Tribology Testing of Fasteners: Optimization of Materials

Summary: Almost 300 samples of various combinations of screw, insert sizes and materials have been evaluated for the tendency to galling on the Micro-Tribometer UMT by CETR. Among the insert materials, inconel and stainless steel showed the best results, bronze inserts were the worst. Out of the five screw materials, camtronic, electropolished and silver-plated stainless steel were the best, followed by titanium; while the regular stainless steel was the worst. Most of the combinations showed wear particles on all of the post-test samples. Only electropolished and silver-plated stainless steel screws in stainless steel inserts showed wear particles on just a few samples. The uneven visual wear of the inserts was observed to be especially high when they were tested with harder screw materials. Different thread dimensions affected the friction levels, but did not seem to affect the above ranking of the materials. The friction torque often increased with the number of insertions. The results depend upon the mechanical tolerances and debris of the screws and inserts.

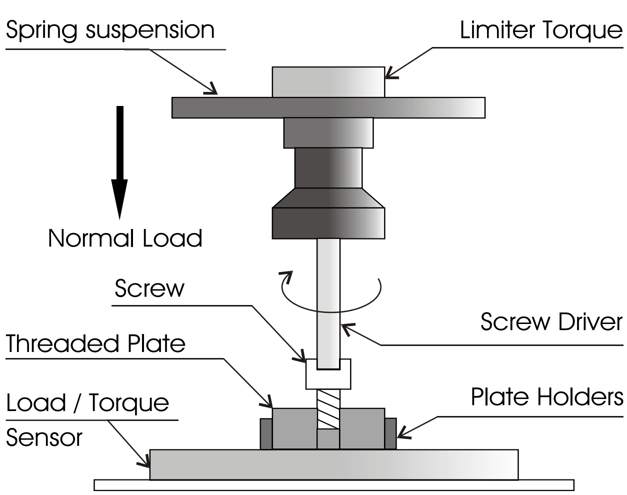


Fig. 1. Schematic of Fastener Galling Experiment Setup

Experimental procedure: All samples were carefully checked before each experiment for the presence of chips and metallic fines, by inverting the plates and striking them on a hard surface (so-called, "knocking" test). Then the screws and threads were cleaned ultrasonically in acetone before each experiment, for 10 min. After cleaning, each screw was inserted and removed subsequently in the threaded plate, ten times in a row. The micro-tribometer has a precision vertical linear motion system for lowering and raising the screw; its vertical spindle provides clockwise and counterclockwise rotation of the screw. All tests were done at the rotational speed of 20 rpm, except of some tests at higher speeds 200 rpm and 400 rpm. The screws were tightened after each insertion. Table 1 presents the data for recommended tightening torque. Each sequence of ten insertion was made into a new insert; the used screws and inserts were preserved for further microscopic examination. The axial load and torque were continuously measured during each insertion to determine their levels and changes over the ten cycles. The threaded plates were stationary attached directly to the load and torque sensor. Figure 1 shows the schematics of the test setup. The sensitivity of the sensor was 0.06 N in load and 1 N*mm in torque measurements. The accuracy of both the load and torque measurements in this experiment was estimated at 5%. After the test, each sample was inspected by both the "knocking test" and optical microscopy for the presence of surface wear and wear particles. Also, a number of photographs were taken.

Results and discussions: Three different insert materials and five different screws materials were analyzed. All combinations are represented in Table 2. Threads in the aluminum plates for holding the inserts were made with two methods, rolling and cutting.

Table 1. Recomended torque for screw tightening

Size / Material	Recommended Torque	
	inch - lb	N - mm
10-32/SS	30	3000
10-42/Titanium	30	3000
4-40/SS	5	575
M2.5/Camtron	4	460
8-32/SS	20	2306

Center for Tribology, Inc. 1711 Dell Avenue, Campbell, CA 95008, USA
Phone: 408/376-4040 Fax: 408/376-4050 Email: sales@cetr.com

Table 2. Test Samples

Group I		Group II		Group III	
Size of SS Insert	Screw Material	Size of Iconel X-750	Screw Material	Size of Bronze Insert	Screw Material
10-32 10-24 4-40 M2.5	Electropolished SS Silver Plated SS SS Titanium Camtronic	8-32	Electropolished SS SS	10-32	Electropolished SS SS

Group I-stainless steel inserts: 230 stainless steel inserts of different size (rolled and cut threads) were analyzed with the electropolished and silver plated stainless steel, stainless steel, titanium and camtronic screws. The examples of the raw data for the rolled 10-32 threads are presented in Tables 3.

Table 3. Fastener galling experiment Screw 10-32 electropolished (Rolled)

Insert	Load,	Torque, N*mm																			
No	N	R60	R12	R50	R45	R33	R14	R55	R24	R25	R21	R31	R17	R59	R26	R34	R40	R28	R41	R09	R43
1	9.3	12.5	15.4	19.8	23.5	18.2	13.1	17.4	13.7	9	13.8	4.5	19.3	7.6	9.8	9.7	8.7	9.7	3.6	14.1	10.7
2	9.3	13.7	15.5	21.7	24.7	22.8	17.3	21.1	15.3	11	23.6	12.5	25.7	8.6	16.1	12.4	10.5	12.4	4.3	15.6	16
3	9.3	14.7	15.8	19.2	23.2	23.1	17.3	21.2	17.3	12	28.3	12.7	22.6	8.9	16.2	15.2	12.6	15.2	4.2	17.1	17.6
4	9.3	14	16.6	18.4	23.6	22.3	17.3	19.9	16.3	12.1	29.3	13	21.9	9.3	17	17.4	14	17.4	4.1	16.9	18.2
5	9.3	12.8	15.5	17.4	26.3	21.5	20.5	17.1	13.3	12.4	28.3	13.1	23.6	9.3	19.2	18.5	14.1	18.5	4.2	16.6	16.7
6	9.3	13.5	15.7	18.1	27.1	21.5	17.9	18.5	16	12.5	26.5	13.4	21.8	9.8	17.3	18.8	15.1	18.8	4.4	16.2	17.4
7	9.3	13.7	15.7	16.8	25.4	21.3	16.5	18.3	15.2	13.1	29.5	14	21.3	9.8	17.6	18.8	14.9	18.8	4.5	15.2	17.3
8	9.3	13.8	15.8	17.4	27.6	22.5	17.5	18.6	14.7	12.9	31.7	13.6	22.9	9.9	17.8	18.7	15.2	18.7	4.5	15.4	17.2
9	9.3	13.9	15.4	18.2	27.2	21.7	17.4	19.1	15.2	13.3	35.2	13.4	20.3	10.3	17.2	18.8	15.5	18.8	4.6	15.5	16.9
10	9.3	13.6	15.9	17.3	27.4	21.8	17.3	21.4	15.4	13.3	32.4	14.3	21.4	10.6	18	19.2	16.1	19.2	4.6	15	17.2
Average	9.3	13.6	15.7	18.4	25.6	22.1	17.7	19.3	15.2	12.5	29.4	13.3	22	9.6	17.4	18.2	14.7	18.2	4.4	15.8	17.2
Stdev	0	0.6	0.4	1.5	1.7	0.6	1.1	1.6	1.2	0.7	3.4	0.6	1	0.6	0.9	1.3	1.1	1.3	0.2	0.9	0.6

Fig.2 demonstrates the dependence of friction torque on number of insertions for rolled and cut threads with different screw materials. Camtronic screws have the smallest torque values and their fluctuations, followed by titanium, then electropolished and silver plated stainless steel, tailed by stainless steel. The difference in friction torque and coefficient between rolled and cut threads was not significant.

The post -test microscopic inspection of inserts tested with titanium screws showed uneven wear of the insert surfaces and the presence of wear particles. The screw surfaces did not have any visible changes, because of their higher hardness.

Group II -Inconel inserts: 20 samples with 8-32 Inconel X-750 inserts (10 stainless steel and 10 electropolished screws) were analyzed. The torque value increased with the number of insertions and was not uniform. Electropolished screws showed worse results than stainless steel (Fig. 3, A).

Group III - bronze inserts: 20 samples with the bronze inserts (10 electropolished and 10 stainless steel screws) were analyzed. The torque values were not uniform and increasing with the number of the insertions (Fig 3,B). Microscopic inspection of the thread surfaces after test showed the traces of wear: smoothened areas along the insert body. A lot of bronze particles were discovered in the gap between the insert rings.

Center for Tribology, Inc.
1711 Dell Avenue, Campbell, CA 95008, USA
Phone: 408/376-4040 Fax: 408/376-4050 Email: sales@cetr.com

Calculation of the coefficient of friction: Coefficient of friction μ was calculated as

$$\mu=(2Tpd+Fdl/Fd^2p-2Tl)cos$$

where μ is coefficient of friction;
T is torque;
F is load;
d is average diameter of the screw;
l is pitch;
is the thread angle.

Fig. 4 presents the calculated results. The differences in materials, as well as absolute friction levels, were significantly affected by thread dimensions. Two dimensions 4-40 and 10-32, tested with similar materials (stainless steel inserts and various screws) showed a large difference in friction. This may be due to the fact that the larger-diameter fasteners had a significant adhesion (molecular) component in friction, which is proportional to the contact area. As a result, larger diameters showed higher friction. The difference in coefficient of friction between diameters 2.54 mm (4-40) and 4.44 mm (10-32) was 40%, 120% and 86% for electropolished, silver plated and stainless steel screws, correspondingly. The diameter, however, did not seem to affect the ranking of the materials.

The friction torque often increased with a number of the insertions. This increase was the smallest for the camtronic screws (less than 40%) and the highest for bronze inserts (more than 200%). This might be due to the increase in contact area as a result of running-in processes, that are more intense for softer materials.

The post-test inspection of all the combinations of inserts and screws showed that 100% of stainless steel insert/stainless steel screw samples had significant amount of chips and fine metallic particles. These particles were discovered by both the "knocking" test and the optical inspection of threads and screws before and after insertions. Only 1.5% of the stainless steel insert/silver screw samples showed a small amount of flake-like silver particles. No wear particles were found in stainless steel insert /electropolished stainless steel screw samples.

All the results depend a lot on the quality of the screws and inserts, including their mechanical tolerances and debris. Some of the samples, obtained from well known suppliers of fasteners, had out-of-spec mechanical tolerances and excessive debris preventing the complete insertion of the cap screws for their entire length. There are three important examples of the above:

1. silver coating on the screws, known as a solid lubricant, in our experiments often required additional efforts for insertion. This might be due to the fact that the vendor plated the coating on the already-in-spec screw, and so the coating thickness reduced the nominal screw-to-insert separation and over-tightened the interface. (By the way, the coating thickness can be up to 10 μm, but it gives the lowest friction at about 0.1-1 μm.);
2. the electropolished screws often had a very loose interface with inserts, which might be due to the material removal by etching from the already-in-spec screws. This may be the reason for their lower friction torque;
3. several stainless steel screws showed very high torque spikes during insertion. Optical inspection of such screws showed the

Figure 2

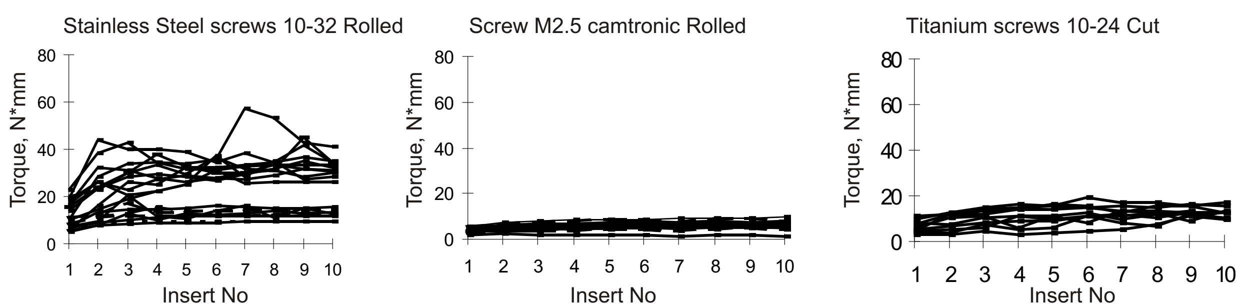


Figure 3

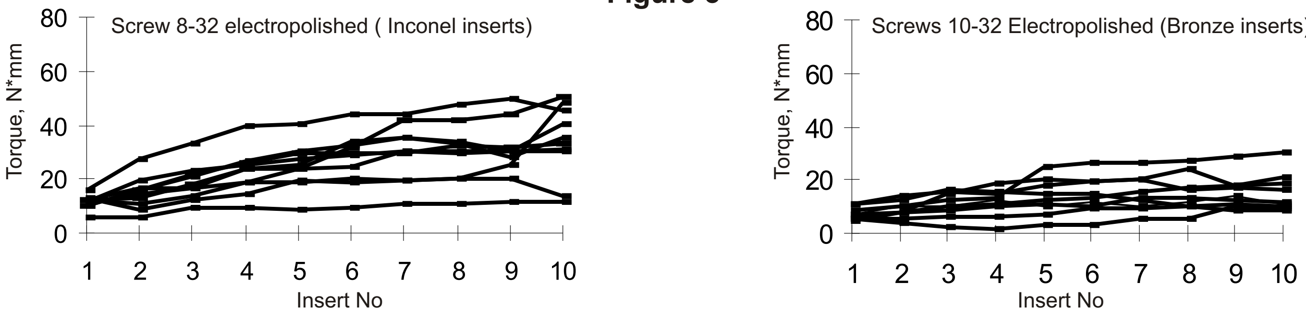
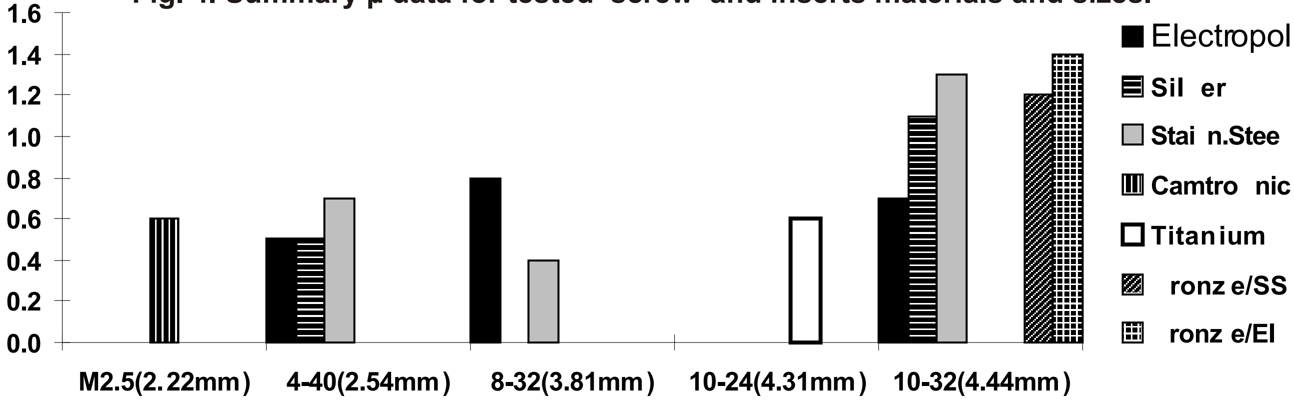


Fig. 4. Summary μ data for tested screw and inserts materials and sizes.



Conclusions

1. Among the insert materials, the best results were shown by inconel and stainless steel, with the bronze inserts being the worst.

2. Out of the five screw materials, three (camtronic, electropolished and silver-plated stainless steels) were the best, followed by titanium, while the regular stainless steel was the worst. The only exception was the combination with inconel, were the regular stainless steel was better than the electropolished one.

3. Most of the combinations showed wear particles on 100% of the post-test samples. Only electropolished and silver plated stainless steel screws, in stainless steel inserts, showed wear particles on 0-1.5% of the post-test samples.

4. The uneven visual wear of the inserts was observed to be especially high when they were tested with harder screw materials, namely, stainless steel inserts tested with titanium screws and bronze inserts tested with stainless steel screws.

5. The friction levels were significantly affected by thread dimensions. This may be due to the fact that the larger -diameter fasteners had a significant adhesion (molecular) component in friction, which is proportional to the contact area. The diameter, however did not seem to affect the above ranking of the materials.

6. The friction torque often increased with a number of insertions. This increase was the smallest for the camtronic screws (less than 40%) and the highest for the bronze inserts (more than 200%)

7. The difference in friction torque and coefficient between rolled and cut threads was not significant.

8. All the results depended a lot on the quality of the screws and inserts, including their mechanical tolerance and debris.

Patent 5,795,990 of 8/18/98

Center for Tribology, Inc.
1711 Dell Avenue, Campbell, CA 95008, USA
Phone: 408/376-4040 Fax: 408/376-4050 Email: sales@cetr.com