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Gasket Characteristics in Flanged Joints

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ABSTRACT

Correct function of a flanged joint is given if it is tight and if its integrity is guaranteed for the entire period of operation. To a large degree, the reliable function of a flanged joint is determined by the behaviour of the gasket. Therefore, to achieve function of a flanged joint the user needs detailed information on deformation and tightness characteristics and on long-term characteristics of the gasket. These data are necessary for selection purposes, for the calculation of the prestress values (torque) during mounting and - if appropriate - for tightness and stress analysis.

In Europe, gasket factors for circular flanges with the gasket floating between the flanges are defined in a European standard (prEN 13555, 2002). The main purpose of this standard is to define gasket factors (and the test procedures for their evaluation) for use in calculations (EN 1591, 2001). Presently, these gasket factors are tested within the scope of a European research project.

Additionally, within the scope of the German nuclear code KTA gasket factors and a calculation procedure for flanged joints with metal-to-metal contact are provided. This approach has been proven in a research project, too.

The paper gives a critical overview over the state of gasket testing and typical results.

KEY WORDS: flanges, bolted flange connections, flanged joints, tightness, gasket factors, gasket characteristics, tightenning characteristics, deformation characteristics, calculation

INTRODUCTION

Basically, there are existing two different designs on bolted flanged connections (BFC), the gasket floating between the pair of flanges and the meat-to-metal contact type (MMC), see **figure 1**. These two types do not differ only in their geometrical design, but also the function of the two types is completely different. Also, the gasket types used in the two different type of flanges, have different deformation and tightness behaviors which are described by gasket characteristics.

The first step towards a correct function of a flanged joint is a sufficient seating of the gasket during assembly, presumed that the choice of the gasket is appropriate for the joint (including demands, design and loads). In this step, external and internal leakage channels are closed. This seating (or predeformation) of the gasket determines the tightness characteristics of the gasket in operation.

As flanged joints are bolted joints, the forces of the individual parts (flanges, bolts, gasket) change from assembly to operation states and viceversa, depending not only on the loads (internal pressure, external forces and moments etc.), but also on the stiffness characteristics of the parts. Thus, the prestress value that has to be applied during assembly depends on the necessary gasket stress for predeformation as well as on the change of the stress between assembly and operation.

For a choosen prestress value a tightness analysis is performed. In this step it has to be shown, that the gasket stress in every state of operation is higher than the minimum necessary gasket stress for the demanded tightness class. Additionally, a stress analysis has to be performed to limit the stresses in the individual parts of the joint.

Tightness analysis and stress analysis have to be performed iterativly; direct (one-step) calculations incorporate too many simplifications to be accurate. The calculations for use in tightness analysis and stress analysis have to use relevant and realistic gasket factors, regard stiffness of flanges, bolts and gasket, regard realistic operation loads like

internal pressure, external forces and moments, temperature, temperature distributions, deformations etc., determine the necessary gasket prestress level for assembly and determine gasket stress in operation.

For flanged joints with the gasket floating between the flange faces there is a European standard calculation procedure under construction (prEN 1591 /3/), that allows a tightness analysis as well as a stress analysis. This standard procedure can - as every calculation procedure - only give reliable results, if realistic gasket factors are used. Gasket factors and the necessary tests to determine these factors are defined for example in DIN 28090 and prEN 13555.

In the following paper, the necessary gasket factors are discussed for the gasket floating between the pair of flanges as well as for the meat-to-metal contact type.

NECESSARY GASKET CHARACTERISTICS FOR FLOATING TYPE

The gasket factors as defined in DIN 28090 and prEN 13555 are summarized in **tab. 1**. These gasket factors can be classified in factors describing the tightening characteristics and factors describing deformation characteristics.

Tightening Characteristics

For every gasket there is a certain minimum gasket stress in the state of assembly ($\sigma_{VU/L}$ or $Q_{MIN(L)}$), that is necessary to reach the requested leak rate (or tightness class). This minimum gasket stress is determined using the loading part of the curve in **fig. 2**.

During service, it is necessary to maintain at least a sufficient minimum gasket stress in every relevant operating state ($\sigma_{BU/L}$ or $Q_{SMIN(L)}$). This minimum gasket stress depends on the applied predeformation of the gasket during mounting of the joint. The highest value of $Q_{SMIN(L)}$ equals $Q_{MIN(L)}$; with an increase in predeformation of the gasket during assembly the $Q_{SMIN(L)}$ -value decreases.

Deformation Characteristics

To prevent destruction of the gasket or drastic changes in tightening capabilities, the upper limits of the gasket stress in the state of assembly (σ_{VO} or $Q_{SMAX}(RT)$) and in operation (σ_{BO} or Q_{SMAX}) have to be regarded.

To determine the changes of the gasket stress between the state of assembly and operation, the stiffness of the gasket - described using the elastic recovery (represented by the slope K_I and the intercept E_0) - is a necessary gasket factor.

Finally, creep and relaxation of the gasket under operating conditions must be known, because this can result in a drastic unloading of the joint. Δh_D or g_C is the gasket factor, that takes this characteristic into account.

DETERMINATION OF THE GASKET FACTORS FOR FLOATING TYPE

For the determination of the relevant gasket factors it is necessary to perform

-   compression tests (E_0, K_I and $Q_{SMAX}(RT)$)
-   compression-creep tests (Q_{SMAX})
-   relaxation tests (g_C) and
-   leak rate tests ($Q_{MIN(L)}$ and $Q_{SMIN(L)}$).

Regarding the compression tests and the leak rate tests a similar loading device (servo-hydraulic-press) can be used; both tests are performed with a steady increase in gasket stress resp. a constant gasket stress. Also, the compression-creep test (to determine σ_{BO} or Q_{SMAX}) can be performed in the same test rig.

In principle the creep/relaxation tests can be performed in a servo-hydraulic press, too. As there are a lot of parameters affecting creep and relaxation, a lot of (long-term) tests are necessary. Thus it is more convenient to use several simple mechanical test rigs.

Compression Test

For the necessary compression test a new test rig was developed. This servo-hydraulic press is capable to load up to 1 MN, **fig. 3**; gaskets up to 150 mm diameter can be tested. Great attention was paid to the fact, that the test rig design is modular. Depending on the type of test, different components (heating plates for temperatures up to 400°C, isolation- and cooling plates, different flange face designs etc.) can be used.

The load (gasket stress) is measured by a load cell on the bottom of the test rig, the gasket deformation is recorded using 3 displacement transducers and the temperature profile is controlled, too. LabView-Software is used for data logging and online evaluation. The entire test can be performed under software-control; thus automatic tests according to international standards or user defined procedures are possible.

An example of a compression test curve is given in **fig. 4**. This curve also shows unloading parts to determine the elastic recovery. The gasket factors representing the elastic recovery depend on the gasket material; it is not possible to transfer these constants to other gaskets materials and types.

Fig. 5 shows compression test results for different graphite gaskets with the same dimensions. In the first case the maximum gasket stress in assembly is about 50 MPa ($Q_{SMAX(RT)}=0.8*$ stress at destruction), in the second case about 140 MPa. The difference in the gasket factors may have its reason in different material densities.

Leak rate test

Due to the modular design, the above test rig can be modified to perform leak rate tests. The heating and cooling plates are replaced by plates for leak rate tests, that are connected to a separate measurement device, **fig. 6**. The leak rate measurement principle is based on the pressure decay method; using a differential pressure measurement method, leak rates down to about 10^{-4} mg/m/s can be measured. The tests can be performed manually, but – as the tests are time consuming – the possibility to perform automatic (software-controlled) tests has major advantages.

Normally, the leak rate tests are performed at constant internal pressure and different gasket stress levels. On the base of software controlled pressurizing and depressurizing tests with several different internal pressure levels are possible. The load (gasket stress) is kept constant during the measurement steps. Thus leak rates are recorded for loading and unloading to determine the gasket factors $Q_{MIN(L)}$ and $Q_{SMIN(L)}$.

Fig. 7 shows two examples of the recorded leak rate curves, one is measured using a graphite (flat) gasket, the other using a kamm-profiled gasket with a graphite layer on both sides. The dimensions of both gaskets are similar. The $Q_{MIN(L)}$ values of the graphite gasket are significantly higher than those of the kamm-profiled gasket. The same characteristic can be determined for the $Q_{SMIN(L)}$ values. With the flat gasket a leak rate class of 0.001 cannot be reached at 40 bars.

Relaxation test

As said above, the creep / relaxation behaviour of gaskets depends on many parameters. Therefore it is necessary to have more than one test rig to determine the necessary gasket factors within a reasonable time. To minimize the costs, it was decided to develop a „simple" test rig with a mechanical loading possibility.

The new developed relaxation test rig consists of two plates with high stiffness that are compressed; the gasket is situated between these plates, **fig. 8**. It is possible to heat the plates up to 400°C. The device is loaded mechanically using a nut. The maximum load is 300 kN, the maximum gasket diameter that can be tested is 100 mm.

The stiffness of the test rig can be modified by exchanging a specially designed stiffness-module, that lies in line with the force flow of the gasket. Thus different stiffness of real flanges can be simulated. Two stiffness levels are designed up to now. The force is controlled via the deformation of the stiffness device, which was calibrated in a hydraulic press.

GASKET CHARACTERISTICS FOR METAL-TO-METAL CONTACT TYPE

The most important dimensions of MMC design are given in **fig. 9**. The gasket is either located in a groove or there are inner and outer retaining rings. The most important gasket factors can be derived from following discussion: Function can be achieved,

- if a perfect contact of the flange plates is reached during mounting and remains stable during all states of operation, and
- if the gasket stress in all states of operation remains above the gasket stress, which is necessary to keep the tightness class.

These demands result in a gasket factor necessary to reach contact (σ_{MMC}), **tab. 2**; this gasket stress is the minimum gasket stress for that joint. If there are additional forces and moments acting on the joint in operation, the bolt forces in assembly must be increased to make sure, that σ_{MMC} is the lower boundary. The gasket stress σ_{MMC} cannot be increased, once that contact is reached. Thus σ_{MMC} determines the tightness class, that can be reached with this construction ($p_{MMC/L}$ for tightness class L = f(σ_{MMC})). If there is no creep or relaxation of the gasket, above discussed gasket factors are enough to control the joint. If there is creep/relaxation a gasket factor g_c (similar to the one from prEN 13555) has to be taken into account.

σ_{MMC} is determined in a compression test. The test rig is the same as shown above (for flat gaskets of "floating" type; simply the gasket plates are modified, so the gasket can be placed in a groove. Some test results are given in **fig.10**. The plot demonstrates, that the correct seating and thus the correct function depends on the gap between gasket and groove and on the difference of the initial gasket height and the depth of the groove (resp. height of the retainer rings).

The maximum internal pressure for the demanded tightness class is determined in the same test rig using the leak rate modules. The leakage test must be performed with the flanges in contact, that means, that the load must be high enough, that the metal-to-metal contact is reached and not lost during the leakage test. For different internal pressure levels, the leak rates can be measured and the maximum internal pressure for the several tightness classes $p_{MMC/L}$ can be determined, see **fig. 11**.

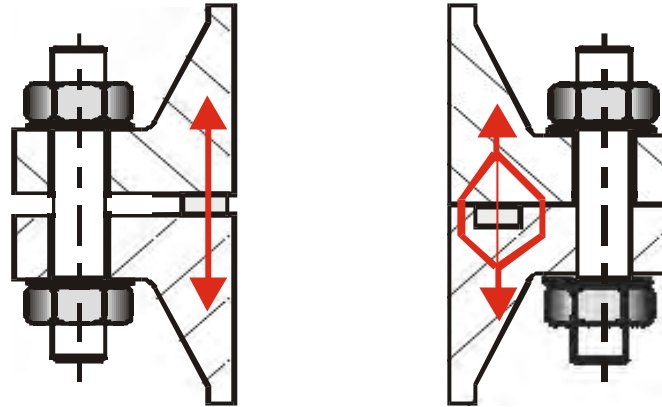The test procedure for creep/relaxation of the gasket is actually developed.

CONCLUSIONS

If the function of a tightening joint (flanged joint, stuffing box) has to be guaranteed, it is necessary to
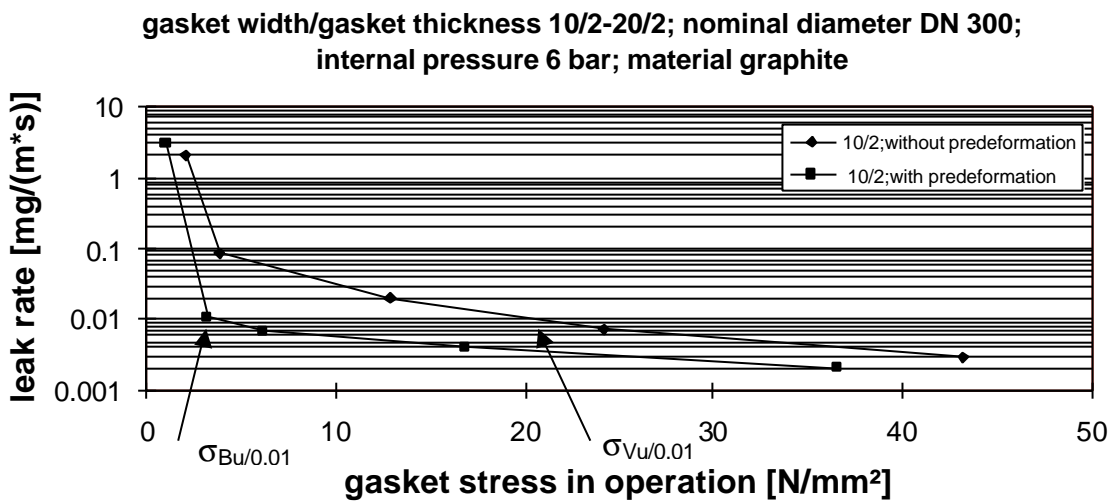
- know the relevant loads,
- make a suitable selection of the flanges and bolts (gland and bolts),
- make a suitable selection of the gasket,
- have the gasket factors available,
- perform a calculation (prestress, tightness analysis, stress analysis) and to
- have a qualified assembly procedure.

Regarding flanged joint designs with the gasket "floating" between the flanges, there are standards for the gasket factors at least in Europe. There are test rigs and test procedures to determine these gasket factors. And there are standardized calculation procedures, that use these gasket factors, too. Using the ASME calculation procedure, the factors m and y are not sufficient for tightness analysis and the "PVRC gasket factors" are not included in a calculation procedure.

Regarding flanged joint designs with metal-to-metal-contact, there are no standards for the gasket factors worldwide, but the definitions of the most important gasket factors are commonly known. They can be determined in standard test rigs. Although there are no standardized calculation procedures, a step by step procedure similar to that with floating gaskets is possible.
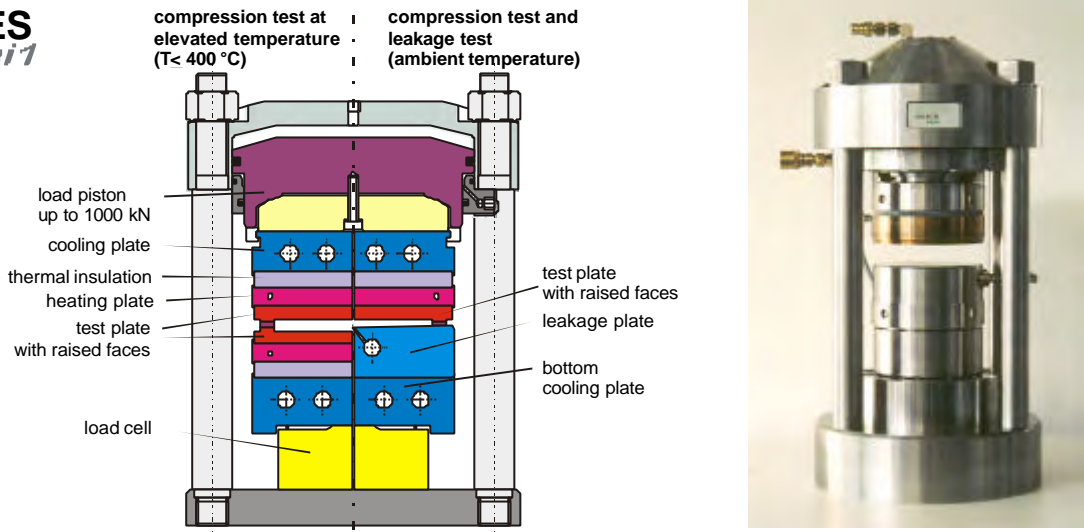
Figure 1:   bolted flange connections of floating (left) and metal-to-metal contact type (right)
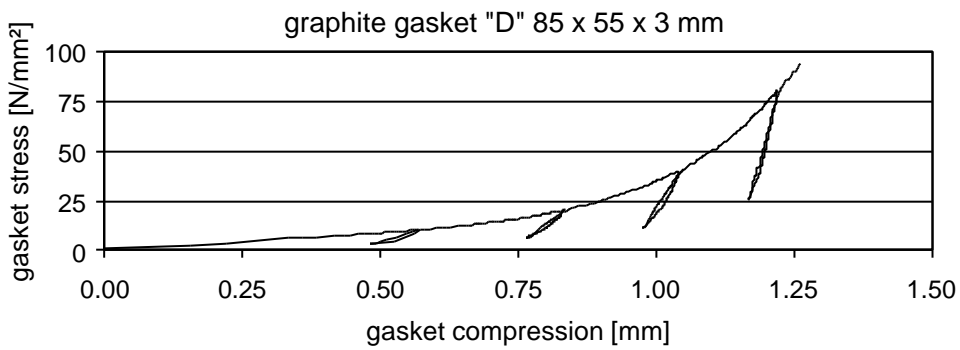

gasket width/gasket thickness 10/2-20/2; nominal diameter DN 300; internal pressure 6 bar; material graphite

Legend:
- 10/2;without predeformation
- 10/2;with predeformation

y-axis: leak rate [mg/(m*s)]

x-axis: gasket stress in operation [N/mm²]

$\sigma_{Bu/0.01}$

$\sigma_{Vu/0.01}$

Figure 2:   leakage test of a graphite gasket

Table 1:   gasket characteristics and related test procedures for floating type of gaskets

gasket factors acc. DIN 28090	gasket factors acc. prEN 13555	description	test type	test rig
$\sigma_{VU/L}$	$Q_{MIN(L)}$	minimum assembly gasket stress	leakage test	TEMES$_{fl.ai1}$
$\sigma_{BU/L}$	$Q_{SMIN(L)}$	minimum operation gasket stress	leakage test	
σ_{VO}	$Q_{SMAX}(RT)$	maximum assembly gasket stress	compression test	
σ_{BO}	Q_{SMAX}	maximum operation gasket stress	compression test	
E_D	E_0, K_I	elastic recovery intercept, slope	compression test	
Δh_D	g_C	creep factor	creep / relaxation test	TEMES$_{fl.relax}$

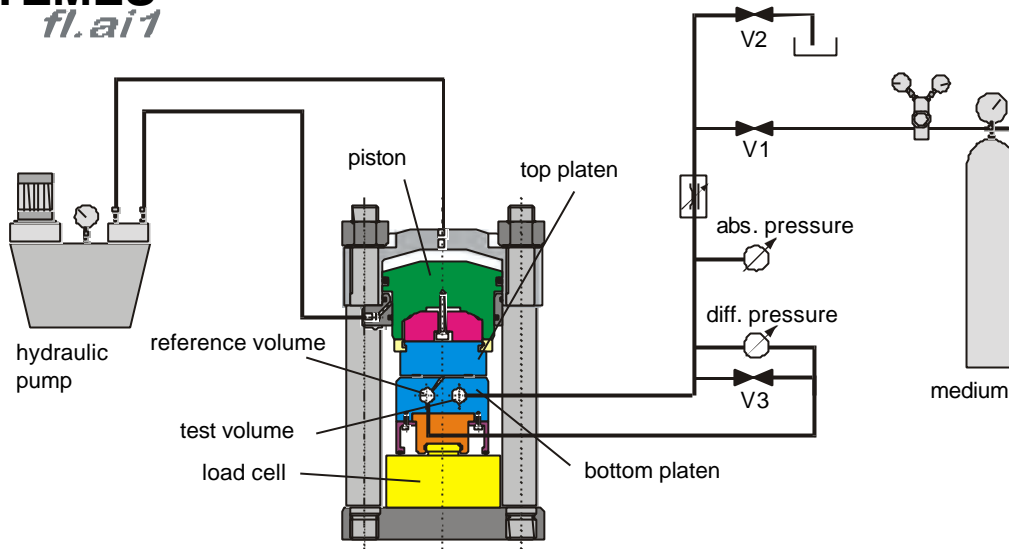**Figure 3:** test rig for compression and leak rate tests

Figure 4: compression test curve with unloading segments for elastic recovery
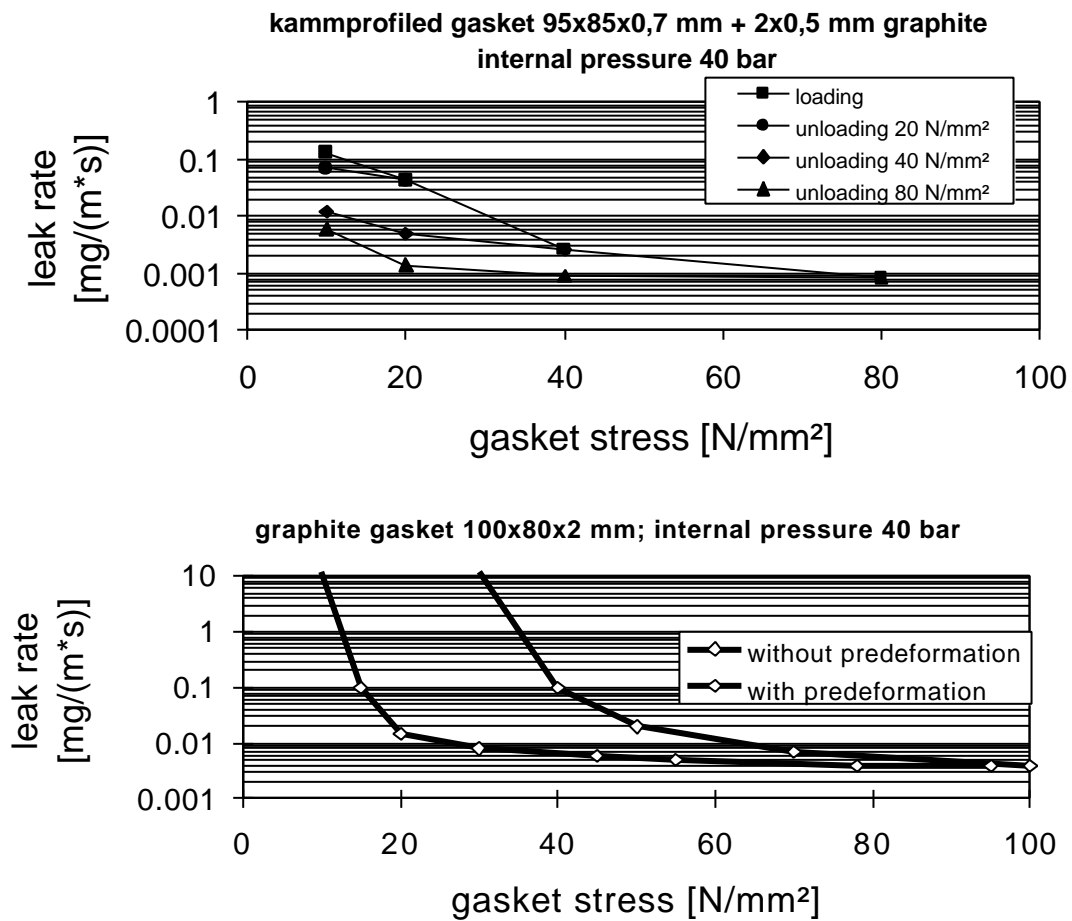

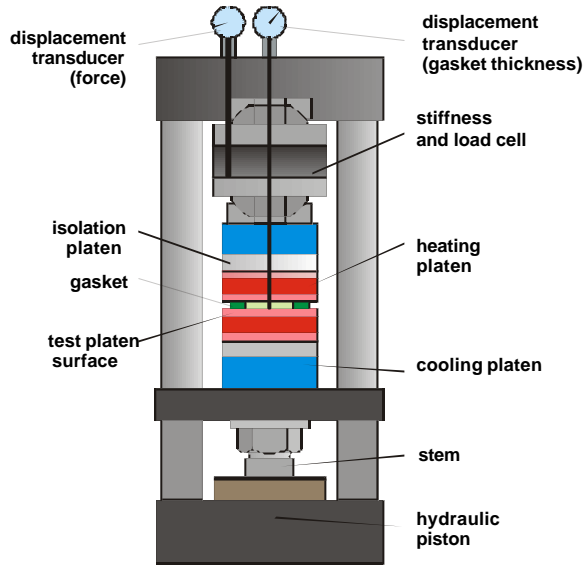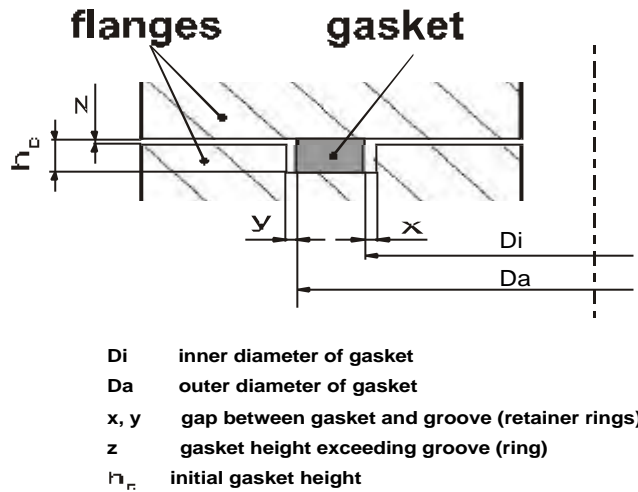**Figure 5:** compression test curves for different material qualities

Figure 6: schematic drawing of the leakage test rig

Figure 7: leakage test curves for a graphite and a kamm-profiled gasket

Figure 8: creep relaxation test rig

Di	inner diameter of gasket
Da	outer diameter of gasket
x, y	gap between gasket and groove (retainer rings)
z	gasket height exceeding groove (ring)
h_Γ	initial gasket height

Figure 9: relevant dimensions for metal-to-metal conact design

Table 2: gasket characteristics and related test procedures for metal-to-metal contact type of gaskets

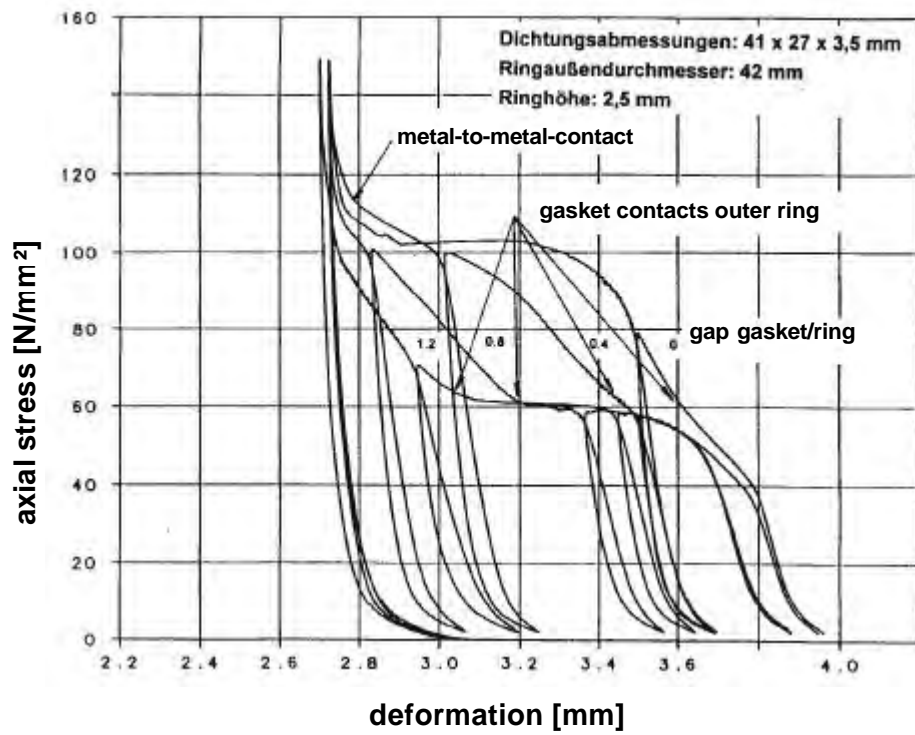| gasket factors	description	test type of test	test rig
σ_{MMC}	gasket stress to reach metal-to-metal contact	compression test	$TEMES_{fl.ai1}$
$p_{max/L}$	maximum pressure for given tightness class L	leakage test	
g_C	creep factor	creep / relaxation test	$TEMES_{fl.relax}$

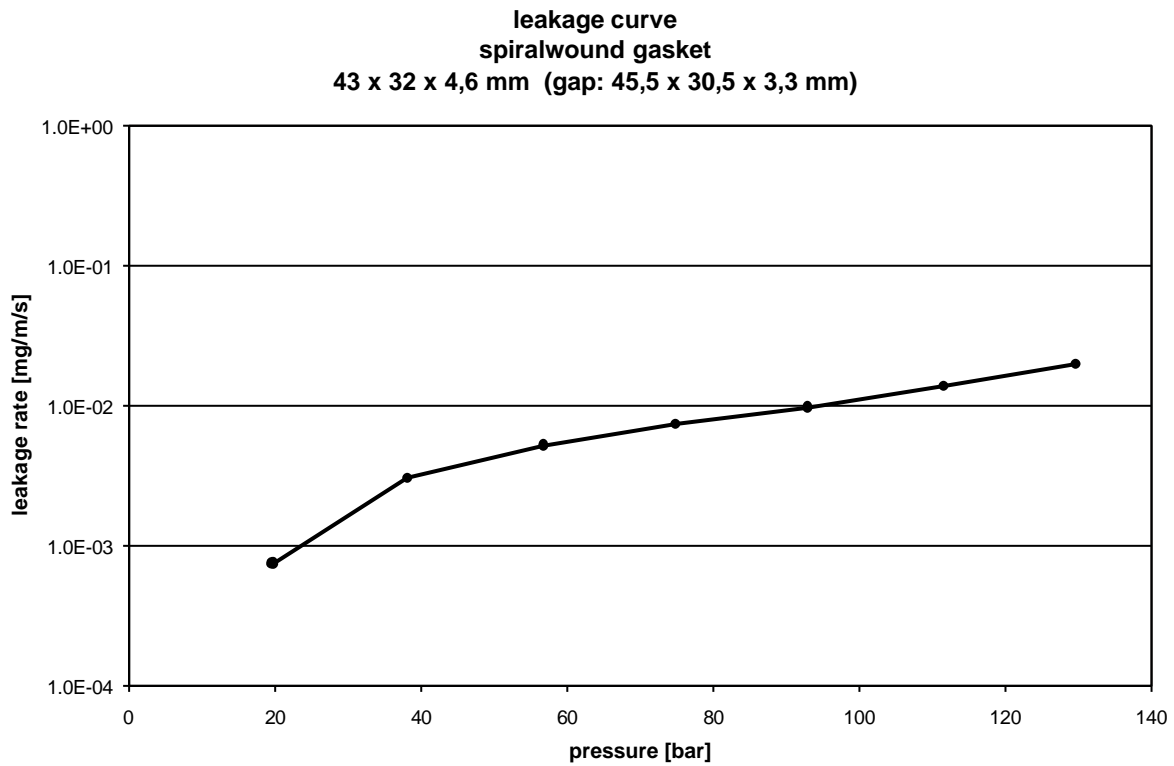**Figure 10:** compression test curves (parameter: gap between gasket and retainer ring)

Figure 11: leakage curve for metal-to-metal contact