THE RELATIONSHIP BETWEEN THE TIGHTENING TORQUE AND THE CLAMP FORCE OF SMALL INDUSTRIAL SCREW FASTENERS

Joseph O. Arumala, Robert McCulley, Emin Yilmaz

University of Maryland Eastern Shore/ /Filtronic Comtek Inc./
University of Maryland Eastern Shore

Abstract

Screw fasteners used in the assembly of microwave filters were subjected to tensile and torque tests to determine their yield strengths and the torque that can safely be applied during the assembly process. 2-56, 4-40, 6-32, and 8-32 screws with or without nylok and silver plate finish were tested in the project. Special holders were manufactured for the tensile tests. The torque tests utilized a rotary torque transducer attached to a display unit and a load cell washer. The results obtained show that the published yield and tensile strengths of the screws are quite conservative. The clamping forces generated in the screws were well below the yield strength of the screws. The nut factor in the torque formula decreased with the nylok and silver finish and thus increased the clamping force.

Introduction

This project began with the need to establish engineering torque values for various fasteners and to determine the associated clamp forces generated during the assembly process of microwave filters manufactured at Filtronic Comtek Inc. (see Figures 1 and 2). The filters designed at this facility utilize up to 400 screws per filter. The screws are in the range of 0-80 to 8-32 in size. In order to define proper torque values, the yield and ultimate tensile strengths of each fastener must be determined. Most fastener manufacturers will not give maximum torque recommendations due to liability issues but those that do, will not guarantee desired results due to the variation of applications. Applying the proper torque to fasteners in order to induce clamp force is essential in providing a reliable bolted assembly. There is a direct link between the torque applied and the resulting clamp force. Unfortunately there are many factors involved during the tightening process which must be understood in order to achieve a solid bolted joint design. The fastener engineer must know the strength of the fastener and how much stress (tension) can and will be induced during the torque process. Since tensile force in a fastener cannot be measured during assembly, the torque that creates this tension should be understood and those variables that affect tension must be controlled.

The most critical value in determining the torque is the nut factor "K". Due to its wide range, when possible, nut factors should be determined experimentally rather than relying on tables. The recommended procedure for evaluating "K" factors is to insert a load cell or force washer between the assembly and apply a specific torque (1).

An initial purpose of this project was to design and manufacture tensile testing machine specimen holders to test the strength of 2-56, 4-40, 6-32, and 8-32 pan and socket head screws used in the assembly of R. F. Microwave Filters (see Plates 3 and 4). The design and construction of the specimen holders were assigned as a design project in ETME 475-Mechanical Systems Design course. The manufactured holders were used to measure yield stresses and ultimate stresses of different size screws at UMES. The clamping force as a function of torque was measured at Filtronic Comtek. The data were evaluated to correlate measured axial stress values to applied torque. The yield stress of the screws was a very difficult property to evaluate due to the small sizes of the screws. To make the situation worse, the lengths of these fasteners are extremely short which makes holding the fastener during the tensile testing very difficult.

This paper presents the results of our analysis and the experiences we had in bringing industry problems to the classroom. The project was a valuable experience for the student involved and for us, as faculty, in trying to solve an industry problem.

Project Description

The goal in high quality torque assembly is to apply as much clamping force as possible without reaching the yield strength of the screw fastener. Typical optimal torque techniques will approach 75-85% of fastener tensile yield strength (1). This will ensure high clamp force to resist loosening but not to the point of yield, which can cause stress failures later when the product is in service. The general formula related to torque is T = KDF (1) where T is the torque, K, the nut factor, and D, the screw diameter, and F, the clamping force. T, K, and D, combine to provide the axial clamping force “F” between the two parts being assembled. This variable “F” can not be readily measured and is a critical element in defining proper torque values for various fasteners. The torque, T, will be calculated from the above formula, K has been established to be 0.25 for stainless fasteners against aluminum threads, and the diameter can easily be measured with calipers. It is therefore critical that the missing variable “yield strength” be determined for each fastener and 80% of this used as the “F” value to establish proper torque values for the assembly process.

Holding the screws to measure “F” was the object of the tensile test machine specimen holders. They must hold the screw fasteners under test conditions similar to that used in the filter assembly. The grip length (unsupported thread area under head) of each fastener must be 0.125 (3) and thread engagement beyond this length must be 2 times fastener diameter. The holding fixtures must be designed to fit into the existing tensile test machine at UMES Material Testing Laboratory.

Procedure

Three activities were carried out to determine the force in the screw fasteners. They were: fabrication of specimen holders for the tensile tests, tensile tests on the screws using a 30, 000 lb. Tinus Olsen Universal Testing Machine, and using a torque transducer to measure the torque applied to the fasteners. A data acquisition system consisting of ASYST software, Data Translation DT 2805 Data acquisition board and a computer, was used to collect and plot the load applied and the elongation of the screws during the tensile testing. The rotary torque transducer has a display unit attached and an angle encoder that plots torque versus angle of rotation. A load cell was integrated with the torque transducer to plot the tension force in the screws in pounds on the same graph of torque and angle of rotation. Plate No. 1 shows the test set up for the Torque Test. Plate No. 2 shows a close up view of the load cell washer and a screw in a torque test.

Tests and Test Results

The tensile tests were performed on two types of screws, the socket cap and the pan head. The sizes of the screws are 2-56, 4-40, 6-32, and 8-32. The cross-sectional areas of the screws are as shown in Table 1. The tests were carried on until the screws failed. Figures 3 and 4 are typical plots from the data acquisition system. The measured average tensile strengths of the screws are as follows: 2-56, 400 lb., 4-40, 700 lb., 6-32, 1014 lb., 8-32, 1725 lb.

Table 1 Average Strengths of Screws from Tensile Tests

Screw Type	Tensile Strength (psi.) (Tensile Test)	Tensile Strength (psi.) (Manufacturers Values)
2-56 Socket Cap (MD)	108,108	80,000
2-56 Socket Cap (NH)	97,297	
2-56 Pan Head (MD)	93,513	80,000
2-56 Pan Head (NH)	92,972	
4-40 Socket Cap (MD)	122,331	80,000
4-40 Socket Cap (NH)	97,351	
4-40 Pan Head (MD)	116,225	80,000
4-40 Pan Head (NH)	97,268	80,000

4-40 5/16 Phillips Socket Cap (MD)	109,034	80,000
6-32 Socket Cap (MD)	111,566	80,000
6-32 Pan Head (MD)	111,661	80,000
8-32 Socket Cap (MD)	123,214	80,000
8-32 Socket Cap (NH)	119,910	80,000
8-32 Pan Head (MD)	96,875	80,000

The torque test was carried out on the same types of screws as the tensile test. Typical plots from the tests are shown in Figure 7. The average loads from the torque tests are: 2-56, 371 lb., and 4-40, 555 lb. Typical results are shown Table 2 below. The results are from samples run with thru hole aluminum plates tapped H5 and plated with .0002 silver.

Table 2 Results of Torque Tests on Screws

Screw Size	Finish	Torque (lb.-in.)	Force (lb.)	K value
2-56 socket cap	nylok	5.88	210	.32
2-56 socket cap	silver	5.91	192	.36
4-40 socket cap	nylok	9.67	312	.28
4-40 socket cap	silver	10.19	225	.40
6-32 socket cap	nylok	13.0	479	.20
6-32 socket cap	silver	14.6	232	.46
8-32 socket cap	none	30.0	438	.42
8-32 socket cap	nylok	28.3	686	.25

The strengths of screws from the tensile tests and the manufacturers published values are shown in Table 3.

Table 3 Comparison of Tensile Strengths of Screws

Screw Size	Yield Strength (Tensile Tests) (lb.)	Tensile Strength (Manufacturers published values) (lb.)
2-56 socket cap	320-585	296
4-40 socket cap	500-840	483
6-32 socket cap	900-940	727
8-32 socket cap	1200-1700	1120

Calculations

The material used for the screw holders was 302 stainless steel (see Figures 3 and 4) with a yield of 40, 000 psi. and an ultimate tensile strength of 60, 000 psi. Table 4 shows the Tensile Stress Areas and those theoretically calculated yield and tensile values expected.

Table 4 Engineering Properties of the Screws.

Screw Size	Tensile Area (in^2)	Material Yield Strength (psi)	Calculated Yield (lb.)	Material Tensile Strength (psi)	Calculated Yield (lb.)
0-80	0.0018	40,000	72	60,000	108
2-56	0.0037	40,000	148	60,000	222
4-40	0.00604	40,000	242	60,000	362
6-32	0.00909	40,000	364	60,000	545
8-32	0.014	40,000	560	60,000	840

Summary

Screw Size 2-56 For a torque setting of 5 in-lb., an average of 371 lb. of clamp force was obtained. There was no measurable difference in clamp force with or without nylok. The combination of silver plate and nylok did show a reduction in friction by almost half causing the clamping force to increase accordingly.

Screw Size 4-40 For a torque of 10 in.-lb., an average of 555 lb. of clamp force was obtained. There appeared a slight decrease in friction with nylok parts compared to standard which increased the clamp force 15-30 lb. Similar results were found with the silver plated screws.

Screw Size 6-32 This is the first screw size that showed a noticeable difference in clamp force using nylok. At a torque of 15 in-lb., an average of 330-lb. clamp force was obtained on a standard socket cap screw. Using nylok screws this same torque produced 500 lb. of clamp force due to the reduction in the K value from .33 to .21. These forces are well below the 727-lb. maximum allowed by the screw manufacturers.

Screw Size 8-32 Similar results compared to the 6-32. Reduction in the K value from .42 to .25 caused an increase in clamp force from 438 lb. to 686 lb. Both are well under the tensile strength of 1120 lb.

It should be noted that the screw fasteners used in the filter assembly are made of 302 stainless steel and can have either no finish, nylok patch, silver plate finish of .0001”-.0002”, or silver plate with nylok patch. The load cell used in this work is a 2000 lb. cell with an ASTM uncertainty of 6 11 lb. the ASTM uncertainty of the torque transducer is 6 .01223 in.-lb. the "K" value is calculated from the formula T = KDF. "K" is often referred to as the nut factor that is a combination of thread friction, underhead friction and the geometric factor.

Conclusion

The specimen holder and inserts appear to be strong enough for the maximum force of 1200 lb. with a safety factor of 2. The tensile tests showed higher strengths for the screws than the published values. The yield strengths from both the tensile and torque tests are higher than the published values. The published values indicate that the yield strength of the screws are 50% of the ultimate strength. However, the tensile tests show a higher percentage. The clamping force seem to increase by the nylok/silver plate finish for 6-32 and 8-32 screws. The clamping forces generated in all the tests were below the yield stress of the screws. The nut factor decreased with the use of silver/nylok-finished screws for the 6-32 and 8-32 screws. The decrease in the nut factor resulted in an increase in the clamping force.

References

1. Handbook of Bolts and Bolted Joints, edited by John H. Bickford, and Sayed Nassar, Mercel Dekker, Inc, N.Y., 1998, pp. 560-569
2. Fastener Standards, Industrial Fasteners Institute, Cleveland, OH, 1998, 6^{th} ed., pg. A-9
3. Engineering Fundamentals of Threaded Fastener Design and Analysis, Ralph S. Shoberg, RS Technologies, Farmington Hills, MI, 1997, pp. 1-6

Biographical Information

Joseph O. Arumala is an Associate Professor in the Construction Management Technology at the University of Maryland Eastern Shore. He is an experienced Civil/Structural Engineer with a MS. and a Ph.D. degrees from Clemson University. Dr. Arumala teaches civil engineering oriented courses including Statics; Strength of Materials and Structural Design courses.

Robert McCulley is a Quality Engineer with Filtronic Comtek Inc. He has a BS in Information System Management, and a BS in Mechanical Engineering Technology and is currently finishing a BS degree in Electrical Engineering Technology at UMES. His work involves research, analysis and design of threaded fasteners in the assembly of microwave filters used in the cellular industry.

Emin Yilmaz is a Professor and the Coordinator of the Mechanical Engineering Technology Program at the University of Maryland Eastern Shore. He has a Ph.D. in Nuclear Engineering from the University of Michigan. Dr. Yilmaz has broad and comprehensive knowledge of various engineering and technical disciplines. He is a Professional Engineer and teaches all core courses in the program.

Plate No. 1 Torque Test Set Up

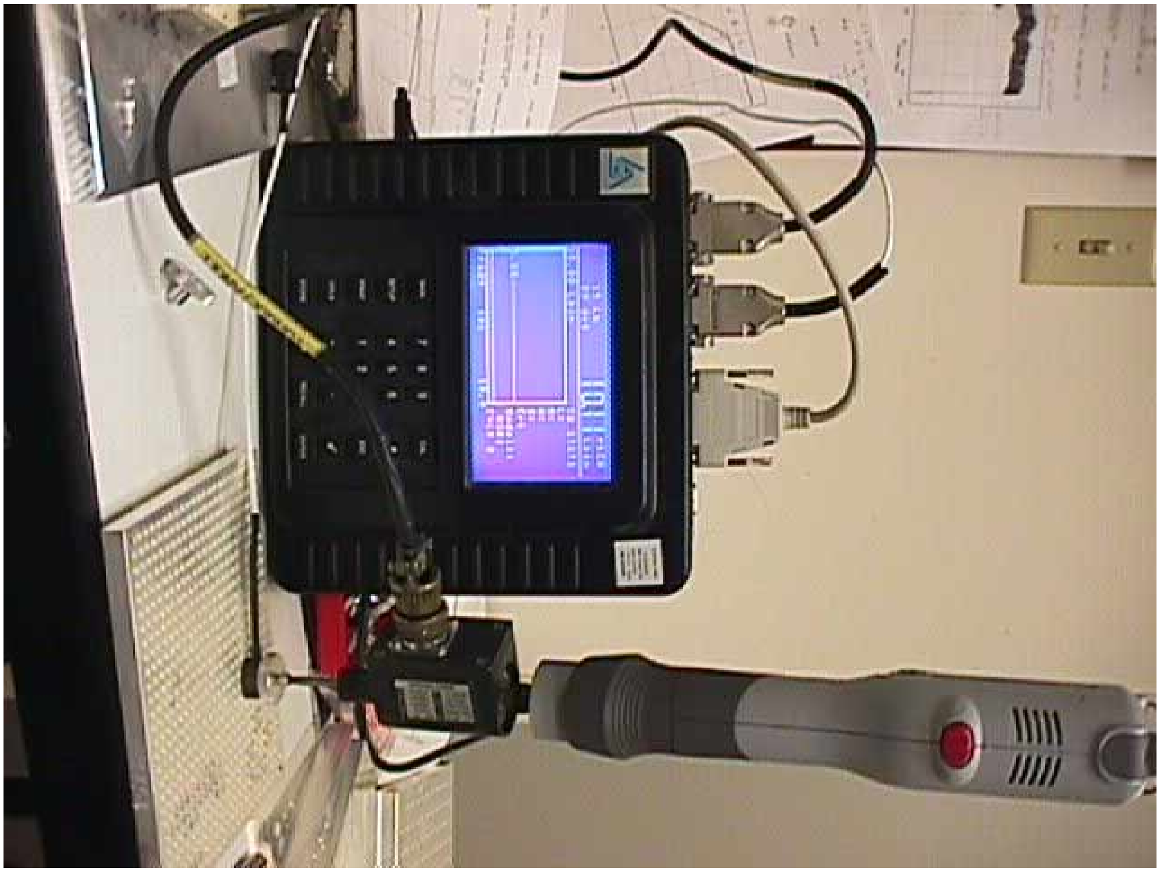


Plate No. 2 A Close Up of Load Cell Washer and Screw

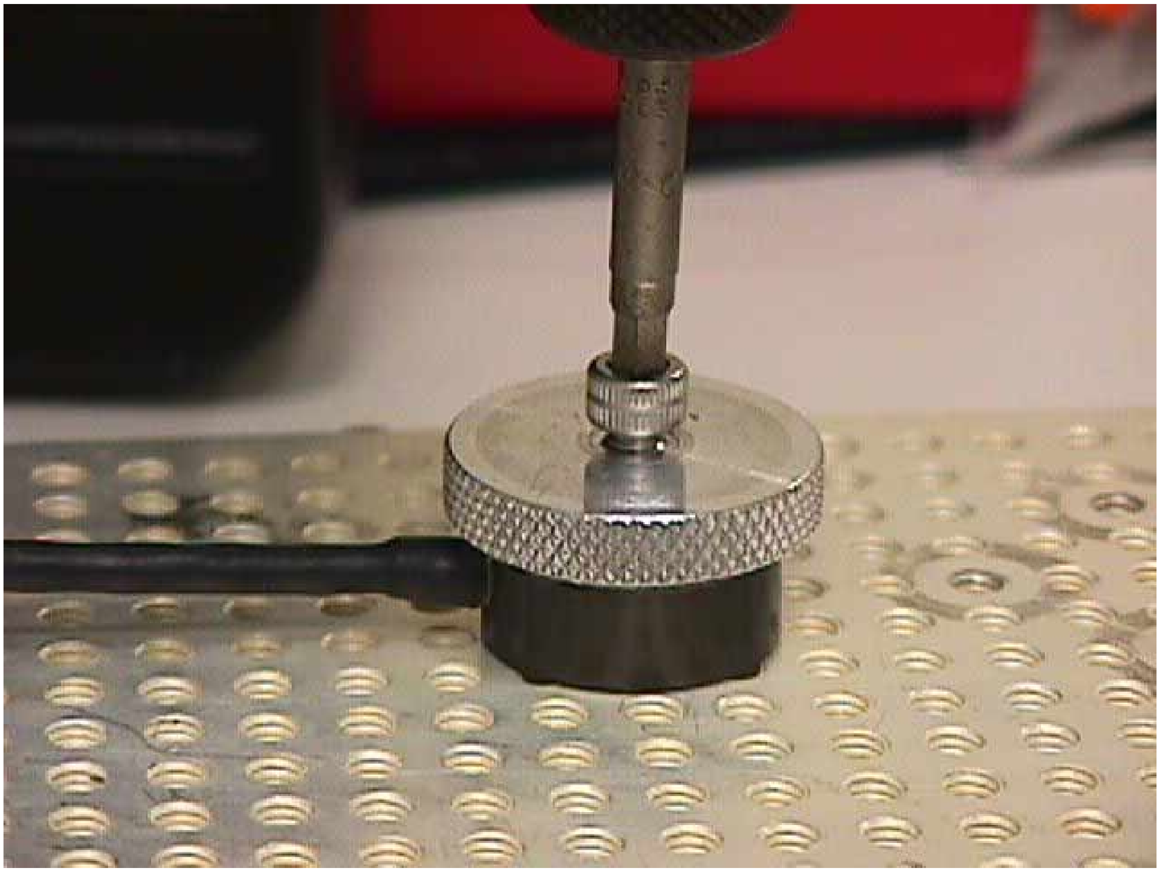


Plate No. 3 Micro Wave Filter with Screw Fasteners

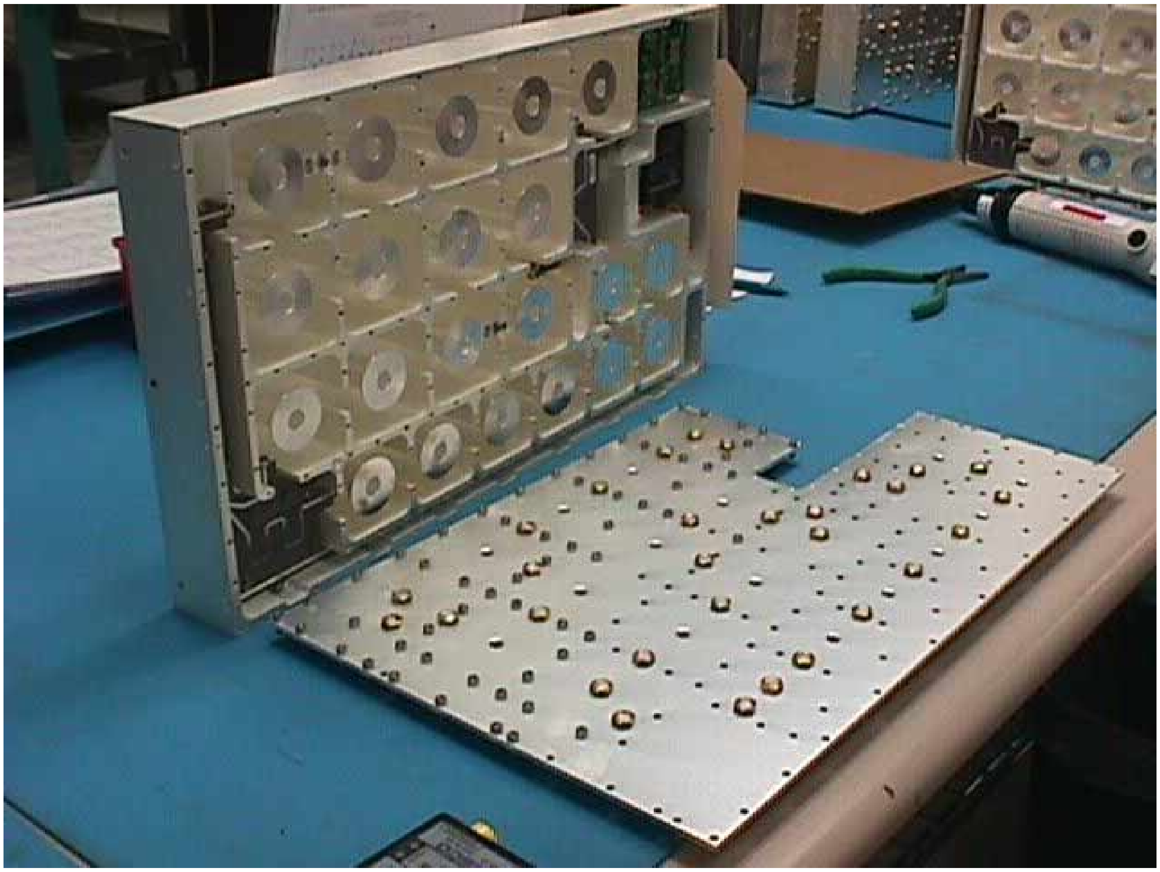


Plate No. 4 Micro Wave Filter with Screw Fasteners

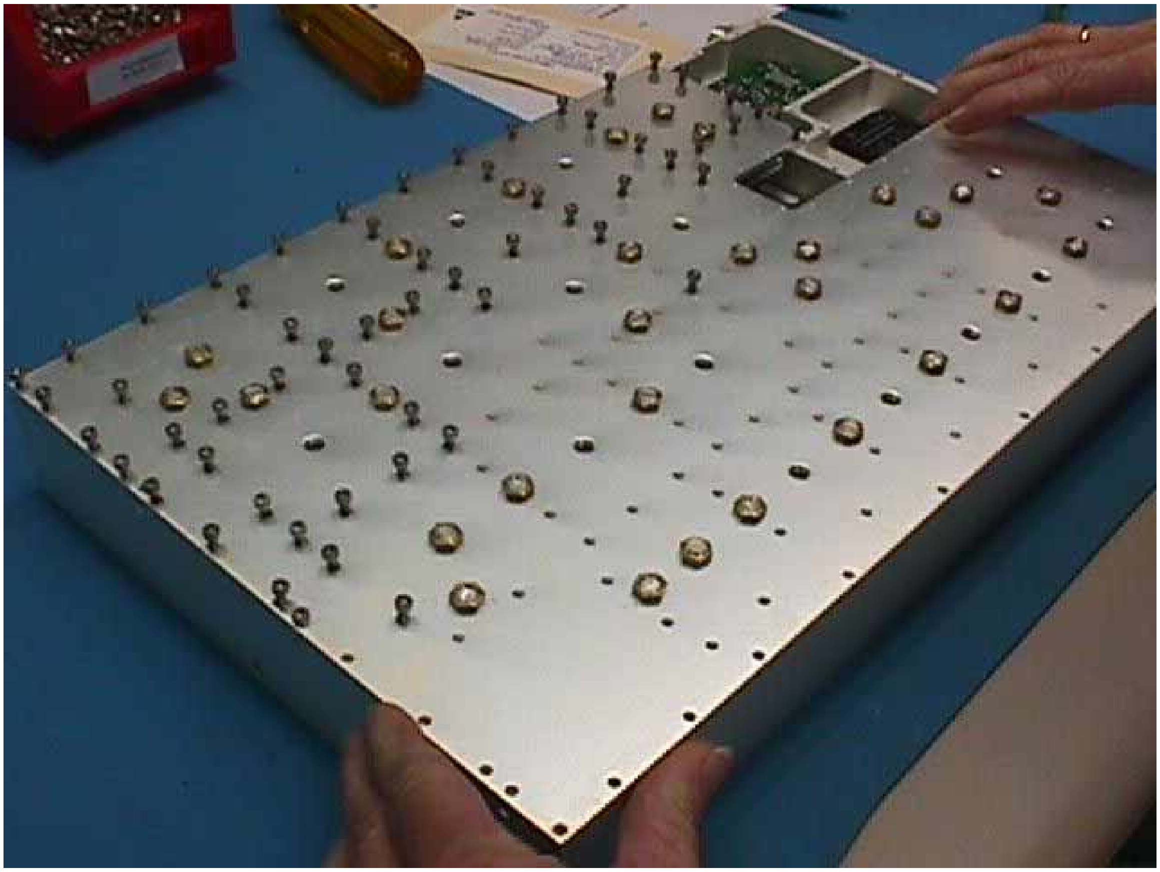


Figure 1 Force Components of a Screw Fastener

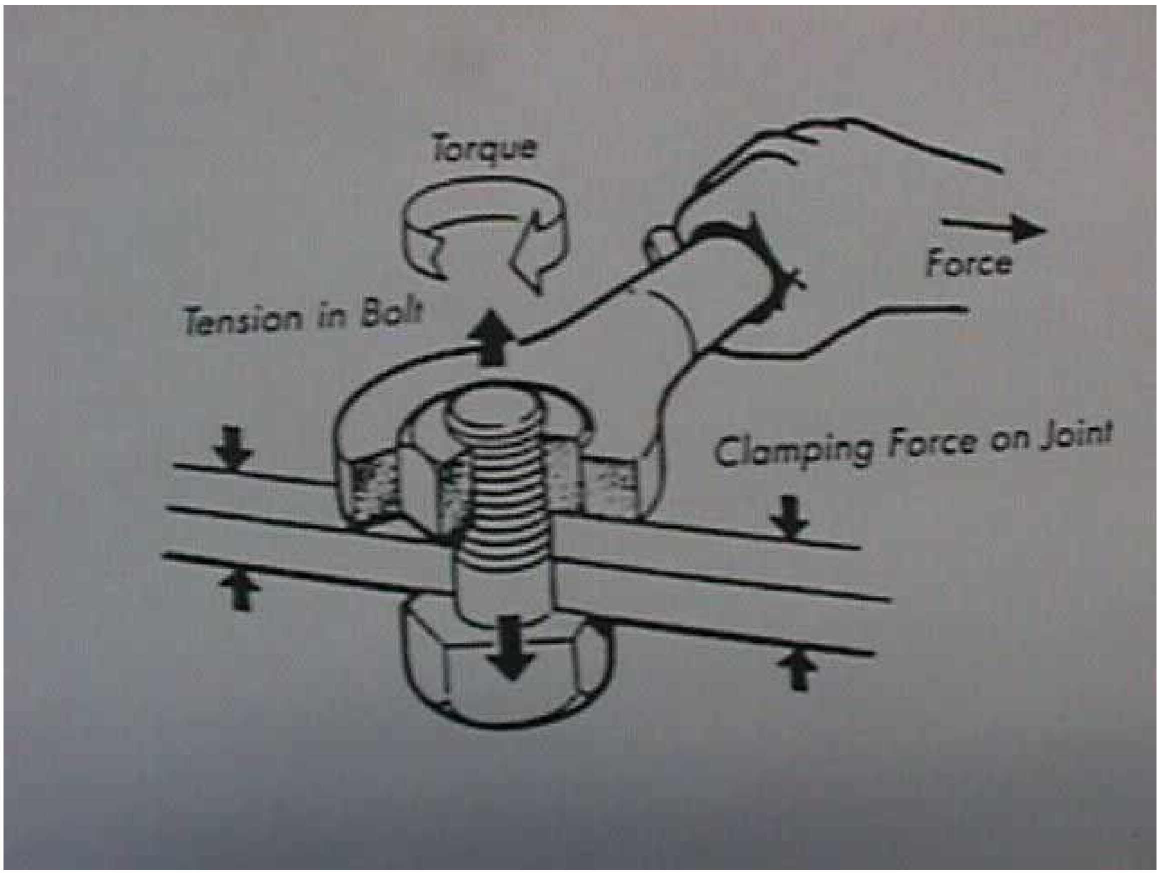
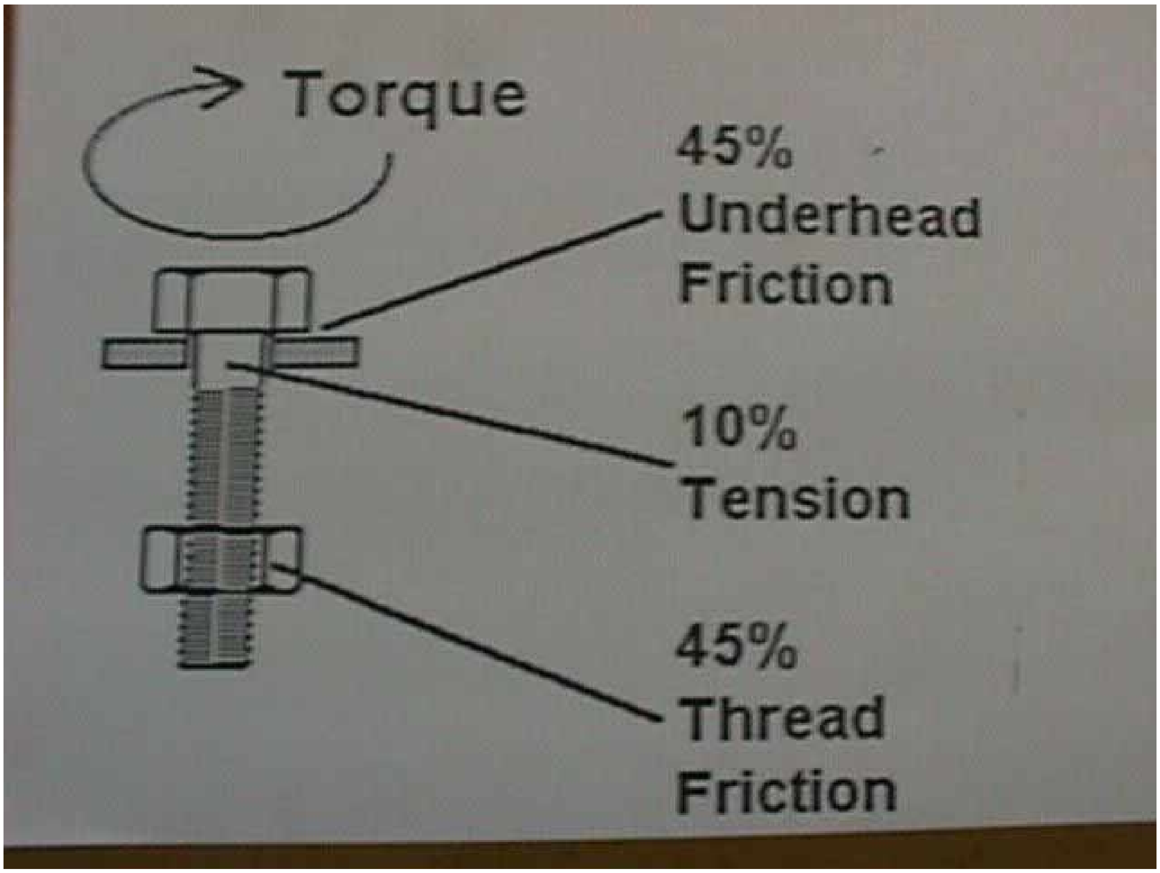


Figure 2 Force Distribution in a Screw Fastener



°

Figure 3 Test Holders

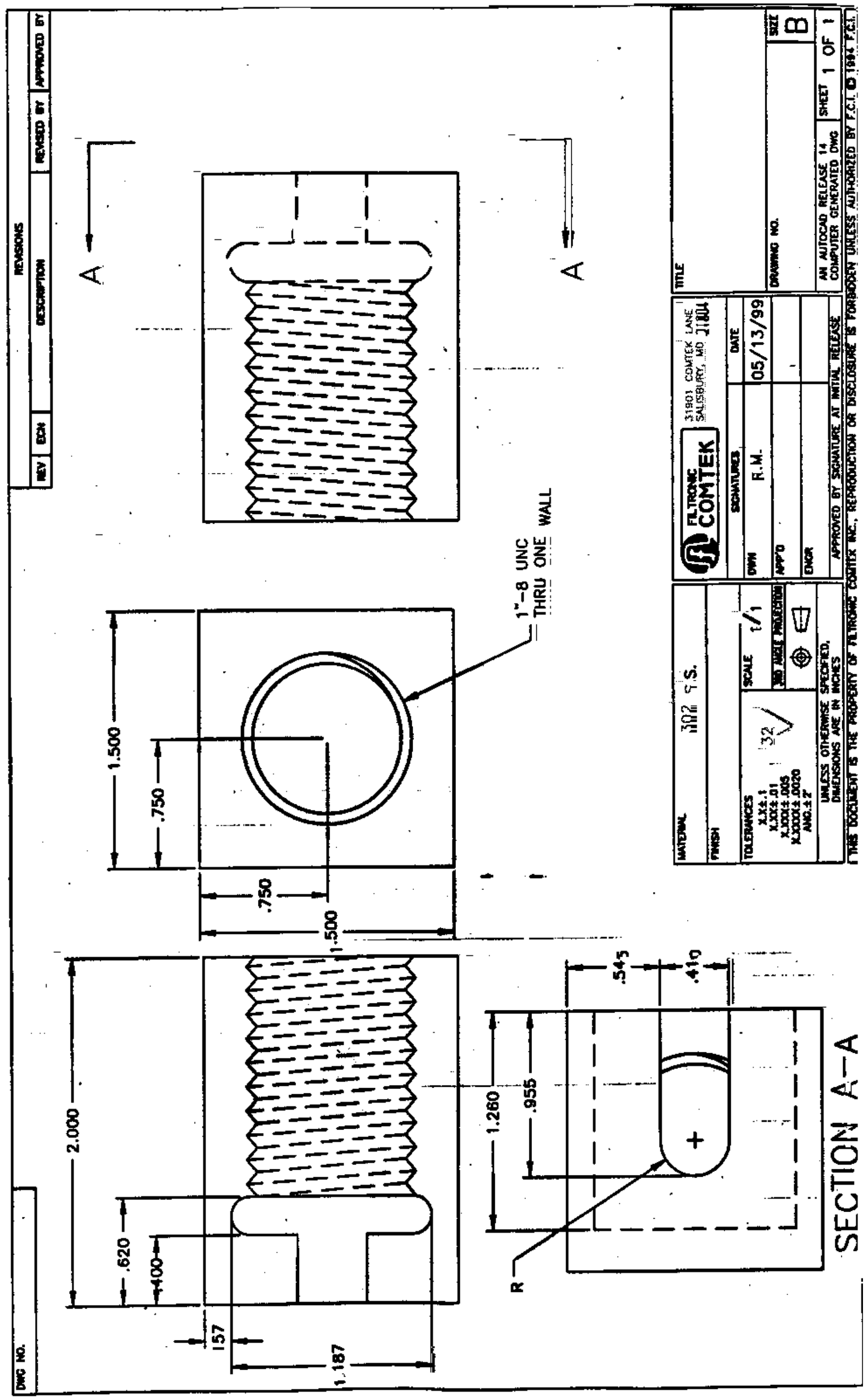


Figure 4 Screw Holders for the Tensile Tests

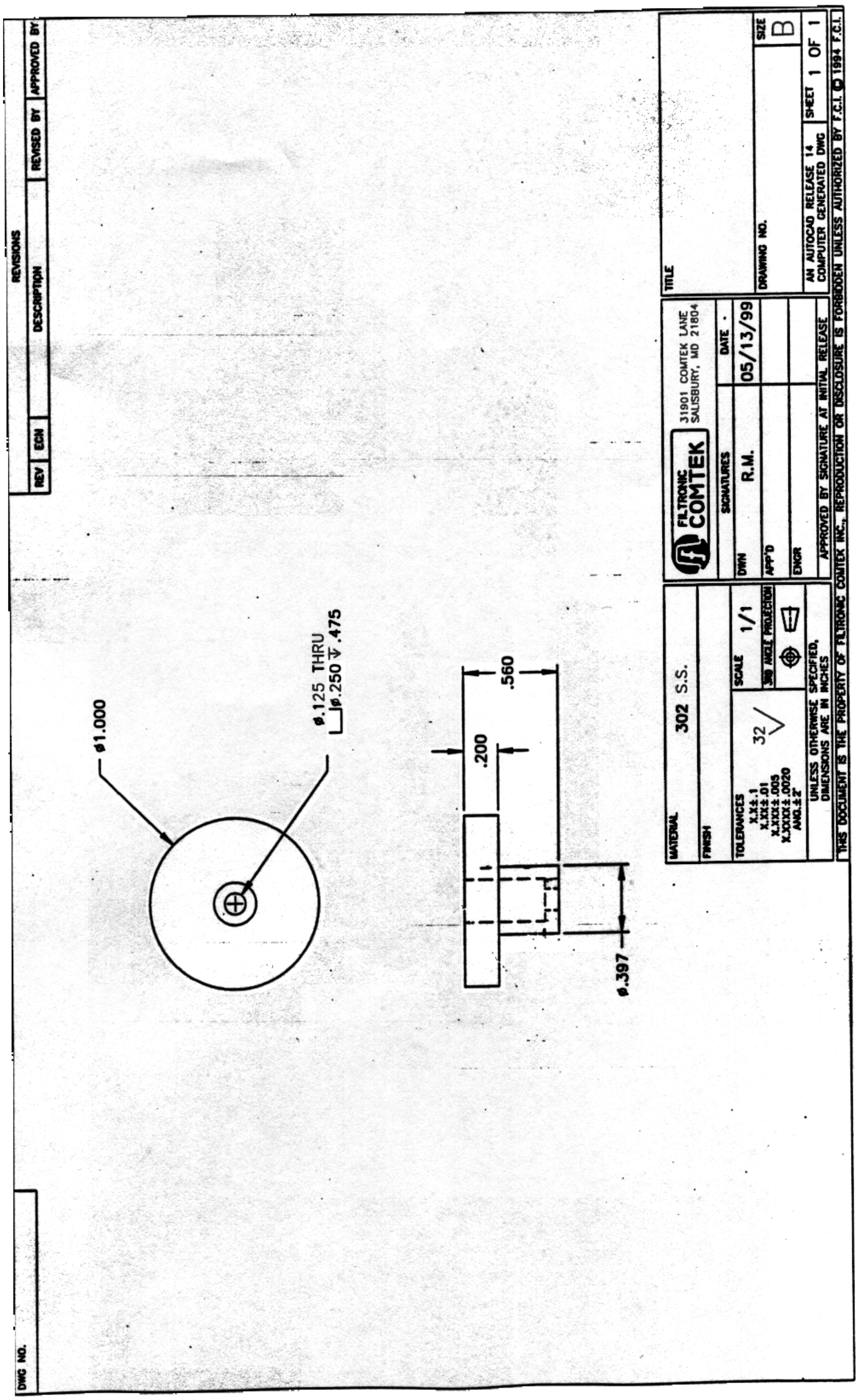


Figure 5 Tensile Test Result on a 4-40 Screw

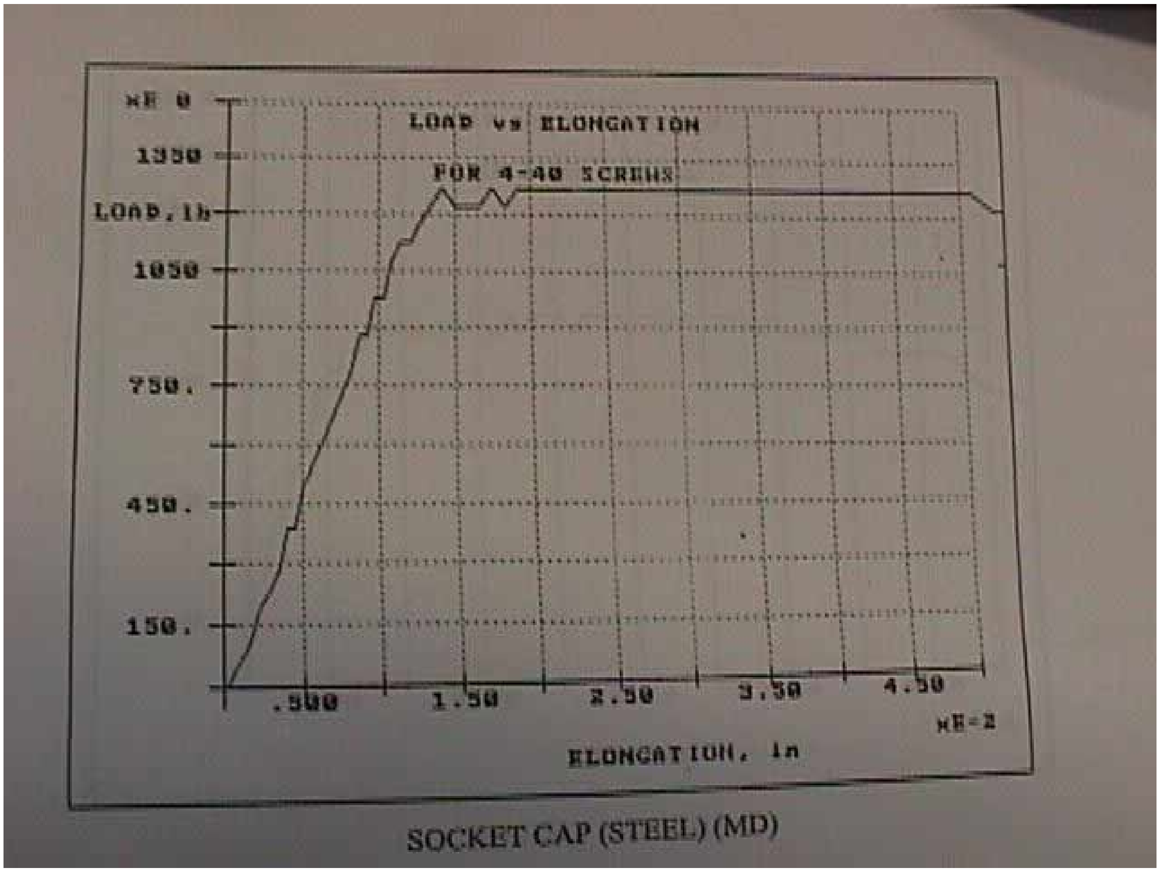
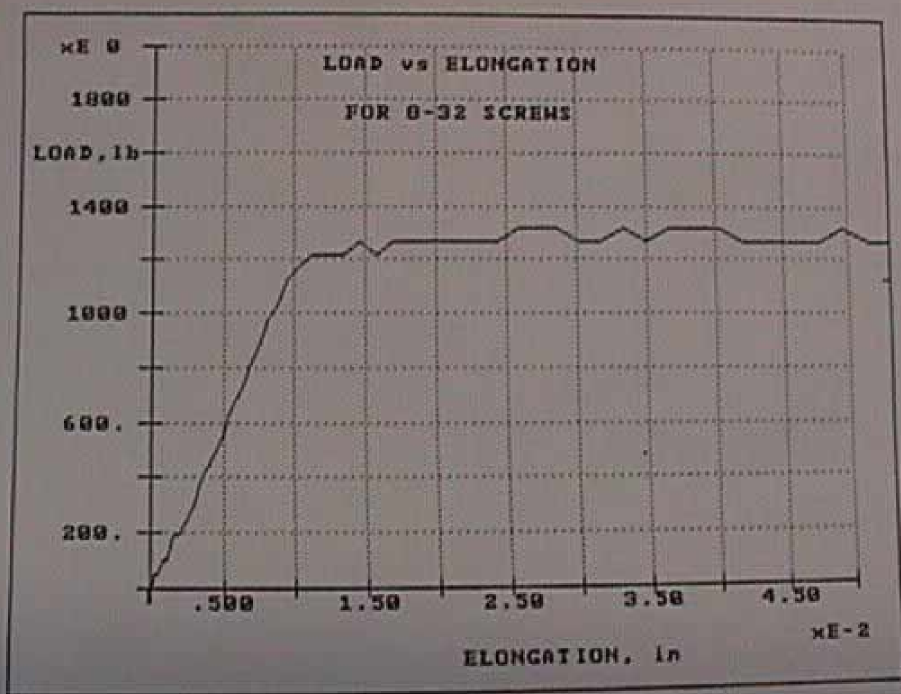


Figure 6 Tensile Test Result on a 8-32 Screw



PAN HEAD (MD)

Figure 7 Torsion Test Result for a 2-56 Screw