SWANSEA METROPOLITAN UNIVERSITY
PRIFYSGOL FETROPOLITAN ABERTAWE

Faculty of Applied Design and Engineering

High Torque Fastener Systems

The total sheet metal fastener solution

An independent evaluation and performance testing of the High Torque Fastening System

Sept 2006

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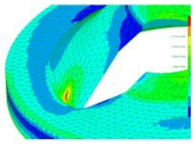
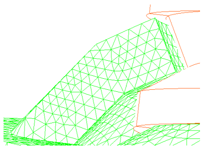
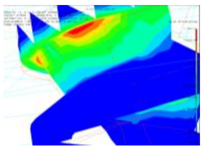


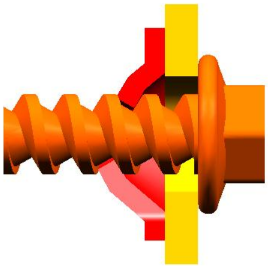




Introduction

Swansea Metropolitan University is helping manufacturing industry to acquire innovative high technology. The University has established itself in providing a local research and development resource to support companies in product and process development. Although this initiative was originally intended to support the automotive sector, it has proven attractive to a much wider spectrum of companies. A particularly successful example of this collaborative industrial research is the relationship that has developed with High Torque Fastener Systems. The University provides Finite Element Analysis and physical laboratory testing which underpins the development of their sheet metal fastener system, enabling the company to break into new markets including white goods, domestic appliances and information technology in addition to high profile automotive applications. Customers involved in previous development which are now in production include Land Rover, Panasonic, Ford, and Caterpillar. The table below shows a range of High Torque thread diameters that have been tested for a given material gauge.

Material Thickness	Thread Diameters
0.5-0.6mm	Ø3.0 to Ø4.0
0.7-0.8mm	Ø3.5 to Ø6.0
0.9-1.0mm	Ø4.0 to Ø8.0
1.1-1.2mm	Ø5.0 to Ø6.0
1.5-1.6mm	Ø6.0 to Ø8.0
1.9-2.0mm	Ø8.0 to Ø10.0



The fastener material used for all tests was BS3111/9/2 (Boron), Heat Treatment harden & temper grade 8.8. The sheet material containing the High Torque helix form used was Bright Cold Rolled Mild Steel BS EN 10140 1997. This is consistent with fasteners and sheet metal material being used out in the field by customers of High Torque Fastener Systems. A number of tests have been conducted on samples of the High Torque Fastener System product, with a view to assessing the performance of the fastened joint under specific conditions.

This report contains the following tests which have been carried out to date:

1	Pull-out Load
2	Torque Investigation
3	Static Clamp Load
4	Vibration Testing
5	Environmental Testing
6	Finite Element Analysis
7	Electrical Continuity

In addition to the test conducted at Swansea Metropolitan University, this report contains a section at the rear showing various testing which has been completed by High Torque Fastener Systems customers.

1. Pull-Out Load

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To determine the pull out load that the High Torque Fastener Systems product can withstand.

Test Procedure

Various size sample plates and fasteners were tested using the Hounsfield tensile testing machine and a custom-designed holding jig. As shown below (Figure 1) a 40mm square sample plate was inserted into the retaining block and held in position via the retaining plate, the corresponding fastener for the sample plate was inserted into the holder and held in position.

The assembly was inserted into the Hounsfield testing machine and held in position via retaining pins; force was applied along the centre axis of the fastener until the fastener or formed helix deformed, with the results recorded. 50 samples were tested for each size variation.

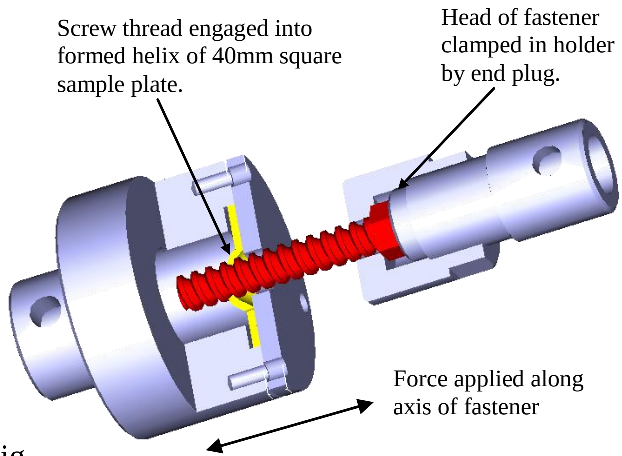

Figure 1 – Hounsfield tensile testing machine and test jig.

Results

Thickness	Diameter	Newtons				Lbs Force			
		Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
0.5 / 0.6	3	420	513	455	23.1	94	115	102	5.2
0.7 / 0.8	4	827	1112	933	54.5	186	250	210	12.3
	5	1017	1121	1075	21.5	229	252	242	4.8
	6	983	1277	1078	48.8	221	287	242	10.9
0.9 / 1.0	4	1000	1166	1100	35	225	262	247	7.9
	5	1491	1804	1647	63.4	335	406	370	14.3
	6	2108	2182	2134	19.3	474	491	480	4.3
	8	3124	3356	3232	55.8	702	754	709	12.5
1.1 / 1.2	5	1899	2323	2193	87.2	427	522	493	19.6
	6	3012	3362	3156	85.9	677	756	709	19.3
1.5 / 1.6	6	3860	5218	4503	300	868	1173	1012	67
	8	4659	7094	6141	590	1047	1595	1381	132.7
1.9 / 2.0	8	9057	10015	9648	240	2036	2251	2168	54
	10	13509	13952	13750	117	3037	3137	3091	26.4

Table 1 Pull Out test results

Table 1 summarises the pull out load results with the force measured in both Newton's and Pounds Force.

1. Pull-Out Load

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Table 2 below shows the standard deviation for all 50 samples tested for each size. The standard deviation is a useful value; because we can say that statistically, there is a 99.7% probability of the pull-failure occurring within 3 standard deviations of the mean value i.e. 99.7% probability of failure occurring within the range, mean +/- 3σ.

Thickness	Diameter	Mean +/- 3σ (Newtons)
0.5 / 0.6	3	455 +/- 69
0.7 / 0.8	4	933 +/- 164
	5	1075 +/- 64
	6	1078 +/- 147
0.9 / 1.0	4	1100 +/- 104
	5	1647 +/- 190
	6	2134 +/- 58
	8	3232 +/- 167
1.1 / 1.2	5	2193 +/- 261
	6	3156 +/- 258
1.5 / 1.6	6	4503 +/- 900
	8	6141 +/- 1770
1.9 / 2.0	8	9648 +/- 720
	10	13750 +/- 351

Table 2 Pull-Out probability

The failure mode in all cases appeared to be the deformation of the helical form in the plate at the point of contact with the screw thread. It was noted that the load would rise until the initial point of failure, which was accompanied by a sudden drop in load as the screw thread pulled free of the plate.

However, for some sizes the load would again rise as the thread of the fastener made a second point of contact with the formed helix in the sample plate until, once again, the screw thread pulled clear. Clearly it is this first failure point for which the loads above have been reported, since it is considered that this point constitutes failure.

Conclusions

During testing it was noted that the amount of force required to pull the fastener through the formed helix was higher than expected. This investigation into has concluded that with the varying amount of material that is displaced from the external to internal points of the helix causes the force to be dissipated at varying degrees around its parameter giving a larger supporting area. Unlike conventional nut inserts where the supporting material is spread evenly around the fastener axis resulting in a substantially reduced supporting area.

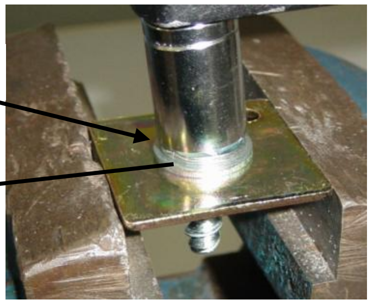
2. Torque Investigation

To determine the rotational torque characteristics of each variation of the High Torque Fastener Systems formed helix and mating fastener.

Test Procedure

As shown in figure 1 below, a 40mm square plate with the High Torque helix formed in the centre was clamped horizontally in a vice; a washer (minimum thickness matching the sample plate) was inserted onto the fastener, prior to the fastener being engaged into the sample plate, stopping the head of the fastener from coming into contact with the rear of the square plate during the test.
The matching fastener (heat treated to grade 8.8) was engaged into the formed helix and tightened using a proto-dial torque wrench equipped with slave pointer to record the maximum torque level when tightened. In each batch of samples tested, the maximum torque reached was recorded, with 50 samples tested for each size.

Sample plate



Enlarged view of sample plate and fastener assembly, being held during testing operation

Figure 1 Destructive tightening torque setup

Results

Thickness	Diameter	Newton / Meters (Nm)				Lbs ft				Lbs in			
		Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
0.7/ 0.8	3.5	1.9	2.4	2.16	0.15	1.4	1.77	1.60	0.11	16.82	21.24	19.15	1.32
	4	2.2	3	2.53	0.17	1.62	2.21	1.86	0.12	19.47	26.55	22.36	1.46
	5	2.4	3.4	2.94	0.24	1.77	2.51	2.17	0.18	21.24	30.09	26.06	2.15
	6	3.8	6.2	4.43	0.46	2.80	4.57	3.27	0.34	33.63	54.87	39.23	4.10
0.9 / 1.0	4	2.5	3.4	2.93	0.25	1.84	2.51	2.16	0.19	22.13	30.09	25.93	2.25
	5	3	4.6	3.91	0.29	2.21	3.39	2.88	0.21	26.55	40.71	34.59	2.58
	6	6.1	8.2	7.10	0.4	4.5	6.05	5.24	0.30	53.99	72.58	62.84	3.54
	8	8.9	10.2	9.68	0.26	6.56	7.52	7.14	0.19	76.77	90.28	85.71	2.26
1.1 / 1.2	6	4.5	6.2	5.60	0.34	3.32	4.57	4.13	0.25	39.83	54.87	49.53	2.99
1.5 / 1.6	6	8.75	11.5	10	0.71	6.45	8.48	7.43	0.52	77.44	101.78	89.22	6.27
	8	15	19.5	16.95	0.90	11.06	14.38	12.50	0.67	132.76	172.59	150.02	8.01
1.9 / 2.0	8	25.5	29	27.46	0.71	18.81	21.39	20.25	0.52	225.69	256.67	243.02	6.29
	10	38	39	38.62	0.46	28.03	28.76	28.48	0.34	336.33	345.18	341.82	4.10

Table 1 Torque to failure results

Table 1 summarises all the destructive tightening torque results for the sizes tested. In all cases the mode of failure was the deformation of the plate "helix” as the material was pulled inwards by the tightening of the fastener.

2. Torque Investigation

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Table 2 shows the standard deviation for all 50 samples tested for each size. The standard deviation is a useful value; because we can then say that statistically, there is a 99.7% probability of the failure occurring within 3 standard deviations of the mean value i.e. 99.7% probability of failure occurring within the range, mean +/- 3σ.

Thickness	Diameter	Mean +/- 3σ (Nm)
0.7 / 0.8	3.5	2.16 +/- 0.45
	4	2.53 +/- 0.51
	5	2.94 +/- 0.72
	6	4.43 +/- 1.38
0.9 / 1.0	4	2.93 +/- 0.75
	5	3.91 +/- 0.97
	6	7.10 +/- 1.20
	8	9.68 +/- 0.78
1.1 / 1.2	6	5.60 +/- 1.02
1.5 / 1.6	6	10 +/- 2.13
	8	16.9 +/- 2.7
1.9 / 2.0	8	27.5 +/- 2.13
	10	38.6 +/- 1.38

Table 2 Destructive torque probability table

Conclusions

When compared to existing fastening designs which incorporate a single thread engagement (SMS – sheet metal screws etc.), the characteristics of High Torque Fastener Systems design has major benefits.

The controlled forming operation of High Torque Fastener Systems helix allows the formed sheet material to accurately match the profile of the core of the fastener giving improved engagement properties between the two halves of the assembly (sheet material and fastener), resulting in higher than expected torque values.

3. Static Clamp Load

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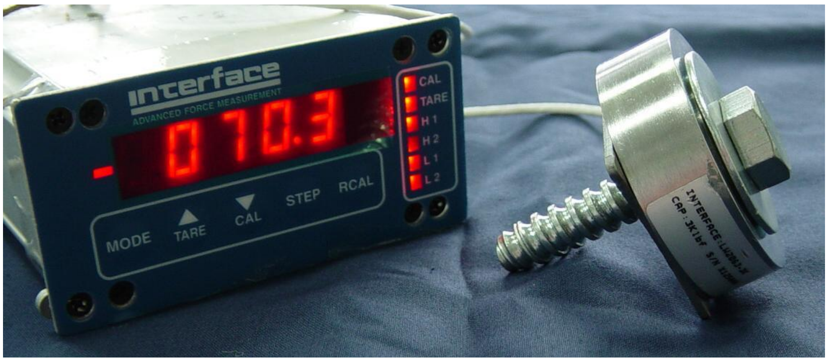
To determine the clamp load characteristics of each variation of High Torque Fastener Systems formed helix and mating fastener.

Test Procedure

Each sample was assembled with a 40mm square plate clamped horizontally and an Interface Force Measurements LW1525 load washer inserted between the plate and the screw head. The screw was tightened to a value of 90% of the minimum failure torque and observations were taken over a period of 24 hours at approximately 22°C ambient temperature. Three values were recorded (initial clamp load, load after 30 minutes and load after 24 hours) for the test.

Figure 1 – Clamp load setup.



12 samples were tested for each size; the purpose of this test is to look at any relaxation in the assembly that may occur and not the maximum amount of clamp load that can be achieved.

Results

Thickness	Diameter	Newton's			Lbs Force			% Decrease	
		Initial Load	30 Min Load	24 Hour Load	Initial Load	30 Min Load	24 Hour Load	After 30 Mins	After 24 Hours
0.7 / 0.8	4	561	552	544	126.1	124.1	122.4	1.6	3.0
	6	839	828	822	188.6	186.2	184.7	1.3	2.1
0.9 / 1.0	4	685	672	659	153.9	151.1	148	1.8	3.8
	5	822	808	799	184.8	181.7	179.7	1.7	2.8
	6	1388	1366	1343	312.1	307.1	302	1.6	3.2
1.1 / 1.2	6	850	829	808	191.0	186.5	181.7	2.4	4.9
1.5 / 1.6	6	1767	1729	1708	397.2	388.7	383.9	2.1	3.3
	8	3256	3216	3176	731.9	723	713.9	1.2	2.5
1.9 / 2.0	8	5368	5291	5295	1206.7	1189.5	1190.4	1.4	1.4

Table 1 Clamp load results

Table 1 summarises all the clamp load results. The clamp load showed a small initial decrease, and then settled down over the 24-hour period. Beyond this the decrease is minimal due to the locking effect in the fastener which arises from a relatively small deflection in the helical form.

3. Static Clamp Load

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Conclusion

High Torque Fastener Systems design, once assembled and tightened to the required torque, utilises the minor deflection of the helix into the thread core to achieve lock up and maintain joint integrity.
This minor deflection in the helix acts as a spring, allowing the system to minimise the amount of relaxation in the assembly over a given period of time, as shown in table 1.
The results obtained during these tests on the various panel sizes, goes some way in highlighting the integral characteristics within the High Torque Fastener Systems design to maintain clamp load after being assembled.

4. Vibration Testing

To determine the effects of vibration on High Torque Fastener Systems formed helix and mating fastener.

Test Equipment

The research programme between Swansea Metropolitan University and High Torque Fastener Systems has been enhanced by the acquisition of a £30,000 Derritron VP30 Electrodynamic vibration test rig specifically brought into the materials laboratory for the testing of the HTFS product.

This equipment gives the capability of examining how the fastener behaves when subjected to various vibration conditions with the aim of mimicking physical vibration conditions encountered out in the field but under laboratory conditions.

Initially the university has focused on Fixed Sine Vibration at a single frequency where the vibration table will oscillate up and down at the same rate in the form of a sine wave. Beyond this the equipment also has the capability of performing Swept Sine Vibration and Random Vibration where varying frequencies between 0.1Hz and 6553Hz can be used in 0.1Hz increments. It can also be used to test more specific situations.

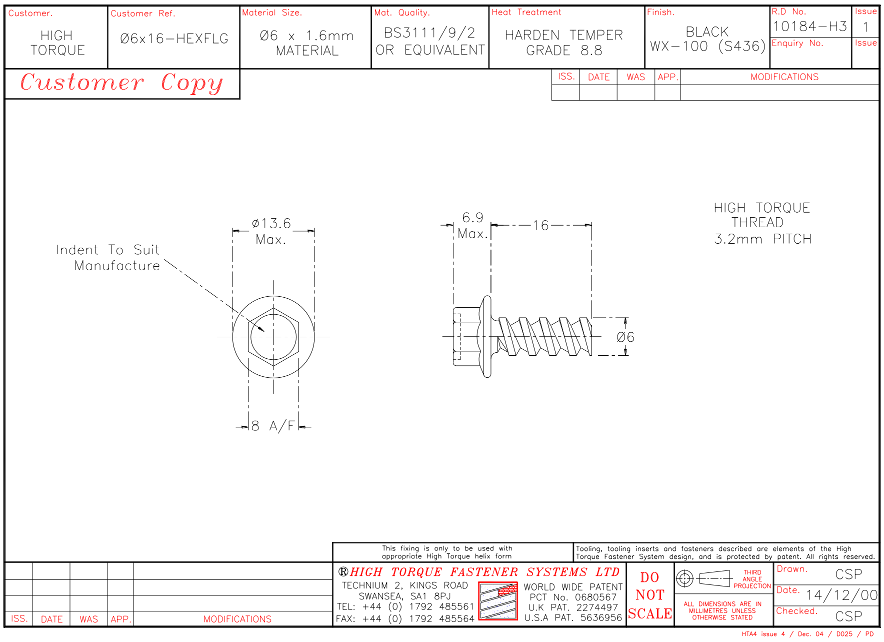
Derritron TW1500 Amplifier
Primarily designed as direct coupled matching drive sources for Derritron electromagnetic vibrators, these amplifiers give high efficiency operation over a wide frequency range.

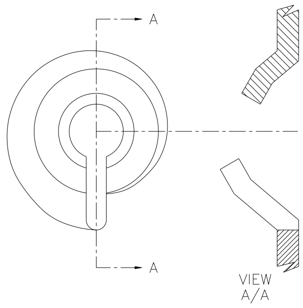
Derritron VP30 Vibrator
Derritron vibrators are designed for continuous operation under sine, random noise and shock conditions.

Swept Sine Controller
PSC programmable swept sine controller.

Fastener Specification

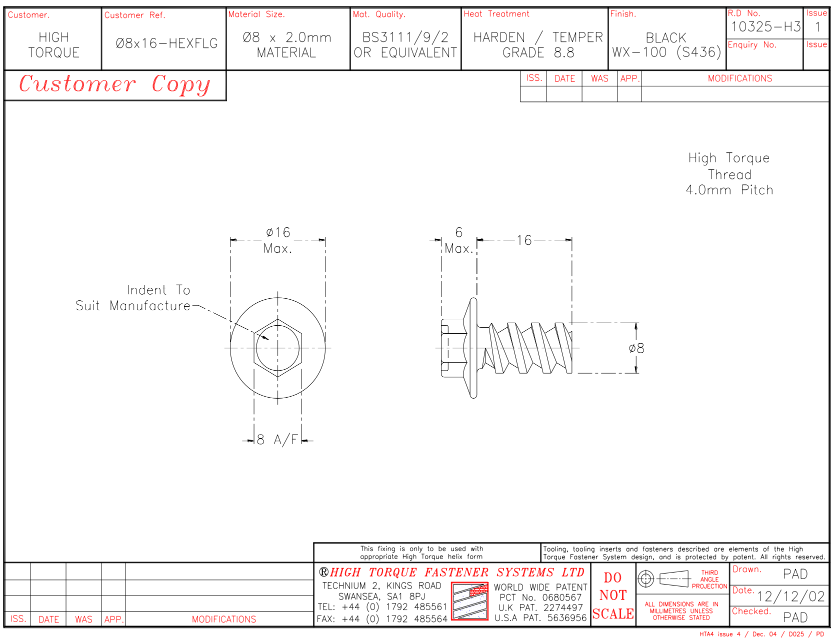
A number of test sections similar in design, with a range of bends and folds have been used during these tests. Each of the panels has the High Torque helix formed in different positions allowing for variations in the vibration trial. The fasteners used during tests are production supplied parts and drawings of both fasteners and test panels are shown below.

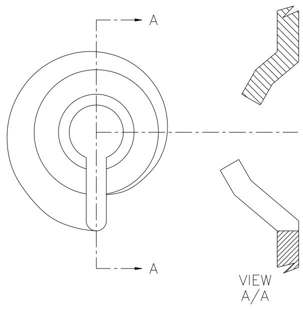




Ø6 x 1.6 High Torque Helix Form

Ø6 x 1.6mm fastener specification drawing



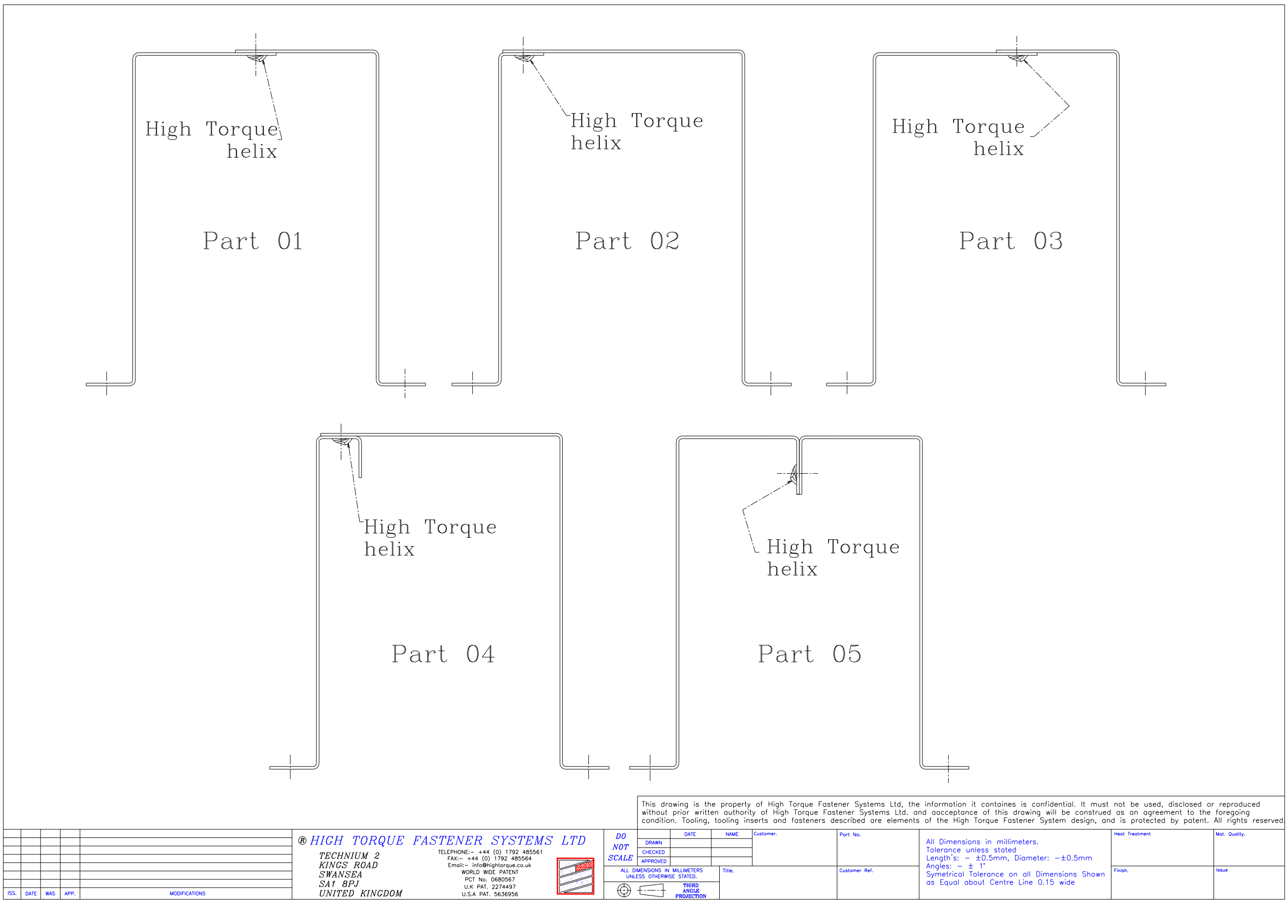


Ø8 x 2.0 High Torque Helix Form

Ø8 x 2.0mm fastener specification drawing

4. Vibration Testing

Panel Designs



The above drawing (shows panels 01, 02, 03, 04 and 05), the deviations in panel design and positions of the High Torque formed helix, allowed for a variety of vibration test criteria when attached to the VP30 vibration equipment.

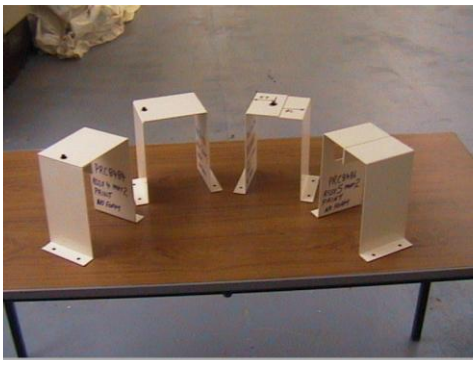


Figure 1 with some of the assemblies as indicated above, ready to undergo the vibration test cycle

Figure 2 showing component attached to VP30 Vibrator prior to testing

4. Vibration Testing

Test procedure

As previously noted this test is to evaluate the vibration characteristics of the High Torque Fastener Systems in both of the following screw diameters and panel thickness.

- Ø6mm fastener in 1.6mm thick material
- Ø8mm fastener in 2.0mm thick material

These were inserted into the various panel designs, and attached to the shaker via the manufactured face plate.
Each design variation was vibrated over a period of 12 hours, and tested at the following frequency ranges and displacements.

- 16Hz to 60Hz with a displacement of 1.5mm
- 60Hz to 200Hz with a displacement of 4mm

The fastener and panels for all design layouts were assembled using the following torque settings: -
Ø6mm fastener in 1.6mm thick material

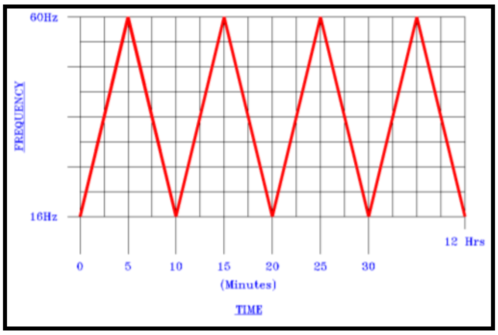
i) 4.0Nm (minimum recommended tightening torque)
ii) 8.0Nm (maximum recommended tightening torque)

Ø8mm fastener in 2.0mm thick material

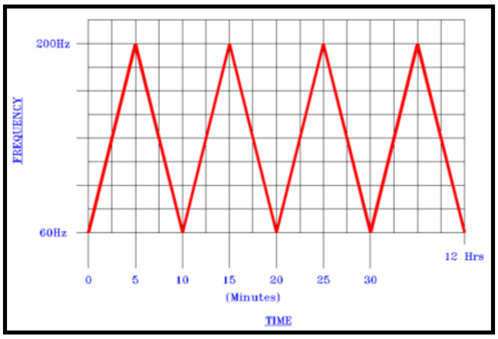
iii) 16.0Nm (minimum recommended tightening torque)
iv) 22.0Nm (maximum recommended tightening torque)

Test duration (machine time) – 10 days per screw and plate size
(5 designs x 12 hours x 2 torque settings x 2 vibration frequencies).

The time displacement from bottom to top of both frequency range tests is set at approximately 5 minutes as indicated in the graphs below.



<u>Frequency range 1 – Displacement 1.5mm</u>



<u>Frequency range 2 – Displacement 4mm</u>

4. Vibration Testing

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Observations

Assembly torque figures shown in the tabulated data were taken from a Proto dial torque wrench with slave pointer, after the 12 hour period observations were made of the assemblies, and the information tabulated: -

Diameter – 6mm

i) 4.0Nm – None of the assembled components had shown any evidence of loosing their integrity whatsoever, with the joint maintaining its assembly torque of 4.0Nm.

ii) 8.0Nm – None of the assembled components had shown any evidence of loosing their integrity whatsoever, with the joint maintaining its assembly torque of 8.0Nm.

Diameter – 8mm

iii) 16.0Nm – None of the assembled components had any evidence of loosening, the only observation being design layout (part 02) indicated a minor twisting of the assembled plates.

iv) 22.0Nm – None of the assembled components had any evidence of loosening, the only observation being design layout (part 02) indicated a minor twisting of the assembled plates.

Design Layout	Thread Diameter (mm)	Material Thickness (mm)	Assembly Torque (Nm)	Break loose torque before test (Nm)	Break loose torque after test (Nm)	Assembly torque after test
01	6	1.6	4.0	1.6	1.6	No Change from initial assembly torque.
			8.0	3.7	3.7	
	8	2.0	16.0	7.0	8.5	
			22.0	9.0	10.0	
02	6	1.6	4.0	1.6	1.6	
			8.0	3.7	3.7	
	8	2.0	16.0	5.0	5.5	
			22.0	11.0	11.5	
03	6	1.6	4.0	1.6	1.6	
			8.0	3.7	3.7	
	8	2.0	16.0	7.0	7.5	
			22.0	10.5	11.0	
04	6	1.6	4.0	1.6	1.6	
			8.0	3.7	3.7	
	8	2.0	16.0	5.5	6.5	
			22.0	10.5	11.0	
05	6	1.6	4.0	1.6	1.6	
			8.0	3.7	3.7	
	8	2.0	16.0	6.0	6.5	
			22.0	10.0	10.5	

4. Vibration Testing

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Conclusions

Much work has previously been carried out to explain why the High Torque Fastener System product is able to withstand vibration, unlike a conventional fastener where the bolt is put under tension and stretched which requires extreme torque loadings to achieve, the High Torque fastening system achieves the same results but uses only a fraction of the assembly torque loading. The High Torque product does not follow the same principal as a conventional fastener; it's the helical form that is primarily put under tensile loading, thus reducing the stress in the bolt. The locking engagement in the fastener arises from a relatively small deflection in the helical form, requiring less torque to achieve sufficient securing tension.

With the small amount of deflection needed to achieve lock up, the helical form tries to re-set itself to its original formed position. This flexibility acts as a natural spring, with the added benefits of helping prevent the fastener working loose in application where vibration is present. This eliminates the need for any shake proof washers or patch technology to achieve similar results as would have previously been required. The results obtained during these tests on the various panel designs, goes some way in highlighting the integral characteristics within the High Torque design to withstand vibration.

These test results are consistent with similar tests carried out by Swansea Metropolitan University along with field trials carried out by customers of High Torque Fastener Systems. From these tests we can conclude that the High Torque Fastener System does withstand extreme vibration conditions for the size tested and will not work loose provided that the recommended assembly guidelines are adhered to.

5. Environmental Testing

The following climatic tests have been carried out to try and replicate the range of temperatures that the High Torque Fastener product might be subjected to in its customer's applications. Trials were conducted to determine the effects of a variety of temperatures on High Torque Fastener Systems screw-helix assembly, and its ability to maintain joint integrity, through expansion or contraction between the different materials.

Component Specification

As shown in figure 1 below, two 40mm square plate with the High Torque helix formed in the centre were clamped together, and assembled to the recommended assembly torque, using a proto-dial torque wrench equipped with slave pointer.

Figure 1
Picture of Environmental test chamber.

Test Procedure

A number of tests were conducted where all samples were assembled using the assembly guidelines noted below, using a torque wrench with a dial and slave pointer or digital screwdriver (which ever is required).

Range of test samples

Sample sizes	Assembly Torque (Nm) Minimum	Maximum
Ø6 x 0.8mm Material	2.0	2.4
Ø6 x 1.0mm Material	2.8	3.5
Ø6 x 1.2mm Material	2.6	3.4
Ø6 x 1.6mm Material	4.0	8.0
Ø8 x 2.0mm Material	16.0	22.0

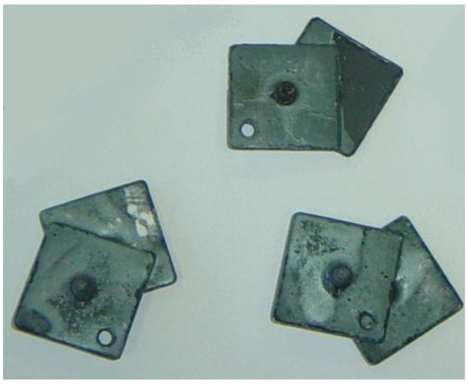
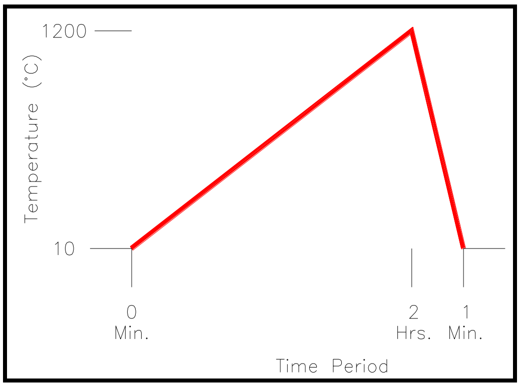


Figure 2
Example of various size plate and screw sizes used during test

5. Environmental Testing

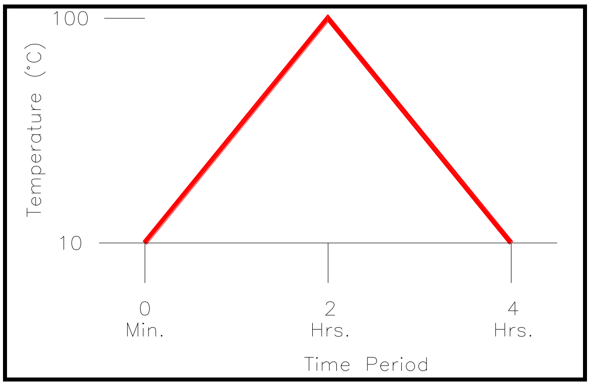
<u>**Test 1** **(1200°C with shock)**</u>

1. Assemble parts and increase ambient temperature to a maximum of 1200 degrees centigrade
2. Allow parts to cool down rapidly by immersing in water (trying to create in shock effect in the joint).



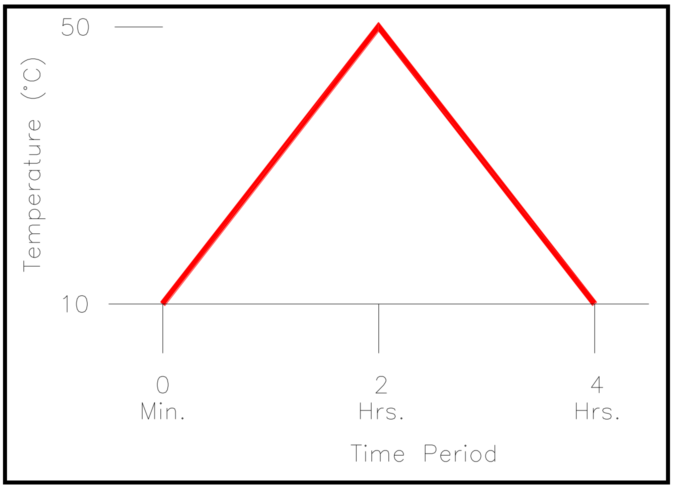
<u>**Test 2** **(100°C)**</u>

3. Assemble parts and increase ambient temperature to 100 degrees centigrade
4. Allow parts to cool down naturally in air.



<u>**Test 3** **(50°C)**</u>

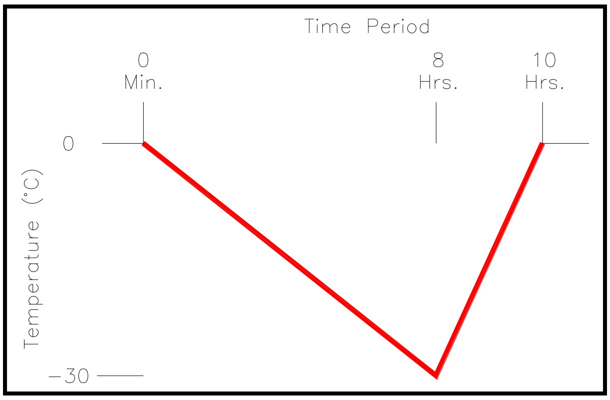
5. Assemble parts and increase ambient temperature to 50 degrees centigrade
6. Allow parts to cool down naturally in air.



5. Environmental Testing

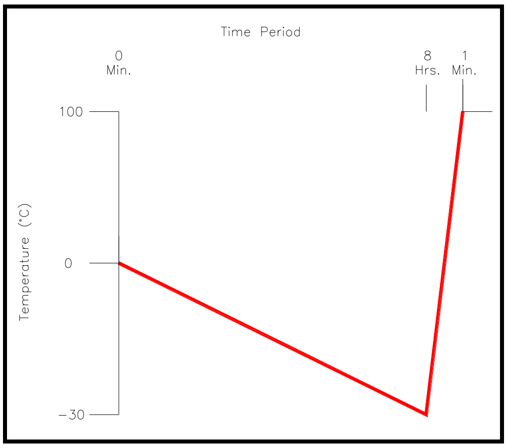
<u>Test 4 (-30°C)</u>

7. Assemble parts and decrease ambient temperature to -30 degrees centigrade
8. Allow parts to acclimatise in air



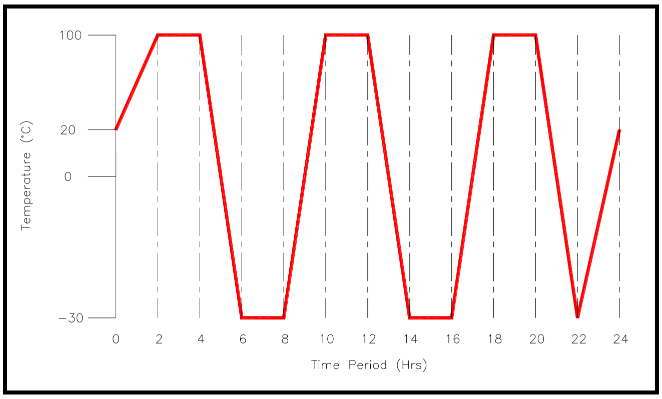
<u>Test 5 (-30°C with shock)</u>

9. Assemble parts and decrease ambient temperature to -30 degrees centigrade
10. Create a shock effect in the joint by quickly increasing temperature to 100 degrees centigrade.



<u>Test 6 – Cyclic Testing (-30°C to 100°C)</u>

11. Subject assemblies to a varying degree of temperatures over a 24hr period.



5. Environmental Testing

Results

After removal from the various test environments, the following results were recorded, for both break loose and assembly torque.
As noted below no difference was evident between original insertion and retightening torque, across all sample plate and screw range.

Thread Diameter (mm)	Material Thickness (mm)	Assembly Torque (Nm)	Retightening Torque (-30°C to 100°C)	Break loose Torque before test (Nm)	Break loose Torque (-30°C to 100°C)	Break loose Torque (1200°C)
6	0.8	1.4	No Change	0.75	No Change	2.0
6	1.0	2.8	No Change	1.5	No Change	6.0
6	1.2	3.4	No Change	1.8	No Change	13.5+
6	1.6	8.0	No Change	2.0	No Change	13.5+
8	2.0	16.0	No Change	5.0	No Change	13.5+

Observations

The results were documented after each of the above trials and the following noted: -

- Inspection of both plates and screws before and after hot and cold trials (noting condition etc.)
- Note any disengagement due to expansion or contraction.
- Appearances of increased adhesion within the joint (noting reasons)
- Comparison in break loose torque before and after trials.

Conclusion

It is the opinion of the writer that when the High Torque Fastener System assembly is subjected to the various climatic environments as indicated in these trials, there are little or no discernable differences in its attributes.

1. In trials (-30°C to 100°C) there where no discernable differences in the assembled joints tightening torque figures after the tests.
2. In trials (1200°C) a significant increase in adhesion between the screw and sheet material was observed. This is caused by surface carburisation on both the screws and sheet material. (see photo below)
3. None of the test pieces disengaged during the temperature trials.

The only observation noted during the trials, is that when the High Torque Fastener system is utilised in a very high temperature environment, the joint integrity is increased between the fastener and the formed sheet material as shown below.

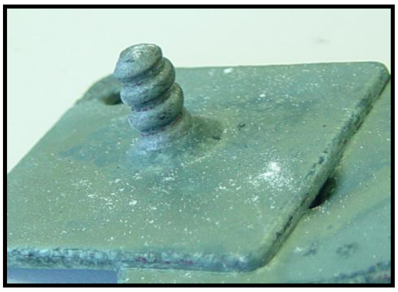


Figure 3
High carburisation between fastener and sheet material after high temperature trial (1200°C)

6. Finite Element Analysis

The ever-increasing advances in computer technology have enabled engineers to simulate physical conditions eliminating the costs of traditional prototype based research and development. At Swansea Metropolitan University, I-DEAS CAD software is used to model components[1]. Figure 1 shows a typical High Torque fastener design used in the analysis. It is then possible to perform a finite element analysis of the component. The finite element method is a numerical method used to solve complex engineering problems. The method was first developed almost fifty years ago and has become so well established that today it is considered to be one of the best methods for solving a wide variety of practical problems efficiently. I-DEAS has been used to analyse the performance of the High Torque system under mechanical loads. This allowed the engineer to run numerous simulations of the problem greatly reducing project time-scales and resulting in a more thorough investigation.

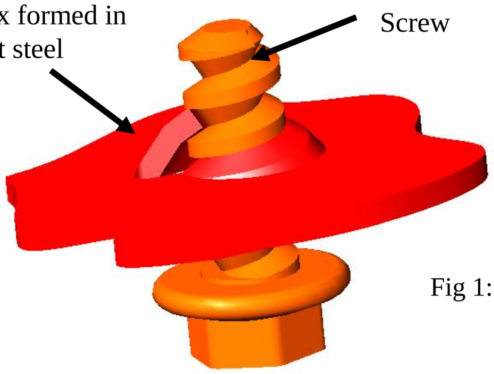


Fig 1: Typical CAD model used in the analysis

A geometric non-linear calculation has previously been undertaken by imposing various loads and restraints on the helix geometry alone. The non-linear has the advantage over the simpler linear approach in that as the traction becomes progressively larger in magnitude, the displacement of the fastener plate is more accurately modelled. A linearly increasing traction was imposed on the surface of contact between the screw and the fastener plate. This permitted a range of imposed loads that helped to determine the point where the maximum calculated stress on the plate exceeded the permitted value. This report looks at a geometric linear calculation with contact, analysing both the helix form and the thread of the fastener. Incorporation of plasticity into a non-linear model with contact will form the basis of future work.

Meshing and Boundary Conditions

Considerable effort has gone into obtaining an accurate finite element mesh (Figure 2a). Parabolic tetrahedral elements were used throughout the calculations. Experience has taught us that calculated surface stresses tend to overestimate the problem areas. The industry standard is to use three elements through the thickness of any component in order to correctly model the stresses through that thickness. This was considered important, since comparisons between calculations for different fastener designs required a consistent approach to meshing and hence the accuracy from calculation to calculation. This proved to be very time consuming, but has resulted in a meshing methodology that we now have confidence in. The head of the bolt was not included in the analysis to allow more elements to be used in the areas of interest around the base of the helix and the area of contact between the helix form and the bolt (Figure 2b).

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[1] **Donne, K, Payne, C.** (2004) *Computer Modelling of Novel Metal Fasteners.* IMechE 5th International Conference on Quality, Reliability & Maintenance. Oxford University

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The head of the bolt will be used in future work for evaluating torque when friction under the head will be important. The accuracy of the mesh was increased until the total error norm for each calculation was less than 5%.

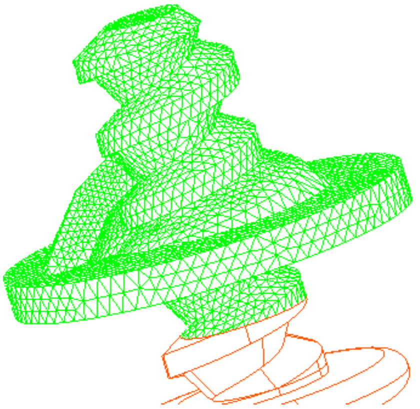


Fig 2a: Typical mesh being used in the analysis

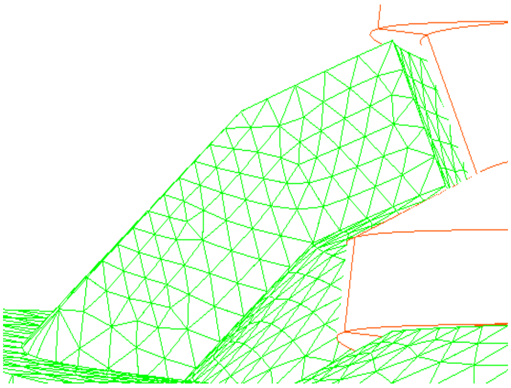


Fig 2b: Concentration of elements around the areas of interest

The lateral surface of the fastener plate was restrained to represent the presence of the larger plate geometry (Figure 3). This diameter is consistent with that of the experimental test and that of any clearance hole that would exist on assembled products. Initial analysis involved a translation calculation. All surfaces of the bolt were restrained with the y & z axis remaining constant at zero to simulate the bolt pulling through the helix form.

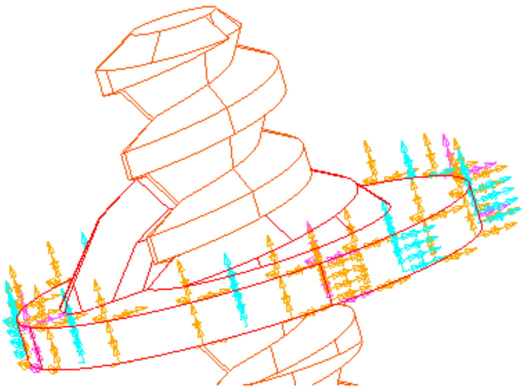
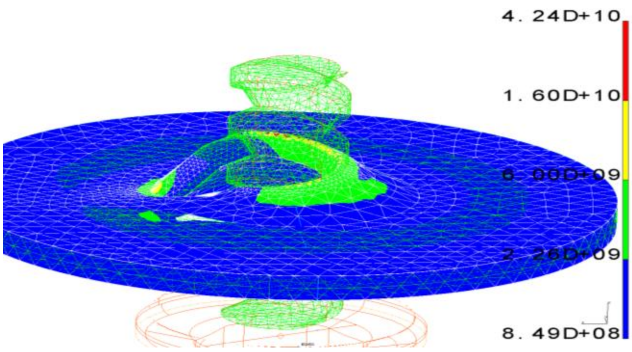


Fig 3: Boundary Condition Restraints around the plate geometry

Finite Element Analysis Results

Fastener Diameter 4mm for 1.0mm material has been used here as an example. Figure 4a shows the Von-Mises stress plot for a 5mm axial displacement of the screw, and figure 4b the stress concentration at the base of the leg. It is important to observe that, although the maximum stress value significantly exceeds the Yield Stress for the material, it is the depth of penetration that determines failure. This is entirely consistent with numerous simulations performed for other industrial clients, where this observation is used in predictive modelling.

6. Finite Element Analysis



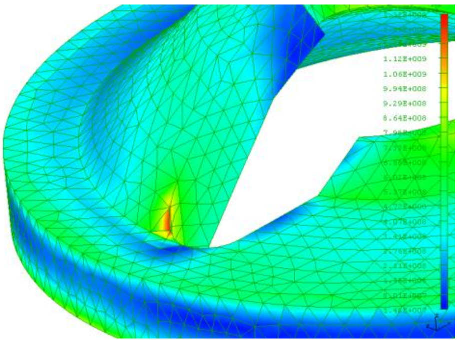
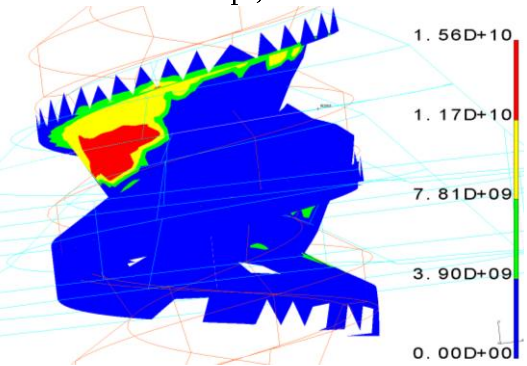


Fig 4a: Von Mises stress for a 5mm screw displacement

Fig 4b: Violation of yield stress at base of helix

The computer model is proving useful in clarifying the failure mode of the fastener. Figure 5a shows the contact stress on the screw surface, while Figure 5b shows the contact stress on the helix surface. The maximum value of the contact stress on the screw is less than that on the helix, but is of a similar order of magnitude. For mild steel, the predicted failure mode is due to failure of the helix form and this is confirmed by experiment. Further tests indicate that when a work-hardened helix is used, the failure mode is then due to the screw thread failing. Future computations will concentrate on modelling the non-linear behaviour of the helix-screw interaction with plasticity and creep included, in order to develop a predictive model that can be applied to novel applications of the fastener concept, in non-standard sizes.



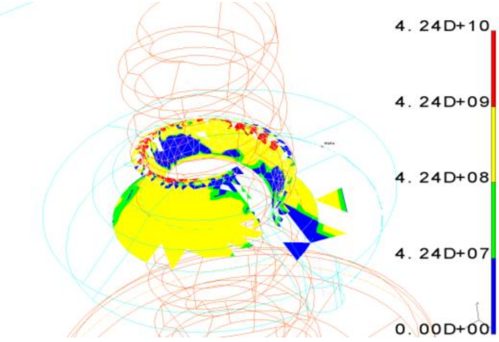


Fig 5a: Contact stress on screw

Fig 5b: Contact stress on helix

Conclusion

The computer model shows that simply exceeding the plastic limit does not immediately lead to failure. The violation of the yield stress must occur through a significant depth of the wall thickness. As more experiments are performed, the model can be calibrated so that this penetration through the wall can be quantified. Currently it appears that some 75% of the wall thickness at the base of the slot must be violated before failure occurs. There is an analogy with a simple beam cantilever: the free end of a cantilever experiences the greatest deflection – just like the helix in the fastener. However, the fixed end of a cantilever experiences the highest stress – just as seen in the base of the slot. A more accurate criterion for predicting failure can be made after we calibrate the model with further experiments. We will then refine the 75% estimate above with a more accurate figure.

The computer model is intended to predict failure for yet-to-be-manufactured geometries and other materials. However, at present, the customer should refer to the experimental values in determining fastener performance. Please note that fastener performance may vary in applications due to the influence of product geometry and environmental factors.

7. Electrical Continuity

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To determine the electrical conductivity of each a sample of High Torque Fastener Systems formed helix and mating fastener.

Test Procedure

At random a 4mm diameter High Torque Fastener Systems fixing was selected for electrical continuity analysis. Two 0.8mm thick coated steel plates were used during the tests and tightened to the recommended torque setting.

The experiment was carried out using a Fluke Multimeter (8840A), and involved clamping two steel sample plates together to its maximum torque setting of 1.1Nm using a Dial Torque Wrench (resolution 0.1Nm). Connecting the two positive leads to one plate and the two negative leads to the other and observe reading. The setup utilising 4 terminals eliminates errors introduced due to the resistance of the connecting leads.
A second test was applied using a 500V megger again connecting the leads to each plate and subjecting it to 500V, again recording results. This process was repeated six times for each sample, loosening and retightening to the specified torque.

Test Plates 1

Tests	Megger (Ω) Res ± 0.1Ω @ 500V	Resistance (Ω) Res ± 0.001Ω
1	0.0	0.032
2	0.0	0.023
3	0.0	0.013
4	0.0	0.004
5	0.0	0.001
6	0.0	0.000

Observations

- Paint was stripped off on initial tightening.
- On second test a slither of paint and metal came off.

7. Electrical Continuity

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Test Plates 2

Tests	Megger (Ω) Res ± 0.1Ω @ 500V	Resistance (Ω) Res ± 0.001Ω
1	0.0	0.002
2	0.0	0.005
3	0.0	0.001
4	0.0	0.002
5	0.0	0.004
6	0.0	0.005

Observations

- ❖ Paint removed on initial first test.
- ❖ Metal removed while dismantling.
- ❖ Paint removed.

Test Plates 3

Tests	Megger (Ω) Res ± 0.1Ω @ 500V	Resistance (Ω) Res ± 0.001Ω
1	0.0	0.025
2	0.0	0.004
3	0.0	0.011
4	0.0	0.025
5	0.0	0.022
6	0.0	0.022

Observations

- ❖ Paint removed on initial first test.

Conclusion

The random variation between the 1st measurements of each of the three samples, we believe, is explained by the varying amount of surface paint removed during the initial engagement.
The results of these initial experiments suggest that the contact resistance (a measure of continuity) between the components is undetectable by the industry-standard Megger measuring device.
For scientific evaluation, the high precision Fluke meter indicates that the largest observed resistance value is typically 0.03Ω, an order of magnitude smaller than the Megger can detect.
The above conclusions remain valid for repeated slackening and retightening.
The measurements of the three samples indicate satisfactory electrical continuity for each individual fastener used in the application to the same specifications used in the samples. Use of multiple fasteners will improve the electrical bonding of the two plates.