AN EFP IMPACT IN COMPARISON WITH THE IM FRAGMENT IMPACT TEST

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Abstract. *One of the most common threats in the military Out of Area Operations is the IED-EFP against light armoured vehicles, trucks etc. Besides the direct danger to the personnel, a hit of an IED-EFP in a vehicle's munition bunker will most likely end in a catastrophic event with many casualties. The development of IM munitions is already a major step towards increased munition safety. STANAG 4439 prescribes the tests for munitions to pass in order to be IM. However, the question rises whether the IED-EFP is a different kind of threat than the impact tests described in STANAG 4439, in particular the fragment impact test following STANAG 4496.*

In a first attempt to answer this question, TNO carried out an investigation using the TNO high velocity fragment impact test and the simulation tool ANSYS/Autodyn. An IM high velocity fragment impact test result has been compared with a series of simulations on the same munition item. The velocity of the projectile for both cases is around the prescribed 2530 m/s. Another series of simulations has been performed with 2 different types of EFP's. To choice of the proper EFP's for this comparison was based on literature from studies with respect to the shape and velocities of EFP for military use. In this investigation these military EFPs should be seen as a worst case scenario of the IED-EFP with respect to shock impact. The results of this investigation will be presented in this paper.

Introduction

During the IM technology workshop held at "Instituut Defensie Leergangen" (IDL) The Hague, The Netherlands in June 2011, one of the discussions in the Warhead working Group was focussed on the IED-EFP (Improvised Explosive Device- Explosively Formed Projectile) threat for munitions. The question that came up was: "Is an IED-EFP a different or bigger threat than the standard IM fragment used in STANAG 4496?" The (IED –)EFP is a projectile that is formed in a complex explosive forming process, producing a fragment with a velocity in the range of 1500-2400 m/s. The standard IM fragment is a 14.3 mm, 15.56 mm long, 18.6 gram steel cylindrical fragment with a maximum speed of 2530 m/s. In order to compare the standard IM fragment with a "standard" EFP, a small literature survey was carried out to determine the characteristic parameters of an (IED-)EFP. With these characteristic EFP's (two types) and the standard fragment impact projectile, simulations have been performed and compared. Also several other fragment impact scenarios have been simulated with interesting results. The fragment impact simulation results can also explain the outcome of the full scale IM fragment impact test series.

Full Scale IM fragment impact test

TNO is capable performing the IM high speed fragment impact tests at 2530 m/s +/- 90 m/s. The 50 mm gun developed by TNO is shown in figure 1. Recently, an IM fragment impact test series was performed on a 90 mm shaped charge (SC) weapon, with a thin-walled warhead casing. Several shots were performed in this series, one hit the munition item above the center line of the warhead (higher than expected), and resulted in a burn of the warhead. The high hit could be confirmed by the video and high speed video recordings. Directly after impact of the fragment at a speed of ~2505 m/s, (corrected for travelling distance for about 17 m/s per meter) the test item started burning for about 10 minutes. The result of the burning is shown in figure 2. No blast loads were recorded from the burning.

Figure 1 TNO's 50 mm gun for launching the standard IM fragment to a speed of 2530 m/s.

Figure 2 Burning of the Shaped charge warhead after being hit with a fragment.

Another shot hit the thin walled warhead in the centre at a speed of 2564 m/s (corrected for traveling distance). The high shock pressure of the fragment resulted in a violent reaction. The shape of the liner is shown in figure 3 and will be compared with the shape of the liner from the simulations. The simulations in the last paragraphs of this paper will definitely explain this violent reaction.

Figure 3 The shape of the copper liner after the reaction.

What is the EFP threat?
Before simulations could be carried out, the characteristic parameters of the EFP needed to be determined. IED-EFP devices are assembled by terrorists and are produced from parts of UXO's on the battle field and form one of the biggest threats for our soldiers in Out-of Area Operations. An example of such an IED-EFP is given in figure 4. A copper, bowl-like shape is placed on top of a confined explosive and is initiated by a standard initiator.

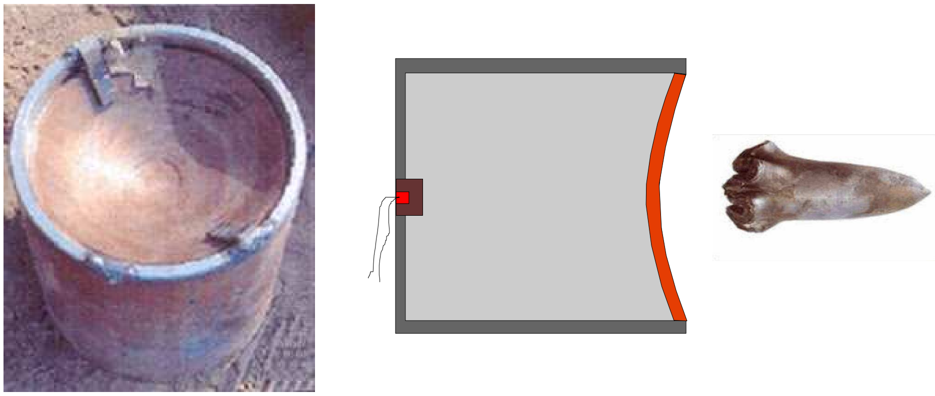

Figure 4 Example of an IED-EFP and a sketch of such a vehicle in de middle and a possible form of the EFP formed.

After initiation of the explosive, the copper liner will be formed in the shape as the projectile as shown on the right hand side of figure 4.

In the past, Weickert and Gallagher, Weimann (1, 2) investigated the forming of the EFP's as a function of parameters such as the length over diameter ratio, the thickness and length of the confinement etc. Most liners are made from copper. The papers reveal that many different shapes can be formed in a velocity range between 1500-2400 m/s, as a function of the parameters mentioned above. However, in relation to munitions and investigating the differences of shock waves from a standard IM fragment and an EFP, the average shape of the EFP's is translated in a worst case fragment with respect to shock. This is a projectile having a cylindrical shape with a hemispherical nose. The following characteristic parameters of two different EFP's have been determined in an arbitrary manner.

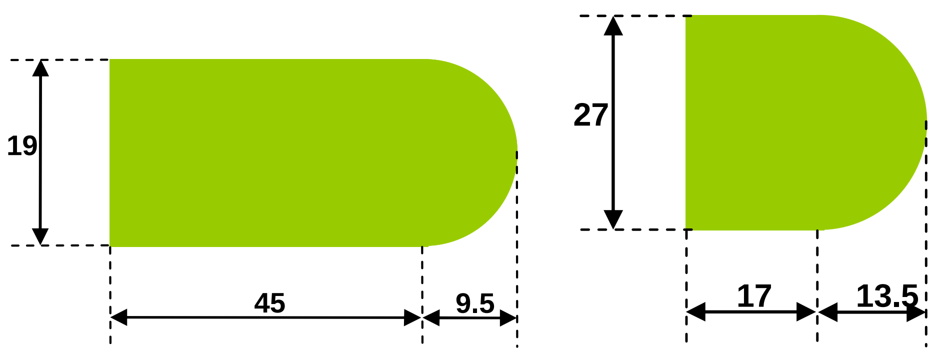

Figure 5 The characteristic parameters of the two basic EFP's.

Figure 5 shows the dimensions of the two EFP's, as used in the computer simulations. Both are made form copper with the first having a mass of 130 grams and the second one of 133 grams. Both types have a velocity of 2100 m/s. So, these two EFP's will be compared to the IM fragment impact projectile in the computer simulations.

Model
For the computer model, a typical 90 mm shaped charge warhead was used, which was also used in the full scale test series. Figure 6 shows the model set-up with the grid and materials used in the simulations. The

epoxy launch tube (purple) covers the warhead with the explosive (yellow) confined in between the aluminum casing (light blue) and a copper liner (red). The fragment/EFP, in green, hits the pipe at the prescribed velocity and travels through the warhead after penetrating the launch tube. For the calculations, a typical high solid loading HMX filled explosive, such as PBXN9, is used.
The reaction of the explosive material was not simulated, just the pressures produced by the impacting projectiles and the reflecting shock waves.

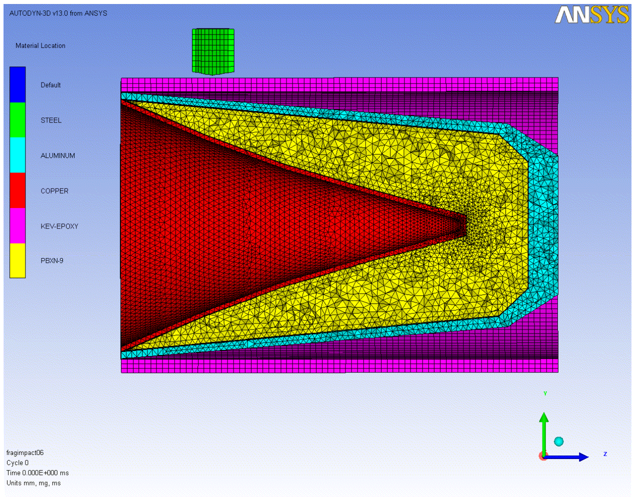

Figure 6 Grid and materials used for the simulation.

Simulation
The simulations have been carried out with Ansys/Autodyn 3D version 13.0 and 14.0 as well as the pre- and post-processing. For properties of the materials, standard values, as available in Autodyn, have been used.

Fragment impact simulation
The first simulation was performed with the standard fragment at a velocity of 2560 m/s impacting the tube at the location as shown in figure 6. In figure 7, the pressure in the explosive is shown just after the fragment penetrates through the launch tube and impacts the aluminum casing. In figure 7 also the pressure is shown at a different time interval (9 µs after impact), at the moment that a reflection wave is coming back from the copper liner.

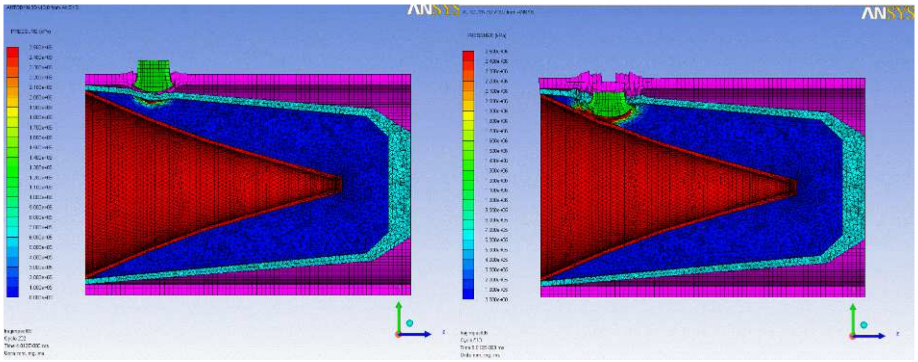

Figure 7 Pressure in the explosive (blue) due to the fragment impactg at 2560m/s.

This is also shown in the graph of figure 8. On the left the location of the different gauges are shown corresponding with the pressure curves on the right hand side of figure 8.

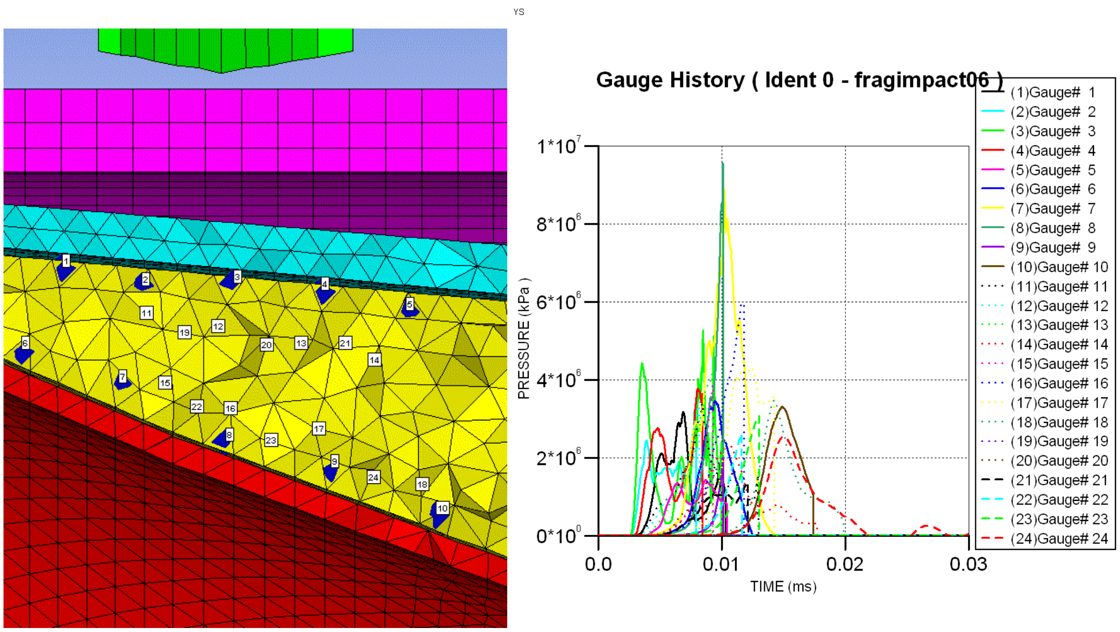

Figure 8 location of the gauges on the left and the corresponding pressure graphs as a function of the time on the right.

The graph in figure 8 shows that in gauge 3, right after the first shock wave enters the explosive, a pressure just over 4 GPa is produced. However, after reflections from the copper liner, pressures around 9 GPa can be found in gauges 7 and 8, near the copper liner.

Another calculation was performed with an off-centre shot at 2505 m/s, as shown in figure 9, based on the first full scale experiment. The picture shows a cross-section of the warhead. The picture on the right hand side represents the moment that the reflection wave comes back from the copper liner. Also interesting to see that the fragment has a velocity change in the x-direction. (see figure 10 right hand side picture)

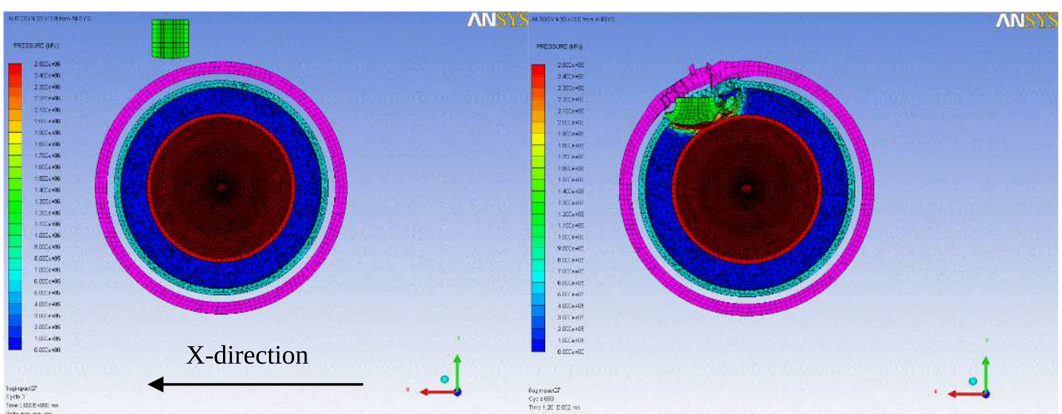

Figure 9 Cross-section pictures of the SC warhead in off-center impact scenario. On the left the location of impact on the right after penetratin the warhead.

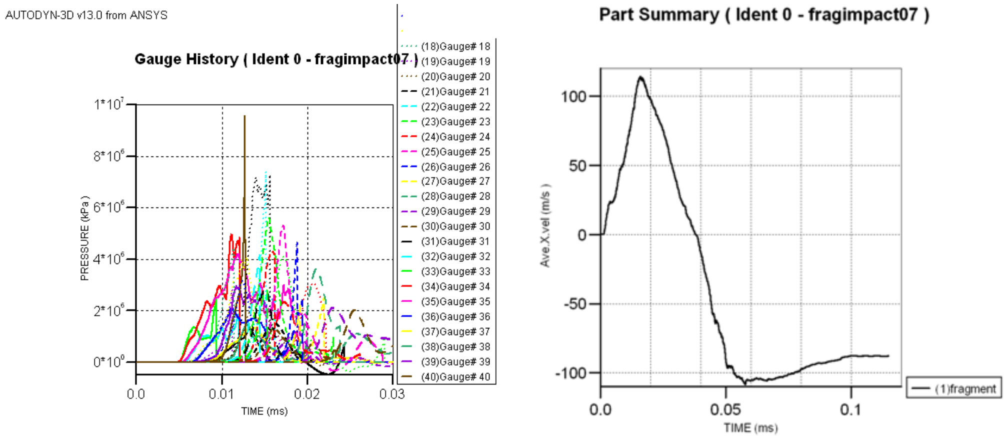

Figure 10 The pressure in the explosive with an off-centre impact location (left) and the velocity change in the x-direction (right).

Also in this off-center scenario the pressures are still high and the build-up of the pressure is different than the center-line shot. A shot that would be even more off-center will, in the end, lead to a lower pressure and induce a fire in the warhead instead of a prompt shock detonation. This has been shown in the first full scale fragment impact test with the results shown in figure 2. No more simulations have been carried out for this scenario yet.

EFP simulations

The following simulation was performed with the the long, small diameter EFP at a velocity of 2100 m/s. The impact location is the same as in the fragment impact simulation.

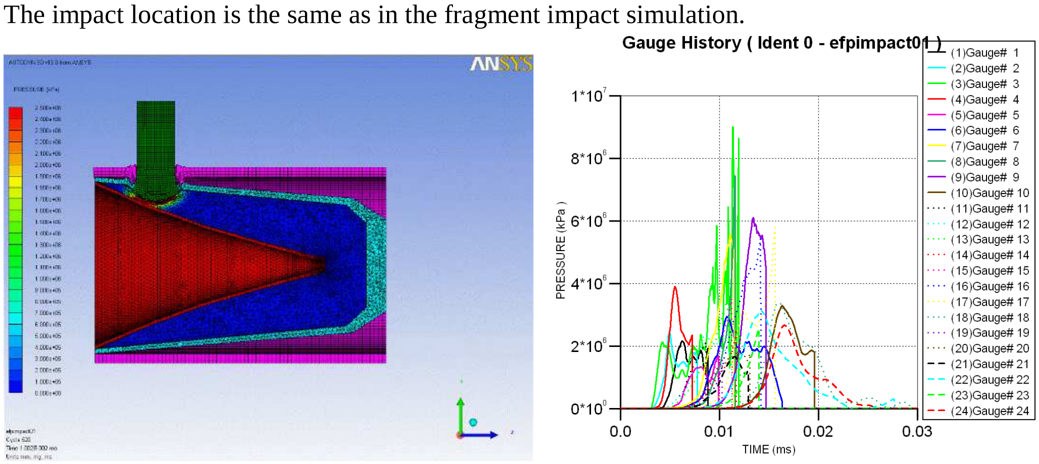

Figure 11 Results of the simulation with the long EFP (19 mm diameter).

Figure 11 shows the results of this simulation, showing the pressure in the explosive right after the reflection of the copper liner on the left hand side picture. The pressures of the first impact of the EFP on the aluminum casing are a little lower (<4GPa) due to the lower impact speed of 2100 instead of the 2530 m/s of the projectile. Also the pressure after reflection of the copper liner around 11 µs is a somewhat lower, but still in the range of 9 GPa.

The next simulation was carried out for the short EFP with the diameter of 27 mm, again at a velocity of 2100 m/s. In figure 12, the results of this simulation are shown. The highest pressures can be found after reflection of the wave from the copper liner and have a value around 8 GPa. Probably the different shape and impacting angle has its influence on the superposition of the two colliding shock waves.

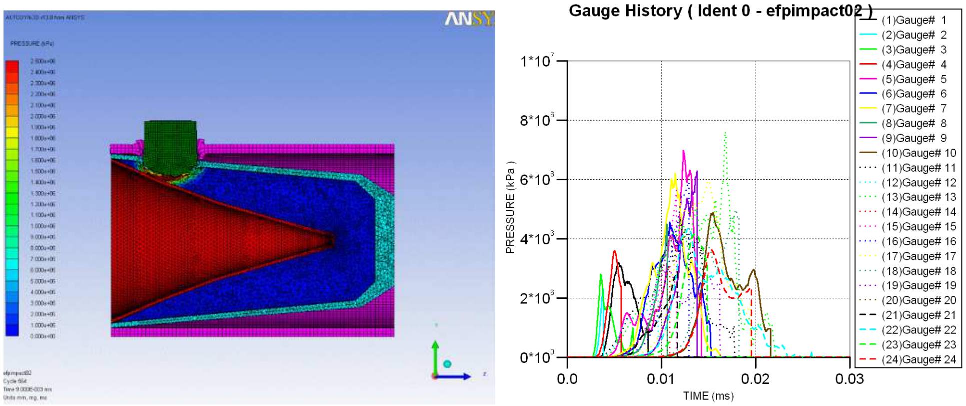

Figure 12 Result of the simulation of the short thick EFP (27mm) at a velocity of 2100 m/s.

Discussion

Several impact scenarios have been carried out. Figure 13 shows a detailed picture of the copper cone after an impact. Although no explosive reaction is simulated the shape of the liner after impact has large similarities with the experimental result shown in figure 3. So the location for impact is chosen correctly.

Figure 13 Copper cone of the SC after impact of a fragment.

In Figure 14, three different impact scenario's have been compared, the pressure of the IM fragment with the pressure waves of the two EFP's. It is clear that the first impact produces the highest pressure for the fragment scenario but is due to the higher initial velocity of 2560 m/s of the projectile. This results in pressures just over 4 GPa and normally initiates most explosives in this kind of applications. The reflection on the copper liner however, produces the highest pressures in all scenario's. One has to keep in mind that the all gauges were arbitrary taken and it is certainly possible that in a location in between the pressures plotted in the graphs, could be somewhat higher than shown. Probably due to the shape of the EFP and the impact angle to the copper liner, the maximum pressure is higher for the long EFP than the short, thick EFP but certainly not higher than the IM fragment. An (IED-) EFP with a somewhat higher impact velocity will give higher peak pressure but is rather unlikely.

It also shows that the pressure peaks from the EFP are somewhat wider than the peaks from the fragment and are the result of the larger dimensions of the EFP's in comparison to the fragment of 18.6 grams.

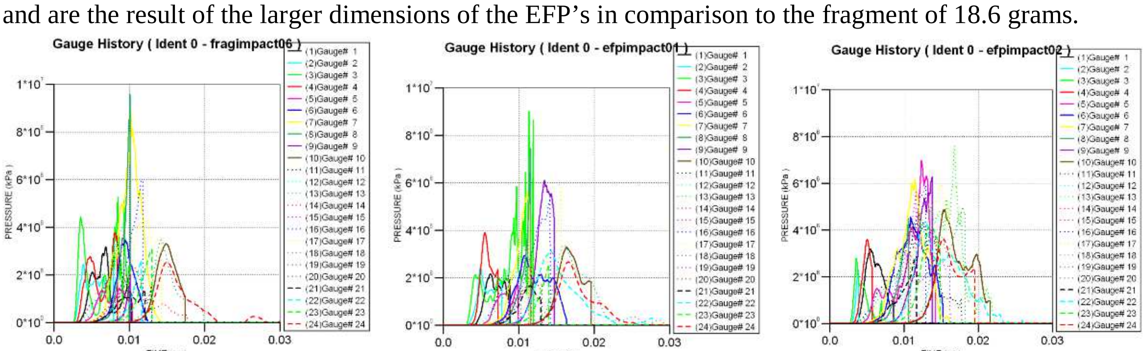

Figure 14 The shock pressures in the explosive due to the impact of the projectiles; fragment impact at 2530 m/s left, 19 mm EFP at 2100 m/s middle and the 27 mm EFP at 2100 m/s on the right.

So, for pure munition impact it shows that the threat of a EFP is not larger than that of an IM fragment. However, in the case that any kind of protection in present in front of the munition item, erosion of the projectile takes place, also lowering the impact velocity of the projectile on the warhead. The light fragment looses his velocity at a higher rate that the heavy EFP's. This leads to a higher impact speed of the EFP in comparison to the IM fragment and therefor could form a bigger threat.

Also for thick-walled munition the aspects of the rarefaction wave will come into place and have a strong influence on the amount of shock energy that can reach the explosive. So, in that case the 27 mm EFP projectile will produce a larger shock than the IM fragment impact projectile.

Another interesting aspect is the aiming location for the real life IM fragment impact test. In general it seems logical to aim for the location with the most explosive material. However, another simulation shows that this is truly not the worst case. Figure 15 shows the results of this simulation.

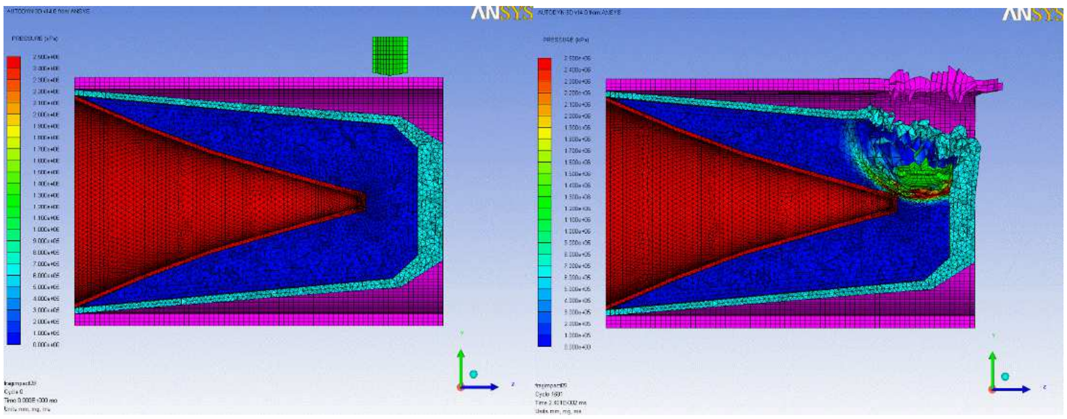

Figure 15 Fragment impact simulation with fragment impacting near the bulk of the explosive material.

The location of impact for this scenario is shown on the left hand side of figure 15. The right side shows the pressure near the copper liner. Figure 16 shows that the maximum pressure reached during to whole penetration process has its maximum around 5 GPa. No significant reflection wave is coming from the copper liner but from the aluminum casing. The maximum shock pressures reached are about a factor two lower than in a reflecting scenario's with a copper liner of a shaped charge. But this can happen for any warhead having a material layer at the opposite side of the impact side, while the impacting projectile is still producing high shock waves during penetration.

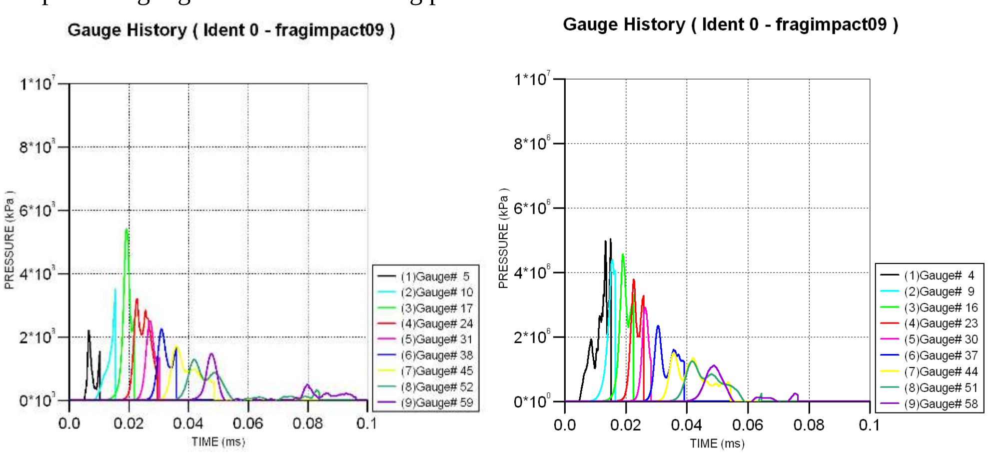

Figure 16 Pressures during the impact around the bulk of the explosives.

Conclusions

An investigation has been carried out to explore the differences in threat of an IM fragment impact projectile at 2530 m/s in comparison to a typical (IED)- EFP impact. Two different EFP shapes at a velocity of 2100 m/s have been chosen, to compare the shock impact for both types with the shock impact of the IM fragment projectile. As a target, a 90 mm shaped charge was chosen and different scenarios have been simulated. Also full scale IM testing on a comparable type of munition has been performed.

The simulations were performed with Ansys/Autodyn. The initiation and reaction of the explosive filling was not determined in the simulations. Instead, the pressure was calculated inside the explosive to see the differences between the different projectiles and scenario's.

The calculations revealed for pure impact on a thin-walled munition article, such as a shaped charge, the EFP impact at 2100 m/s does not form a bigger threat than the standard IM fragment impact projectile at 2530 m/s. Due to the higher velocity of the IM fragment maximum peak pressure is even a little higher.

However, in the case of a packed or protected munition article, processes such as erosion of the fragment and fragment mass of the projectiles after penetration of the barrier will probably be in favor for the EFP's and will result in higher pressures for the EFP. More research is needed for those types of scenario's.

However, another and maybe more important factor is the impact location for full scale IM testing: A reflection wave coming from a material layer behind the explosive can have a big influence on the effective shock waves in the explosive. The reflection wave can double the pressure and definitely lead to a prompt shock initiation of the explosive. So, not the location with the bulk of explosive is the worst case impact location but the location with a layer of material behind the location of impact. For the shaped charge this is near the location where the copper liner and the casing coincide.

In order to answer the question about the differences in threat between the EFP and standard IM fragments: In a thin-walled warhead with a pure impact the differences are negligible. However in the case of a thick walled warhead or a barrier in between the projectile and the warhead, it seems that the EFP could form a bigger threat than the standard IM projectile. However, in order to be sure about this statement it should be confirmed by more testing and simulations.

References

[1] K. Weimann "Research and Development in the Area of Explosively Formed Projectiles Charge Technology", Propellants, Explosives, Pyrotechnics I B, 294-298 (1993).

[2] C. Weickert and P. Gallagher, "Parametric study of the effect of a confinement ring on the shape of an explosively formed projectile", 13th International Symposium on Ballistics, Stockholm 1-3 June, 1992.