Relaxation of the **Bolted Flange Connection**

Performance of a bolted flange may be characterized by its strength and sealing capability. Its sealing capacity is directly related to the bolt-up strategy used during assembly, as improper practice may result in leakage from the joint.

This study researches the relaxation of a bolted flange connection, considering temperature cycling and various bolt grades in conjunction with different semi-metallic gaskets.

By Robert Taylor, Technical Director, 3S Superior Sealing Services LLC

The test temperatures for this study were: 300°F (149°C), 500°F (260°C), 650°F (343°C) and 800°F (427°C), where each temperature setting will cycle three times to obtain the relaxation value for each cycle.

The three types of bolt materials for evaluation included ASTM A193 B7, ASTM A193 B16 and ASTM, B8M, CL2, along with gasket styles of Spiral Wound Gasket with Inner Ring, Spiral Wound Gasket with no Inner Ring and the Kammprofile Gasket (grooved metal gasket with covering layers), all in accordance to ASME B16.20 – 2017.

The above variations and conditions were tested at two different initial bolt stresses of 35,000 psi (241 MPa) and 65,000 psi (448 MPa), with a constant internal pressure of 150 psi (10.3 Bar).

The results showed relaxation values for the different bolt and gasket types versus the various temperature cycling conditions indicated above. Focus questions included: does a certain gasket style offer lower relaxation properties through less creep and/or higher recovery? Does a certain bolt grade offer better stress retention? Is there variation in initial bolt stress for the different style of gasket? How does the initial bolt stress affect the relaxation properties of the bolted connection?

Test Equipment

The test machine used in this study consists of:

1. *Temperature controller.*
2. *Flanges:*
   - *a) 2 of 4" 300lb RF WN flanges to ASME B16.5.[2]*
   - *b) Flange material – ASTM A182 F11 Class 2.*
   - *c) Schedule 80.*
3. *Flange insulation.*
4. *Thermocouples.*
5. *Data collection.*
6. *Internal pressure inlet.*
7. *All the above are shown in Figures 1 & 2.*

Type of Bolting & Lubricant

A commercially available intelligent bolting system was used in all tests performed. This enabled stress readings to be taken at initial bolt up and at ambient temperature at the bottom of each temperature cycle.

Figure 1: Test Machine Setup.

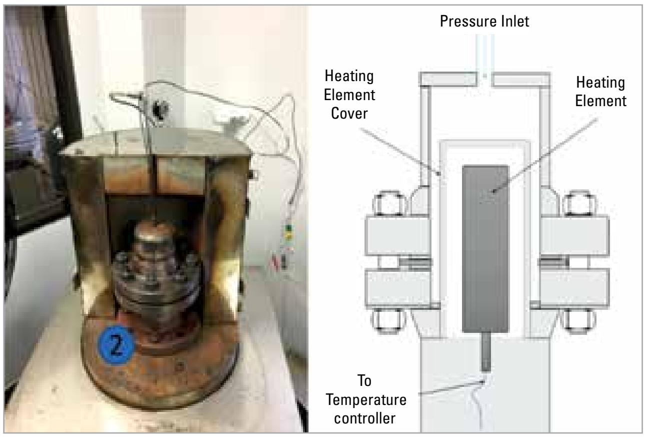

Figure 2: Test Machine Setup.

Bolt dimensions = 0.75" – 10 x 4.75" all thread stud

Bolt grades

1. ASTM A193 B7 – Gr. 2H with hardened washers.
2. ASTM A193 B16 – Gr. 4L with hardened washers.
3. ASTM A320 B8M CL2 – Gr. 8M with 316SS washers.
4. High temperature lubricant with a K factor of 0.17.

Types of Gaskets

Gaskets tested were:

1. Spiral Wound Gasket with Inner Ring – 316SS-316SS-FG (flexible graphite)-CS (carbon steel) Outer Ring.
2. Spiral Wound Gasket without Inner Ring – 316SS-FG-CS Outer.
3. Kammprofile Gasket – 316SS-FG Facing.

All gaskets were in accordance with ASME B16.20-2017.[3]

Gaskets were tested from three different manufacturers to analyze if this had an impact on the relaxation results.

Spiral Wound Gaskets without Inner Rings were chosen due to the high volume currently sold into the market.

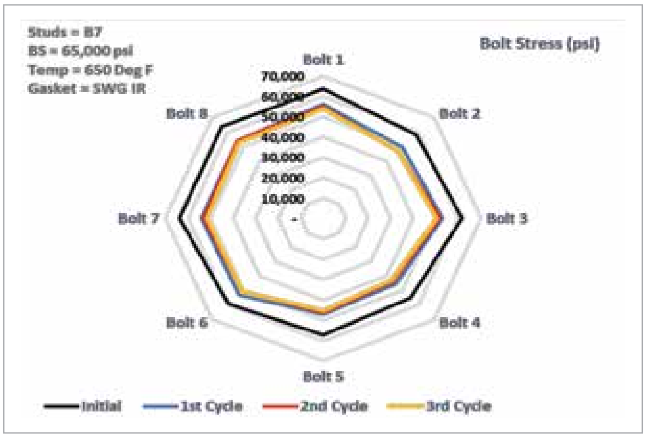

Figure 3: Recording of Bolt Tightening.

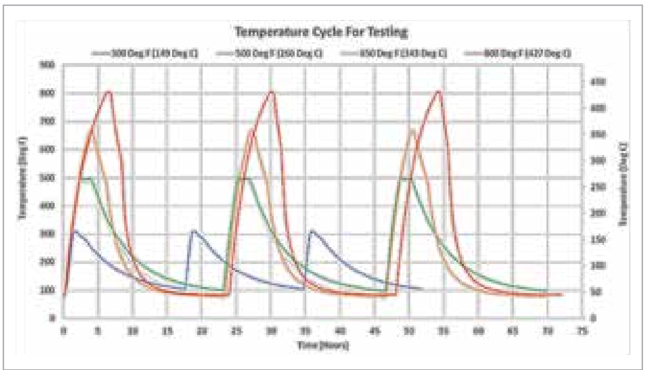

Figure 4: Temperature Cycling Procedure.

Bolt Up Procedure

Each test followed the same bolt up procedure; the standard Star Pattern was used with two circle passes. A calibrated torque wrench was used in all tightening steps. After bolt up, readings were taken from the intelligent bolts and recorded as shown in Figure 3.

Recording each test in this way enables analysis of the variation in bolt stress per stud. The resulting test data can be found in the results section.

Figure 4 represents the temperature cycling procedure used for each test at the given test temperatures.

Initial Bolt Stress Values

The two initial bolt stresses chosen were:

1. 35,000 psi (241 MPa)
2. 65,000 psi (448 MPa)

35,000 psi (241 MPa) is just above the minimum required bolt stress for a 4" 300lb spiral wound gasket in ASME PCC-1 Appendix O. [1]

65,000 psi (448 MPa) is a typical stress used on the size of flange.

Gasket Style & Sample Size (35,000 psi)

The first stage of testing analyzed the relaxation of the three different gasket types.

- Spiral Wound Gasket without Inner Ring (SWG NO IR)
- Spiral Wound Gasket with Inner Ring (SWG IR)
- Kammprofile Gasket (KAMM)

		B7	B16	B8M CL2
300 °F (149 °C)	SWG NO IR	4	5	4
	SWG IR	5	5	5
	KAMM	4	4	4
500 °F (260 °C)	SWG NO IR	5	5	5
	SWG IR	5	5	5
	KAMM	5	5	5
650 °F (343 °C)	SWG NO IR	6	6	6
	SWG IR	6	6	6
	KAMM	6	6	6
800 °F (427 °C)	SWG NO IR	6	6	6
	SWG IR	6	6	6
	KAMM	6	6	6

Table 1: Results will show an average of the above sample size.

Results Summary (35,000 psi)

The relaxation results at 500°F (260°C) showed a slight increase over the results for 300°F (149°C) for each combination, but still followed a similar pattern of no gasket or bolt material being superior to the other.

At 650°F (343°C) the relaxation values increased more on the Spiral Wound Gasket without inner ring. The Kammprofile Gasket and Spiral Wound Gasket with Inner Ring were very similar and did not increase significantly over the results at lower temperatures.

The relaxation figures at 800°F (427°C) had increased overall but a significant increase could be seen in the Spiral Wound Gasket without Inner Ring. In addition, the bolt material seemed to have an effect on relaxation when a Spiral Wound with inner ring is tested.

Figure 6 is a summary of the average initial bolt stress per test at 35,000 psi (241 MPa). This is broken down into gasket styles to better understand if there is variation in this scenario.

Initial bolt stress results showed there was a big variation when using a spiral wound gasket without inner ring. The other two gasket types were consistent, within the ± tolerances of the intelligent bolting and torque wrench.

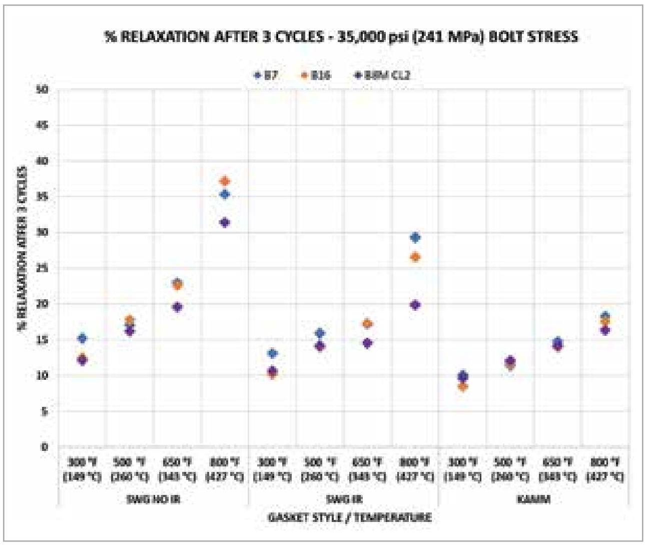

Figure 5: Total Relaxation Summary (35,000 psi).

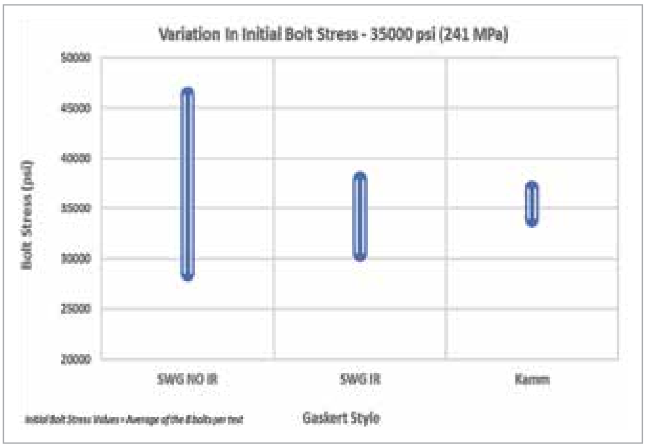

Figure 6: Average Initial Bolt Stress.

Gasket Style & Sample Size (65,000 Psi)

The second stage of testing analyzed the relaxation of the three different gasket types at the higher bolt stress.

- Spiral Wound Gasket without Inner Ring (SWG NO IR)
- Spiral Wound Gasket with Inner Ring (SWG IR)
- Kammprofile Gasket (KAMM)

		B7	B16	B8M CL2
300 °F (149 °C)	SWG NO IR	3	3	3
	SWG IR	3	3	3
	KAMM	3	3	3
500 °F (260 °C)	SWG NO IR	3	3	3
	SWG IR	3	3	3
	KAMM	3	3	3
650 °F (343 °C)	SWG NO IR	5	5	5
	SWG IR	5	5	5
	KAMM	5	5	5
800 °F (427 °C)	SWG NO IR	5	5	5
	SWG IR	5	5	5
	KAMM	5	5	5

Table 2: Results will show an average of the above sample size.

Results Summary (65,000 psi)

As can be seen from the results, there is very little difference in relaxation between the gasket style, initial bolt stress and bolt material at 300°F (149°C).

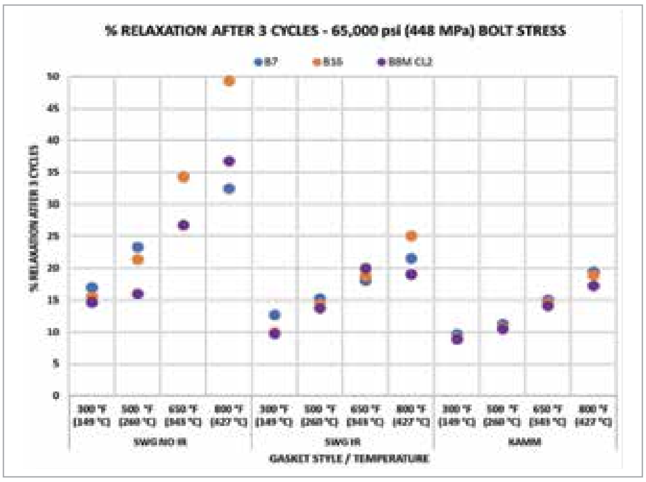

Figure 7: Total Relaxation Summary (65,000 psi).

The relaxation results at 500°F (260°C) showed a slight increase over the results for 300 Deg F (149°C) for each combination. Spiral Wound Gasket without Inner Ring showed a higher relaxation value for B7 and B16 studs.

The relaxation results at 650°F (343°C) followed a similar pattern to results at 35,000 psi (241 MPa) bolt stress. A big increase can be seen on Spiral Wound Gasket without Inner Ring over the other two gasket styles. There is no difference (within experimental error) between the bolt grades for Spiral Wound Gasket with Inner Ring and a Kammprofile Gasket.

The relaxation results at 800°F (427°C) for 65,000 psi (448 MPa) showed higher inconsistencies for Spiral Wound Gasket without Inner Ring over the lower bolt stress testing. For Spiral Wound Gasket with Inner Ring and Kammprofile Gasket, a higher bolt stress does not affect the relaxation values for the different bolt grades.

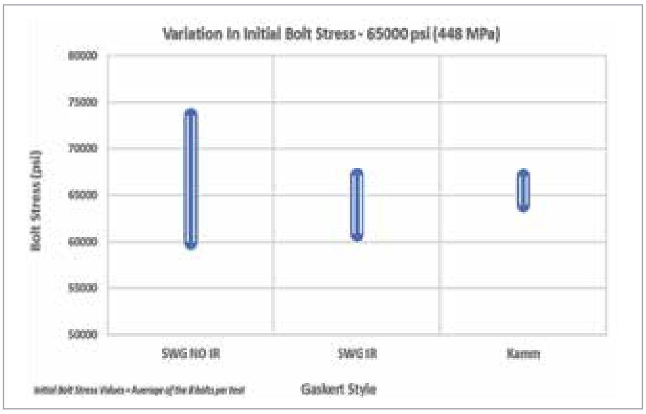

Figure 8: Average Initial Bolt Stress.

Figure 8 is a summary of the average initial bolt stress (per test) at 65,000 psi (448 MPa). This is broken down into gasket styles to better understand if there is variation in this scenario.

Initial bolt stress results show there is a big variation when using a Spiral Wound Gasket without Inner Ring, as high percentage of the results were above the target bolt stress. This is understandable due to the winding area compressing further under the higher stress. After a certain point the bolt force would just be compressing a small portion of the outer ring that sits within the raised face section of the flanges i.e., reducing contact area.

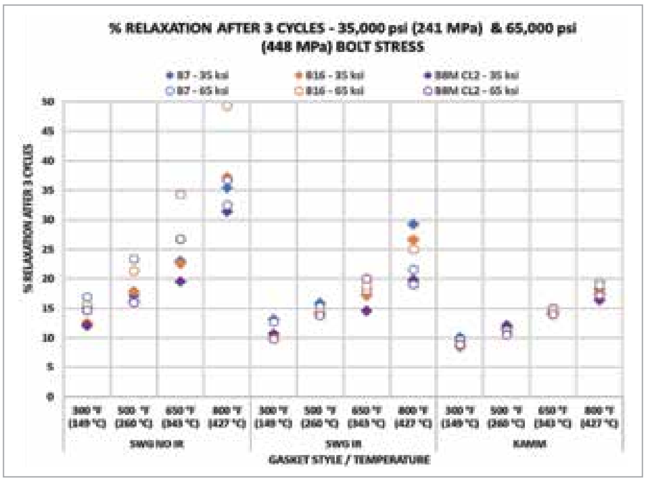

Figure 9: Total Relaxation Summary (35,000 & 65,000 psi).

Summary of Results at 35,000 & 65,000 psi Initial Bolt Stress

1. For Spiral Wound Gasket with Inner Ring and Kammprofile Gaskets, the relaxation values at the two different bolt stresses are similar.
2. The relaxation results for Spiral Wound Gasket without Inner Ring are higher and more erratic at 65,000 psi (448 MPa).
3. The bolt grade has an effect on the results for both styles of Spiral Wound Gasket, B8M CL2 showing low relaxation at all temperatures whereas all bolt grades had similar results for the Kammprofile Gasket.

Conclusion

- All tests show, as the temperature increases the more relaxation occurs.
- Spiral Wound Gasket without Inner Rings have higher relaxation values and become more erratic at the higher bolt stresses.
- Kammprofile Gasket results show consistency per bolt grade and follow a linear pattern as the temperature increases.
- Bolt grade selection affects the relaxation results on both styles of Spiral Wound Gaskets only, ASTM B8M CL2 showing lower relaxation results.
- All bolt grades showed similar results for Kammprofile Gaskets.
- In all tests conducted there was no internal pressure drop recorded from the set point of 150 psi (10.3 Bar).

ACKNOWLEDGEMENT:

- 3S Superior Sealing Services LLC.

REFERENCES:

1. ASME PCC-1-2019 “Guidelines for Pressure Boundary Bolted Flange Joint Assembly”.
2. ASME B16.5-2017 “Pipe Flanges and Flanged Fittings”.
3. ASME B16.20-2017 “Metallic Gaskets for Pipe Flanges”.

ABOUT THE **AUTHOR**

Robert has worked in the gasket industry for over 20 years, starting his career as a test engineer at a manufacturer in the United Kingdom. He progressed to become technical manager, developing biaxally orientated PTFE materials, compressed sheet and semi-metallic gaskets. His extensive knowledge and experience of gasket development and technical specifications provided an opportunity to further his career in the industry in the United States of America. Now in his role as technical director at 3S Superior Sealing Services, he leads the department focusing on product development, continuous improvement and customer support. Through this work, Robert has written a number of technical papers focused on solutions and best practices for end users.