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AN EXPERIMENTAL INVESTIGATION OF THE FACTORS THAT CONTRIBUTE TO THE CREEP- RELAXATION OF COMPRESSED NON-ASBESTOS GASKETS.

José C. C. Veiga
Carlos F. A. Cipolatti
Ana M. F. de Sousa

Teadit Ind. Com. Ltda
Rio de Janeiro, Brazil

David W. Reeves

Chevron Refining Technology
Richmond, CA, USA

ABSTRACT

The adequate tightness of flanged joints contributes to maintaining safe working conditions in numerous equipment and industrial installations. The new sealing technologies and materials can require more careful selection, handling and installation than previous asbestos equivalents. Many research studies have been conducted to understand and improve the assembly bolt load of piping joints in order to minimize the likelihood of leakage. The selection of the bolt load must consider many factors, such as: minimum gasket stress to achieve a seal; the maximum stress that will damage the joint components and the amount of gasket stress lost to creep-relaxation under room temperature and service condition. It is well known that the bolt load decrease to some degree after the initial assembly due to creep-relaxation characteristics of the gasket. ASME PCC-1 recommends restoring the gasket load, after a minimum 4 hours, due to short-term creep-relation.

This paper intends to investigate factors which may influence the creep-relaxation characteristic of the compressed non-asbestos gasket. In order to reproduce real field condition, ASME B16.5 class 300lbs flanges were used in this experimental investigation.

1. INTRODUCTION

1.1 BACKGROUND

Bolted flange connections for piping and pressure vessels loose bolt load over time given the effects of the operating temperature and pressure. This loss of bolt load may result in a leak of a connection that has been operating successfully for some time [1]. The creep relaxation of gaskets is a well know phenomena and it has been subjected to innumerous studies [2-4] however, the current ASME Code [5] does not give a specific procedure to assure that the problem is addressed properly at the design, installation and pressure testing of the joint.

In 2001 ASME issued the PCC-1 -2000 Guidelines for Pressure Boundary Bolted Flange Joint Assembly [6] partially addressing the issue by recommending to tighten the bolts using a standard percent of bolt material yield, which is approximately twice the design stress at room temperature.

Most gasket manufactures and end-users recommend re-tighten the bolts some time after gasket installation in order to compensate for short term creep relaxation. Both ASME PCC-1 and the FSA Gasket Installation Guidelines recommend waiting 4 hours before re-tightening [6-7].

A chart to properly select the bolt load has been presented by Brown and Reeves [8]. This chart is showed in Figure 1 and clearly addresses the problem. In order to keep the joint tight it is necessary to install the gasket with an initial stress Y% which is higher than the minimum X% required to seal.

This Y% stress has to compensate for the uncertainties of the tightening method, stress loss due to thermal loading, load loss due to the internal pressure and any external loading, and the creep of the gasket over time. The stress Y% must also be less than the maximum permissible for the gasket material, bolts and flanges in order to avoid damaging any of them.

1.2 METALLIC GASKETS FIELD EXPERIENCE

Field studies conducted by Chevron Refining Technology in the *El Segundo Refinery* have determined that there is a long term relaxation of corrugated metal gaskets with flexible graphite covering. Figure 2 shows the average stud load loss over an 18 month long period of a critical Heat Exchanger application. It can be seen that after the bolt-up and before system start-up there was a loss of 30% of the initial stud load. The stud load was hot-torqued and after 18 months in service there was a 55% stud load loss. The chart also shows a continuous load loss that explains why it is common to observe in the field that gaskets performing well for a period of time and without any apparent cause start to leak. To reduce the likelihood of a leak, an assembly and bolt-up procedure [10] has been developed and adopted successfully in Chevron Refineries. This procedure requires a re-torque of the bolts when the Heat Exchanger is between 250°F (121°C) to 400°F (204°C). Brown RAST [9] study of gaskets for heat exchanger has confirmed the field results. The gasket comparison of this study was performed after a 300°F (150°C) hot-torquing

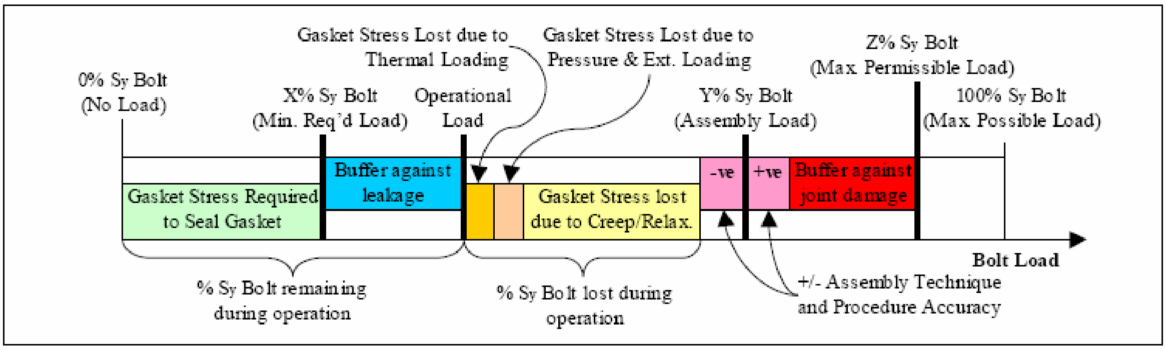


Figure 1 – Bolt Assembly Load Selection Criteria [8]

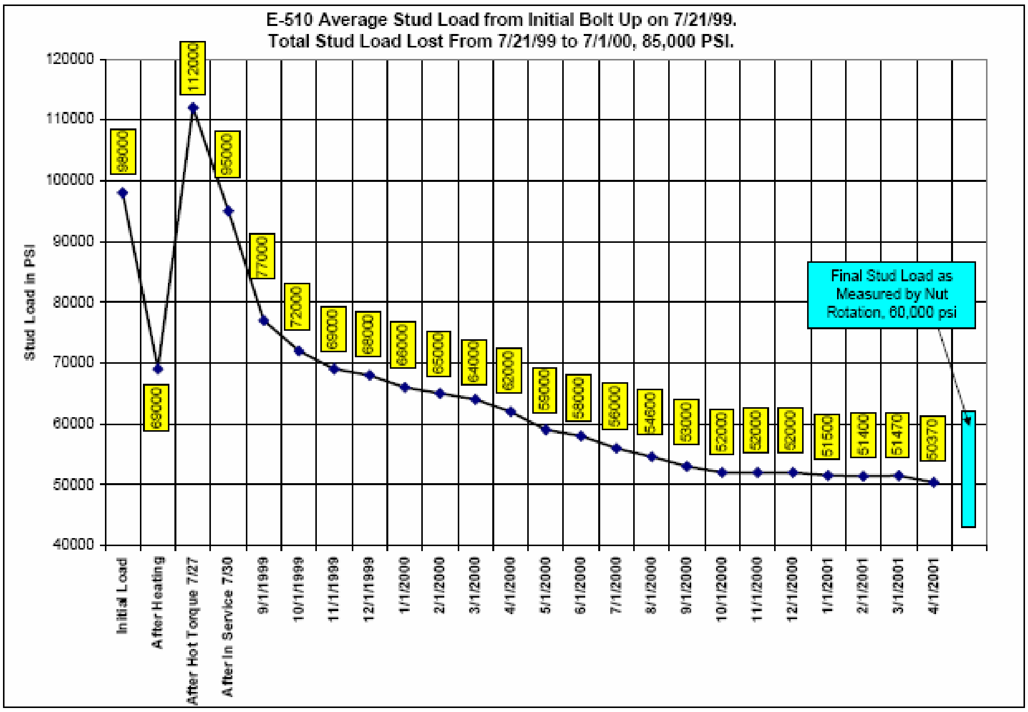


Figure 2 – Stud Load Lost from 7/21/00 to 7/01/00; 85,000psi

1.3 OBJECTIVE OF THIS PAPER

Gasket manufactures, as well as the FSA Gasket Installation Guidelines, recommend not to use Hot-Torquing especially for elastomeric based gaskets as they have a tendency to harden when subjected to high temperatures. The preferred way of reducing the bolt load relaxation is re-tightening the bolts sometime after the installation and before start-up. However, the Heat Exchanger Gasket results indicate that hot-torquing reduces significantly the possibility of a long term gasket failure.

This paper intends to investigate factors which may influence the creep-relaxation characteristic of the compressed non-asbestos gasket like the effects of temperature, gasket load and the tightening of the bolts before and after heating the flanges. The objective is to minimize the yellow area in Figure 1, with the aim of assuring a leak free joint for the duration of the service life. In order to reproduce the real working condition, ASME B16.5 class 300lbs flanges were used in this experimental investigation

2. EXPERIMENTAL

The gasket creep-relaxation was investigated focusing on the influence of temperature and gasket load. The effects of the re-tightening procedure was measured, named here as "*Room Temperature Torquing*", when re-torquing is applied 4 hours after the gasket is installed at room temperature according PCC-1-2000 recommendation [6] and "*Hot-Torquing*" when the torquing is applied 4 hours after heat is applied. The 2^2 Factorial Design (Table 1) with two experimental factors (Temperature and Gasket Load) at two levels (low (-1) and high (+1)) was used to study if experimental factors have influence on the response variable, considering both types of re-tightening procedures.

Table 1 - Experimental run according Complete Factorial Design

Run	Temperature, °F (°C)		Gasket Load, psi (MPa)	
1	-1	77 (25)	-1	7250 (50)
2	-1	77 (25)	+1	20300 (140)
3	+1	392 (200)	-1	7250 (50)
4	+1	392 (200)	+1	20300 (140)
Central point	0	234 (112)	0	13775 (95)

The temperature and gasket load values adopted were based on recommended working conditions; therefore the following criteria was used:

✓ The temperature should be lower than maximum temperature recommendation of respective compressed non-asbestos gasket [11] or be lower than 400°F, which is the limit recommended for Hot-Torquing according to Chevron Procedure [10] since in this temperature the stud and nut friction factor increase substantially as the lubricant burns off.

✓ The Gasket Load must be higher than the minimum required to seal [5,12].

The Response Variable is named here as "*Torque Retention*", and it is defined as percent of the Gasket Load Loss. The analyses of the experiment were done using the software Statgraphics Plus version 5.

Material: Three styles of Non-Asbestos Fiber Sheet 1/16in were tested. Table 2 shows the composition of each one. The gasket tested was a ring type, size 2 inches class 300, $2^3/_8$" (60.4mm) ID and $4^3/_8$" (111.25mm) OD.

Table 2 - Samples of Non-Asbestos Fiber Sheet

Material	Manufacturer	Fiber	Rubber
Sample #1	A	Carbon Fiber	NBR
Sample #2	B	Aramid Fiber	NBR
Sample #3	A	Aramid Fiber	SBR

Heating: The flanges were heated from room to test temperature in one hour. The heat rate is shown at Table 3. Heating is by electrical cartridge heaters inside the flanges to simulate actual field conditions.

Table 3 – Heat Rate Test

Temperature, °F (°C)	°F/min	°C/min
392 (200)	6.5	3.3
234 (112)	3.9	1.9

Apparatus: A pressure vessel composed by two ASME B16.5 Standard Flanges with a heating cartridge inside, outside insulation and a digital controller was used for the test. Calibrated 5/8 inches bolts (ASTM A193 B7) with tempered washer GRB 5/8 were used to measure the bolt load.

Test Procedure:

1. Ensure the flange assembly has been cleaned
2. Ensure the bolts, nuts, washers are not damaged and the nuts can be freely assembled on the bolts.
3. Clean bolt, nuts and washers with an organic solvent. Lubricate them with molybdenum disulfide anti-seize
4. Cut standard ASME 2 inches class 300 ring gaskets.
5. Center the gasket on the raised face of weld neck flange.
6. Torque the bolt according ASME PCC-1 [6] tightening in three increments of 20, 50 and 100%.
7. Re-tightening procedures:
  7.1 Room Temperature Torquing: After 4 hours, re-tightening the bolts and then raise the temperature to set test condition.
  7.2 Hot-torquing: turn the heating on, after 4 hours re-tightening the bolts.
8. Measure the bolt load every 2 hours
9. After 12 hours, cool down the flanges to room temperature.

3. RESULTS AND DISCUSSION

3.1 FACTORIAL DESIGN ANALYSES

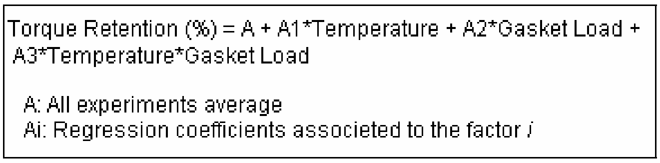
The Complete Factorial Design analyses for all samples are shown in attachments 1 to 6. Each analysis shows:

- ANOVA Table: In general, the purpose of ANOVA is yield values that can be tested in order to determine whether a significant influence exists between investigated factors (in this case, they are Temperature, Gasket Load and their interactions) and variable response (Torque Retention). As a result, P-value lower than 0.05 means that the respective factor has a significant influence on Torque Retention.

- The Estimated Effects Table and Pareto Chart: They show the factors in decreasing order of importance regarding the *Torque Retention* influence;

- Main Effects and Interaction Plots: They shown if the investigated factors have a positive or negative effect on the *Torque Retention;*

- Equation Model Regression: A regression equation (Figure 3) which has been fitted to the data is presented. This model can be used to generate the predicted values of the Torque Retention, considering the studied limits.

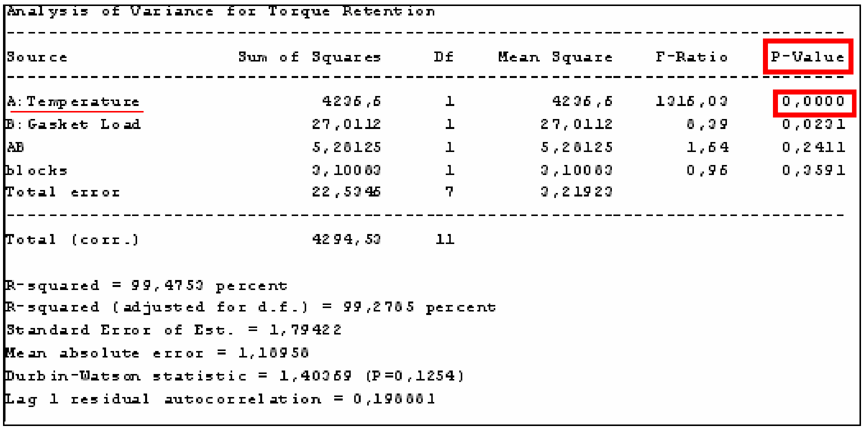


Torque Retention (%) = A + A1*Temperature + A2*Gasket Load + A3*Temperature*Gasket Load

A: All experiments average
Ai: Regression coefficients associeted to the factor *i*

Figure 3 – Regression Equation model Example

The presented analysis shows that, independent of the tested material and the re-tightening procedure, the main factor that contributes to gasket creep-relaxation is the Temperature. For an example, according to the Figure 4, which shows the ANOVA Table for Sample #1 tested after "*Room Temperature Torquing*", the P-value of Temperature factor is 0.000. Comparing this value with the other P-values it is possible to see how strong the temperature influence is. The same results can be verified through Pareto Chart (Figure 5). A similar result was observed for the other materials tested.



```
Analysis of Variance for Torque Retention
--------------------------------------------------------------------------------
Source                  Sum of Squares     Df   Mean Square    F-Ratio   P-Value
--------------------------------------------------------------------------------
A:Temperature                   4236,6      1        4236,6    1316,03    0,0000
B:Gasket Load                  27,0112      1       27,0112       8,39    0,0231
AB                             5,28125      1       5,28125       1,64    0,2411
blocks                         3,10083      1       3,10083       0,96    0,3591
Total error                    22,5346      7       3,21923
--------------------------------------------------------------------------------
Total (corr.)                  4294,53     11

R-squared = 99,4753 percent
R-squared (adjusted for d.f.) = 99,2785 percent
Standard Error of Est. = 1,79422
Mean absolute error = 1,18958
Durbin-Watson statistic = 1,40369 (P=0,1254)
Lag 1 residual autocorrelation = 0,198881
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Figure 4 – ANOVA Table – Sample #1 at *Room Temperature Torquing Procedure*

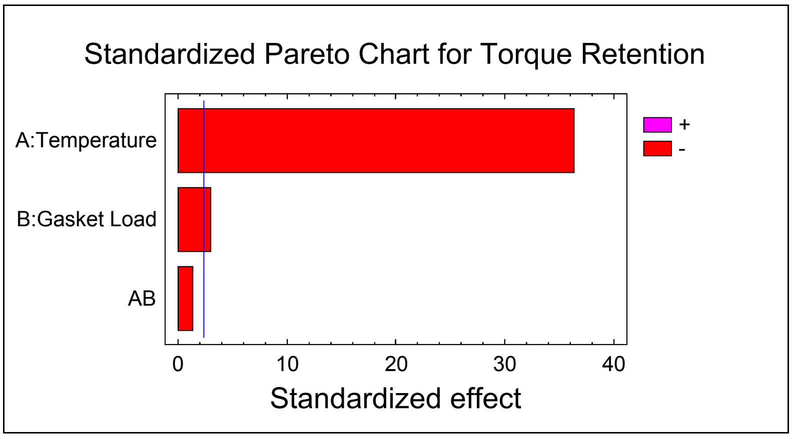

Figure 5 – Pareto Chart – Sample #1 at *Room Temperature Torquing Procedure*

According to the Main Effects Plots, Temperature has a negative effect on the *Torque Retention*; as a consequence Torque retention decreases as the Temperature is increased. Figure 6 shows this chart for Sample #1 as an example.

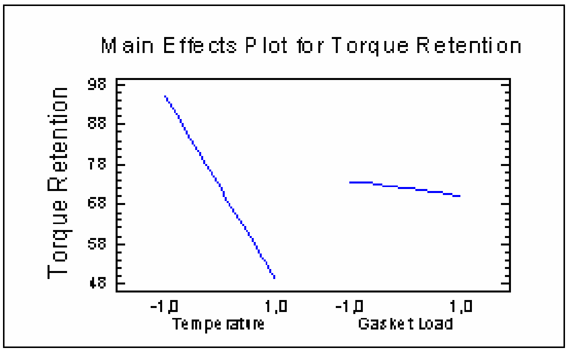

Figure 6 – Main Effects Plot – Sample #1 at *Room Temperature Torquing Procedure*

The Temperature influence is more perceptible when comparing *Room Temperature Torquing* and *Hot-Torquing* results. As an example, Figure 7 shows the Pareto's Charts for Sample #3 for both types of re-tightening procedures.

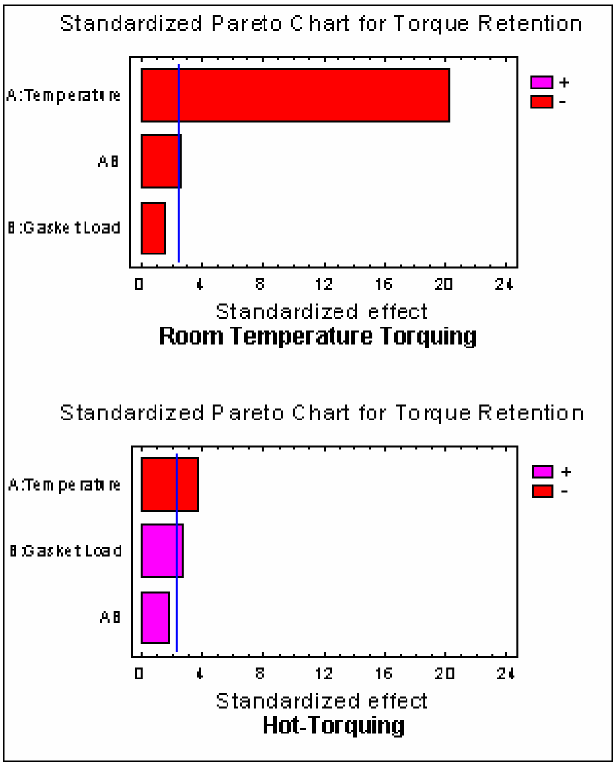

Figure 7 – Pareto Chart at Sample #3

3.2 RE-TITGHTENING COMPARISON

Figures 8 and 9 show *Room Temperature Torquing* and *Hot-Torquing* Estimated Response Surfaces for sample #1. Based on these charts, it is possible to observe when the *Hot-Torquing* was applied, the Estimated Response Surface is nearly parallel to the Temperature and Gasket Load plane, but on the other hand, when *Room Temperature Torquing* was used, a significant reduction of *Torque Retention* was observed as the Temperature increases. The same conclusion was observed for sample #2 (Figures 10 and 11) and for sample #3 (Figures 12 and 13).

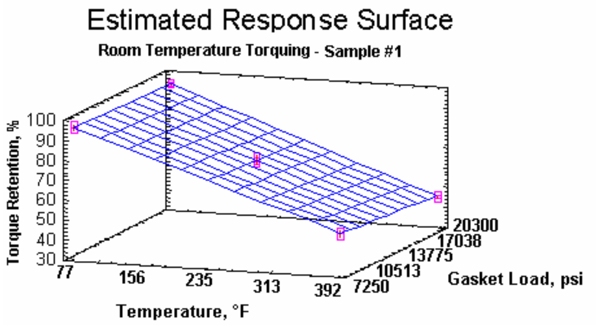

Figure 8 – Estimated Response Surface for Sample #1; Room Temperature Torquing

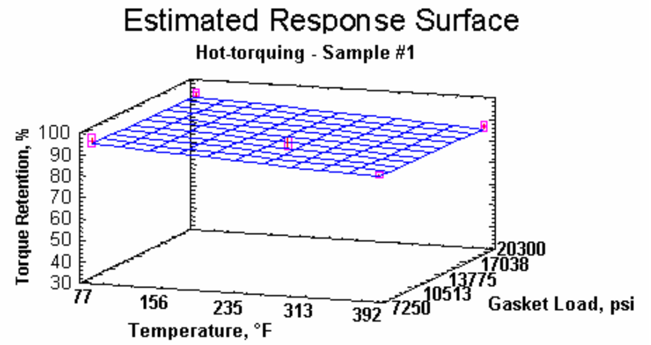

Figure 9 – Estimated Response Surface for Sample #1; Hot-Torquing

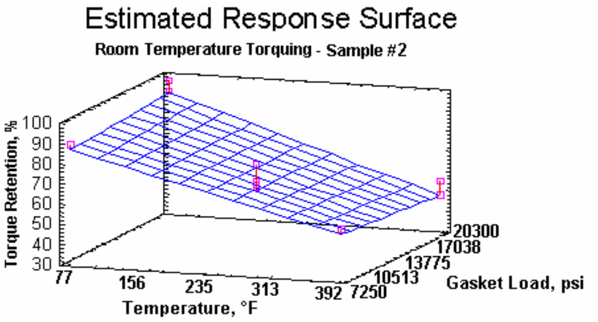

Figure 10 – Estimated Response Surface for Sample #2; Room Temperature Torquing

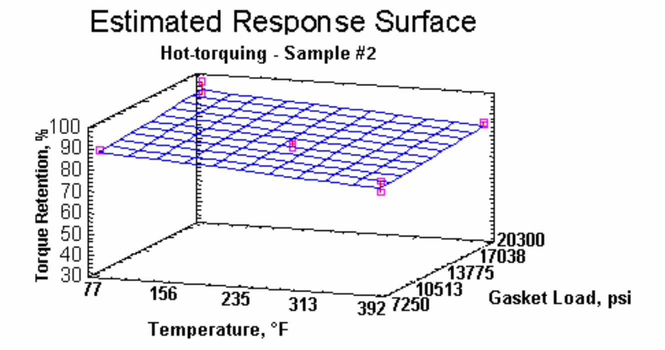

Figure 11 – Estimated Response Surface for Sample #2; Hot-Torquing

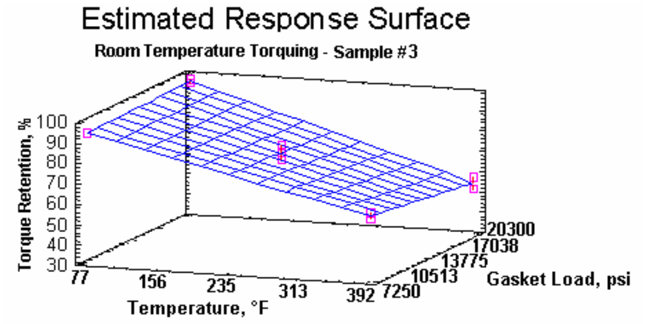

Figure 12 – Estimated Response Surface for Sample #3; Room Temperature Torquing

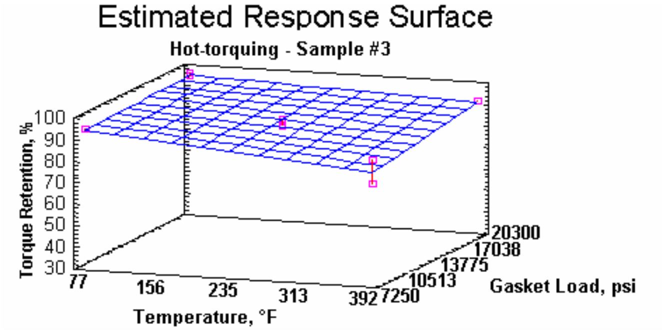

Figure 13 – Estimated Response Surface for Sample #3; Hot-Torquing

These results show that the re-tightening procedure has a significant influence on the *Torque Retention* and it suggests that *Hot-Torquing* could be more effectively used in compressed non-asbestos gasket installation since it minimizes the gasket creep-relaxation.

The lower performance of the *Room Temperature Torquing* procedure, when compared to *Hot-Torquing* results, can be explained by the fact that Temperature is the most important factor that contributes negatively to gasket creep-relaxation. Thus, re-torquing at room temperature can restore only short-term creep relaxation due to room temperature gasket relaxation, but, on the other hand, the Hot-Torque procedure can restore the more pronounced effect of creep relaxation due to temperature.

Similar conclusion regarding *Hot-Torquing* was observed in the tested with corrugated metal gaskets with flexible graphite covering conducted by Chevron [10].

3.3 PREDICTION OF TORQUE RETENTION

To test the prediction of the regression equation obtained by Experimental Design, extra tests were carried out according to the Table 3.

Table 3 - Extra Test Condition

Material	Re-tightening procedure	Temperature	Gasket Load
Sample #1	Hot-Torquing	356°F (180°C)	12180psi (84 MPa)
Sample #2	Room Temperature Torquing	356°F (180°C)	10150psi (70 Mpa)
Sample #3	Hot-Torquing	302°F (150°C)	14500psi (100 Mpa)

The Torque Retention Predictions, as shown in Table 4, suggest that regression equations can be used as a tool to estimate a gasket creep relaxation, as the test results are in accordance with respective predicted values.

Table 4 - Estimation Result using Statgraphics Plus version 5 (95%CL) for Torque Retention (%)

Regression Equation		**Test Results**
Fitted value	**Forecast**	
Sample #1 - Hot-Torquing		
88	82 – 94	84; 85
Sample #2 - Room Temperature Torquing		
56	41 – 71	46; 65
Sample #3 - Hot-Torquing		
90	83 – 97	83; 86

Note: CL: Confidence Level

The results presented suggest that Regression Equations obtained by Experimental Data can be used in order to predict the yellow area [8] in the Bolt Load Chart for a specific gasket. Thus, test criteria and procedures must be discussed and developed with the purpose of assuring applicability.

4. Conclusion

Based on the 2^2 Factorial Design Analyses, the most important experimental factor which contributes to gasket creep-relaxation is Temperature.

Hot-Torquing is a procedure that contributes to restoring stud load loss due to gasket creep relaxation; it can be used to minimize the yellow area of the Bolt Load Chart.

Although the results show *Hot-Torquing* as a recommended re-tightening procedure for compressed non-asbestos gasket fiber, it is important to call attention to the fact that elastomeric based gaskets have a tendency to harden when they are subjected to elevated temperatures. It means that a *Hot-Torque* procedure must be developed in order to guarantee safe installation and long life service time.

Experiments can be used to produce a model for gasket creep-relaxation prediction; however Field Test must be carried out in order to validate the equation.

References

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[12]. Teadit Ind. Com Ltda, " *"Y" stress and "m" Factor for the Calculation of the Gasket Bolting",* Internal Test Procedure, mai/2004, RJ, BR

ANALYZE EXPERIMENT – ATTACHMENT 01
SAMPLE # 1 – ROOM TEMPERATURE TORQUING

```
Analysis of Variance for Torque Retention
--------------------------------------------------------------------------------
Source                     Sum of Squares     Df      Mean Square     F-Ratio     P-Value
--------------------------------------------------------------------------------
A:Temperature                    4236,6        1           4236,6     1316,03      0,0000
B:Gasket Load                   27,0112        1          27,0112        8,39      0,0231
AB                              5,28125        1          5,28125        1,64      0,2411
blocks                          3,10083        1          3,10083        0,96      0,3591
Total error                     22,5346        7          3,21923
--------------------------------------------------------------------------------
Total (corr.)                   4294,53       11

R-squared = 99,4753 percent
R-squared (adjusted for d.f.) = 99,2785 percent
Standard Error of Est. = 1,79422
Mean absolute error = 1,18958
Durbin-Watson statistic = 1,40369 (P=0,1254)
Lag 1 residual autocorrelation = 0,198881
```

```
File name: D:\Meus documentos\sample#1.sfx

Estimated effects for Torque Retention
----------------------------------------------------------------------
average         = 72,0083 +/- 0,517947
A:Temperature   = -46,025 +/- 1,26871
B:Gasket Load   = -3,675  +/- 1,26871
AB              = -1,625  +/- 1,26871
block           = 1,01667 +/- 1,03589
----------------------------------------------------------------------
Standard errors are based on total error with 7 d.f.
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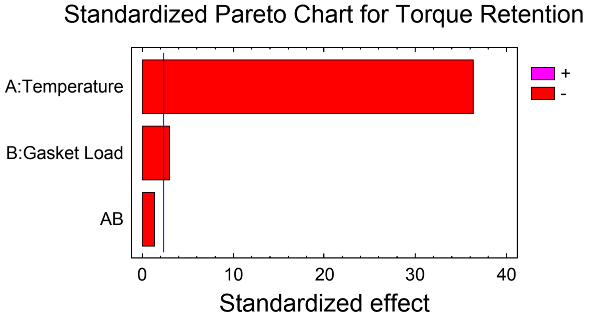

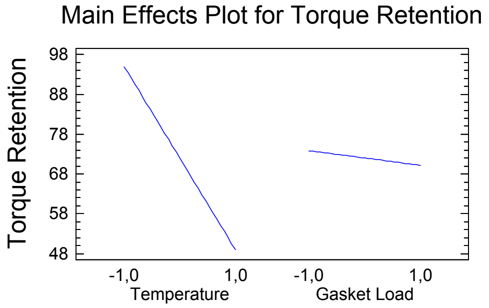

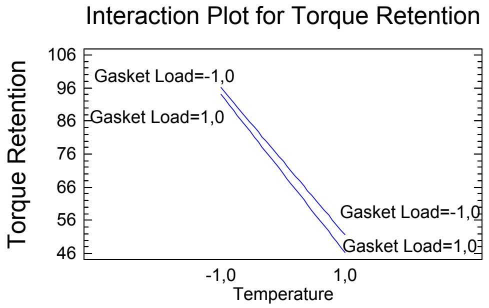

```
Torque Retention = 72,0083 - 23,0125*Temperature - 1,8375*Gasket Load
- 0,8125*Temperature*Gasket Load
```

Torque Retention (%)

Temperature (°C) = (X – 112,5) / 87,5   25°C ≤ X ≤ 200°C
Gasket Load (MPa) = (Y – 95) / 45   50 MPa ≤ Y ≤ 140 MPa

ANALYZE EXPERIMENT – ATTACHMENT 02
SAMPLE # 1 – HOT-TORQUING

```
Analysis of Variance for Torque Retention
--------------------------------------------------------------------------------
Source                   Sum of Squares     Df    Mean Square    F-Ratio    P-Value
--------------------------------------------------------------------------------
A:Temperature                  86,4612       1        86,4612      16,67     0,0035
B:Gasket Load                  5,95125       1        5,95125       1,15     0,3153
blocks                         6,16333       1        6,16333       1,19     0,3073
Total error                    41,4808       8         5,1851
--------------------------------------------------------------------------------
Total (corr.)                  140,057      11

R-squared = 70,3828 percent
R-squared (adjusted for d.f.) = 63,8012 percent
Standard Error of Est. = 2,27708
Mean absolute error = 1,60556
Durbin-Watson statistic = 1,51993 (P=0,1392)
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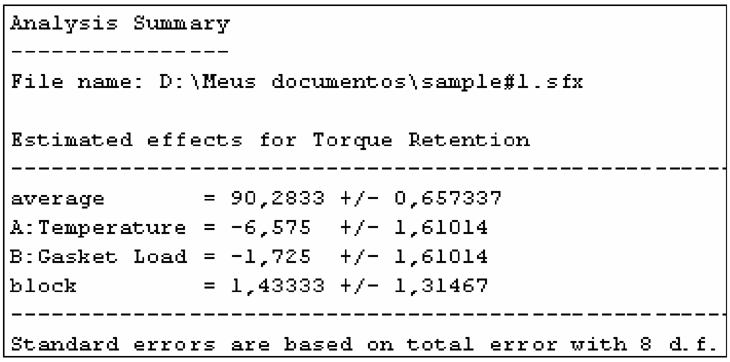

```
Analysis Summary
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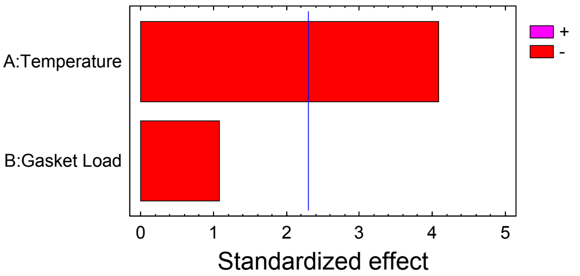
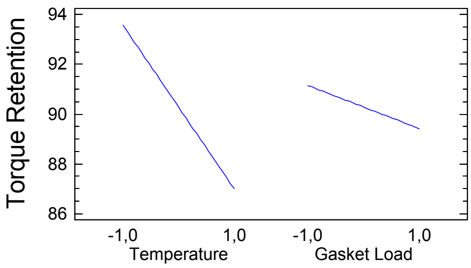
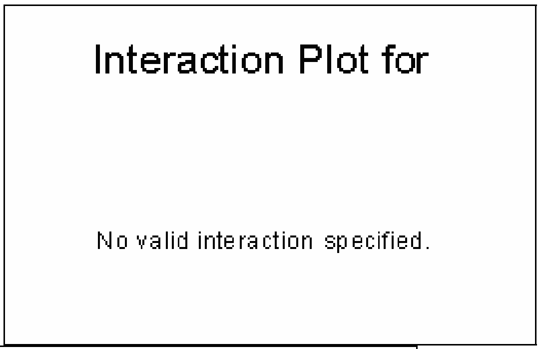
Estimated effects for Torque Retention
----------------------------------------------------------------------
average        = 90,2833 +/- 0,657337
A:Temperature  = -6,575  +/- 1,61014
B:Gasket Load  = -1,725  +/- 1,61014
block          = 1,43333 +/- 1,31467
----------------------------------------------------------------------
Standard errors are based on total error with 8 d.f.
```

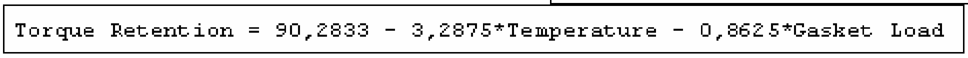
Standardized Pareto Chart for Torque Retention



Main Effects Plot for Torque Retention







```
Torque Retention = 90,2833 - 3,2875*Temperature - 0,8625*Gasket Load
```

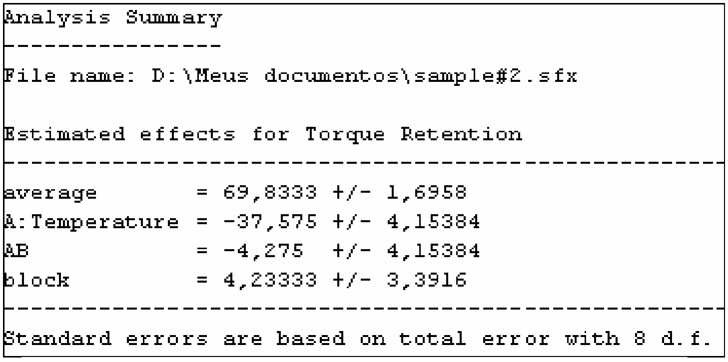
Torque Retention (%)

Temperature (°C) = (X – 112,5) / 87,5 — 25°C ≤ X ≤ 200°C
Gasket Load (MPa) = (Y – 95) / 45 — 50 MPa ≤ Y ≤ 140 MPa

ANALYZE EXPERIMENT – ATTACHMENT 03
SAMPLE # 2 – ROOM TEMPERATURE TORQUING

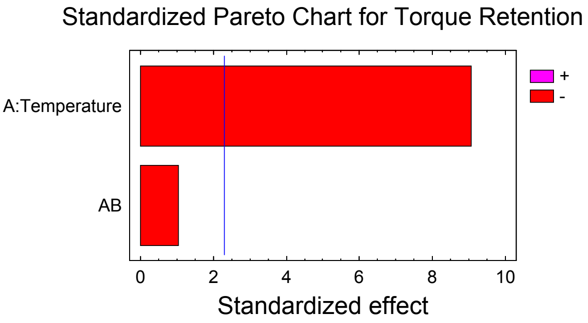
```
Analysis of Variance for Torque Retention
--------------------------------------------------------------------------------
Source                  Sum of Squares     Df    Mean Square    F-Ratio    P-Value
--------------------------------------------------------------------------------
A:Temperature                  2823,76      1        2823,76      81,83     0,0000
AB                             36,5512      1        36,5512       1,06     0,3335
blocks                         53,7633      1        53,7633       1,56     0,2473
Total error                    276,071      8        34,5089
--------------------------------------------------------------------------------
Total (corr.)                  3190,15     11

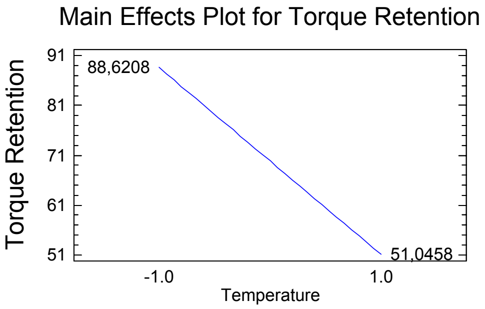
R-squared = 91,3461 percent
R-squared (adjusted for d.f.) = 89,4231 percent
Standard Error of Est. = 5,87442
Mean absolute error = 3,93889
Durbin-Watson statistic = 1,70308 (P=0,1770)
Lag 1 residual autocorrelation = 0,110692
```

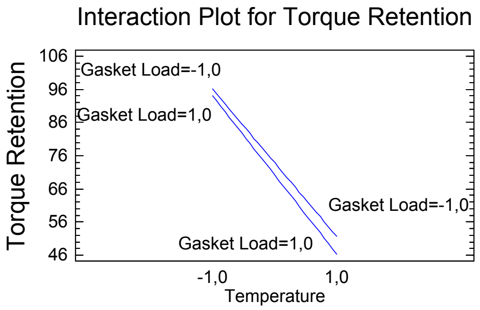


```
Analysis Summary
----------------
File name: D:\Meus documentos\sample#2.sfx

Estimated effects for Torque Retention
----------------------------------------------------------------------
average        = 69,8333 +/- 1,6958
A:Temperature  = -37,575 +/- 4,15384
AB             = -4,275  +/- 4,15384
block          = 4,23333 +/- 3,3916
----------------------------------------------------------------------
Standard errors are based on total error with 8 d.f.
```







```
Torque Retention = 69,8333 - 18,7875*Temperature -
2,1375*Temperature*Gasket Load
```

Torque Retention (%)

Temperature (°C) = (X – 112,5) / 87,5   25°C ≤ X ≤ 200°C
Gasket Load (MPa) = (Y – 95) / 45   50 MPa ≤ Y ≤ 140 MPa

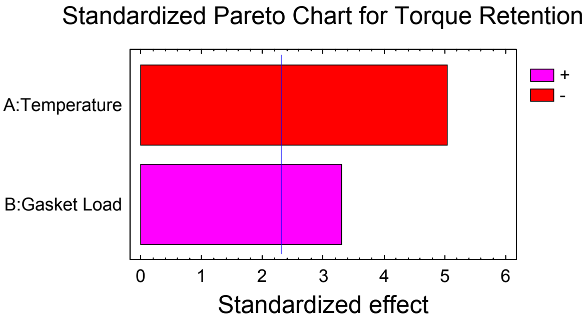
ANALYZE EXPERIMENT – ATTACHMENT 04
SAMPLE # 2 – HOT-TORQUING

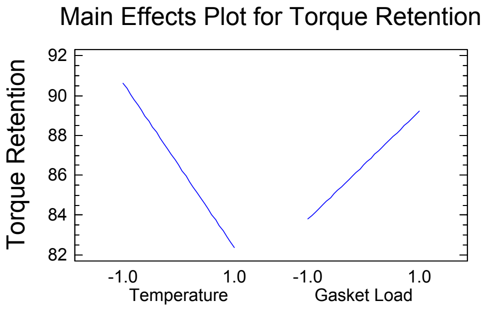
```
Analysis of Variance for Torque Retention
--------------------------------------------------------------------------------
Source                 Sum of Squares     Df    Mean Square    F-Ratio    P-Value
--------------------------------------------------------------------------------
A:Temperature                 136,951      1        136,951      25,35     0,0010
B:Gasket Load                 58,8612      1        58,8612      10,90     0,0108
blocks                        15,4133      1        15,4133       2,85     0,1297
Total error                   43,2142      8        5,40177
--------------------------------------------------------------------------------
Total (corr.)                  254,44     11

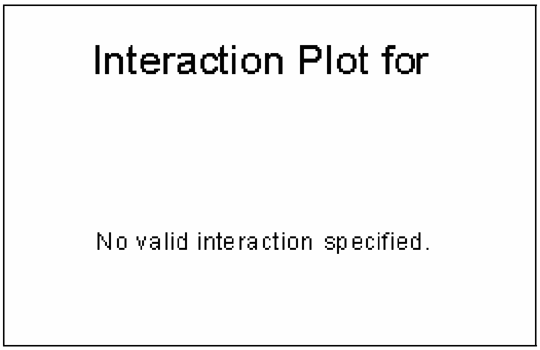
R-squared = 83,016 percent
R-squared (adjusted for d.f.) = 79,2417 percent
Standard Error of Est. = 2,32417
Mean absolute error = 1,5875
Durbin-Watson statistic = 1,1511 (P=0,0354)
Lag 1 residual autocorrelation = 0,244461
```

```
Analysis Summary
----------------
File name: D:\Meus documentos\sample#2.sfx

Estimated effects for Torque Retention
----------------------------------------------------------------------
average        = 86,5    +/- 0,67093
A:Temperature  = -8,275  +/- 1,64344
B:Gasket Load  = 5,425   +/- 1,64344
block          = 2,26667 +/- 1,34186
----------------------------------------------------------------------
Standard errors are based on total error with 8 d.f.
```






Interaction Plot for

No valid interaction specified.

```
Torque Retention = 86,5 - 4,1375*Temperature + 2,7125*Gasket Load
```

Torque Retention (%)

Temperature (°C) = (X – 112,5) / 87,5 25°C ≤ X ≤ 200°C
Gasket Load (MPa) = (Y – 95) / 45 50 MPa ≤ Y ≤ 140 MPa

ANALYZE EXPERIMENT – ATTACHMENT 05
SAMPLE # 3 – ROOM TEMPERATURE TORQUING

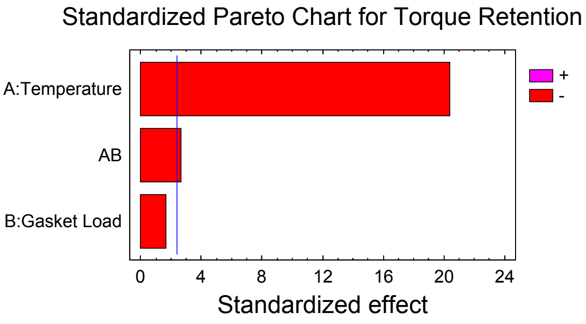
```
Analysis of Variance for Torque Retention
--------------------------------------------------------------------------------
Source                 Sum of Squares     Df     Mean Square     F-Ratio     P-Value
--------------------------------------------------------------------------------
A:Temperature                 2679,12      1         2679,12      413,96      0,0000
B:Gasket Load                  17,405      1          17,405        2,69      0,1450
AB                              44,18      1           44,18        6,83      0,0348
blocks                        3,10083      1         3,10083        0,48      0,5111
Total error                   45,3033      7          6,4719
--------------------------------------------------------------------------------
Total (corr.)                 2789,11     11

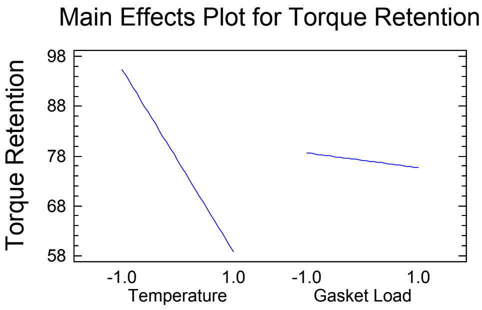
R-squared = 98,3757 percent
R-squared (adjusted for d.f.) = 97,7666 percent
Standard Error of Est. = 2,54399
Mean absolute error = 1,45833
Durbin-Watson statistic = 2,82024 (P=0,0593)
Lag 1 residual autocorrelation = -0,414748
```

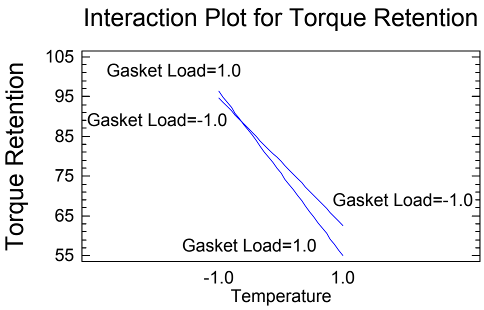
```
Analysis Summary
----------------

File name: D:\Meus documentos\sample#3.sfx

Estimated effects for Torque Retention
----------------------------------------------------------------------
average        = 77,1417 +/- 0,734388
A:Temperature  = -36,6   +/- 1,79888
B:Gasket Load  = -2,95   +/- 1,79888
AB             = -4,7    +/- 1,79888
block          = 1,01667 +/- 1,46878
----------------------------------------------------------------------
Standard errors are based on total error with 7 d.f.
```







```
Torque Retention = 77,1417 - 18,3*Temperature - 1,475*Gasket Load -
2,35*Temperature*Gasket Load
```

Torque Retention (%)

Temperature (°C) = (X – 112,5) / 87,5 25°C ≤ X ≤ 200°C
Gasket Load (MPa) = (Y – 95) / 45 50 MPa ≤ Y ≤ 140 MPa

ANALYZE EXPERIMENT – ATTACHMENT 06
SAMPLE # 3 – HOT-TORQUING

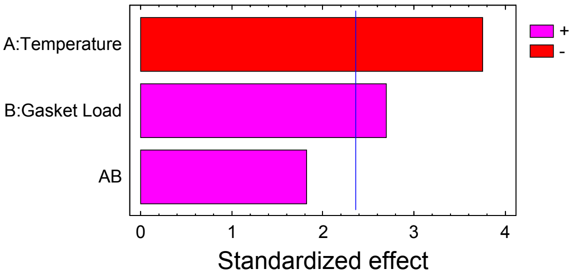
```
Analysis of Variance for Torque Retention
--------------------------------------------------------------------------------
Source                    Sum of Squares     Df     Mean Square     F-Ratio     P-Value
--------------------------------------------------------------------------------
A:Temperature                   111,005      1         111,005       14,04      0,0072
B:Gasket Load                    57,245      1          57,245        7,24      0,0311
AB                                25,92      1           25,92        3,28      0,1132
blocks                            17,28      1           17,28        2,18      0,1829
Total error                       55,36      7         7,90857
--------------------------------------------------------------------------------
Total (corr.)                    266,81     11

R-squared = 79,2512 percent
R-squared (adjusted for d.f.) = 71,4703 percent
Standard Error of Est. = 2,81222
Mean absolute error = 1,7
Durbin-Watson statistic = 2,37893 (P=0,2206)
Lag 1 residual autocorrelation = -0,220737
```

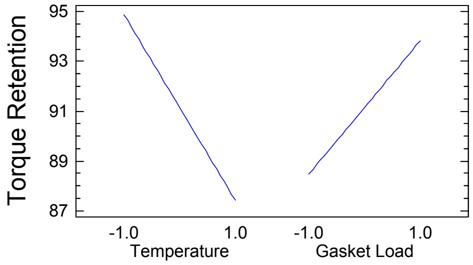
```
Analysis Summary
----------------
File name: D:\Meus documentos\sample#3.sfx

Estimated effects for Torque Retention
----------------------------------------------------------------------
average         = 91,15 +/- 0,811817
A:Temperature = -7,45 +/- 1,98854
B:Gasket Load = 5,35  +/- 1,98854
AB              = 3,6   +/- 1,98854
block           = 2,4   +/- 1,62363
----------------------------------------------------------------------
Standard errors are based on total error with 7 d.f.
```

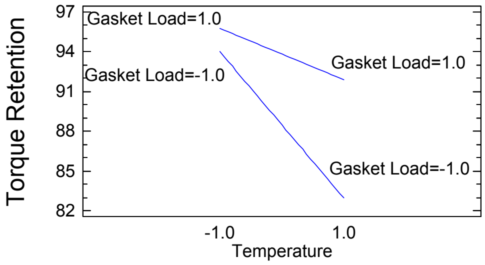
Standardized Pareto Chart for Torque Retention



Main Effects Plot for Torque Retention



Interaction Plot for Torque Retention



```
Torque Retention = 91,15 - 3,725*Temperature + 2,675*Gasket Load +
1,8*Temperature*Gasket Load
```

Torque Retention (%)

Temperature (°C) = (X – 112,5) / 87,5   25°C ≤ X ≤ 200°C
Gasket Load (MPa) = (Y – 95) / 45   50 MPa ≤ Y ≤ 140 MPa