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Bolt Anti-Seize Performance in a Process Plant Environment

Warren Brown
The Equity Engineering Group
Shaker Heights, OH, USA
iwbrown@equityeng.com

Luc Marchand
TTRL /Ecole Polytechnique
Montreal, QC, Canada
luc.marchand@polymtl.ca

Thierry LaFrance
TTRL /Ecole Polytechnique
Montreal, QC, Canada
thlafr@polymtl.ca

ABSTRACT

This paper details recent testing that was performed as an extension of earlier work on nut factor and high temperature Break-out performance of selected anti-seize products. Comparison is made between previous results obtained on C-Si bolts (ASTM A193 B7) with more recent tests on 316 Stainless Steel bolts (ASTM A193 B8M). The bolt nut factor versus temperature and the required Break-out torque after one week at elevated temperature are detailed.

In addition, common theories regarding the unsuitability of anti-seize containing graphite on stainless steel and the use of milk of magnesia as an anti-seize are quantitatively tested by comparison with standard anti-seize products. The test methods used are designed to closely mimic actual bolt assembly in a process plant environment. The paper, therefore, presents useful information that will enable more accurate assembly of bolted flanged joints on pressure vessels and piping in any process plant environment.

INTRODUCTION

Bolt anti-seize products play an important role in the operation of pressure vessel and piping joints in process plants. During joint assembly they reduce the friction at the nut face and thereby allow the user to set the desired bolt by using measurement of torque. In addition, a good anti-seize enables pipe-fitters or boilermakers to disassemble bolted joints without needing to cut bolts or split nuts. This greatly reduces the effort and time required to complete maintenance activities on bolted joints and results in tremendous net savings, due to reduced turn-around duration and associated increase in plant availability and productivity.

In the past, the end user has had to rely on manufacturer supplied data or reference material, such as Bickford [1], for commentary on the effectiveness of the different bolt anti-seize products available and tables of friction (nut) factors. However, as noted in Bickford, there is a wide variation in the performance of "similar" anti-seize products. Table 1 is re-produced from Bickford and demonstrates the range that can be expected for the nut factors of several typical anti-seize products.

Table 1 – Typical Nut Factors (from Bickford [1])

	min.	mean	max.
Everlube 810	0.09	-	0.115
Fel-Pro C54	0.069	0.086	0.103
Fel-Pro C670	0.08	0.132	0.23
Fel-Pro N5000	0.08	0.095	0.15
Machine Oil	0.1	0.21	0.225
Never-Seize	0.11	0.17	0.21

The listed values for different lubricants in the above table are obviously obtained from testing, however the limits of the applicability of such nut factors or an explanation of the testing conducted to obtain them was not given. Such a table is, therefore, only useful if the end-user assumes the values apply to their application and if they use one of the listed lubricants.

Ideally, an end user should be able to request the anti-seize performance characteristics from the manufacturer. However, this has proven to be an unrealistic expectation and, as will be shown later in this paper, the manufacturers themselves are often not aware of the performance characteristics of their own anti-seize products when applied in a process plant environment. It should be noted that this is not, generally, the fault of the anti-seize manufacturer. They will, most appropriately, quote test results obtained from standardised testing. The available standardised tests (such as SAE-J174 [2] and ISO-16047 [3]) are focussed on automotive or aerospace applications and as such the thread forms and bolt sizes around which the tests were designed are different to those commonly used in pressure vessel and piping bolted joint applications. The results are, therefore, often not applicable to process plant applications and this can lead to inappropriate nut factors and inaccurate setting of bolt loads.

The refining and process industries have not developed their own standardised tests and, therefore, it is impossible to select a bolt anti-seize based on comparative nut factor or disassembly performance for applications in those industries. Not only are the bolts and tightening techniques in a process plant different to automotive or aerospace applications, but the conditions over which anti-seize products are used are also different. For example, pressure vessel and piping bolted joints are not assembled in a controlled environment and so the ambient temperature during assembly can vary from –40°C to +50°C (-40°F to +120°F) or worse. In addition, a common practice in refineries is to tighten a bolted joint as it heats up to between 175°C to 230°C (350°F to 450°F), in order to regain lost bolt load due to gasket relaxation (hot-torque). So nut factor data can be required, for one joint alone, over a 270°C (500°F) temperature range.

The various factors that affect anti-seize performance in the process plant environment have not been comprehensively studied for a wide range of lubricants to date. It is common to neglect the effect of temperature, bolt size, amount of lubricant applied, bolt material, joint surface finish and variation in "generically similar" lubricants. For example, the guideline on pressure vessel and piping joint assembly, ASME PCC-1 [4], uses a single friction factor of 0.16, which equates to nut factor of around 0.2 depending on bolt size, for all non-coated bolt applications. It will be seen later in this paper that the use of a single value for all applications may result in gross under-loading or over-loading of a joint.

The lack of standardised testing for anti-seize performance led to the development of two simple test procedures at TTRL/Ecole Polytechnique in Montreal, Canada during 2002. These tests were specifically aimed at developing performance test measures for anti-seize products in process plant (specifically, oil refining) applications. The testing consisted of a nut-factor test, performed at five different temperatures and a Break-out test, performed after ageing of the test assembly in an oven to simulate actual bolted joint operation. The focus of the initial test program was to provide comparative test data on different anti-seize products using results gathered with test methods that closely matched actual process plant joint assembly and operation.

Results from the initial testing on ASTM A193-B7 studbolts were presented in Brown [5]. While this bolt type is the most common used in the refining industry, the behaviour of anti-seize products with stainless steel materials was known to be different. Since stainless steel is used in high temperature, and therefore critical applications in refining, the original test methods were recently extended to include testing on 316SS (ASTM A193-B8M) bolts.

TEST METHOD SUMMARY

The first series of tests were performed on 7/8 inch diameter UNC, ASTM A193-B7 studbolts with ASTM A194-2H nuts and ASTM F436 through-hardened washers. The second series of tests were conducted using 7/8 inch diameter UNC, ASTM A193-B8M studbolts with A194-8M nuts and 304 Stainless Steel washers. The nut factor tests were conducted using a load cell to measure the applied load and a strain-gauged ring spanner to measure the applied torque (Fig. 1). The bolts and nuts were lubricated at only one end and tightened through a solid metal cylinder. A new bolt and nut were used for each test. The cylinder was heated to maintain the test surfaces at the required test temperature. For the tests conducted at temperatures above ambient, the bolts were first soaked in an oven at the test temperature for one to two hours prior to testing. Six bolts were tested for each lubricant and each temperature value. The data collection system allowed the recording of over 50 test points for each of the bolts tested. Each of the nut factors for a given lubricant and temperature are therefore obtained from the statistical treatment of over 300 test points.

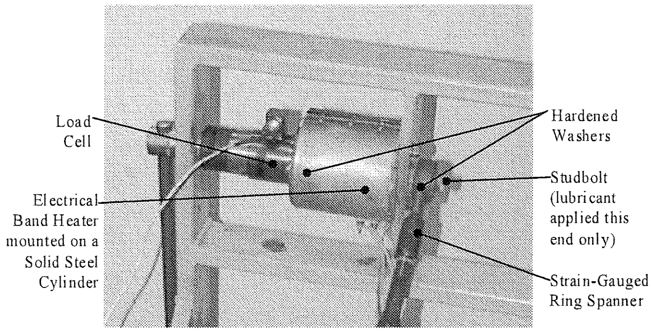

Figure 1 - Nut Factor Test Rig

Nut Factor tests were conducted at a total of five different temperatures: -5°C (23°F), 25°C (75°F), 40°C (105°F), 100°C (210°F) and 200°C (390°F). Ten different types of lubricants, from a variety of manufacturers, and two special lubricant mixtures were tested. The lubricants are identified as following:

CE1 - ceramic based lubricant (max. temp: 1650°C/3000°F, Nut Factor: N.A.)

CU1 - copper based lubricant (max. temp: 982°C/1800°F, Nut Factor:0.16)

CU2 - copper based lubricant (max. temp: 982°C/1800°F, Nut Factor: 0.12 [1])

GR1 - Graphite based lubricant (max. temp: 1095°C/2000°F, Nut Factor: N.A.)

MO1 - molybdenum disulfide based lubricant (max. temp: 400°C/750°F[2], Nut Factor.: 0.10 [3])

MO2a - molybdenum disulfide based lubricant (max. temp: 1316°C/2400°F[2], Nut Factor.: 0.08 [3])

MO2b - molybdenum disulfide based lubricant (max. temp: 1316°C/2400°F[2], Nut Factor.: 0.08 [3])

MO3 - molybdenum disulfide based lubricant (max. temp: 1316°C/2400°F[2], Nut Factor.: 0.16)

NI1 - nickel based lubricant (max. temp: 1315°C/2400°F [4], Nut Factor: N.A.)

NI2 - nickel based lubricant (max. temp: 1370°C/2500°F, Nut Factor: 0.15 [3])

MH1 – Magnesium Hydroxide & SAE 30 Oil Mix

CC1 – Calcium Carbonate & SAE 30 Oil Mix

Notes:
[1] = Nut Factor for stainless steel application
[2] = pro-rated performance to 1500°F
[3] = at 75°F, further information available from manufacturer
[4] = this value taken from can, literature lists 760°C/1400°F as limit

The listed values for maximum temperature limits and nut factors were taken from the available manufacturer literature for the product being tested. A notation of N.A. indicates that the data was not readily available from the manufacturer. It should be noted that MO2a and MO2b were identical products with different methods of application (MO2a = paste and MO2b = aerosol). In addition, MO3 was the manufacturer's high temperature version of the MO2a paste.

Additional measurements were conducted on the ASTM-A193 B8M bolts using two "home-made" blends, one of engine oil and magnesium hydroxide and a second of engine oil and calcium carbonate. These two products are commonly found in antacid products (such as Milk of Magnesia) which are used in refineries for high-temperature stainless steel applications that are found to be difficult to disassemble. These products are believed to enable ease of disassembly, based on industry experience. The two blends were identified as MH1 and CC1 respectively.

The Break-out torque tests examined the effect of prolonged exposure to temperature on the lubricating capabilities of the anti-seize products. This test was conducted by assembling the ASTM A193-B7 bolts (lubrication applied to all contacting surfaces of the nut, washer and bolt) onto a solid carbon steel (grade 1020) cylinder (Fig. 2). The ASTM A193-B8M bolts were assembled on a 304SS cylinder, so that thermal expansion did not affect the bolt load during the test. The cylinder was then placed in an oven (Fig. 3) at a high temperature for the period of one week. The temperature used for the A193-B7 bolts was held at 315°C (650°F), which represents a typical to high temperature application for these bolts. Since the ASTM A193-B8M bolts are used in higher temperature applications, the hold temperature was increased to 455°C (850°F). After a week at temperature, the cylinder was removed from the oven, allowed to cool and then the torque required to disassemble the bolt from the cylinder was recorded (using the same strain-gauged ring spanner from previous tests).

Break-out torque test results were also obtained by testing ASTM A193-B7 bolts that were in the "as-received" condition (i.e.: not lubricated, other than a light coating of oil left by the manufacturing process). These test results were used as a measure of whether or not the anti-seize was effective in reducing the required Break-out torque when compared to not using anti-seize. Unfortunately, due to bolt and nut galling, a similar baseline test could not be conducted on the ASTM A193-B8M bolts.

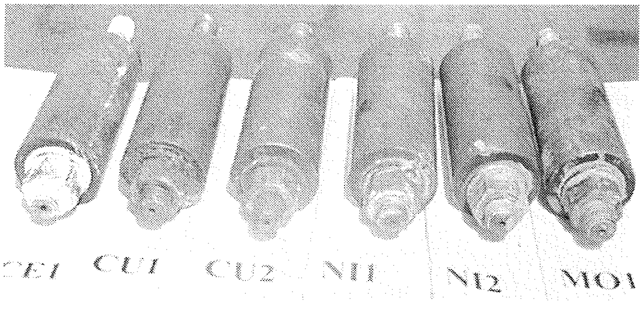

Figure 2 – Break-out Torque Test Fixtures

Figure 3 – Break-out Torque Test Oven

NUT FACTOR TEST RESULTS

The bolt load corresponding to a given applied torque is often calculated from the following equation:

$$F = T/(K.D) \qquad [1]$$

where: T = applied torque (N.m, ft-lbs), D = bolt nominal diameter (m, ft), F = bolt load (N, lbs), K = dimensionless "Nut Factor"

This simple equation does not fully account for the effects of bolt diameter or thread pitch on the achieved load. However, it is generally considered sufficient for use in a process plant environment, where the accuracy achieved by torque is considered to be ±30%.

The obtained nut factors for each lubricant and each temperature tested are shown in Fig. 4. It is evident from the graph that the actual temperature during joint assembly can have a significant effect on the nut factor. For some anti-seize products the difference in achieved load for a given torque applied during winter as compared to summer may be as high as 30% to 50%. This would mean that tightening a joint with a low nut factor would result in 30% to 50% error in obtained load <u>in addition</u> to the normal ±30%. So the actual bolt load may be 20% to 80% lower than the desired level due to torque error and the effect of temperature on the nut factor. Obviously if this is not accounted for during joint assembly then it will be very difficult to improve joint integrity. Since this sort of variation is undesirable, it may also be a reason for choosing one anti-seize over another.

For most of the anti-seize products listed, there is a significant variation between the ambient temperature nut factor and the hot-torque nut factor (at 200°C, 392°F), indicating a need to revise the specified torque value for a joint during the hot-torque stage of tightening. However, since most joints should not require hot-torque, the results for B7 bolts seem to suggest that an average nut factor of around 0.16 to 0.18 would be appropriate. This compares poorly to the values for nut factors quoted by the manufacturers, which all tended to be lower and would therefore lead to a specified torque that would under-load the bolt. In fact, of the seven tested, only one manufacturer quoted a nut factor that was within 10% of the measured value.

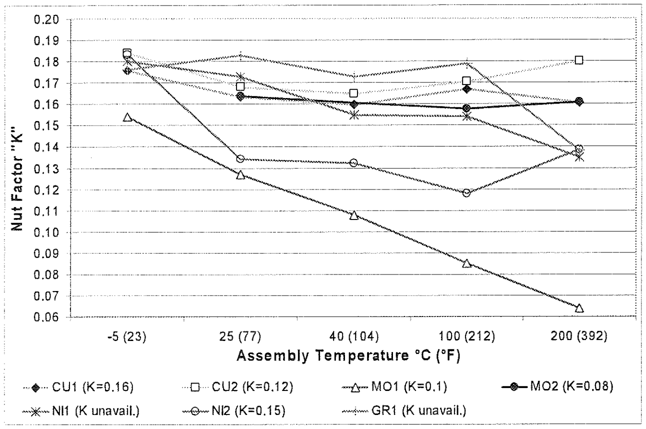

Figure 4 - Nut Factor Results – B7 Bolts

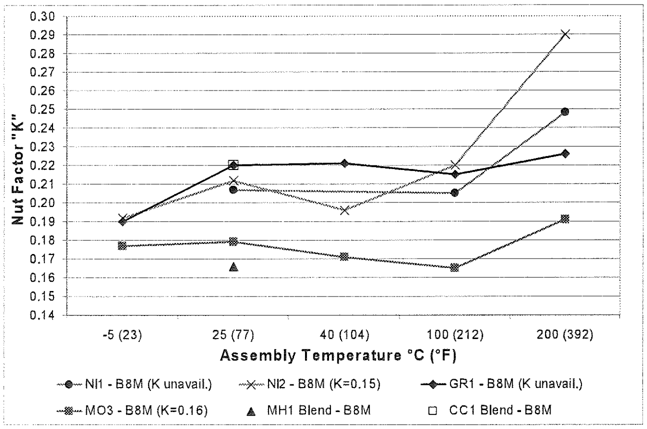

Figure 5 - Nut Factor Results – B8M Bolts

The results for the B8M bolts are graphed in Fig. 5. The first noticeable difference is that the nut factors for B8M bolts are all considerably higher, with a common ambient value of 0.21 for the three similar anti-seize products. The variation in nut factor for the hot-torque case is even more pronounced with the B8M bolts and in all cases the nut factor increased. This indicates that the bolts would be under-loaded if the same torque value was used for hot-torque as was used for ambient tightening. For example, if NI2 was used, the hot-torque bolt load would be only 67% of the ambient load with the same torque value. Once again, the manufacturer supplied nut factors were considerably lower than the test results.

BREAK-OUT TORQUE TEST RESULTS

Bolt anti-seize products serve three basic functions:

1. Lubricate the bolt during assembly in order to achieve more uniform pre-load.
2. Prevent galling of the nut, washer and bolt.
3. Facilitate bolt disassembly.

Since most anti-seize products use an oil base, it should be possible for them to achieve even lubrication and prevent galling during assembly. Therefore, the major difference between anti-seize products can occur at the disassembly stage. The Break-out test performed in this testing is designed to determine which anti-seize product has better performance during disassembly by measuring the peak torque required to disassemble the bolt. In addition, a visual inspection of the nut, washer and bolt surfaces was conducted to look for galling. In all cases it was found that there was a direct correlation between the amount of galling seen and the required disassembly torque.

The Break-out torque results for the B7 bolts are presented in Fig. 6. It can be seen that five of the nine anti-seize products made it easier to disassemble the bolt, by comparison to the bolts without anti-seize. Of those five, only one lowered the required torque by half and the other four lowered the required torque by approximately 25%. Another interesting point to note from this graph, is that the performance of the products appears to be inverse to the listed maximum temperature of the product, with the lowest temperature rated product performing the best.

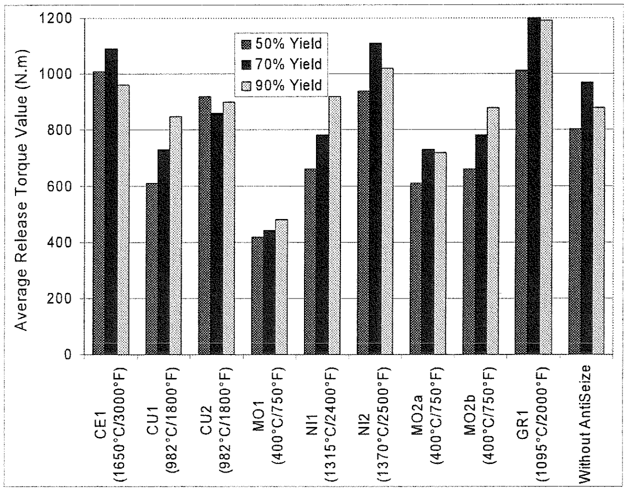

Figure 6 - Break-out Torque Results – B7 Bolts

The break-out torque results for the B8M bolts are shown in Fig.7. The results are not directly comparable to the B7 results, as the assembly torque for the bolts was much lower, due to the lower yield of B8M bolts. In fact, the break-out torque results for the majority of the B8M bolts are around 2.5 to 3 times the assembly torque, which is a significant increase. It can be seen that the trend for the results is similar to the B7 bolts, with the NI2 and MO3 out-performing the GR1 lubricant. However, it does seem that the NI2 anti-seize is slightly better than the MO2, which is the inverse of the B7 bolt results. This is possibly due to the small percentage of graphite in the MO2 anti-seize, as graphite in anti-seize products is thought to react with stainless steel at high temperatures and cause galling. This theory is also supported by the fact that the NI1 anti-seize also contains a small percentage of graphite and it can be seen that the performance was worse than the NI2 product.

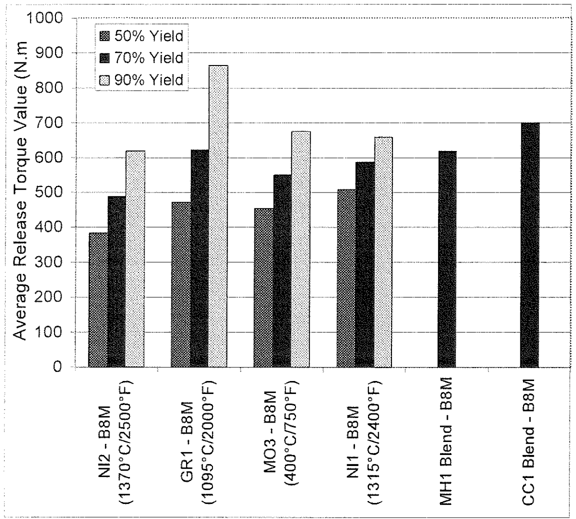

Figure 7 – Break-out Torque Results – B8M Bolts

The testing performed on the MH1 and CC1 mixtures did not support the belief that they provide better break-out performance than standard anti-seize products. The break-out torque for both of these products was comparable to the GR1 anti-seize, but worse than the other products tested. It could be that this difference in industry experience and test result is due to other factors, such as the fact that the base for the mixture was oil versus water for normal Milk of Magnesia products. This could affect the break-out results or could result in much lower bolt loads being achieved in the field, which would lead to an apparent (but false) improvement in break-out performance. Alternatively, the laboratory testing may be missing a secondary or longer-term effect. For example, there could be a difference in the coking behaviour or oxidation of the bolt/nut interface due to the Magnesium Hydroxide that was not found by the short-term laboratory testing.

As mentioned previously, there was a direct correlation between the amount of galling seen and the require break-out torque. This can be clearly seen by comparing the post-test photographs of the different products. The MO1 anti-seize (Fig. 8) had the best break-out torque on the B7 bolts and it is clearly evident that there is no galling and the final surface finish has a polished appearance. Conversely there is galling evident on the NI1 cylinder, nut and washer surfaces (Fig. 9). The difference was less dramatic with the B8M bolts, however it was still apparent that more galling existed on with the GR1 anti-seize (Fig. 10) as compared to the NI1 anti-seize (Fig. 11) at the 90% of yield torque value.

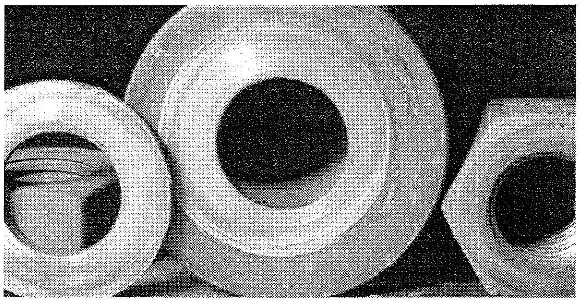

Figure 8 – B7 Break-out Test Cylinder – MO1

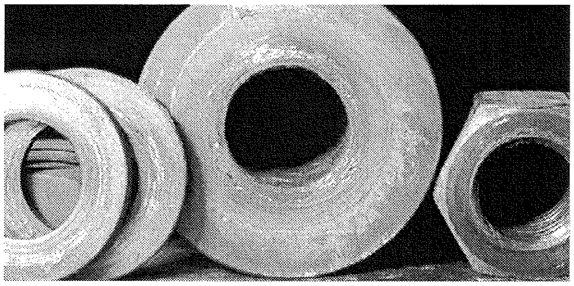

Figure 9 – B7 Break-out Test Cylinder – NI1

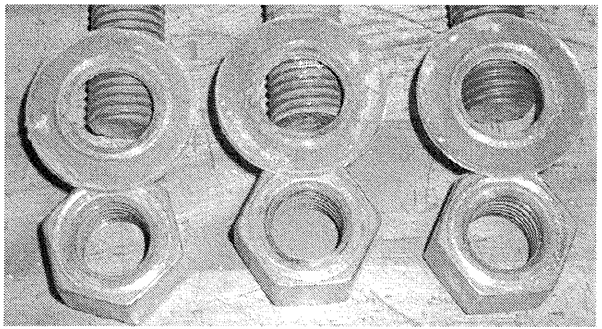

Figure 10 – B8M Break-out Test Cylinder – GR1

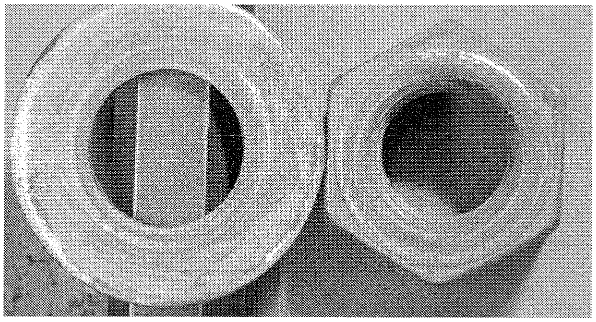

Figure 11 – B8M Break-out Test Cylinder – NI1

CONCLUSIONS

These tests demonstrate the need for product specific and application specific testing for all anti-seize products in order to determine an appropriate nut factor value. The tests also demonstrated the worth of having a practical, comparative test method for the selection of an appropriate anti-seize product. For selection of an anti-seize, the test method must consider all significant variables that will influence the performance of an anti-seize in the field, as it was shown that the performance of the anti-seize products tested was not consistent between assembly performance and disassembly performance. In addition, the testing did not find a "perfect" anti-seize product among those tested and so knowledge of the test results allows "application specific" decisions to be made.

The testing also demonstrated the lack of availability of suitable data from the anti-seize manufacturers for process plant applications. It should be noted, however, that the manufacturer of several of the products tested has since updated their product datasheets to include these test results. This further confirms the willingness of the manufacturers to supply test data if a suitable test method is available. It is the process industry that should push for such standardised testing of anti-seize products. Use of anti-seize products without appropriate test results will significantly contribute to pressure vessel and piping bolted joint leakage and extended unit turn-around periods, due to difficulty disassembling joints. The cost to the process industry per day, far out-weighs the cost of comparative anti-seize testing.

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