in the main be governed by their resistance to corrosion by infiltration through injuries. Other physical properties, such as electric puncture resistance and so on are not of interest in this connection. Pipe sections with the named polyethylene coatings No. 1, 2, and 3, and plates with the polyurethane coatings, sprayed with and without bonding agents, No. 4 and No. 6, were tested in fresh water and artificial sea water to DIN 50907, both saturated with air, using both the alternating immersion method and permanent immersion. All specimens featured a 2 mm wide gash through the coating down to bare metal to simulate injury. Infiltration corrosion was measured as a function of the exposure time.

Discussion of the results

Fig. 26 shows a cross-section for specimens No. 2, 3, 4, and 6. The numerous very large pores in the sinter coating a) obviously stem from the sintering process crack products. However, these pores remain without any adverse effect on material properties. The hard-bonded polyethylene extrudate b) is absolutely dense. The adhesive can still be seen on the left. The sprayed PUR elastomer c) also exhibits numerous larger and smaller air pockets. Microporosity cannot be recognized at this magnification. The entrapped air totals some 20 %, but no direct connection exists between atmosphere and steel surface. d) shows a completely dense, two-cast layer. The separating line can be detected, as the first layer hardened out to an excessive degree before the second layer was applied.

Fig. 27 surveys the measured physical and technological values of the various coatings.

The electric resistance of the coating before and after exposure to water and the spark test show the expected relationships.

The polyurethane specimens behave better under shock loads measured in terms of specific impact energy or simply by striking with a hammer as compared with the polyethylene specimens. Cast polyurethane specimens are the equal of polyethylene as regards resistance to static loading determined in 24 h penetration tests. Due to the air pockets, sprayed polyurethane specimens are much more elastic. Although they exhibit a greater indentation depth, the surface is not damaged. A great proportion of the impression is reversible, and returns over longer periods of time on the load being removed.

The influence of temperature on the polyurethane coating may also be disregarded. No coaxial length displacements were to be noted on a coated section of pipe of defined length between coating and pipe at - 30 and + 50° C. At these temperatures, the layer thickness difference was $>$ 2,5 ‰.

As the insensitivity of polyethylene coatings against the influence of water has often been described, several measured values are given in respect of polyurethane coatings.

Resistance to hydrolysis of PUR-coated pipes has been proved during 220 days exposure test to 0,1 normal HCL, NaOH, and NaCl. For each of the three solutions the values specified in the German gas-water association were exceeded.

A steel tank coated with a 2 mm layer of polyether polyurethane and with a total area of about 10 m^2 under cathodic protection showed within four years a very minor change in the current absorption rate from 0,034 to 0,12 $\mu A/m^2$. In other words, storage in water, even at higher temperatures, does not significantly alter the properties of the polyurethane coating.

There is a definite rate of water absorption. This is accompanied by a slight decrease in hardness.

As the material is thus made flexible by the water, favourable results may be expected under an abrasive stress, for example the abrasive action of sand applications, as breakwater, etc. A comparative investigation made using coated plates in a rotating drum with a sand-water mixture having a definite grain distribution produced only a very minor degree of abrasion loss after 440 000 revolutions in the case of the polyurethane elastomers used here. This abrasion loss was substantially lower than the rate encountered in analogous tests with filled high-grade epoxide resin coatings. In contrast, tar epoxide resin coatings are much softer.

While in the water vapour test at different temperatures (Fig. 28) all polyethylene coatings No. 1, 2 and 3 display no effects externally or at the boundary point between coating and steel (apart from a slight adhesion loss), the results for the polyurethane coatings are differentiated. The cast polyurethane No. 5 shows with the thicker layer of 2,7 mm, no effects apart from a certain adhesion loss at the boundary surface. In contrast, the layer thickness 1,4 mm displays heavy blistering. Adhesion is completely lost. The sprayed polyurethane coatings No. 4 do not behave so well. With the thick layers of 3,9 mm, the only effect to be noted is a marked adhesion loss.

In contrast, specimen No. 4 with a thinner layer of 1,9 mm has a heavily blistered appearance. Adhesion is completely lost. Fig. 29 shows the appearance of specimens No. 4 (sprayed polyurethane 1,9 mm thick, bottom) and No. 5 (cast polyurethane 2,7 mm thick).

Analogous investigations into polyurethane coatings sprayed on to a bonding agent under the designation specimen No. 6 are planned.

Reduction of the electrical values following exposure to water is expectedly lower in the case of polyethylene as compared with polyurethane. However, it is reversible in the case of polyurethane, attaining the original values after drying.

Resistance to infiltration corrosion and adhesion power under exposure to sea water and fresh water with coating injuries are much different. The sprayed polyurethane showed no infiltration corrosion using a bonding agent, this being true of both the exposure test and the alternating immersion test, over a test period of 210 days. (Fig. 30)

The specimens show no effects at all up to now. The test is being continued. Cast polyurethane is not being tested, as it is not intended for such applications.

Whereas all polyethylene coatings produced reasonable results in the fresh water tests, the sea water tests clearly demonstrated the superiority of the polyurethane elastomers sprayed over a bonding agent as regards resistance to infiltration corrosion. Specimen No. 3 of the polyethylene coatings produced by far the best results. Fig. 31 shows the behaviour of the coating specimens in artificial sea water after 80 days exposure. From left to right, we have specimens No. 3 (hard-bonded extruded polyethylene), No. 1 (soft-bonded extruded polyethylene), No. 2 (sintered polyethylene), and No. 6 (sprayed polyurethane with bonding agent), the lower half giving the appearance on termination of the investigation. The appearance following the alternating immersion tests.

Preview of further developments

In view of its good properties, polyethylene has already won a secure place for thick plastic coatings. In addition, however, the polyurethane elastomers will gain in interest for civil engineering purposes. However, the large-scale use of polyurethane elastomers is still attended by certain problems, which are being intensively investigated at the present moment.

The adhesive power under severe stressing is to be further improved by means of a special mix for the adhesion base using also active corrosion protection pigments and special chemical pretreatment. The reference material being a tar epoxide about 300 µm.

The mixes used to date are doubtlessly not optimum; they are being changed under the following aspects:

Reduction of the initial costs by increased use of filler materials and tar.

Reduction of swelling by testing DD spray systems blended with tar.

Flexibility also at lower temperatures to eliminate premature failure under mechanical stresses, for example abrasion by ice and sand.

Improvement of application techniques (perhaps also by improving the mix) for coating operations largely independent of weather conditions, for example bridge abutments. Initial tests using a gas-fired manually-operated heating appliance were succesful.

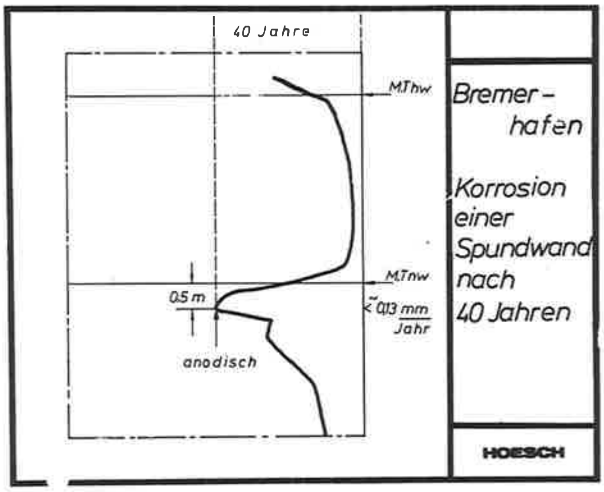


Fig. 1: Corrosion of a sheet pile in principle in Bremerhaven after having been in use for a period of forty years

MTnW = MLTL (mean low tide level)

MThW = mean high tide level

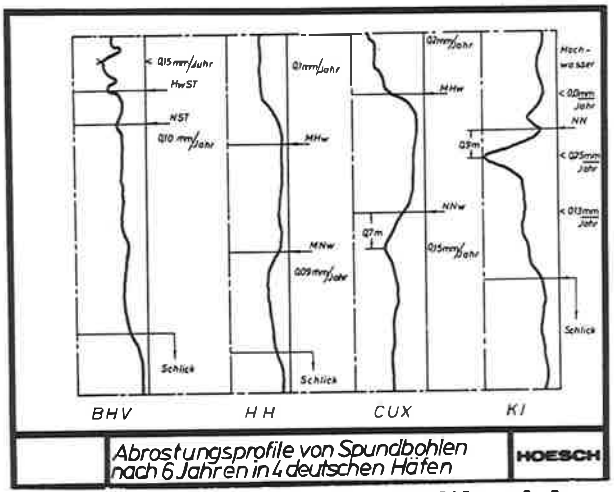


Fig. 2: The different rusting profile of four test angles after 6 years of use in four German harbours

NN = MSL (mean sea level)

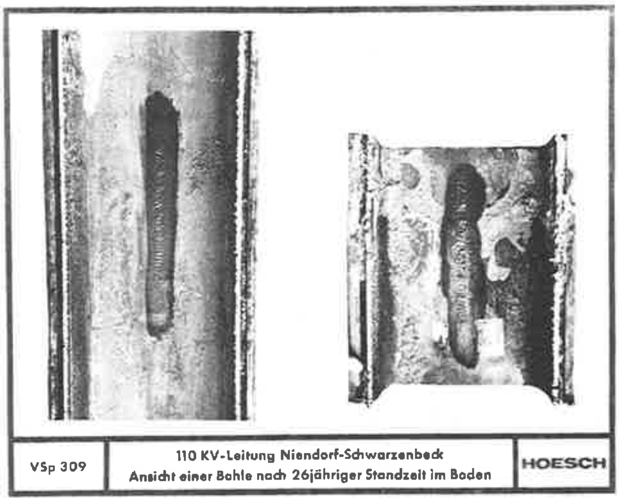


Fig. 3: The rolled-in lettering of a pile from a 110-KV-line mast which was extracted after 26 years

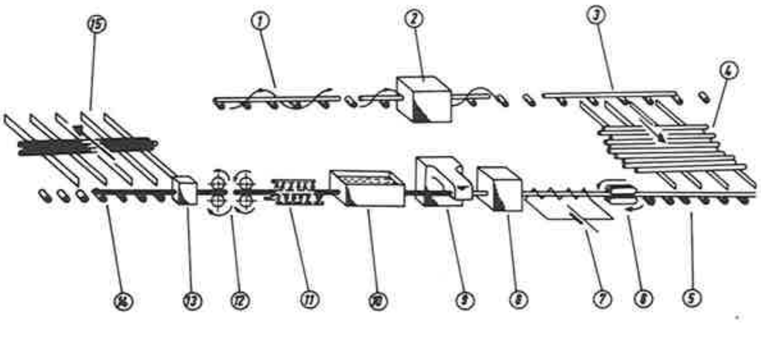


Fig. 4: The scheme of a production line for extrusion coating with high pressure polyethylene

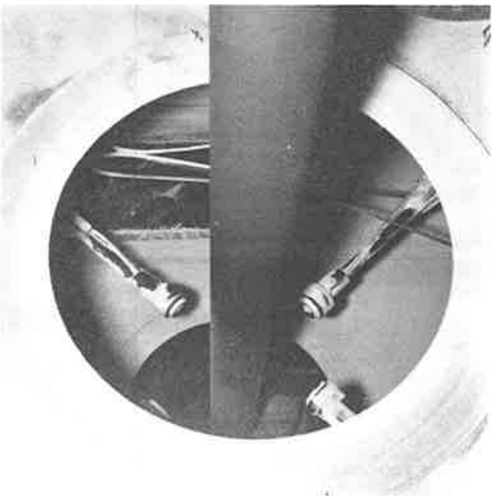


Fig. 5: The electrostatic application facility of the bonding agent

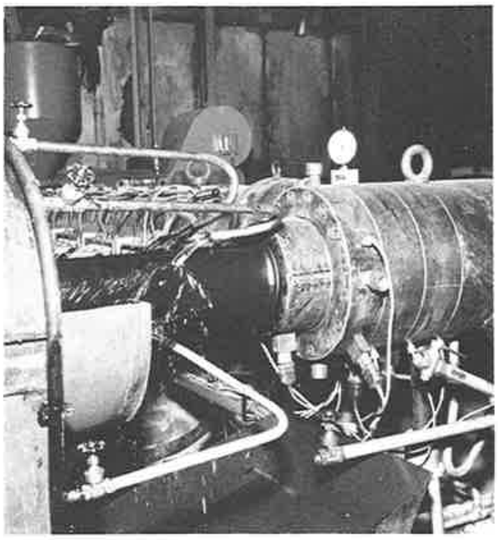


Fig. 6: Continuous extrusion facility of the Polyethylene

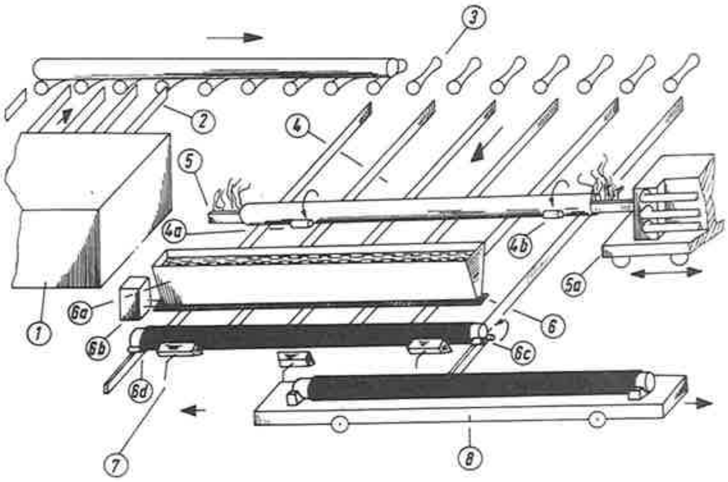
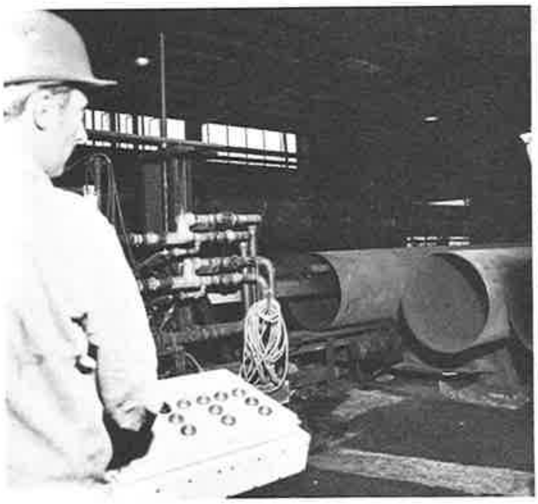


Fig. 7: The scheme of the sinter coating process



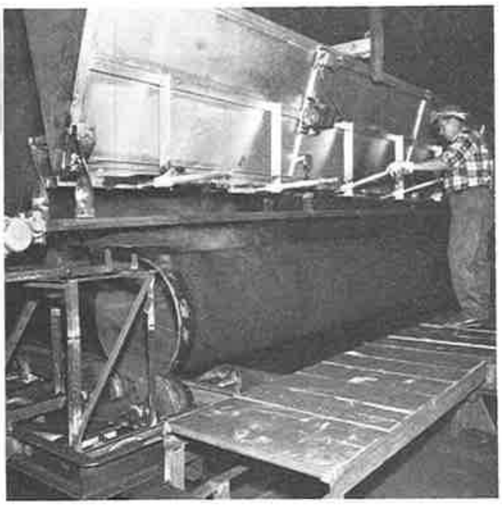


Fig. 8: Fig. 9:
The application facility of the sinter coating process

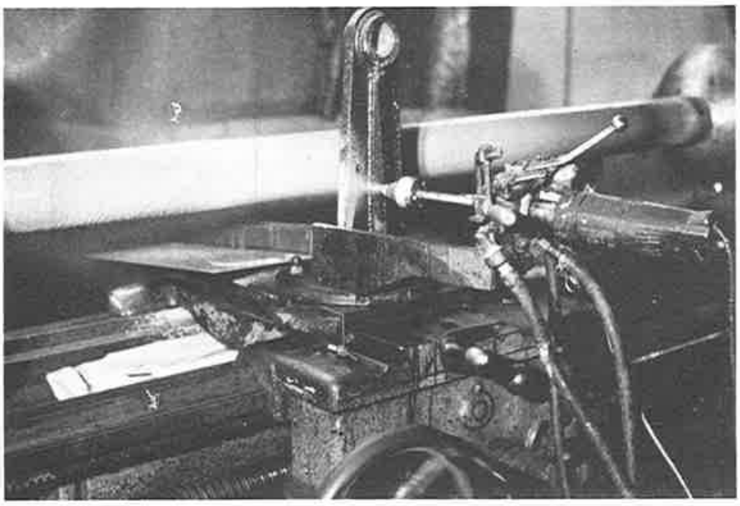


Fig. 10: The spraying process using the example of pipe coating

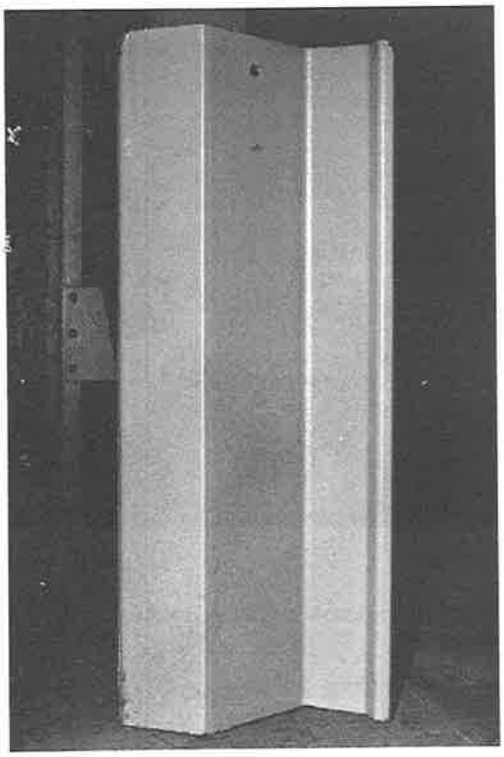


Fig. 11: Vertical coated sheet pile

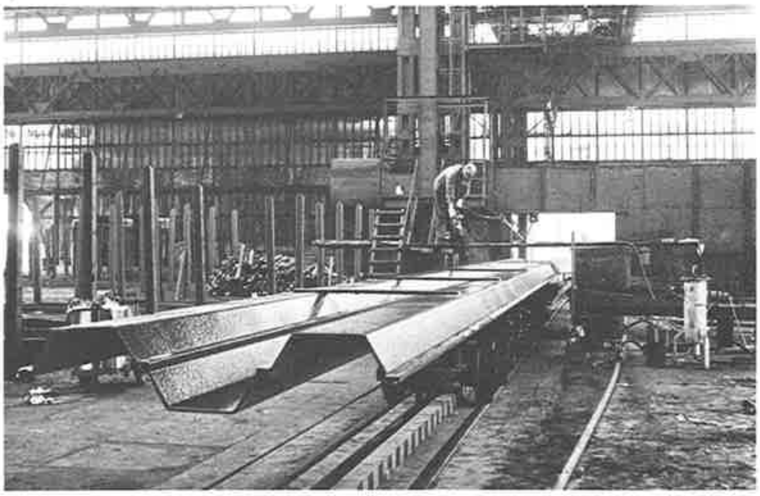


Fig. 12: Coating of sheet piles

Fig. 13: Repair procedure of PUR-coated sheet piles at Bensersiel

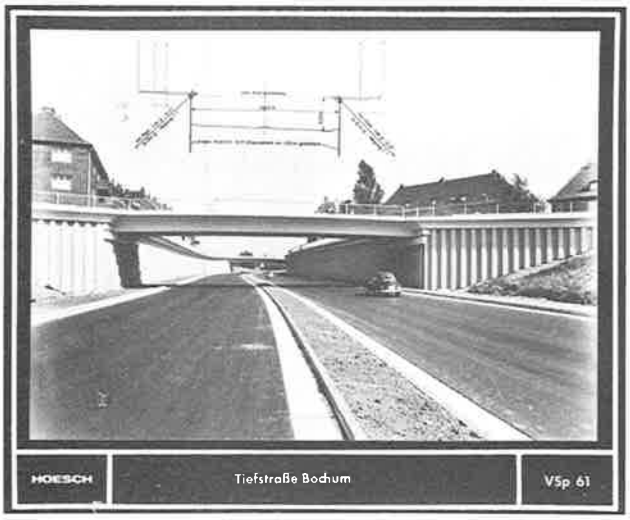


Fig. 14: The oldest bridge abutment at Bochum

Fig. 15: The coating procedure of a bridge abutment at Hamm

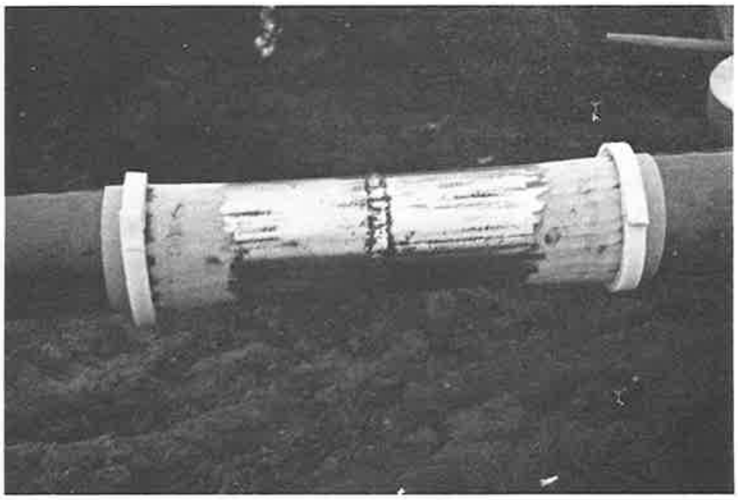


Fig. 16: Cleaned surface for the insulation of a circumferential weld

Fig. 17: Applying of a circumferential weld

Fig. 18: A PUR-coated pipe after driving through a railway embankment

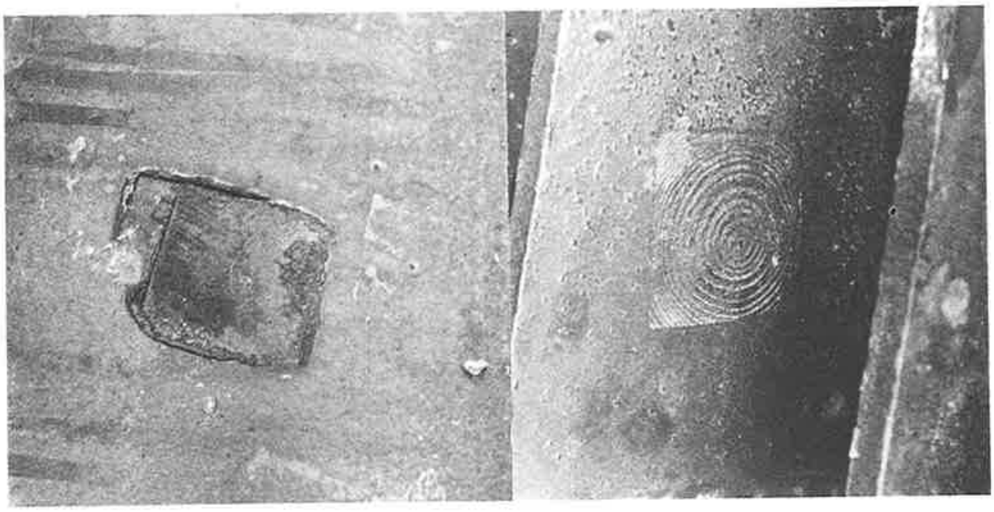


Fig. 19: Insensitivity of PUR-coated sheet piles to damage during transportation left, tar epoxide coated pile right

Fig. 20: Fire retarding PUR-coatings allow welding

Fig. 21: Removing of damaged coatings

			Beschichtungsstoff	
			PE	PUR
Anwendungsbereich bei mäßiger mech. Belastung			-60 · · · +80	-30 · · · +80
Dichte	[g/cm^3]		0,91 · · · 0,92	~1,1
Härte	[Shore D]		75	60 · · · 85
Torsionsmodul G'	[dyn/cm^2]	-40° C	$5 \cdot 10^9$	$> 10^{10}$
		0° C	$2 \cdot 10^9$	$6 \cdot 10^9$
		+40° C	$8 \cdot 10^8$	$8 \cdot 10^8$
Bruchdehnung bei 20°C	[%]		ca 20	40 · · · 60
Zerreißfestigkeit bei 20°C	[kg/cm]		100 · · · 150	100 · · · 120
Linearer Ausdehnungskoeffizient	[1/°C]		$2{,}3 \cdot 10^{-4}$	$1{,}6 \cdot 10^{-4}$
spez. Durchgangswiderstand	[Ω/cm]		$\sim 10^{16}$	$\sim 10^{14}$
Elek. Durchschlagfestigkeit	[kV/cm]		400	200
Wasserdampfdurchlässigkeit	$10^9 \cdot$ [g/cm·h·Torr]		2,3	9,5

Tabelle 1

Fig. 22: Physical and technical values of coating materials Polyethylene und Polyurethane

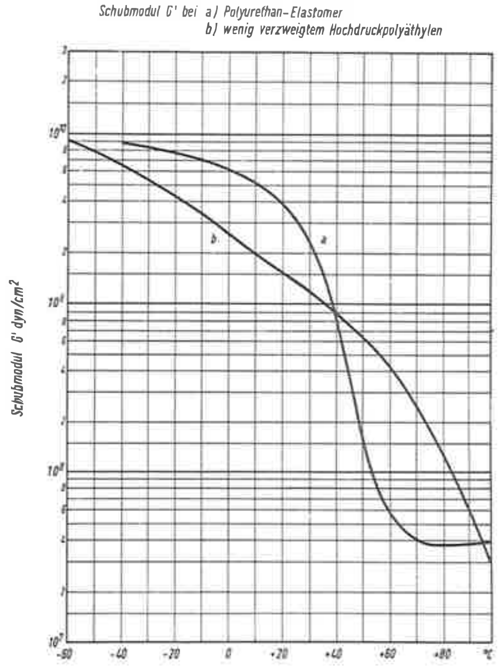


Fig. 23: Modulus in torsion G' as a function of temperature for weakly-branched high-pressure polyethylene (PE) and filled polyether polyurethane (PUR), sprayed

1. Rohrbeschichtung durch schlauchextrudiertes Polyaethylen auf schwimmendem Kleber,
2. Rohrbeschichtung durch aufgesinterte Polyaethylenschicht,
3. Rohrbeschichtung durch extrudierte Polyaethylen-Wickelschicht auf festem Schmelzkleber aus Copolymerisat,
4. Gespritzte Polyurethanbeschichtung in zwei Schichten ohne Haftvermittler,
5. Gegossene Polyurethanbeschichtung in zwei Schichten ohne Haftvermittler,
6. Gespritzte Polyurethanbeschichtung in zwei Schichten mit Haftvermittler.

Versuchsmaterialien

Fig. 24: Investigated coated materials

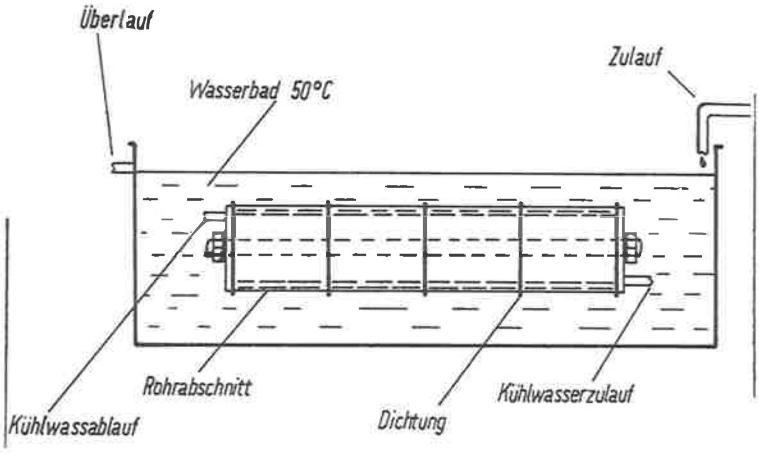
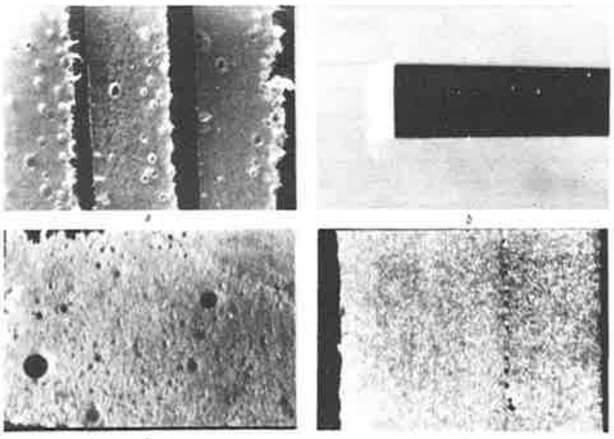
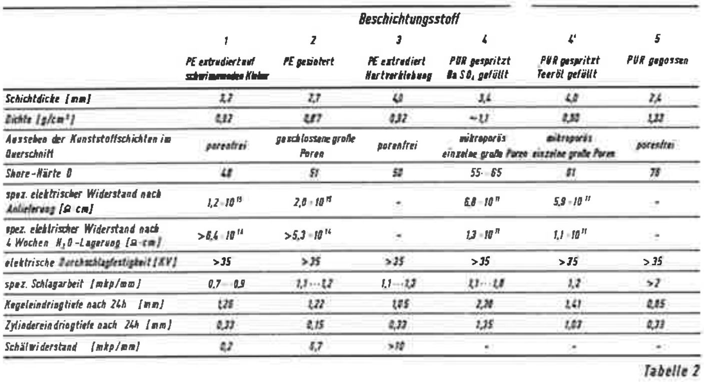


Fig. 25: Stressing of the coating under varying water vapour pressures and temperature



Querschnittsaufnahmen verschiedener Beschichtungen
a = PE gesintert
b = PE extrudiert
c = PUR gespritzt
d = PUR gegossen

Fig. 26: A cross section of the coated specimens



	Beschichtungsstoff					
	1	2	3	4	4'	5
	PE extrudiert auf schwimmenden Kleber	PE gesintert	PE extrudiert Hartverklebung	PUR gespritzt $BaSO_4$ gefüllt	PUR gespritzt Teeröl gefüllt	PUR gegossen
Schichtdicke [mm]	3,2	2,7	4,0	3,4	4,0	2,4
Dichte [g/cm³]	0,92	0,87	0,92	~1,1	0,90	1,22
Aussehen der Kunststoffschichten im Querschnitt	porenfrei	geschlossene große Poren	porenfrei	mikroporös einzelne große Poren	mikroporös einzelne große Poren	porenfrei
Shore-Härte D	48	51	50	55…65	61	78
spez. elektrischer Widerstand nach Anlieferung [Ω cm]	$1,2 \cdot 10^{15}$	$2,0 \cdot 10^{15}$	-	$6,8 \cdot 10^{11}$	$5,9 \cdot 10^{11}$	-
spez. elektrischer Widerstand nach 4 Wochen H_2O-Lagerung [Ω cm]	$>6,4 \cdot 10^{14}$	$>5,3 \cdot 10^{14}$	-	$1,3 \cdot 10^{11}$	$1,1 \cdot 10^{11}$	-
elektrische Durchschlagfestigkeit [KV]	>35	>35	>35	>35	>35	>35
spez. Schlagarbeit [mkp/mm]	0,7…0,9	1,3…2,2	1,1…1,3	1,1…1,8	1,2	>2
Kegeleindringtiefe nach 24h [mm]	1,26	1,22	1,06	2,30	1,41	0,85
Zylindereindringtiefe nach 24h [mm]	0,33	0,15	0,33	1,35	1,03	0,33
Schälwiderstand [mkp/mm]	0,2	5,7	>10	-	-	-

Tabelle 2

Fig. 27: Comparison of several technological properties of thick section coatings of weakly branched high-pressure polyethylene (PE) and polyether polyurethane (PUR) filled with barium sulphate or tar oil in the sprayed and cast states

	Beschichtungsstoffe							
	1	2	3	4		4'	5	
Schichtdicke (mm)	3,2	2,7	2,9	1,9	3,9	2,9	1,4	2,7
Aussehen	o.B.	o.B.	o.B.	stark blasig	o.B.	o.B.	stark blasig	o.B.
Grenzfläche Stahl-Kunststoff	o.B.	o.B.	o.B.	Wasser, kein Rost	o.B.	wenig Wasser kein Rost	Wasser, kein Rost	o.B.
Haftung	geringer Haftungsverlust	geringer Haftungsverlust	geringer Haftungsverlust	totaler Haftungsverlust	deutlicher Haftungsverlust	totaler Haftungsverlust	totaler Haftungsverlust	geringer Haftungsverlust

Tabelle 3

Fig. 28: Effects of 5 weeks' of exposure to water vapour at varying temperatures on coatings of weakly branched high-pressure polyethylene (PE) and polyether polyurethane elastomer filled with barium sulphate or tar oil in the sprayed and cat states

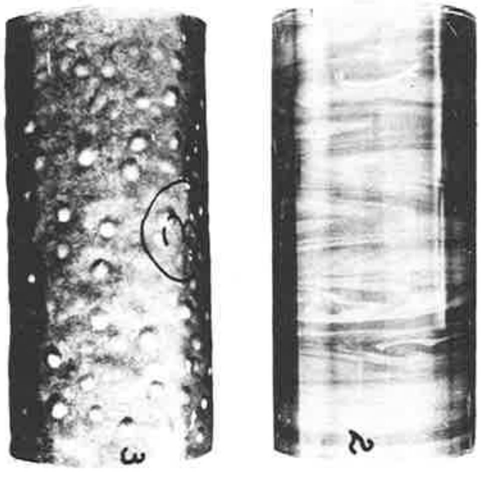
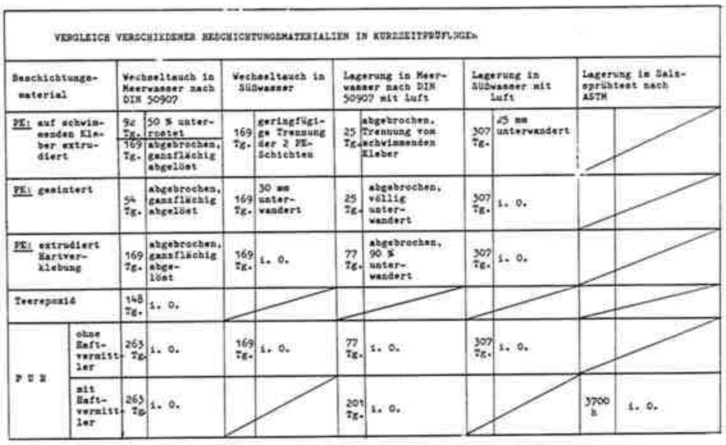


Fig. 29: Sprayed PUR 1,9 mm thick left, cast PUR 2,7 mm thick right



VERGLEICH VERSCHIEDENER BESCHICHTUNGSMATERIALIEN IN KURZZEITPRÜFUNGEN

Beschichtungsmaterial		Wechseltauch in Meerwasser nach DIN 50907		Wechseltauch in Süßwasser		Lagerung in Meerwasser nach DIN 50907 mit Luft		Lagerung in Süßwasser mit Luft		Lagerung im Salzsprühtest nach ASTM	
PE: auf schwimmenden Kleber extrudiert		92 Tg. 169 Tg.	50 % unterrostet abgebrochen, ganzflächig abgelöst	169 Tg.	geringfügige Trennung der 2 PE-Schichten	25 Tg.	abgebrochen. Trennung vom schwimmenden Kleber	307 Tg.	25 mm unterwandert		
PE: gesintert		54 Tg.	abgebrochen, ganzflächig abgelöst	169 Tg.	30 mm unterwandert	25 Tg.	abgebrochen, völlig unterwandert	307 Tg.	i. O.		
PE: extrudiert Hartverklebung		169 Tg.	abgebrochen, ganzflächig abgelöst	169 Tg.	i. O.	77 Tg.	abgebrochen, 90 % unterwandert	307 Tg.	i. O.		
Teerepoxid		148 Tg.	i. O.								
P U R	ohne Haftvermittler	263 Tg.	i. O.	169 Tg.	i. O.	77 Tg.	i. O.	307 Tg.	i. O.		
	mit Haftvermittler	263 Tg.	i. O.			207 Tg.	i. O.			3700 h	i. O.

Fig. 31: Behaviour of coating specimens with respect to infiltration corrosion,
from left to right: hard bonded extruded PE
soft bonded PE
sintered PE
sprayed PUR with bonding agent

DISCUSSION

Question

Dr. Mennenöh has shown himself a powerful advocate of the thesis that plastics and other synthetic materials every now and then prove themselves to be powerful allies of conventional materials, in this particular case: steel. He has also succeeded in showing that often the solution of our technological problems lies in the right combination of materials.

In the course of his lecture Dr. Mennenöh drew attention to the financial side of protection of steel structures and remarked, if I remember rightly, that some of the solutions used today, are rather expensive.

Now I have some experience with epoxy resins - the zinc rich variety and the coal tar variety - which in combination are used to protect steel structures. They may or may not, as Dr. Mennenöh said, be rather expensive, that will depend, for example, on circumstances and specifications.

I would like to ask the speaker a question about the costs of eventual repairs. Even a thick plastic coating on a structure can be damaged, and what then happens with the underlying steel? With zinc rich coatings, there are no problems, as these coatings do protect the underlying steel even over quite broad scratches.

Answer

I am sorry, but I cannot give exact figures about costs, we only have a general idea. When we coat a structure with polyolefine - thickness 2 millimetres - it will cost between 15 and 20 DM per square metre.

Question

What about the protection against damage zinc offers?

Answer

Do you mean protection by zinc in respect to costs?

Question

Yes, and in respect to repairs.

Answer

We have discovered that coating with zinc or aliminium is simply not a solution to the problem of protecting steel structures that are exposed to seawater. You always have to protect the metallic coating with an organic one. So, why should you not use the organic coating as the only protection, even if that means that you have to make it rather thick? The metal coating will only make your costs greater.

Question

How much more?

Answer

Again, I cannot cite exact figures. In our opinion, applying zinc or a zinc rich primer, will cost about 20 DM per square metre, and the application of a top layer of, for example, tar epoxide, will add another 15 DM per square metre. We hope to make our thick polyolefine coatings less expensive than the sum of those two items.

Question

What temperature gradients occur in the thickest layers you are using?

Answer

With resins, we have a maximum temperature differential of 10 to 15 degrees centigrade per 2 millimetres during curing.

Question

I accept that, but in use you will have a temperature gradient in the coating.

Answer

When we started our investigations, we had to use a kind of polyethylene that was only suited to low temperatures. But now we use grades of polyethylene which behave uniformly over a large range of temperatures.

Question

But you have no information about the temperature gradient in the coating when the structure is in use?

Answer

I am sorry, I seem to have misunderstood your original question. We do have information about that subject, and I can show some slides, if there is time for it.

Chairman

Let us do that after coffee,then Dr. Mennenöh can prepare his comments. We will have these slides before the next lecture. Any more questions?

Question

Do you use high-density or low-density polyethylene? These two kinds show a large difference in properties, especially in an abrasive environment.

Answer

We use low-density polyethylene, and at the present moment there are no pressing reasons to start to use the high-density form.

Question

But if I understood your tables rightly, the low-density form simply is not good enough.

Answer

Again I seem to have been misunderstood. It simply is not a question of material, it is a question of bonding. You have to ensure that the coating adheres very well to the underlying metal. If the adherance is not good, water will penetrate the interface between metal and coating, and then you will have corrosion. But if the bond between coating and metal is deep, the coating will prevent corrosion even after is has been damaged. The only important parameter is the adhesion of the polyethylene coat to the underlying metal.

Question

I agree that low-density polyethylene adheres to steel rather easily. But you still have to use bonding agents. What kind of bonding agents do you use, ionomers, copolymers, primers, or something else?

Answer

We use multi-component polymers.

Question

Based on acrylic acid?

Answer

Yes.

Question

If I understood the drift of your lecture fully, it appears to me that you depend on laboratory tests and that you hope they will correlate with behaviour in use under agressive conditions. It is always dangerous to extrapolate from laboratory tests.
You talked about corrosion in an harbour. I would like to point out that there you have not only the rise and fall of the tide, you have too diurnal variations in temperature and salinity of the water as well. In my experience, a changing physical chemical environment is a far more agressive situation than a steady environment, however agressive that may be. Another comment is that the use of artificial seawater has very serious drawbacks. I do not know how you prepare it, but there is in fact no substitute for fresh seawater straight out of the sea.

Answer

I fully agree, it always is difficult to extrapolate from this kind of laboratory tests. That is the reason why we started with projects like that in Bensersiel. There we can study the behaviour of a structure under rather severe conditions. But we are still in the stage of development and testing, as the structure at Bensersiel was completed only in May 1970, less than a year ago. In a few years we will know whether the coatings behave as satisfactory as we hope they will.

Question

Is it known to Dr. Mennenöh that adhesive bonding between polyethylene and metals is enhanced when the bonding layer contains a small percentage of unsaturated fatty acids? This has been published somewhere.

Answer

This is completely new for me. I thank you for this remark and I certainly will tell our scientists at home about it.

After the coffeebreak Dr. Mennenöh presented some slides, about the measurements his firm had carried out on water permeation and temperature gradients in various coatings. The results indicated that at equal thickness coatings of polyurethane were not as good as those of polyethylene. Other results indicated that a good bond between the coating and the underlying metal is of prime importance.

Possibilities of plastics and metals in the packaging industry

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Thomassen & Drijver-Verblifa
Deventer
The Netherlands

If the theme of this Conference had been in the form of a question the answer would have been shortly: both.
In the packaging industry keen competion is a normal picture.
But more and more it is realised that the best technology and therefore also the best marketing policy is to take the best properties of several materials and combine those.

In order to explain this thesis an introduction into the materials involved might be welcome.
First I have to make restrictions, because to cover the whole packaging field would take to much of your time and postpone your lunch.
I want to restrict myself to

1. packages for food with
2. contents up to 5 liters and
3. made of metal and/or plastic

I. METALS

Let us first take those metals important as materials. There are 3 involved, iron, aluminium and tin. As you all know, tin is not used as a single material but as a covering for iron. This combination, timplate, is by far the most widely used metal in packaging. What are the properties determining the use as a packaging material?
I take the liberty to choose only a few viz.:

1. Strength to protect the contents
2. The possibility of forming or shaping
3. The possibility of closing
4. Impermeability to solids, fluids, gases and light
5. Resistance to a wide range of temperatures (low for deep frozen foods, high for heat processed foods).

Considering this choice you might remark that quite a number of important requirements are neglected. To name a few: absence of taste, non toxicity, ease of disposal and so on. However for a comparison of metals and plastics the five chosen properties are sufficient.
Let us consider those five:

1. Strength

It is impossible to define this property physically. The main purpose is protection of the food and therefore it can only be defined in connection to this. Therefore in one case a very rigid material is necessary and this rigidity of course could be specified. In another case however flexibility would be an advantage or certainly not a disadvantage. I have to mention only "shrink packaging" to give you an example.
Apart from this, for a package there is also the important unmeasurable "feel". I could not better explain this than by showing you a package of applesauce in a flexible pouch.
You can imagine the reaction of the customer!
However a pouch of milk is an existing package and mayonnaise is also sold in a pouch.
So a general rule cannot be given, but steel (tinplate) has good strength and aluminium also, but less for the same thickness.
Consequently, even taking the lower specific weight of aluminium into consideration, aluminium is more expensive for the same strength.

2 and 3 Forming and Shaping/Closing

I have taken points 2 and 3 together, because the same reasoning applies to them. The technology of manufacturing articles from metal is very old compared to that from plastics. It is therefore clear that the production of metal packages is more advanced then that of their competitors (or should I say allies ?)
Forming and closing is very easy in the case of tinplate containers and machinery for great speeds is used.
For tinplate the joining by solder gives this metal an advantage over aluminium, for the latter material the formability is easier (impact-extrusion, deep drawing).
Two new methods of forming are developed in the U. S. A., viz. gluiing and welding of the sideseams.
This makes the use of steel without tincoating possible (this material is called "tin free steel") and offers a slight price-advantage to the users.
Welding of aluminium is also possible, but high-speed welding of containers of aluminium is not (yet) a commercial operation.
Closing both metals using the well-known doubleseaming technique is a very well controlled operation.

4. Impermeability

In the thicknesses used for rigid packages the 2 metals are completely impermeable to influences from the surroundings. For solids and liquids this goes without saying, but also for gases as oxygen and also for light. The combination of oxygen and light is inducing fotosensitive changes in many foods and therefore many efforts of the packaging industry are spent to eliminate or reduce this effect.

5. Temperature resistance

Without going into detail about conservation methods, I have to take a little of your time in explaining the two methods of conservation of foods important in this connection.
The first one is heat sterilisation, aimed at killing all bacteria and spores in the container. The conditions for this process are rather severe, viz. up to 120 - 130° C during 1 hour or shorter at higher temperatures.
The second one is deep freezing. This process does not kill all bacteria and spores, butpostpones the multiplication at low temperatures. For the two metals in question both conservation techniques give no problems.
We might take into consideration other processes for conservation, as freeze-drying, radiation and aseptic filling. However these are not applied to the great majority of foods and therefore I will not spend more time on discussing these.
It is clear that metals give no problems for the two types of conservation.

II. PLASTICS

Let us see now where plastics fit in.
First a word about the two groups thermohardeners - thermoplastics.
Considering the materials in the first group and the productionprocess for making articles, I do think that time spent in evaluating their possibilities is wasted. The cheaper representatives are lacking the essential qualities of strength (brittle), have a bad odour and can only be made in darker colours, the more expensive materials are not only expensive as raw material but require a slow and costly production process. As closures e.g. for bottles and tubes thermohardeners are used. Thus only certain thermoplastics have to be discussed. For insiders in the plastics world the following materials are in my mind:
Polyolefines, PVC, Polystyrene, PVDC, Polyamides and Polyethyleneterephtalate (Polyester).
Where do they stand with the five criteria ?

1. Strength

Defined as rigidity it is clear that the thermoplastics are in another class! If taken as resistance to shock however or impact resistance, some plastics easily beat metals. I have seen filled bottles of rigid PVC drop from 4 meters high and still look the same and I am sure you know many more examples. Conclusion is therefore that as a class metals and plastics have their pros and cons and one cannot speak of a winner.

2. Forming and shaping
Here the thermoplastics group certainly has an advantage.
It is well known that the possibility for shapes in plastics is nearly unlimited, while in metal the cylindrial shape is predominant. However I have to remindyou that production speeds are much lower than with metals, not only because the technology is young, but also because of the well known fact that heating and cooling restrict the productioncycle so much that large speeds are impossible.
The only way to increase production is to multiply the number of machines or moulds.
As an example: Thermoforming machines nowadays can make e.g. 1500 articles per minute, but are equipped with up to 80 moulds.
An interesting phenomenon is that the plastics industry tries to adopt techniques from the metalindustry. Example: cold deepdrawing done on a normal excenter press and with tools derived from their metal colleagues.

3. Closing
As all packages for foods have to be closed hermetically, this operation is as important as the manufacturing of the package itself. In principe this is a very natural operation with some type of sealing and although it is not always as simple as that, there is not a real disadvantage here compared to metals.
However for the production speed, the same remarks can be made as above: double seaming is a very fast operation ! (50.000/hr)
When a package is closed, it has to be opened again. The time of convenience asks for features as "easy opening" devices. The easy opening of beer- and soft drink-cans has opened a big market for aluminium, because this construction in tinplate is not (yet) possible.
When thinking of plastics, my thoughts go to easier opening and many ideas are already realised or will be in future. Example "Pealable seal" in which a completely hermetic seal can be peeled open relatively easy.

4. Impermeability
Now here is the first problem for plastics!
All thermoplastics are more or less permeable to gasses and light, so in absolute sense no representative of this group could meet the requirement.
The plastics industry however learnt very quick that there are great differences between the various raw materials, as the following slide (Fig. 1) shows.
So the choice of material became important. Moreover they could combine two or more materials in order to obtain a number of properties "tailor made" for the particular application. (Sometimes even high permeation is wanted, as e.g. when packing fresh red meat. This needs enough oxygen to maintain the red colour associated with "freshness".)
The requirement of absolute impermeability is necessary, when a food has to be kept for a very long time e.g. a year or more. In that case plastics and metals become real allies, because the best way of reaching this is a combination of aluminium and one or more plastic films. So a development of which our American colleagues are rather proud is the "Astronauts Menu", the food taken with Apollo 11. (Fig. 2).
This proves undoubtedly that a package can be made for foods with a long shelf life, but quite different from the conception of the "tincan". This "Flexible Can" can be manufactured on existing equipment and could be used for many heat processed foods.
It has the advantage that the processing time can be reduced compared to a metal can, so that the taste of foods in some cases is better than in cans.
If this package has such big advantages, why they does this flexible can not replace the rigid can? These are a number of reasons for that of which the main are:

1. The technologies of filling, closing and sterilising are not yet enough developed;
2. The expenses of package and handling are high;
3. There is reluctance to adopt this package from bacteriological point of view; it is easier damaged than a rigid can and therefore greater risk is involved.
   For acceptance by the normal consumer (as opposed to an astronaut) a mechanical protection is necessary, e.g. in the form of a carton.

It is my opinion, that in a few years time this package (which is on the market on a small scale) gradually will reach a commercial stage.

I have a few samples here. But before that, very much work has to be done. I have to mention here the work done by some aluminium companies. They suggest a laminate of heavier aluminium foil with HDPE or PP.

Although this conception does look more like a "can", the remarks given apply also, because these packages have not the strength associated normally with a fully processed food.

5. Temperature resistance

If we try to meet the requirement of resistance to sterilisation, it is clear that a few victims fall from the list I mentioned earlier.

These are low Density Polyethylene, PVC, Polystyrene and PVDC.

The remaining "happy few" are High Density PE, Polypropylene, certain Polyamides and Polyester. I will try to eliminate one candidate more viz. the Polyester-group. In laminations, this group certainly has its merits, but packages made on other ways are not (yet) possible on an economic way. On the other side, I could add now as examples other plastics as Polycarbonate and Polymethyl pentene (TPX). They posess the required temperature resistance, but they fail on other points, mainly because their permeability is high.

Moreover their price is high compared to the conventional materials. The now remaining candidates are Highdensity PE, Polypropylene and Polyamides 11 and 12.

Now let me elaborate some time on an example. Suppose somebody wanted to know if a can for ham e.g. 5 lbs in the familiar oval style could be made from plastics.

First we would make a list of requirements and then we would probably say:

No this is impossible.

However: Here is one, which seems to become popular in the U.S.

What is the explanation?

There are 3 reasons why in this particular case a can of HD Polyethylene is completely satisfactory.

1. The product is pasteurized at say 80° C, so the temperature requirement is no problem.
2. Because the ham is pasteurized it has to be kept under refrigeration (4° C). At this low temperature permeation of oxygen is very slow.
3. Because it is a rather large piece of meat, it needs a stiff container, therefore a high wallthickness: Permeability no problem.

Another interesting combination is a Japanese idea: A can with fruits in syrup with a transparant lid of Polycarbonate.

For the second type of conservation; deep freezing, there are also restrictions on materials.

Examples are Polystyrene and Polypropylene becoming brittle at low temperatures.

It is fair to say however that Polypropylene is improved very much and also certain types of Polystyrene can be used.

However I will not trouble you with more plastic names, but return to the original subject.

SUMMARY

Competitors and Allies

It is evident that the packaging industry realizes the possibilities of all available materials.

Many succesfull developments have proven this point and many more will follow. A very good example of how complex a packaging problem is, is the packaging of milk. Collect-

ing the litterature about this subject for some time one can see that not one, but many solutions are possible.
Packaged pasteurized milk can be found in coated paper, returnable glass, Polyethylene pouches (one or more layers), blown bottles of Polyethylene and thermoformed cups of Polystyrene.
The only material not present is . . . metal!

Mr. Chairman, I hope to have made myself clear although I realise that I have only given a very restrected view on the matter. If there are any questions I will gladly try to answer those.

HOW DOES IT WORK?

Dubbed the "Lunar Lunch Box," new flexible foil-and-film pouch was designed by Continental Can Company for Apollo astronauts. To eat from it, astronauts snip off end with scissors and spoon out contents. Sample menus include turkey with gravy, and beef with potatoes. The pouches and their contents are "retorted," or cooked and sterilized, just like canned foods. They were taken along on the Apollo 11 Flight to the Moon.

DISCUSSION

Question

Seeing the tremendous progress the packaging industry has made and seeing that the packaging of food has been perfected to such an extent, we may stand at the beginning of a new development. At the moment, there exists already food, packed in such a way as to eliminate the need for cooking utensils and dishes. Do you think think that this is a portent for the future?

Answer

It is a difficult and challenging question, as it is very difficult to predict what will happen in the long run. A good approach is to look what the customer might do. It is known that customers like convenience and are prepared to pay somewhat more for it. This has happened with respect to cans, for if you look honestly at it, a tin can is a rather nasty thing to open. So the industry developed cans that are easy to open. They are a bit more expensive, but they have been accepted by the public because they are convenient. Now we have already whole meals, packaged in such a way that they can be cooked in their containers. But whether this is a portent of the future, whether it will replace the existing methods of preparing a meal, that is something I cannot predict.

Question

Today, one of the main problems is environmental pollution. Are there new plastics who do not have the disadvantage of never vanishing?

Answer

This is a question that either calls for a lengthy, or for a very short answer, and I have to opt for the latter. The packaging industry is very well aware of the pollution problem, and realises that it is partly responsible for the problem. The industry - in Europe and America - is aware of it and is doing quite a lot of research to solve it. One possible solution is the development of plastic materials that are bio-degradable. But we are at the moment in a strange situation. For tens of years we asked the chemists to give us better materials, with lower permeability, better resistance to organic acids and what not. Now we have to tell them that the plastics they developed are very good as packaging materials, but are wholly unacceptable from the environmental point of view. That is the problem in a nutshell. Metals have an advantage over plastics as they corrode rather easily.

Remark

Not everybody will agree with the last point. Metals are not bio-degradable and their corrosion products are endangering the environment.

Remark

I would like to make a point in connection with bio-degradable plastics. Quite a number of environmental specialists think that it simply is not a solution to the problem. Technically, the development of these plastics is an extremely tough proposition. But even if we could develop them, we might be worse of in the long run. One of the pleasant things about modern plastics is their biological inertness. When left by man, they are an eyesore, they can smother plants, but they do not fertilize the environment. If they are any good, bio-degradable plastics will do just that, and then we may have on our hands a problem of pollution of unforeseeable dimensions. In my opinion, for the moment education of the public is the best solution. We can teach man not to regard his environment as a receptacle for his filth. It has been done in the United States, and the slogan 'Don't be a litterbug' has been remarkably successful.

Question

I fully agree with the previous remark about the dangers of starting to use bio-degradable plastics. Although the theme of the conference is metals and plastics, I would like to ask a question about glass. How does the speaker regard glass as a packaging material?

Answer

In the first place, I would like to say that I, too, fully agree with the remarks on the dangers of using bio-degradable plastics. As was remarked in the question, glass is not the subject of these conference, which is devoted to plastics and metals. But I can say a few things about this packaging material. It is a very good material, which has a big share of the market. The glass industry is doing a very good job in improving its properties and I think the industry has not reached the end of that road yet.

Question

Can plastics compete with tin free steel as a packaging material for soft drinks?

What do you mean with 'soft drinks'? The carbonated variety?

Yes.

Answer

In the United States tin free steel is used to package carbonated soft drinks, but they had to solve a number of nasty corrosion problems. Also, American firms have developed new materials which seem to be very promising, but they are still in the trial stage.

Question

You said that it is possible to replace a tin can by a plastic one. But you solved the question of easy opening in the same way as with a tin can. So what are the differences between plastic and tinplate? Is the one cheaper than the other?

Answer

Now I have to go somewhat deeper into this. Some packaged foodstuffs are very aggressive on tinplate. We have to do something about that and we put in an anode of aluminium alloy to protect the tinplate by electrochemical means. Concerning the devices for easy opening of a can, they are mostly made from aluminium. Then you too get electrochemical effects which cause corrosion and which have to be suppressed. Strange as it may seem, an aluminium top on a plastic can still can give rise to corrosion problems. It is possible to suppress that by using an aluminium anode.

Question

But what about the costs of tinplate and plastic?

Answer

I am not wholly sure about actual prices, but the plastic can is competitive with the tinplate one.

Remark

Just a small remark about the question of convenience of opening and use in the kitchen. As a man I am often confronted with the really difficult things, and they turn out to be always plastics. My wife can open any metal can, but some plastic containers give difficulties. Then she has to use tools of the workshop, rather than of the kitchen. Plastic screwcaps are an example. Secondly, my wife prefers the old fashioned glass bottle for milk, because any other type of package makes a mess of the kitchen. So I think that the industry could devote more research to convenience in the kitchen.

Answer

Do you have a specific example?

No, I didn't bring my kitchen with me.

Remark

The question certainly came from the metal industry.

Question

Till now, we have been discussing plastics, metals and glass as packaging materials. But are not we forgetting to discuss how the consumers think about the whole thing? Consumers have found ways to organize themselves and they are often quite vociferous.

Answer

You are quite right. We had developed a new package some time ago, and we wanted to know how the public would react. So we engaged a marketing firm that sampled our potential public. We were quite amazed about the answers to the questions, they differed greatly from what we had expected. We have studied the final report, but we simply don't know what we should do now.

Question

I would like to make a few comments on the waste and litter problem. The Society of Chemical Industry has made a study about it and has published a monograph. The problem of plastic waste certainly can be solved by using special containers which can be crushed easily. The crushed waste then can be burned in special furnaces. This leaves the litter problem unsolved. Now it has been said that one can only surmount this by education, but as far as I know there exists in the United States a soft drink manufacturer who buys back plastic bottles merely for the purpose of destroying them. This clearly is a move in the right direction. Another thing we ought to do is to print on the package a short advice on the right way of disposal. Does the speaker think that this may help to solve the litter problem?

Answer

Yes, certainly. But I must add that the soft drink manufacturer in the United States got only about 10 per cent. of his plastic bottles back, as far as I know. Maybe the deposit was not high enough. As to your second remark, we are wholly in favour of printing on the package a short advice about the right ways of disposal. But as a manufacturer of packaging materials, we cannot do very much about this. That is up to the people who use our materials. We can urge them to do it, but we cannot force them.

Remark

There is a good example - the aerosol can. These cans were getting a bad name because of explosion dangers and so on. Then the aerosol industry in many countries, including the Netherlands, started to print on these cans a short advice about use and disposal. This has worked very well.

Question

What about the subject of toxicology? If I am well informed, the Dutch government is preparing a law on this.

Answer

Can you be somewhat more specific ? Do you mean the toxic properties of all packaging materials ?

No, I meant the migration of atoms or compounds from the packaging material into the food packed.

This is a very big subject, but I can give a short survey. The metals aluminium, iron and tin have been known for a very long time and have been studied extensively. Under normal conditions these materials are not dangerous at all. If the food to be packed contains aggressive substances, you can always laquer or coat the metal. The pick-up by food of substances from plastic materials too has been studied intensively. The Dutch government intends to regulate by law which materials may be used for packaging food. The draft of the law has been published and it prescribes all kind of tests on the migration of compounds from the packaging material into food. It still has to be passed by Parliament.

Pipe crosses river

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Some time ago I was asked if it would be possible for Wavin N.V. to contribute to a conference, discussing the subject "Plastic and Metals, allied materials", allies and competitors.
Our factory is mainly manufacturing plastic pipes, mostly made of PVC. We do know the properties of all other kinds of pipe as competitive materials, but, on the face of it, allied materials are not our business.

Yet, I decided to accept the invitation and I have chosen as my subject to discuss an application, at which properties of steel and those of PVC are combined, namely, the high corrosion resistance of PVC and the great strength of steel.
I am going to describe to you a project, at which we delivered the pipes for an underwater main across one of the Dutch rivers.

Description of the project

In the summer of 1964 our factory was invited to deliver the pipes for the watersupply in Zealand Flanders.
In figure 1 you see in the south-west the Rhine-Scheldt delta.
An underwater main for watersupply, consisting of pipes diameter 40 cm for 6 atmospheres working pressure, had to be laid across the Scheldt. In figure 2 it is shown that the track has to pass a wide part of the river Scheldt more or less an estuary.
In figure 3 it is shown that the track of the underwater main was rather complicated.
The underwater main mainly consisted of a part 2 to be laid through the mud flats, lying at the east side, a territory which will be flooded in winter, and where we had to reckon with the future Rhine-Scheldt canal, whose track had not yet been determined, and a part 1 to be laid across the fairway of the river. The other parts are not of interest for the discussions.

The underwater main had to be pulled across this river in August 1965, in combination with a steel underwater main for high pressure gas transport, to be laid in the same trench. The time of pulling was determined by the season. The length of part 1 of the underwater main is 1.700 m and that of part 2 800 m. The depth of the Rhine-Scheldt canal was about 5,40 m below the average water-level and the deepest spot under the fairway is 23 m.
The organizations involved in a project like this are:

the principals
the designer
the combination of contractors performing the job
the suppliers of the pipes

Choice of material

We are now going to discuss the possibilities of the combinations of materials to be used for such a water-main. They have been summarized in figure 4.
In choosing the materials mainly 3 facts had to be considered:

firstly the tensile stresses, occurring when pulling over the underwater main;

secondly the corrosion caused by the salt water at the outside of the pipe;

thirdly the corrosion caused by fresh water at the inside of the pipe.

The possibilities were:

a) A steel pipe provided with an asphalt cover at the inside and a layer of concrete at the outside, meeting all requirements. This pipe can stand the tensile stresses and is protected against corrosion by fresh and salt water at the inner and at the outer side.
b) A PVC pipe not meeting all requirements. It is not strong enough, namely, to stand the tensile stresses occurring when it is being dragged across the bottom of the river, but it has a very good resistance against the corrosion of both fresh and salt water.
c) A combination of both materials: that's to say a PVC pipe with a steel mantle, so that the advantages of the very good corrosion resistance of plastic are being combined with the strength of steel. The weight of the steel pipe can also add to the load necessary for the sinking of the plastic pipe.

From experience, the principal, having applied much PVC pipe already, chose possibility b) for the underwater main across the Rhine-Scheldt canal and possibility c) for the part across the fairway of the river.
Next the method by which the pipes are being joined is very important. In figure 5 the various possibilities have been indicated, namely:

- a cemented joint be means of a double coupler; this joint can absorb axial tensions, but the construction on the job-site is less safe;
- a joint by means of a double coupler and rubber sealing rings; this coupling cannot absorb axial tensions but this method is safe and simple;
- lastly a tensile resistant coupler by means of a specially constructed socket to be sealed with rubber sealing rings and being able to absorb the axial tensions. This method is expensive.

This last construction was chosen for the pipe line.

Description of the underwater main

The laying of the first part of the underwater main across the fairway was going to be performed by dragging the pipe across the bottom of the river. As already mentioned the tensile stresses calculated were of such a nature that it was necessary to reinforce the PVC pipes with a steel mantle. Figure 6 gives the proposed construction of the pipe. A steel pipe with a PVC pipe within and the space in between filled with reinforced concrete. The PVC pipes joined by means of the tensile resistant couplings. The steel mantle and the reinforced concrete were not only necessary because of the strength but also to enable us to sink the pipe. The water in the trench has a higher specific gravity of about 1,8, caused by the sand thrown up during the dragging of the pipe.

The second part of the underwater main had to be laid in that part of the mud flats, where in future the Rhine-Scheldt canal would be built. To this end a trench of about 800 m in length was dug out in view of the uncertainty concerning the track of the future canal. The depth was 5,4 m below the average water-level.
This part of the underwater main would be constructed as a floating main. The tensile stresses, occurring at this, would not be so heavy that a steel reinforcement was necessary; therefore the second possibility was chosen, namely, PVC pipes of 20 m length with tensile resistant couplings. This part of the main was being constructed to a total length of 800 m on the dry part of the mud flats.
The pipes were put on sleepers and bound to each other by means of a steel construction. After this the main was suspended to lorries and then being pulled across the trench.

In figure 7 is given the sinking scheme of this floating main; in phase 1 the remaining underwater weight including the ballast is clearly negative; also in phase 2, during which the outer pipes of underwater main combination are being filled with water, the main is still floating, whereas the underwater weight is becoming positive, when in phase 3 the inner pipes are being filled so that the main will sink.

Tests

The next item to discuss are the tests done beforehand. These are indicated in figure 8. In the first place a pressure test of the tensile resistant coupling. In this test the coupling was being placed between two straight pipes, after which a three point bending test was performed. It appeared, that, when the pipe was put under pressure, burst occurred in the socket at a curvature radius of 50 metres. This indicated, that the required curvature radius of 150 metres could be amply exceeded.
In the second place a bending test under vacuum, at which a curvature radius of 23,5 metres could be reached without any trace of collapse. So, it was taken for granted, that any possible vacuum occurring in the pipeline would never have any reverse effect.
Finally a PVC pipe at the inner side of a steel mantle, at which the space in between was filled with concrete, was tested. A length of pipe of 60 metres was put under a pressure of 10 atmospheres for one hour; one of the ends of the pipe was pulled up; at a difference in height of 2 metres the curvature radius appeared to be about 400 metres on a length of 8 to 10 metres in the middle of the testpipe. At a difference in height of 2,7 metres between both ends, flowlines appeared in the steel and the curvature radius had sharply decreased to 90 metres at that spot. After a part of the mantlepipe had been removed from the spot where the smallest curvature radius occurred, it appeared that the reinforcement in the concrete was displaced. The concrete did not stick to the PVC pipe.
In this position the pipe was again put under a pressure of 10 ato whereafter in about half an hour, burst occurred in the socket. This was considered to be a positive result.

After part 2 of the underwater main, 800 metres in length, had been put together, it was pressurized up to 10 ato. There were many troubles which should not have come out when the problems with a project like this were sufficiently considered.
It appeared namely, that the pipe put on sleepers had so much friction-resistance, that alterations in length, during the pressure test occured shock wise as a result of which great quantities of water began to move. This caused burst in the endcaps and in some of the sockets.
It also appeared, that the pipe very often contained air during the pressure test. It is known that this may also cause great local stresses as a result of which too large tensions will occur. After these troubles the sockets and the joints were being repaired, so that the pressure test was quite successful at 6,5 ato, in some cases the pressure was increased up to 10 atmospheres.
Nevertheless the customer did not completely trust the joints concerned and a new construction to support this joint was being looked for. The solution was found in putting steel clips around the pipe and the joint. You will also see them in the film. It was at that time impossible to develop new types of joints, because the end of the season was approaching.

The pulling-over of the underwater main and the final pressure test

I need not say much about the pulling-over operation; it took us two days. You will get an impression of it in the film.
After the underwater main had been pulled over and after it had been sunk, it was being ballasted with gravel and clay. Then the pipeline was being tested again under pressure. It appeared, that fracture had occured in the pipes. An investigation carried out by divers proved, that the location of the fracture was at one of the slopes. The end of the pipe was frayed and the distance between the two ends of the pipe was about 50 cm; under the pipe was a space of about 40 cm.
Calculations made afterwards proved, that the damage was most likely caused by the fact, that the pipe was not supported and heavily loaded at that spot. The calculated maximum tensile stress exceeded the tensile strength of PVC. The pipes were byond repair; the material was lost. Later on, an underwater main consisting of two PVC pipes, partially covered with steel pipes, was laid on the same spot. The steel pipes were joined by means of welded strips.
All this caused the principal to change the material for part 1 of the underwater main. The steel pipe construction was chosen (see figure 5, possibility 1).

Conclusions

I should like to draw some conclusions:

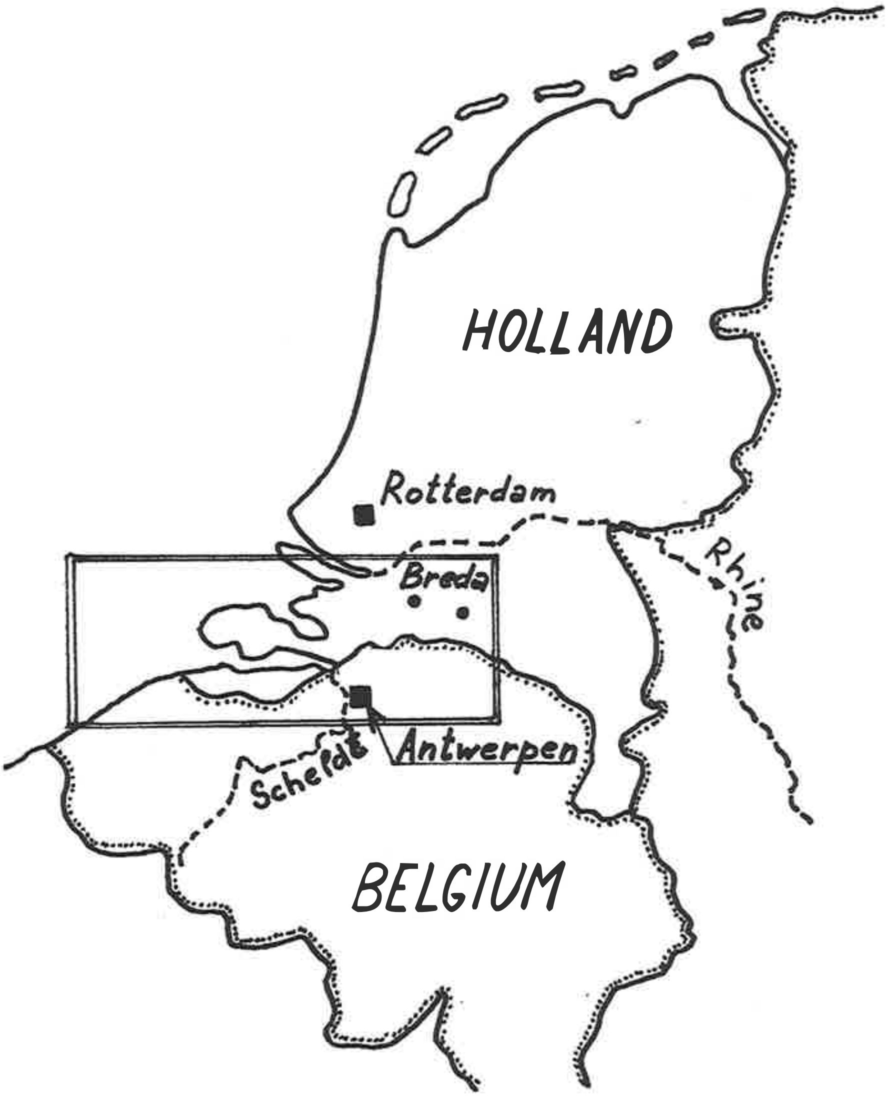
1. I discussed an example of plastics and metals, allied materials, at which we made use of the greater strength and the heavier weight of steel when the project was being performed, and of the good corrosion properties of PVC when the pipe was in normal operation. The PVC pipe is deeply buried under the bottom of the sea; the steel pipe has done its duty and may rust away.
   From this example it will be clear to you, that also in the field of pipelines good constructions can be made, by applying traditional and modern materials.

2. In the case described fracture in the underwater main could have been avoided. This damage was most likely caused when the trench was being filled. Based on our experiences acquired and the improvements of the constructions in the last few years, we have every confidence in performing such a project again.

3. From this, for our use in 1965 great project, we learned that it is necessary to appoint a project leader for any kind of greater projects. The task of this employee will be the supervision of the planning, the preparation and the realization of the project. He will have the possibilities of calling in the assistance of all departments of our factories, Central Development Department, Product Development Department and the respective internal and external counsellors.
   It is also necessary, that with this kind of projects from the very beginning good cooperation arises between the Commercial Department and the project leader on the one side and the customer and the other organizations concerned on the other side. Besides, the supplier of the materials has to insure all risks, in case damages should arise.

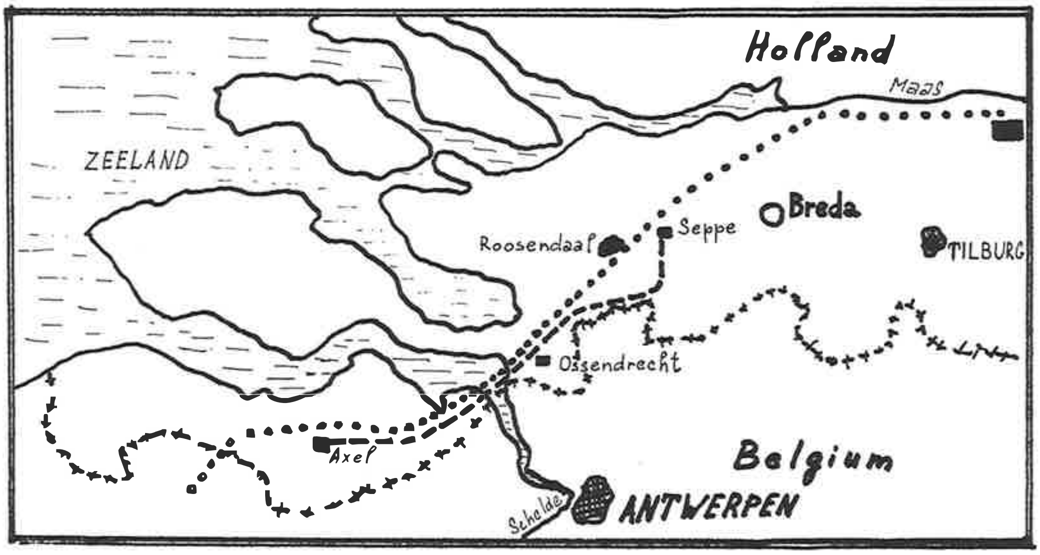
4. From experiences acquired with underwater main constructions for water supply, for low pressure gaspipes and sewer-pipes, it still appears, that PVC is one of the best materials.
   Other plastics too can be used to this end and especially I have to draw your attention to high density polyethene, which can be extruded in long lengths and diameters and can be joined by means of welding or special couplings.
   In any situation the material should be carefully chosen, so that an optimal use of the properties can be achieved.

Fig. 1.



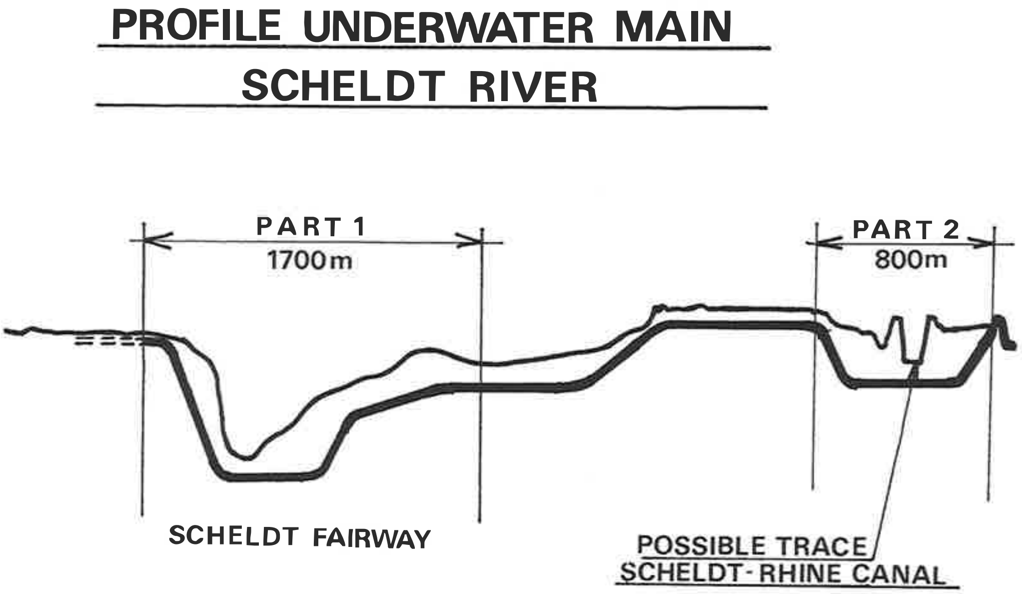
1. Map of Holland

Fig.: 2



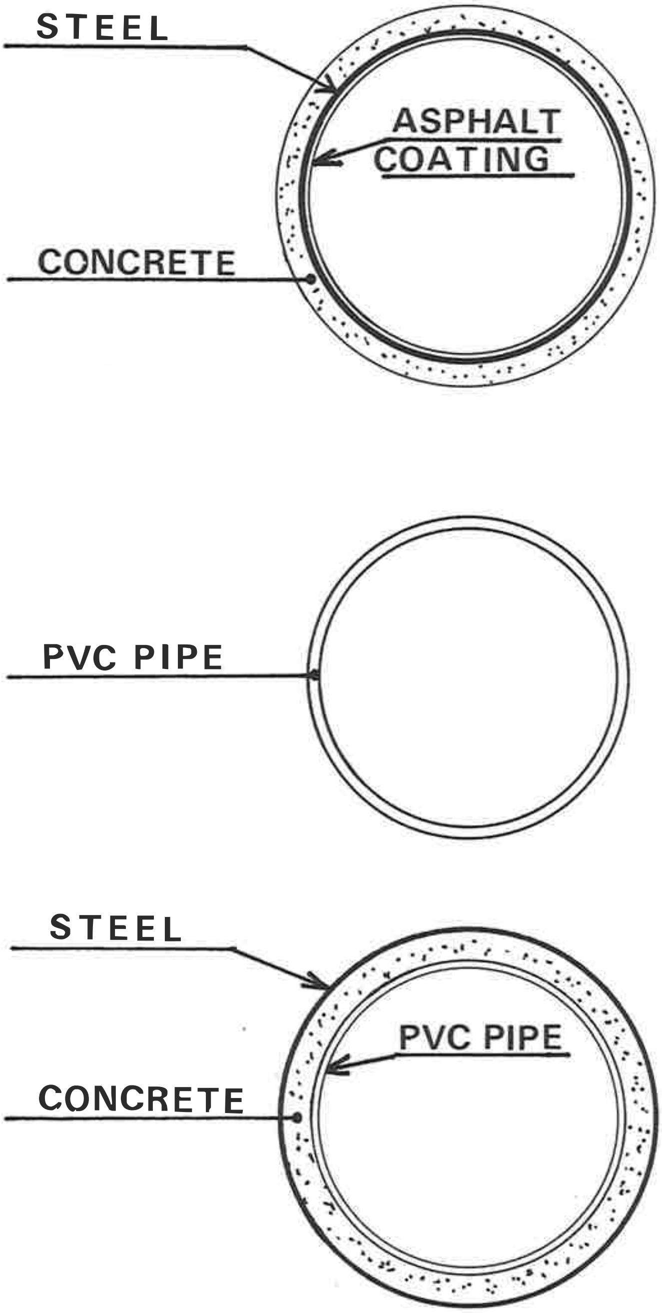
2. Rough map of the track

Fig. 3.



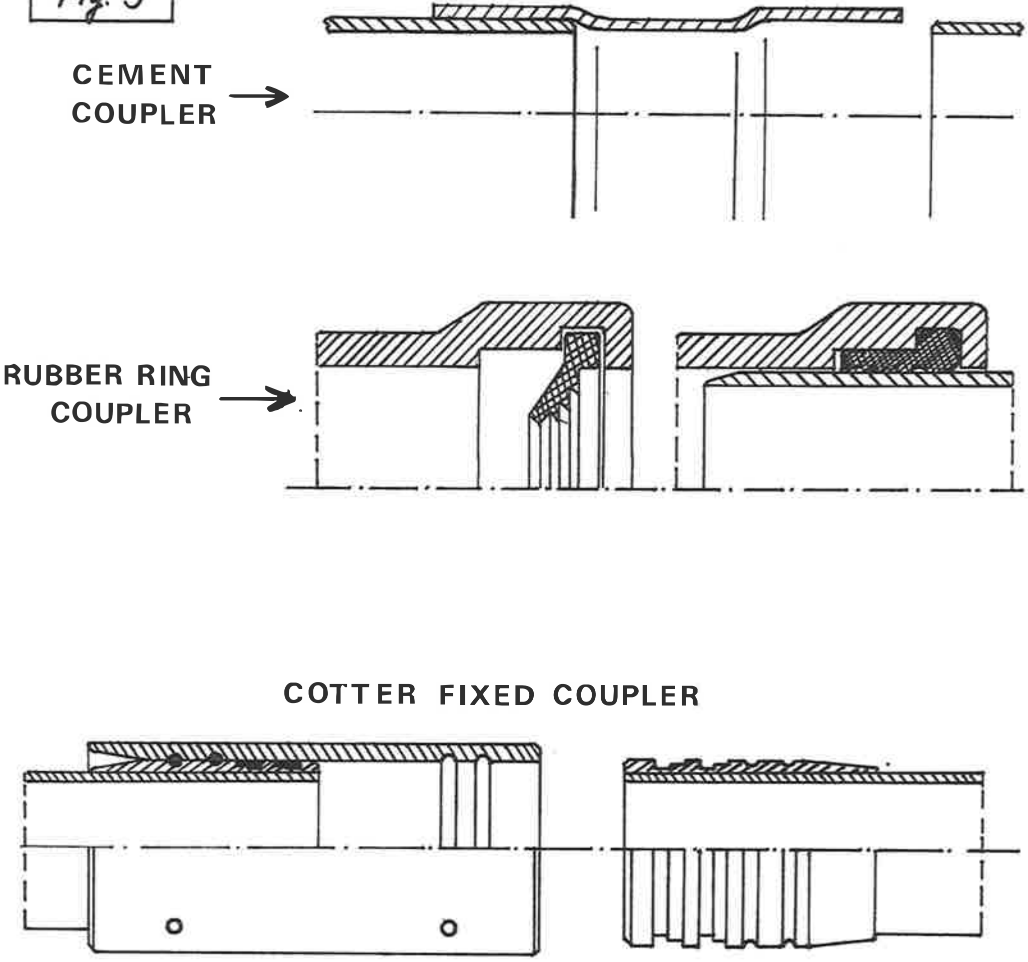
3. Cross-section of the whole underwater main

Fig. 4.



4. Possibilities for the choice of material

Fig. 5



5. Possibilities for the coupling of the pipes

Fig. 6.

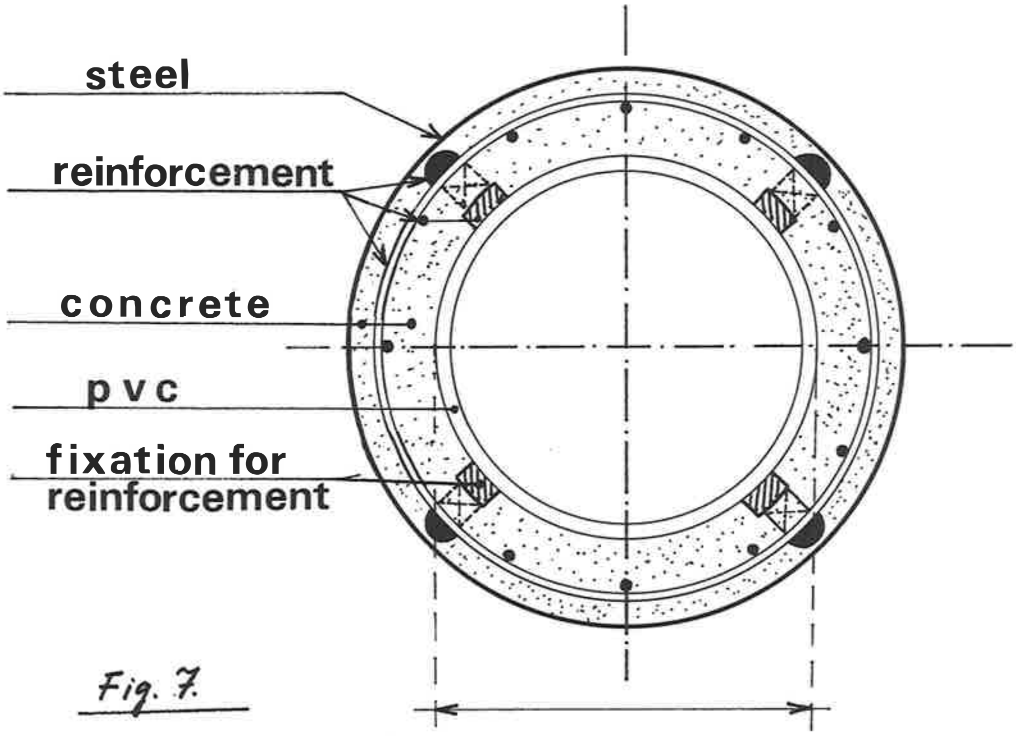


Fig. 7.

6. Pipe construction of the underwater main

7. Testing of the various parts

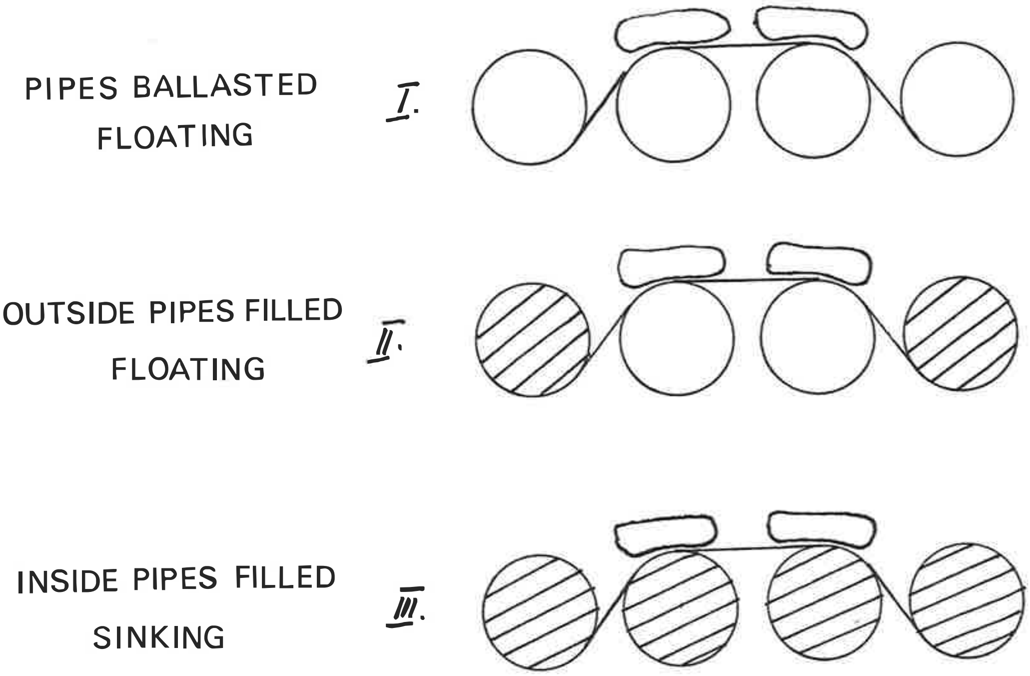
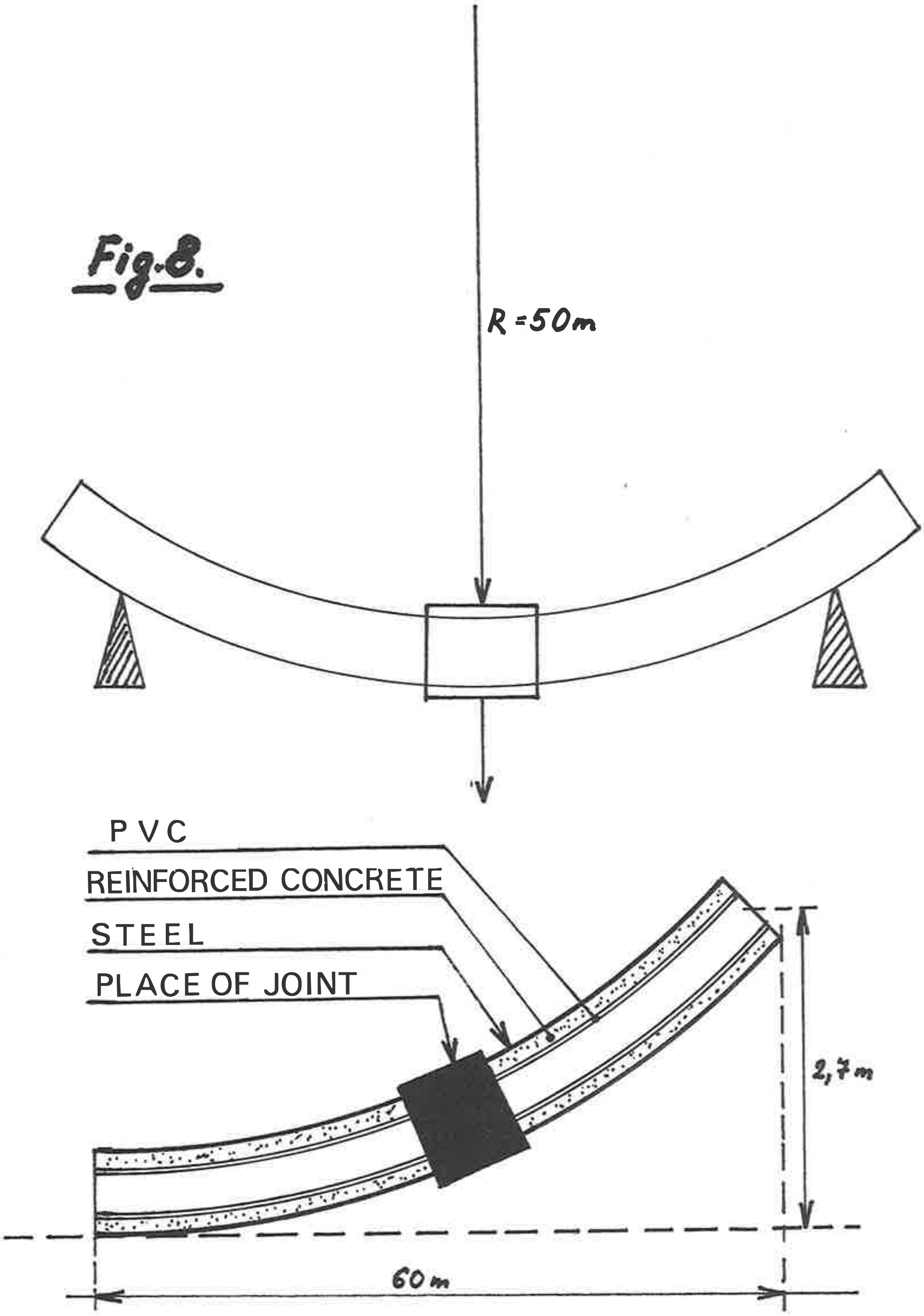


Fig.8.



8. Scheme of the sinking of the floating main

Field Joints in Polyurethane insulated Pipes

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Introduction

The use of insulated pipelines has increased during the last few years both for the transport of hot and cold fluids. Several types of insulated pipelines have been and are being used, some of them of considerable length.
As insulation several types of material have been used.
Without claiming to give a complete summing up I would mention: Glass fibre, Glass wool, Glass foam, Concrete foam, Rock wool and last but not least Polyurethane foam. Most of these products are used in the form of half shells, a few of them, concrete foam and polyurethane foam, can be applied as one uninterrupted insulation. This must be considered as a big improvement as half shells never fit very closely and small gaps and slits can hardly be avoided. All these irregularities influence the insulation and diminish their quality.

We compared several types of insulation materials. We insulated pipes with several different materials in such a way that in each case the heat loss through the insulating layer was the same. In this type of test polyurethane foam gives by far the best results. Time does not permit to discuss the results of this test more fully.
I would only mention that the λ factor or the K-factor (if either metric or British system is used) is dependent on the temperature. At higher temperature the heat conduction of polyurethane foam has a higher value. This property is also related to the density of the foam, the lower the density the better the insulation, but at low densities the mechanical properties are also lower.
For good insulation properties it is important that the cellstructure of the foam be closed. These cells contain in most cases freon 11 (trifluoro-chloromethane) a substance that has excellent properties for our purposes; it is a bad heat conductor.
It is obvious that there should be few or no open cells in direct communication to the air in order to have a high insulation value. The temperature of the jacket varies depending on the conditions, i.e. ground temperature and level of water-table.
With a temperature of 120° C of the fluid in the carrier on dry summerdays and at a depth of about 150 cm pipe we found jacket temperatures of about 40° C. In winter under wet conditions and a circulating fluid of 100° C we occasionally found about 10° C. The most important mechanical property is the compressive strength. To keep the carrier pipe plus its load in the original concentric position this compressive strength - at a temperature under operating conditions - must be high enough. More precisely it is the resistance to creep which is important in this respect.
Very little is known until now about this property. It can be said that high compressive strength and good creep resistance are interrelated.
Now a few words about the chemistry of polyurethane:
Urethanes are the reaction products of 2 substances containing respectively a hydroxy group and an isocyanate group. The urethanes are stable products and in its formation no by-products are formed. If the two substances contain instead of 1 active group, two or more per molecule high molecular products are formed (polymers). The properties of these polymer urethanes or polyurethanes depend upon those of the original components (polyols and isocyanates).
More active groups per molecule can give more bands in the final product. If these groups are part of stable and rigid molecules the final products can be rigid and strong. Polyols derived from molecules with ringstructures like glucose can give very stable structures after reaction with appropriate isocyanates.
The chemistry of polyurethane is very complicated and numerous products can be obtained by varying the nature of components, catalysts etc. These problems are however not the subject of this paper.

The foams are prepared in rather complicated and automatic machinery. Continuous streams of components well metered and of controlled temperature and pressure are mixed in a high speed mixer. Dependent on formulation, the product starts foaming in most cases after about 30 secs. Within a few minutes the foam is stable and hardened, although several hours of curing are needed to form the final product. Generally the foam thickness is about 2" - 2½" (5 - 6.5 cm). The foam has a higher density near surfaces like carrier pipe and jacket and near the endclosures.

Pipes

Although our subject covers the field joints it is necessary to say a few words about the pipes. This paper covers pipe sizes of 4" (10 cm) and above.
In my introduction I mentioned the carrier pipe and the insulation viz. polyurethane foam. I have to add that as the polyurethane itself is neither resistant to heavy mechanical loads or shocks - the compressive strength of a foam of a density of 60-70 kg per m^3 is about 5 kg/cm^2 - nor is it corrosion resistant.
Polyurethane buried in the soil would very soon be decomposed by the action of the water in the ground.
Therefore a protective jacket is necessary. Various jacket materials are used e.g. polyethylene, p.v.c. and steel. In most cases these jackets are pipes, although other forms are used e.g., extruded wraps etc. Here we will deal with jackets in the form of pipes.
By putting carrier and jacket in a concentric position and bringing in the mixture of components, the foam develops between carrier and jacket and the final product viz. the insulated pipe is formed. The insulation is then one monolitic structure. During foaming-in the pipe can be placed in different positions: vertical, tilted or horizontal.
The latter method asks for rather sophisticated equipment but enables long joints of pipe (up to 16 m) to be produced with an uniform foam, as there can be no influence of varying hydrostatic pressure as occurs when a vertical position is used.
The horizontal position is used by Bredero Price and the investigations mentioned later on are made with these type of pipes. Bredero Price has a license from an American Company Triangle Price who has used this process sucessfully for many years.
Of the jackets mentioned previously polyethylene and steel are the subjects of our investigations. (P.V.C. is used mainly for small diameter pipe).
Steel as jacket material offers many advantages. It is strong and watertight welds can be made easily, if some precautions are taken. As it is liable to corrosion however some protection has to be applied. It is well known in what way this corrosion protection can be provided, therefore shall not dwell on this subject here.
Polyethylene on the other hand is light in weight, easy to handle, very resistant to corrosion in the ground but it is difficult to obtain a good field-joint.
This paper covers these two types of insulated pipe more closely and in detail.
The manufacture of both types can be carried out with essentially the same equipment.
The concentricity of the steel jacket and carrier pipe might pose some problems as the sagging of both pipes will not be equal. Generally the outer pipe (4" - 5" larger than the carrier) will have less sagging than the inner pipe. By loading the outer pipe, exact concentricity can be obtained; some spacers in the annulus might help.
A polyethylene jacket (wallthickness 5-10 mm) on the other hand is rather flexible when empty and has to be supported. Well designed clamps are used to give ample support and to match the sagging of the inner pipe. If we want a foam of a high density say 60-80 kg/m^3 (3.5-5 lbs/cf) the foam has to be formed under pressure. Therefore the annular space must be closed after bringing in the polyurethane mixture. In this way pipes up to 16 m long can be manufactured.
The cut-back of the jacket and the foam is about 15 cm to allow the welding of the carrier pipe in the field. This brings me to the main topic of my paper, viz. the field joint.

Field Joints

Experience shows that a successful insulated pipeline requires continuous insulation and a continuous jacket. There are systems that interrupt the insulation at the field joints. I feel however that this is poor practice and diminishes the quality of the pipeline considerably, even of the heatloss can be tolerated. When joining up steel in steel pipes the best way to carry out the work is the following:

The pipes are brought into position and the carrier pipes welded. The field-joint outer jacket has to be provided. This can be achieved by welding steel half shells into the jacket. In one of these half shells is a hole (1-2" dia.) to pour-in the polyurethane after welding. The welds made in this way are fillet welds as the half shells slightly overlap the jackets.
Butt welds are stronger but require exact fitting to both jackets.
This is difficult to achieve due to lining-up problems therefore fillet welds are made.
Now there rises a problem. When heating the polyurethane foam it will burn. Apart from destroying the foam also creates noxious vapours thereby hindering the welders. Moreover, the resulting damaged polyurethane never bonds with the new foam. I investigated the behaviour of foams under various welding conditions and gave much attention to the bonding of new foam to old. I observed that heating and welding of the steel near the foam surface gave rise to serious burns and very bad bonding. This was less so if the welding was carried out a few centimeters from the foam surface. If however, welding was carried out in an inert atmosphere by blowing carbon dioxide or nitrogen into the empty space no burning took place, and good bonding of foam to foam good be achieved.
The new foam was brought in by a small mobile machine. After the foam had been formed the small hole through which it was introduced was closed by welding on a small piece in steel.
These types and all other field joints were tested by burying them at water-table level and then pumping hot oil through the inner pipe. The temperature in some tests was 120° C, in others 100° C. To aggrevate the conditions the hot oil stream was cycled on a daily basis. About half a day of hot oil stream was followed by half a day of cooling down. In this way expansion and retraction causes high stresses to the system. Tests had a duration of two months or one month.

After two months at 120° C the steel in steel field-joints were in excellent condition. No alterations could be observed. In this test, the steel jackets were protected by a black bitumenous paint giving enough corrosion protection for the duration of the test.
In actual practice other types of corrosion coating are necessary.
The usual types are:
Bitumen coat and wrap, Somastic, etc.

Polyethylene jacketed pipes are treated in another way.

When joining the carrier pipes are welded together, there are several possibilities for joining of foam and jacket. We can start with producing the foam or we start with making the water tight jacket as described for the steel in steel structure.
Making the foam first means that we must apply a mould that either can be used several times or can be expendable.
An expendable mould can be a piece of polyethylene or p.v.c. tubing that stays on the pipe and on top of which later on a water tight closure can be applied. The expendable mould acts also as a mechanical reinforcement and as a support for the watertight seal.
In our tests we tried several of these systems. Products were used as watertight barrier. I will only mention a few of them.
Thin-walled sleeves of expanded polyethylene. If p.e. is irridiated with gamma-rays a product is formed that after previous expanding can be shrunk back to a smaller diameter by heating with a torch-flame. The main producer is these RayChem Corp. Between jacket and shrink sleeve is a layer of adhesive. The sleeves provide a good and reliable watertight finish to the joint. this was proved when after 2 months testing the joint was opened up; the foam was in excellent condition.
When the field joint is not watertight, water will enter and the foam structure will collapse.
Other ways of making watertight closures are tape systems.
A.M.P. (U.S.A. Cie) produces a tape on p.e. base with a separate adhesive. These tapes are expanded and can be shrunk down after being wrapped on.
The wrapping takes rather a long time as the tape is not very flexible this is a serious

disadvantage. It could be partly overcome by using wider tape. The tape we used was about 8 cm wide. The results were acceptable under favorable circumstances. An other product was a British product from "Servicised Cie". It is a bituminous mass impregnated onto fabric. The bituminous mass is sticky and adheres well to the polyethylene. The bituminous mass can be delivered separately and can be used to fill up holes, to smooth sharp edges. etc. This product proved to be satisfactory although application is time consuming.

The other way to make the field-joint is to use a removable mould. As such a sheet of thin steel plate (1.5 - 2 mm) overlapping both jackets can be used. The plate is fixed over the void and fastened with a steel band and a clamp, and foamed in.

After removing the mould - and to make this possible the steel plate is previously treated with a mould release (e.g. wax) - a shrink sleeve of the RayChem type as described earlier is applied.

As stated before this type of shrink sleeve gives a good water tight fit. A possible disadvantage is its thickness of 2 - 3 mm.

A very good way to combine jacket and mould is in a new system in which a polyethylene sleeve, is welded to the jacket.

Hoechst A.G. together with Reifenhauser A.G. developped this welding system. A small size p.e. extruder fitted with a flexible, heated hose extrudes a continuous stream of molten p.e. on preheated surfaces of jacket and sleeve. A special piece of equipment called a "shoe" made out of teflon is moved along the area to be welded. Through this "shoe" both hot air for preheating and the viscous molten p.e. mass is pressed. This gives a very good bond. To test the weld, a test joint was subjected to a hydrostatic pressure test of 5 atm, in which only the foam was damaged.

If before welding a piece of Al tape or a thin wire is put between the two pipes it is possible to test for tightness using a small high frequency, high voltage generator. If there is a leak heavy sparking is observed.

It takes about 6 min. to make a circumferential weld on a jacket having a 450 mm diameter (circumference about 1.4 m). After both welds are made, the void is foamed-in in the usual way and the small hole is closed using the same welding system.

The results with this kind of field-joints are very good.

There are many other ways for making a field joint and we investigated more types and more variations than mentioned above.

I only mention - without going into details - some of them.

We investigated the use of rubber rings (O-rings) between shrink-sleeves and jacket. They did not give a better water stop.

We experimented with steel sleeves that are slipped over the p.e. jackets and are fastened with bolts using rubber rings of special shape to make the joint watertight. As there is in these systems a constant load on the polyethylene and because this substance is liable to cold flow a steel reinforcement has to be inserted into the p.e. jacket. This means that costs for such a system are very high.

Moreover I investigated the use of polyurethane elastomers. Virtually these are polyurethanes without foam structure.

These products have far better water resistant properties than the foams have. We applied thin layers of this product perpendicularly to the carrier pipe and the jacket. For not too high temperatures these systems are excellent, but application is complicated and therefore expensive. The advantage should be that if by chance somewhere in the buried pipeline the jacket should be damaged the water that then enters is stopped at the polyurethane elastomer barriers.

It is my opinion that for temperature below 100^{0} C this particular concept warrants further investigation.

Endcaps

A special kind of field joints is the end cap. These have to be watertight. After much trial and error we succeeded a good endseal in developping. This consisted of a piece of bare carrier pipe was welded to the end of an insulated joint. A 60 cm long piece of steel pipe of the diameter of the jacket and having an internal flange fitting the carrier pipe, was slipped over the prolonged carrier and welded to it in such a way that a small slit between p.e. jacket and endcap remained open. A steel mould of appropriate dimensions is fitted and the void is filled with foam. Then a RayChem sleeve is used to make it water tight. The long steel jacket is needed to prevent overheating of the water tight sleeves or wraps. This was investigated by fixing thermocouples to the steel endcap and observing the temperature drop when buried. Previous experiments with endcaps of about 10 cm these failed, however the latest developped was entirely successful the temperature went down to about 20° C (in winter under cold and wet conditions).

Prices

Last but not least we reach the pleasant or unpleasant subject of money!
This is a difficult problem at the best of time but here virtually impossible!
This is due to the many variables affecting the costing of any individual system e.g. pipe diameter, foam density and thickness, type of outer jacket, quantity etc. that no two projects are alike. This means that a large project is virtually custom made and that general price information can only be used as an indication and no more.
As an example a p.e. jacketed joint having a carrier pipe of an outer diameter of about 10" and a foam thickness of 2" will cost anywhere between ƒ 50 and ƒ 150 per m.
A field joint for such a system could cost between ƒ 25 and ƒ 180 a joint. These prices largely depend on the situation in the field, which might be vary tremendously. It can only be said that each and every project needs to be costed and bid seperately.

DISCUSSION

Question

This morning, Mr. Gibbs mentioned in his lecture low modulus of elasticity as a problem in quite another construction than the pipelines we are discussing now. Here, it is a question of the amount of energy stored in the material. A material with a low modulus stores more energy than one with a high modulus, and this means that certain defects in the structure may become critical. Now, in this case we have a rather complex situation where steel and plastic are used together. The combination may change the properties of both materials in respect to strength, not strength calculated on the basis of the forces acting on the material, but calculated as the energy stored in the material. If plastic of a certain thickness is used inside a steelpipe, the stored energy of the whole system is increased when the combination is stressed. This causes a reduction of the critical size of defects in steel, that can be allowed. Has any work been done on this problem, which is of course a problem of fraction mechanics?

Answer

(De Putter) This is a very difficult question to answer out of hand. I agree that the limit to which the structure can be stressed, is determined not by the strength, but by the deformation allowable. So when you have a PVC pipe with a steel one around it, the maximum load the construction can take, will be determined by the force necessary to deform the steel pipe. That determines the limit of stability of the combination. But as far as I know, there has not been done experimental of fundamental research on this question.

Remark

I agree, but you still have a steel pipe around a plastic one. If they are of equal thickness, the amount of energy stored in the plastic will be much greater than that stored in the steel. In case of fraction, the energy equation is dominated by the plastic material.

Answer

(De Putter) Well, it seems to me that it will depend on the way the materials are bonded. When you have a strip of steel bonded to a strip of plastic and you put the combination under tension, then the elongation will be determined by the steel, as it has the higher modulus. So it depends on the steel pipe how much tension the combination can take.

Question

I wonder if Dr. Geerling could comment on the long term stability of the polyurethane foam. It is attractive for its low coefficient of heat conduction, but is not it an extremely vulnerable material?

Answer

(Geerling) The answer is no, it certainly is not. In actual practice, pipelines like these are used to transport hot oil and even molten sulphur. Some have been in use now for about seven years and their isolation still is in perfect condition.

Question

Have you any experience with the new polyisocyanurate foam?

Answer

(Geerling) As far as I know we don't have experience with that particular type of foam.

But I would like to add something to my answer to the previous question. There are many types of polyurethane and not all of them show good temperature resistance. As a matter of fact, there are only a few with good temperature resistance that at the same time maintain their good mechanical properties over long periods. You have to choose you polyurethane with great care, if you just take one from the shelf, so to say, you are inviting trouble.

Question

I have two questions for Mr. De Putter. He discussed the kind of pipe used and mentioned that it consisted of an outer steel pipe, an inner plastic pipe and an intermediate layer of concrete. Then he discussed the welding tests and the rather severe bending tests the combination had to undergo. What happened with the concrete, did it crack or not?
My second question is of a more general nature. What do you do when you need a pipeline like this? Do you go to a supplier of steel pipe asking him to arrange for a plastic pipe to put inside, or do you go to a supplier of plastic pipes with the request of putting a steel one over it?

Answer

(De Putter) As to your first question, the welding tests showed that we would not have serious difficulties with the layer of concrete. In the bending test the concrete cracked, as a consequence of the larger shear.
As to your second question, I think you can order your pipeline just as you like, it won't make any difference. A supplier of steel pipes will in my opinion certainly consult a supplier of plastic pipes, to get an idea what combinations can be made. And a supplier of plastic pipes will certainly start to obtain information about steel pipes.

Question

Could Dr. Geerling comment on the maximum size of a pipe insulated with polyurethane foam?

Answer

(Geerling) We have not gone higher than diameters of 12 feet, but in my opinion we could handle pipes with larger diameters.

Question

Is not the most important point the capacity of the foam to carry load?

Answer

(Geerling) Of course it is, but that is not a big problem. If your steel pipe is not to heavy - 12 feet diameter and a wall thickness of $\frac{1}{4}$ inch is quite usual - then the foam can carry the weight easily. In my opinion you could enlarge the diameter to 20 feet without difficulties. We never investigated it however, as insulated pipelines of that diameter have not yet been build.

Anti-vibration three-layer composite plate - mode of action, workability, and applications sketched on the basis of an example

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1. Together with air and water pollution control measures, the suppression of noise is gaining in significance as part of the campaign against the continually worsening effects civilisation is exerting on our environment. In a number of countries, noise levels are limited in dB (A), for example, in areas where annoyance occur to an involuntary listener, i.e. in industrial works, streets, houses, schools, hospitals, etc., with a further noise level restriction for day and night hours. These regulations give due consideration to determinations which indicate that noise is not merely annoying, but can also lead to illness and even permanent injuries. Whereas it is very easy to draw up such regulations, their technical implementation is usually anything but simple. In many cases, noise suppression measures have not yet progressed beyond the experimental stage.

2. In view of the complexity of sound generation and transmission, a distinction should be made from the very outset in connection with noise suppression measures between the restraining of sound transmitted by air and through solids on the one hand - i.e. insulation - and the attenuation of sound transmitted by air and through solids on the other - which overlaps with absorption. Insulation is aimed at deflection on the sound energy by means of reflecting planes without substantially transforming it into other forms of energy, whereas with attenuation the sound energy is transformed usually into heat and thus removed from the vibrating system. If noise suppression measures are to be effective, both mechanisms - insulation and absorption - must be combined. Where noise generation as such cannot be prevented, attenuation measures constitute the purest form of soundprotection. They are of great significance as regards dampened metal structures with large areas or large spaces.

3. The attenuation of - mainly - bending oscillations in plate structures using a plastic layer has been a standard practice for some considerable time. The anti-vibration compounds used in the automotive industry are an example. The attenuating or damping effect of these coatings results from the relaxation in the plastic material, which is subjected to tensile and compressive stresses caused from the bending oscillations of the structure. Loss factors of 0,1 are usually obtained when the correct thermoplastics and filler materials with adequate thickness are used.

   Sheet-and-plastics combinations have recently been introduced to the market in the form of semi-finished materials, the relaxing plastic is sandwiched between the two plates. Damping in this sandwich combination is also effected by relaxation of the plastic, but its position between the two plates means that tension-compression is replaced by shear relaxation. In view of the different mechanism, the loss factor is one magnitude higher than that of an anti-vibration coating, i.e. approximately 1. A further point of interest is that the damping effect of these sandwiches is relatively independent of the plastic layer thickness, in contrast to the plate-one-coat combination. The temperature range of the technically effective loss factor - $d > 0,05$ - is gratifyingly high at max. 90°C when optimum plastics are used as the sandwich core (Fig. 47/70). *1 The absence of soft, sticky surfaces is a further adventage of these systems.

   At this occasion I must mention, that the attenuation is only caused by relaxation in the plastic. Due to the mechanical behaviour of plastics in dependance of the temperature the relaxation is also greatly dependend of the temperature. This attribute belong to both systems:
   sheets with one layer - sheets with an intermediate layer.

Normal thermoplastics in combination with steel cause an effective attenuation in a 50°C-range. Greater amounts in the temperaturerange are to obtain by mixing suitable plastics or better by controlled copolymerisation of suitable monomers. We have chosen the latter way. Only this process give the guarantee of constant attenuation-behaviour over long time, because no diffusion or plasticizermigration can occur.

Now comparatively I will give you some attenuation-factors of several materials:

steel without clamping	0.0001
steel with clamping	0.01
plywood	0.01 - 0.02
steel with an outer layer	0.1 - 0.2
steel with an intermediate layer	0.5 - 1.0

Plates of this type provide the acoustic engineer with a semifinished product ideally suited to noise suppression and which caters for virtually all demands to be made on soundproofing materials.

> The composite plates have high-tensile strength, and are thus suitable for supporting structures; they are flexible against bending, i.e. their coincidence frequency is sufficiently high; $f_G = f\left(\frac{\text{area-mass}}{(\text{stiffness in bend})}\right)$ they are heavy, i.e. their restraining value in the Berger formula is good, and they are extremely well damped by absorption, i.e. they exhibit scarcely any resonance or sound transmission through the solid body.

4. A number of rules must be observed when drawing up dimensions and processing these composite plates to produce a finished article if faulty designs are to be avoided. The rules are based on the facts that the special-purpose plastic core between the plates is a mass

4.1. that is unsuitable for transmitting power,

4.2. that has a thermal conductivity value lower than that of metals by more than two decimal magnitudes,

4.3. that is an electrical insulator, and

4.4 that represents a non-metallic inclusion phase in the metal matrix.

Ad 4.1. The soft plastic core influences dimensioning thus, that structures which have to be made thicker in accordance with the symmetry ratio of the plate systems. As the symmetric ratio - ratio of the thicknesses of the metal plates - influences damping, and as ratios below 1 : 4 are not desirable, soundproofed structures manufactured out of these sandwiches are about 25 - 60 % heavier (Fig. 1/68). The increased weight per unit of area benefits restraining.

Naturally, the increased weight does not be applied to structure not designed for stiffness (no bending, no torsion).

Ad 4.2. The greatly inferior thermal conductivity of plastics as compared with metals should also be taken into consideration when making hoods of these sandwiches - e.g. for hot machines. Standard sandwich plates are supplied with three different plastic core thicknesses i.e. 0,2; 0,3 and 0,5 mm matched to the thickness of the metal plates. Due to the difference in the thermal conductivity values of steel and plastics, heat transfer is limited only by the latter. Thus, the following heat-transfer coefficients as related to the thickness of the plastic core can be expected (Fig. 10/68). Where the indicated heat transfer factor is inadequate, additional cooling must be provided.

Ad 4.3. +
4.4. These two points cover in the main the special features of this combination material for resistance and fusion welding. I should like to restrict discussion of these processes to references on the relevant literature, *1 *2 only a limited number of illustrations concerning weldability may be shown.

10/69	-	a spot-welded hood structure
48 + 49/70	-	fusion-weld specimens from 3,3 mm thick systems
50/70	-	inert-gas-welded specimen with composite plate about 1 mm thick.

As regards welding, the following is also of interest:

As the molecular structure of plastics, and not their chemistry influence the atenuation characteristics, a whole range of these materials could be used for damped plates, e.g.:

> bitumens, loosely cross-linked epoxides, plasticized PVC, polyvinyl acetate copolymers, PUR a.s.o.

Acetates have come to the forefront as core materials for these sandwich plates in view of the possibility of using the semi-finished product in the manufacture of structures by welding. The illustrations of welds shown earlier cover sandwiches with PVAc core layers.

I should now like to quickly run through several illustrations showing the range of items that can be made using sandwiches of this type: (6/18, 8/68, 9/69, 11/69, 12/69, 14/69, 15/69, 17/69, 23 - 25/70, 27/70, 30/70, 32/70, 38/70, 39/70, 40/70, 44/70, 45/70, 46/70). The illustrations are interesting not only as regards their subjects, but also as clear proof of the fact that this semi-finished product of steel and plastic processes adequate workability.

5. Before turning to a description of the acoustic efficiency of this sandwich in a specific example, together with details of the expense of work, I should like to make the following statement: The high attenuation value of these systems is effective only when the layer of plastic is subjected to a shear stress, which is the case when flexural waves or shear waves occur in the sandwich. Fortunately, in the case of plate structures flexural waves are the main cause of sound radiations. The flexural wave velocity is not a material constant, and increases mainly to the root of the frequency. ($c = \sqrt{w} \times \sqrt{B}/M$). It will be realized that with small areas and low frequencies long flexural waves dont traverse the areas and thus cannot be attenuated. Consequently, no high expectations should be held as regards small units and frequencies of less than 100 cycles. Fig. 51/70 shows the relationship between flexural wavelength and frequency in sandwich systems. The system thickness is plotted as the parameter. It can clearly be seen that below 100 cycles the flexural wavelengths are $>$ 43 or 17 cm, according to the sandwich plate thickness. As thinner systems have short flexural waves small parts should be kept thin for effective attenuation of flexural waves at low frequencies; normally, this also accords with structural demands. Any required restraining should be obtained by other means in these instances, if it is necessary.

This characteristic by no means indicates that sandwich plates are useless for small items. Many small-area plate components, for example in cars, are subjected to undesirable resonance with higher frequencies which can be effectively attenuated using these systems. The human ear obtains definite relief from absorption measures against such resonances even though the effect can never be rendered objective by integral level measurements, scarcely by measurements in the octave bands, only occasionally in tertiary band spectra, and in fact only by single frequency analyses.

6. And now an interesting example which is not connected with our concern: it was reported on during a VDI (Association of German Engineers) meeting at June 11th - 12th, 1970 in Bamberg by Dr. Piening, which indicates the objectivity of the matter. *4

In modern ships, the driveunits, cabins and lounges are arranged as closely together as possible, and often in the stern to keep the line shafting short. This construction system permits a goodsized hold and good accessibility for loading and unloading operations. However, it also means that the crew is accomodated directly above or next to the engine, which calls for special noise-suppression measures.

6.1. Conventional designs are shown in Fig. 52/70. They cater for elimination of both the immediate transmission of noise by air from neighbouring noisy rooms, and also the transmission of sound by solids, which in turn causes airborne sounds via flexural waves. The noise suppression measures comprise the following elements:

6.1.1. Roof and wall baffle panels

These panels are made of thin sheets, and are mounted in front of the radiating wall on flexible supprots. The elements reflect the sound radiated by the wall, bulkhead, or deck. As the sound flowing through the supports into the baffle panel can considerably increase the radiation of the latter, the insulating effect of the connection must be high.

6.1.2. Floating intermediate floorings

These are panels which are stressed by the occupants of the room and by the furniture; the structure must therefore be stiff. As in the housebuilding industry, mineral wool panels are bonded to the deck as flexible underlay, and topped by additional layers of concrete as a firm, heavy surfacing. An effective structure calls for a thickness of 80 - 100 mm, which is awkward under the cramped space conditions aboard ship.

These floorings also work on the basis of reflection mechanisms.

6.1.3. Absorbing surfaces

These are formed by sound-absorbing materials e.g. mineral wool-plates covered with dust guards, perforated sheeting, etc. This reduces the noise level by a certain, for practical reasons limited amount. Certain difficulties are met through contamination in day-to-day conditions. In machine rooms, there is also a danger of flammable gases and oil redisues collected in the absorption materials.

These measures reduce the noise level by about 35 dB. The noise levels in the various rooms are shown in Fig. 52/70.

6.2. Even though the old soundproofing system significantly reduced the noise level, the three-layer plate/plastic/plate systems can produce greater reductions, at the same time, it must be emphasized that a considerable amount of the absorbing surfaces (absorption materials) can be saved. The old and the new details of construction are sketched for comparison in Fig. 53/70. The new method is characterized by the following measures:

6.2.1. Baffle panels

As flexural waves are rapidly dissipated by damping in the panel, the flexible supports can be replaced by rigid connections without noticeably affecting the soundproofing effect. Apart from the costs for rubber elements, the easier fitting produces savings.

6.2.2. Sound-attenuation floor

The old system with the floating intermediate flooring is in principle reflection, i.e. an insulation mechanism. In contrast, the new sound-attenuation floor works on the absorption principle. The whole living quarters is equipped with an integral floor of sandwich plates laid on supports. To obtain the required stiffness under the load imposed by furniture, separating walls, etc., an unsymmetrical system 3/1 mm was selected, the thicker plate being on top. The joints between the individual plates are strapped.

The large absorbing area of this floor is an ideal attenuating member against sound transmission by solids throughout the entire ship.

6.2.3. Damped supporting walls

As mentioned above, the bending stiffness of composite plate systems is not as high as that of the homogeneous metal plate; thus, for the time being, their use in supporting walls is restricted to lower bending loads unless excessively thick units are used. In the case of more highly-loaded walls, resort can be made to extremely unsymmetrical composite systems bonded, with the thinner plate to the existing structure. The structure and the thin side of the sandwich form a single unit flanking the active relaxing plastic on the one side. The other flank is the thicker plate of the unsymmetrical system. This method was used for several bulkheads and surfaces of frames in the vicinity of the gearing, where high solid-body sound levels were encountered. As a result, the gearing is now inaudible in the whole ship.

The effect of the three measures using sandwich plates is shown in Fig. 54/70. The figures in brackets are the sound levels with the old system. It will be noticed that the use of sandwich plates in the way described has improved the lowering of sound level by about 7 - 10 dB as compared with the old method, a result that coincides with experience gained using such plates. With the high loss factor for flexural vibrations in the systems the solid-body sound level is reduced by some 20 - 30 dB, which in turn equates with an induced air-sound level reduction of $L_L = 1/2 - 1/3\ L_K$. This general experience factor was confirmed by the measurements in this particular instance.

Only in the vicinity of the propeller effect is not as high. This can be traced to the fact that the propeller excitation lies below 10 cycles, generating flexural wavelength of $>$ 1 m. These waves in the sandwich plate of the thickness in question cannot be adequately attenuated.

7. Now, the cost aspect is naturally of interest.
What does the sound level reduction of 7 - 10 dB cost in comparison with the old design?
The shipyard quotes the extra cost at 20 %, which appears justifiable when taking into consideration the fact that sandwich plate costs about three times as much as solid plate of the same gauge. This extra cost is very modest when compared with the halving of the audible sound produced by the noise level reduction obtained.

In this example the expense of sandwich-use was 20 % higher in comparison with normal sheet and conventional noise suppression devices, yet at a more effective accustical level. The higher costs are not always the case. In a large chemical plant the noise of rotation compressors of 105 dB (A) was lowered to 86 dB (A) by a double hood-construction of 1 mm sheet with a 5 cm miniral fibre-core. The price of this hood is 2.500,-- DM. The same effect was reached by a single hood of a sandwich system 0,5/1 mm with a mineral fibre plate - 5 cm thick - glued at the inside (Fig. 41/70). The price of this hood is only 1.400,-- DM i.e. 56 % of a conventional construction for noise suppression.

Finally in the combinations between steel-sheet and plastic for noise control measures - as you see - metals and plastics are ideal allies-especially in concern of the sandwich-technic with an intermediate plastic layer.

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VDI-Fachtagung Kunststofftechnik Bamberg June 11th/12th 1970

DISCUSSION

Question

It is very gratifying to hear that pollution by sound can be combatted effectively. Now my question concerns one of the graphs you showed, the one that gave the dependence of the damping factor on temperature. For one of the materials there was a very convenient peak about 20 degrees centigrade. Now one expects a material, showing this behaviour, to be rather frequency dependent. How does the damping factor change with the frequency of the sound?

Answer

We have measured the dependence on frequency in the range between 100 and 4000 cycles per second. And over 2000 cycles a second the system shows a somewhat greater stiffness.

Question

I understand that at higher frequencies the material behaves somewhat stiffer. But in the region mentioned - 100 to 4000 cycles - do the characteristics of the system remain virtually constant?

Chairman

The question is about the following point: If there is a peak in the graph giving the dependence of damping on temperature, you can expect a corresponding peak in the graph giving the dependence of damping on frequency.

Answer

In the range between 100 and 4000 cycles, damping is nearly independent of frequency, the damping factor remains virtually constant. But we discovered a relation between temperature and frequency. The graph for temperature versus damping factor showed a peak around 20 degrees centigrade. Now if you expose that material to sound of high frequencies, you find that the peak in the damping factor has shifted to a higher temperature.

Question

You stated that the nature of the plastic involved is not very important. Could you enlarge on that?

Answer

That is true, We have made systems with polyurethane, which are stiffer than systems with polyacetate, and in some cases we use soft PVC.

Question

And you always have optimum damping at a temperature of about 20 degrees centigrade?

Answer

No certainly not, and I do fear I didn't make myself sufficiently clear. There are many types of plastics that can be incorporated into the three layer system, but it is extremely important to choose the right type of plastic in relation to actual operating circumstances. If you have to hood a machine that generates and radiates a lot of heat, you must choose a plastic that does not contain a plasticizer. Then you get a system that at room temperature is very stiff and shows only moderate damping, the peak in damping capacity lies at a higher temperature.

So we concentrate on three types; the first has its peak in damping capacity at 20 degrees centigrade, with the second and third type the peaks lie around 65 and 90 degrees centigrade.

Question

I have two questions. In Germany there is much interest in noise reduction, and one hears values of 40, 60 and even 90 dB. Now in your lecture you mentioned a factor of 10. Could you enlarge upon that?
Secondly, in building doors and other things that can be opened often are notorious noise leaks. Is your three-layer composite a solution to that problem?

Answer

In Germany we have strict regulations about noise reduction. In factories noise has to be reduced to at least 90 dB and if possible, to a lower value. You can do that in two ways. You can design the machinery in such a way that it does not generate much noise, but if that is impossible, you can try to attenuate the noise generated. That is where these three-layer composites come in. If it is impossible to shield the machine, the people who attend the machines have to be shielded in some or other way from the source of the noise.
As to buildings, that are very difficult propositions indeed. The structure has all kinds of resonant frequencies and noise is conducted in quite unexpected ways. It is very difficult to calculate beforehand how a particular type of noise will be propagated in the building structure. You can do something with walls, as you can put in the type of wall that will attenuate noise. As to doors and other holes in walls, they are indeed notorious leaks. Whether it is attractive to put in our three-layer composite is not a question of engineering, but of costs, as the composite is rather expensive.

Question

The suppression of noise is particularely important in agricultural machinery. Is there no other way to suppress noise than by using shear in the intermediate plastic layer?

Answer

Yes, that is possible. But in that case you do not use shear to attenuate noise, you use the effects of compression and tension in a material, and that is less effective than shear.

Question

But can your composite be used in agricultural machines?

Answer

Certainly. I can add that the composite is used to solve another serious problem in noise suppression. The material is used to hood air-compressors of the kind you see in the streets.

Question

The composite you discussed reduces noise. But I wonder whether it does not too show an increased resistance against fatigue.

Answer

We have tested our material for fatigue resistance. So far, we think that the composite shows an enhanced resistance against fatigue. As a matter of fact, in some cases we found an enhancement of a factor between 10 and 100. But please, don't quote me, we are still testing.

Question

Can you corrugate the composite?

Answer

Yes, that is no problem. A user can bend the composite over rather large angles.

Question

I am somewhat surprised that this material is not used more universally, but the restriction seems to be the price. Is it used in German cars?

Answer

Yes, it is.

Question

Is it possible to construct a car out of it?

Answer

No, it is not stiff enough. And secondly it is too expensive.

Question

You did show a slide where part of an agricultural machine was protected against noise by your composite. What part of the machine was so protected?

Answer

Only the cabin.

Question

But do not the vibrations go through by way of the seat?

Answer

That could be, but in this case the suspension of the seat was designed in such a way that it damped the vibrations.

Question

Can we hope that this material will become cheaper in the near future?

Answer

That is a difficult question to answer. At the moment we produce these composites in short runs, and that is rather costly. If we could go over to mass production, the price would come down of course.

Non shrink or low profile polyester moulding compounds for the automotive industry

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Despite much discussion over the past years in the United Kingdom about the potential use of glassfibre reinforced polyesters in the automotive industry, to date progress has been slow. It has been suggested that this lack of progress has been mainly due to the relatively high material cost and low production rates as compared with traditional materials.

In the U.S.A. the situation is quite different. The usage of G.R.P., particularly in the automotive industry, has increased rapidly over the past few years and the prospects for the future excite the imagination. For example, in 1969, 28.000 tons of D.M.C. were used on passenger cars in the U.S.A.

It is probably true to state that the most important contributory factor in this rapid growth has been the introduction of 'non-shrink' or 'low profile' polyester moulding compounds.

Although these compounds have been exploited extensively in the U.S.A. it should be born in mind that the original technology was developed in the U.K. In fact the most successful moulding compounds used in the U.S.A. are still based on British 'know how'.

To appriciate fully the significance of these non shrink compounds reference should be made to the quality and type of moulding compounds previously available for quantity production of automotive parts using the technique of hot moulding in heated matched tools.

PREFORMED GLASS FIBRES OR TAILORED MAT REINFORCED POLYESTER

Tailored mat is placed in the tool heated to about 110-130°C and the catalysed polyester resin is poured on to the glass. The tool is closed at a pre-determined rate, causing the resin to flow. By the time the tool has closed completely and full pressure developed, the glass mat is impregnated and curing begins.

The pressing time is usually of the order of $1\frac{1}{2}$-2 minutes for mouldings $^1/_{10}$" thick.

As an alternative to tailored mat, or where mat is not suitable, glass fibre preform may be charged into the mould. The preforms are manufactured by blowing chopped glass rovings on to a perforated screen, the shape of which approximates to that of the final moulding. Suction holds the fibres in place whilst a binder is sprayed on to the preform (about 5% on weight of glass). The preform is then placed in an oven to cure the binder.

This process has been used for several years producing many types of mouldings including automotive body panels.

This disadvantages of this process are:

(1) Considerable amount of experience is necessary to produce satisfactory preforms.

(2) There is a limit to the complexity of the shape which can be moulded.

(3) Major changes in section thickness must be avoided.

(4) Until the recent introduction of 'low profile' resins, the quality of the surface of these mouldings was poor, mainly due to the presence of fibre pattern which would show through a paint finish. It is therefore necessary to abrade and fill the surface prior to paint application.

Following the introduction of 'ready to mould' polyester compounds, especially the low and non shrink materials, these disadvantages have been overcome.

Complex shapes can be moulded with ribs and bosses without sink marks. The quality of the surface is excellent with no fibre pattern or ripple and requiring no pretreatment other than solvent cleaning before paint application. Paint systems normally used on steel automotive panels requiring high baking temperature can also be used.

'READY TO MOULD' POLYESTER MOULDING COMPOUNDS

Dough Moulding Compounds

Essentially these materials, as the name implies, are 'doughs' or fibrous putties prepared by mixing polyester resins with fillers, glass fibre reinforcement, catalyst, mould release agent and other ingredients to achieve specific properties. It is essential to use the correct type of mixer otherwise degradation of the glass fibres will take place.

Compositions vary considerably but typical formulations consist of:

polyester resin	25-35%
catalyst	0.5-1.0%
lubricants	1%
filler & other ingredients	45-60%
chopped glass fibres	10-25%

The material is supplied either as a random mass or in rope or billet form. The latter makes handling easier and by cutting suitable lengths of this extruded dough, the correct charge weight can be achieved with little difficulty.

METHOD OF MOULDING

Polyester dough moulding compounds are thermosetting and application of heat and pressure is necessary to cause the material to flow and cure. Moulding is generally carried out on compression moulding presses, although transfer moulding can be used and recently injection moulding has been successful.

The moulding conditions required depend largely on the compound and design of the moulding. Pressures ranging between 200-2000 p.s.i. are required but for most cases this is limited to between 500 and 1000 p.s.i. The moulding temperature ranges between 120 and 150°C. The cure time will depend on the type of compound, mould temperature and shape and size of the moulding. For 1/8" thick mouldings this can be as short as 15 seconds.

PROPERTIES OF DOUGH MOULDING COMPOUNDS

The mechanical and electrical properties of the compounds will depend largely on the composition. It is the intention, however, to confine discussion of properties to the sophisticated non-shrink dough moulding compounds. These compounds which are truly engineering materials have outstanding properties when compared with conventional compounds.

GENERAL PROPERTIES

TABLE 1

Property	Value
Specific Gravity	1.8-2.0
Weight oz/ins^3	1.04
Mould shrinkage in/in	nil
Coefficient of Linear Expansion per °C	1.1×10^{-5}
Moulding tolerance ins/ins	±0.0005
Water Absorption 1 day 25°C - mg	20-40

COMMENTS

Of special interest is the coefficient of expansion which is similar to steel. This means greater freedom of component design where marriage of steel and a plastic material is desired or where metal inserts are incorporated in a moulding.

It will be observed that the mould shrinkage when tested according to the British Standard method is nil.

This explains why the quality of the surface is excellent and the absence of sink marks adjacent to ribs and bosses.

The moulding tolerance of ±0.0005 ins is particularly important since it is possible to hold tolerances which can only be achieved in metal by an expensive machining operation.

ELECTRICAL PROPERTIES

TABLE II

Property	Value
Power Factor 1 Mc/sec.	0.02-0.03
Permittivity 1 Mc/sec.	5-5.5
Volume Resistivity ohm/cm	10^{12}-10^{14}
Surface Resistivity ohm after 24 hours in water	10^{14}-10^{16}
Electric Strength volt/mil	250-350
I.E.C. Comparative Tracing Index Volts	1000
Arc Resistance secs.	130

COMMENTS

For automotive applications the electrical properties are more than adequate. In fact these materials are ideal for a wide application in the elctrical industry.

MECHANICAL PROPERTIES

TABLE III

Property	Value
Tensile Strength lbs/in^2 Kg/cm^2	6000-9000 457-633
Youngs Modulus lbs/in^2 in Tension Kg/cm^2	1.0-1.4 x 10^6 0.07-0.98 x 10^6
Flexural Strength lbs/in^2 Kg/cm^2	12,000-16,000 844-1125
Youngs Modulus lbs/cm^2 in Flexure Kg/cm^2	1.0-1.4 x 10^6 0.07-0.098 x 10^6
Izod Impact Strength ft. lb/in notch	3.0-6.5

The figures for tensile and flexural strength are lower than usually associated with glass reinforced polyester. However it is possible to obtain much higher strength as will be shown later.

THERMAL PROPERTIES

Graphs 1-4 show the effect of temperature on the mechanical properties. The tests have been carried out at the temperatures indicated. It will be observed than even at temperatures as low as -60°C there is no loss in strength compared with that at room temperature. This is a property which cannot be claimed for some metals - for example, the impact strength of zinc decreases rapidly below 0°C.

At higher temperatures, although there is a loss in strength, this is appreciably less than for most thermoplastics, particularly at temperatures greater than 100°C.

Further work is on hand to study long term effect of temperature on properties. The results obtained so far are given in Graphs 5-9. It will be observed there is no significant loss in strength after 6 months at temperatures in the range 80°C-120°C.

This is of particular importance where application of the D.M.C. is for components 'under the bonnet' and near the engine.

EFFECT OF ENVIRONMENTAL CONDITIONS ON PROPERTIES

The effect of natural and accelerated weathering on the mechanical properties of mouldings made from a non shrink D.M.C. has been studied and excellent results have been noted.

Even after 5 years natural weathering in the U.K. there has been no significant loss in mechanical properties. Deterioration in appearance does however take place.

For most automotive applications this loss in appearance is not a disadvantage since body panels will be painted and, as will be mentioned later, painted panels withstand the effects of weather better than painted steel panels. This means that corrosion problems associated with metal body parts do not exist with polyester D. M. C.

The resistance to lubricating oils and petrols is also excellent as is shown in Graphs 10-18. Components made from such non shrink D. M. C. can therefore be considered for many 'under the bonnet' applications.

The resistance to coolants, particularly glycol/water at elevated temperatures is not satisfactory. At temperatures greater than 60°C there is a serious loss in strength. The existing compounds are therefore not recommended for applications involving permanent contact with engine cooling systems, e.g. water pumps. It is expected, however, that this problem will be overcome in the not too distant future when a D. M. C. with adequate resistance to glycol/water systems at elevated temperatures will be developed.

QUALITY OF SURFACE

Mention has already been made of the excellent quality of the surface of mouldings made from these non shrink D. M. C. It is important, therefore, that the finish of the tool surface is of a high standard if best advantage is to be taken of the properties of the material.

FINISHING

To date it has not been possible to produce non-shrink D. M. C. which gives mouldings with even colour. In automotive parts, particularly exterior components, this is not a disadvantage. It is essential, however, that the components can be finished with the same paint systems used on the steel body. In addition the following requirements should be satisfied.

1. No special treatment of the surface (such as dry sanding) should be necessary.
2. Adhesion of the paint film to the moulded surface must be satisfactory and withstand weathering.
3. Where a D. M. C. component is fitted to a car body it must be capable of withstanding the high baking temperatures used for stoving the paint finishes.

Excellent results are obtained and the above requirements are met if the following procedure is adopted.

(a) The moulding is degreased by dipping in solvent such as isopropyl alcohol.

(b) A special stoving primer such as one based on an epoxy ester is applied to the moulding and stoved for approximately ½ hour at 130-140°C.

The primed moulding can then be fitted to the primed steel body and normal finishing techniques used. The usual paint systems such as alkyd/amino, hydroxylated acrylic/amino, or thermoplastic based paints may be employed and the mouldings will withstand even the high temperatures used for the thermosetting paint systems.

Accelerated and natural weathering tests, on mouldings treated in this manner, including 18 months exposure in Florida have given excellent results. In fact it has been reported that the results are superior to those observed on steel parts since little degradation of the D. M. C. mouldings takes place.

FIXING METHODS

Conventional moulded-in inserts may be used or studs may either be moulded in or preferably driven into moulded or drilled holes. It is interesting to note that studs without self tapping threads may be used. The diameter of drilled holes follows conventional metal practice but the diameter of moulded-in holes should be 0.010-0.030 in. smaller than drilled holes, depending on the diameter of the stud. Where studs are incorporated in bosses, it is recommended that the diameter of the boss should not be less than three times the diameter of the stud

Examples of 'pull out' forces required on studs with various diameters are given in table IV.

TABLE IV

Stud Diameter ins	Length of stud in Mouldings-ins	Pull out force lbs
0.16	0.5	350
0.24	0.5	550
0.375	0.5	1620

Note (1) The load was applied at a strain rate of 0.1"/sec.
(2) The studs had S.A.E. thread

Fastenings may also be rivetted to the D.M.C. moulding, or mouldings may be bonded together using either an epoxy or polyester based adhesive.

HIGH STRENGTH POLYESTER MOULDING COMPOUNDS

Mention has already been made of the lower strength of mouldings made from D.M.C. as compared with those made from glass fibre reinforced polyester resins. Table V compares the properties of mouldings made from the two materials.

It is possible to formulate D.M.C. with high strengths but such compounds do not have non shrink properties and excellent surface quality.

This problem has been overcome to some extent by the development of sheet moulding compounds (S.M.C.)

S.M.C. consists of chopped strand glass fibre mat which is impregnated with specially compounded polyester resins. Essentially the process consists of mixing polyester resin with catalyst, filler, pigment and 'gelling agent' and then impregnating the mat with this mixture. The impregnated mat is then sandwiched between polyethylene film, passed through rollers to effect consolidation and then wound into rolls. The function of the gelling agent is to increase the viscosity of the resin after impregnation since the initial viscosity of the mix is relatively low.

The rolls of impregnated glass mat are then stored for a period of days during which time the viscosity of the resin mix increases and finally forms a rubbery gel. During the 'maturing' period thorough wetting of the glass fibre takes place and the mat binder dissolves. This means that the final product flows as a homogeneous mixture of resin, filler and long glass fibres, resulting in mouldings of high strength comparable with that obtained from hot set preformed glass fibre/polyester resin.

Instead of using chopped strand mat, machines are now available for producing the mat in situ. Glass rovings are fed through a chopper and deposited on to the polyethylene film and the resin mix applied; from thereon the process is similar to that described previously.

This improvement in the production of S.M.C gives a lower priced product since the price of chopped rovings is lower than that of mat. The compound obtained by this process is also superior - higher strengths for the same glass content can be obtained. In addition it is simpler to produce S.M.C. with different glass contents ranging from 15-35%. Evidence is also being accumulated to suggest that the use of glass with mixed fibre lengths gives improved results.

Typical properties of mouldings made from sheet moulding compound with 25% glass are given in table VI.

TABLE V

Comparative Mechanical Properties of Glass Filled D.M.C. and Hot Pressed Glass/Polyester

Property	D.M.C.	Glass/Polyester
Izod Impact ft.lb/in notch	3-6.5	10-20
Flexural Strength p.s.i.	12,000-16,000	25,000-45,000
Youngs Modulus in Bending p.s.i.	1.0-1.4 x 10^6	1.3-1.8 x 10^6
Tensile Strength p.s.i.	6000-9000	10,000-25,000
Youngs Modulus in Tension p.s.i.	1.0-1.4 x 10^6	1.0-1.8 x 10^6

TABLE VI

Properties of Polyester S.M.C. Mouldings

Property	Value
Mould shrinkage	0-0.001 in/in
Specific Gravity	1.8 approx.
Izod Impact Strength	5-8 ft.lbs/in. notch
Flexural Strength	18,000-25,000 p.s.i.
Youngs Modulus in bending	1.25-1.5 x 10^6 p.s.i.
Tensile Strength	12,000-15,000 p.s.i.
Youngs Modulus in Tension	1.25-1.5 x 10^6 p.s.i.

COMMENT

Apart from the improved mechanical properties it is significant that the shrinkage factor is higher than for non shrink D.M.C. which of course is nil. This means that mouldings with ribs or bosses may not be free from surface sink marks.

To date it has not been possible to produce S.M.C. which is completely non shrink. To overcome this defect the design of the component can be changed so that such a defect will not be apparent. Such a procedure may, however, restrict the use of S. M. C.

Fortunately there is an alternative techniwue for producing high strength mouldings . which is described below.

REINFORCED D. M. C.

The technique of producing high strength D. M. C. involves combining continuous glass-fibre strand mat and the D. M. C. and so place the mat that it reinforces one surface of the moulding only.

The mat drapes well and follows the contours of complicated mouldings. The non-reinforced surface will, of course, have the high quality of the non-shrink D. M. C. and no sink marks will occur with bosses or ribs.

Typical results obtained for the mechanical properties of the D. M. C. and reinforced D. M. C. are given below. Specimens were cut from 1/8" moulded sheet and the glass reinforcement was 1½ oz/sq. ft. continuous strand mat.

TENSILE STRENGTH

As would be expected only a slight improvement in tensile strength is observed.

Tensile strength of D. M. C. : - 5000 p. s. i.
" " Reinforced D. M. C. : - 7500 p. s. i.

IMPACT STRENGTH

The difference in impact strength between the D. M. C. and reinforced D. M. C. varies depending on the test method used.

TABLE VII

Test Procedure	Impact Strength of D. M. C.	Impact Strength of Reinforced D. M. C.
Izod-ft. lb/in notch	4.2	6.5
Charpy-ft. lb/in	1.0	2.4
Falling Ball-Energy ft/lb	0.6	3.4

In the case of the reinforced D. M. C. the load was applied to the non reinforced surface.

COSTS OF D. M. C. MOULDINGS

The following table gives a comparison of the cost per unit volume of non shrink D. M. C. with other materials.

It is envisaged that if the production of D. M. C. is increased and where the usage justifies the moulder manufacturing his own compound from specifically formulated resins the above cost per unit volume for D. M. C. could be reduced by as much as 50%.

This, of course, should increase the potential usage of D. M. C. very considerably and would permit the use of the compound for applications which hitherto could not be considered because the cost was higher than for traditional materials.

EXISTING SUCCESSFUL APPLICATIONS OF NON-SHRINK & LOW-SHRINK D.M.C. IN THE AUTOMOTIVE INDUSTRY

It is in the U.S.A. that these materials have been used extensively for exterior and interior body parts. Many of these parts have replaced zinc die castings, others have replaced pressed steel and in some cases it is claimed that the design of a component was such that it could only be produced in non-shrink D.M.C.

It is also claimed that in nearly every case a part made from D.M.C. results in a lower cost and reduced weight as compared with a similar part made in metal. The usual corrosion problem associated with metal is also eliminated.

In 1969 the number of components produced in the U.S.A. was considerable and amounted to over fifteen million, and represented approximately 28,000 tons of D.M.C.

POTENTIAL NEW APPLICATIONS

Body Parts

In view of the successful applications described previously the next stage is to consider large body panels made from these specially formulated compounds, bonnet lid, wings, doors, boot lid, are obvious examples.

This, of course, poses several questions:

1. Can mouldings with large flat areas incorporating bosses and ribs be produced free from 'sink marks' and other surface blemishes?
2. Will such mouldings have the required strength properties?
3. Although such mouldings will offer a weight saving and greater freedom in styling over traditional materials, can they be produced competitively or preferably offer a cost reduction?

The production of large flat areas incorporating ribs and bosses free from sink marks does present problems. Considerable development work is on hand to solve these problems and there is every indication that these will be overcome in the not too distant future.

Experience so far indicates that:

(a) Ribs must be designed correctly.

(b) The tool must be designed to give maximum pressure on the material during the complete flow cycle.

(c) The press must have sufficient power so that the build up of pressure is as rapid as possible. In addition, the guiding system of the press should be such as to maintain complete parallelism of the platens during the closure of the press and up to full closure of the tool.

For some panels D.M.C. will have adequate strength, for others the obvious choice would be S. M. C. because of the higher strength obtained with this material. However, as already mentioned S. M. C. is not completely non shrink in which case reinforced D. M. C. offers a solution, where ribs or bosses are incorporated in the moulding.

For simple pressed steel shapes requiring a minimum number of tools, D. M. C. or related products will usually be more expensive than steel. However when more complex shapes are considered requiring several tools a cost-saving can be effected by using D. M. C.

For example, cost studies have been carried out on bonnet lids and it has been shown that if this component can be produced complete with reinforcing ribs and bosses with D. M. C., there is an appreciable reduction in the component cost.

Similar exercises have been carried out on other components which require several sub-assembly operations and here again cost savings can be effected.

It now remains to establish whether such large components can be successfully produced and there is considerable activity in this area both in the U. S. A. and the U. K. at present. It is expected that before the end of 1970 several of the problems which have been encountered in the production of large panels will be overcome as a result of which the potential market for D. M. C. or related products will be substantial. For example, it could result in at least 100 lbs weight of D. M. C. being used per car.

ENGINE PARTS

Because of the attractive properties of non shrink D. M. C., namely:

good heat resistance
low coefficient of thermal expansion
moulding tolerances can be accurately controlled and
therefore no machining is required

studies are being undertaken to establish the suitability of D. M. C. for components 'under the bonnet'.

The fact that such work is being undertaken in itself is of special interest since these compounds are the first plastic materials which satisfy the above requirements.

Some of the components which are being considered are listed below:

Oil filter head
Timing gear cover
Rear oil seal housing
Rocker cover
Various gear box covers and plates
Engine fan & water pump drive pulley
Dynamo drive pulley
Dynamo support bracket
Distributor body
Windscreen wiper motor housing
Fuel pump
Carburettor
Clutch hydraulic pistons

In most cases the use of non shrink D. M. C. effects a cost reduction compared with traditional materials and particularly where a machining operation is necessary with metals. Several prototype components have been moulded and are under test and the results so far indicate considerable promise.

Another area which promises attractive potential is to use D. M. C. instead of machined and/or diecast aluminium or zinc alloy for components 'under the bonnet'. This is entirely a new application with little or no background experience to call upon. The approach has therefore been different from that used for body components.

During discussions on the latter it was possible to demonstrate the successful use of D. M. C. for components by showing mouldings which have been produced in the U. S. A. For 'under the bonnet' applications is has been necessary to establish the different environments which components have to encounter - for example, the temperature ranges from -40°C to +120°C and in the case of components in contact with engine oil the temperature might exceed 140°C. The component might be totally immersed in engine oil or contact might be on one side only.

It was therefore essential to study the effect of temperature on the mechanical properties for extensive periods and examine the behaviour in various fluids at elevated temperatures.

Having established that under such environmental conditions the properties of the D. M. C. were either unchanged or if changed were still adequate, consuderation could then be given to using D. M. C. for the several components which hitherto have been fabricated from traditional materials.

Cost studies were carried out and in most cases it was shown that significant savings could be effected.

The next stage was to fabricate components so that they could be fully evaluated under field conditions. Several difficulties were encountered, for example:

1. To produce an exact replica of the metal component in D. M. C. might not necessarily result in a satisfactory component because of design considerations.

2. It might not be possible to redesign the component to give optimum results because such changes could not be accommodated on the final component.

3. The cost of the tool might be considered prohibitive for evaluation work. (For optimum results, particularly for components which have to be fabricated to close dimensional tolerances it is essential to use a correctly designed mould made from tool steel). It some cases acceptable mouldings were produced in tools previously used for die casting metals.

Despite these difficulties several prototype components have been produced and these are now being subjected to field trials. So far the results have been very promising and where failures have occured it has been established that this was due to incorrect design.

CONCLUSIONS

The significant properties of non shrink D. M. C. are:

1. Retention of properties over a wide temperature range

2. Non shrink properties which give excellent surface finish and absence of sink marks

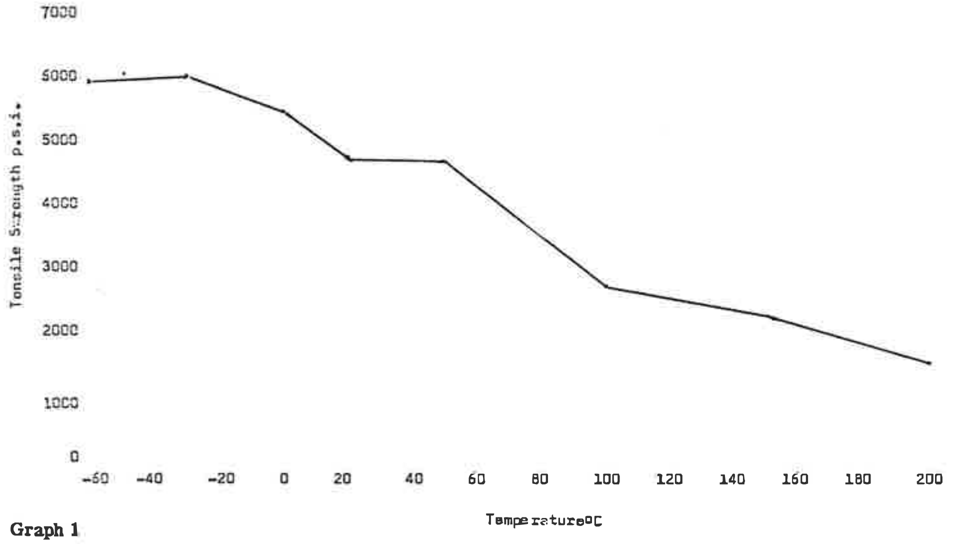
3. Mouldability to extremely close tolerances

4. Low coefficient of thermal expansion

5. Good resistance to hostile environments.

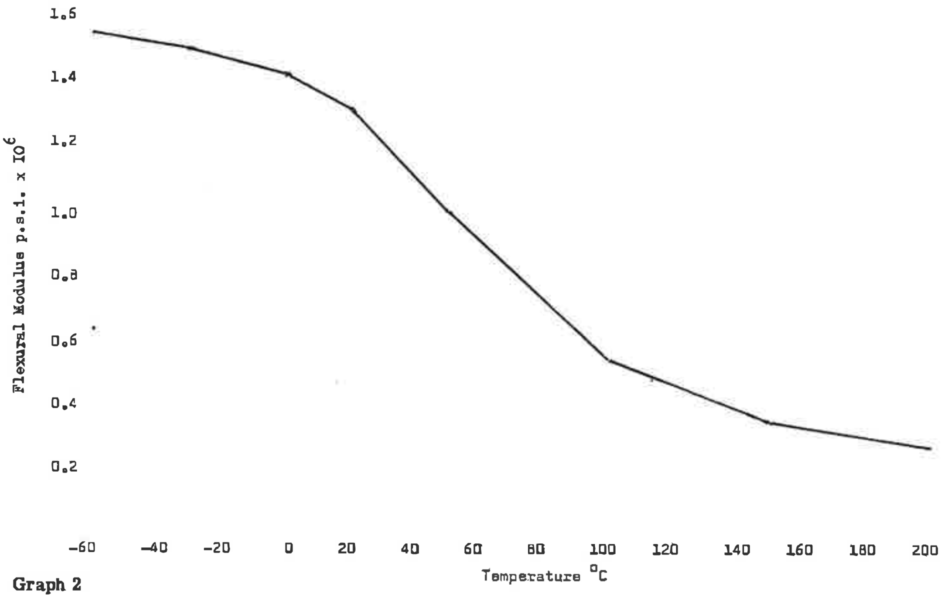
Although discussions have been confined to the use of D. M. C. in the automotive industry there are many other applications which should and are being considered. Zinc alloys, aluminium die castings and lightly stressed steel fabricated components are obvious areas for replacement by these compounds.

There still remains much to be done. The material manufacturer must concentrate more effort to supply effective engineering design data; he must continue development work to reduce costs even further and increase the strength properties. The machinery manufacturer must keep pace with this development and produce presses with improved design to give faster cycles. If the automotive engineer wishes to exploit the undoubted advantages of these materials he must be prepared to understand and co-operate in the development of new processing technology necessary with these compounds. Finally there must be a considerable capital investment in the future if the promise of large usage of glass reinforced polyester compounds is to be realized.



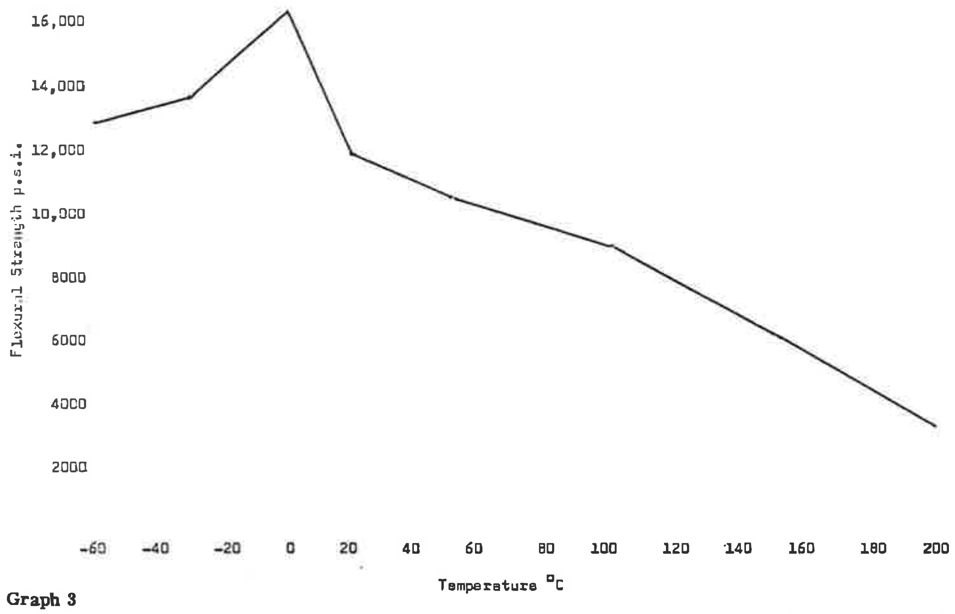
Graph 1

Effect of Temperature on Tensile Strength of Mouldings made fron non shrink D.M.C. (Cellobond K.515).



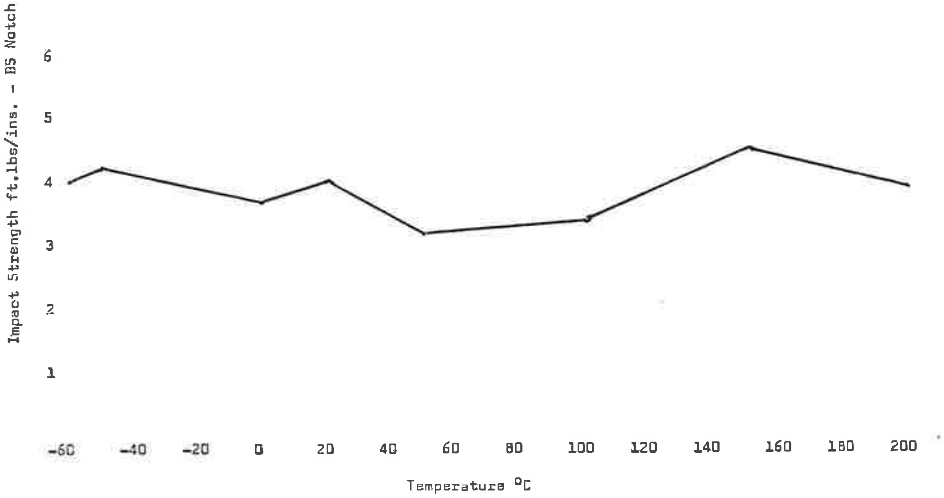
Graph 2

Effect of Temperature on Flexural Modulus of Mouldings made from non shrink D.M.C. (Cellobond K. 515)



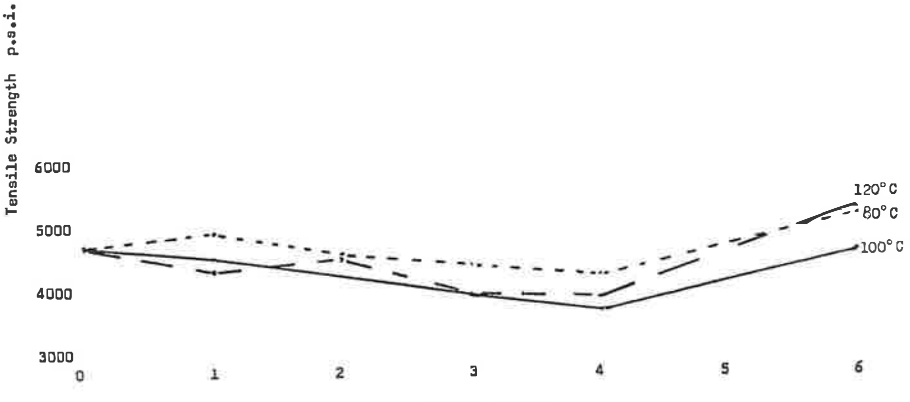
Graph 3

Effect of Temperature on Flexural Strength of Mouldings made from non shrink D.M.C. (Cellobond K. 515).



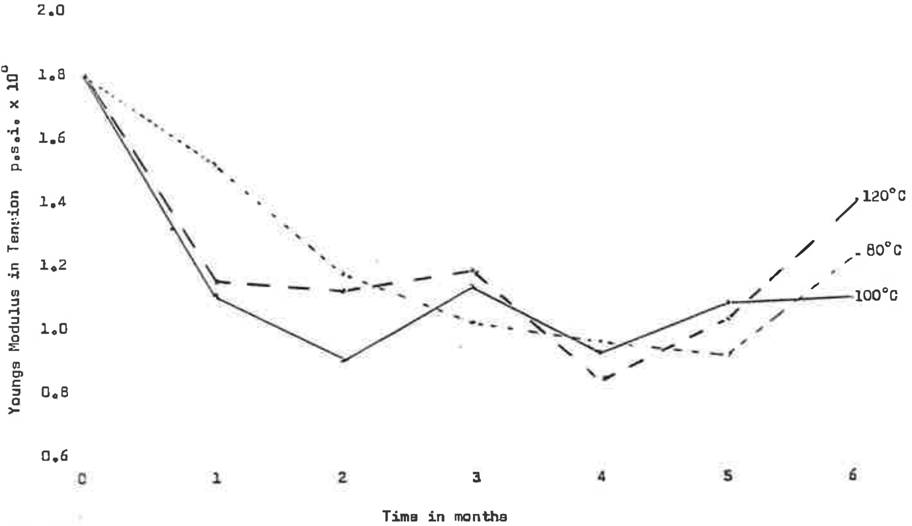
Graph 4

Effect of Temperature on Impact Strength of Mouldings made from non shrink D.M.C. (Cellobond K. 515).



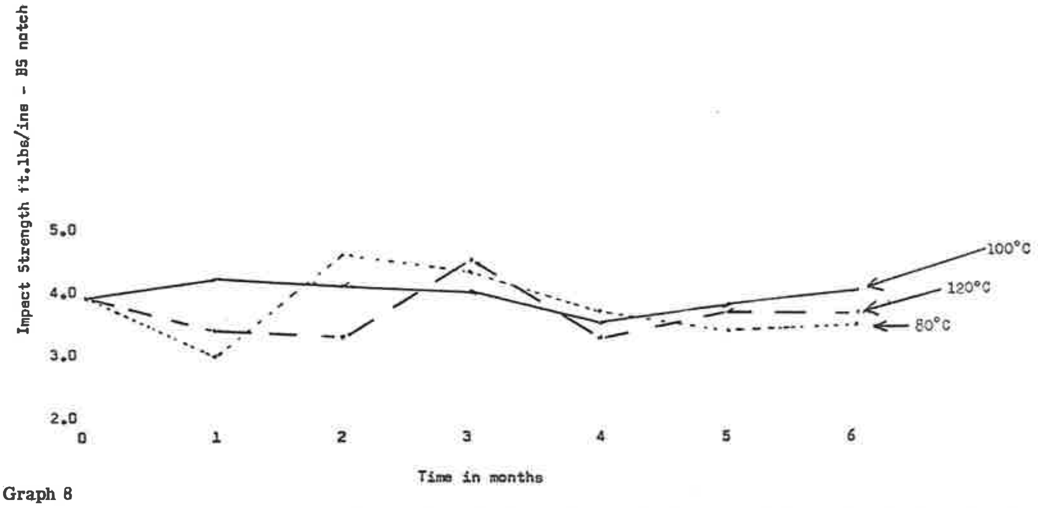
Graph 5

Long Term effect of Temperature on Tensile Strength of Mouldings made from non shrink D.M.C. (Cellobond K. 515).



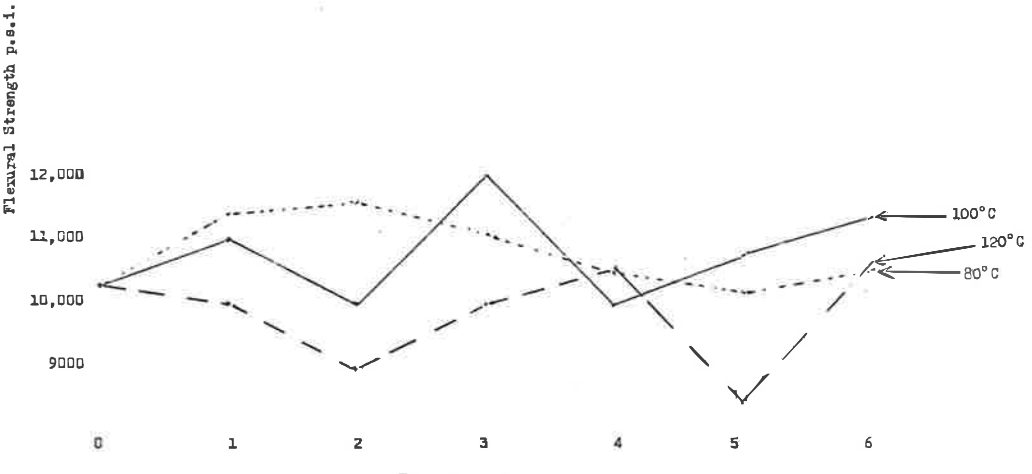
Graph 6

Long Term effect of Temperature on Youngs Modulus in Tension of Mouldings made from non shrink D.M.C. Cellobond K. 5150.



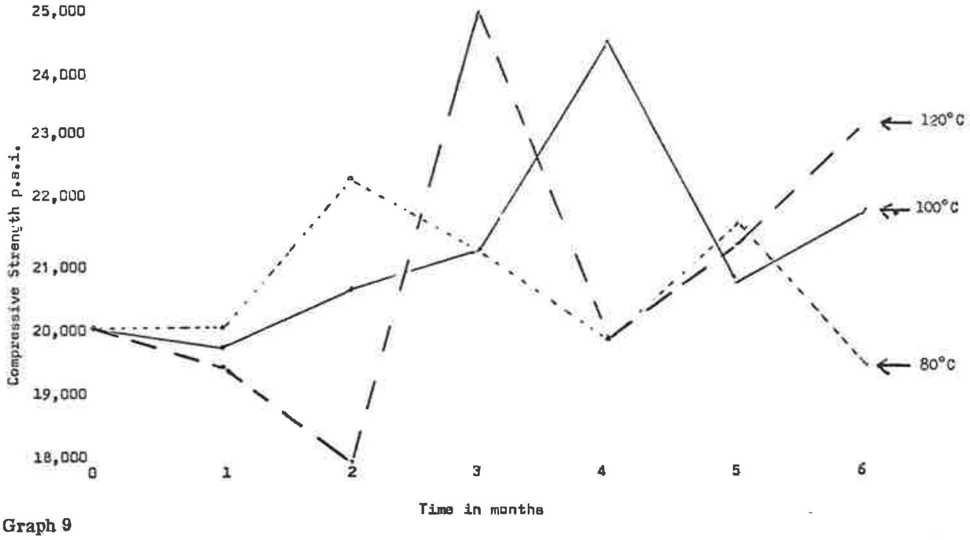
Graph 8

Long Term effect of Temperature on Impact Strength of Mouldings made from non shrink D.M.C. (Cellobond K. 515)



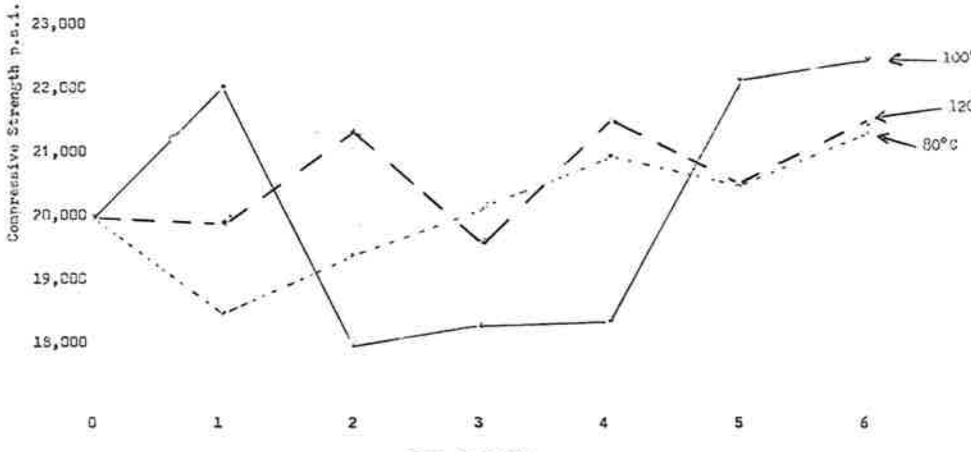
Graph 7

Long Term effect of Temperature on Flexural Strength of Mouldings made from non shrink D.M.C. (Cellobond K. 515)



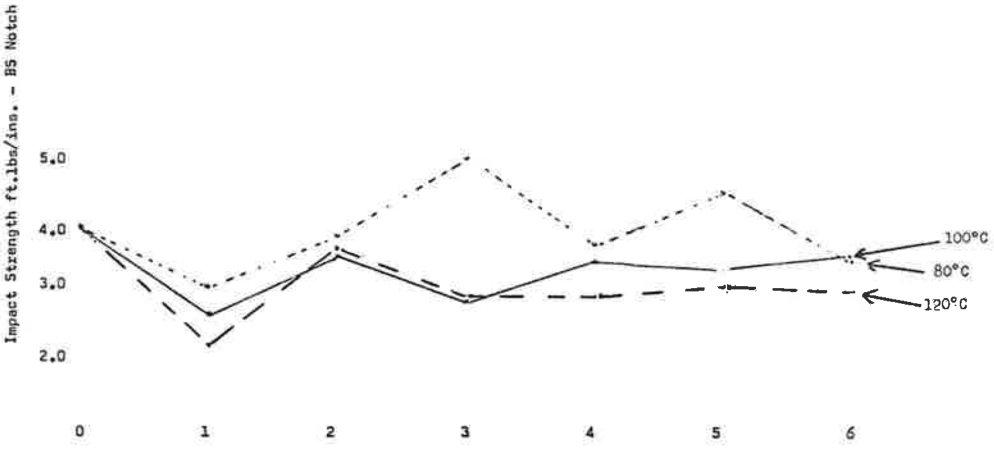
Graph 9

Long Term effect of Temperature on Compressive Strength of Mouldings made from non shrink D.M.C. (Cellobond K. 515)



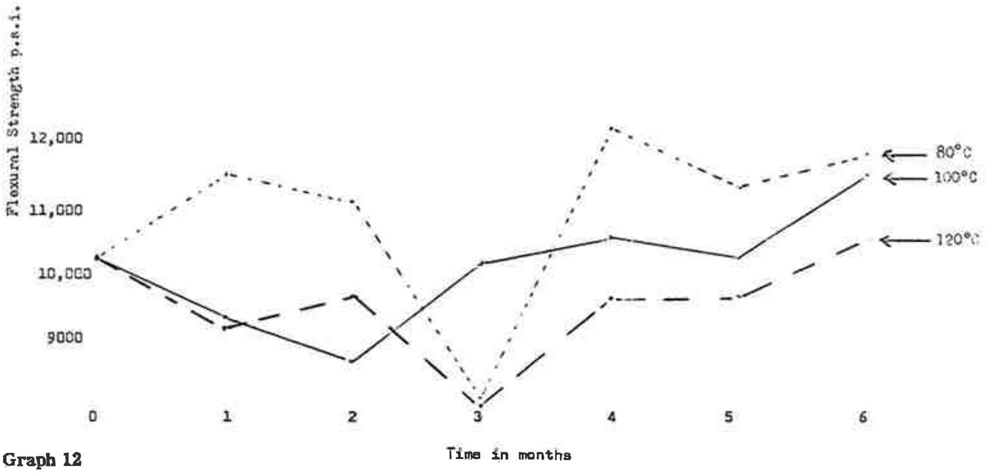
Graph 10

Effect of immersing mouldings made from non-shrink D.M.C. (Cellobond K. 5150 in lubricating oil B.P. Viscostatic) on Compressive Strength



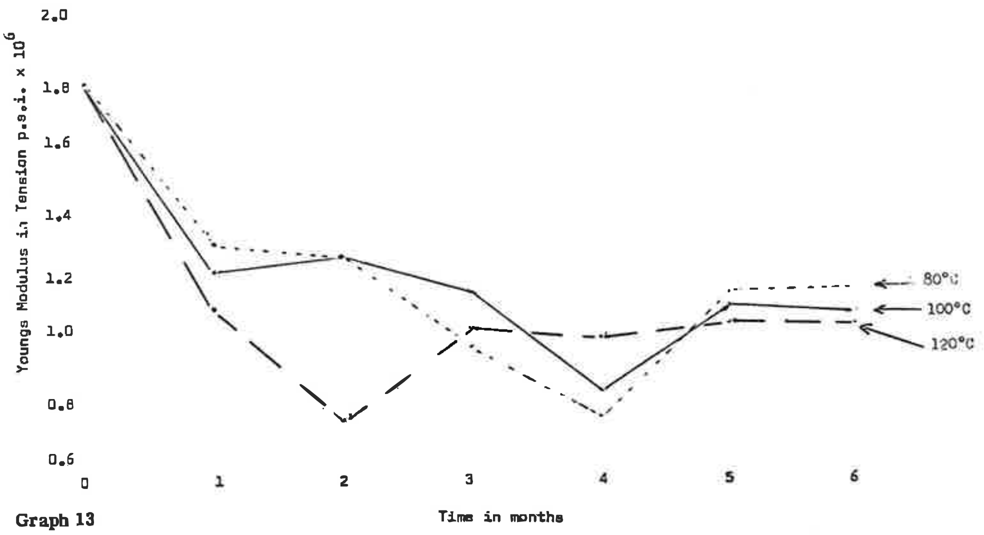
Graph 11

Effect of immersing mouldings made from non-shrink D.M.C. (Cellobond K. 515) in lubricating oil (B.P.Viscostatic) on Impact Strength.



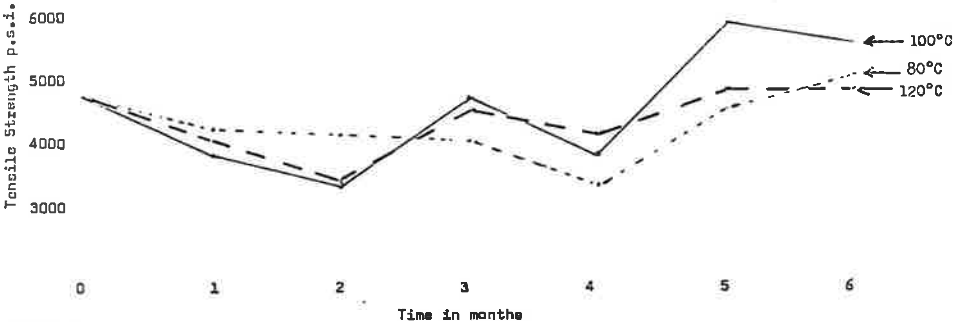
Graph 12

Effect of immersing mouldings made from non-shrink D.M.C. (Cellobond K. 515) in lubricating oil (B.P. Viscostatic) on Flexural Strength.



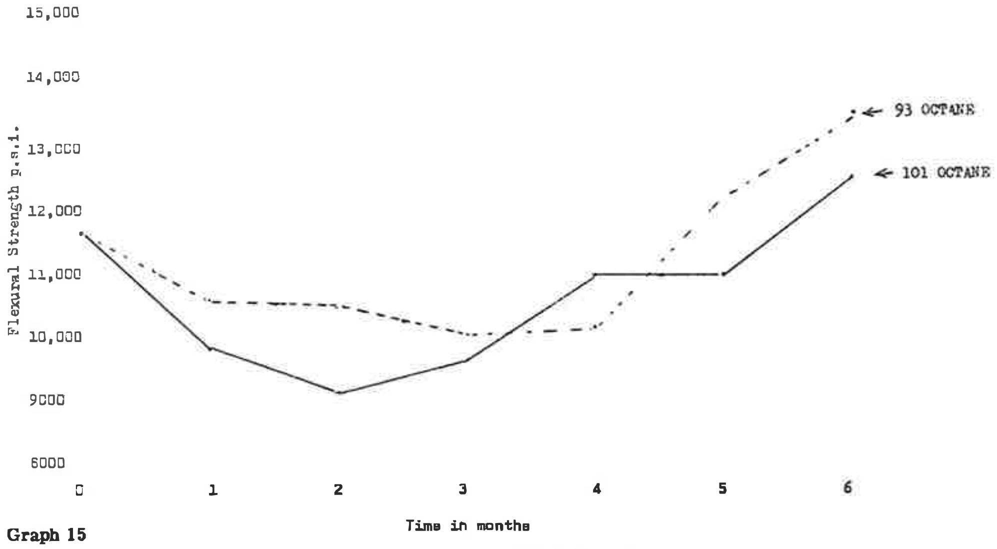
Graph 13

Effect of immersing mouldings made from non-shrink D.M.C. (Cellobond K. 515) in lubricating oil (B.P.Viscostatic) on Youngs Modulus in Tension



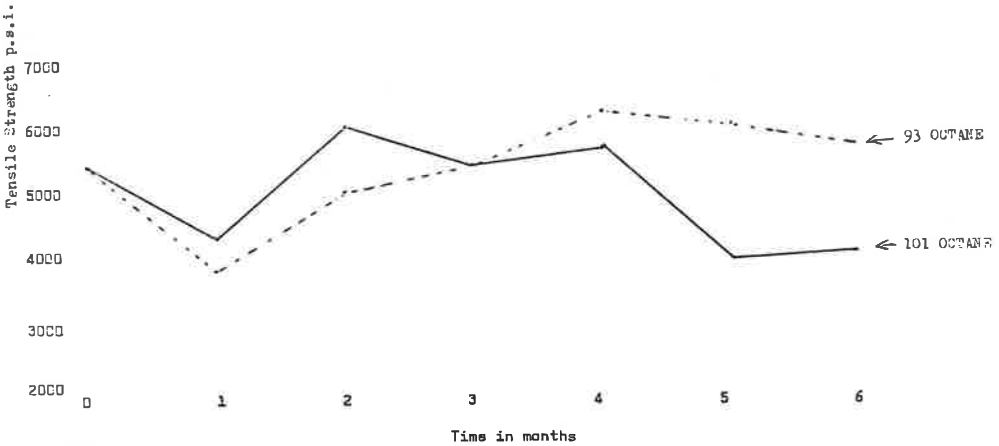
Graph 14

Effect of immersing mouldings made from non-shrink D.M.C. (Cellobond K. 515) in lubricating oil (B.P. Viscostatic) on Tensile Strength.



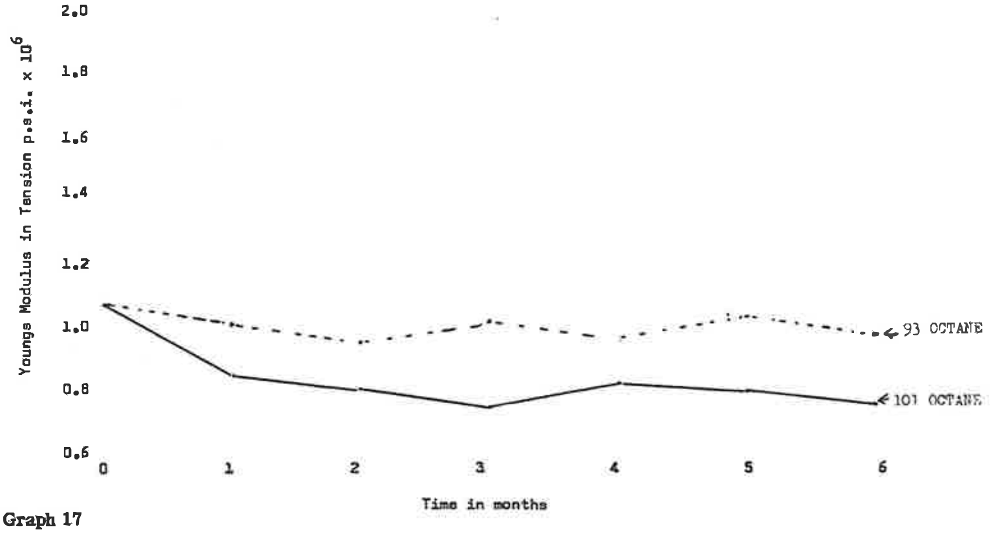
Graph 15

Effect of immersing mouldings made from non shrink D.M.C. in Petrol on Flexural Strength.



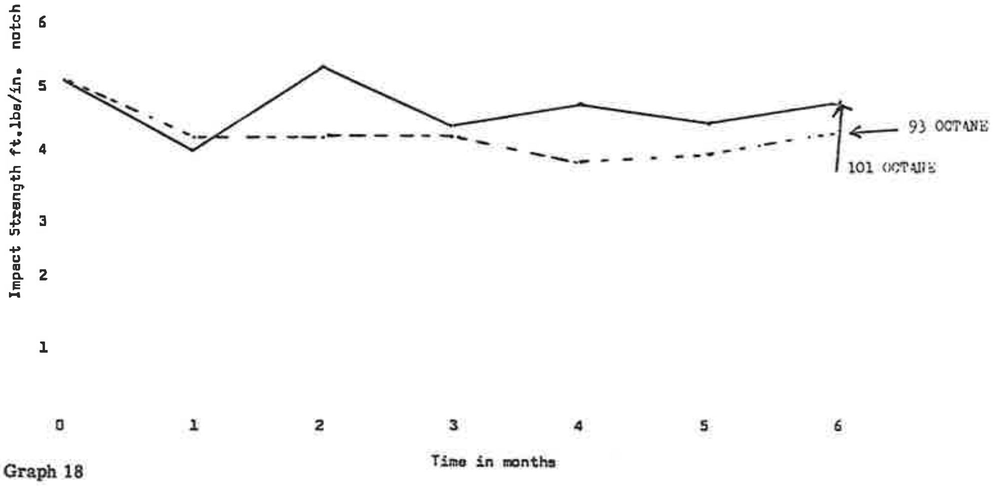
Graph 16

Effect of immersing mouldings made from non shrink D.M.C. in Petrol on Tensile Strength.



Graph 17

Effect of immersing mouldings made from non shrink D.M.C. in Petrol on Youngs Modulus in Tension



Graph 18

Effect of immersing mouldings made from non shrink D.M.C. in Petrol on Impact Strength.

An Engineering Comparison of Die Cast Zinc and Injection Molded Polymers

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WITH MORE THAN TWO DOZEN PAPERS in the literature (see References) comparing zinc die castings with unfilled injection molded plastics, the designer still waits for truly comparative test data to guide him to the best materials selection. Truly comparative test data, on identical test specimens, have yet to be presented. Recognizing this need, the International Lead Zinc Research Organization, Inc. contracted with the United States Testing Co. in 1968 to design and conduct such a study.

In the initial phase of designing the test program, it became apparent that sound plastic specimens could not be produced and satisfactorily tested to metal industry testing standards due to internal voids and sink marks occurring in thicker sections when molded at economical cycle rates. This deficiency of plastics is due to their high coefficient of thermal expansion and low thermal conductivity coupled with the rapid chill employed in the injection molding process.

It was therefore decided that appropriate dies would be provided so that the zinc die cast samples could be made to the identical geometry required by the plastics industry standard testing procedures. This approach had the added advantage of meeting the plastics industry on its own terms and dispelling any possible criticism that the tests were "slanted" to favor zinc die casting.

TEST PROGRAM

The materials selected for this study were a commonly used die cast zinc (SAE 903) and five unfilled, injection molding grade, engineering thermoplastics - ABS, polyacetal, polycarbonate, polypropylene, and nylon. The properties evaluated and test methods used are listed in Table 1.

All plastic samples were injection molded to the shape required for test with the exception of the fatigue samples. These samples were machined from 3-1/2 in. diameter discs, 1/8 in. thick. All the zinc samples were die cast to shape and no surface machining was performed prior to testing. Unless otherwise indicated, test results were the average of five identical samples.

For the plated specimens, samples of ABS, polycarbonate, polypropylene, and SAE 903 zinc die casting alloy were plated with approximately 0.5 mil of bright leveling acid copper and 1.0 mil of duplex nickel followed by 0.040 mil of micro-cracked chromium containing about 1200-2000 cracks/in. (Micro-cracked chromium is generally used on plastics for improved corrosion protection only and on zinc die castings for improved corrosion protection and low temperature impact resistance).

The data that follow illustrate that SAE 903 zinc alloy is a much stronger, stiffer, creep, impact and fatigue resistant material than all the unfilled thermoplastics tested. Furthermore, this superiority in physical properties prevails over temperatures from -40 to +80 C.

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*Note
The paper was written in co-operation with L. S. Lazar
United States Testing Co.

Table 1 - Program Test Procedures for Die Cast Zinc and Plastics

Property
Mechanical
Tensile
Flexural
Shear
Impact
Creep
Fatigue
Tapping
Physical
Dimensional stability
Heat distortion
Weathering
Flammability
Stress cracking

TESILE STRENGTH

The tensile strength of each material, through the range -40 to +80 C, is depicted in Fig. 1. The SAE 903 alloy is shown to be more than six times stronger than the weakest of the plastics (polypropylene) at room temperature and more than three times stronger than the strongest of the plastics (polycarbonate). As anticipated, all of the materials show a decline in the tensile strength with increasing temperature. However, the zinc alloy exhibits a continuing superiority in tensile strength over polymeric materials throughout the range investigated. All of the plastics exhibit an almost linear relationship of tensile strength with temperature variations.

PLATED TENSILE STRENGTH

Fig. 2 illustrates that plating does not significantly affect tensile strength at room temperature. As expected, the stiffness of plastics is affected by plating, as Fig. 3 illustates. The flexural properties, as expected, follow the tensile behavior.
For example, Fig. 4 illustrates the flexural strength-versus-temperature relationships. Of the plastic materials, polycarbonate was least sensitive to temperature while polypropylene showed the greatest reduction in strength over the range of temperature investigated. Zinc, while also reduced in strength by temperature increases, nevertheless remains approximately 5 times stronger than the plastics.
The effect of plating on the flexural strength and flexural modulus is shown in Figs. 5 and 6, respectively.

SHEAR STRENGTH

The shear strength relationships of the various materials are expressed in Fig. 7. The zinc die cast samples exhibited a superiority in strength for this property, over the plastics, in the general ratio 5 : 1, which was maintained throughout the entire range of temperature under investigation. The curve obtained for the polycarbonate material showed little slope, demonstrating a high degree of stability under the test conditions. The decline in strength with temperature was considerably greater for the other polymers.

EFFECT OF NOTCHES ON STRENGTH

Tensile specimens of the ASTM D 638 type were prepared with what are normally regarded as stress raisers. One group of specimens contained a 1/16 in. hole midway along the test region and on the center line of each specimen. The other group had a pair of notches of 0.010 in. radius on opposite sides of the test specimen in the middle of the test region. The results of tension test of these materials were compared with samples without stress raisers to determine stress concentration factors (Fig. 8). The results were different from what might be expected. That is, while it might be expected that specimens with holes or notches would fail at lower stresses, this was not always the case. This apparently is due to the complex rather than uniaxial stresses that develop particularly within materials that draw down locally. In these cases the presence of a notch or hole gives an apparent negative stress concentration factor as in the case of nylon or polycarbonate. The state of triaxial tension that can exist near the center of the draw-down region of a tensile specimen may be reduced by drilling a hole in that region so that dual regions of more nearly uniaxial tension can result. The case of SAE 903 illustrates this effect.

Plated samples were also tested with the same results (Fig. 9).

IMPACT STRENGTH (TENSILE TYPE)

Since zinc die casting alloys are normally impact tested using an unnotched Charpy bar and plastics are tested using a notched Izod bar, it was decided that neither of these types of test would be satisfactory to establish a true comparison of the materials. Useful data were obtained when tensile impact tests, as described in MIL-P-8045B, were conducted on the samples.

Normal ASTM D 638 bars were used with a pendulum type impact tester. The zinc die cast alloy was more than twice as resistant to impact stresses as the strongest of the plastic materials (polycarbonate and nylon 6/6), and zinc was about eight times stronger than ABS under impact conditions. For example, the tensile impact strength of SAE 903 is 2600 ft-lb/in.^{2} while nylon is 1100 ft-lb/in^2, polycarbonate is 1200 ft-lb/in.^{2} and ABS is 330 ft-lb/in.^{2}. Polyacetal and polypropylene are about equal to each other in impact resistance at 540 ft-lb/in.^{2} and 530 ft-lb/in.^{2} respectively.

CREEP STRENGTH

The creep behavior of SAE 903 die cast zinc is a deficiency well-recognized by the designer and metallurgist. In fact, extensive recent alloy research has led to zinc die casting alloys with improved creep behavior. Yet, this inferiority under constant load is only true when comparing zinc to steel and other high performance metals. Plastics, however, are "plastic" and creep to a far greater extent than any zinc alloy. So, if the designer looks for permanence under load he should choose zinc over any plastic. Comparisons of the apparent creep moduli (100 hr) of the various plastics and SAE 903 zinc die casting alloy are shown in Table 2.

Table 2 - Creep of Die Cast Zinc and Plastics

Material	Apparent Modulus of Elasticity at 100 hr, psi
ABS	210,000**
Nylon 6/6	60,000**
Polyacetal	192,000*
Polycarbonate	290,000*
Polypropylene	44,000**
SAE 903	7,300,000*

*4000 psi load **2000 psi load

Table 3 - Fatigue Strength of Die Cast Zinc and Plastics

Material	Flexural Fatigue Strength at 10^7 cycles, psi
ABS	2200
Nylon 6/6	2000
Polyacetal	3500
Polycarbonate	1000
Polypropylene	2600
SAE 903	9200

FLEXURAL FATIGUE BEHAVIOR

The flexural fatigue behavior of these materials was measured in accordance with ASTM D 671. Fatigue is damage caused by alternate stressing. While this damage can be imposed axially (in tension, compression, or both) in flexure or torsion, in a random or uniform pattern of loading of various wave forms, ASTM D 671 specifies a simple sine wave in cantilever bending flexure.
The results obtained indicate that SAE 903 has a flexural fatgue strength, at 10 million cycles, which is almost three times as great as the strongest plastic tested.
Results of these tests are summarized in Table 3.

TAPPING PERFORMANCE

Sections of each material, 1/2 in. in thickness, were tested for tapping characteristics under the following threading conditions: with self-tapping screw sizes #6, #8, and # 10; starting hole sizes 32, 25 and 17, respectively, were used.
The force required to strip the threads made by each self-tapping screw, that is, to produce free turning and loss of material engagement, was measured by a torque wrench having a maximum capacity of 100 in.-lb.
The results are summarized in Table 4. The zinc die cast material proved to be greatly superior to all plastics for this property. Among the polymers, polycarbonate exhibited the most desirable thread retention properties followed by ABS, polyacetal, polypropylene, and nylon.

Table 4 - Tapping Performance of Die Cast Zinc and Plastics

Screw Size	Force to Strip, in.-lb #6	#8	#10
ABS	15	15	23
Nylon 6/6	5	10	14
Polyacetal	13	12	20
Polycarbonate	20	26	26
Polypropylene	5	7	16
SAE 903	*100	*100	*100

*No failure at maximum load

DIMENSIONAL STABILITY

Investigations through the range 80-120 C performed on tensile coupons showed all of the plastics as well as the SAE 903 capable of withstanding the minimum temperature of 80 C without dimensional change. At 90 C, a slight shrinkage of the ABS (approximately 1/8 in. of length) was developed. This tendency to distortion increased for the ABS with temperature and complete relaxation of the residual molding stresses was developed at

100-110 C.

Table 5 - Heat Distortion Characteristics of Die Cast Zinc and Plastics

66 psi

Sample	Heat Distortion Temperature, F
ABS	174
Nylon 6/6	159
Polyacetal	304
Polycarbonate	288
Polypropylene	150
264 psi	
ABS	161
Nylon 6/6	124
Polyacetal	189
Polycarbonate	266
Polypropylene	138
SAE 903*	in excess of 420

*SAE 903 will not deflect 0.010 in. at this temperature under 264 psi stress.

HEAT DISTORTION

Table 5 depicts heat distortion temperatures versus applied load for each material. The superiority of zinc die casting alloy under these conditions is clearly demonstrated.

Table 6 - Effect of Weathering on Tensile Strength of Die Cast Zinc and Plastics

Material	Tensile Strength, psi (as received)	Tensile Strength, psi (500 hr weathering)	Change in Tensile strength, %
ABS	6,410	5,940	- 8
Nylon 6/6	6,990	7,670	+10
Polyacetal	7,920	5,210	-34
Polycarbonate	9,890	8,760	-11
Polypropylene	4,520	3,190	-30
SAE 903	40,200	40,400	+ 0.5

WEATHERING

The results of tensile strength tests performed after 500 hr of aging in an Atlas DLTS Twin Arc weatherometer are summarized in Table 6 and the effect of 500 hr of UV exposure in a FDA-R-Fade-O-Meter are summarized in Table 7. The zinc die cast samples remained unaffected by either type of exposure while most of the plastics were deleteriously affected.

One possible explanation for the increase in tensile strength of the nylon is that the material is dried by the exposure. That is, when nylon loses water, its strength increases.

Table 7 - Effect of Ultraviolet Radiation on Strength of Die Cast Zinc and Plastics

Material	Tensile Strength, psi (as received)	Tensile Strength, psi (500 hr UV exposure	Change in Tensile strength, %
ABS	6,410	6,310	- 1.6
Nylon 6/6	6,990	7,370	+ 5.4*
Polyacetal	7,920	5,890	-26
Polycarbonate	9,890	8,620	-13
Polypropylene	4,520	3,130	-37
SAE 903	40,200	40,400	+ 0.5

* The increase in tensile strength is probably due to the effect of moisture on nylon. Nylon is very sensitive to humidity.

Table 8 - Flammability Characteristics of Die Cast Zinc and Plastics

Material	Burning Rate, in./min
ABS	1.60
Nylon 6/6	Nonburning
Polyacetal	0.89
Polycarbonate	Nonburning
Polypropylene	0.78
SAE 903	Nonburning

FLAMMABILITY

SAE 903 zinc die casting alloy was compared with the five plastics in accordance with the provisions of ASTM D 635. The results are shown in Table 8. While this test procedure indicates that two of the plastics are nonburning, the designer must, nevertheless, be fully cognizant of the additional hazards of plastics in the presence of burning gasoline such as accurs frequently under high speed, rear end automotive collision conditions.
In a recently approved procedure (ASTM D 2863) where plastics are burned in a chamber containing various oxygennitrogen mixtures, all of these plastics burn.

STRESS-CRACKING

The resistance to stress-cracking of the polymer materials was determined under test conditions described in Method 6053 of Federal Standard No. 406 using isopropyl alcohol, gasoline, ethylene glycol, liquid car wax, and paste car wax as reagents. The specimen was set up as a Class I lever with the fulcrum 2 in. from the clamped end and a load of 2.6 lb suspended at a 4 in. overhang from the fulcrum.
This loading for the 4 in. overhang and 0.25 in. thick specimen produces an outer fiber stress of 1000 psi in plastic at the fulcrum point. While the specimen was stressed, reagent was applied to the top surface of the plastic above the fulcrum point. After thorough drying of the reagent, the specimen was carefully examined for any evidence of surface defects, cracks, or crazing.
The polycarbonate displayed an immediate tendency toward stress-cracking in the presence of gasoline. It was unaffected by the other reagents as were the remaining plastic materials. SAE 903 was unaffected by any of these exposures.

COST CONSIDERATIONS

This program has resulted in the compilation of a substantial volume of data which verifies that die cast zinc is stronger, stiffer, and more thermally resistant than the five common unfilled injection molded plastics tested here under identical procedures. The plastics industry recognizes that the density of SAE 903 is 5 to 8 times greater than most unfilled thermoplastics and this fact is emphasized in their literature by frequent references to the high strength/weigth ratios and low cost per cubic inch of plastics. Conversely, the metals industry stresses integrity and high strength that is maintained over a wide temperature range. Both statements are true as far as they go, but which is the best choice for the designer to make when he needs maximum strength and stiffness at the lowest price?

In order to determine the relative costs of using various materials, it is important to establish the minimum amount of each material required to attain the needed strength and/or stiffness. This should be done as a function of product design but, for the purposes of this paper it was mathematically convenient to establish the minimum width and thickness dimensions and corresponding weights of 10 in. long square rods, in each material, that would fail at specified load under the particular test conditions. The details of the calculations, based on this approach, are described in Appendix B.

Using the material densities and material prices (at the time this paper was prepared) the formulas in Appendix B generate the data tabulated in Table 9. Since the absolute prices are of little significance (based on arbitrarily selected stress levels), it is much more meaningful to compare the cost of each plastic, for each property level, to the equivalent cost of SAE 903 zinc die casting alloy.

The results summarized in Table 9 illustrate that although SAE 903 is 5 to 8 times more dense than the plastics evaluated, it is less expensive to use in most applications requiring strength and stiffness. The low cost per pound, coupled with the high strength and stiffness of SAE 903, more than compensate for its high density and account for its properties/cost superiority.

Table 10 illustrates the cost for equivalent levels of properties of the plastics tested as a function of the cost of SAE 903. For example, this table indicates that an ABS rod would cost 2.54 times more than an SAE 903 rod to withstand the same tensile load. When viewed in this manner, only polypropylene, an extremely low cost, low density plastic comes close to the properties/cost performance of SAE 903. On the other hand, the table shows that polypropylene would cost more than 37 times the cost of SAE 903 for equivalent stiffness under tensile creep conditions.

The study reported here has dealt only with unfilled polymers. Future work will be directed toward repeating these tests with the same five plastics filled with various amounts of glass fiber reinforcement. While it is well-known that glass fibers produce marked increases in the mechanical properties of plastics, they also, simultaneously, cause substantial increases in the plastic prices due to the additional processing and controls required. The results of this additional study will be reported on a later date.

CONCLUSION

A series of mechanical and physical property tests have been successfully conducted, for the first time on a truly comparative basis, to compare SAE 903 zinc die casting alloy with the five most commonly used injection molded plastics. These tests have conclusively shown in almost all cases, under the various types of tests conducted, that SAE 903 zinc die casting alloy is the preferred economical choice over the plastics when the cost of equivalent load bearing capability is the primary engineering consideration.

Table 9 - Comparative Costs of Plastics and SAE 903 Die Cast Zinc for Equivalent Levels of Various Properties

Material	Density, lb/in. 3	Cost,* ¢/lb	Cost of 10 in. long square rod, cents** Tensile Strength at 24 C	Tensile Strength at 80 C	Flexural Strength at 24 C	Tensile Creep (100 hr) at 24 C	Tensile Impact Strength at 24 C	Flexural Fatigue Strength at 24 C
ABS	0.038	41.0	0.28	0.52	96	0.37	4.72	141
Nylon 6/6	0.041	75.0	0.52	0.81	189	2.57	2.78	297
Polyacetal	0.051	65.0	0.34	0.75	168	0.87	6.11	220
Polycarbonate	0.043	80.0	0.42	0.54	163	0.60	2.88	527
Polypropylene	0.032	31.0	0.22	0.47	77	1.13	1.86	81
SAE 903	0.24	18.5	0.11	0.15	70	0.03	1.70	155

* Costs at time of paper preparation (carload lots or maximum quantity bracket). All calculations are based on these figures.

** See Appendix B for cost calculations.

Table 10 - Ratio of Cost of Plastics to Cost of SAE 903 Die Cast Zinc* for Equivalent Levels of Various Properties

Material	Tensile Strength at 24 C	Tensile Strength at 80 C	Flexural Strength at 24 C	Tensile Creep (100 hr) at 24 C	Tensile Impact Strength at 24 C	Flexural Fatigue Strength at 24 C
ABS	2.54	3.46	1.37	12.3	2.78	0.91
Nylon 6/6	4.72	5.40	2.70	85.6	1.64	1.91
Polyacetal	3.09	5.00	2.40	29.0	3.60	1.42
Polycarbonate	3.82	3.60	2.33	20.0	1.70	3.40
Polypropylene	2.00	3.13	1.10	37.7	1.09	0.52

* SAE 903 die cast zinc = 1.0

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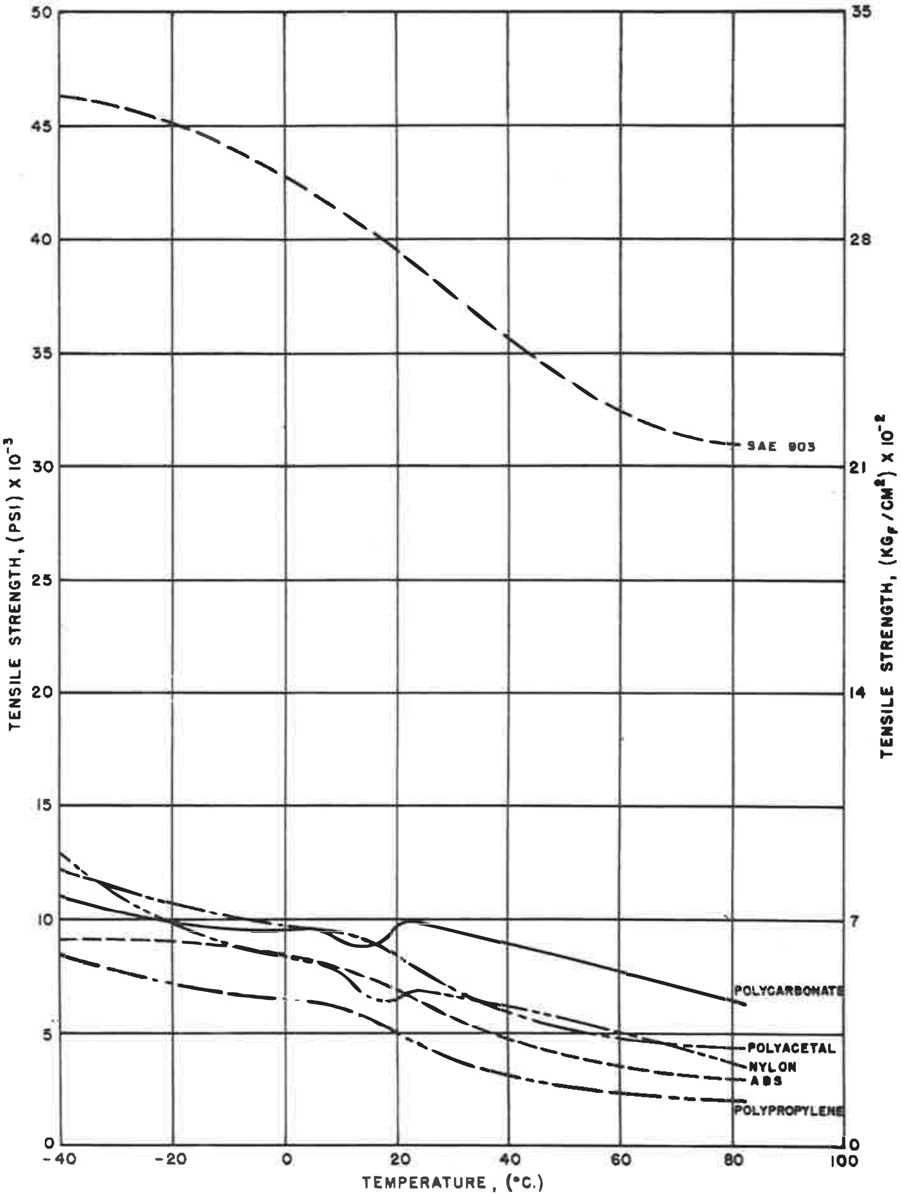

Fig. 1 - Chart of tensile strength versus temperature

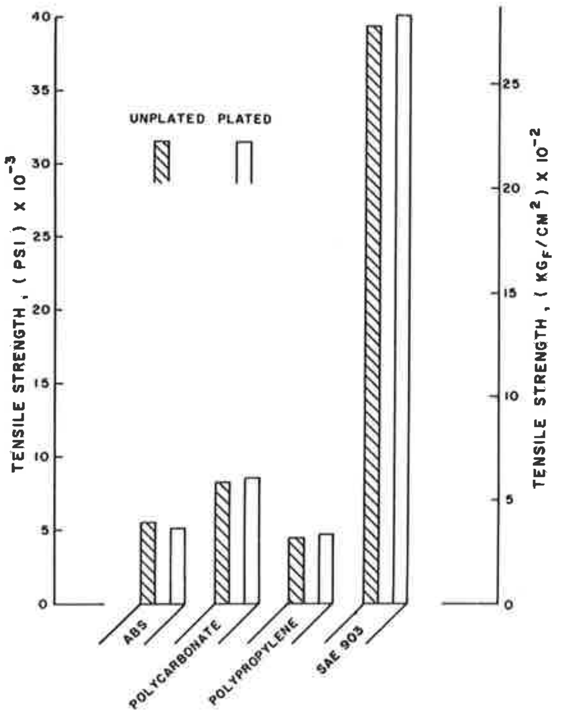

Fig. 2 - Effect of plating upon tensile strength of materials (ASTM D-638) (0.2 in./min)

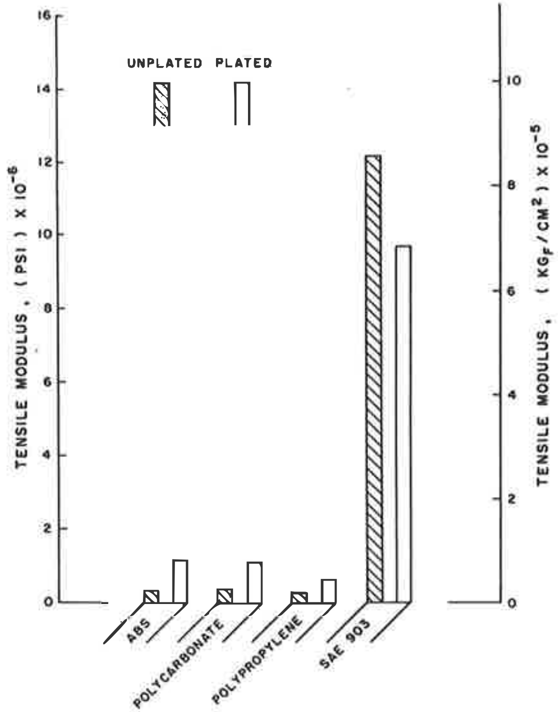

Fig. 3 - Effect of plating upon tensile modulus of materials (ASTM D-638) (0.2 in./min)

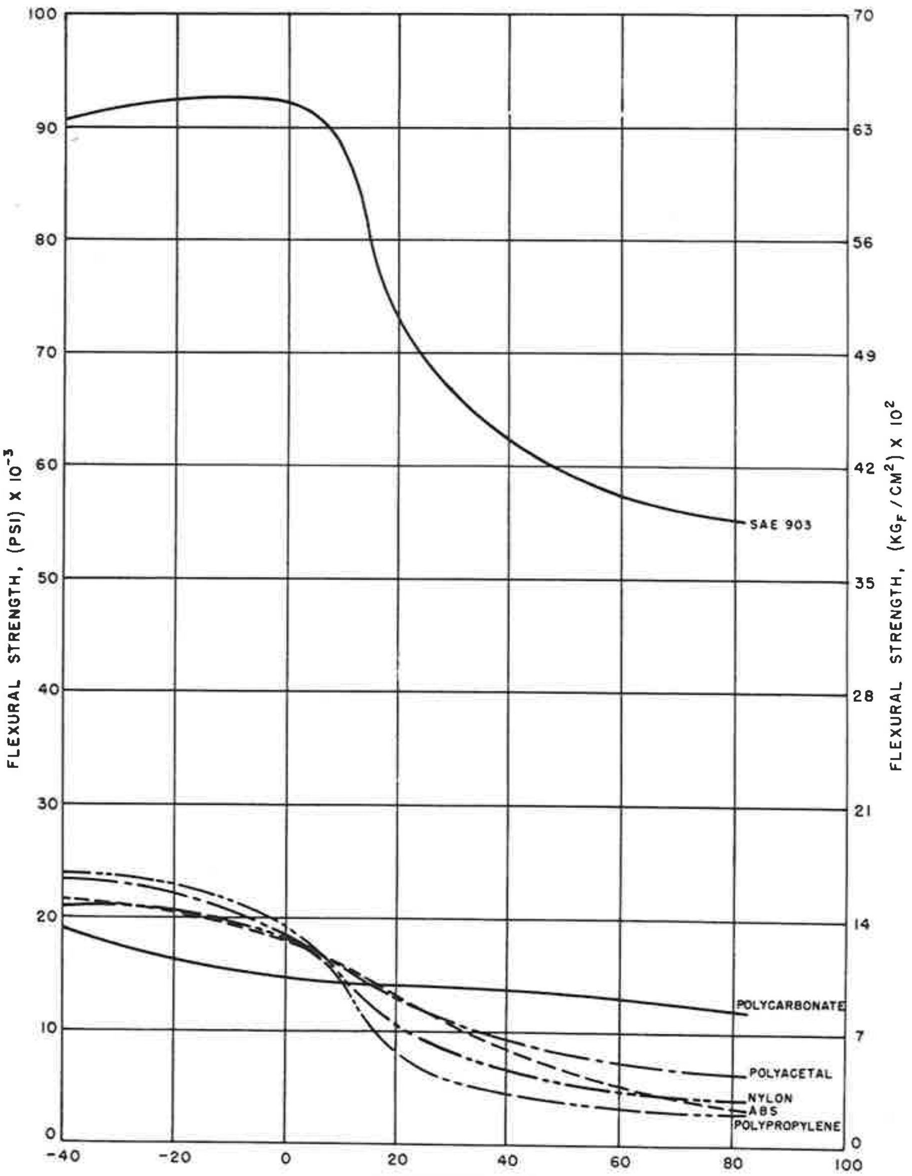

Fig. 4 - Chart of flexural strength versus temperature

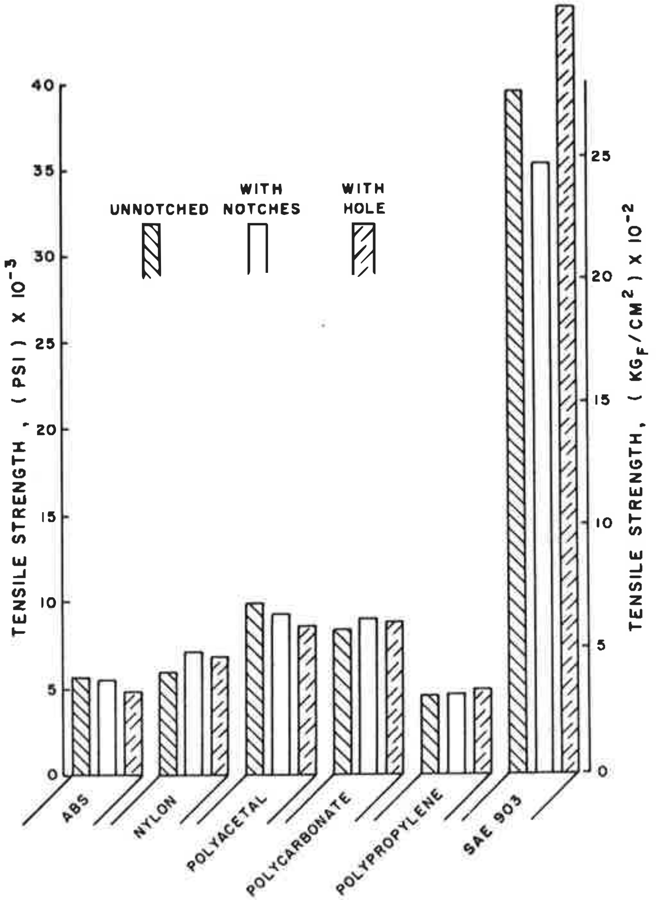

Fig. 8 - Effect of notches upon tensile strength of materials (ASTM D-638) (0.2 in./min)

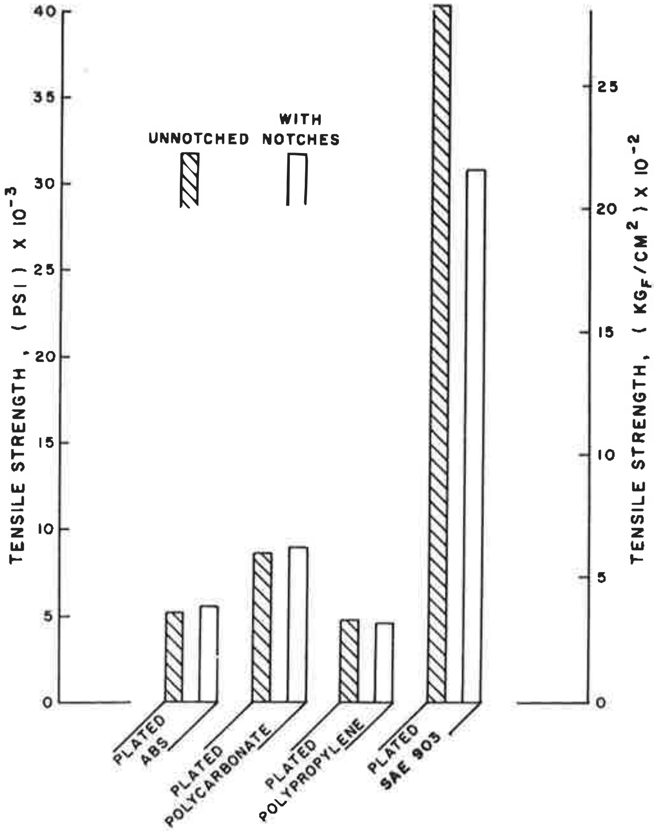

Fig. 9 - Effect of notches upon tensile strength of plated materials (ASTM D-638) (0.2 in./min)

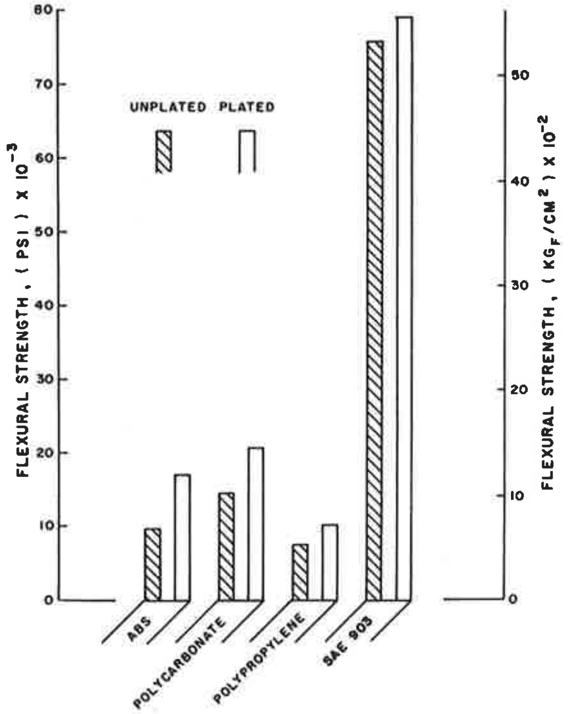

Fig. 5 - Effect of plating upon flexural strength of materials (ASTM D-790) (0.1 in./min)

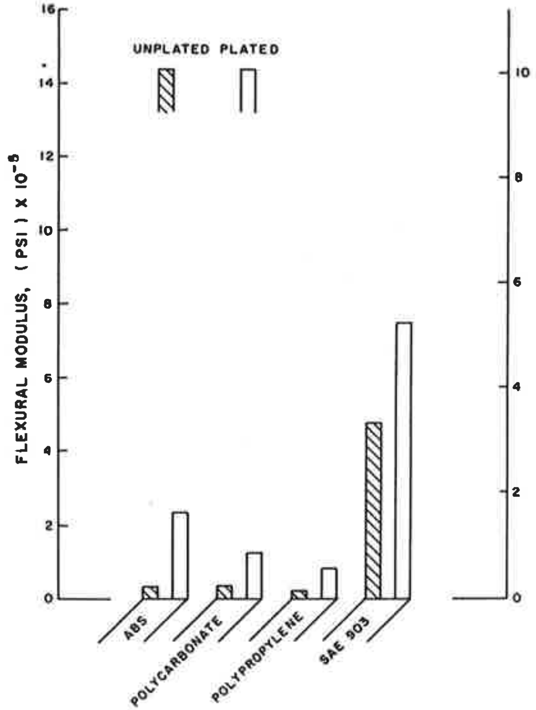

Fig. 6 - Effect of plating upon flexural modulus of materials (ASTM D-790) (0.1 in./min)

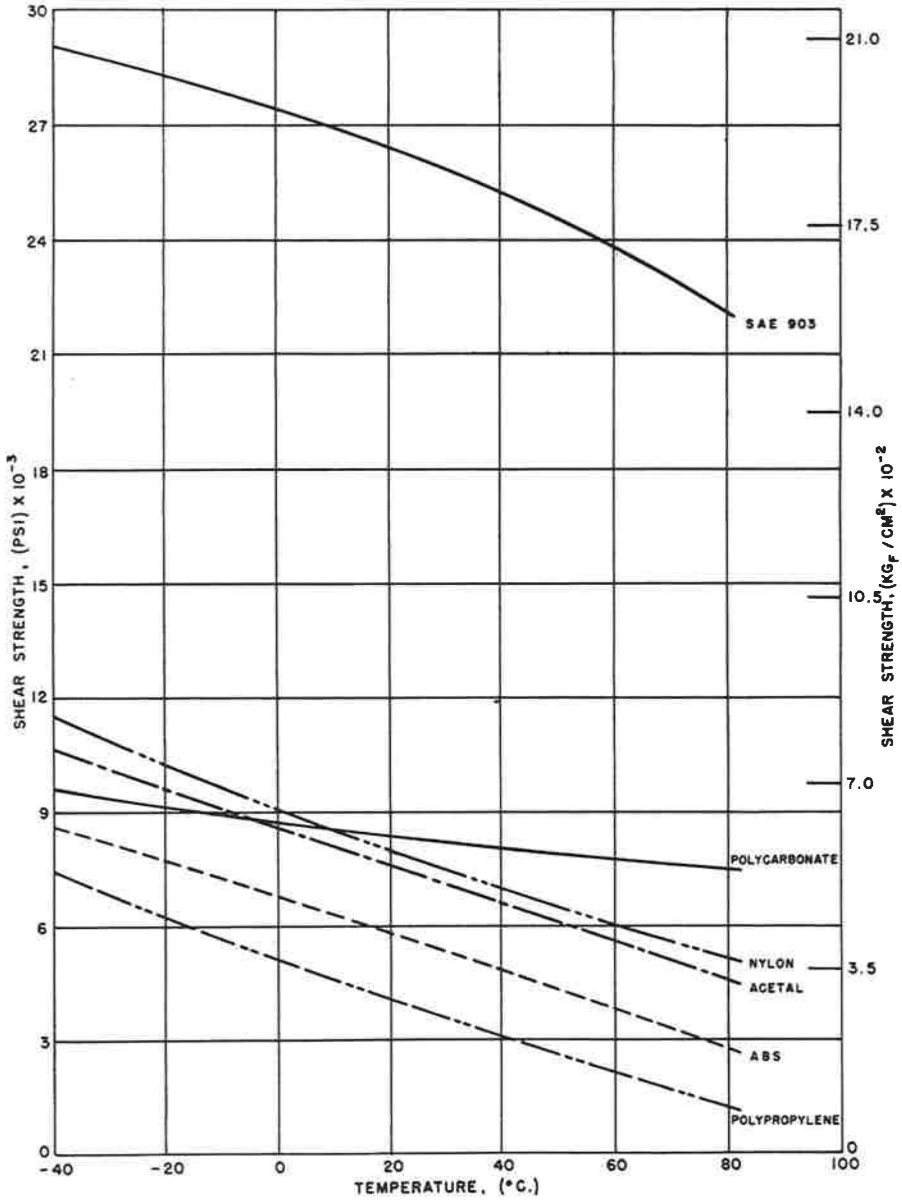

Fig. 7 - Chart of shear strength versus temperature

APPENDIX A

ILLUSTRATIONS OF FIXTURES AND TEST SPECIMENS

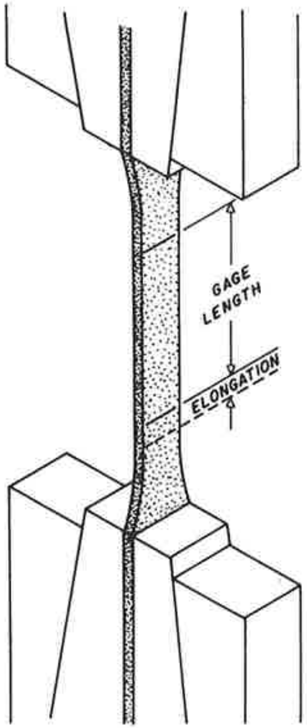

Fig. A-1 - Tensile test apparatus

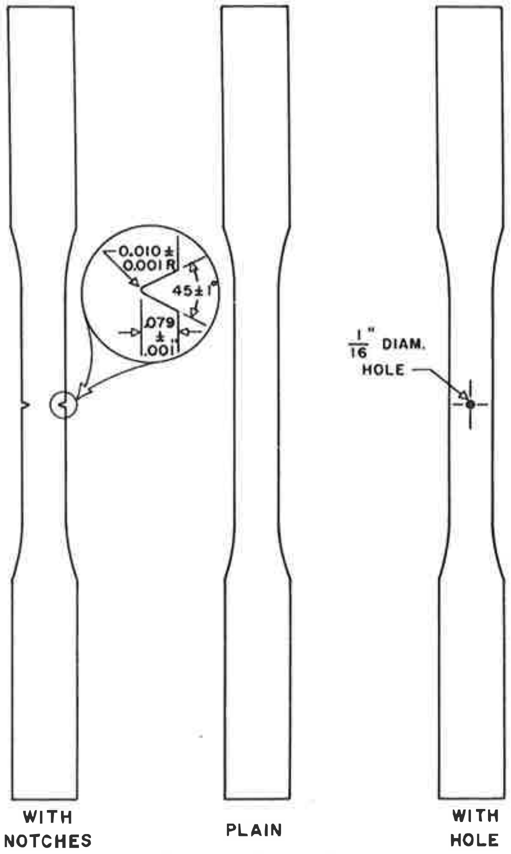

Fig. A-2 - Tensile specimens

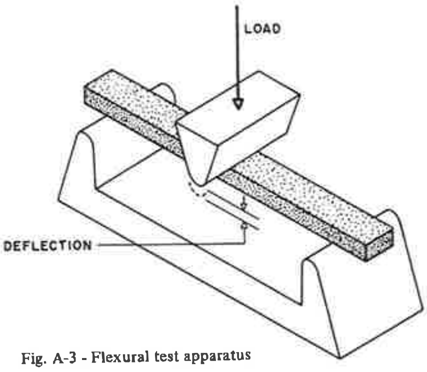

Fig. A-3 - Flexural test apparatus

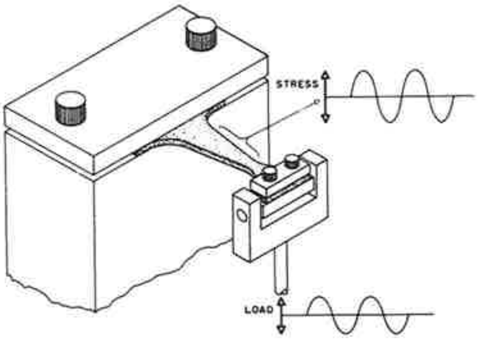

Fig. A-4 - Flexural fatigue apparatus

APPENDIX B

The cost analyses presented in this report are based on the required dimensions and corresponding weight of a 10 in. long square rod which will fail at the specified load and temperature. Specifically, the cost calculations were arrived at as follows:

TENSILE (AT 24 C AND 80 C)

Example: Find the minimum cost of a 10 in. long rod just able to withstand a tensile load of 100 lb (at the temperature indicated).

Formula: $$\text{Cost of rod} = \left(\frac{P}{\sigma}\right) (d)\ (L)\ (C)$$

P = Load, lb
σ = Tensile strength, psi
d = Density, lb/in.^{3}
L = Length of rod, in.
C = Cost, ¢/lb

FLEXURE (AT 24 C)

Example: Find the minimum cost of a 10 in. long rod just able to withstand a flexural load of 10,000 lb.

Formula: $$\text{Cost of rod} = \left(\frac{3PL}{2\sigma}\right)^{2/3} (d)\ (L)\ (C)$$

See preceeding section for definition of formula symbols.

TENSILE CREEP (AT 24 C)

Example: Find the minimum cost of a 10 in. rod which does not strain more than 2% (0.02 in./in.) in 100 hr under a 100 lb load.

Formula: $$\text{Cost of Rod} = \left(\frac{P}{E_a \epsilon}\right) (d)\ (L)\ (C)$$

P = Load, lb
E_a = Apparent modulus at 100 hr, psi
ϵ = Strain, in./in.
d = Density, lb/in.^{3}
L = Length of rod, in.
C = Cost, ¢/lb

TENSILE IMPACT (AT 24 C)

Example: Find the minimum cost of a 10 in. long rod able to just support an impact load of 100 ft-lb.

Formula: $$\text{Cost of rod} = \left(\frac{P}{\sigma}\right) (d)\ (L)\ (C)$$

See preceeding section for formula symbols.

FLEXURAL FATIGUE (AT 24 C)

Example: Find the minimum cost of a 10 in. long rod just able to withstand a reversed, alternating flexural load of 1000 lb for 10^7 cycles.

Formula: $$\text{Cost of Rod} = \left(\frac{6PL}{\sigma}\right)^{2/3} (d)\ (L)\ (C)$$

See preceeding section for definition of formula symbols.

DISCUSSION

Question

I have a question for Mr. Davies. You did show us a slide with an experimental bonnet you had designed. In my opinion the material you discussed has quite a future when used for the rather small parts of a car. But when you start to use it for structural elements, I begin to have doubts, for then safety is involved. Now, a crash is something that can happen to a car and its occupants. Then steelplate crumples and so an often large amount of the available energy is used up as energy of deformation. I have the impression that steelplate has a far greater capacity for the absorption of energy than the material you just have discussed. So here we have a safety problem, and I would like to hear your opinion about it.

Answer

(Davies) This certainly is a very good question to start with. The whole problem is that in a crash there suddenly becomes available a large amount of kinetic energy that has to be removed in a short time. It is still a controversy whether the material should absorb the energy and crumple as a consequence, or whether it should break or fracture in a certain way. I have to be careful here, because I don't want to disclose confidential information. Now, the structural part I showed to you, was designed to break in a certain way. We experimented with it, and in frontal crashes it behaved just as we had calculated. A steel one will crumple, and then the dash-board will be pushed towards the driver, because the load is transmitted in that way. By causing the bonnet to fracture in a certain way, this is prevented. We consulted car manufacturers, and they expressed the view that it was not a hazard, but a safety bonus.
Coming back to the overall view about safety, I don't think that reinforced plastics constitute a hazard to passengers or drivers. I am not talking about an all plastic car, what I am interested in is sticking in little bits, and perhaps larger pieces, of plastic into the existing structure. I realize that there are car bodies made from plastic, but the car still has steel as a structural member. We are concerned to use plastic materials to keep the wind and rain out. They may, perhaps, take part of the load, but that will not result in a loss in safety.

Question

But what about repair?

Answer

(Davies) There is no problem, because you can repair a metal car body with polyester glass repair outfits, and you can do exactly the same thing with a part made from reinforced plastics.

Question

But the polyester will have the advantage?

Answer

(Davies) I certainly would not like to put it like this. There are cases where a steel component must be replaced, whereas the same component made of polyester can be repaired. But in other cases it will be the other way round.

Question

Mr. Herrschaft has given us a lot of data about his material. Can Mr. Davies imitate him, and give us the design data on the material he has discussed?

Answer

(Davies) We are very concious of the fact that we have not been supplying as much design data as we should, but work is going on to provide fatigue data, creep data and so on. But it took us a rather long time to develop this material and the testing program also takes time. Now I would like to make a comment in passing. Recently, we have consulted engineers and designers on several occasions about their design of certain parts, made from, for example, zinc or alumium. Then we asked them why they had used a certain thickness here, why they had a boss there, why this and why that. In many cases they answered that they knew from experience that it should be done like that. In other words, also they had desing data, they did not use them. I have always in mind this example, when people criticise the plastic industry because it does not provide enough design data. But I grant that we are not as far as the metal industry at the moment, and I think we will catch up before long.

Question

I would like to ask you: What is the idea behind this all? Do you just replace metal by reinforced plastic, or do you provide a better design in plastic or what not? And what about the claims of Mr. Herrschaft that a design in zinc SAE 903 can be as much as five times cheaper than in any other material?

Answer

(Davies) The whole purpose behind it is to sell polyester resins and plastics. We tackled the car manufacturers because we thought that we could offer them something important. The automotive industry is very concerned about decreasing costs and weights. We can offer the car industry a material that can do both things. In my opinion we have been rather successful up till now. Some of the mouldings I showed on the screen, are being mass-produced in the US, they are not laboratory curiosities. In the UK, the car industry has not yet adopted our composite material for mass production, but we feel certain that they will do so in the near future. They will do it for the same reason the American industry started to use this material: it reduces costs.

Chairman

Could we ask Dr. Herrschaft for his comments?

Answer

(Herrschaft) We did not expect that the presentation of our paper would convince the automotive industry to quit using plastics. We simply have to recognize that plastics are here to stay, and they certainly have a place in many types of designs. If you look at the information we have presented here, you might come to a false conclusion and start to ask: Why should anybody use plastics if zinc is much better? There is more to that than meets the eye. The zinc industry can die-cast the metal in very thin sections that still have good mechanical strength, and I have yet to see a plastic material that is the equal of zinc in this respect. But zinc die-casting is much older than injection moulding of plastics, and I fear that the industry, producing car grills and other decorative elements, became rather complacent. It was not before plastics began to steal markets, that they were alerted to the fact that they had to get their own house in order and do a better job. The better job must come from utilizing the full engineering capabilities of zinc die-castings. Nowadays, it is evident that in the past many zinc die-castings were overengineered. In other words, if you can take a zinc die-casting and replace it, thickness for thickness, with a plastic of considerably lower mechanical properties, the only logical conclusion is that there was something wrong with the original zinc die-cast object. We are busy to rectify that.

Question

Dr. Herrschaft, in your paper you compared zinc with reinforced plastics. What is your opinion about the material Mr. Davies has discussed? If you had known this material, would the conclusions of your paper have been different?

Answer

(Herrschaft) That is a difficult question to answer. It is not easy to say how this material would have stood up in the comparative tests. But as I said at the end of my lecture, we are looking with a critical eye at plastics reinforced by glass fibre. We selected plain plastics as references because they can be injection moulded, and we think that injection moulding of plastics is a real threat to zinc die-casting. But it was gratifying to see that Mr. Davies is not cutting in on the zinc market, but goes after the steel market.

Question

Dr. Herrschaft has compared zinc for die-casting with unfilled plastics. The comparison has been carefully done, but I do ask myself whether it is pertinent, whether the properties measured have an influence on the function of a part, made either from zinc or from plastic. The second point I want to make is that a good designer knows the weaknesses of his materials. In a good application of plastics he will avoid these weaknesses and try to exploit their good characteristics. So I am somewhat critical of the fact that you put in your title "an engineering comparison". We have learned that you can design in plastics with good succes, but in many cases you will have to make a new functional analysis of the part you want to produce.

Answer

(Herrschaft) Well, what we did, was of course a laboratory type of experiment, that was based on established test procedures and that had no direct relationship to functional design of a component. But I think there are some valuable lessons to be learned from the investigation, and they sound a note of warning to the zinc die-casting industry.
Of course I don't have any argument with your second comment that with proper design you can make a good part in plastic. But it is my impression that many of the applications where plastics have replaced zinc in automotive components, are applications where little or no load in service was involved. Just take an automotive grill, for instance. About all it has to do is just to sit there and look pretty, support its own weight and have resistance to gravel and stones thrown up from the road. During its life it is not exposed to large structural stresses, except in a crash, and then you call your insurance company and have it replaced. But you can have a wholly different situation when your plastic structure is stressed. I would like to draw your attention to an article named "$50 Million Lesson" - Modern Plastics, reference 25 in the bibliography. It was written in Modern Plastics by their own editor and it cited the case of the $50 million recall of a few million cars by an American manufacturer. They had to be recalled for servicing because a small plastic part slowly fractured in use. The broken pieces could find their way into the throttle mechanism and block it, and then the throttle remained permanently open. This naturally caused quite a dangerous situation, and the plastic part had to be replaced by a metal one. Total cost to the manufacturer: $50 million. The firm clearly had tried to save a fraction of a cent by using plastic instead of metal, and that backfired into a tremendous additional cost to the manufacturer. As the British say, they had been penny wise and pound-foolish. This unexpected fracture could have been caused by anything between a wrong choice of material and faulty design or inadequate testing. Now I am not citing this case to prove that plastics are unreliable materials, that would be nonsense. I cite it to point out that, just like all other materials, plastics have their good points and their drawbacks.

Question

You have given a comparison of prices, but that was for rods. And in practice we do not use rods, we use shaped articles. So we should really compare the prices of finished articles made from various materials. Secondly, you have confined your comparison to unfilled plastics. There are, however, reinforced ones with different and better properties, and they too should be compared with zinc. Lastly, I think that one of the advantages of plastics is that they are easily processed.

Answer

(Herrschaft) Let me take your points one by one. Of course we should compare costs of finished articles, and there is more to the overall cost picture than presented in this paper. But it will not be easy to compare finished articles. You cannot simply replace the metal by some kind of plastic, that course of action would lead straight into disaster. The mechanical properties of the two materials are far too different to do that. If you want to replace a metal by a kind of plastic, you have to rethink your whole design. If you have done that, you must face the question whether the function of the two articles still is exactly the same. To make a meaningful comparison, you should admit only finished articles that functionally are wholly equivalent. We considered the cost of the material on a performance basis, and tried to relate it to a number of mechanical properties. As to your second comment, I said before that we are looking into reinforced plastics. Some of them may become dangerous competitors of zinc. Lastly, we cannot deny that plastics have many advantages. Plastics can be moulded in such a way that there is no need for trimming, and they can be moulded in colour if it is desired. An advantage of zinc is that cycle rates are much faster, because of its higher thermal conductivity. Mr. Davies showed a slide with a long instrument panel and he mentioned a moulding time of 2 minutes. Now, in zinc, you can make that within 15 seconds. If plating is involved, both materials are in the same position, as both require a special treatment before you can plate them.

Question

I would like to come back to the quastion of safety. Can Mr. Davies comment on the fire hazard of his material? It has, for instance, come to my knowledge that cars with an ABS body on a steel frame will not be allowed on German roads, because the authorities think that the fire hazard is too great.

Answer

(Davies) This is an important question, as the problem of flammability is a very real one. In cars you need a material with a low spread of flame. We can achieve this with our material. But we asked the car industry what standards they wished us to meet, and they did not know. That is not our only problem. There are no international standards, and nearly every country has its own procedures of testing the fire hazard of these materials.

May I make just one remark before I finish? Mr. Herrschaft mentioned a plastic part of a car that failed, but one sometimes hears of cars being recalled by the manufacturer because a metal part is in danger of failure. I think that possibly it was slightly unfair to blame the plastic, as these things are nearly always caused by faulty design.

The second point I would like te make is in the comparison of costs. For example, if you go to a car manufacturer to tell him that you can make a certain part in plastic, the only thing he is interested in is cost. You must be able to convince him that there is an advantage in price, otherwise you will be nowhere. In the case of the bonnet, we were able to do so. The cost of the material is higher than that of steel, but the cost of the finished part is slightly less. The manufacturer gets an additional bonus, for the weight of a plastic bonnet is less than that of a steel one. There is also the question of painting. Our material has one serious disadvantage. To quote or misquote Mr. Ford, you can have it in any colour you wish, as long as it is white. We simply cannot colour it. It has to be painted, and you will not save any money on that. In don't think that this is a serious disadvantage, because the matching of the colour of paint to a coloured piece of plastic is very difficult.

Question

I would like to aks Mr. Davies a few questions. Is it possible to mould to a reproducable high gloss surface? How does the surface of DMC compare to surfaces of thermoplastics in terms of hardness and resistance to scratching? Thridly, is your material resistant to detergent solutions when hot?

Answer

(Davies) We can mould our material to a very high gloss. The quality of the surface depends entirely on the quality of the tool. The surface of our material is harder than that of thermoplastics, but that does not mean that the mar resistance is better. We would not recommend our material for use in the kitchen, the mar resistance is not good enough. The resistance to detergents is good, we did quite a lot of research on that. But the resistance against water near its boiling point leaves something to be desired. The water-pump of the cooling system of a car cannot be made of it, but it is resistant to detergents.

Application of metals and plastics in office machinery production and economical and technical reasons in the choice

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Since it first entry in the field of precision mechanic industries, nearly in the past 1920, Olivetti, formerly a small manufacturing company of electro-mechanical equipments, found the way to its surprising growth also thanks to the development of highly sophisticated production technologies happily combined with design politics evolving in close harmony with those technologies.

First generations of machines had been produced with large use of the old traditional mechanic technologies (turning, milling, grinding, tapping, etc.): design of first typewriters had an unqualified physiognomy and showed effects of its derivation from other products. It was soon clear that these technologies didn't fit to a mass production of low cost, low weight, consumer goods and that the full design and concept of the product was to be revolutioned in order to adapt itself to new technologies characterized with higher production rates and lower costs.

So, new machines had issue, where steel plate parts and automatic lathe turning were the two main technologies.
Still today, these technologies have a paramount importance in office machine production, and a high percentage of components of office machines are produced with these very reliable and inexpensive technologies; time has not passed uselessly also for these technologies, that have enjoyed, since then, a fair amount of progress and evolution: high speed and automatic presses, high speed steels for tools and dies, developments in design of dies, have made possible the attainment of better quality and efficiency standards.

One characteristic is nevertheless common to these technologies, and somewhat dampered their ability of solving all technical problems proposed from design evolution: both of them allow for just two significant dimension geometry of the parts, radius and height in the case of turned parts, surface geometry (thickness being a constant) in the case of steel plate.
This necessitated simplifying the concept of the machines to allow the execution of specific, logic functions by means of parts simple in design, normally flat or with bendings. The performance of more complex kinematic functions was entrusted to parts obtained by joining many elementary parts, welded or punched or simply assembled together, with sharp increase of costs and quality problems, as well as to "solid" parts, normally castings, worked with expensive tool work operations (milling, grinding, boring, etc.).
Structural parts were made with cast-iron and coverings were made with stamped steel plates with expensive finishing, and assembly costs and with very low freedom in design.

After the 2nd world war a new metal working technology, the die casting, came to face the trend towards higher freedom of design and reduced cost in structural and covering parts.
Meantime, need for form complexity of mechanical parts was too rapidly growing, owing to required higher degree of intricacy of the kinematic motions, specially in the field of mechanic calculators and accounting machines. Simple mating of flat parts (cams, gears, levers) was becoming unsatisfactory from cost, quality, and realiability point of view and was still unable to allow for the necessary design freedom. So Olivetti recurred to a new technology that showed high potential possibilities, and that was rapidly taken to a world primacy level, the metal powder sintering.

So, a strong team of metal working technologies was introduced in this production, automatic turning, presswork, die casting and metalsintering, and still today plays a fundamental role.

But they are no more alone: plastics have joined the group. The history of plastics is, in our company, at the beginning a history of design and of costs, more than of design evolution. The first entry of plastics in our company arose from the production of keytops: the old keytop, made with paper, metallic ring and transparent cover, was too expensive and poor in design. The advent of two colour plastic keys greatly reduced costs and gave the opportunity of starting a revolution in design and appeal of the product. It was the explosion of colour, of modern design not just on keytops, but on the whole machine, whose traditional, casual black dress had been since then tied with the poor traditional design of keys. The cover of the machines turned to light alloys die casting and fantasy colours arrived triumphantly under the grey eyes of book-keepers and the blue eyes of young typists.

The second step in plastics were the bodyworks and the aesthetical parts, like small covers, levers, paper indexer and transparent covers, hand controls, and so on. Some of these parts are today definitely and irreversibly turned to plastics, and no alternative is today foreseeable; other parts, like big covers, are today produced or with plastic or with light alloys, and competition is still open, many arguments being in favour of each of them, arguments of cost, design, quality, reliability, weight, customer's reputation, fire hazards, and so on.

In the last 10 years a new development, the issue of new engineering plastics, opened new possibilities of application in office machines as well as in many other industries: that of kinematic motions. Recurring to plastics was now not principally, or not at all, a matter of economic choice. Of course, being industry fundamentally an economic animal, all its choices cannot but be economically justified, but in this case the first and most promising drive to plastics was not strictly economic, but logic, mechanic.

The office machines, above all calculators and accounting machines, are basically transformers of logic inputs into logically elaborated outputs: the more complex the elaboration the more intricate will the mechanic be. Needless to say, electronics took the lion's share in this field, and day after day this competition between mechanic and electronic logics is turned to an even greater success of the second thanks to the continuous progress in sophistication and cost reduction of electronic components. But even so, in electronic calculators, a great number of functions is still entrusted to mechanic groups and these functions become more and more complex and affected with problems of speed.

Engineering plastics are the answer to this new challenge. In the search for a technology able to solve all design problems that new logics imponed, all metal working technologies showed severe limitations. Also metal sintering, while being a good step, still causes limitations to the design freedom for its need of uniform compression of the powder, for the possibility of pressing over limited number of levels, for the deformation occurring during oven treatments, and so on. Quickly complexity of form of the metal sintered parts was taken from our designers to the limit of possibilities of that technology, and beyond that, and the need came for subsequent assembly, joining, welding operations that again increased costs and reduced quality and reliability of parts.

So, in reverting to engineering plastics was not a consequence of a search for economical alternatices, but was effect, and cause, of new possibilities, new freedom in design.

Today, in our production, plastics and metals are in an every-day competition, a game where, design, physic properties, costs, product quality, technology and organisation developments play the decision role.

TECHNICAL CONSIDERATIONS IN THE CHOICE BETWEEN METALS AND PLASTICS

Complex and multiform are considerations that can play, case after case, in the choice between metals and plastics.

One could think that the first question should be, when would the attention be taken to material properties, "which metal, if any?", "which plastics, if any?", and then "plastic or metal?". The fact is that this choice normally is unconsciously made by the designer already at the moment of the first ideation of the machine and is then related to a technology better than to a specific material. Successively, within the technology, the best material is chosen and its aptitude is checked.

The technical considerations that play in this choice can be related to design of the part, to physical properties, to exigencies of weight or noise reduction, to precision requirements, to product life and reliability, to environment and ambient considerations.

Design of a part must be always oriented according to the material choice: a plastic enclosure cannot have the same design as a die casting one, nor can a plastic gear be the same as a metallic one; but in many cases, as I mentioned at the beginning, the full design, the same function of the part, demands a technology. This is particularly the case of plastics that, thanks to their extreme design flexibility, are unreplaceable in the construction of intricate parts having multiple functions.

Multiple groups of cams, gears, clutches, control levers, flanges or supporting parts, show no practical alternatives to plastics: their sheer conception is the consequence of a status in the designer's mind that I would like to call "thinking in a plastic mood".

Mechanical properties of plastics are quite peculiar indeed, but it must be emphasized that their simple comparison with those of metals can be deceiving; they are deeply influenced by the ambiental conditions, by the characteristics of the solicitation, by the previous mechanical or thermic history, or by the technologic condition during molding.

All these phenomena are not only extremely complex but also very poorly known. Many attempts and researches have been successfully conducted in order to analyze the trends and to explain the phenomena, but when a designer looks for practical data or values that help him in safe calculation of a mechanical element, then the situation appears, much less comfortable. The great amount of existing literature is research oriented and gives little or no practical information; manufacturers, by their side, make considerable efforts to display with forms or graphs behaviour of some of their materials, but unless the designer is clever enough to discriminate between unequivocal technical information and not just promotional, the really useful information is extremely rare.

The best, or the only possible remedy in this situation is that, after the first rough theoretic calculations in the design phase, prototypes should be submitted to severe and extended practical tests.

Apart from these considerations, mechanical properties of plastics can generally be thought to be "inferior" to those of metals, but a deeper consideration of their peculiarities can lead to the identification of their exceptional possibilities. Let's take, for example, the elastic modulus. Acetal resins, have a rigidity of the order of one seventieth of that of steels, but this is not necessarily a deficiency: first of all, the question is how often the rigidity with which a steel part is provided is really necessary, or is it not often excessive, being the design of that part related to a general geometry requirement and not to a need of rigidity.

According to this, we see that in many cases, a lower rigidity gives no practical troubles, but on the contrary can help in reducing the consequence of dimensional errors (plastics allowed interferences not admissible with steels), in reducing shock forces on impact supporting parts, in reducing noise, in giving possibility of elastic fit assembly.

Given therefore that mechanical characteristics are always to be judged in view of each part's working conditions, let's point out which characteristics seem to be the most interesting: low specific weight is an important point in office machines, whose parts have kinematic, logic functions and no or little power transmission duties, and where increasing speed of machines was only hampered by need of containing kinetic energy increase. High impact and good shock absorbing properties share with the low specific weight in allowing for increased speeds while reducing shock solicitations, wear, noise and failures. High elongation and low rigidity are the key to plastics elastic elements.

On the other hand, yeld stresses, rigidity, hardness are considerably minor, and may require overdimensioning of parts.

The sensibility of plastics to temperature and generally to environment conditions is, on the contrary, an absolutely unfortunate factor and must be carefully investigated to avoid misleadings and failures. Calculating parameters and practical test conditions must take account of the extreme ambient conditions that a machine may have to face: for instance, an office machine can face extremely low temperatures when it is transported in ships or in trucks in northern countries, to the high temperatures when it is placed in an unconditioned ambient in hot countries, at sun exposure.

Such temperature variations can reduce or deeply modify properties of plastic parts, and their dimensions too. An 80°C of temperature variation from extreme cold to extreme hot will produce a relative dimensional variation between a plastic and a steel part of about 0,006 per mm of dimension, which is enough to hamper the operation of a machine if allowance is not given for such variation.
A rise in temperature also produces variations in mechanical characteristics: reduces rigidity and hardness, increases creep and elongation, changes irregularly shock and wear resistance. Similar variations are introduced, in some plastic materials, from moisture absorption.
On the other hand, plastics do not fear rust, do not need oiling or greasing, reduce maintenance on machines.

Lastly, an example of useful application of heat sensitivity of plastics: a small metal sintered gear, keyed on the shaft of the motor of a cheap adding machine, was replaced with a low melting plastic, which had the property of softening in the event of overheating of the motor, and worked as a motor protector in the case of machine jamming. This saved about a quarter of a dollar per machine.

In conclusion, no material can be considered absolutely better than another, and no technology can be considered substitutive of another. Every one has its points of superiority, that a good engineer must deeply recognise; case after case, his material policy must aim to take the best advantage of them.

WHICH PLASTICS?

Fishing in the broad sea of plastics which one is the best, or the most suited for every specific application, is a challenge where engineers should resort more often to fantasy than to technical reasons. Physical and mechanical characteristics are normally hard to know and hard to compare; often increasing of one characteristic couples with the detriment of another, and general balances result opinable.

Practically, however, the width of the selecting range is reduced from considerations of practice, of existing know-how, of availability in the area, or in the company's store. We must not forget that introducing a new material for every new part or application in products as complicated as office machines, would take costs of stores, costs of production, and, above all, costs and times of starting of new products, to the sky.
So it becomes reasonable and wise that, provided that a customary use of and a good level of acquaintance with some materials be assested through the various groups in the company, attention and preference be accorded to them.

So, in ten years our company developed a policy of using plastic materials, as result of historical choices and decisions which resulted excellent in most cases, and good enough

in others. We can roughly divide the application field in office machinery production in two groups: one of aesthetical parts and the other of mechanical parts.
In the first group we have covers, casings, and various controls on the machine. These parts are normally made with ABS in a grade with high modulus, hardness and scratch resistance, except for a type of small, cheap adding machines that have polypropylene covers; this allows cost and noise reduction and use of cheaper packings.

A big competitor of plastics in this field is die cast aluminum: with this technology we produce chassis and covers of standard electric typewriters, of teleprinters, desk top computers and big accounting machines.

Second type of aesthetic parts are the keytops, and two colour control parts. Here the absolute ruler is ABS, in a grade with high melt flow index, and low rigidity. These parts, always present in a great number of our products, are produced with a peculiar technology developed in our company on a special two colour machine of our design, which allows high standards of quality and automation and reduction of tooling and molding costs.
Another type of aesthetic parts are the transparent paper guide and other transparent items, made with acrylics or with AS.

The boom of mechanical plastic parts technology clashes with the entry in our company of acetal resin.
Formerly, polyamides had supported the impact of first applications, but their high degree of dimensional and physical variability caused problems and some discouraging drawbacks.

Acetal resins, thanks to their good stability, to their excellent combination of characteristics, and to the diversification of types with different molecular weights and various filling and reinforcements have little by little entered into designers' minds and experience, and have answered the large range of needs and applications.

Our normalization provides today the application of high molecular weight acetal to gears, springs, elastic parts and impact resistant parts; of medium grade acetals to cams, small gears, and generic parts; of low grade to tiny parts not submitted to high solicitations. A glass reinforced type is used for structural parts and a molybotenium disulfide filled type or a teflon filled type to parts with friction or wear problems. Differences between homo- and co-polymer are in our opinion irrelevant.
Polyamides have still a good number of applications specially where precision is not the first requirement, and where high wear resistance, and low friction are requested, like in bearings, bushings, slides, or in parts having strong rubbing action against acetal resin parts.
Electrical insulating parts are made in materials that comply with fire safety requirements: modified PPO and polycarbonate or thermosets for current supporting parts, modified PPO and polyamides for coverings and protections.

PROBLEMS CONNECTED WITH THE USE OF PLASTICS

Extensive use of plastics gives rise to different kinds of problems, mainly technical, but also of production management, of quality, and commercial.

Technical problems are mainly connected with the complexity of physical behaviour of the material and with its low degree of knowledge and predictability.
The answer to this problem has been found in our company grouping and centralizing the technical staffs charged with plastics technology; which has allowed the progressive sedimentation of know-how and experience, the establishment of standards and regulations, and the execution of exhaustive testing on new applications.
In despite of this, it would be unrealistic to affirm that all problems have been today overcome. Behaviour in operation of plastic parts must still today be kept under severe observation, and only diligent life testing of machines in extreme environment conditions

can today give a total confidence in the reliability of the product.

Also engineering and tooling of precision or sophisticated plastic parts creates difficulties of a degree unusual in metal technologies. Predicting dimensional precision obtainable on plastic parts is often a matter of experience and sensibility, combined with a fair amount of guess-work: the same concept of tolerance is in the case of plastics to be reviewed, as the allowance for the variation of a dimension must include the possible variations in dimensions between the cavities, in molding conditions, in material quality, in ambient conditions during molding and during use of parts. Finally it must also be considered the fact that a geometrical elementary shape in a plastic part is nothing more than an abstraction (a hole is never cylindrical nor round), and that dimensions should be checked between a quasi-infinite number of points.

In any case, however reliable a speech on plastic tolerances could be, this speech has not still been done, and in our knowledge no dimensional quality standards have been until today published or established, unlike what has been done for metals and, in a field much near to plastics, in die casting.
It would be desirable that such an enterprise be undertaken by some of the many public or private plastics associations or research committees; industries like ours have neither the possibility nor the convenience to afford such a program, but can undertake partial or occasional studies, as probably each one does, and could in my opinion contribute to a general research plan each one laying its own stone of the great building.

Practically, on this problem the solution comes today from experience and from extensive testing: large use is made in our company of prototype molds that give the opportunity of having large number of prototype parts fit for all necessary tests and measurements.

A second type of problem is today expected from the side of overcoming new fire, hazards regulations.
Fire is of course a heavy threat for products made with plastics, as its consequences are potentially terrifying for human life and goods, and it's necessary that greatest attention be paid to reducing dangers.

It must be pointed out however, that no thermoplastic material is fully uncombustible, and that all tests so far made tried to give rather than absolute evaluations, an indication of a preference to be given according to the design of machine. This principle was aimed at eliminating fire dangers of the entire machine without trying to reach the absolute safety of every part. According to these specifications our policy in materials allowed for self-extinguishing polymers (U. L. Classification) like polycarbonates, modified PPO and nylons for electric parts, and for ABS or polypropylene for external covers of small, portable and attended machines, while light alloys were prescribed for covers of heavy or unattended machines.

Should some new regulation (today at level of draft under examination of international committees) be issued, a complete revision of material politics would be necessary that probably allow for no thermoplastic polymers on electric insulating parts, but just thermosets, and practically no plastics at all for covers.

Not to be overlooked is, at the end, also the customer's opinion about plastics. It must be frankly admitted that still today customer's opinion on plastics is just that of a cheap material, and that, except for some kinds of products, customers are inclined to transfer this reputation to the whole product hidden under a plastic cover. This is a consideration that still keeps today a number of products faithful to the good old aluminium dress.

COST CONSIDERATIONS

I left cost considerations to the last point, as in my opinion costs cannot be the leading factor in a long sighted material politicy.

The simple approach of comparing the cost of a same part with same functions and same "value", when made in metals or in plastic is a poor one and if the plastics market had been based just on an economical alternative to metals, its growth would have been much poorer than actually.
The big success of plastics has consisted in the fact that they have opened new paths, they have invented new products and new markets, where to use other materials would have been unnatural more than antieconomical.

When the approach is that of replacing a metallic part with a plastic one, then an open minded designer should take the opportunity of adding new functions and new value to the part; the cost confrontation will then be done not simply on cost basis, but on value.

Comparing two equally possible solutions, one in plastics with one in steel plate, comparison is normally propitious for steel thanks to lower material cost and higher cycle speed, though frequent need of heat or surface treatment on steel parts can reduce this difference. Presence of rivets, spring heads, hubs or other parts connected to the steel part, easily reverses the economic balance, as these attachments can be obtained in a plastic part in the same molding operation in one piece with the principal part.

Another possibility that must be investigated is that of incapsulating in the plastic other metallic parts, like shafts, that in original design would have been joined with an assembly operation. This means using plastics as a construction material and at the same time as an assembling means, and transferring manual operation from assembly lines to the molding shop with the possibility of including assembly time in open machine time.

A cost analysis has been made, for instance, for evaluating the opportunity of replacing the actual steel plate ribbon spools, with a plastic type. Production costs of this item result in this case reduced by about 40%. High production rate of the item is such to allow pay-off of new tooling in 0,8 year.

Same considerations can be made in the comparison between metal sinterings and plastics.

Cost per volume of metal powders are equal or little higher than engineering plastics, but short cycle times, and low cost of tooling makes a metal sintered gear of 40 mm in diameter cost twenty to thirty per cent less than a plastic one, both technologies being considered at a maximum of automation and efficiency. This difference increases as the thickness of the part grows, and decreases increasing surface or volume of production. When a gear is fitted with an hub provided with a pressure screw to ensure blocking of the gear on the shaft, then the screw cannot be locked on plastics, and of consequence gears made of plastics need the insertion of a metal hub. This increases drastically the cost of the plastic alternative, as it can no longer be produced automatically, and makes a metal sintered gear cost 60% less than a plastic one.

Once more cost balance is possible just between parts that are absolutely alike, that is when design of the part is such to be producable as well in plastics, as in metal sintering without second operations. But continuous trend towards increased part intricacy makes production lay-outs of sintered parts more and more frequently intrigued with second operations of welding, drilling, tapping, grinding, that result normally unnecessary with plastics, and economic balance in then reversed.

Cost balance between die cast aliminum and plastic covers is normally not influenced by design complexity, as the two technologies are basically the same and consequently is theoretically possible to obtain in both cases the same part conformation.
Cost per of volume of plastic material is about 40% lower than aluminum alloys, and the difference increases for the fact that a plastic covering can be normally molded in an uniform thickness configuration. On the other hand, die casting times and costs are 20% less than plastics and practical difference is bigger as normally thicknesses of aluminum covers are lower. In favour of plastics is the difference in quality between the two parts "as molded": a die casting part needs to be deburred, deprived of ventings and

degated; the surface must be accurately inspected, polished and then painted. A plastic part comes out from the mold already finished and coloured; degating too can be automatically performed.

New developments play in favour of both alternatives: new glass filled compositions give to plastics the opportunity to reach the same rigidity and stability of metals, with few minor consequencies on surface quality and colour flexibility.
On the other hand, "vacuum molding", a new development recently introduced in some of our die casting machines, promises prominent gains to metal covers, as it permits obtaining castings with no flashes, no burrs, and with perfectly smooth surface.
In an economical balance between plastics and die casting, consideration must be given also to savings in packing and shipping costs allowed by the higher sturdiness of the second.

A detailed cost analysis was made in 1969 for a 2 parts cover of a standard manual typewriter of new design.
Die casting v.s. plastics difference resulted in working costs: minus 16% in molding and plus 470% in alter molding operations, that is a total of plus 83% in total working costs. Adding a plus 45% in material costs, we have a 67% of major cost of the aluminum cover. Savings in packing and shipping costs reduce this amount to a total net difference of 23% in favour of plastics.

New vacuum molding technique, not yet employed in this production, should reduce drastically the cost of 2nds operations on die casting parts, so the total end difference should, at the end, be about zero.

It may be interesting knowing that in this case preference was already given to the aluminum alternative.

In 1970 we examined the possibility of producing in plastics a small cooling fan previously produced in aluminum. In this case, savings given by plastics, were 0,02 cents of material, 0,4 cents of molding costs; 1,6 cents of second operation costs. Total 2,02 cents (minus 70% of cost of die cast solution). Considering the high rate of production of this part, pay off of new tooling was less than 8 months.

CONCLUSION

A policy on materials is not and cannot be, in a company that intends to be in step with progress, a quiet and still pool but is a rapidly moving brook.

All human activities, and mechanical technologies too, enjoy a continuous process of improvement and development; no technology is today at a stop point, and no technology is going to be surpassed or obsolete. Truth is that one of them, I mean plastics, is just now reaching the maturity age, has still an unveiled, huge potential of growth, and is still far from having given the picture of the place that in the future it will occupy in mechanical field.

In this moving panorama finding time after time the way to the best technical and economical potential benefits may be easier in smaller companies, with simpler production programs. In an industry with so many diversified and complex products like the office machine the "best" is often more than a goal, a far target.

A possible way of helping large companies to proceed coherently and energetically towards that target is to assign to some centralized technical groups the care of a technology, each with the task of developing its field and of promoting its knowledge and applications in all the production units of the company.

The productions policy of the company will then enjoy the results of the know-how collected from all these competing forces.

TECHNOLOGICAL COMPOSITION (IN % OF PIECES) OF OFFICE MACHINERY.

	AUTOM. LATHE	STEEL PLATE	METAL SINT.	DIE CASTING	PLASTICS	OTHER COMPONETS
(1950) MEDIUM MECH. CALCULATOR	29%	60 %	1,8%	-	1,2 %	8 %
(1965) BIG MECHANICAL CALCULATOR	30%	42 %	15%	0,6%	5,4%	7%
(1966) ECONOMY ADDING MACHINE	30%	43%	6 %	—	9%	12 %
(1966) TELETYPEWRITER	21 %	38%	15 %	1 %	16 %	9 %
(1968) STANDARD TYPEWRITER	21 %	46 %	4 %	2 %	15 %	12 %
(1970) NEW PRODUCT	23%	43 %	7 %	0,2 %	16 %	10,8%

DISCUSSION

Question

I would like to ask a somewhat general question. In your company, is it necessary to stimulate the designers to use plastics, or is it the other way round?

Answer

At first, it certainly was necessary to stimulate the designers. I know from experience, because then I was a member of the design research and development group. We found it a stiff task to increase the use of plastics. A few years ago I was transferred to the production group, and now I sometimes have to discourage the application of plastics. There are perhaps two causes for this ironical situation. Firstly, we manufacture office machinery and that contains a great number of moving parts, which are small and often of complex shape. So our designers need kinimatical design data, which sometimes simply are not available. Secondly, our designers seem to have become quite enamoured with the materials and they sometimes think you can do everything with plastics. Then we must convince our designers that in many cases it is impossible, because, for example, it would be very expensive to meet their wishes as to quality and precision.

Remark

(Staverman) Thank you very much. I think you have made a good case for your idea that there should be institutions who try to improve on the existing technology of certain materials and who do research on possible new applications. This certainly is a challenge to an organisation like TNO. In my opinion, TNO has already recognized the need for this, as it is active in these fields of research.

Question

We have heard of many speakers that the manufacturers of raw materials, plastic materials mainly, cannot give enough information to the designers of new applications. We also heard, here and in other conferences, that some materials have become firmly established by now and do find their way in all sorts of applications. This prompts me to ask the panel a question about international standarization.
What does the panel think about the time when international standarization of certain plastics would become feasible, or even necessary in order to promote rational use of these materials?

Answer

(Staverman) I am very sorry that Dr. Goppel could not be here today, as he certainly would have liked to comment on this question. In my opinion we should not be surprised that the metal industry can, and the plastic industry cannot provide designers with all kinds of facts and data about their materials. The use of plastics is much younger than that of steel and many other metals. On the other hand I have the impression that the plastic industry is very well aware of these problems and that it is trying continuously to improve on the number and kind of data it can provide to customers. But it is a process that wil take time and I think it is wrong to start to blame anyone. As Dr. Danieli has stated in his paper, this work of evaluation should not only be done by the manufacturers and consumers of these materials, but also by other institutions. In this country TNO is already engaged in that type of work. Maybe Dr. Danieli would like to comment on the question?

(Danieli) Yes, certainly. I fully agree that we should not start to blame anybody. But when I see the enormous range of plastics that are available today, then I can only ask the producers: Please, do not develop any new ones for, say, the next 2000 years. By then, we will know what we can do with the existing ones.

Question

I would like to ask a question with regard to the safety aspect you mentioned. When I hear the remark that plastics will burn, I always get a bit edgy. You nearly never hear that remark about plywood, paper or a number of other materials that will burn just as well or better. Also, the advantages of plastics are hardly ever stressed. When you look for example, at wiring systems, it is obvious that the modern variety is far safer than the previous one. Then, you had copper wires, covered by an insulation that slowly detoriated, lying in steel pipes, now you have wires with PVC insulation lying in non-conducting PVC pipes. This prompts me to ask you whether there are pleasant safety factors involved in the use of plastics in your electrical equipment, because of the, let us say, lack of conductivity.

Answer

Yes, of course. I think that the majority of the electrical applications of today, not only in office machinery, but in all fields, just are possible because plastics exist. I would not know how we could do without them. With regard to the fire hazard that we are discussing, people are saying that plastic may be dangerous because they can burn. That simply is a fact of life, but one that can have important consequences. In my lecture, I told you that when you use the most advanced techniques, hoods of typewriters can be made from plastic or aluminium and there is almost no difference in cost. But if we had to add to the plastic a filling that made it incombustible, then the cost picture would be radically altered. So we are apprehensive about changes in safety regulations, not because we cannot produce a certain object from another material, but because that could involve us in an expensive phase of re-tooling.

(Staverman) I thought that the point of the question was that, although their inflammability can be a disadvantage of plastic, their insulating properties can bring you a safety bonus.

Question

Well, let me re-phrase my question. Of course it is obvious that plastics are used in many applications just because they are insulators. That was not my point. But in other cases you use plastic because as a construction material it is satisfactory, and then the fact that it is an insulator gives you a safety bonus. For example, if you have an electrical office machine and something goes wrong inside, the metal parts come under electrical tension, then the user will not get a shock, if the hood is made of plastic. Now, this gives you a safety bonus.

Answer

Well, that is a difficult question, because here you enter a field that I do not know too well. So please accept that I am rather ignorant on this subject. In the example you gave, it seems to me that the use of plastic for the hood does indeed give you a safety bonus if you look at electrical safety. But the plastic hood still could be a fire hazard. When you design a new piece of machinery, you obviously have to conform to all pertinent safety regulations.

Remark

I would like to return to some previous remarks. In the first place, as long as there is no international standarization of plastic materials, we have to do it ourselves. This is what happens in all big companies. They have to restrict the number of plastics that can be used, for otherwise all their products would become too expensive. But this also means that the time is ripe for international standarization. As to the plea of Dr. Danieli to the producers, asking them to stop developing new plastics, there is quite a good deal to be said in favour of that. At the moment we are flooded with literature on all kinds of plastic materials, that often paints a rather rosy picture, by stressing the good points and being quiet about the disadvantages. We simply cannot start to use all the different plastics that are on the market, but we certainly can use clear specifications of the pro's and cons of these materials. Perhaps the producers can join forces to develop a computer programme containing all engineering data of plastics. Then the consumers could feed in their requirements and the machine would give them a list of the materials that could be used for a particular application.

Remark

The various remarks about standarization and the need for it, leave me somewhat amazed. Some 20 years ago, a number of people recognised that sooner or later the consumers of plastics would start to ask for international standarization. They established a technical committee of the International Organization of Standarization (ISO) that was charged with the standarization of plastics. Its first meeting was at New York in 1950. Since then, the technical committee has accomplished a lot of work. It started with terminology and test methods, but since a few years its activities are concentrated on drafting specifications of raw materials and semi-finished products. For a number of plastics this task has been finished, and the specifications are available for anyone who wants to use them. Some firms do require that the plastics they purchase, conform to ISO specifications. But it is very disappointing to hear at this conference that the magnificent work of this technical committee of ISO apparently is not widely known.

Contents