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BOLTED JOINT CONSISTENCY WITH STAINLESS STEEL FASTENERS

Abstract

Bolted joint design can be a challenging task when faced with the number of factors that lead to a safe and reliable joint. Failure to understand these factors can be catastrophic if proper attention is not given to each and every component in the joint. In this article we will discuss an approach to minimize fluctuations with respect to coefficient of friction when using stainless steel as well as nickel- and cobalt-based fasteners.

Introduction

As is well known in the fastener industry, ~90% of installation torque can be lost to friction under the head of the fastener and in the threads. Due to the fact that this percentage is so high, minimizing any variation with fastener behavior can have a significant impact on the consistency of the clamp load generated in the joint. The dimensionless number that dictates the friction is commonly referred to as Coefficient of Friction (CoF). It is not uncommon for the CoF to be given as a range of values, ex. .38-.42. These given CoF values are initial values and do not take into account surface degradation from adhesive wear, commonly known as galling, that occurs with multiple installs. The relationship between CoF and clamp load is explained using the formula:

$$T = k\,d\,F$$

where T = input torque, k = Coefficient of Friction, d = nominal fastener diameter and F = Clamp load

Using the example values of .38-.42 for CoF mentioned above, there can be up to a 10% difference in the joint clamp load. In an ideal installation, a complex piece of equipment can be used to measure clamp load at each and every fastener, this can be costly and time prohibitive. In order to eliminate CoF variation it is very common to use other methods such as field applied lubricants, or pre-applied waxes or dry films lubricants. This can create other variables such as how much of the lubricant should be used, what type of lubricant should be used, etc.

So far we've only discussed initial fastener use but in many cases fasteners are reused as a cost savings measure. In other cases, with more exotic materials, reuse would be a great cost advantage but many of these joints are so critical in nature that replacing the fasteners is mandated as part of a preventative maintenance schedule.

Bodycote, the world's leader in thermal processing services, has just the solution to these common threaded fastener issues. Kolsterising®, part of the Specialty Stainless Steel Processes (S3P) group within Bodycote, has been shown to eliminate the above mentioned issues with respect to CoF. Kolsterising® is a low temperature carbon-based diffusion process that increases the surface hardness up to 1200HV0.05 (~72 HRC). This hardened layer has a gradual profile allowing the surface to retain its ductility with no risk of embrittlement. As opposed to some other high temperature processes, this hardened layer is part of the base material therefore there is no risk of cracking, chipping or delamination.

No concessions have to be taken as far as fit/form/function and gaging as there will be no change to the dimension of the part after Kolsterising® . The temperature used in this process is merely used to accelerate the diffusion process, yet is low enough to not initiate any phase changes or risk carbide precipitation causing negative impacts to the corrosion resistance of the base material. Lastly, unlike with common practices mentioned above, there are no foreign materials being applied to the surface of the fastener, so there is no risk of contamination in sensitive environments such as the semiconductor and medical industries, among others. Below we will take a look at recent testing that has been conducted with commercially available F593G hex bolts and comparable hex nuts and its impact on CoF.

The parameters for various test conditions and results can be seen in Table 1. The untreated test conditions S1-S5 allowed us to find the point at which minimal installs could be performed before the surface degradation became so significant that the joint cold welded itself and seized completely. This occurred at 108 ft-lbs (80% of yield strength). It is worth noting that even at 54 ft-lbs (40% of yield strength), which represents the industry-recommended dry installation torque for the ½”-13 stainless steel fasteners, visible thread damage was observed. As reference, carbon steel and alloy steel fasteners recommended installation torque values can be closer to 75-80% of yield strength. For the treated fasteners, S6-S8, we used the 108 ft-lbs as a starting point. As can be seen, we performed 100 installs with a treated bolt and untreated nut and had no signs of galling or thread damage. As the installation torque was continually increased, we ended up in a torque to yield condition (S8), yet there were still no signs of thread degradation. One particular point to highlight is that only the bolt was treated in this test matrix. In instances where the fastener is assembled into a large mating component, these drastic improvements can be achieved by only treating the fastener. Another approach is to treat a nut to be used in conjunction with various lengths of the same diameter and thread pitch bolt.

Fastener Test Results

GALLING TEST RESULTS

Sample ID	Bolt Condition	Torque (ft-lbs)	% Yield of Bolt	# of Installs	Galling	Description
S1	Untreated	54	40	100	Not seized, spins freely	Visible thread damage
S2	Untreated	81	60	100	Not seized, spins freely	Visible thread damage
S3	Untreated	108	80	8	Seized	Visible thread damage
S4	Untreated	94	70	100	Not seized, spins freely	Visible thread damage
S5	Untreated	101	75	100	Not seized, spins freely	Visible thread damage
S6	Treated	108	80	100	Not seized, spins freely	No or minimal damage to threads
S7	Treated	121	90	100	Not seized, spins freely	No or minimal damage to threads
S8	Treated	135	100	100	Not seized, spins freely	No or minimal damage to threads

TABLE 1: THIS TABLE SUMMARIZES THE PARAMETERS AND RESULTS FOR VARIOUS TEST CONDITIONS. THE PROCEDURE WAS TO APPLY TORQUE USING A TORQUE GUN; LOOSEN/BACK-OFF FOUR REVOLUTIONS, REPEAT, AND INSPECT EVERY 25 CYCLES.

A magnified comparison of conditions of S1 and S8 can be seen in Figure 1 and shows the surface degradation that can occur upon subsequent installs. The negative impact that occurs to the thread surface can clearly be seen when installed in a dry condition using industry recommended torque values. Treated fasteners can prevent this from occurring, not only at recommended torque value, but even when torqueing to yield conditions.

FIGURE 1: THESE SEM IMAGES COMPARE THE INTEGRITY OF THE THREADS BETWEEN UNTREATED AND TREATED TEST CONDITIONS. THE FLANK OF UNTREATED S1 FASTENER DISPLAYS SIGNS OF ADHESIVE WEAR AND POSSIBLE GALLING AFTER REPEATED INSTALLS AT 54FT-LBS. WITH THIS MAGNITUDE OF SURFACE DETERIORATION AT THE FLANK THE FASTENER WILL BEHAVE INCONSISTENT AND NOT BE ABLE TO ACHIEVE THE DESIRED CLAMP LOAD FOR A GIVEN INSTALL TORQUE. WHEREAS THE TREATED FASTENER’S FLANK, WITH REPEATED INSTALLS AT 135FT-LBS, IS SMOOTH AND FREE OF SUCH DEFECTS RESULTING IN A SYSTEM THAT WILL EFFICIENTLY AND CONSISTENTLY TRANSFER TORQUE INTO CLAMP LOAD.

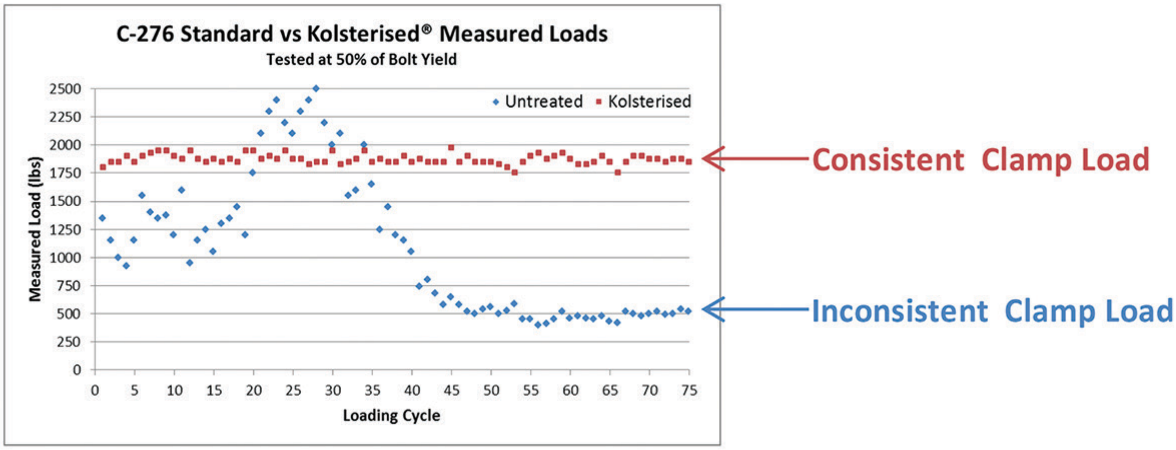

FIGURE 2: THIS PLOT COMPARES THE MEASURED CLAMP LOAD OVER 75 LOADING CYCLES WHEN TORQUED TO 50% OF BOLT YIELD STRENGTH FOR C-276 UNTREATED AND TREATED FASTENERS.

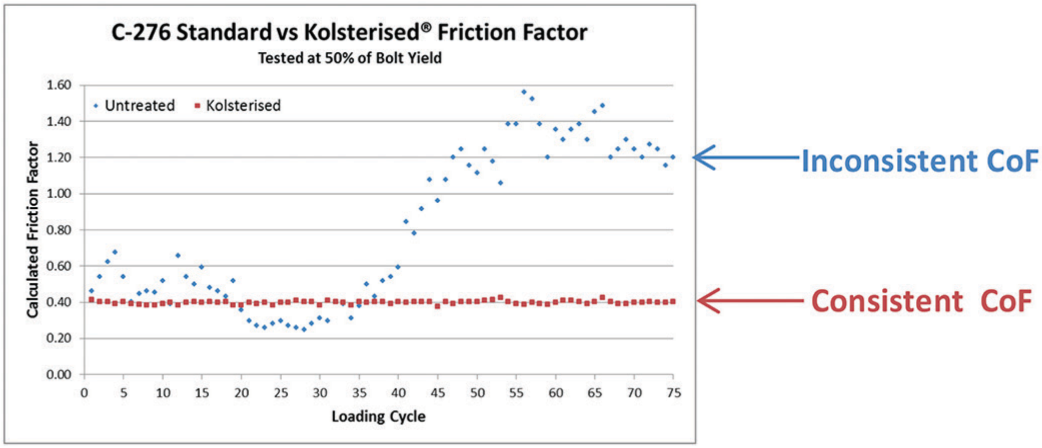

FIGURE 3: THIS PLOT COMPARES THE FRICTION FACTOR OVER 75 LOADING CYCLES WHEN TORQUED TO 50% OF BOLT YIELD STRENGTH FOR C-276 UNTREATED AND TREATED FASTENERS.

While a completely cold welded joint is the worst case scenario, we should also consider the surface condition leading up to this point. This was investigated by K. Clark[1] on various types of fasteners, including B8M Class 1, B8M Class 2, and Hastelloy® C-276 fasteners. It was observed for the untreated conditions that as surface degradation occurs, the CoF increases and, if the same installation torque is being used, the clamp load of the joint can be decreased significantly. Figure 2 shows fluctuation of clamp load over subsequent loading cycles, while Figure 3 shows the translation to CoF over the same loading cycles for Hastelloy® C-276 fasteners. As shown, the behavior of the treated fastener remains constant as the treatment prevents galling and adhesive wear from occurring.

Conclusion

In conclusion, it is a well-known fact that while the fastener may fail, it is typically not the fastener to be identified as the problem but more likely the root cause is due to improper fastener selection or improper installation. Kolsterising® can be a great option to explore when looking to achieve a more consistent clamp load in a joint where stainless steel fasteners are being used. In addition, because the safety factor can be truncated, more than 40% of the fastener's potential can be utilized. This can also be an opportunity to use fewer fasteners or potentially move to smaller fasteners. Both of these can be opportunities for fastener cost savings as well as less drilling/tapping operations in the manufacturing process of the mating components in the joint.

Other Uses

In addition to the advantages in threaded joints, Kolsterising® has also been utilized to improve fatigue strength due to the high compressive stresses generated through the diffusion process. The compressive stresses created through Kolsterising® will be more significant and consistent to those created through shot peening, regardless of part geometry. The improvements to fatigue strength and fatigue life have been of interest to those in the spring industry as it is a challenge they have to work with on a daily basis. Kolsterising® had its first success in a type of high point stress sealing application. The high surface hardness, coupled with the ductility of the hardened layer, provided the only solution to that particular market's pain point. This application can be closely related to how a set screw functions. There is potential to increase the holding power due to the increased "biting" effect into a mating shaft. This increased "biting" effect can then lead to less set screws required or moving to smaller set screws. As mentioned previously, this can lead to savings with the fasteners themselves as well as in machining operations.

[1] K. Clark (2017), The Effects of Low Temperature Carbon Diffusion Treated Fasteners on Thread Galling Resistance, 2017 ASME Vessel and Piping Conference, Hawaii, 2017.

Customer Testimonial

"Since we have started Kolsterising our stainless steel nuts, bolts, and screws, we are no longer concerned about hardware breaking or galling. Because of this, we have seen a rise in efficiency and productivity. Our assemblers love the ease of use and feel that it would be a benefit in every application."

North Park Metalworkers – Rhinebeck, NY

About The Author

Derek received his B.S. in Material Science & Engineering from Rutgers University in 2000. He then spent 10+ years in the fastener industry prior to joining Bodycote in August 2016 with a strong focus on further developing the fastener market here in North America. Derek can be reached by email: derek.dandy@bodycote.com, by phone: 848-213-1484 or visit our website at www.bodycote.com/s3p