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Test Report

Customer:	Kukil Inntot Co., Ltd. 17 Tapgeol-gil, KOR - 689-871 Ulsan
Project number (amtec):	303 556
Report number:	303 556 1/b
Test procedure:	Shell Specification MESC SPE 85/300 (dated February 2016)
Material:	Steel Rubber Gasket K/# KSR-ES-H
Date:	March 21th, 2018
Pages:	16
Appendices:	38

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Test results are only relevant to the test objects submitted.

1. Subject of Investigation

The subject of investigation was a steel rubber gasket manufactured by Kukil Inntot Co., Ltd. which is named

- Steel Rubber Gasket K/# KSR-ES-H.

The steel rubber gasket is made of EPDM with a metal ring insert. An EPDM O-ring is placed at the inner diameter of the gasket.

2. Goal of Investigation

The goal of the investigation was the qualification of the gasket material Steel Rubber Gasket K/# KSR-ES-H in accordance to the Shell Specification MESC SPE 85/300 (dated February 2016: Procedure and Technical Specification for Type Acceptance Testing (TAT) of Gaskets).

The Shell Specification MESC SPE 85/300 describes several testing procedures for the evaluation of the gasket compressibility and the tightness characteristics of the gasket material at ambient and elevated temperature.

In this project different tests were performed in respect of the Shell approval:

- Shell leakage test at ambient temperature (MESC SPE 85/300 - 3.3.2),
- Shell leakage test at 85 °C (MESC SPE 85/300 - 3.3.2),
- Compression test at ambient temperature (MESC SPE 85/300 - 3.3.4: EN 13555),
- Compression test at 85 °C (MESC SPE 85/300 - 3.3.4: EN 13555),
- Relaxation test at ambient temperature (MESC SPE 85/300 - 3.3.4: EN 13555),
- Relaxation test at 85 °C (MESC SPE 85/300 - 3.3.4: EN 13555),
- Leakage test (MESC SPE 85/300 - 3.3.4: EN 13555),
- Shell cycle test at 85 °C (MESC SPE 85/300 - 3.3.5),
- Hot Blow Out test at 85 °C (MESC SPE 85/300 - 3.3.6),
- Aged Tensile Relaxation Screening at 85 °C (MESC SPE 85/300 - 3.3.7),
- Cold Compression / Hot Recovery Test (MESC SPE 85/300 - 3.3.11: ASTM F36-15) and
- Leak Test with nitrogen (MESC SPE 85/300 – 3.3.12: ASTM F37-06).

3. Test Specimens

The dimensions of the test specimens for the different tests were 4" Class 300 with OD = 177 mm and ID = 115 mm. The thickness of the gasket was 5.8 mm. The thickness of the covered metal ring was 4 mm.

The contact area of the gasket with the test platens is OD = 157.2 mm and ID = 115 mm.

Besides the following dimensions were tested without a metal insert:
- ATRS: 127 mm (5 inch) x 12.7 mm (0.5 inch),
- ASTM F36-15: 4 x ∅ 6.4 mm x 5.2 mm and
- ASTM F37-06: ∅ 43.9 mm x ∅ 33.6 mm x 5.2 mm

A visual examination of all test specimens was done prior and after testing. All test specimens are in accordance to the applicable design standard.

4. Testing Equipment

The gasket tests were carried out on the following testing equipment:

Multifunctional test rig TEMES$_{fl.ai1}$ No.: 010 181, 010 506 and 010 588
Gasket Testing Unit Klinger No.: 010 317
ATRS (Aged Tensile Relaxation Screening) fixture

Photos and the schematic view of the testing equipment TEMES$_{fl.ai1}$, ATRS fixture and of the gasket testing unit Klinger are shown in **appendices 1 to 3**.

4.1 Multifunctional Testing Equipment TEMES$_{fl.ai1}$

The servo-hydraulic press TEMES$_{fl.ai1}$ is capable to load up to 1 MN. Gaskets up to 180 mm diameter can be tested.

Depending on the type of test, different components (heating platens for temperatures up to 400 °C, insulation and cooling platens, 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 by three 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.

Also, the simulation of different flange stiffnesses can be realized within the equipment. In dependence on the gasket deformation the gasket surface pressure is reduced automatically according to the nominal stiffness.

Due to the modular design, the above test rig can be modified to perform leakage tests. The platens for compression tests are replaced by platens for leakage tests, which are connected to a separate measurement device, see appendix 1. The leak rate measurement principle is based on the pressure decay method. Using a differential pressure leak rates down to about 1.0 10^{-4} mg/m/s can be measured. For higher tightness classes a leak detector can be used.

5. Test Procedure

5.1 Fugitive Emission: Shell leakage test at ambient and elevated temperature (MESC SPE 85/300 - 3.3.2)

The Shell leakage test is carried out at ambient and at elevated temperature. For the tests at elevated temperature first the temperature is raised to the required test temperature under an initial gasket stress. Afterwards the gasket is compressed in steps of 10 MPa to a gasket stress of 80 MPa at ambient and 70 MPa at elevated temperature. After reaching the first gasket stress level the test volume is pressurised with 51 bar at ambient temperature and 46.6 bar at 85 °C according to ASME B16.5-2003 - PT-Rating for Group 1.1 Materials. For the leakage measurement helium is used as test medium.

The leak rate can be classified in tightness classes:

- Class A: ≤ $1.78 \cdot 10^{-9}$ Pa·m³/s/mm,
- Class B: ≤ $1.78 \cdot 10^{-8}$ Pa·m³/s/mm.

Shell TAT recommends a maximum gasket stress of 63.7 MPa, which is equivalent to a maximum bolt stress of 361 MPa. The leak rate of this gasket stress level is measured separately during the leakage test. The calculation of the gasket stress, which is calculated from the bolt stress, was done with an effective cross section area of 199 mm² per bolt referred to an OD of 157.2 mm and ID of 115 mm of the Elastomer flat gasket.

5.2 EN 13555 (MESC SPE 85/300 - 3.3.4)

According to the European Standard DIN EN 13555 (dated July 2014) the determination of the following gasket characteristics, which are necessary for the calculation according to DIN EN 1591-1 (dated April 2014), was done:

- Maximum allowable gasket stress Q_{smax} (RT, 85 °C),
- Modulus of elasticity E_G (RT, 85 °C),
- Creep relaxation factor P_{QR} (40 MPa – RT and 30 MPa - 85 °C),
- Change in gasket thickness due to creep Δe_{Gc} (40 MPa – RT and 30 MPa - 85 °C),
- Minimum required gasket stress in assembly $Q_{min(L)}$ (40 bar) and
- Minimum required gasket stress in service $Q_{smin(L)}$ (40 bar).

5.2.1 Compression test

The compression test can be carried out at ambient or at elevated temperature. For the tests at elevated temperature first the temperature of the gasket is raised to the required test temperature under an initial gasket stress. Then cyclic compression and recovery loadings on the gasket at progressively higher surface pressures are carried out until the gasket collapses or the maximum load of the test machine or the maximum gasket stress specified by the manufacturer is reached.

The gasket stress of the loading cycle prior to collapse is taken to be the maximum allowable gasket stress at ambient temperature Q_{smax}(RT) or the maximum allowable gasket stress at the test temperature Q_{smax}(T).

The unloading cycles of the Q_{smax} test allow the generation of values of the modulus of elasticity E_G. The E_G value is determined for each gasket stress level of the

different unloading cycles, the E_G value is also dependent on the test temperature level.

5.2.2 Creep relaxation test

The factor P_{QR} is the ratio of the residual and the initial gasket stress from a relaxation test. The deflection Δe_{Gc} is the change in gasket thickness due to creep.

The test is performed by using the stiffness simulated control mode. The load will be decreased according to the creeping of the gasket and the nominal set point for stiffness simulation. A stiffness of 500 kN/mm is typical for a PN designated flange and 1500 kN/mm for a Class designated flange. For this test the stiffness of the rig shall be 500, 1000 or 1500 kN/mm.

The test procedure consists of loading the test gasket until the initial load is applied. The loading is then held for 5 minutes. Then the temperature of the test rig is raised until the test temperature is reached and the temperature is held constant for a period of 4 hours. During the heating period and at elevated temperature the stiffness controlled mode of the equipment is activated. After the 4 hour period the remaining load after relaxation is noted and P_{QR}, the ratio of the residual load to the original load, and deflection Δe_{Gc} are calculated.

5.2.3 Leakage test

The leakage test procedure consists of loading and unloading the gasket in a cyclic manner with measurement of the leak rate at several effective gasket stress levels with an internal gas pressure of 40 bar.

The procedure therefore consists of loading to 5 MPa, holding the load and measuring the leak rate and then raising the gasket stress to 10 MPa. The load is then held whilst the leak rate is measured. In the next step the load is reduced to 5 MPa and the leak rate is measured. Then measurements are done for the next loading - unloading cycle at 20 MPa, 10 MPa, and 5 MPa and so on until either the 80 MPa loading - unloading cycle is completed or the value of Q_{smax} would have been exceeded.

The lowest gasket stress level is set to 5 MPa.

The test gas used for this test shall be helium.

From the generated leakage curve the minimum required gasket stress in assembly $Q_{min(L)}$ (40 bar) and the minimum required gasket stress in service $Q_{smin(L)}$ (40 bar) in dependence on the gasket surface pressure prior to the unloading Q_A can be evaluated for different tightness classes L.

5.3 HOTT: Shell cycle test at 85 °C (MESC SPE 85/300 – 3.3.5)

In the leakage test at elevated temperature the gasket is compressed with a maximum gasket stress of 30 MPa. After heating up to 85 °C the specimen was pressurized with 46.6 bar helium (in accordance to ASME B16.5-2003 - PT-Rating for Group 1.1 Materials), no load compensation of the internal pressure is done.

After one hour the test rig is cooled down to ambient temperature. The thermal cycle is repeated three times. During the last thermal cycle, the pressure loss shall not exceed 1 bar.

5.4 Hot Blow-Out test (HOBT1), (MESC SPE 85/300 – 3.3.6)

The HOBT1 test can be performed in a fixture joint (NPS 3 in., ASME class 150) or in a hydraulic test rig, in which the stiffness of the flange can be simulated. In the amtec lab the HOBT1 tests are carried out in hydraulic testing equipment.

The HOBT1 test procedure consists of different steps, which may be described as follows:

1. The gasket is compressed to the required gasket stress of 34.5 MPa (5000 psi).

2. The gasket is left undisturbed for 5 minutes before it is reloaded up to 34.5 MPa (5000 psi). During this period it creeps and relaxes according to the defined stiffness of the test rig.

3. The gasket is left undisturbed for 30 minutes before the test temperature 85 °C (482 °F) is applied with an increasing rate of 1.7 K/min (3 °F/min). During this period the gasket is therefore left to creep and relax according to the defined stiffness of the test rig (780 kN/mm / 4,400.00 lb/in).

4. After the 30 minutes waiting period, the specified helium pressure is applied to the test rig. Because of the increasing internal pressure, the gasket stress is decreasing. For most PTFE based materials, this may lead to the sudden blow-out of the gasket, in which case, the blow-out temperature, the actual internal pressure and the gasket stress are recorded.

For the elastomer flat gasket Steel Rubber Gasket K/# KSR-ES-H the following testing parameters were chosen:

- Initial gasket stress: 34.5 MPa,
- Test temperature: 85 °C,
- Maximum internal pressure: 70 bar.

5.5 Aged Tensile Relaxation Screening (MESC SPE 85/300 – 3.3.7)

The ATRS (aged tensile relaxation screen test) procedure is a screening test method. Its purpose is to assist manufacturer with product development and to assist end users in their tasks of evaluating claims and for screening the available gasket materials for the particular application being considered.

Two stacks (5 in. long x 0.5 in. wide) are placed carefully and aligned symmetrical to the bolt. The compressive load in the fixture is determined by measuring the stud elongations at room temperature. Pre- and post-aging specimen thicknesses are determined by measuring the depth of the guide pins.

The load is applied with a hydraulic tensioner. The load is maintained for 1 min to allow creeping of the material to occur more easily through the loading process. The maximum load of 25,000 lb is maintained by locking the fixture nuts. The actual stud bolt elongation is measured immediately after loading to determine the exact load. The loaded bolt length measurement is taken just after the completion of loading.

Pre- and post-aging compressive stress is calculated on the basis of a constant specimen area during the loading and aging process. The resulting change of area is not taken into account in the computation of the compressive stress because the ATRS procedure is only interested in the overall bolt load relaxation resulting from the effect of thermal exposure on the specimens.

After aging at 85 °C for 96 hours, the fixture is removed from the oven and cooled to room temperature. The remaining stud elongation and specimens total thickness are then measured.

5.6 Cold Compression/Hot Recovery Test (MESC SPE 85/300 – 3.3.11)

Three tests with a gasket material of type B according to ASTM F36-15 were performed.

The test specimen is centred upon the anvil and a preload is applied and maintained constant for 15 s. Within the next 10 s the major load is applied. After further 60 s the load is decreased again to the original preload.

The gasket thickness is measured at the end of each dwell time under preload, major load und preload again. From these measurements the compressibility and recovery are calculated.

The tests were performed with a test procedure according to Type B gasket material. The preload is defined to 4.4 N and the major load is defined to 356 N.

5.7 Leak Test with nitrogen (MESC SPE 85/300 – 3.3.12)

Three leak tests in accordance to ASTM F37-06 Test Method B with Nitrogen as test medium were performed.

The specimen was compressed at the beginning of the test in the testing equipment within 5 minutes to the gasket stress level. Afterwards the test volume is pressurized, the test pressure level is adjusted. After a dwell time of 2 minutes for the relaxation of the gasket and for the thermodynamic equilibrium condition, the leak rate is measured three time periods by the pressure drop method using a very sensitive differential pressure unit. The leak rate can be calculated from the change of pressure during the measuring period under consideration of the mean gasket circumference.

6. Results

All test results of the gasket material Steel Rubber Gasket K/# KSR-ES-H are summarized in **appendices 4 to 6**.

6.1 Fugitive Emission: Shell leakage test at ambient and elevated temperature (MESC SPE 85/300 - 3.3.2)

In the Shell leakage test at ambient temperature the gasket was compressed in 6 steps from 40 MPa to 80 MPa. The detected leak rate at 40 MPa gasket stress at an internal pressure of 51 bar was $1.5 \cdot 10^{-10}$ Pa·m³/s/mm, see **appendix 7**. The leak rate was nearly constant with increasing gasket stress. The leak rate at a gasket stress of 63.7 MPa, which is equivalent to a bolt stress of 361 MPa, was $1.4 \cdot 10^{-10}$ Pa·m³/s/mm, which is lower than the Tightness Class A.

For the maximum gasket surface stress of 80 MPa the leak rate was $1.7 \cdot 10^{-10}$ Pa·m³/s/mm, which is lower than the Tightness Class A.

In the Shell leakage test at 85 °C the gasket was compressed in 7 steps from 20 MPa to 70 MPa. The leak rate at 20 MPa gasket stress at an internal pressure of 46.6 bar was $1.6 \cdot 10^{-8}$ Pa·m³/s/mm, see appendix 7. The leak rate at a gasket stress of 30 MPa, which is equivalent to a bolt stress of 170 MPa, was $1.4 \cdot 10^{-8}$ Pa·m³/s/mm, which is a lower than the Tightness Class B.

For the maximum gasket surface stress of 70 MPa the leak rate was $5.4 \cdot 10^{-9}$ Pa·m³/s/mm, which is lower than the Tightness Class B.

6.2 EN 13555 (MESC SPE 85/300 - 3.3.4)

All tests according to EN 13555 with the material Steel Rubber Gasket K/# KSR-ES-H were performed twice; they are listed in appendices 4 and 5. All gasket characteristics which are necessary for the use of the flange calculation code EN 1591-1 are summarized in these tables.

6.2.1 Compression tests

In appendix 4 the results of the compression tests with loading and unloading cycles are given, the gasket characteristics are

- the maximum allowable gasket stress Q_{smax} (RT),
- the modulus of elasticity E_G (RT),
- the maximum allowable gasket stress Q_{smax} (85 °C) and
- the modulus of elasticity E_G (85 °C).

Compression tests were performed at ambient temperature and at elevated temperature at 85 °C. According to EN 13555 loading and unloading cycles were carried out to determine the deformation behaviour of the gasket material. The compression curves and the corresponding graphs of the modules of elasticity for the different test temperature levels are shown in **appendices 8 to 11.**

In both compression tests at ambient temperature no collapse of the gasket specimens can be recognized until the maximum load of 100 MPa is reached. In the diagrams of the modules of elasticity a big increase of the modulus of elasticity E_G could be recognized from 80 MPa to 100 MPa gasket stress. The gaskets were not damaged after the tests.

The maximum allowable gasket stress Q_{smax} at RT is set to 100 MPa.

In the first compression test at 85 °C a big compression of the gasket could be recognized at a stress level of 40 MPa. Also in the diagram of the modules of elasticity a big increase of the modulus of elasticity E_G could be recognized at this stress level. The gasket was damaged after the first test.

In the second compression tests at 85 °C the maximum gasket stress was set to 30 MPa. In this compression test no collapse of the gasket specimen could be recognized. The gasket was not damaged after the test

After a verification of the maximum allowable gasket stress Q_{smax} with further creep relaxation tests, see next chapter, the maximum allowable gasket stress Q_{smax} at 85 °C is set to 30 MPa.

The modulus of elasticity E_G at ambient temperature is nearly constant with increasing gasket stress. For the tests at 85 °C the modulus of elasticity E_G increases nearly linear with increasing gasket stress.

6.2.2 Creep relaxation tests

In appendix 3 the gasket characteristics of the creep relaxation tests for two gasket stresses, two temperatures and one stiffness levels are listed:

- creep relaxation factor P_{QR} (40 MPa, RT, 500 kN/mm) and
- creep relaxation factor P_{QR} (30 MPa, 85 °C, 500 kN/mm).

In total 4 creep relaxation tests were performed. The initial gasket stress level was set to 40 MPa at RT and 30 MPa at 85 °C. For the stiffness the typical value for a PN designated flange (500 kN/mm) was chosen.

The results of all creep relaxation tests are given in **appendices 12 to 15**. The creep relaxation factors P_{QR} are 0.92 resp. 0.93 (40 MPa, RT, 500 kN/mm) and 0.68 resp. 0.53 (30 MPa, 85 °C, 500 kN/mm). The deflection Δe_{Gc} of the gasket Steel Rubber Gasket K/# KSR-ES-H at RT is 58 µm resp. 46 µm and in tests at 85 °C is 168 µm resp. 253 µm.

There is a big variation within the double tests at elevated temperature measureable.

To verify the maximum allowable gasket stress Q_{smax} at elevated temperature further creep relaxation tests at certain temperature and stress levels have been performed. The results of these creep relaxation tests are given in **appendices 16 and 17.**

In the first test the initial gasket stress level was set to 40 MPa at 100 °C. The gasket was damaged after the test.

In the second test the temperature was reduced to 85 °C at an initial gasket stress level of 40 MPa. Cracks could be recognized at the gasket after the test.

After that the initial gasket stress was reduced to 30 MPa at 85 °C. In both tests, see appendices 14 and 15, no damage of the gasket specimen occured and the maximum allowable gasket stress Q_{smax} at 85 °C was verified to 30 MPa.

6.2.3 Leakage tests

The tightness behaviour of the gasket material Steel Rubber Gasket K/# KSR-ES-H was examined in two leakage tests at 40 bar helium. In appendix 5 the determined gasket characteristics

- minimum required gasket stress in assembly $Q_{min(L)}$ and
- minimum required gasket stress in service $Q_{smin(L)}$ in dependence on the gasket surface pressure prior to the unloading Q_A

are listed for both tests in dependence on the tightness class L.

For the determination of the leak rate two different measurement devices were used in parallel. The pressure drop method with a differential pressure was used for the leak tightness evaluation for leak rates higher than $1.0 \cdot 10^{-3}$ mg/m/s, for lower leak rates the signal of the helium leak detector was taken for the calculation of the leak rate.

The graphical presentation of the leakage curves are shown in **appendix 18**. The tightness class $L_{0.01}$ was reached when the gasket stress raised above 5 MPa. Therefore the minimum gasket stress in assembly for the tightness class $L_{0.01}$ is set to $Q_{min(0.01)}$ = 5 MPa. The lowest tightness class which could be reached was $L_{0.000001}$; therefore a gasket stress of 30 MPa in test 17-703 is necessary.

A very low leak rate could be measured at a low gasket stress level. The leak rate stays nearly constant at a very low level with an increasing gasket stress up to 80 MPa. The lowest leak rate which could be measured was $5.5 \cdot 10^{-7}$ mg/m/s at 60 MPa in test 17-703.

During the unloading cycles the leak rate is stable. In all unloading curves no drastic increase of the leak rate (or sudden blow-out) is observed.

The minimum gasket stress in service for the tightness class $L_{0.01}$ for an initial gasket surface pressure Q_A of 60 MPa is $Q_{smin(0.01)}$ = 5 MPa in both tests.

6.3 HOTT: Shell cycle test at 85 °C (MESC SPE 85/300 – 3.3.5)

For the Shell cycle test at elevated temperature the steel rubber gasket was compressed initially with 30 MPa. After heating up to 85 °C, the specimen was pressurized with 46.6 bar helium. During the thermal cycles in the leakage test at 85 °C no pressure drop could be measured, see **appendix 19**.

During the last thermal cycle the pressure loss is less than 0.1 bar. The gasket material Steel Rubber Gasket K/# KSR-ES-H has passed the Shell requirement of a pressure drop less than 1 bar.

The gasket does not stick on the flange after the HOTT test. The gasket adhesion at maximum design temperature of 85 °C for over one hour could be considered as acceptable.

6.4 Hot Blow-Out test (HOBT1) - (MESC SPE 85/300 – 3.3.6)

One Hot Blow-Out test with the material Steel Rubber Gasket K/# KSR-ES-H has been carried out for the measure of its margin of safety against Blow-Out.

In **appendices 20 and 21** the results and the diagrams of the HOBT test of Steel Rubber Gasket K/# KSR-ES-H are shown.

During heating up to 85 °C the gasket stress decreases. During the 1st pressurization with Helium to 46.6 bar the gasket stress decreases to 20 MPa. With a maximum pressure of 70 bar and a dwell time of 2 x 15 minutes no blow out could be recognized.

The gasket material Steel Rubber Gasket K/# KSR-ES-H has passed the Hot Blow-Out test at a temperature of 85 °C with an initial gasket stress of 34.5 MPa and an internal pressure of 70 bar.

6.5 Aged Tensile Relaxation Screening (MESC SPE 85/300 – 3.3.7)

Following the defined test procedure, the specimens were placed between the test platens, the initial gasket thickness was measured after assembly and the compressive stress was applied to 4.351 psi with a hydraulic tensioner. Afterwards the nut was fixed and the initial bolt load and the gasket thickness after loading were measured. One layer of gasket specimen were used on each stack.

The samples were put in an electrical oven for 96 hours at 185 F resp. 85 °C. After cooling down to ambient temperature, the remaining gasket stress and the gasket thickness after aging were measured.

One test of the material Steel Rubber Gasket K/# KSR-ES-H was performed. In **appendix 22** all results of the test are listed.

The gasket deflection during loading is 3.18 mm. The gasket deflection after aging is 3.50 mm. The creep relaxation factor determined from the division of the initial load by the remaining load is 80.8%.

The gasket material Steel Rubber Gasket K/# KSR-ES-H has **passed** the Shell requirement of a higher quality parameter $Q_p > 1$.

6.6 Cold Compression / Hot Recovery Test (MESC SPE 85/300 – 3.3.11)

In **appendix 23** the results of the compressibility and recovery tests are listed. Three tests of the material Steel Rubber Gasket K/# KSR-ES-H were performed.

For the test procedure according to Type B gasket material the average compressibility of the gasket sheet Steel Rubber Gasket K/# KSR-ES-H in three tests, between preload and major load, is 37.4%, the average recovery between major load and unloading to the preload is 97.1%.

6.7 Leak Test with nitrogen (MESC SPE 85/300 – 3.3.12)

In **appendix 24** the results of the leak tests according to ASTM F37-06 are listed. Three tests of the material Steel Rubber Gasket K/# KSR-ES-H were performed.

The gasket stress level was set to 20.7 MPa (3,000 psi) and the internal pressure to 2 bar (29 psi).

In all tests the leak rate was measured three times at ambient temperature. The time period for recording one leak rate depending on the test sample was maximal 3 hours. The gasket were such tight, that the leak rate after 3 hours of measuring could not be determined. The leak rate was set to a dummy value of 0.0035 ml/h for each test.

The average leak rate of the tests was calculated to 0.0035 ml/h.

6.8 Gasket adhesion (MESC SPE 85/300 – 3.3.13)

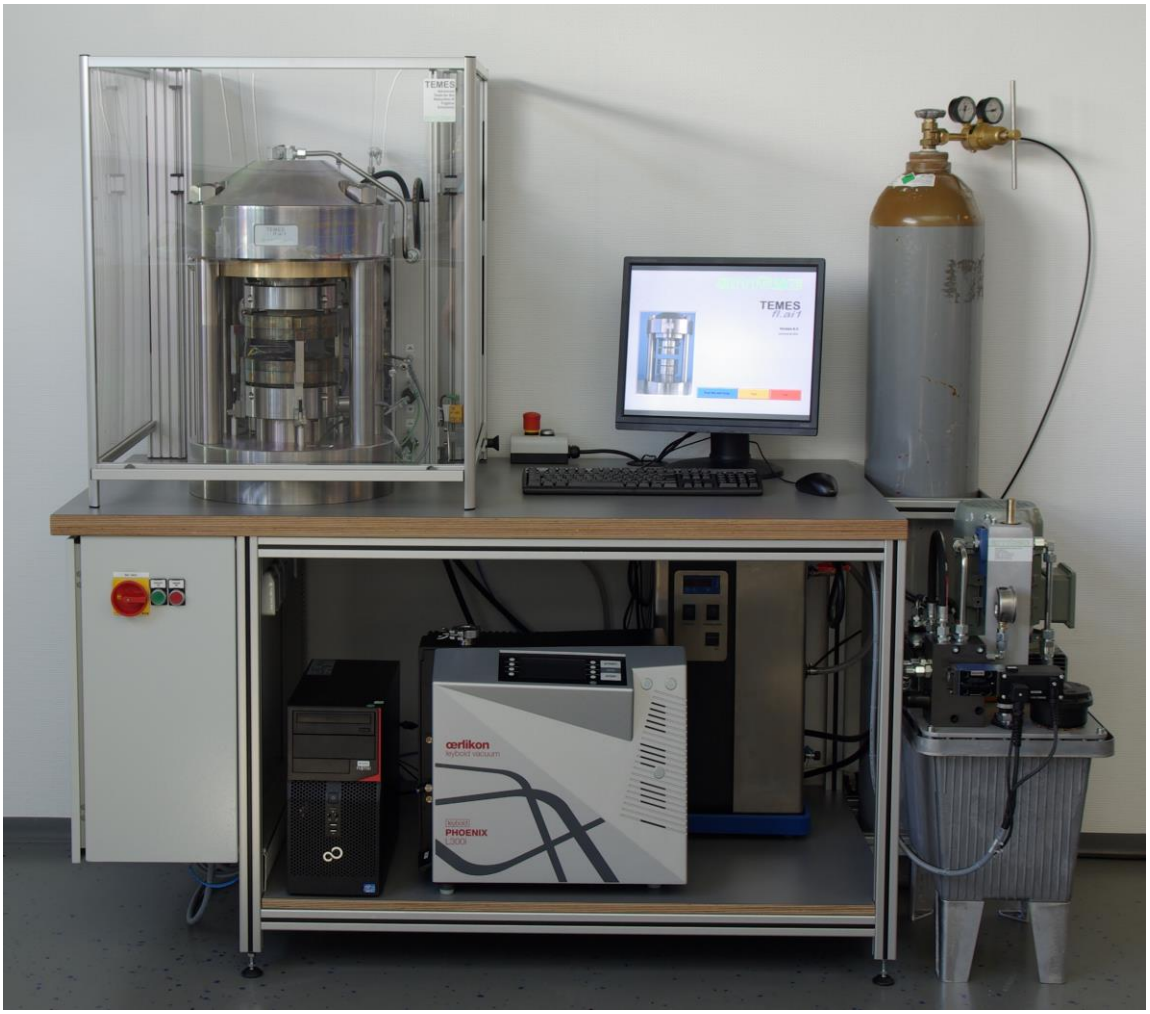
In **appendix 25** photos of the adjacent flanges after tests at ambient temperature with the gasket specimen's Steel Rubber Gasket K/# KSR-ES-H are represented. The gasket does not stick on the flange.

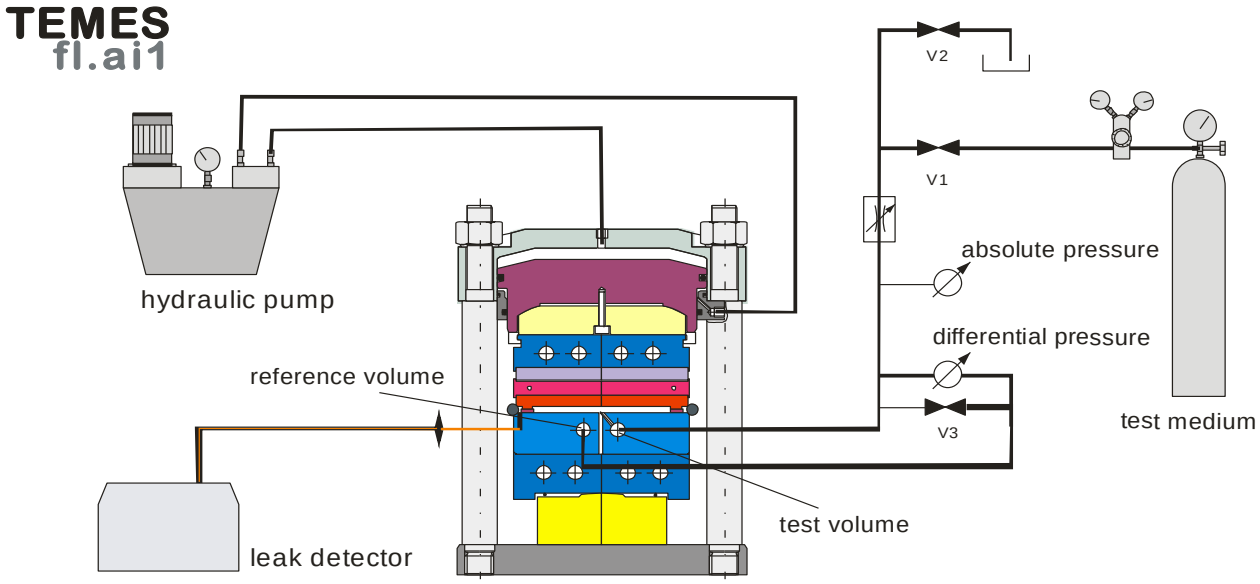
The gasket adhesion could be considered as acceptable.

7. Photo documentation

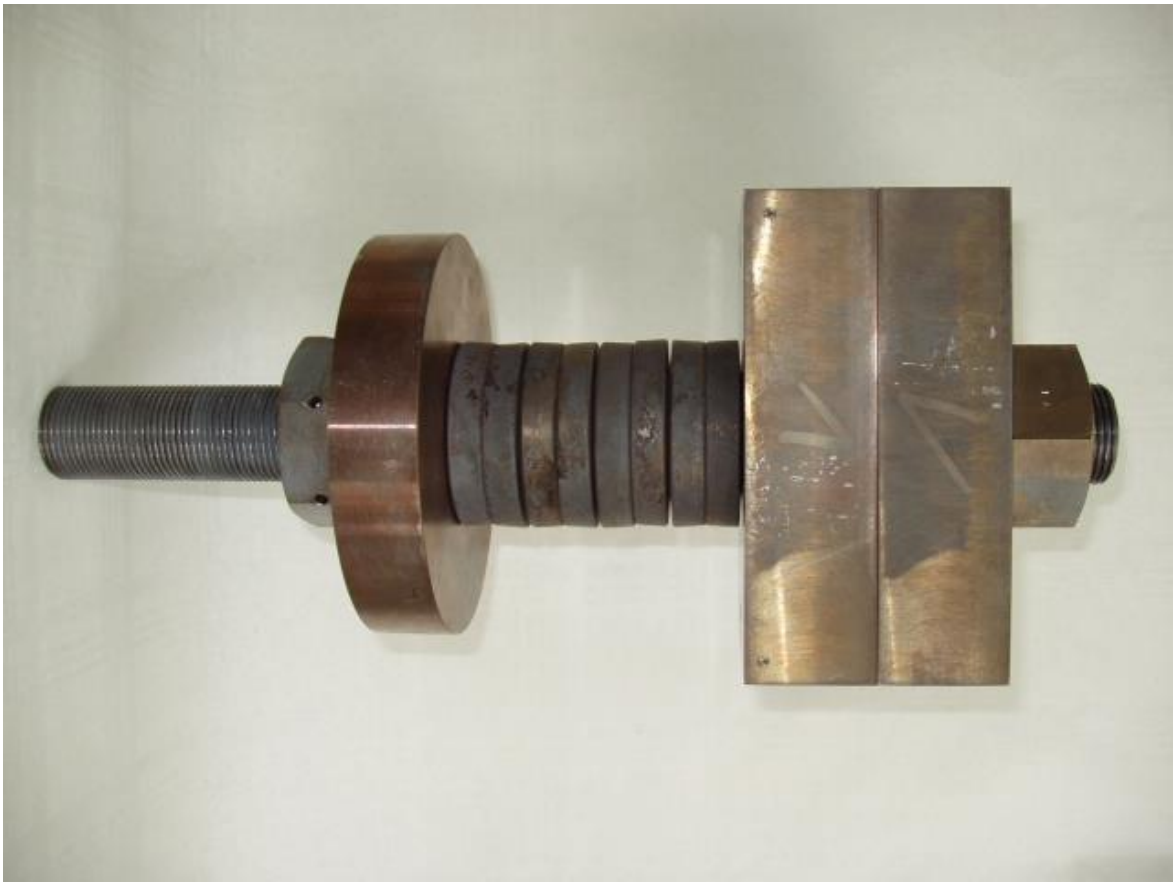
In **appendices 26 to 38** photos of the tested gasket specimen's Steel Rubber Gasket K/# KSR-ES-H for the different test procedures are presented.

Gasket Specimens 17-722, 17-716, 17-706 and 17-708 showed cracks and were damaged after the test.





Testing Equipment TEMES*fl.ai1* (1000 kN)



ATRS (Aged Tensile Relaxation Screening) fixture

Testing Equipment KLINGER Dichtungstechnik

Table 1: Data Sheet for Gasket Characteristics (EN 13555)

Manufacturer: Kukil Inntot Co., Ltd.

Product: **Steel Rubber Gasket K/# KSR-ES-H**

Maximum allowable Gasket Stress Q_{smax} [MPa]

T [°C]	25	25	85	85
Q_{smax} [MPa]	100	100	30	30
Test #	17-710	17-712	17-716	17-718

Modulus of Elasticity E_G [MPa]

T [°C] / Q [MPa]	25		25		85		85	
	E_G [MPa]	e_G [mm]	E_G [MPa]	e_G [mm]	E_G [MPa]	e_G [mm]	E_G [MPa]	e_G [mm]
0		5.710		5.780		5.780		5.750
1		3.870		3.962		3.900		3.924
5	328	3.576	-	-	205	3.552	192	3.567
10	1486	3.451	-	-	586	3.385	610	3.404
20	9797	3.320	8891	3.348	2084	3.154	2001	3.182
30	10958	3.237	9559	3.253	5129	2.825	3856	2.954
40	9185	3.169	8250	3.185	-	-	-	-
50	8841	3.109	7608	3.132	-	-	-	-
60	9149	3.045	7299	3.086	-	-	-	-
80	11694	2.921	12834	2.939	-	-	-	-
100	49217	2.734	26438	2.738	-	-	-	-
Test #	17-710		17-712		17-716		17-718	

Creep-/Relaxation Factor P_{QR} [-]

Change in gasket thickness due to creep Δe_{GC} [µm]

	T [°C] / Q [MPa]	25	25	85	85
C = 500 kN/mm	30			0.68	0.53
	Δe_{GC} [µm]			168	253
	Test #			17-713	17-720
	40	0.92	0.93		
	Δe_{GC} [µm]	58	46		
	Test #	17-700	17-702		

Table 2: Data Sheet for Gasket Characteristics (EN 13555)

Manufacturer: Kukil Inntot Co., Ltd.

Product: **Steel Rubber Gasket K/# KSR-ES-H**

Minimum required Gasket Stress in Assembly $Q_{min(L)}$ [MPa]

L / p [bar]	10	1	0.1	0.01	0.001	0.0001	0.00001	1.00E-06	1.00E-07
40	5	5	5	5	5	6	8	30	-
Test #	17-703								
40	5	5	5	5	5	5	5	-	-
Test #	17-709								

Minimum required Gasket Stress in Operation $Q_{smin(L)}$ [MPa]

p = 40 bar	L / Q_A [MPa]	10	1	0.1	0.01	0.001	0.0001	0.00001	1.00E-06	1.00E-07
	10	5	5	5	5	5	5	5	-	-
	20	5	5	5	5	5	5	5	-	-
	40	5	5	5	5	5	5	5	5	-
	60	5	5	5	5	5	5	5	5	-
	80	5	5	5	5	5	5	5	5	-
	Test #	17-703								

Minimum required Gasket Stress in Operation $Q_{smin(L)}$ [MPa]

p = 40 bar	L / Q_A [MPa]	10	1	0.1	0.01	0.001	0.0001	0.00001	1.00E-06	1.00E-07
	10	5	5	5	5	5	5	5	-	-
	20	5	5	5	5	5	5	5	-	-
	40	5	5	5	5	5	5	5	-	-
	60	5	5	5	5	5	5	5	-	-
	80	5	5	5	5	5	5	5	-	-
	Test #	17-709								

Table 3: Data Sheet for Gasket Characteristics (Shell)

Manufacturer: Kukil Inntot Co., Ltd.

Product: **Steel Rubber Gasket K/# KSR-ES-H**

Shell leakage test at ambient temperature

Test pressure:	51	bar
Shell required gasket stress level:	63.7	MPa
Leakage rate:	1.44E-10	Pa·m³/s/mm
Shell tightness class:	A	
test no.	17-714	

Shell leakage test at 85 °C

Test pressure:	46.6	bar
Shell required gasket stress level:	30	MPa
Leakage rate:	1.37E-08	Pa·m³/s/mm
Shell tightness class:	B	
test no.	17-722	

Shell cycle test at 85 °C

Test pressure:	46.6	bar
Initial gasket stress level:	30	MPa
Pressure drop in last cycle:	no	
Requirements:	passed	
test no.	17-732	

Hot Blow-Out test (HOBT1)

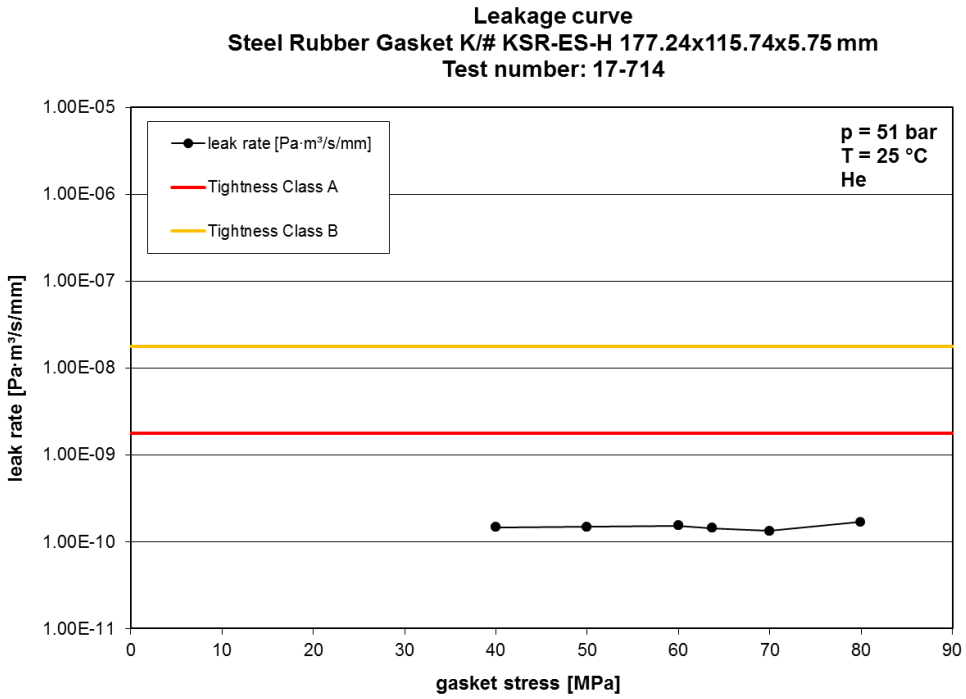
Test pressure:	70	bar
Gasket stress level:	34.5	MPa
Temperature:	85	°C
Requirements:	passed	
test no.	17-753	

Cold Compression / Hot Recovery Test
ASTM F36-15

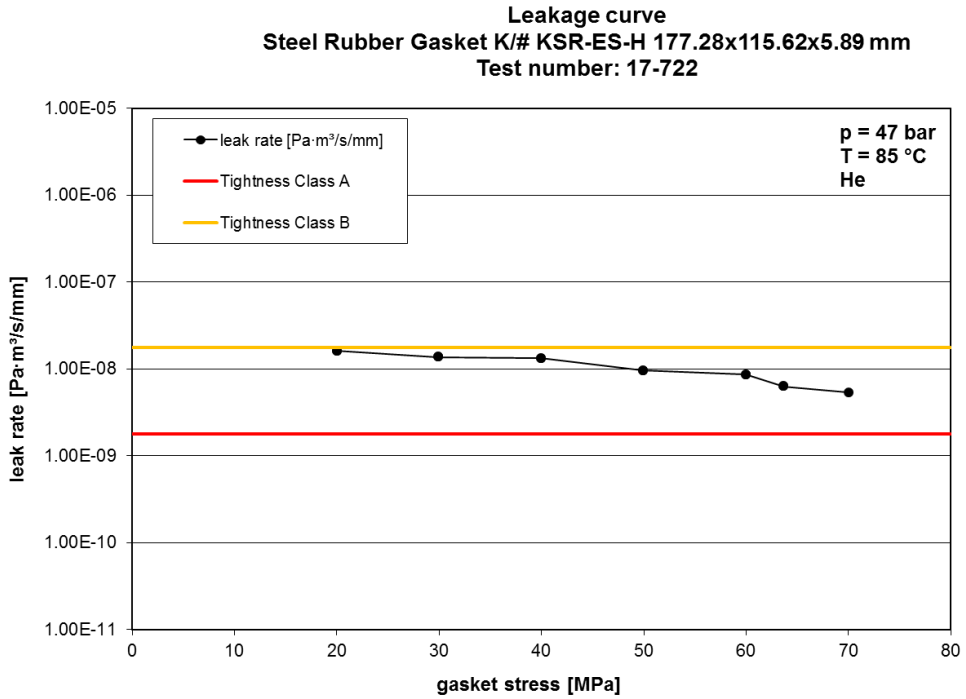
Initial gasket stress level:	2.76	bar
Compressibility (average):	37.4	%
Recovery (average):	97.1	%
Requirements:	passed	
test no.	17-737 // 17-738 // 17-739	

Leak Test with nitrogen
ASTM F37-06

Test pressure:	2	bar
Initial gasket stress level:	20.1	MPa
Leak rate (average):	0.004	ml/h
Requirements:	passed	
test no.	17-699 // 17-701 // 17-707	

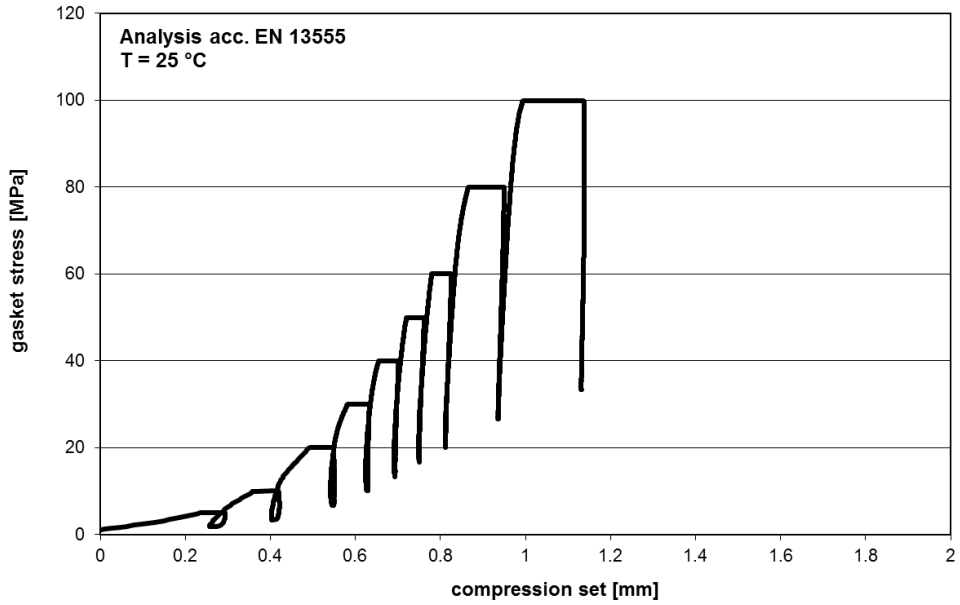


Shell leakage test (RT) according MESC SPE 85/300 - 3.3.2

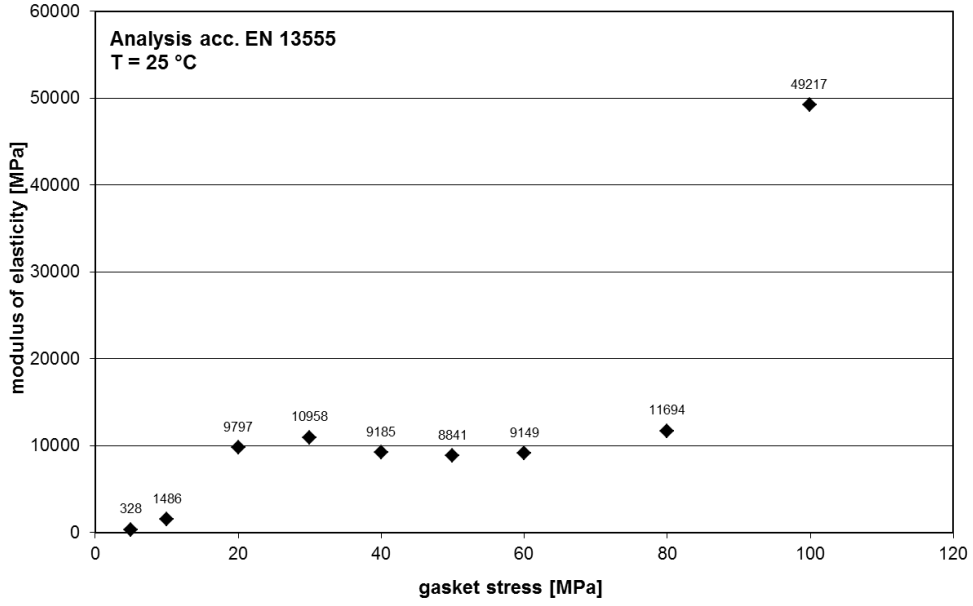


Shell leakage test (85 °C) according MESC SPE 85/300 - 3.3.2

Compression curve
Steel Rubber Gasket K/# KSR-ES-H 177.32x115.93x3.87 mm
Test number: 17-710

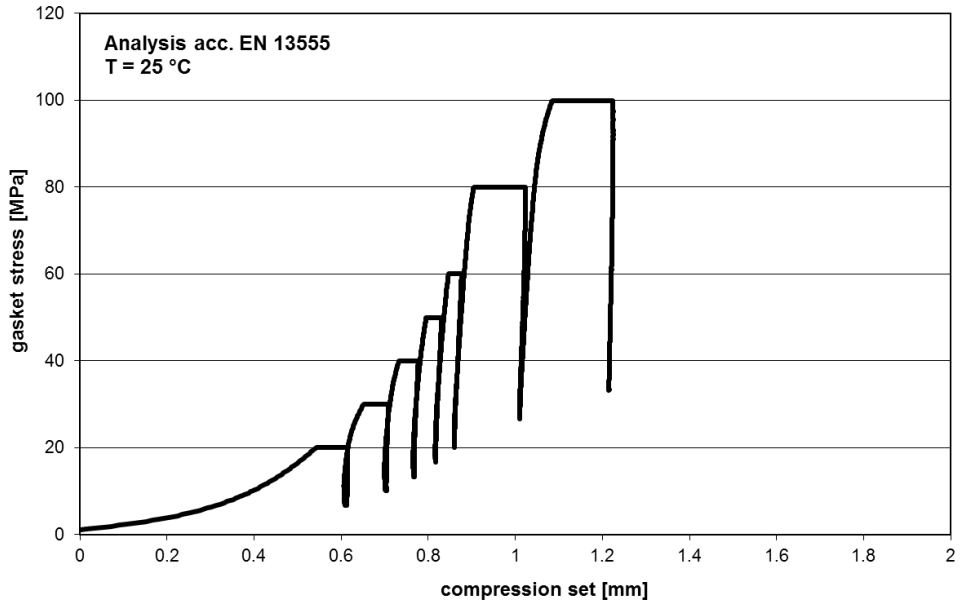


Modulus of elasticity
Steel Rubber Gasket K/# KSR-ES-H 177.32x115.93x3.87 mm
Test number: 17-710

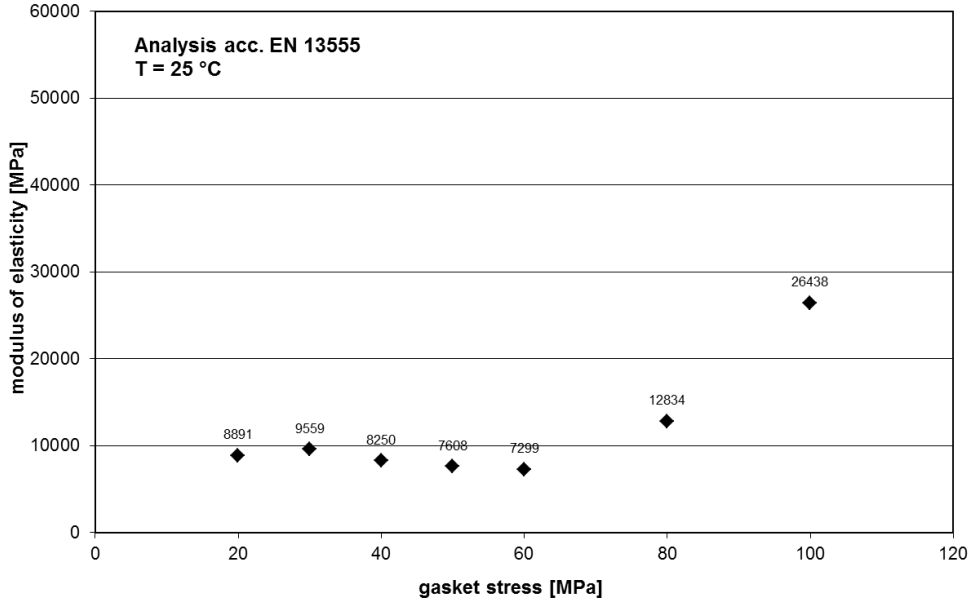


Compression test (RT) according EN 13555

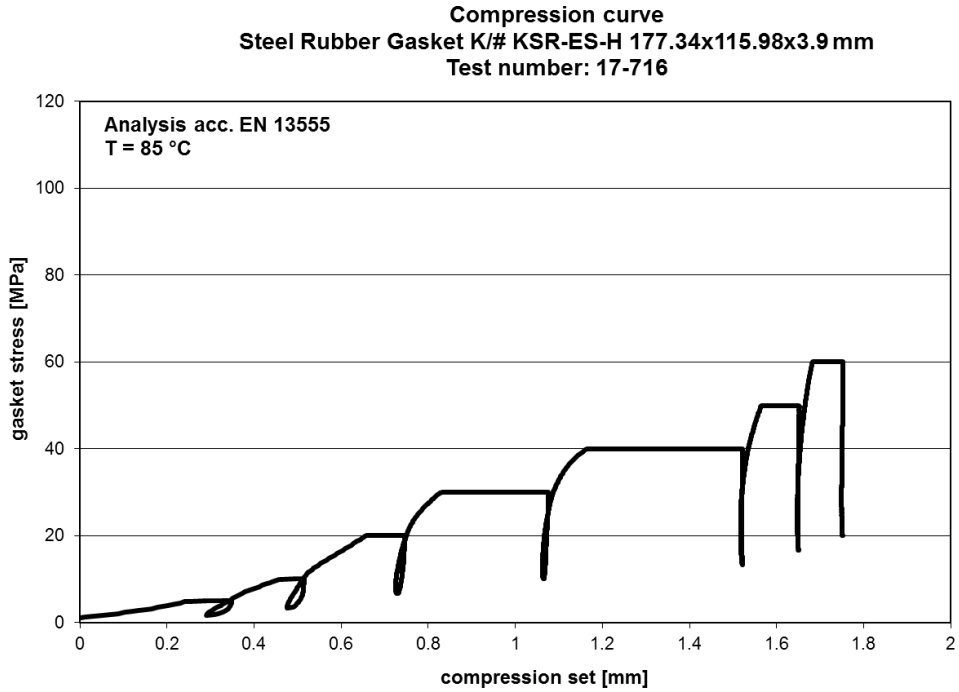
Compression curve
Steel Rubber Gasket K/# KSR-ES-H 177.1x115.67x3.962 mm
Test number: 17-712

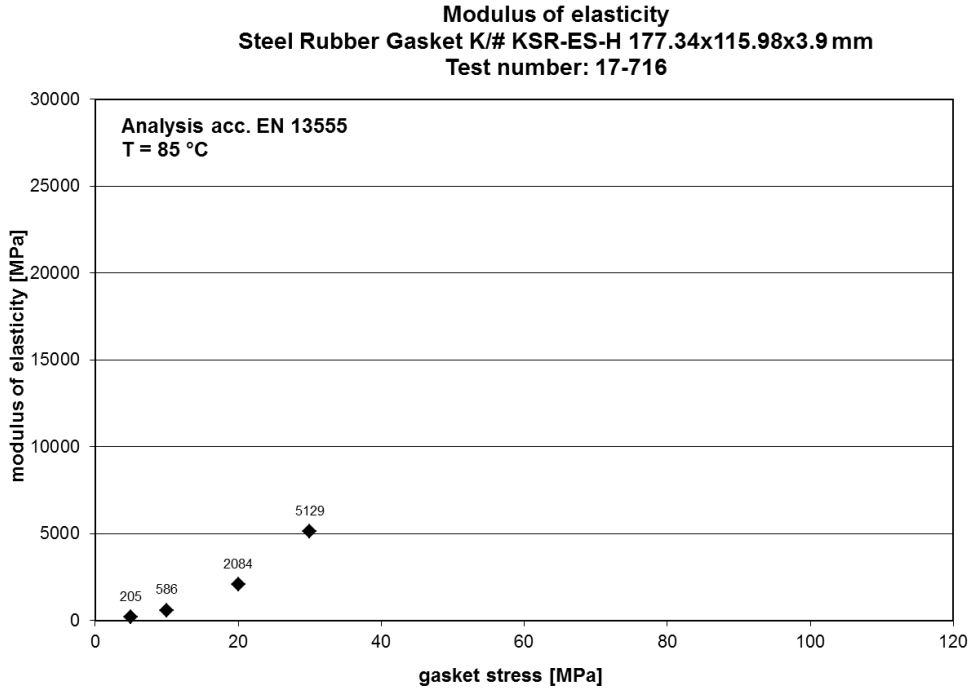


Modulus of elasticity
Steel Rubber Gasket K/# KSR-ES-H 177.1x115.67x3.962 mm
Test number: 17-712

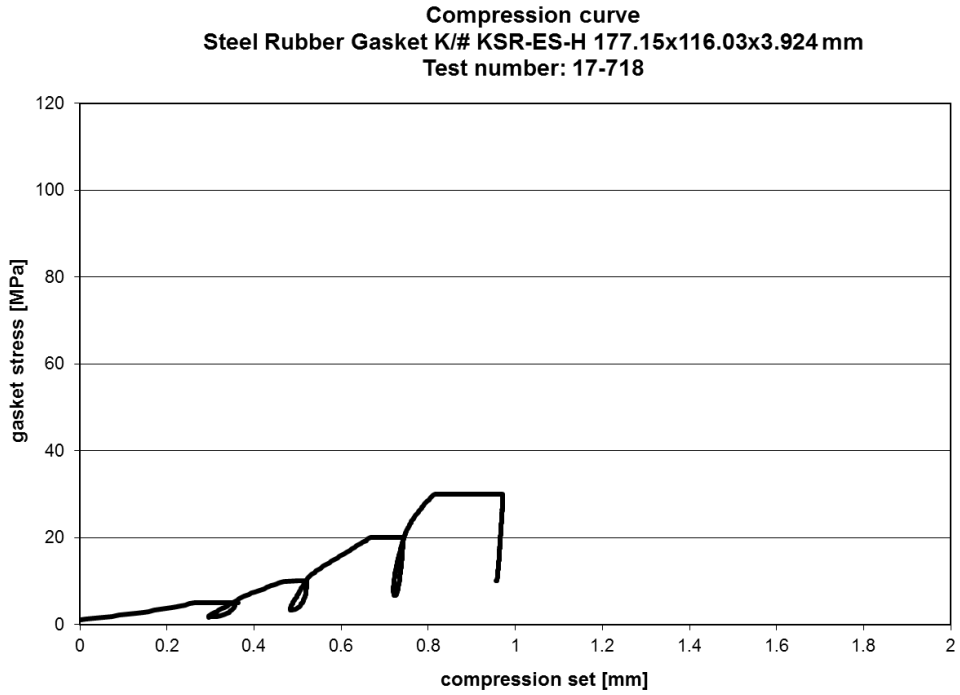


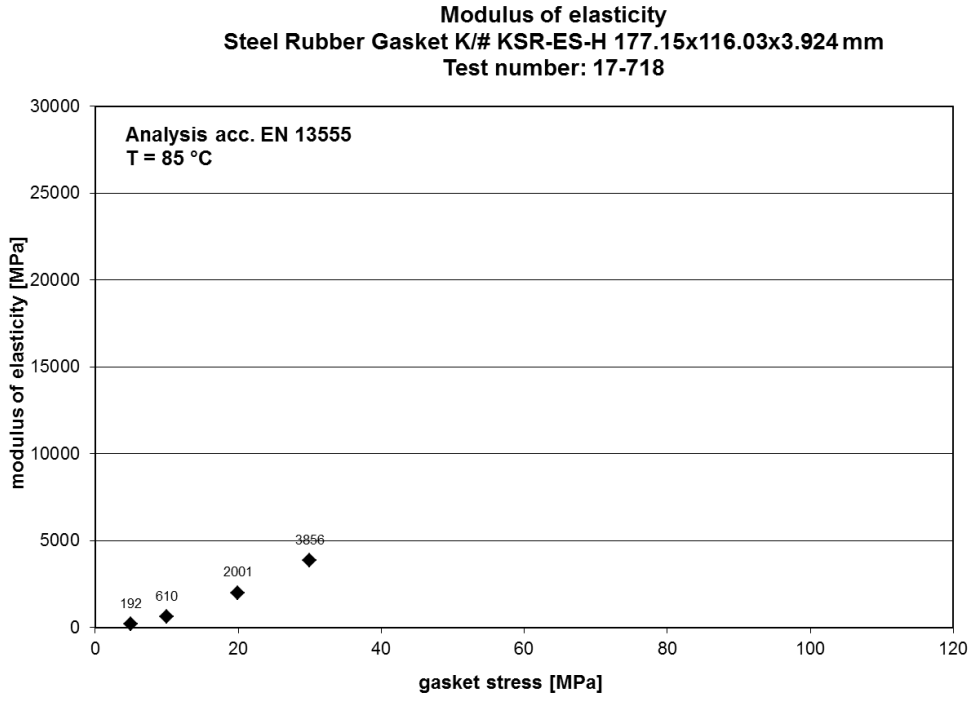
Compression test (RT) according EN 13555





Compression test at 85 °C according EN 13555





Compression test at 85 °C according EN 13555

Creep relaxation test (EN 13555)

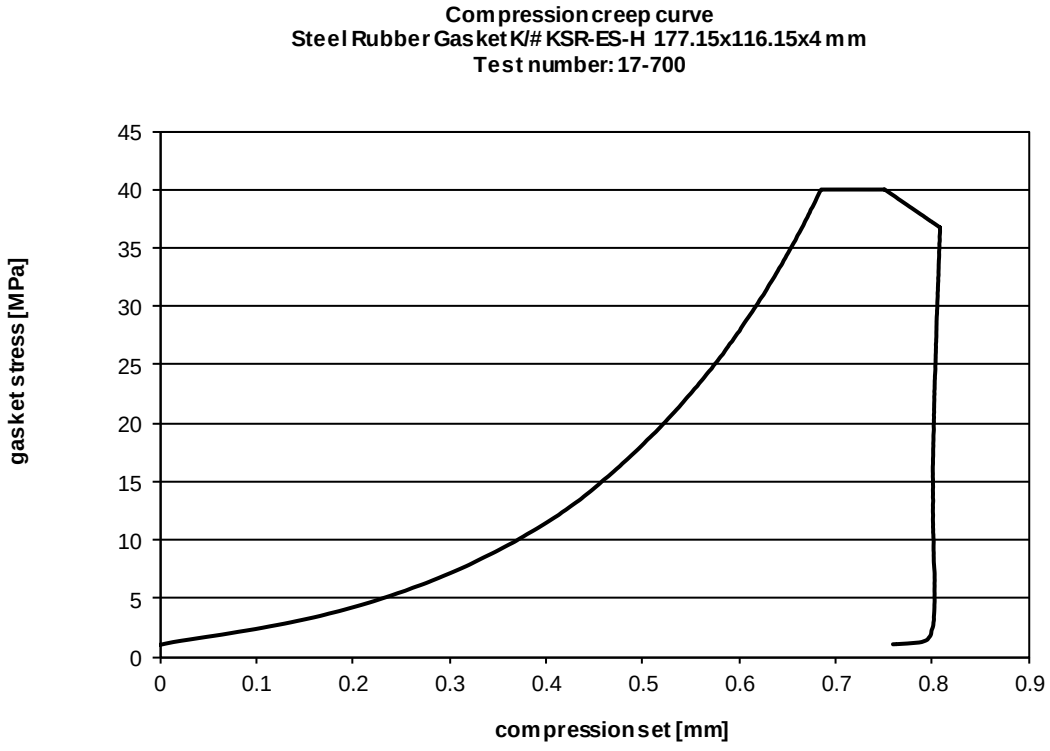
Steel Rubber Gasket K/# KSR-ES-H
177.15x116.15x4 mm
Test number: 17-700

Test parameters

Initial gasket stress Q_i:	40	MPa
Test temperature T_P:	20	°C
Time at T_P:	4:00	hh:mm
Stiffness C:	500	kN/mm

Test results

Remaining gasket stress Q_r:	36.7	MPa
Relaxation factor P_{QR} (T_P):	0.92	
Deflection Δe_{Gc}:	58	µm



Creep relaxation test (EN 13555)

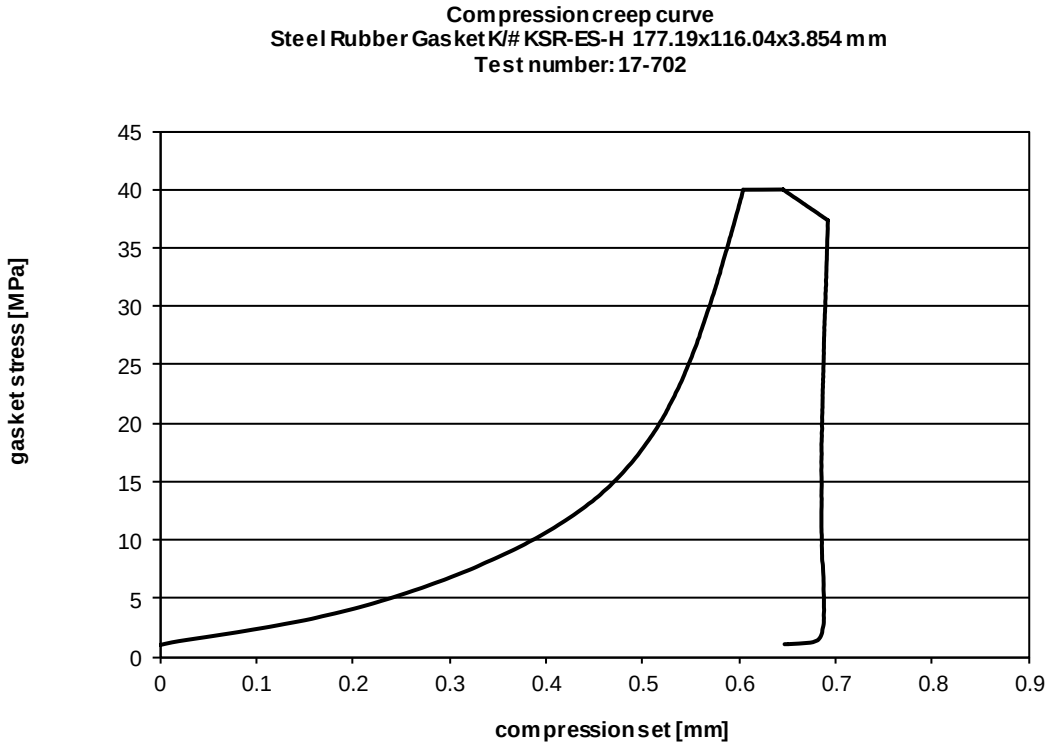
Steel Rubber Gasket K/# KSR-ES-H
177.19x116.04x3.854 mm
Test number: 17-702

Test parameters

Initial gasket stress Q_i:	40	MPa
Test temperature T_P:	20	°C
Time at T_P:	3:59	hh:mm
Stiffness C:	500	kN/mm

Test results

Remaining gasket stress Q_r:	37.3	MPa
Relaxation factor P_{QR} (T_P):	0.93	
Deflection Δe_{Gc}:	46	µm



Creep relaxation test (EN 13555)

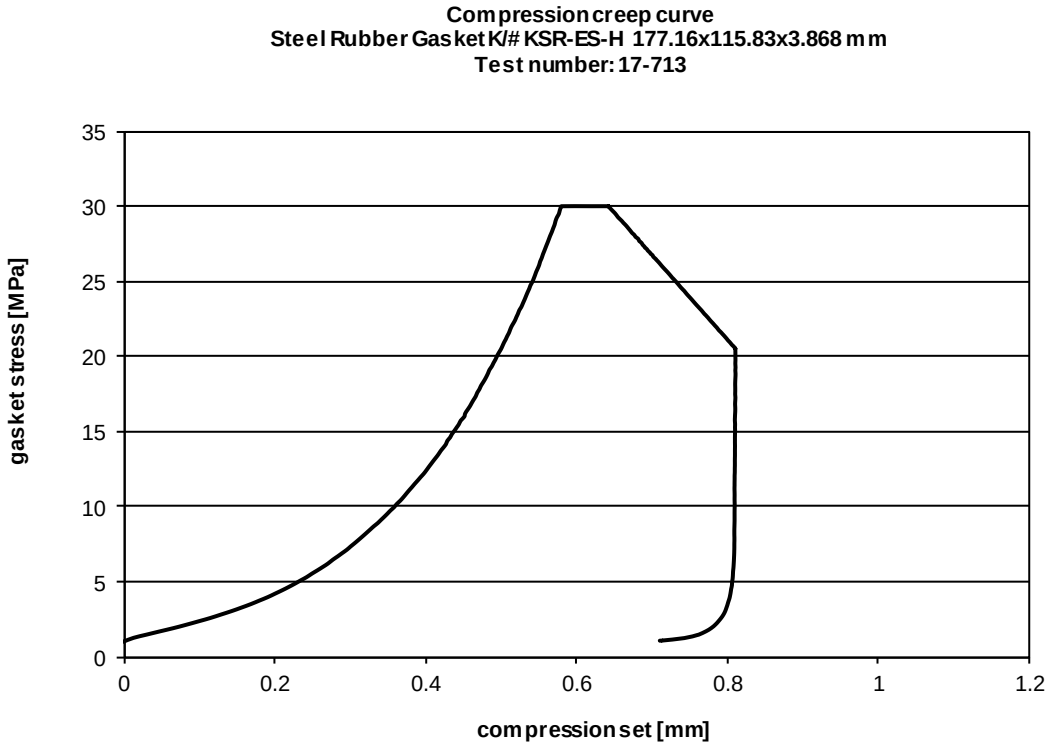
Steel Rubber Gasket K/# KSR-ES-H
177.16x115.83x3.868 mm
Test number: 17-713

Test parameters

Initial gasket stress Q_i:	30	MPa
Test temperature T_P:	85	°C
Time at T_P:	4:00	hh:mm
Stiffness C:	500	kN/mm

Test results

Remaining gasket stress Q_r:	20.5	MPa
Relaxation factor $P_{QR}(T_P)$:	0.68	
Deflection Δe_{Gc}:	168	µm



Creep relaxation test (EN 13555)

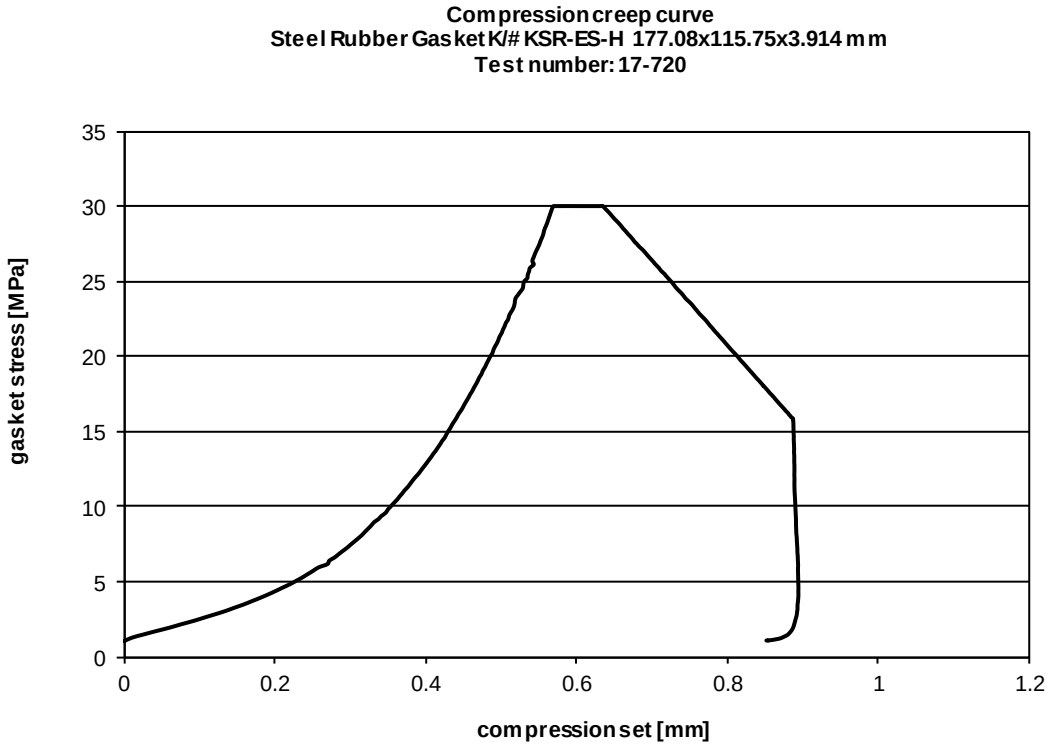
Steel Rubber Gasket K/# KSR-ES-H
177.08x115.75x3.914 mm
Test number: 17-720

Test parameters

Initial gasket stress Q_i:	30	MPa
Test temperature T_P:	85	°C
Time at T_P:	4:00	hh:mm
Stiffness C:	500	kN/mm

Test results

Remaining gasket stress Q_r:	15.8	MPa
Relaxation factor $P_{QR}(T_P)$:	0.53	
Deflection Δe_{Gc}:	253	µm



Creep relaxation test (EN 13555)

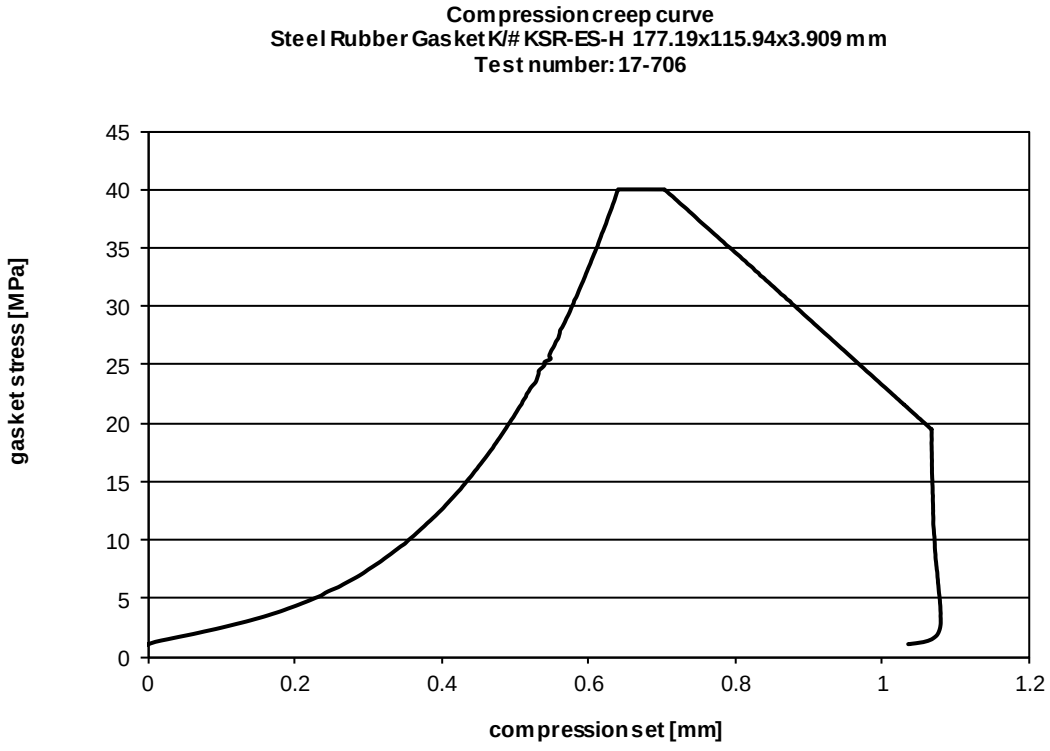
Steel Rubber Gasket K/# KSR-ES-H
177.19x115.94x3.909 mm
Test number: 17-706

Test parameters

Initial gasket stress Q_i:	40	MPa
Test temperature T_P:	100	°C
Time at T_P:	4:00	hh:mm
Stiffness C:	500	kN/mm

Test results

Remaining gasket stress Q_r:	19.5	MPa
Relaxation factor $P_{QR}(T_P)$:	0.49	
Deflection Δe_{Gc}:	364	µm



Creep relaxation test (EN 13555)

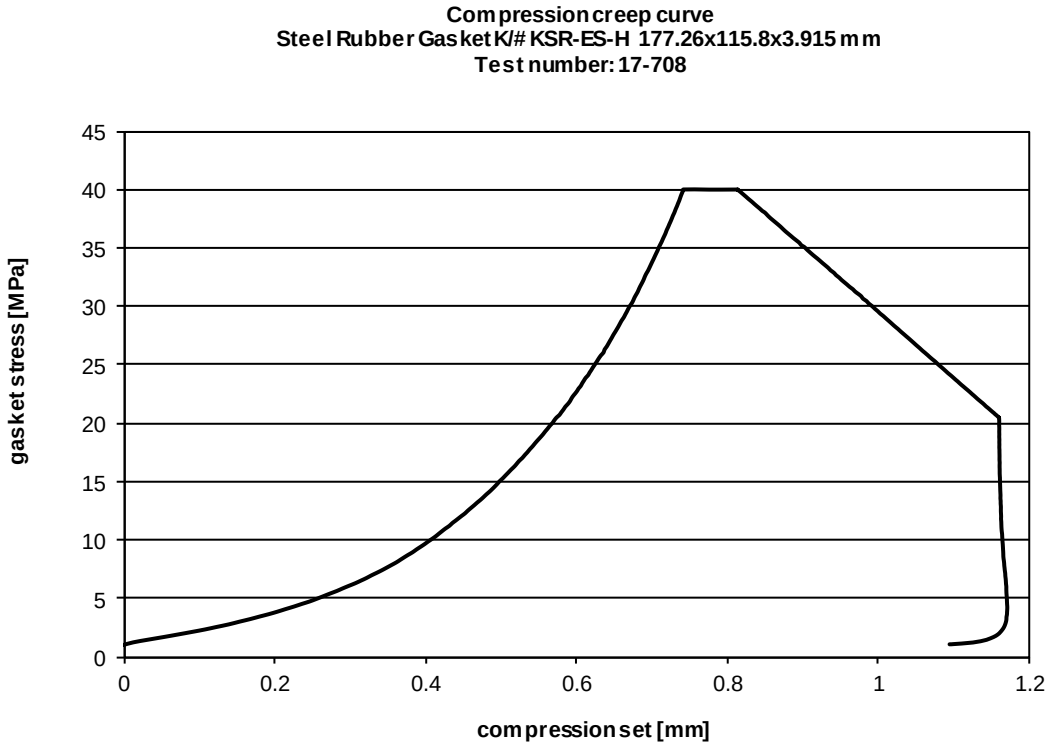
Steel Rubber Gasket K/# KSR-ES-H
177.26x115.8x3.915 mm
Test number: 17-708

Test parameters

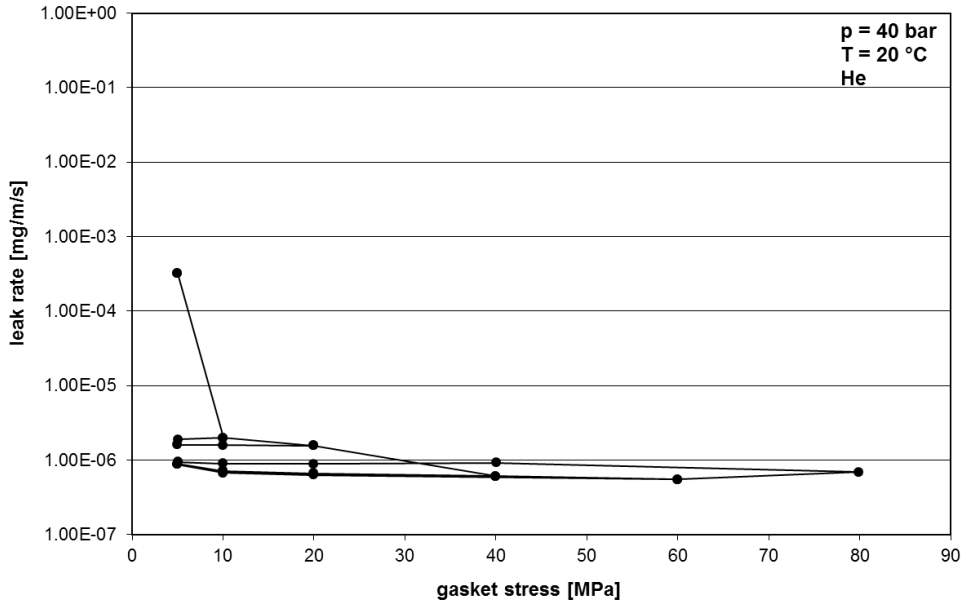
Initial gasket stress Q_i:	40	MPa
Test temperature T_P:	85	°C
Time at T_P:	4:00	hh:mm
Stiffness C:	500	kN/mm

Test results

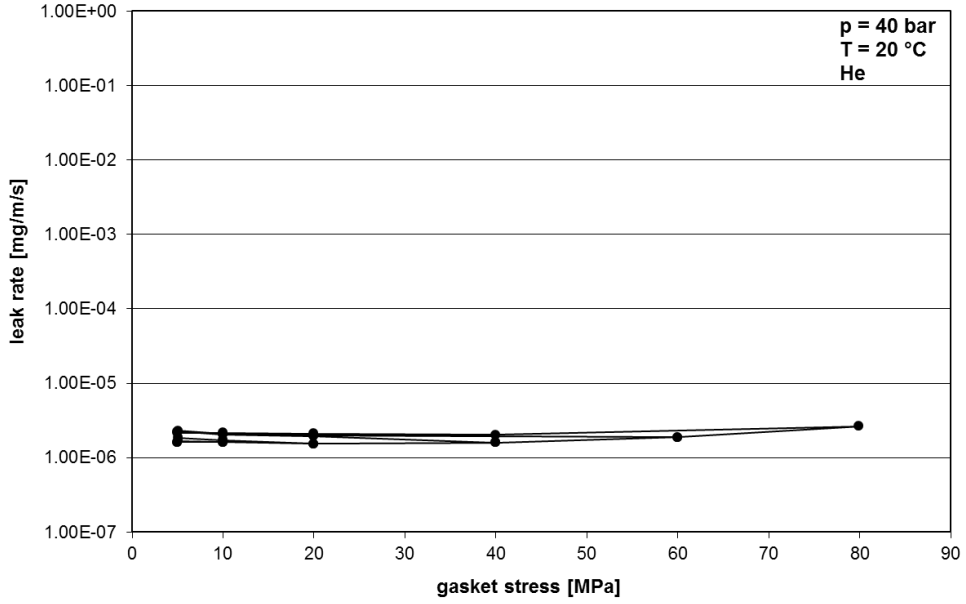
Remaining gasket stress Q_r:	20.5	MPa
Relaxation factor P_{QR} (T_P):	0.51	
Deflection Δe_{Gc}:	347	µm



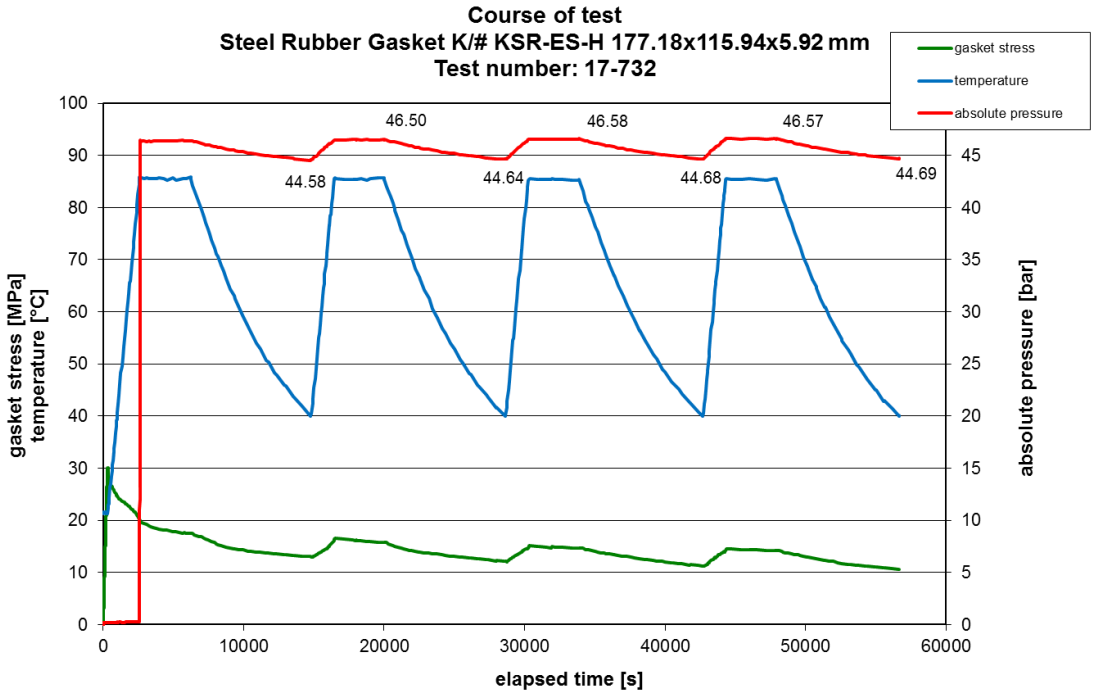
Leakage curve
Steel Rubber Gasket K/# KSR-ES-H 177.16x115.92x5.78 mm
Test number: 17-703



Leakage curve
Steel Rubber Gasket K/# KSR-ES-H 177.27x115.89x3.935 mm
Test number: 17-709



Leakage test according EN 13555



Shell cycle test at 85 °C according MESC SPE 85/300 - 3.3.5

Hot Blow-Out Test HOBT

Steel Rubber Gasket K/# KSR-ES-H
177.18x115.83x5.7 mm
Test number: 17-753

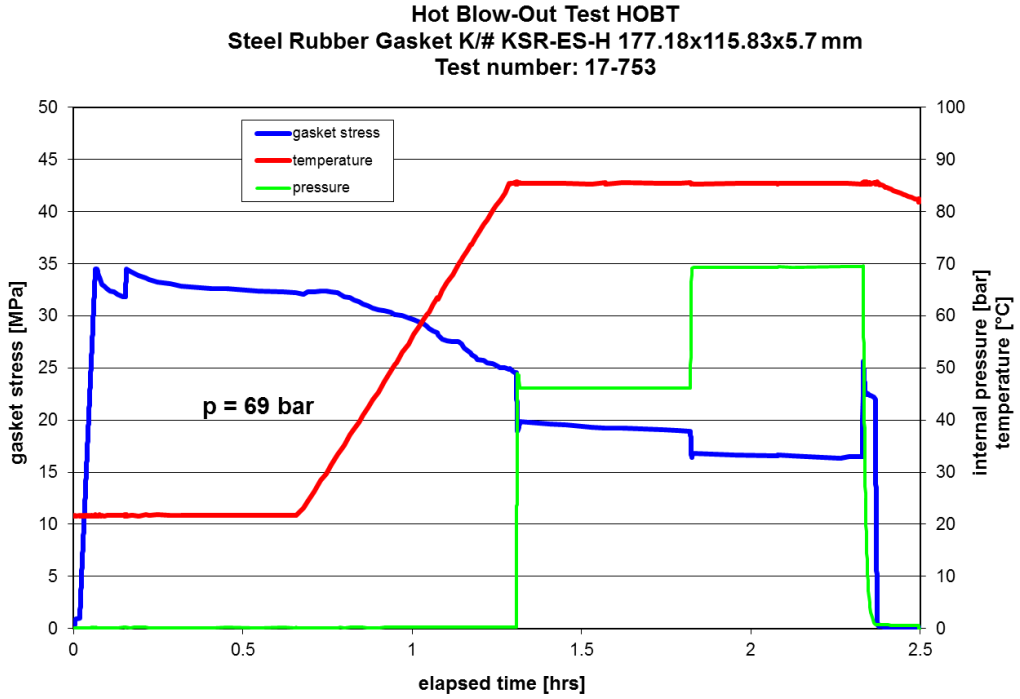
Test parameters

Nominal initial gasket stress:	5000 psi	34.5 MPa
Nominal pressure:	1015 psi	70 bar

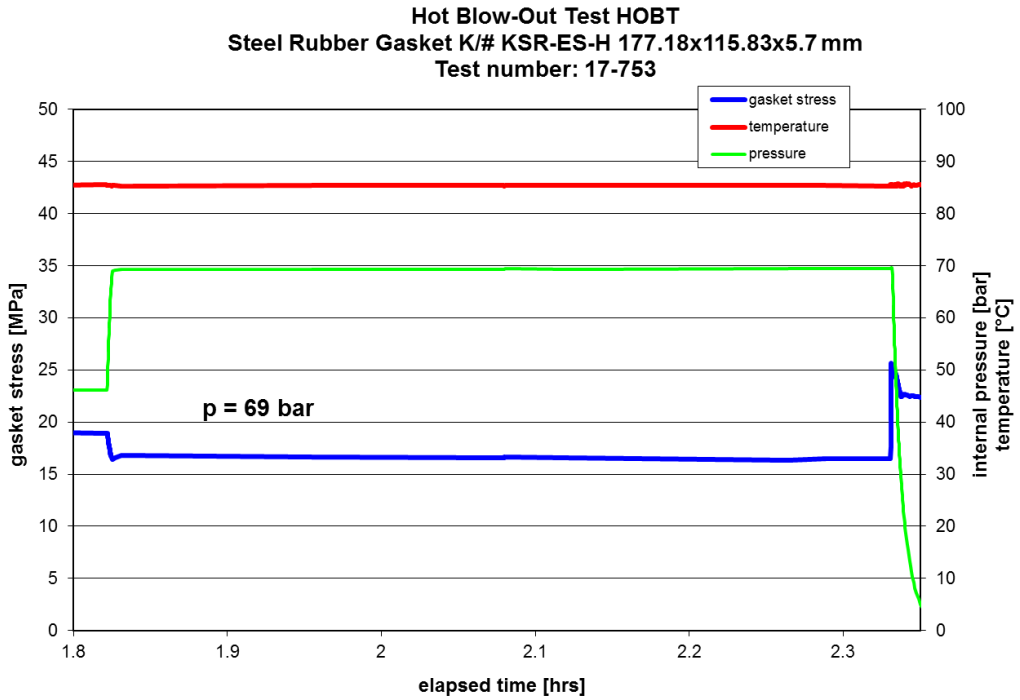
Test results

Initial gasket thickness:	0.2244 in	5.70 mm
Final gasket thickness:	0.1238 in	3.14 mm
Initial gasket stress:	5000 psi	34.5 MPa
Actual test pressure:	1006 psi	69 bar
Gasket stress S_g:	2390 psi	16.5 MPa
Gasket temperature T_g:	186 °F	86 °C

Hot Blow-Out test (HOBT1) according to MESC SPE 85/300 - 3.3.6



HOBT1 – MESC SPE 85/300 - 3.3.6



HOBT1 – MESC SPE 85/300 - 3.3.6

Kukil - Steel Rubber Gasket K/# KSR-ES-H	**18-258**
initial load [kN]	96.78
initial gasket stress [psi]	4351
remaining load after temperatur exposure [kN]	78.22
remaining gasket stress after temperature exposure [psi]	3517
creep relaxation factor [%]	80.8
initial gasket thickness [mm]	5.14
thickness after loading [mm]	1.96
thickness after aging [mm]	1.64
deflection after loading [mm]	3.18
deflection after aging [mm]	3.50
Mechanical Quality parameter	
load retained [%]	80.8
load retained [%] /75	1.08
Load retention quality $\mathbf{Q_{pr}}$	1.16
Tensile break strength [N]	600
Remaining tensile breaking strength TSX [psi]	1600.15
Tensile quality Q_{px}	1.60
Quality parameter Q_p criteria	> 1
Quality parameter Q_p	1.86
Requirements:	**passed**

ATRS according to MESC SPE 85/300 - 3.3.7

ASTM F36B

Compressibility and recovery test
Kukil Steel Rubber Gasket K/# KSR-ES-H - 4 x ∅ 12.8 mm x 5. 12 mm
Test number: 17-737

Thickness under pre-load	5.120 mm
Thickness under load	3.467 mm
Recovery thickness	5.060 mm
Compressibility	32.3%
Recovery	96.4%

ASTM F36B

Compressibility and recovery test
Kukil Steel Rubber Gasket K/# KSR-ES-H - 4 x ∅ 12.8 mm x 5. 35 mm
Test number: 17-738

Thickness under pre-load	5.350 mm
Thickness under load	3.322 mm
Recovery thickness	5.310 mm
Compressibility	37.9%
Recovery	98.0%

ASTM F36B

Compressibility and recovery test
Kukil Steel Rubber Gasket K/# KSR-ES-H - 4 x ∅ 12.8 mm x 5. 23 mm
Test number: 17-739

Thickness under pre-load	5.230 mm
Thickness under load	3.041 mm
Recovery thickness	5.160 mm
Compressibility	41.9%
Recovery	96.8%

Cold Compression / Hot Recovery Test according to ASTM F36 B (MESC SPE 85/300 - 3.3.11)

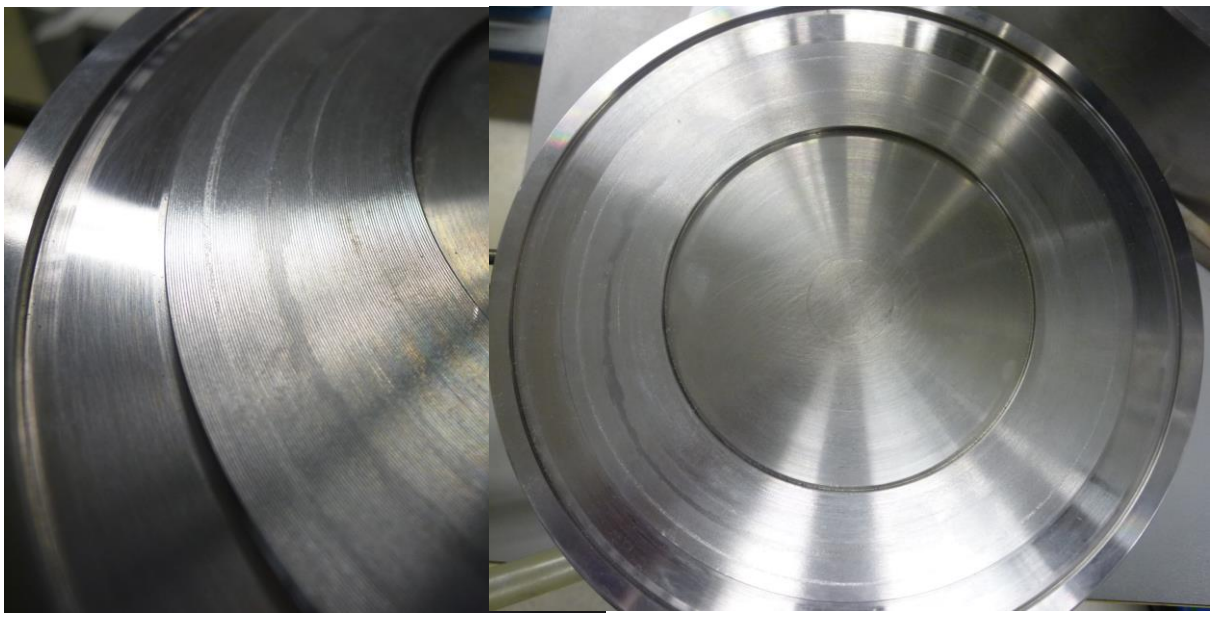
ASTM F37

Sealability Test
Test Method B

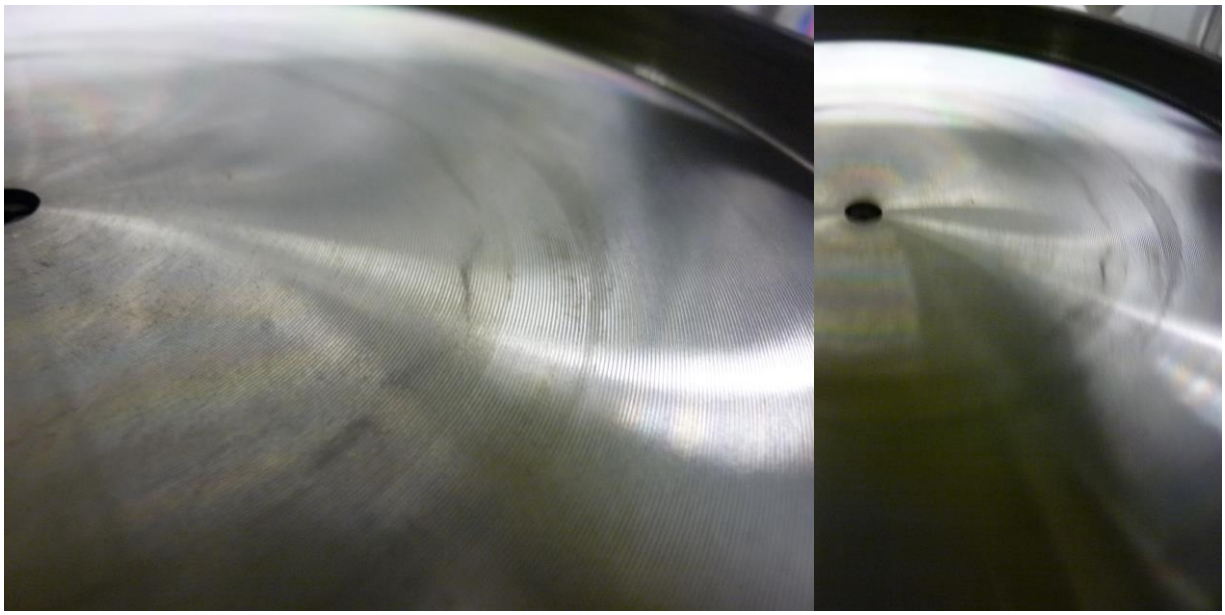
Material	Thickness	Test No.	Compressive Force		Test Pressure		Average Leak rate	meas. 1	meas. 2	meas. 2
	mm		MPa	psi	bar	psi	ml/h	ml/min	ml/min	ml/min
Steel Rubber Gasket K/# KSR-ES-H	5.17	17-699	22.5	3260	2	29	0.0035	5.82E-05	5.82E-05	5.82E-05
Steel Rubber Gasket K/# KSR-ES-H	5.23	17-701	22.9	3320	2	29	0.0035	5.86E-05	5.86E-05	5.86E-05
Steel Rubber Gasket K/# KSR-ES-H	5.24	17-707	22.5	3269	2	29	0.0035	5.84E-05	5.84E-05	5.84E-05
Steel Rubber Gasket K/# KSR-ES-H	average		22.6	3283	2	29	0.004	5.84E-05	5.84E-05	5.84E-05

leak rate not detectable: dummy-values of 1.1 E-5 mg/m/s resp. 0.0035 ml/h

Leak Test with nitrogen
according to ASTM F37B (MESC SPE 85/300 - 3.3.12)



Top flange gasket adhesion



Bottom flange gasket adhesion

Shell leakage test (RT) according MESC SPE 85/300 - 3.3.2

Shell leakage test (T) according MESC SPE 85/300 - 3.3.2

Compression test at RT (EN 13555)

Compression test at RT (EN 13555)

Compression test at 85 °C (EN 13555)

Compression test at 85 °C (EN 13555)

Creep relaxation test at 40 MPa - RT (EN 13555)

Creep relaxation test at 40 MPa - RT (EN 13555)

Creep relaxation test at 30 MPa - 85 °C (EN 13555)

Creep relaxation test at 30 MPa – 85 °C (EN 13555)

Creep relaxation test at 40 MPa - 100 °C (EN 13555)

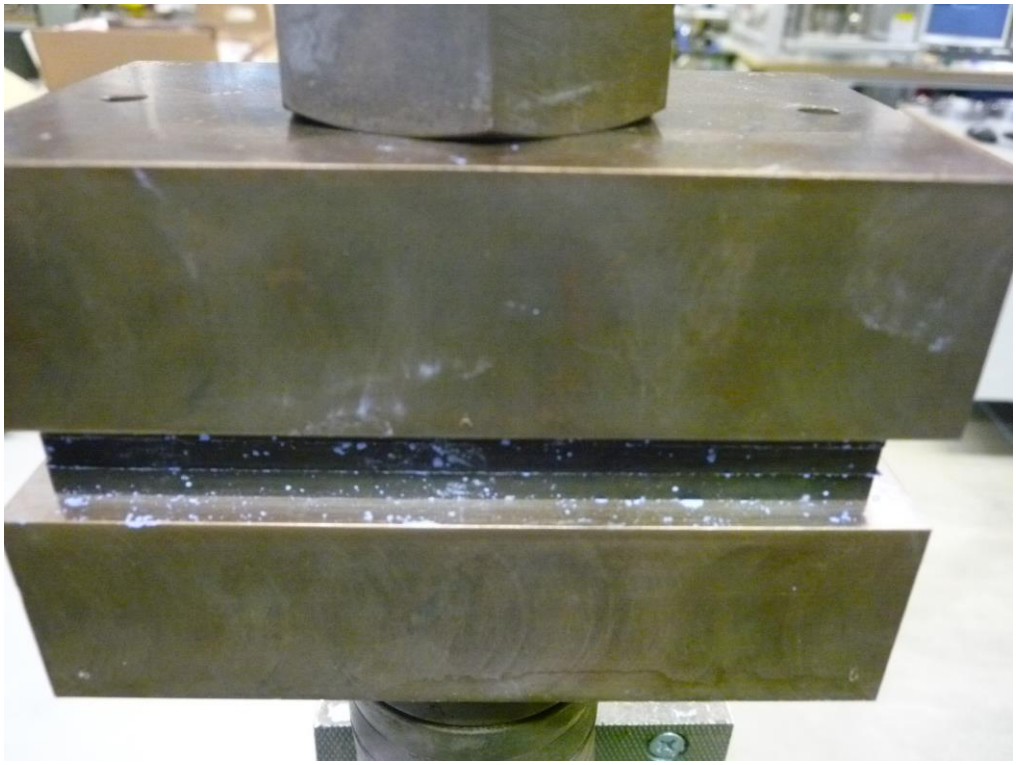
Creep relaxation test at 40 MPa – 85 °C (EN 13555)

Leakage test at RT (EN 13555)

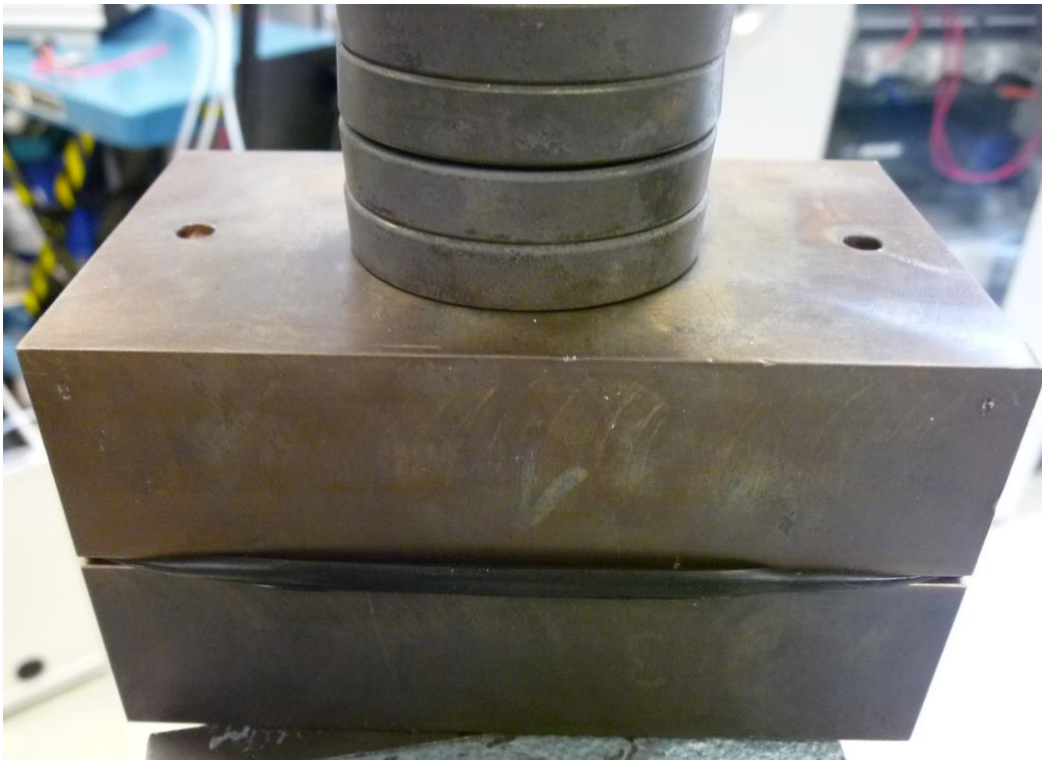
Leakage test at RT (EN 13555)

Shell cycle test (T) according MESC SPE 85/300 - 3.3.5

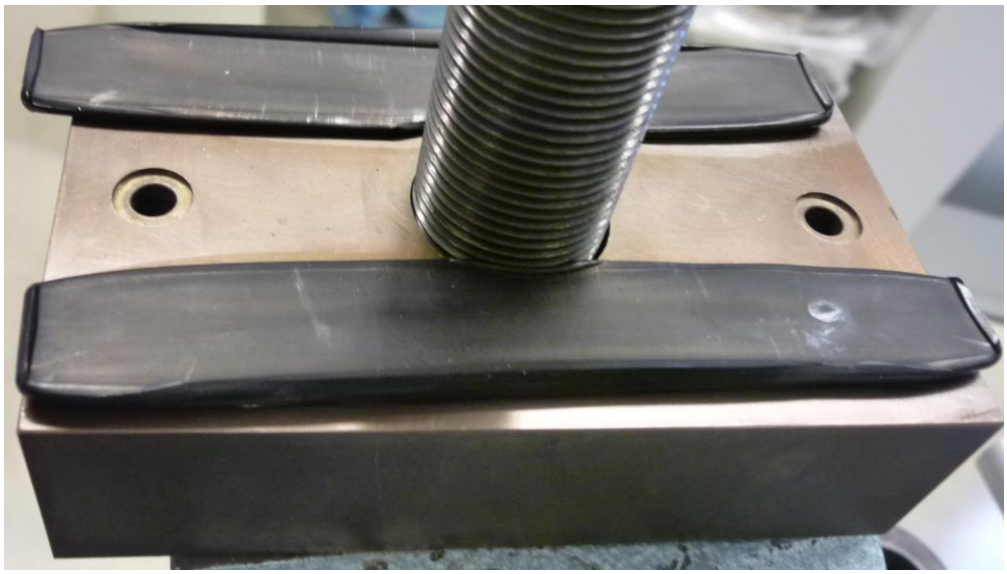
HOBT1 according to MESC SPE 85/300 - 3.3.6



ATRS according to MESC SPE 85/300 – 3.3.7
before loading

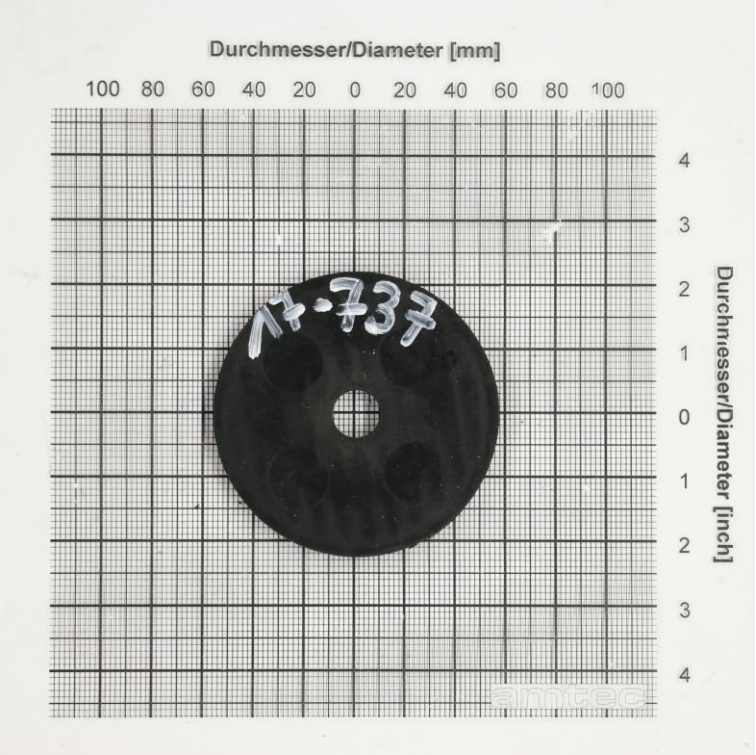


ATRS according to MESC SPE 85/300 – 3.3.7
after loading

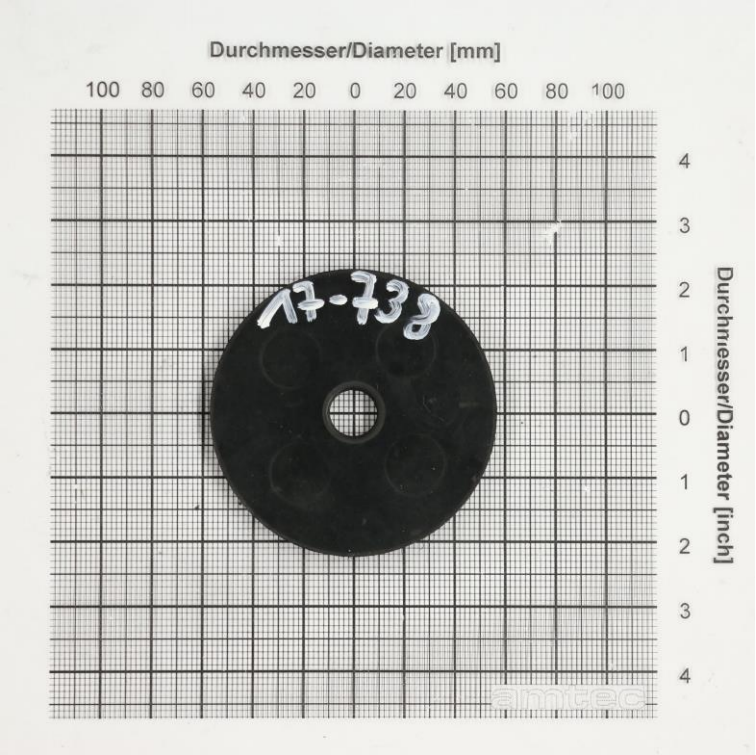


ATRS according to MESC SPE 85/300 – 3.3.7
after the test

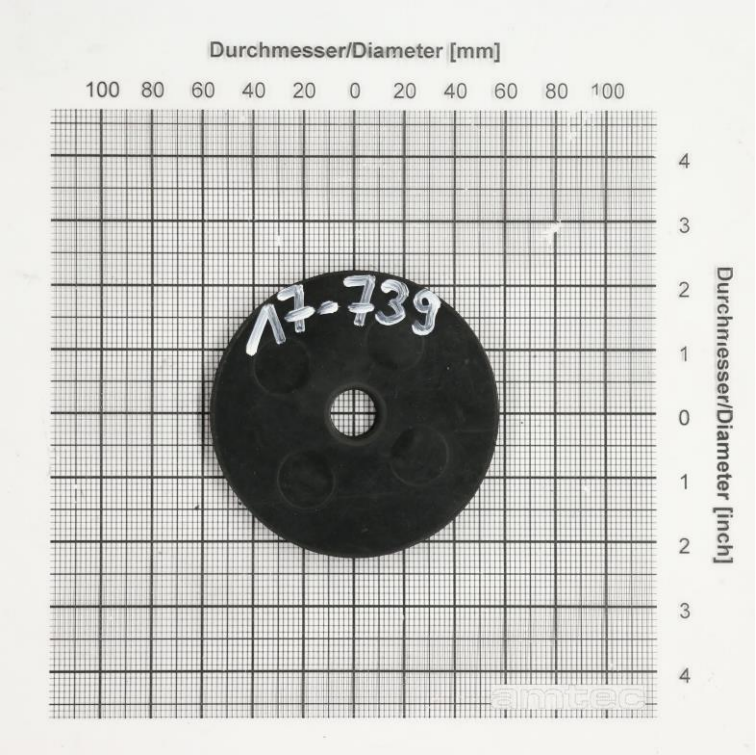
ATRS according to MESC SPE 85/300 – 3.3.7
18-258



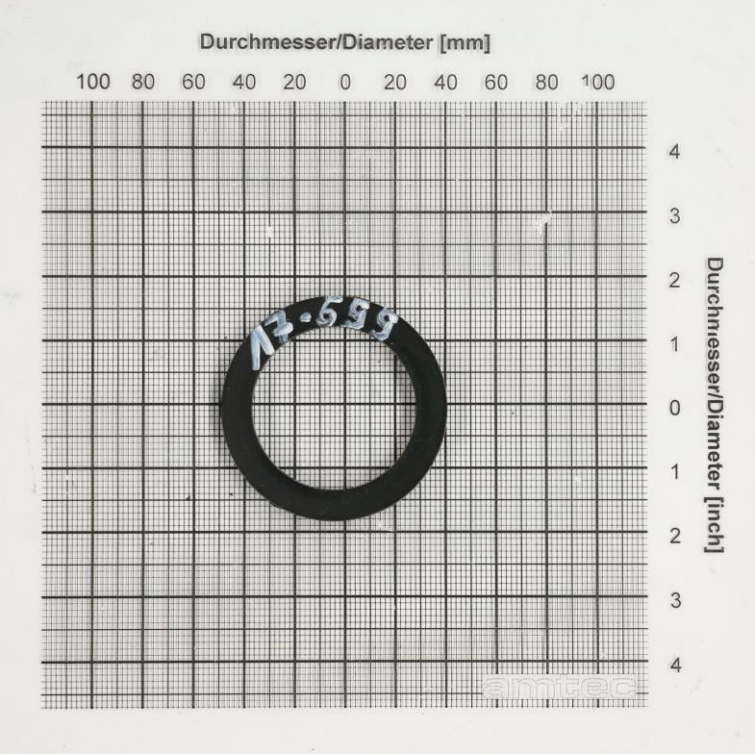
Cold Compression / Hot Recovery Test according to ASTM F36 B (MESC SPE 85/300 – 3.3.11)



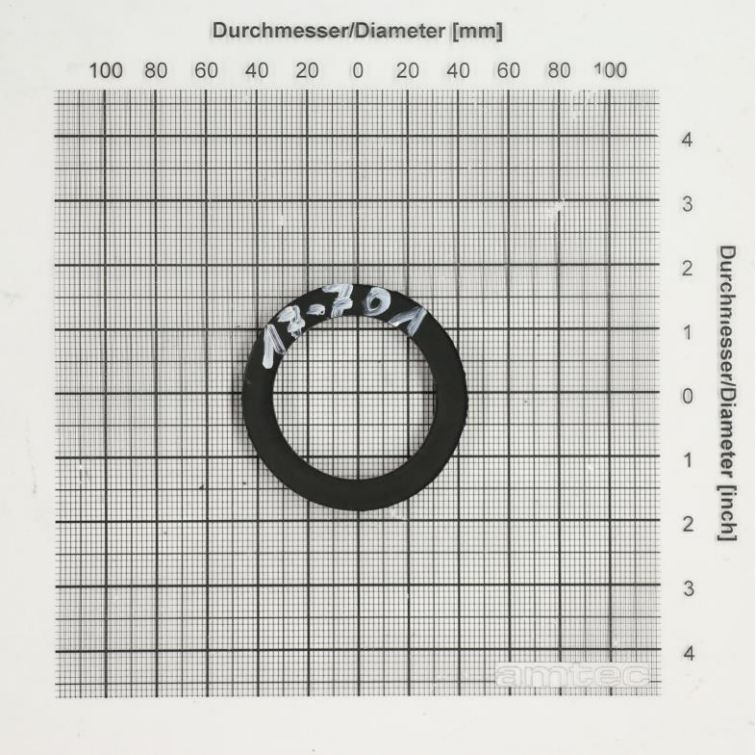
Cold Compression / Hot Recovery Test according to ASTM F36 B (MESC SPE 85/300 – 3.3.11)



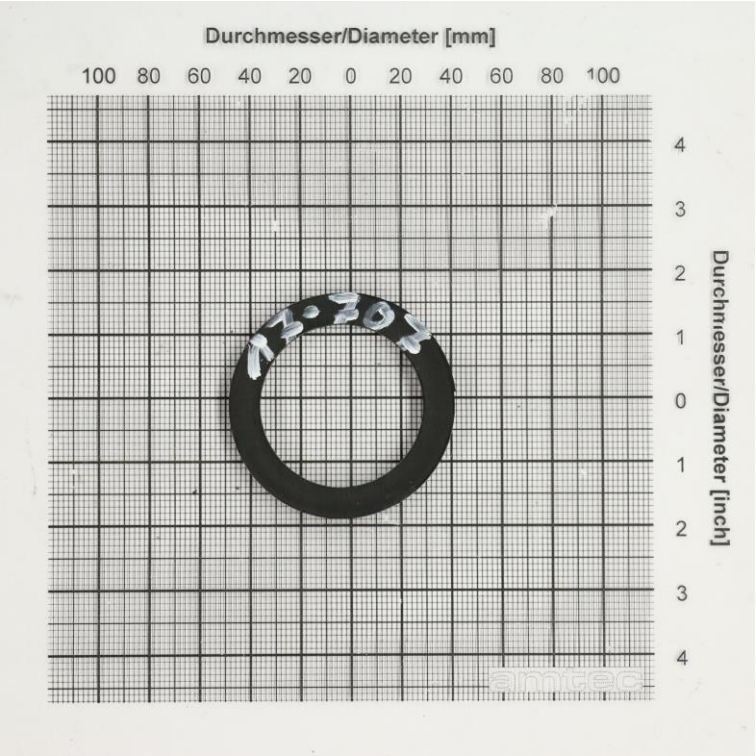
Cold Compression / Hot Recovery Test according to ASTM F36 B
(MESC SPE 85/300 – 3.3.11)



Leak Test with nitrogen according to ASTM F37 B
(MESC SPE 85/300 – 3.3.12)



Leak Test with nitrogen according to ASTM F37 B
(MESC SPE 85/300 – 3.3.12)



Leak Test with nitrogen according to ASTM F37 B
(MESC SPE 85/300 – 3.3.12)