An experimental determination of the gasket-flange surface friction factor, µG

The latest version of EN 1591-1 – a calculation standard for circular bolted flanged joints – now includes lateral forces and shear moments in addition to axial forces and bending moments. This has necessitated the consideration of the friction factor µG. Given that the origins of existing µG literature values are uncertain, the ESA has run a test programme to determine generic data for various types of gaskets.

By Dr.-Ing. Manfred Schaaf, ESA Member

Introduction

In December 2013, a new version of EN 1591-1 was issued. Apart from several other modifications, the treatment of external loads was included in this calculation standard for circular bolted flanged joints. In the former standard, only axial forces and bending moments resulting from the piping system were considered; in the new issue lateral forces and shear moments can also be treated.

There are two possibilities to counterbalance the lateral forces and the shear moments: firstly by metallic contact of the flanges and secondly by friction between the gasket and the flange surfaces. Because the first option cannot occur in the type of flange connection (with a floating gasket between the flanges) covered by EN 1591-1, the lateral displacement of the flanges can only be prevented by friction between the gasket and flange surfaces. Therefore, the friction factor μ_G was introduced in the calculation procedure.

In one of the informative annexes in EN 1591-1 (Annex E), some friction factors are published exemplarily. These factors are based on values published in the German nuclear codes KTA 3201.2 and KTA 3211.2. The origin of these values cannot be retraced anymore. For this reason, it is stated in Annex E that these values are probably very conservative, and that an experimental determination of the factors should be preferentially used. Incidentally, overly conservative friction factors lead to higher required bolt forces to counterbalance the external loads, which may result in an overstressing of the components of the bolted flanged joint.

Therefore, the European Sealing Association (ESA) decided to determine generic data for different types of gaskets which could be published in the next revision of EN 1591-1.

In this paper the results of this project are presented.

Testing equipment and test procedure

The necessity to study different test parameters and the simulation of real operational conditions led to the configuration of the testing equipment used in this project. The following parameters were of interest to determine generic friction characteristics for different types of gaskets:

- axial load (gasket stress)
- temperature
- flange surface finish
- gasket thickness.

The standard testing equipment which was originally developed for determining gasket characteristics, e.g. according to EN 13555, could be adapted very easily for performing the friction tests. An additional heatable plate is installed between the heated raised faces of the standard test rig. Therefore, a set of two gaskets, one on the bottom and one on the top of the intermediate plate, are examined in one test, see Figure 1.

The axial load on the gaskets is applied and controlled by the hydraulic system of the equipment. All test plates - the standard test plates on the top and the bottom as well as the intermediate plate - are heated up to the test temperature with a defined heating rate. After a dwell time at constant temperature, the gasket stress is reduced from the initial (or assembly) gasket stress Q_A to the minimum required gasket stress in operation $Q_{Smin(L)}$. This procedure simulates the operational behavior in a bolted flanged joint.

The additional intermediate plate can be removed in the radial direction using a hydraulic tensioner, as shown in Figure 2. The necessary hydraulic force of the tensioner F_{rad}, which is required for the radial movement of the intermediate plate, and the axial force F_{ax}, which is required to apply the gasket stress $Q_{Smin(L)}$, can be used to calculate the friction factor under these test conditions.

$$\mu_G = \frac{F_{rad}}{2 \cdot F_{ax}}$$

This test procedure was developed and validated in a former research project and was already included in an informative annex of the last issue of EN 13555.

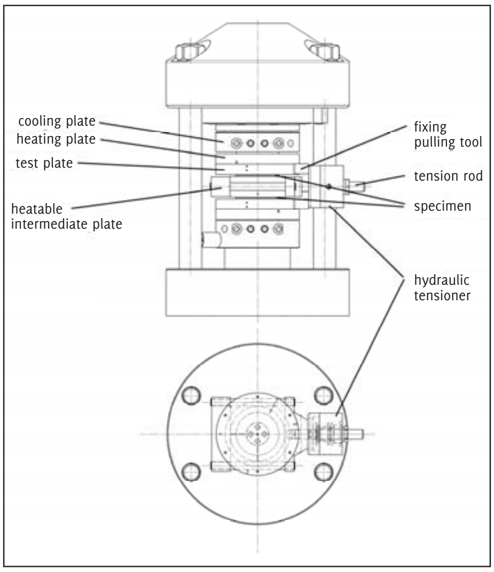

Figure 1: Additional module for friction tests in the testing equipment

About the Author

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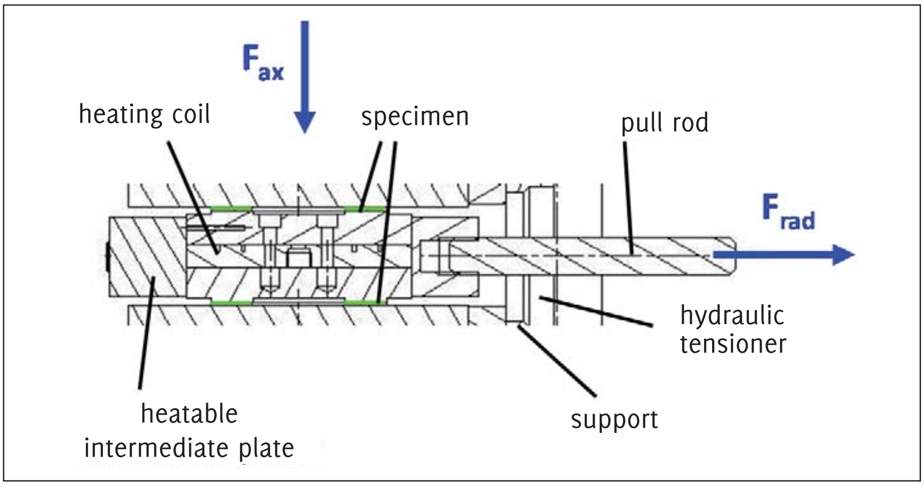

Figure 2: Test setup

Test programme

The project was divided in two phases. In phase 1, the parameters which may influence the friction behavior were studied on three different types of cut gasket sheet materials:

– tanged metal reinforced flexible graphite cut gasket
– compressed fibre-based composite cut gasket, aramid based
– ePTFE cut gasket.

First, different roughnesses of the raised faces of the flange surfaces were examined. Therefore, test plates with a roughness R_a of 3.2 µm, 6.3 µm and 12.5 µm were produced. These are typical roughnesses of the flange surfaces in use in several applications in industry. The variation of the roughness was considered for one gasket thickness (1.5 mm) and for two temperature levels (ambient and maximum temperature of the material).

Also, the test temperature was varied systematically to investigate whether the friction factor is a temperature-dependent characteristic. Of course, the test temperatures were selected in accordance with the gasket material. For all materials, tests at ambient temperature, at a median temperature and at a high temperature were performed. For the graphite-based gasket the elevated temperature levels were set to 150°C and 300°C, 100°C and 150°C for the fibre-based gasket, and 150°C and 230°C for the ePTFE gasket. These tests were all performed with test plates with a roughness of R_a 6.3 µm and gasket sample thickness of 1.5 mm.

Since the examined gaskets are all cut from sheets which are manufactured in different thicknesses, the variation of the gasket thickness was also treated in the last step of phase 1. For all three gasket materials the gasket thicknesses 1.5 mm and 3.0 mm were used in these tests at ambient temperature and the maximum temperature of the material with test plates with a roughness of 6.3 µm.

The goal in phase 2 of the project was the determination of generic values for the friction factor for all different types of gaskets. With the knowledge of the results of phase 1, the test parameters were defined precisely for all types of gaskets.

All members of the Flange Gasket Division of the ESA were allowed to provide gaskets which should be treated in phase 2 of the project. Therefore, a wide range of different type of gaskets were part of this study. The different gaskets, which were supplied for testing, were anonymized with the following codes:

- **GA** Smooth metal reinforced flexible graphite cut gasket, adhesive bonded, without surface treatment
- **GB** Smooth metal reinforced flexible graphite cut gasket, with surface treatment
- **GC** Tanged metal reinforced flexible graphite cut gasket, with surface treatment
- **GD** Smooth metal reinforced flexible graphite cut gasket, adhesive bonded, without surface treatment
- **GE** Expanded metal reinforced flexible graphite cut gasket, with surface treatment
- **GF** Corrugated gasket fully covered with flexible graphite, without surface treatment
- **GH** Tanged metal reinforced flexible graphite cut gasket, without surface treatment
- **FA** Compressed fibre based composite cut gasket, aramid based with graphite filler, with surface treatment
- **FB** Compressed fibre based composite cut gasket, aramid based, with surface treatment
- **FC** Compressed fibre based composite cut gasket, aramid based with graphite filler, with surface treatment
- **FD** Compressed fibre based composite cut gasket, glass fibre reinforced
- **FE** Compressed fibre based composite cut gasket, aramid based, without surface treatment
- **PA** PTFE cut gasket, with silica filler
- **PB** PTFE cut gasket, structured PTFE with glass filler
- **PD** ePTFE cut gasket
- **PG** ePTFE cut gasket
- **PJ** ePTFE cut gasket
- **PK** PTFE cut gasket, with barium sulfate filler
- **PL** PTFE cut gasket, with silica filler
- **PM** PTFE cut gasket, with glass filler
- **PN** PTFE cut gasket, with barium sulfate filler

Test results – phase 1

The goal of the investigation in the friction tests is the determination of the friction factors μ_G (stiction) and μ_{Gdyn} (slide friction) of the gasket materials. Therefore, the pressure in the hydraulic tensioner is increased steadily until the intermediate plate starts to slide. In Figure 3,

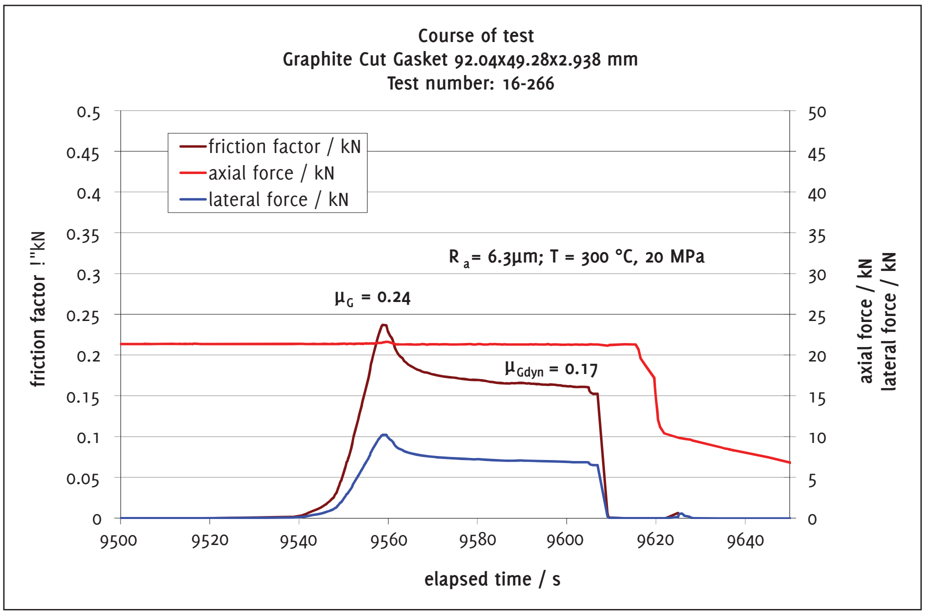

Figure 3: Exemplary course of a friction test

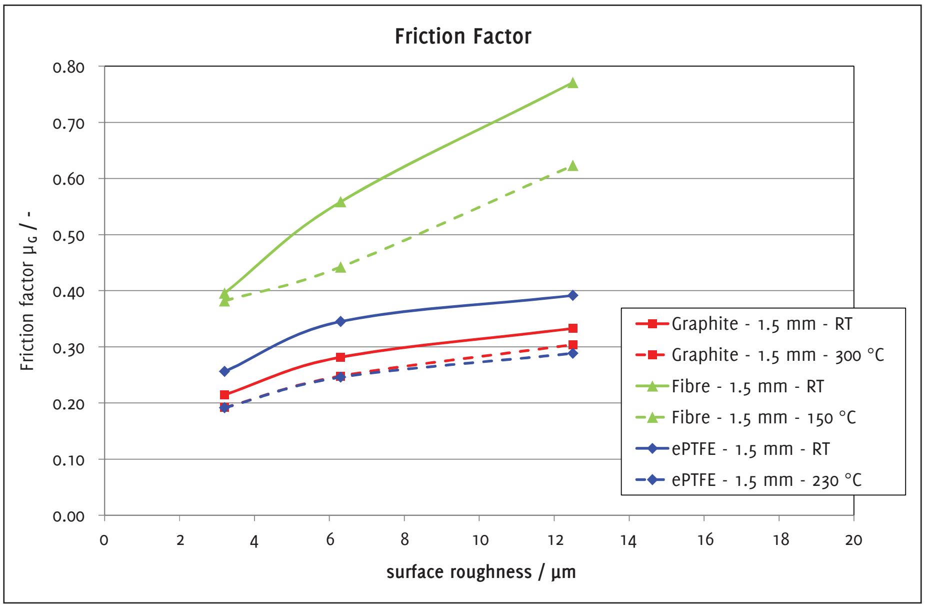

Figure 4: Influence of the flange surface roughness on the friction behavior

an example of a friction test with a graphite cut gasket at 300°C is shown. The stiction coefficient μ_G is approximately 0.24, the slide friction factor μ_{Gdyn} is 0.17. For the assessment of the friction effects between flange and gasket surface in a bolted flanged joint, the stiction is of more importance than the slide friction. So, in all tests, only the stiction factor is evaluated.

The roughness of the test plates has – as expected – a distinct influence on the friction behavior of all gasket materials. As shown in Figure 4, the friction factor increases with a rougher surface finish. The friction factors determined for the fibre based gasket material were extremely high. In these tests it was also visible that the friction factors decrease with increasing temperature.

In the systematic study of the influence of the test temperature, this first indication was confirmed. Figure 5 plots the friction factors determined at three different temperature levels for each gasket material. For the fibre material, the friction factor between RT and 100°C is reduced very strongly. Between the median and the maximum temperatures, the friction factor for the fibre as well as for the graphite gasket is almost identical. For the ePTFE gasket, a reduction of the friction behavior with increasing temperature can be recognized.

The last parameter which was examined in phase 1 was the thickness of the gasket sheet. For all three types of gaskets, samples which were cut from a 1.5 mm and a 3.0 mm sheet were tested. For all materials, no significant influence of the gasket thickness on the friction behavior could be detected. Figure 6 shows that the trend in the friction factor is slightly increasing for the fibre gasket and slightly decreasing for the ePTFE gasket with increasing gasket thickness.

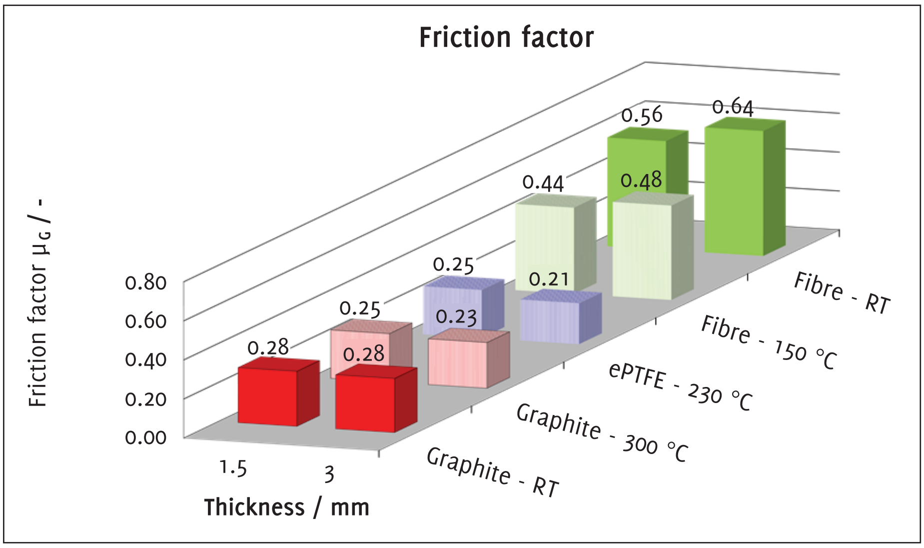

Figure 6: Influence of the gasket thickness on the friction behavior

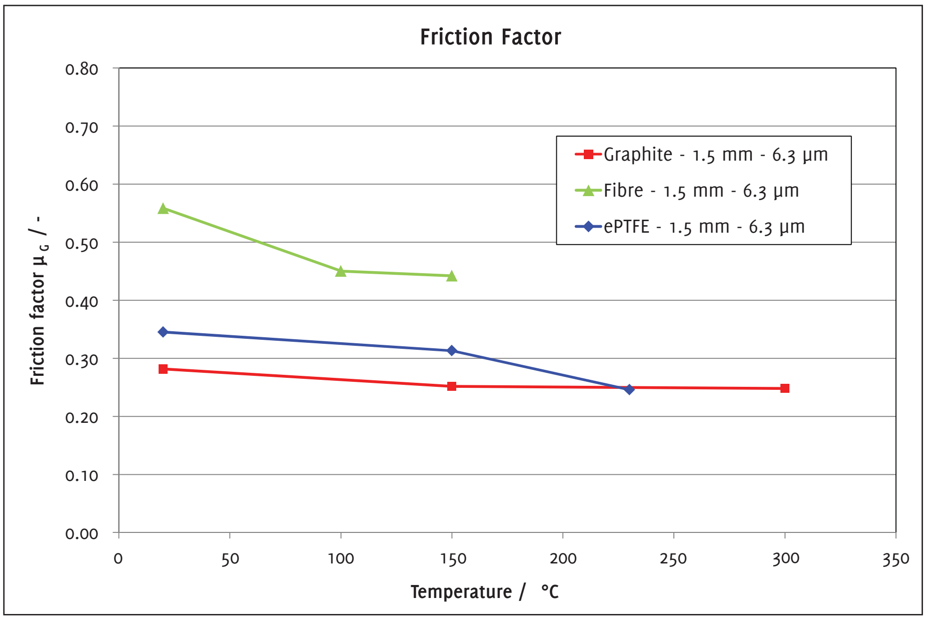

Figure 5: Influence of the test temperature on the friction behavior

Test results – phase 2

Based on the results of phase 1 it was decided that all further tests were to be carried out with a flange surface finish of a roughness R_a of 6.3 µm. Smoother flange surfaces are not commonly used in pipe flanges, and for rougher surfaces the results obtained with 6.3 µm are applicable. Also, the temperature and the gasket thickness were

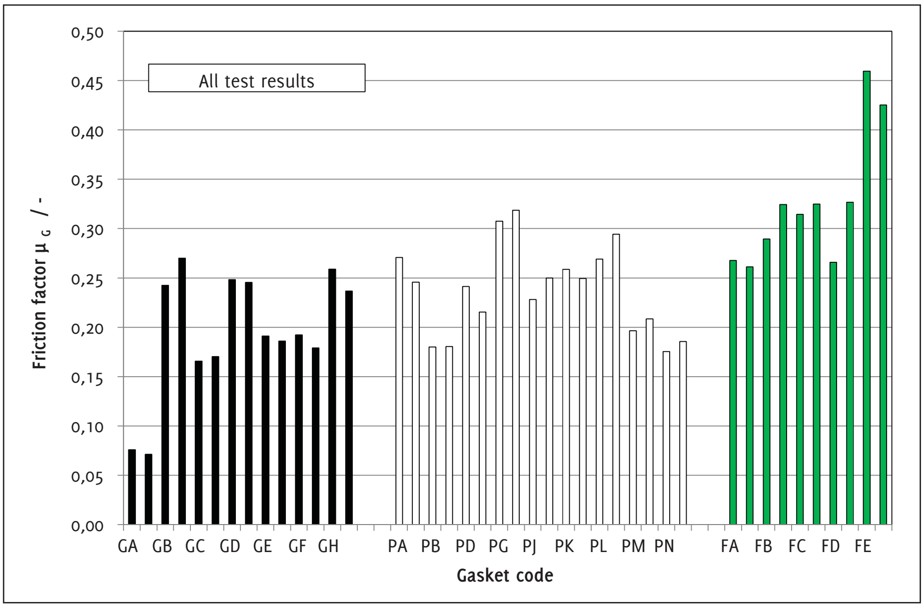

Figure 7: Friction factors for all examined gasket materials (single tests)

the hydraulic force was increased steadily until the intermediate plate started to slide.
Besides the GA material, the flexible graphite cut flat gaskets without an inner eyelet and flexible graphite full faced corrugated gaskets indicate a friction factor of 0.22 ± 0.04, see Figure 8. Due to the test result of the GA material it should be noted that adhesive bonded material might show lower values depending on the adhesive used and depending on the temperature, as components might slide within the gasket material itself when adhesive is liquid at a certain temperature range.
The determined friction factors for fibre based gaskets are shown in Figure 9. The factor for the FA material

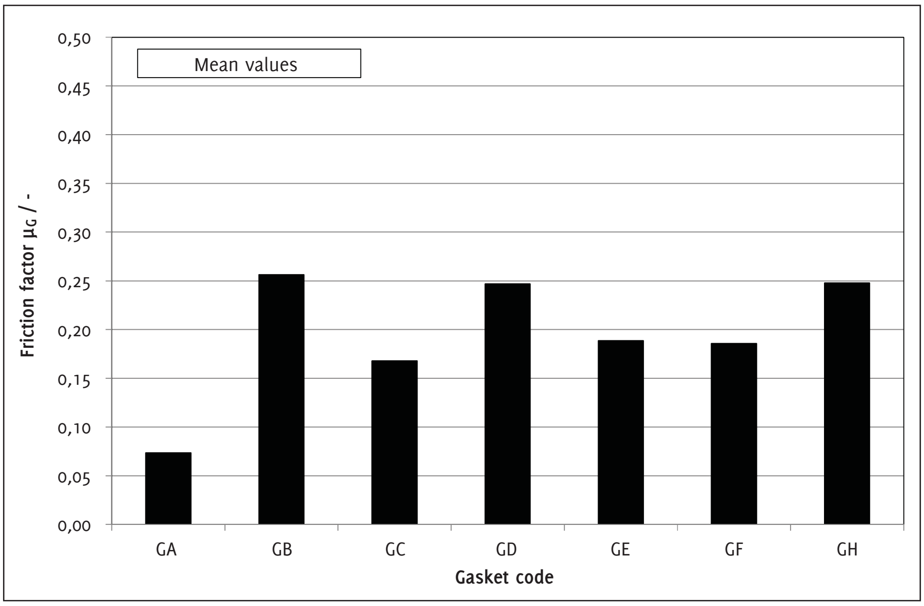

Figure 8: Friction factors for different graphite based gasket materials

not varied anymore. All tests were performed at an elevated temperature level, which was dependent on the gasket material. The temperature was set to 300 C (graphite based gaskets – sheet or cover) and to 150 C (fibre and PTFE based gaskets).
As was the practice in phase 1, all tests were performed twice. Because there was a good reproducibility in the double tests, see diagram in Figure 7, with all test results, only the mean value of this double tests is published.
The procedure in the tests of phase 2 was similar to the one established in phase 1. After loading to a gasket stress of 20MPa and applying the test temperature, the operational gasket stress was simulated by reducing the stress to 5MPa. Under this condition,

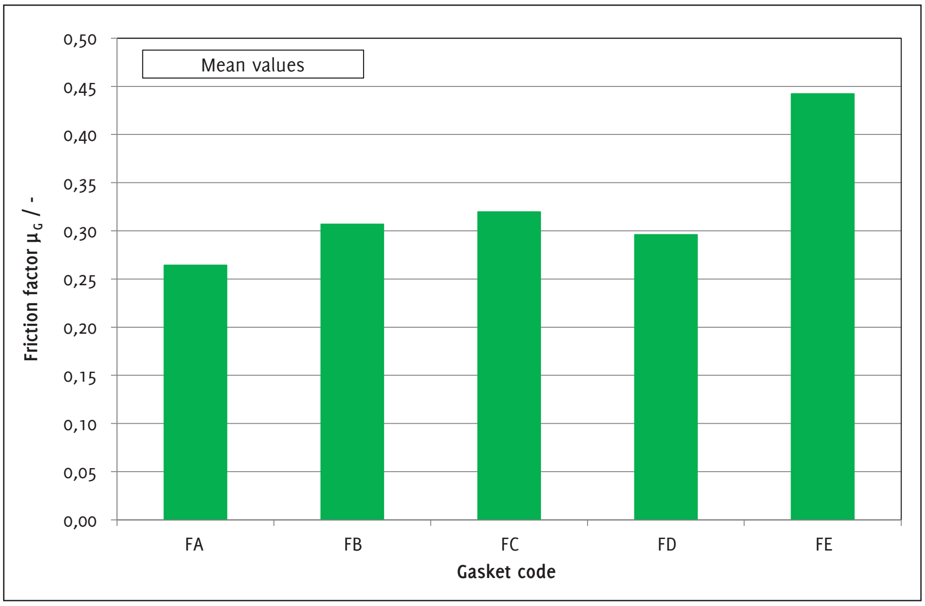

Figure 9: Friction factors for different fibre based gasket materials

is slightly lower, and the factor for the FE material is higher than the mean value, but the other factors show only a slight scatter. The generic friction factor for fibre based gaskets can be defined to 0.30.
For the different PTFE gaskets, it was apparent that the filler has an influence on the friction behavior of the material. On one hand the friction is lower compared to the expanded PTFE materials, and on the other hand the scatter in the values was larger, see Figure 10. Therefore, ESA recommends to create two groups of PTFE gasket materials with respect to a generic friction factor: one for expanded PTFE with a friction factor of 0.26 and one for filled PTFE gaskets with a friction factor of 0.23.

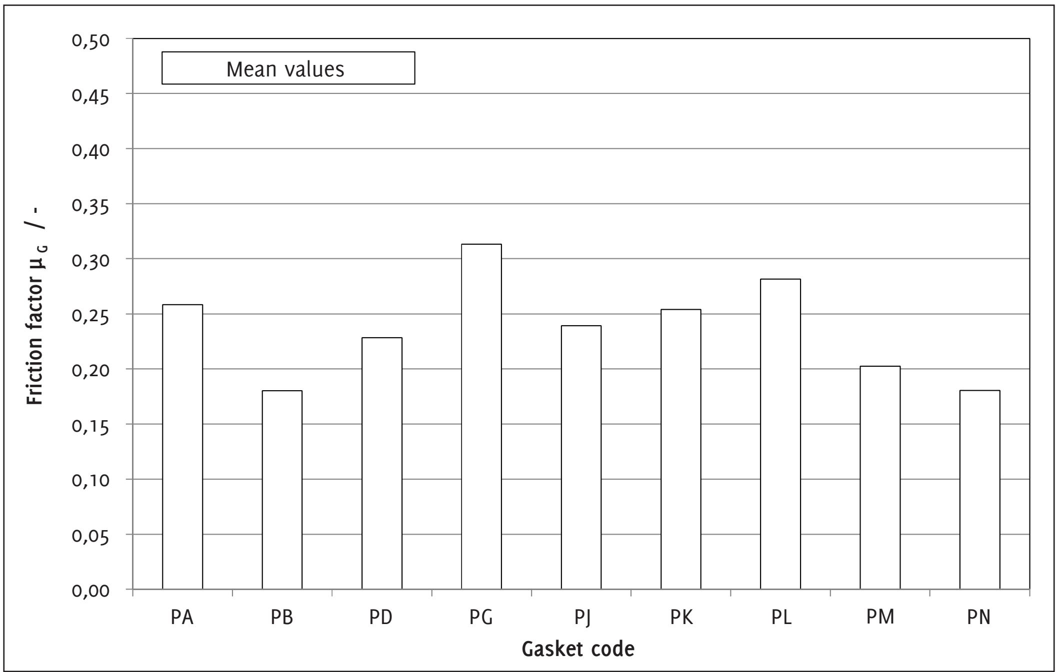

Figure 10: Friction factors for different PTFE based gasket materials

Table 1: Generic friction factors	
Type of Gasket	**Generic Value for μ_G / -**
Gaskets based on flexible Graphite	0.22
Gaskets based on Fibre	0.30
Gaskets based on ePTFE	0.26
Gaskets based on filled PTFE	0.23

Table 1 summarizes the generic friction factors determined in the ESA project for different types of gaskets. These values will be forwarded to the standardization committee CEN TC74 with the request to publish them in Annex E of EN 1591-1. Compared to values indicated in the current informative Annex E of EN 1591-1, the new friction factors are considerably higher. The current values are 0.1 (Graphite), 0.25 (Fibre) and 0.05 (PTFE), respectively. Nevertheless, there are still several types of gaskets for which no sufficient characteristics are available. But as a result of the ESA project, it can be stated that the procedure outlined in EN 13555 is feasible for the determination of the characteristics. Therefore, gasket manufacturers can use this method for the generation of the friction factors of their materials.