PERL - European Research Project on Characterization of Gaskets for Bolted Flange Connections

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ABSTRACT

Great progress was observed in the European standardization in the last years in the field of the design of floating type bolted flange connections. New design rules were developed (EN 1591) which include new definitions of gasket characteristics for the calculation of floating type flanged joints. In addition a new gasket testing standard was drafted (prEN 13555) which assures a comprehensive characterization of gaskets for bolted flanged joints. This draft standard contains some new features which were examined and validated within the European research project PERL (Pressure Equipment - Reduction of Leak Rate).

The gasket testing strategy laid down in prEN 13555 is presented in this paper. Some testing results highlighten the measuring procedures and the evaluation of the gasket characteristics.

1 INTRODUCTION

Within the design of bolted flange connections the gasket as an important part of the joint has to be regarded by means of gasket characteristics which have to describe realistically the behaviour of the gasket under the influence of all loadings and boundary conditions. This includes the effects of the assembly gasket stress, internal pressure, temperature, time, stiffness, flanges and bolt geometry, load changes during service and so on. The gasket characteristics have to be determined experimentally. Several testing procedures developed and standardized in the far past are not adequate for this purpose, e.g. BS 7531 (1992) [1] and DIN 52913 (2002) [2] (determination of the creep strength), DIN 3535 (1986-1999) [3] (determination of the leakage rate), ASTM F36 (1987) [4] (determination of the gasket compression set and recovery), because only special conditions are regarded. First time with DIN 28090 (1995) [5] a gasket testing standard was edited which defines a consistent set of gasket characteristics for the design of bolted flange connections based on the calculation procedure in DIN 2505, and which specifies the corresponding testing procedures. Practical experience with this testing concept showed clearly some shortcomings inherently in DIN 28090. This fact and the need for the harmonization of gasket testing methods in Europe led to activities to improve the gasket testing methods within an European research project BE 5191 [6]. Thereafter new design rules for bolted flange connections were developed in Europe, EN 1591 (2001) [7], which required a re-definition of the gasket characteristics. Therefore a new gasket testing standard was created, prEN 13555 [8] (last version: Final Draft July 2004), which is fully in accordance with EN 1591. Some new features in prEN 13555 were checked within an European research project, PERL [9], and prEN 13555 had to be improved and optimized. Further within PERL all gasket types in the European gasket standards EN 1514 (PN designated gaskets) and EN 12560 (Class designated gaskets) were tested in the full range; these test results were implemented in a comprehensive gasket date base.

The new gasket characteristics definition and testing procedures are the subject of this paper.

2 DEFINITION OF GASKET CHARACTERISTICS

The following gasket characteristics are required for the design of bolted flange connections according to EN 1591:

- **Q_{SMAX}**: the maximum stress that can be safely imposed upon gasket at ambient and service temperature without damage
- **E**: the modulus of elasticity representing the gaskets elastic recovery during unloading (or load changes) at ambient and service temperature
  E is defined by the parameters **E_0** and **K_1**: **$E = E_0 + Q \cdot K_1$** (Q: gasket stress)
  E_0: the intercept of the line of regression of the secant unloading modulus versus gasket stress with the modulus axis
  K_1: the slope of the line of regression of the secant unloading modulus versus gasket stress
- **g_C**: the creep factor of the gasket (in the Final Draft of prEN 13555 g_C is replaced by P_{QR}, see chapt. 4.3)
- **$Q_{MIN(L)}$**: the minimum gasket assembly stress required at ambient temperature in order to seat the gasket into the flange facing roughness and close the internal leakage channels so that the required tightness class L is reached
- **$Q_{SMIN(L)}$**: the minimum gasket surface pressure required under the service pressure conditions, (i. e.) after off loading, so that the required tightness class L is maintained

3 TESTING BOUNDARY CONDITIONS

The nominal dimensions of test samples are:

- inner and outer diameter 49 x 92 mm (DN40 PN40), nominal thickness 2 mm for non-metallic flat gaskets
- DN40 PN40 for all other gasket types

Alternatively NPS 4" test samples according to EN 12560 are used.

For pre-conditioning the test samples are held for 48 hours in air with a relative humidity of (50 ± 6) % at ambient temperature (23 ± 5 °C). The compression platens of the load device have raised face dimensions according to EN 1092-1; for PN40

DN40: 43.1 mm x 88 mm; alternatively raised face dimensions NPS 4" Class 300 according to EN 1759-1 are used. The surface finish of the test platens (3.2 μm < R_a < 6.3 μm) is achieved by lathe turning with the following parameters: helical pitch: 0.3 mm, tool radius: 0.8 mm, depth: 0.015 mm. The R_a values are checked before each test.

4 TESTING PROCEDURES

4.1 Determination of Q_{SMAX} at ambient and elevated temperature

The gasket is loaded and unloaded at a rate of 0.1 MPa / s for PTFE-based gaskets, and 0.5 MPa / s for all other types.

Testing sequence:

- initial gasket loading: corresponding to 20 MPa gasket stress
- 5 minutes dwell time
- heating-up to the test temperature (heating rate 2 K min^{-1}) until the required temperature level is reached; no heating for tests at ambient temperature
- 15 minutes dwell time (only for tests at elevated temperature)
- subsequently loading-unloading cycles with increasing maximum gasket stress. The unloading stress level corresponds to 1/3 of the corresponding maximum stress level. At maximum and minimum stress there is a dwell time of 5 minutes for stabilisation.

The maximum stress levels are equally spaced by 10 or 20 MPa; therefore the gasket stress sequence is as follows:

20 MPa - 6.66 MPa - 30 MPa - 10 MPa - 40 MPa - 13.33 MPa - 50 MPa - 16.66 MPa - 60 MPa - 20 MPa - 80 MPa - 26.66 MPa - 100 MPa - 33.33 MPa - 120 MPa etc.

The gasket stress sequence (cyclic loading-unloading) and the temperature as a function of time are shown in Fig. 1, where the load steps 30 MPa and 50 MPa are not shown.

4.2 Determination of E (= E_0 +Q·K_1) at ambient and elevated temperature

The gasket parameter E depends on the maximum previous stress, Q, and is obtained from the unloading curves (recovery) for each stress level of the test described in chapt. 4.1:

$$E_Q = \frac{2}{3} Q \times \frac{\varepsilon_Q}{\Delta\varepsilon} \qquad (1)$$

The thickness ε_Q of the gasket at the stress Q is used in the formula above and $\Delta\varepsilon$ represents the elastic recovery during unloading from gasket stress Q to 1/3 x Q. The values of E_0 and K_1 are obtained by linear regression, least squares analysis.

4.3 Determination of g_c at ambient and elevated temperature

The test is conducted as a creep relaxation test in a test rig with a known stiffness. 500 kN/mm is typical for PN designated flanges and 1500 kN/mm for Class designated flanges. The creep relaxation can be simulated by means of a compression press used in displacement controlled mode; the stress is reduced according to the resulting creep regarding the stiffness to be simulated.

Testing sequence:

- Loading of the gasket to the initial stress level Q_I at ambient temperature
- 2 hours stabilisation at ambient temperature (5 min in Final Draft 2004)
- Unloading to 1/3 x Q_I at ambient temperature (step deleted in Final Draft 2004)
- 5 minutes stabilisation to measure the gasket thickness to determine the modulus of elasticity E (step deleted in Final Draft 2004)
- Loading of the gasket again to gasket stress Q_I (step deleted in Final Draft 2004)
- Heating-up to the test temperature (heating rate 2 K min^{-1}) until the required temperature level is reached; no heating for tests at ambient temperature
- Time of creep-relaxation: at least 2 hours (4 hours in Final Draft 2004)
- Determination of the final remaining gasket stress Q_R

The factor g_C can be derived from the equation given below:

$g_C = [(Q_R / Q_I) \times (3/2)\Delta\varepsilon] / \{[(3/2)\Delta\varepsilon] + [(Q_I - Q_R) A_G / C]\}$ (2)

where:

Q_I and Q_R are the initial and final surface pressures.

$\Delta\varepsilon$ is the thickness loss when gasket is off loaded to one third of the initial surface pressure before the relaxation effects take place.

C is stiffness of the assembly in which the relaxation took place.

A_G is the area of the gasket at the start of the test procedure.

In the Final Draft 2004 g_C is replaced by $P_{QR} = Q_R / Q_I$ which leads to a simplification and more reliability of calculation method EN 1591 (corresponding modification required).

4.4 Determination of $Q_{MIN(L)}$ and $Q_{SMIN(L)}$ at ambient temperature

The effective surface stress level Q is calculated according to the following formula:

$$Q = Q_A - (p \times (\pi/4) \times D_i^2) / A_G \qquad (3)$$

D_i: inner diameter of the sample (sealing area A_G)

Q_A: gasket stress corresponding to initial load without internal pressure

The gasket stress has to be raised at a rate of 0.1 MPa / s for PTFE based gaskets, 0.5 MPa / s for all other gasket types until the required gasket stress level is reached. The test gas pressure (Helium) has to be raised at a controlled rate.

Testing sequence for the 40 bar leakage test (full test sequence):

The procedure consists of loading to 10 MPa, holding the load and measuring the leakage rate after the leakage rate has stabilised. Thereafter the loading is raised to 20 MPa and held constant whilst the leakage rate is measured. Then the load is reduced to 10 MPa and the leakage rate is measured again. Then measurements are done at 40 MPa, 20 MPa and 10 MPa and so on until the maximum loading is reached (see Table 1 and Fig. 2). At each loading and unloading step, the waiting time before leakage rate measurement is 2 hours. 2 additional tests with reduced stress sequence should be carried out for 10 and 80 or 160 bar, Table 2 and Fig. 3.

5 EXEMPLARY TEST RESULTS

5.1 Q_{SMAX} of a Graphite based gasket at 400 °C

In Fig. 4 the test sequence of a Q_{SMAX}-test which was shown schematically in Fig. 1 is represented for a Graphite based sheet gasket at 400 °C temperature. In addition the gasket thickness change is shown as a function of time which follows closely the cyclic gasket loading and unloading. At about 120 MPa gasket stress a remarkable increase of the thickness change can be seen indicating a destruction of the gasket. The same results are shown in Fig. 5 as gasket stress versus gasket thickness. Again at about 120 MPa gasket stress a sudden increase of thickness reduction happens. This fact is highlighted by means of Fig. 6 where the thickness change during the load cycle at each stress level is plotted versus this gasket stress. The stress level before failure is defined as Q_{SMAX}, here Q_{SMAX} = 100 MPa.

5.2 E of a Graphite based gasket at 400 °C

Fig. 7 shows the elastic recovery modulus E of the gasket - described in chapt. 4.2 - as a function of the gasket stress. By linear regression (least square analysis) the formula for E is delineated:

$$E = E_0 + Q\,K_1 \qquad (4)$$

In the case of Fig. 7 the values of E_0 and K_1 are 258 MPa and 18.7.

5.3 g_C of a Graphite and PTFE based gasket

In the Figs. 8 and 9 the results of g_C-tests on a pure Graphite gasket at ambient temperature, and on a PTFE based gasket at 150 °C are shown. The creep of the Graphite based gasket is rather low therefore the drop of gasket stress is approximately negligible. This results in a g_C-value > 0.95 which yields generally in the temperature range up to 400 °C. In the case of the PTFE based gasket remarkable creep can be seen. The gasket stress drops down from 80 MPa to approximately 50 MPa resulting in a rather low g_C-value of 0.1.

The P_{QR}-values according to the Final Draft 2004 are approximately 1.0 for the Graphite based sheet gasket, and 0.6 for the PTFE based gasket.

5.4 $Q_{MIN(L)}$ and $Q_{SMIN(L)}$ at ambient temperature

A typical result of the leakage test at ambient temperature is shown in Fig. 10 for a Graphite based sheet gasket. The increase of the gasket stress - representing the bolt tightening during assembly - results in a reduction of leak rate or increase of tightening capability. Intermediate unloading - simulating the effects of internal pressure and external forces and moments which reduce the bolt and gasket load - leads to a little reduction of tightness; but compared to the virgin curve the tightening capability is generally improved due to the higher pre-load. Where the loading and unloading curves cross the decades of leak rate (defined as tightness classes) the corresponding gasket characteristics $Q_{MIN(L)}$ (loading) and $Q_{SMIN(L)}$ (unloading) are marked by squares in Fig. 10 (full: $Q_{MIN(L)}$; open: $Q_{SMIN(L)}$). These values are shown graphically in Fig. 11 ($Q_{MIN(L)}$) and Table 3 ($Q_{SMIN(L)}$). $Q_{MIN(L)}$ depends on the internal pressure (here only values for 40 bar are given) and on the tightness class, $Q_{SMIN(L)}$ in addition on the highest level of gasket stress before unloading (defined as Q in Table 3). Good reproducibility is observed in Fig. 11 and Table 3.

6 DETERMINATION OF THE SET OF GASKET PARAMETERS TO BE USED FOR ENV 1591-2 UPDATE

One of the objectives of the PERL project was to provide reliable gasket parameters values to be introduced into the ENV1591-2, in order to perform more accurate calculations according to EN1591-1. For each gasket type, tests were performed on gaskets from various origins (different manufacturers have provided the same type of gasket for testing). The tests were repeated once in order to check the repeatability of the results. It means that for each test temperature, two sets of tests (test 1 and test 2) were performed per manufacturer (see example given in Table 4). From these two tests the mean value of each gasket parameter was obtained (for E_0 & K_1: the mean values of each elasticity modulus was used to determine E_0 & K_1). Thus, a set of gasket parameters for each manufacturer was disposed. Then, calculations were performed according to EN1591-1, Table 5, with the following calculation conditions:

<u>3 steps</u> of calculation :

Step 1 (Tightening): P = 0 bar, T = 20°C, F_{ext} = 0, Safety factor SF = 1,05 (for gasket: SF = 1). The safety factor is applied to the yield stress of the flange and bolt material.

Step 2 (Pressure test): P = 1.5 · P_W, T = 20°C, F_{ext} = 0, Safety factor SF = 1.05 (for gasket: SF = 1)

Step 3 (Service): P = P_W, T = T_W, F_{ext} = 40 kN, Safety factor SF = 1.5 (for gasket: SF = 1)

where

- the working internal pressure P_W is varying from P_{ini} to P_{fin} with a pitch of P_p
- the working temperature T_W is varying from T_{ini} to T_{fin} with a pitch of T_p

For each set of gasket parameters, an allowable tightening range was obtained which corresponds to both leak-tightness and strength criteria. Following the results obtained, the most appropriate gasket parameters from a safety point of view were determined, to be introduced in the ENV 1591-2.

7 OUTLOOK

Research in the field of bolted flange connections in Europe is continued: project PERL and the generation of a comprehensive gasket data base was finalized by the end of 2002. The gasket testing procedures according to prEN 13555 were optimized and verified. All types of gaskets and gasket materials according to EN 1514 (PN designated gaskets) and EN 12560 (Class designated gaskets) were tested (only ring joint gaskets were not regarded):

- Non-metallic flat gaskets with or without inserts
- Spiral wound gaskets
- Non-metallic PTFE envelope gaskets
- Corrugated, flat or grooved metallic and filled metallic gaskets
- Kammprofile gaskets
- Covered metal jacketed gaskets

Together with the new European calculation code EN 1591 this will be the basis for a reliable and optimized design of bolted flange connections including strength and tightness proof.

In addition a test rig for high temperature leakage tests was developed which allows long term aging and thereafter load application in a press with the possibility of stress variation in order to determine $Q_{MIN(L)}$ and $Q_{SMIN(L)}$ values at high temperature and after long term aging.

8 REFERENCES

[1] BS 7531, 1991, Specification for compressed non-asbestos fibre jointing

[2] DIN 52913: 2002-04, Testing of static gaskets for flange connections - Compression creep testing of gasket made from sheets

[3] DIN 3535, Part 1 to 6, 1986-1999, Sealants for gas supply

[4] ASTM F36-87, 1987, Standard test method for compressibility and recovery of gasket materials

[5] DIN 28090: 1995-09, Static gaskets for flange connections
Part 1: Characteristic values and test procedures
Part 2: Gaskets made from sheets - Special test procedures for quality assurance
Part 3: Gaskets made from sheets - Chemical resistance test procedures

[6] Kockelmann, H. and Birembaut, Y., Asbestos-free Materials for Gaskets for Bolted Flanged Connections
Synthesis Report of the Brite Euram Project BE 5191 Focusing on Gasket Factors and Associated Gasket Testing Procedures, 4th Int. Symposium on Fluid Sealing of Static Gasketed Joints, September 17-19, 1996, Mandelieu-La Napoule, France

[7] EN 1591-1:2001 E, Flanges and their joints - Design rules for gasketed circular flange connections
Part 1: Calculation method
ENV 1591-2:2001 E, Flanges and their joints - Design rules for gasketed circular flange connections
Part 2: Gasket parameters

[8] EN 13555 Final Draft July 2004, Flanges and their joints – gasket parameters and test procedures relevant to the design rules for gasketed circular flange connections

[9] PERL, Pressure Equipments - Reduction of Leak rate: gasket parameters measurement, research project sponsored by the European Commision, 11/2000 - 10/2002

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Loading (MPa)	**Unloading to (MPa)**
10	-
20	10
40	20, 10
60	20, 10
80	40, 20, 10
100	40, 20, 10
120	-
140	-
160	40, 20, 10

Table 1: Leakage test at 40 bar (full stress level sequence, see Fig. 2)

Loading (MPa)	Unloading to (MPa)
10	-
20	-
40	-
60	-
80	-
100	-
120	-
140	-
160	40, 20, 10

Table 2: Leakage test at 10 and 80 bar
(reduced stress level sequence, see Fig. 3)

assembly gasket stress Q in MPa	tightness class L (mg / (s·m))				
	0.1	**0.01**	**0.001**	**0,0001**	**0,00001**
40	< 10[+)] (< 10[+)])	10 (< 10[+)])	-	-	-
60	< 10[+)] (< 10[+)])	< 10[+)] (10)	-	-	-
80	< 10[+)] (< 10[+)])	< 10[+)] (< 10[+)])	-	-	-
100	< 10[+)] (< 10[+)])	< 10[+)] (< 10[+)])	95 (80)	-	-
160	< 10[+)] (< 10[+)])	< 10[+)] (< 10[+)])	10[+)] (10[+)])	43 (26)	140 (86)

[+)] 10 MPa: lowest gasket stress during test

Table 3: Gasket characteristic Q_{SMIN} for a Graphite based sheet gasket (values in brackets: repeated test)

Manufacturer	**1**		**2**		**....**		**i**	
Test No	1	2	1	2	1	2	1	2
E_{G1},E_{G2}, E_{G3},E_{G4}								
Q_{SMAX}								
g_C								
$Q_{MIN(L)}$								
$Q_{SMIN(L)}$								
Mean values								
Mean (E_{G1}) Mean (E_{G2}) Mean (E_{G3}) Mean (E_{G4}) $\Rightarrow E_0$ & K_1								
Mean (Q_{SMAX})								
Mean (g_C)								
Mean (Q_{MIN})								
Mean (Q_{SMIN})								

Table 4: Gasket parameter values obtained per temperature

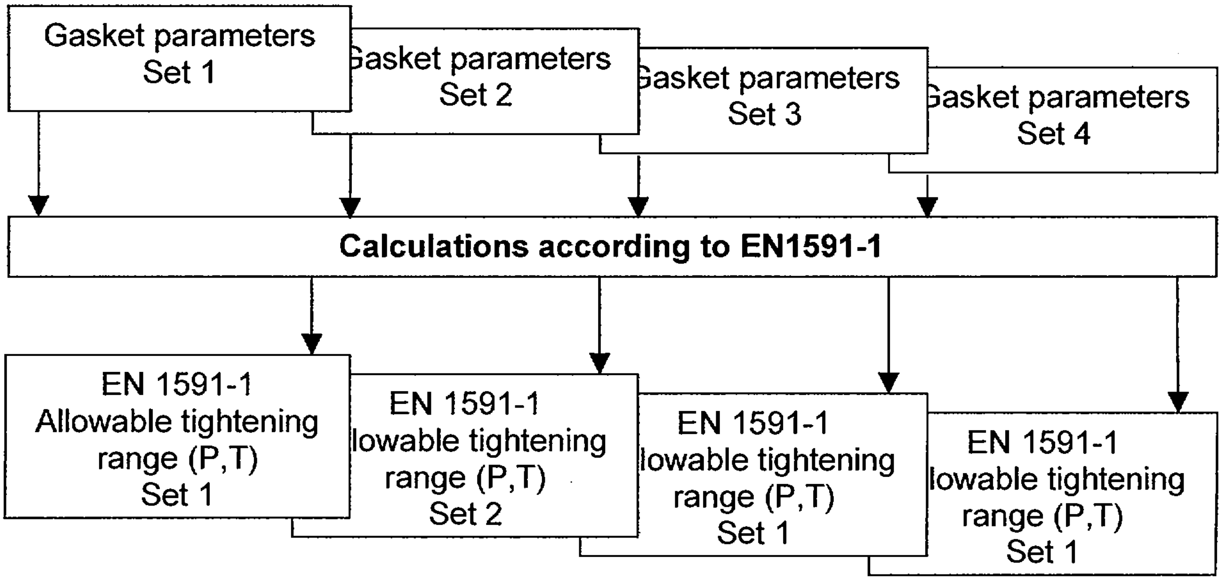

Table 5: Determination process of gasket parameters to be introduced in ENV 1591-2

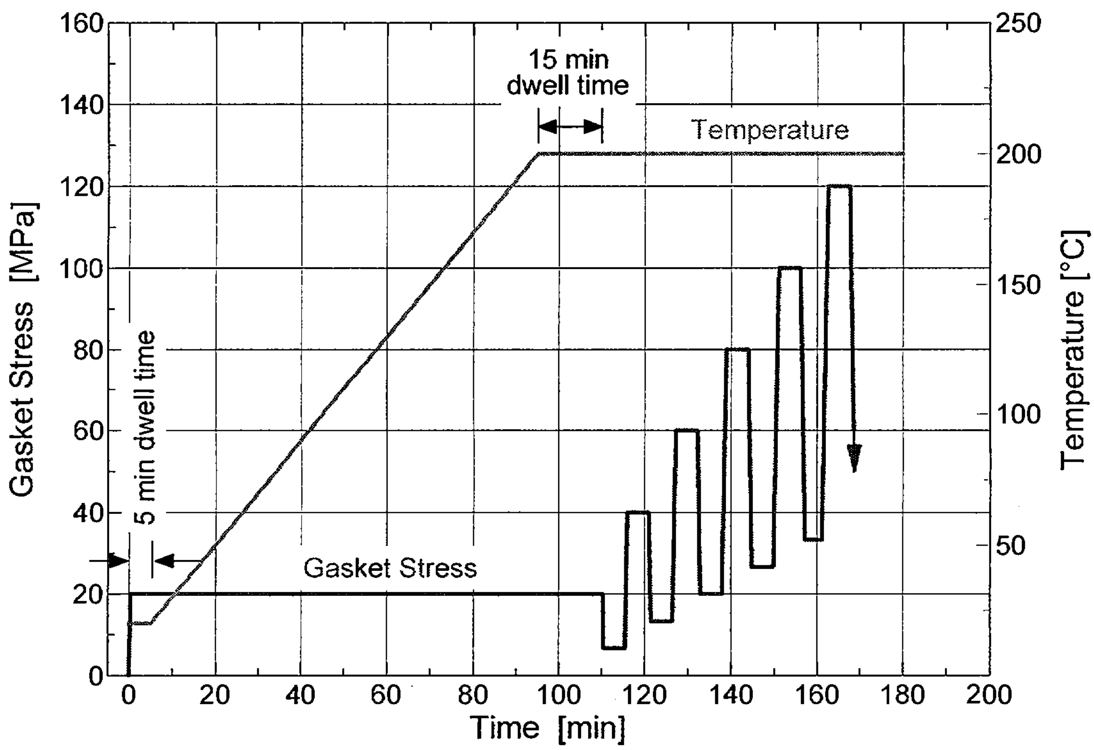

Fig. 1: Test procedure for the determination of Q_{SMAX} at elevated temperature

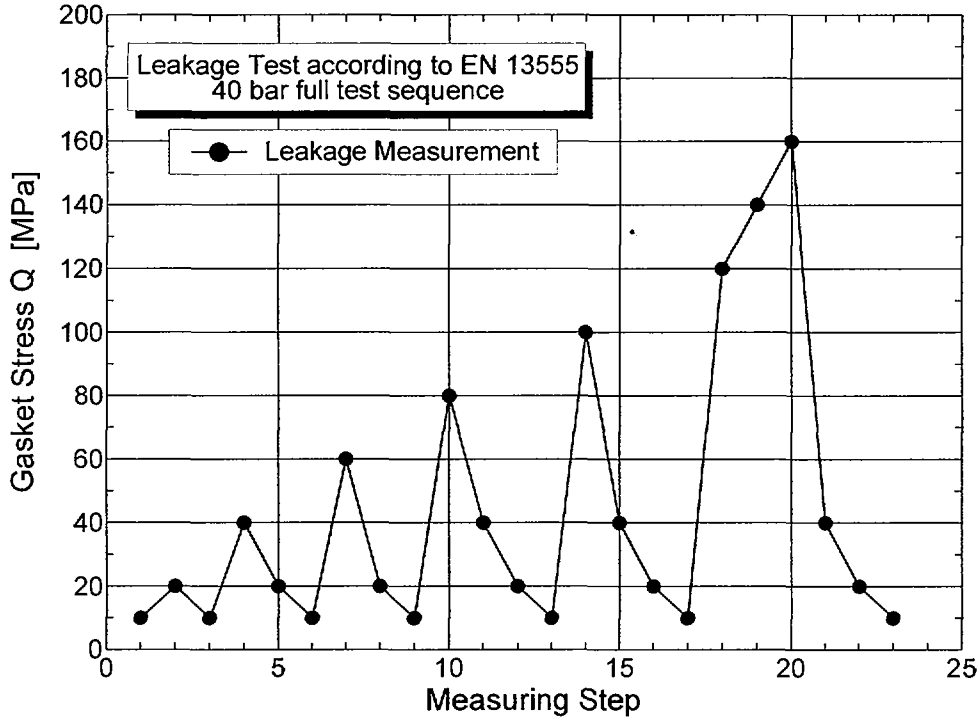

Fig. 2: Leakage test: full test sequencence

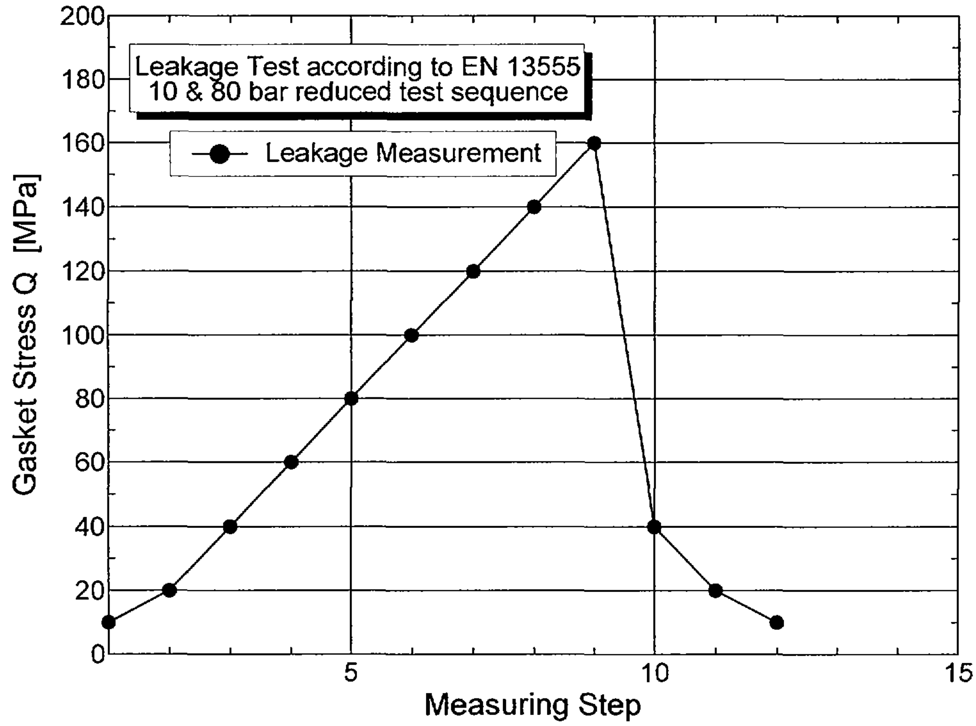

Fig. 3: Leakage test: reduced test sequencence

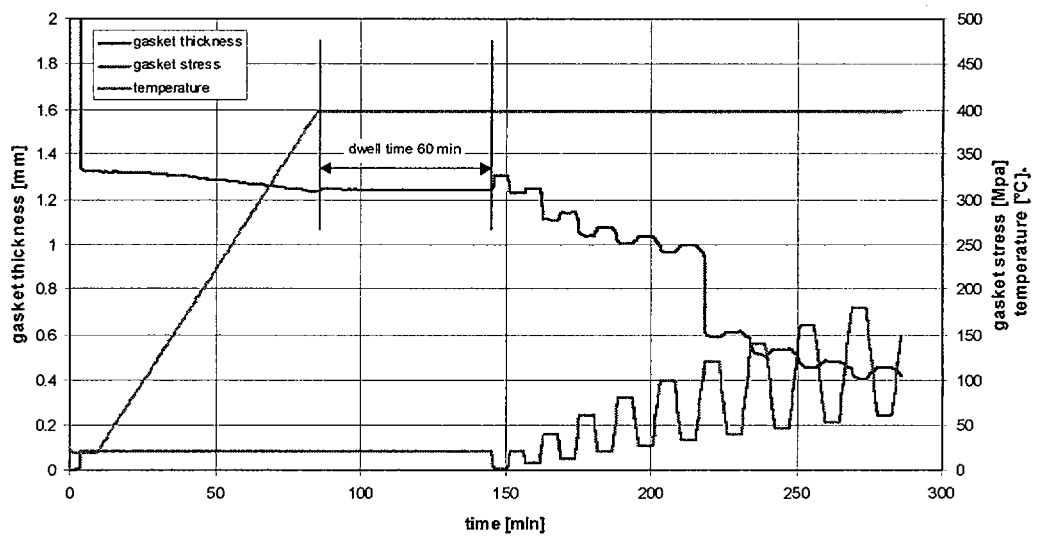

Fig. 4: Example of a test sequence to determine Q_{SMAX} for a Graphite based sheet gasket at 400 °C (gasket stress, gasket thickness, and temperature as a function of time)

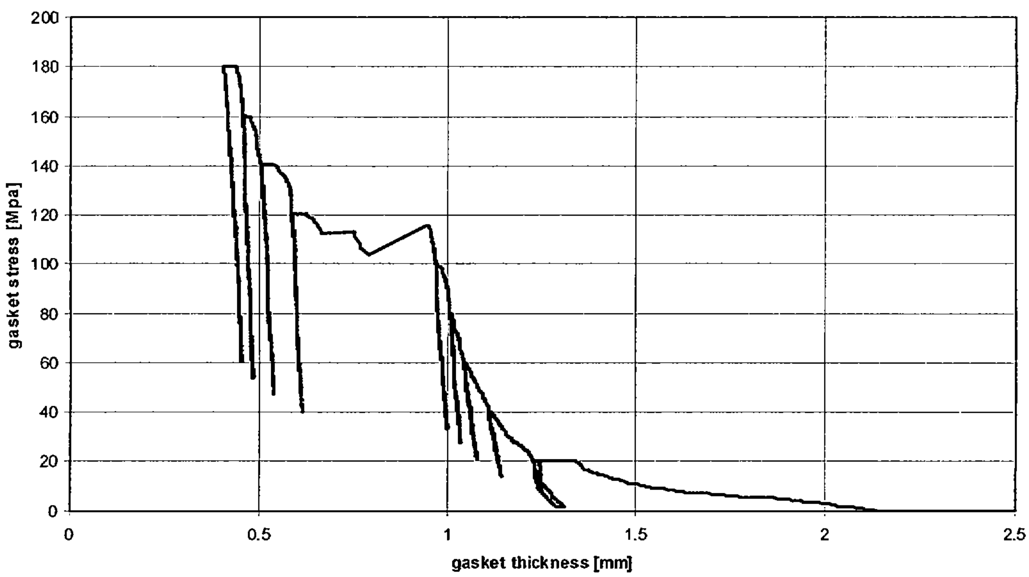

Fig. 5: Test result of a Q_{SMAX}-test on a Graphite based sheet gasket at 400 °C (gasket stress versus gasket thickness)

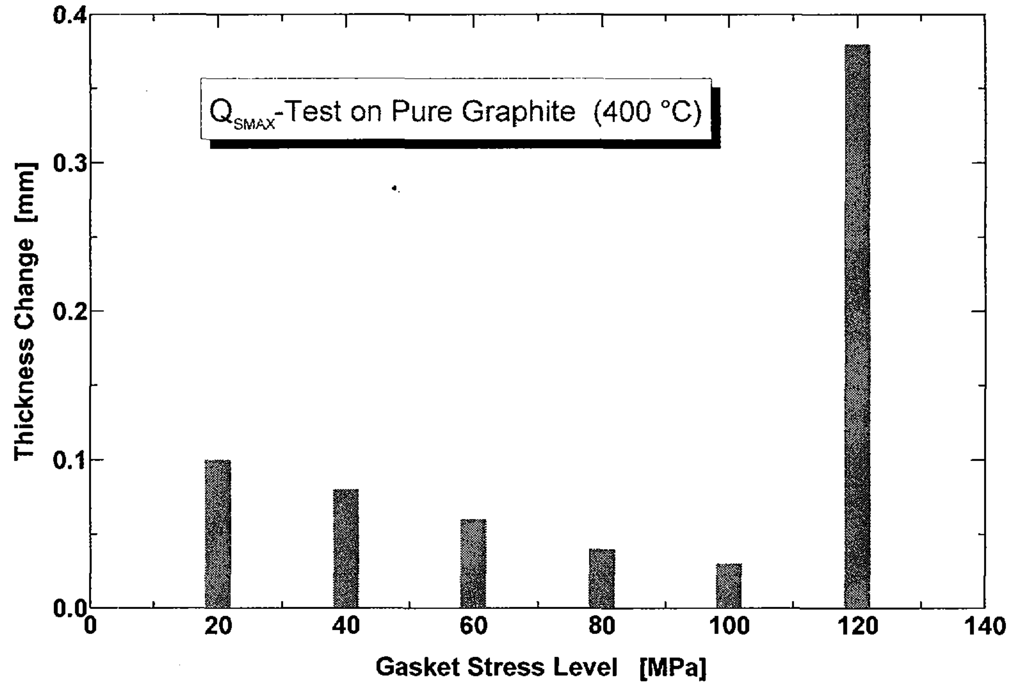

Fig. 6: Evaluation of a test to determine Q_{SMAX} for a Graphite based gasket at 400 °C

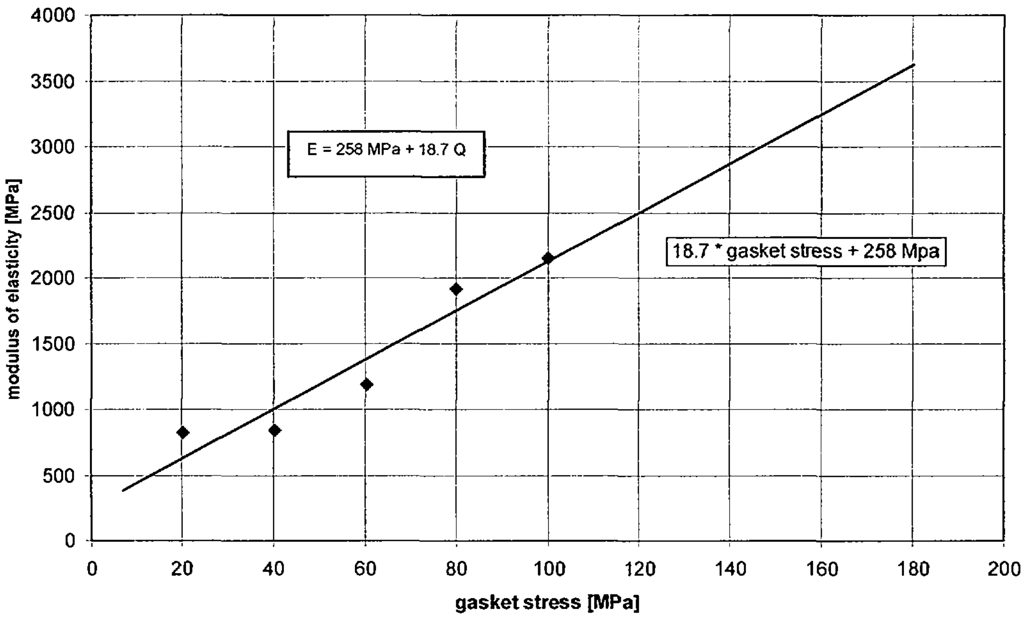

Fig. 7: Modulus of elasticity of a Graphite based sheet gasket at 400 °C

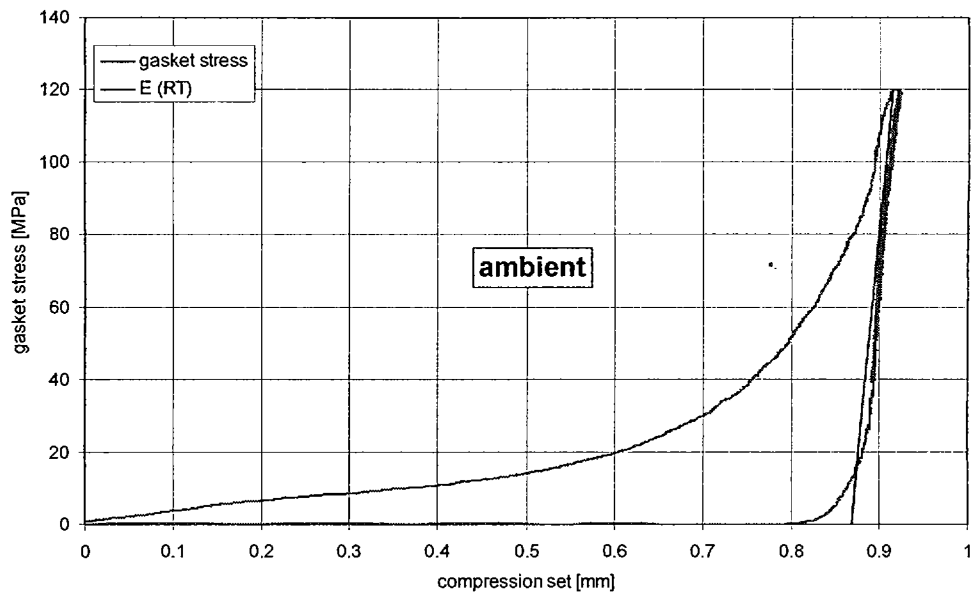

Fig. 8: Compression creep curve to determine g_C on a pure Graphite sheet gasket

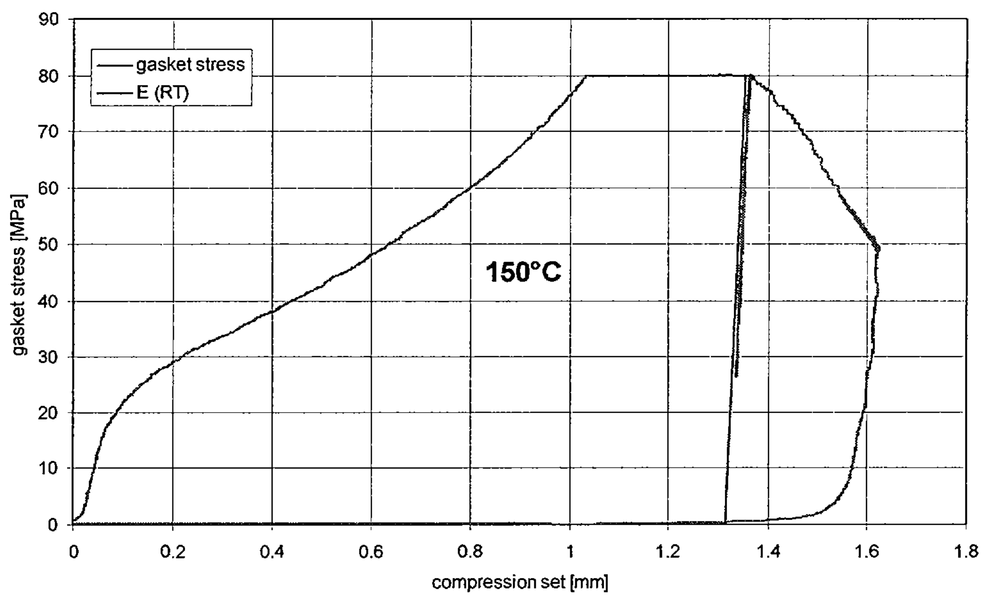

Fig. 9: Compression creep curve to determine g_C on a PTFE-based gasket

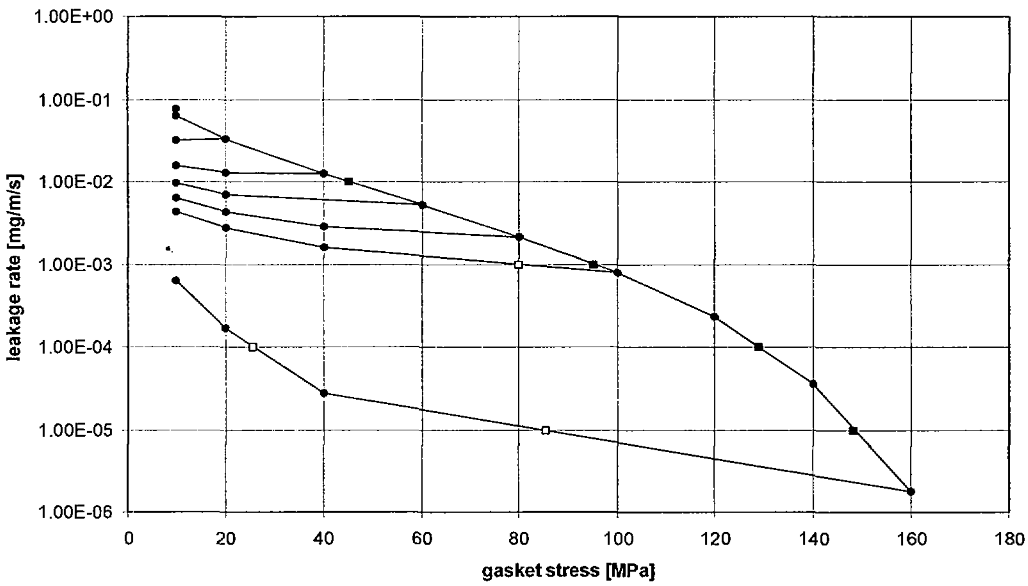

Fig. 10: Result and evaluation of the leakage test on a Graphite based sheet gasket (ambient temperature)

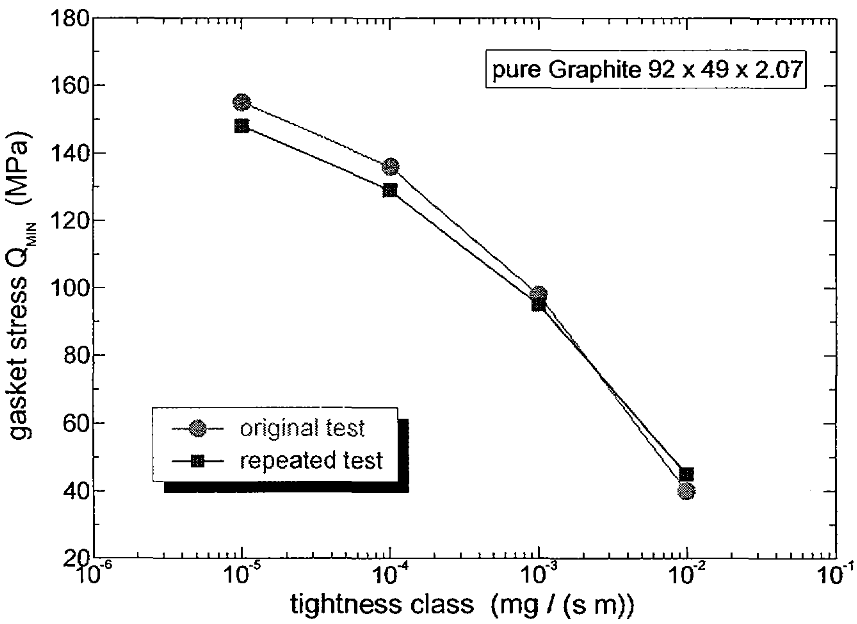

Fig. 11: $Q_{MIN(L)}$ of a Graphite based sheet gasket at ambient temperature