Friction coefficients for steel to steel contact surfaces in air and seawater

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Abstract. Through a series of laboratory friction tests on small scale specimens an understanding of the physical behaviour is gained. The test program of the friction tests contained 12 test specimen variants, with a combination of dry air and seawater environment and various surface conditions and contact pressures.

1. Introduction

In various types of offshore structures, friction-based joints are used, of which the friction coefficient of steel to steel surfaces in air and/or seawater is uncertain. The friction coefficient is known to be dependent on the surface condition, contact pressure and environmental condition. This paper gives the results of the dedicated laboratory friction tests for the derivation of the coefficients of friction for a variety of steel surface conditions and loading conditions, in air and in artificial seawater environment. The objective of the friction measurements is to quantify the coefficient of friction for offshore applications regarding various steel surface conditions.

Through a series of laboratory friction tests on small scale specimens, an understanding of the physical behaviour is gained. The laboratory tests have been executed by TNO in the Structural Dynamics lab in Delft.

2. Friction test set-up, specimens & test program

2.1. Friction test set-up

The test set-up composed of two hydraulic actuators working in perpendicular directions. A horizontal jack has been used to gain the normal force on the steel plates, a servo-hydraulic actuator was used to generate a displacement controlled cyclic movement of one of the plates. In this way, the static friction force is measured at the start of the test and the dynamic friction force during a short time of continued slip between the plates. The hydraulic actuators used in the test set-up are:

1. Frame of max 200 kN for the normal force (F_N) on the steel plates,
2. A 1000 kN servo-hydraulic fatigue test apparatus with hydraulic grips for the friction forces (F_w).

In the tests, the contact pressure has been varied between a low value of 2 MPa and a relatively high value of 40 MPa. The friction test assembly was composed of a double working inner plate and two single working outer plates, see Figure 1 and Figure 2. In this way, the measured friction force during the test was not polluted by the (not always constant) friction of another sliding system in the test setup. In fact, because both sides had exactly the same treatment and quality, an effective contact area

twice the mentioned nominal contact area was used, with contact surfaces of about 100 mm × 40 mm. For creating a realistic corrosive environment, artificial seawater has been used.

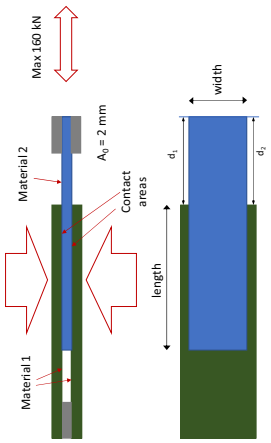


Figure 1. Schematic of the Friction test assembly.

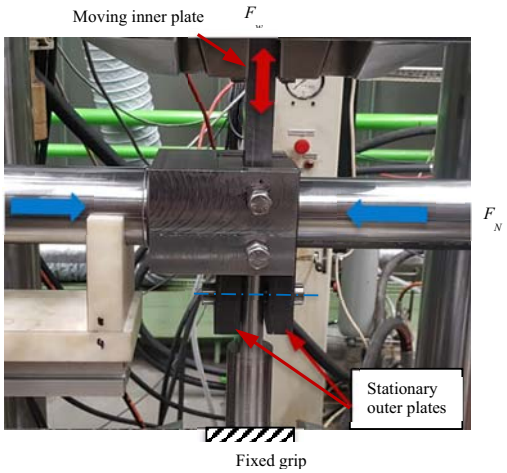


Figure 2. Friction test set-up with specimens tested in air.

Figure 3 shows a plexiglass container for the friction tests in artificial seawater. Before the execution of the friction test, the specimens have been exposed to a preliminary loading. A normal load has been applied during 1 hr. The following measurements have been done during the friction tests: 1) friction load and normal load versus time; 2) displacements of specimens versus time.

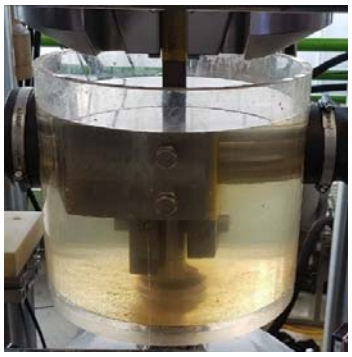


Figure 3. Container for the friction tests in artificial seawater.

The applied test conditions are the following: displacement controlled sinusoidal loading with displacement amplitude, A_0 = 2 mm, frequency = 0.2 Hz, test duration = 120 cycles (10 min).

The coefficient of friction f is determined by:

$$f = \frac{F_W}{2F_N} \tag{1}$$

With F_N = normal load, F_W = measured friction force.

2.2. Friction specimens

All friction specimens are made of steel plate S355ML, 25 mm thick. The test program of the friction tests contained 12 test specimen variants (in total 36 tests), with a combination of dry air and seawater environment, varying contact pressures and (combination of) various surface conditions: clean steel, mill scale, pre-corroded, coated and calcareous layer as a result of cathodic protection.

The contact surfaces of all pre-corroded specimens obtained a rust grade which complies with rust grades according to ISO 8501-1: Grade B: Steel surface which has begun to rust and from which mill scale has begun to flake; Grade D: Surface on which the mill scale has rusted away and on which general pitting is visible under normal vision.

The surface roughness of the specimens was measured for each surface condition, see the results in Figure 4.

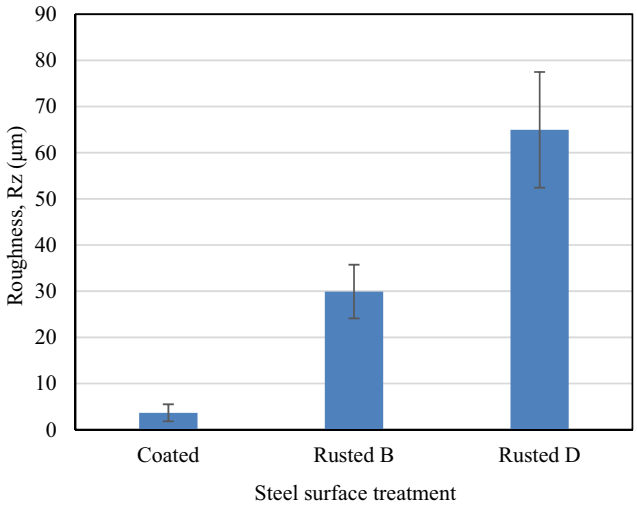


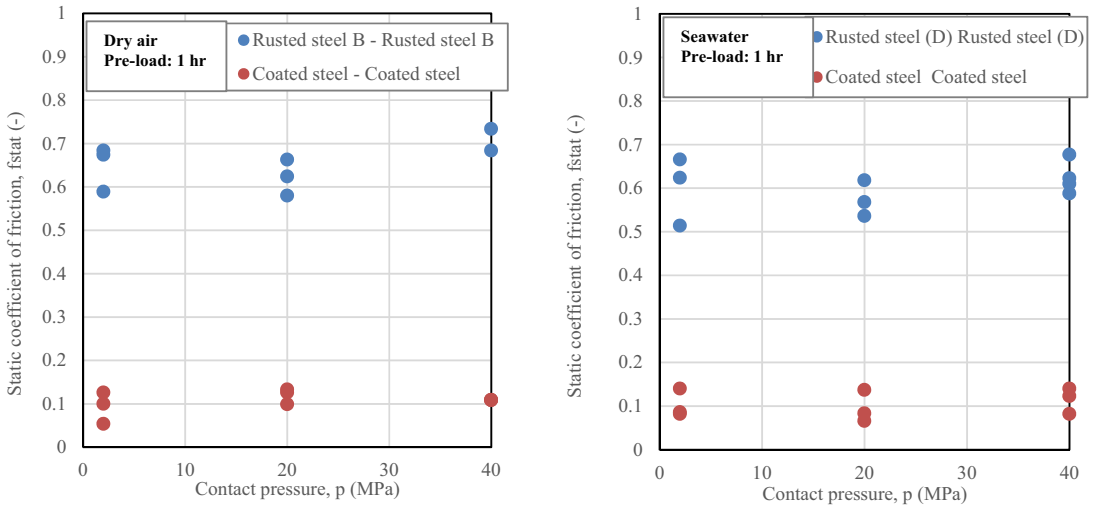
Figure 4. Surface roughness R_z (average distance between the highest peak and lowest valley) for the steel surface treatments

3. Test Results

The static coefficients of friction are determined at the first onset of sliding, after the pre-loading time of 1 hr (in compression). The dynamic coefficients of friction of surface treatments "Rusted steel (B) / Rusted steel (B)" in air and "Rusted (D) / Rusted (D)" in seawater have been averaged during a stable sliding period in compression and in tension. The dynamic coefficients of friction of surface treatment coating have been based on the end values of the friction coefficients after 10 minutes sliding.

3.1. Static coefficients of friction

The static coefficients of friction as a function of the contact pressure for surface treatments "Rusted steel (B) / Rusted steel (B)" and "Coated steel / Coated steel" in air are shown in Figure 5a. The static coefficients of friction as a function of the contact pressure for surface treatments "Rusted steel (D) / Rusted steel (D)" and "Coated steel / Coated steel" in seawater are given in Figure 5b.



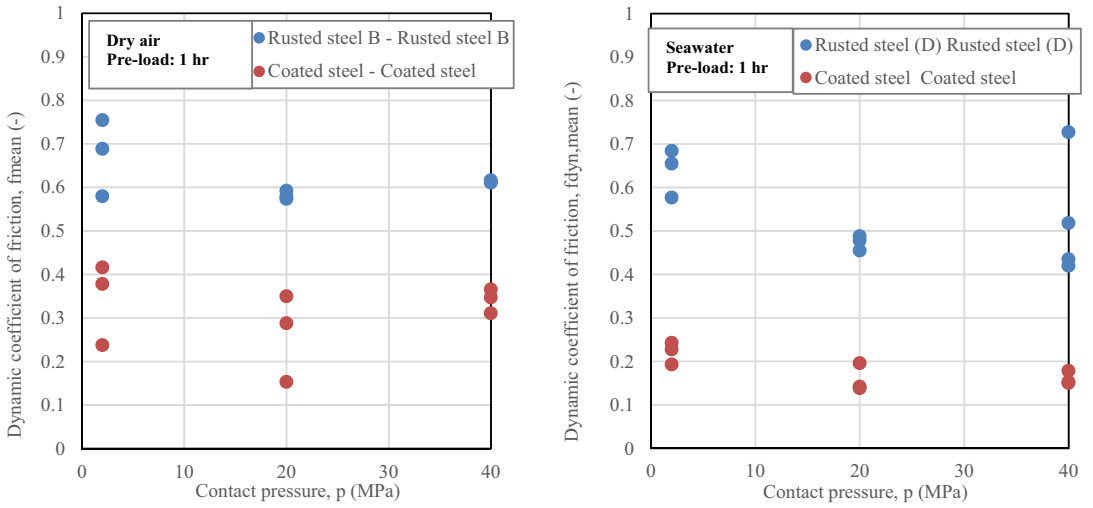
a) b)

Figure 5. The static coefficients of friction at the first onset of sliding, after the pre-loading time of 1 hr (in compression), as a function of the contact pressure for surface treatments "Rusted steel (B) / Rusted steel (B)" and "Coated steel / Coated steel" in air (a) and in seawater (b).

The static coefficients of friction are generally speaking independent of the nominal contact pressure.

3.2. Dynamic coefficients of friction

Figure 6 shows the dynamic coefficients of friction as a function of the contact pressure for the surface conditions "Rusted steel (B) / Rusted steel (B)", and "Coated steel / Coated steel" in air (figure a), and in for the surface conditions "Rusted steel (D) / Rusted steel (D)", and "Coated steel / Coated steel" seawater (figure b).



a) b)

Figure 6. The dynamic coefficients of friction as a function of the contact pressure for the surface treatments "Rusted steel (B) / Rusted steel (B)", and "Coated steel / Coated steel" in air (a), and "Rusted steel (D) / Rusted steel (D)", and "Coated steel / Coated steel" in seawater (b).

A stable sliding period resulted per specimen in a standard deviation of the dyamic coefficient of friction sd < 1% for surface treatments “Rusted steel (B) / Rusted steel (B)” in air and sd < 9% for surface treatment “Rusted (D) / Rusted (D)” in seawater.

A general remark in the determination of the dynamic friction coefficient regards the measurement of the normal load F_N. The hydraulic actuator that has been used was prone to variation. The horizontal load reduced during the friction test to a maximum of 10% in the specimens that were tested with contact pressures p ≤ 20 MPa. This reduction was 10-25% in the specimens that were tested with a contact pressure of 40 MPa. This means, that the dynamic friction coefficient for p = 40 MPa were formally valid for a contact pressure p = 30-36 MPa.

4. Conclusions

This paper gives the results of the dedicated laboratory friction tests for the derivation of the coefficients of friction for a variety of steel surface conditions and loading conditions, in air and in artificial seawater environment. Each friction test comprised of a pre-test, in which an intended normal load is applied on the specimens during a certain time (1 hr), and the real friction test in which, using the same normal load, the middle clamped specimen is cyclically moved during 10 minutes.

The static coefficients of friction are generally speaking independent of the nominal contact pressure.

The mean values of the dynamic coefficients of friction of the combinations in air are:
“Rusted steel (B) / Rusted steel (B)” between 0.57 and 0.75; “Coated steel / Coated steel” between 0.14 and 0.42 with an influence of the amount of contact pressure.

The mean values of the dynamic coefficients of friction of the combinations in seawater are:
“Rusted steel (D) / Rusted steel (D)” between 0.42 and 0.73; “Coated steel / Coated steel” between 0.14 and 0.24 with an influence of the amount of contact pressure.

5. Acknowledgements

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6. References

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