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Fastener Load Tests and Retention Systems Tests for Cryogenic Wind-Tunnel Models

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ABSTRACT

This paper presents the results of a fastener load and retention systems test program, which was carried out as a part of the cryogenic models technology development activities at the NASA Langley Research Center. A-286 stainless steel screws were tested to determine the tensile load capability and failure mode of various screw sizes and types at both cryogenic and room temperatures. Additionally, five fastener retention systems were tested by using A-286 screws with specimens made from the primary metallic alloys that are currently used for cryogenic models. The locking-system effectiveness was examined by simple no-load cycling to cryogenic temperatures (-275°F) as well as by dynamic and static loading at cryogenic temperatures. In general, most systems were found to be effective retention devices. There are some differences between the various devices with respect to ease of application, cleanup, and reuse. Also results of tests at -275°F imply that the cold temperatures act to improve screw retention. The improved retention is probably the result of differential thermal contraction and/or increased friction (thread-binding effects). The data in this paper are provided for use in selecting screw sizes, types, and locking devices for model systems to be tested in cryogenic wind tunnels.

INTRODUCTION

Although fastener strength and retention should always be primary considerations in the design of wind-tunnel models, these factors become even more critical for high-Reynolds-number testing at cryogenic temperatures and under high loads such as those which may be imposed on model systems to be tested in the new National Transonic Facility (NTF) at the Langley Research Center (LaRC) (ref. 1). The looseness, loss, or failure of a fastener could lead to structural component failures, which, in turn, could result in damage to the wind tunnel. For these reasons, two test programs were initiated at LaRC to investigate fasteners and fastener retention systems for model systems to be tested at cryogenic temperatures in the NTF. These investigations were carried out as a part of the cryogenic models technology program at LaRC. (See ref. 2.)

The first test program was carried out to determine the tensile load capability and failure mode at both cryogenic and room temperatures of A-286 screws specified for use in cryogenic models. The second test program was conducted to investigate the effectiveness of various retention systems under no-external-load cryogenic-cycling conditions and under static- and dynamic-loading conditions at cryogenic temperatures.

The data in this report provide the basis for selecting screw sizes and retention systems for use in cryogenic model design and also greatly expand the data on retention systems reported in reference 3. Screws of each type and size were broken under tensile load at room temperature (70°F) and at cryogenic temperature (-275°F). Each fastener system was tested under simulated environmental temperature and loading conditions. Descriptions of the apparatus, facilities, procedures, and results for tensile load and failure mode tests on screws and for breakaway torque tests on fastener retention systems are presented.

Use of brand names in this report or use of particular products in the fastener retention tests does not constitute an endorsement of the products. The products were selected as being representative of their respective classes of retention systems.

ABBREVIATIONS

A-286	A-286 stainless steel
BHS	button head screw
FHSCS	flat head socket cap screw
LN_2	liquid nitrogen
N-40	Nitronic 40 stainless steel
PH 13-8 Mo	precipitation-hardened 13-8 Mo stainless steel
SCS	socket cap screw
18 Ni	18 Ni grade 200 maraging steel
6061	6061-T6 aluminum

FASTENER LOAD TESTS

Description and Procedure

Since load data for screws at cryogenic temperatures are generally not available, a program was developed to determine the tensile load capability and failure mode of A-286 stainless steel screws at both cryogenic and room temperatures. Nine sizes and three types of screws were tested, as listed in table I. The only load test data supplied by the manufacturer are given in table II. The ultimate loads given in table II were based on room temperature tests for only one screw of each size. As purchased, the 10-32 and 1/4-28 screws were threaded for only 1 in. for screw lengths of 1.5 in. and 3.0 in. In use, many of these screws will require threads all the way to the head. Therefore, 10 of each of these screws were modified by continuing the threads to the head and were included in the test program.

The program consisted of applying a tensile load to failure to five of each size and type of screw at room temperature (70°F) and at cryogenic temperature (-275°F). The screws were tested in a load-testing machine. A special set of fixtures was designed and fabricated to fit the load tester to match all the sizes and types of screws. A typical setup is shown in figure 1. For all tests, a strip chart was used to record the load and head movement versus time. The strip chart recordings were used to determine the yield load, the ultimate load, and the elongation of each screw. For the cryogenic tests, the environmental chamber on the load tester was cooled to -275°F, and each screw setup was allowed to soak for approximately 45 to 60 minutes to obtain a uniform temperature throughout the setup.

Results

The results of load tests performed on A-286 stainless steel screws are given in this section. As mentioned previously, the manufacturer's ultimate-load test data are given in table II. These data were based on room temperature tests for only one screw of each size. Tables III and IV give the summarized results at room temperature and cryogenic temperature, respectively. Presented for each size and type of screw are the minimum yield load (determined by 0.2-percent offset in the elongation), the minimum ultimate load obtained, and the number of failures at the head and in the threads.

Principal observations on the failure modes of the screws tested were:

(1) Heads popped off all the 1-72 button head screws at both room temperature and cryogenic temperature.

(2) All socket cap screw failures occurred in the threads.

(3) None of the 2-56, 6-32, 8-32, and unmodified 1/4-28 flat head socket cap screws had any head failures at room temperature.

(4) At cryogenic temperature, the 6-32, 8-32, 1/4-28, and modified 1/4-28 flat head socket cap screws did not have any head failures.

(5) Generally, head failures occurred at lower loads than thread failures for a given screw size and type, and the head failure fractures occurred through the bottom of the socket.

Caution should be used in any attempt to calculate stresses in these screws. The minimum loads listed for most of the flat head socket cap screws are values for a head failure where the exact cross-sectional area is unknown. The data provided in tables III and IV are currently being used to select screws for cryogenic models. As a conservative measure, minimum values were chosen as opposed to using average values. Interestingly enough, the room temperature ultimate (failure) loads do not agree very closely with data supplied by the manufacturer. The manufacturer-supplied failure loads are generally lower for the smaller screws and higher for the larger (larger than 6-32) screws than the values measured in these tests.

FASTENER RETENTION DEVICES

For this program, five fastener retention devices were tested with screws of two sizes, 1/4-28 and 2-56. These devices are described in the following sections. Figure 2 is a cutaway specimen showing each of the five devices installed with a 1/4-28 screw.

Thread Inserts

Self-locking Heli-Coil thread inserts were chosen for these tests. The Heli-Coil insert is a hardened steel insert which is threaded into a tapped hole. The locking feature is a deformed thread in the center, which "clamps" or "binds" the screw thread and increases the torque required to turn the screw.

Modified Thread Forms

The modified thread form chosen for these tests was produced by Spiralock taps. (Spiralock is a trademark of H. D. Holmes, licensed to Detroit Tap & Tool Company.) The Spiralock thread form is a female thread characterized by a ramp at the root of the thread. A screw has a free run into the thread form until the head of the screw touches the surface. Then, as the screw is tightened, the crest of the thread runs up the ramp of the thread form and "locks" the screw in place.

Threadlocker/Sealants

Loctite threadlocker/sealant was chosen as the representative of this class of retention devices. It is a viscous liquid that is applied to the screw threads just prior to assembly. After assembly, confined in the threads and in the presence of metal, the Loctite hardens into a tough plastic, which must be sheared before the parts will move. Medium-strength Loctite 242 was used for the large screws, and mild-strength Loctite 222 was used for the small screws.

Adhesives

The representative of this class was Crest 391 adhesive, which is currently used for cryogenic applications. When cured, Crest remains flexible at room temperatures but becomes very hard at cryogenic temperatures. In this program, the Crest adhesive was applied under the screw heads.

Epoxies

Epoxy filled with aluminum powder was used over and around the screw heads in the test pieces to bond the head to the test piece. The epoxy chosen was Hardman extra-fast-setting epoxy, which has a relatively short cure time of 5 to 10 minutes. The epoxy was filled with aluminum powder in a ratio, by weight, of one part epoxy to two parts aluminum powder.

TEST SPECIMENS

A-286 stainless steel screws ordered specifically for use in NTF models were used in the test program. Screw sizes chosen were 1/4-28 socket cap screws and 2-56 flat head socket cap screws, which are believed to be representative of the largest and smallest screws that will be used in typical model construction.

Five materials currently used in models to be tested in cryogenic environments were selected. These are A-286, Armco Nitronic 40, and PH 13-8 Mo stainless steels; 18 Ni grade 200 maraging steel (18 Ni); and 6061-T6 aluminum (6061). Identical test specimen parts (scaled to be representative of a conventional joint attachment on models) were fabricated from each material for the tests. The parts include a specimen base (fig. 3(a)) used with either a part A (fig. 3(b)) with five 1/4-28 screws or a part B (fig. 3(c)) with nine 2-56 screws. Four specimen bases were fabricated from each material. Two had conventionally tapped holes, one had self-locking Heli-Coil inserts installed, and one was tapped with Spiralock thread form. Three each of parts A and B were fabricated from each material. Test specimen assemblies are illustrated in figure 4.

RETENTION SYSTEMS TESTS

Apparatus

The retention systems tests with no loads applied were conducted in a cryogenic "soak" tank partially filled with liquid nitrogen. (See fig. 5.) Temperature was controlled by placing the specimens on a movable shelf and adjusting the height above the liquid nitrogen. Temperature was monitored with thermocouples attached to the specimens.

The dynamic-load tests were conducted on a shaker table. The specimens were bolted to a block of bakelite attached to the shaker table top and cooled by pumping liquid nitrogen through the specimen during the tests, as shown in figure 6. Temperature was monitored with thermocouples.

The static-load tests were conducted on a tensile tester with an environmental chamber attached as shown in figure 7 and loaded as shown in figure 8. The chamber was cooled with liquid nitrogen. The specimens were allowed to soak until equilibrium temperature was achieved before the loads were applied.

Assembly

For the assemblies, a specimen base was matched with a part A or a part B (fig. 3) and fastened together with the proper screws. (See fig. 4.) For the self-locking Heli-Coil inserts and the Spiralock thread forms, the retention system is an integral part of the specimen base, so there is no preparation required for assembly other than postfabrication cleaning with freon in an ultrasonic cleaner.

For the tests, the Crest adhesive was applied to the underside of the screw heads during assembly. The screws were torqued, and the specimen was set aside for 72 hours at room temperature until the Crest adhesive cured.

For the tests using Loctite sealant, a primer was sprayed on the screw threads, and the Loctite sealant was applied to the threads during assembly. After the screws were torqued, the specimen was set aside for 30 minutes at room temperature until the Loctite sealant cured.

For the tests using aluminum-filled epoxy, the specimens were assembled, and the screws were torqued. An allen wrench was inserted in the screw socket, and the epoxy was filled around the wrench and over and around the screw head. This procedure left the socket open for the torque wrench.

One set of specimens was tested without any retention system as a baseline for measuring the effectiveness of the locking systems. Tightening torque and breakaway torque were measured by using a socket wrench with strain gages attached to the wrench extension. The screws were preloaded to approximately one-fourth of the ultimate load based on the tensile load test data given in this paper. Torque values for each screw were determined through use of a nomograph relating torque to preload. The 1/4-28 screws were torqued to 94 in-lb, and the 2-56 screws were torqued to 2.7 in-lb.

Procedure

The test procedures described below were the same for each of the retention devices and test specimens. A temperature of -275°F was selected as a representative cryogenic test temperature for NTF models.

No-external-load tests.- The first measurement for effectiveness of the system was made before any cryogenic cycling was done. All screws in the test specimen except one, designated the control screw, were broken loose with the torque wrench, and the breakaway torque was recorded. Prior to each reassembly, the test specimens were cleaned with a tap, a die nut, and/or the ultrasonic cleaner, as required.

The test specimen was then reassembled by the original assembly procedures. For the no-load tests, the specimen was then placed in the soak tank and cooled to -275°F. The specimen was allowed to soak at -275°F for approximately 30 minutes and was then removed from the tank. When the specimen reached room temperature, the screws, except for the control screw, were broken loose, and the breakaway torque after one cycle was recorded.

The test specimen was again reassembled and then cryogenically cycled to -275°F and back to room temperature five times. When back at room temperature after the fifth cycle, the screws, except for the control screw, were broken loose, and the breakaway torques were recorded.

For the tests at -275°F, the test specimen was reassembled, placed in the cryogenic tank, and allowed to soak until it was uniformly cold at -275°F. The specimen was then removed from the tank, the screws, except for the control screw, were broken loose within 5 minutes after removal, and the breakaway torques were recorded. After the specimen returned to room temperature, the control screw was broken loose, and the breakaway torque was recorded.

Dynamic-load tests.- For the dynamic-load tests, the test specimen was assembled according to the required procedure and mounted on a 7-in-square bakelite block. The block was then mounted on the vibration shaker table as shown in figure 6. Liquid nitrogen was then pumped through the test specimen to cool it to approximately -275°F. Two thermocouples attached to the specimen were used to monitor the temperature. When equilibrium temperature was reached, the vibration system was turned on. The specimen was vibrated for 30 minutes at random frequencies from 20 to 200 Hz at 9g root-mean-square to simulate a severe vibration condition that a model might possibly experience in a wind tunnel. After the vibration test was complete, the test specimen was allowed to warm to room temperature. The block and test specimen were then removed from the shaker table, the screws were broken loose, and the breakaway torque was recorded.

Static-load tests.- For the static-load tests, the specimen was again assembled according to the required procedure. It was mounted in the environmental chamber on the load tester as shown in figures 7 and 8. The chamber was then closed and cooled to -275°F. When at equilibrium temperature, the specimen was subjected to a predetermined load, the magnitude of which was determined by the size of the screws in the test specimen. For the test specimens with 1/4-28 screws, a compressive load of 7600 lb was applied at point P (fig. 8). For the specimens with 2-56 screws, a compressive load of 540 lb was applied at point P. These were the calculated loads required to load the test pieces up to the screw preload values induced by the tightening torque values of 94 in-lb and 2.7 in-lb, respectively. The load was removed and then reapplied. This procedure was followed until 10 load cycles were completed.

The piece was removed from the chamber and allowed to warm. At room temperature, the screws were broken loose, and the breakaway torques were recorded.

RETENTION SYSTEMS TEST RESULTS

In general, all retention devices tested proved to be effective at retaining the screws in the specimens. The effectiveness varied, however, with different combinations of retention devices and materials. Breakaway torque data in the tests are presented in table V for the specimens with 1/4-28 screws and in table VI for the specimens with 2-56 screws.

The values of breakaway torque presented in the columns headed "before cycling," "after one cycle," "after five cycles," and "at -275°F" are the averaged values for all screws except the control screw in each test specimen. The values in the "control screw" column are single screw values obtained after all other no-load tests were completed (seven cryogenic cycles). The values in the "after dynamic loading" and "after static loading" columns are the averaged values for all the screws in the test specimen.

The data showed some scatter, as might be expected. The static- and dynamic-load tests generally had less than 10-percent deviation from the average value for the 1/4-28 screws and less than 20 percent for the 2-56 screws. The no-load tests had slightly less scatter except for the filled epoxy, which was generally in the 20- to 30-percent range.

The data of tables V and VI are also presented graphically in figures 9, 10, 11, and 12. Figure 9 presents the breakaway torque for the different phases of the tests versus specimen material for self-locking Heli-Coil inserts used with 1/4-28 screws, and figure 10 presents the same information for 2-56 screws. Figure 11 presents the breakaway torque for the different locking systems with 1/4-28 screws versus specimen material for each phase of the tests, and figure 12 presents the same information for 2-56 screws. Figures 9 and 10 allow an easy comparison of breakaway torque for the different phases of testing for one locking device, and figures 11 and 12 allow an easy comparison of breakaway torque for the different locking devices at each phase of testing. Unless otherwise stated, percentage decreases in breakaway torque are referenced to tightening torque.

Heli-Coil Thread Inserts

1/4-28 screws.- For all material specimens, the 1/4-28 screws with Heli-Coil inserts showed little effect from cryogenic cycling; the breakaway torque values ranged from a high of 85 to 90 in-lb for 18 Ni to a low of 70 to 75 in-lb for PH 13-8 Mo. At -275°F, torque increased for all materials with a high in excess of 138 in-lb for 18 Ni and A-286 and a low value of 95 in-lb for 6061. Values for the control screws were lower than the one- and five-cycle data, with the most significant decrease occurring in the PH 13-8 Mo and the A-286 specimens. The values obtained in the dynamic- and static-load tests were somewhat lower than those obtained in the no-load cryogenic cycling tests. These somewhat lower torque values indicated some slight loosening under load.

2-56 screws.- The results for the cryogenic cycling of specimens with 2-56 screws were similar to the 1/4-28 screw results with the exception of the PH 13-8 Mo specimens, which showed decreases (compared with tightening torque) of about 47 percent in breakaway torque after the first cryogenic cycle and 67 percent for the control screw. Breakaway torque values at -275°F were down slightly for all materials except Nitronic 40, which had an increase of 42 percent. The dynamic test values were in the same range as the no-load tests. After static-load tests, all the screws except those in the 6061 were too loose to read breakaway torque values. It is possible that the torque required to overcome the binding action of the self-locking Heli-Coil thread insert was sufficient to prevent the proper clamping load from being applied to the joint.

Spiralock Thread Forms

1/4-28 screws.- The cryogenic cycling tests with no external load applied showed very little change for the Spiralock thread form in 6061. The Nitronic 40 and 18 Ni samples showed some decline in breakaway torque with increased cycling but not a significant amount. The A-286 and the PH 13-8 Mo specimens show declines of 20 to 25 percent in breakaway torque with increased cycling. At -275°F, the 18 Ni and Nitronic 40 specimens showed little change, but the PH 13-8 Mo specimens showed a decrease of 28 percent in breakaway torque. Increases of 20 percent for the A-286 specimens and 14 percent for the 6061 specimens were also obtained. Values for the control screws fell in line with the five-cycle data. Dynamic-load data generally fell within the values for the no-load cycling; however, the static-loading tests yielded the lowest values for breakaway torque with a substantial drop of 56 percent for the aluminum sample.

2-56 screws.- For the no-external-load tests, the breakaway torque values for all the materials with 2-56 screws were uniform at about 65 percent of the tightening torque. The breakaway values at -275°F increased 28 percent and 36 percent for the A-286 and the Nitronic 40 specimens, respectively. The other materials showed slight decreases. The control screw values ranged from 30 percent lower for 6061 to 44 percent and 41 percent lower for A-286 and Nitronic 40, respectively, to significantly lower for 18 Ni and PH 13-8 Mo, which had decreases of 65 and 74 percent, respectively. The dynamic and static tests showed decreases between 20 and 40 percent in the breakaway values.

Loctite Threadlocker/Sealant

1/4-28 screws.- Loctite 242 threadlocker/sealant used with 1/4-28 screws showed breakaway torque values before cycling that were 15 to 20 percent higher than the tightening torque for all the materials except 6061, which was 17 percent lower. No-load cycling produced decreases in breakaway torque for all the materials except 6061. However, the breakaway values were equal to or higher than the tightening torque for the A-286 and the Nitronic 40 specimens and only slightly lower for the 18 Ni specimens. The breakaway values at -275°F were substantially higher, with increases ranging from about 73 percent for 18 Ni to 98 percent for PH 13-8 Mo. The values for the control screws were similar to the five-cycle data for the A-286, Nitronic 40, and 18 Ni specimens. The 6061 aluminum showed a decrease of about 39 percent and PH 13-8 Mo had a substantial decrease of over 60 percent. The dynamic- and static-loading tests showed decreases of 10 to 15 percent for all materials used with Loctite except for decreases of 20 and 29 percent in the static values for 18 Ni and 6061, respectively.

2-56 screws.- Tests on Loctite 222 threadlocker/sealant with 2-56 screws showed little effect from cryogenic cycling on Nitronic 40, 18 Ni, and 6061 samples. Breakaway torque values were 5 to 10 percent higher than tightening torque before and after cycling. Data for A-286 and PH 13-8 Mo were scattered with before-cycling breakaway torque values up 26 and 18 percent, respectively. Breakaway torque values were down as much as 11 percent (compared with tightening torque) after cycling. At -275°F, the screws could not be removed. The breakaway values for the control screws fell within the other no-load cycling values for 6061, were higher for PH 13-8 Mo and Nitronic 40, and were lower for A-286 and 18 Ni.

The dynamic tests did not show any adverse effects on breakaway torque. Values for A-286 and PH 13-8 Mo fell within the range for the no-external-load cycling values. For the other materials, the values were higher than the no-load cycling values. The static-load tests appeared to have the biggest effect on breakaway torque. The static values were within the range of the no-load values except for 18 Ni and 6061 specimens, which showed decreases. The static values were all significantly lower than the dynamic values.

Crest Adhesive

1/4-28 screws.- The no-external-load tests using Crest adhesive under the screw heads showed uniform results for all the materials with 1/4-28 screws. Breakaway torque values before cycling were 15 to 20 percent lower than the tightening torque. Breakaway torque values after one cryogenic cycle were slightly higher than the before-cycling values for all materials. Breakaway values after five cycles were slightly higher than the one-cycle values for all materials except 6061. At -275°F, the breakaway torque values ranged from >137 to >166 percent higher than the tightening torque values. The values shown are for the one to three screws in each material that could be broken loose at -275°F. From one to three screws in each material could not be broken loose without exceeding the limit of 255 in-lb for the torque wrench. Control screw breakaway values were 11 to 36 percent lower for all materials. The dynamic-load tests were fairly uniform with values ranging from a low of 72 in-lb for Nitronic 40 to a high of 81 in-lb for A-286. The static-load tests were very uniform with a low value of 75 in-lb for PH 13-8 Mo and a high value of 78 in-lb for 6061.

2-56 screws.- The no-external-load tests using Crest adhesive with 2-56 screws did not show the uniformity of the tests on 1/4-28 screws. The Crest used with 6061 showed little effect from the cryogenic cycling. Breakaway torque values for A-286 and PH 13-8 Mo samples decreased with cryogenic cycling but still remained higher than the tightening torque. The Nitronic 40 specimens showed breakaway torque 16 and 33 percent higher than the tightening torque after one and five cycles, respectively. A significant drop of about 25 percent (compared with the before-cycling value) occurred after one and five cycles with the 18 Ni. At -275°F, none of the 2-56 screws in any of the materials could be broken loose from the Crest adhesive. For the control screws, the 6061 and Nitronic 40 samples had breakaway values higher than the tightening torque. A-286 was lower with a decrease of 15 percent, and PH 13-8 Mo and 18 Ni were substantially lower with decreases in breakaway torque of 37 and 53 percent, respectively. The dynamic-loading tests showed decreases for the A-286 and the PH 13-8 Mo specimens and increases of 10 percent for the Nitronic 40, 14 percent for the 6061, and 25 percent for the 18 Ni specimens. The static-loading tests showed slight increases for 6061 and PH 13-8 Mo and larger increases of 17 to 20 percent for the other materials.

Epoxy Over Screw Head

1/4-28 screws.- For 1/4-28 screws, after cycling the aluminum-filled epoxy had the highest breakaway torque when used with PH 13-8 Mo and the lowest breakaway torque with 6061. However, the values for all the materials were equal to or as much as 33 percent greater than the tightening torque value. At -275°F, the 6061 showed an increase of about 53 percent in breakaway torque, but the other materials did not change appreciably. Control screw values were somewhat lower for A-286 and PH 13-8 Mo, but the values for the other materials were all higher than the tightening torque. The dynamic-loading tests showed little effect from the loading on the epoxy. Breakaway values were consistent with the no-load values for all the materials. The static-load results were similar to the dynamic-load results with only the aluminum at 88 in-lb showing a breakaway torque lower than the tightening torque.

2-56 screws.- Cycling data obtained for the 2-56 screws show some scatter, with the only significant deviation being a decrease of over 50 percent for the 18 Ni specimens, after one cryogenic cycle. Control screw values were lower than tightening torque, with significant decreases for the PH 13-8 Mo, Nitronic 40, and 18 Ni specimens. Data were limited at -275°F. The sockets in the heads of the screws stripped out in all the screws in the PH 13-8 Mo and the 18 Ni specimens and in many of the screws in the other materials. Those screws that were broken loose showed breakaway torque increases of 39 to 52 percent. The dynamic-load tests showed little effect on the epoxy. Only the A-286 specimens at 2.45 in-lb had a breakaway value lower than the tightening torque of 2.7 in-lb. Values for the static-load tests were lower than the dynamic-load values except for the 6061 specimens. After static loading, the A-286 at 2.31 in-lb, Nitronic 40 at 2.47 in-lb, and 18 Ni at 2.64 in-lb all had breakaway torque values lower than the tightening torque.

No Locking System

1/4-28 screws.- The breakaway torque before cryogenic cycling for all specimens without locking systems was fairly consistent. Values ranged from a low of 78 in-lb for the A-286 specimens to a high of 84 in-lb for the 18 Ni specimens. One cryogenic cycle had little effect on all the materials except PH 13-8 Mo, which showed a 36-percent decrease. Five cryogenic cycles produced decreases in breakaway torque ranging from 19 percent for the Nitronic 40 specimens to 28 percent for the 18 Ni specimens. The breakaway torque at -275°F increased for all materials. The smallest increase was 15 percent for 6061, and the largest increase was 52 percent for A-286. The control screws all showed decreases similar to the five-cycle data with the largest decrease being for PH 13-8 Mo. The dynamic-load tests showed decreases ranging from 15 to 24 percent for all materials. Static-load breakaway values were consistent for all the materials and were within the range of values for the no-external-load cycling.

2-56 screws.- The no-external-load cryogenic cycling tests using 2-56 screws without locking devices had little effect on the A-286, Nitronic 40, and 6061 specimens. The PH 13-8 Mo specimens, however, showed a 73-percent decrease in breakaway torque, and the 18 Ni specimens showed a decrease of 82 percent, both after one cycle. The five-cycle test was an improvement and showed a 40-percent decrease for the PH 13-8 Mo specimens and a 51-percent decrease for the 18 Ni specimens. Breakaway torque at -275°F increased for all materials except 6061. Increases ranged from 4 percent for Nitronic 40 to 14 percent for A-286. The control screws in the A-286, Nitronic 40, and 6061 specimens showed no effect from the cycling when compared with the before-cycling breakaway torque. In 18 Ni specimens, the control screw had a

35-percent decrease compared with tightening torque, and in PH 13-8 Mo specimens, there was a decrease of 89 percent.

The dynamic-load tests showed a decrease in breakaway torque for all materials. Decreases ranged from 15 percent for the 6061 specimens to 44 percent for Nitronic 40 specimens. The static-load tests produced a decrease in the breakaway torque for all materials. Decreases ranged from 16 percent for the 6061 specimens to 34 percent for the A-286 specimens.

DISCUSSION OF RESULTS

The self-locking Heli-Coil thread insert is an effective and convenient device for larger screws and for all materials studied. However, the use of this device for small screws is questionable because of problems encountered with the screw locking in the Heli-Coil.

The Spiralock thread form is a simple and effective device for both sizes of screws and seemed to be relatively unaffected by the cryogenic environment. Taking into account ease of application and the fact that cleanup is not required before reuse, this may be the best locking system for cryogenic applications, particularly with small screws.

Loctite threadlocker/sealant, although very effective at retaining the screws, was not an easy system to use. Initial assembly, which was not difficult, required spraying a primer on, applying the Loctite sealant, and then assembling the specimen. However, subsequent use of the same parts required a tap to be run through the tapped hole, and a die nut to be run over the threads to prevent plastic material buildup.

Crest adhesive was found to be similar to Loctite sealant in that both are very effective locking devices, but both require cleaning for reuse. A major problem is the 72-hour cure time, which would eliminate Crest adhesive for use with model changes to be made in the tunnel.

The aluminum-filled epoxy applied over and around the screw heads was effective but did not have the higher breakaway torque found with the Loctite sealant and Crest adhesive when used with the 2-56 screws.

CONCLUDING REMARKS

Data derived from the test program to determine tensile load capability and failure mode of A-286 screws are provided for use in selecting fasteners for cryogenic model systems. As a conservative measure, minimum yield and ultimate values are provided instead of averaged values. Failure modes of the screws tested were:

(1) Heads popped off all the 1-72 button head screws at both room temperature and cryogenic temperature.

(2) All socket cap screw failures occurred in the threads.

(3) None of the 2-56, 6-32, 8-32, and unmodified 1/4-28 flat head socket cap screws had any head failures at room temperature.

(4) At cryogenic temperature, the 6-32, 8-32, 1/4-28, and modified 1/4-28 flat head socket cap screws did not have any head failures.

(5) Generally, head failures occurred at lower loads than thread failures for a given screw size and type, and the head failure fractures occurred through the bottom of the socket.

Even though some of the retention systems produced breakaway torque values higher than the tightening torque, cryogenic cycling in the absence of mechanical loads generally produced decreases in breakaway torque (compared with before-cycling values) for all the systems tested. In general, most systems were found to be effective retention devices. There are some differences between the various devices with respect to ease of application, cleanup, and reuse. Also, test results at -275°F imply that the cold temperatures act to improve screw retention. The improved retention is probably the result of differential thermal contraction and/or increased friction (thread-binding effects).

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TABLE I.- SPECIAL A-286 SCREW SIZES AND TYPES

Size	Type
0-80	Flat head socket cap screw (FHSCS)
1-72	Button head screw (BHS)
2-56	Flat head socket cap screw (FHSCS) and socket cap screw (SCS)
3-48	Flat head socket cap screw (FHSCS)
4-40	Flat head socket cap screw (FHSCS) and socket cap screw (SCS)
6-32	Flat head socket cap screw (FHSCS) and socket cap screw (SCS)
8-32	Flat head socket cap screw (FHSCS) and socket cap screw (SCS)
10-32	Flat head socket cap screw (FHSCS) and socket cap screw (SCS)
1/4-28	Flat head socket cap screw (FHSCS) and socket cap screw (SCS)

TABLE II.- MANUFACTURER-SUPPLIED ULTIMATE LOADS AT ROOM TEMPERATURE FOR SPECIAL A-286 SCREWS

Size	Type	Ultimate load, lb (a)
0-80	FHSCS	330
1-72	BHS	190
2-56	FHSCS	460
2-56	SCS	725
3-48	FHSCS	780
4-40	FHSCS	1145
4-40	SCS	1090
6-32	FHSCS	1540
6-32	SCS	1500
8-32	FHSCS	2480
8-32	SCS	2180
10-32	FHSCS	3780
10-32	SCS	4180
1/4-28	FHSCS	7080
1/4-28	SCS	6880

[a]Data for one screw only.

TABLE III.- MINIMUM YIELD AND ULTIMATE LOADS AND FAILURE MODES AT ROOM TEMPERATURE

Screw size and type	Minimum yield load, lb	Minimum ultimate load, lb	Number of failures	
			Head	Threads
0-80 FHSCS	206	320	3	2
1-72 BHS	370	387	5	0
2-56 FHSCS	548	680	0	5
2-56 SCS	546	688	0	5
3-48 FHSCS	737	840	2	3
4-40 FHSCS	792	1070	2	3
4-40 SCS	932	1089	0	5
6-32 FHSCS	1465	1725	0	5
6-32 SCS	1465	1678	0	5
8-32 FHSCS	1952	2425	0	5
8-32 SCS	1790	2050	0	5
10-32 FHSCS	3270	3825	3	2
10-32 SCS	3720	4060	0	5
10-32 FHSCS (modified)[a]	2870	3440	2	3
10-32 SCS (modified)[a]	2930	3840	0	5
1/4-28 FHSCS	6550	7100	0	5
1/4-28 SCS	6360	6766	0	5
1/4-28 FHSCS (modified)[a]	5520	6335	2	3
1/4-28 SCS (modified)[a]	5420	6500	0	5

[a]Modified by chasing threads to head.

TABLE IV.- MINIMUM YIELD AND ULTIMATE LOADS AND FAILURE MODES AT -275°F

Screw size and type	Minimum yield load, lb	Minimum ultimate load, lb	Number of failures	
			Head	Threads
0-80 FHSCS	355	396	1	4
1-72 BHS	425	477	5	0
2-56 FHSCS	596	834	1	4
2-56 SCS	655	856	0	5
3-48 FHSCS	710	1079	2	3
4-40 FHSCS	950	1255	4	1
4-40 SCS	1070	1341	0	5
6-32 FHSCS	1700	2125	0	5
6-32 SCS	1650	2066	0	5
8-32 FHSCS	2380	3045	0	5
8-32 SCS	2220	2666	0	5
10-32 FHSCS	4000	4660	3	2
10-32 SCS	4400	5020	0	5
10-32 FHSCS (modified)[a]	3400	4670	1	4
10-32 SCS (modified)[a]	3690	4625	0	5
1/4-28 FHSCS	8090	8966	0	5
1/4-28 SCS	7390	8500	0	5
1/4-28 FHSCS (modified)[a]	6490	7675	0	5
1/4-28 SCS (modified)[a]	6320	8050	0	5

[a]Modified by chasing threads to head.

TABLE V.- AVERAGED BREAKAWAY TORQUE VALUES FOR SPECIAL A-286 1/4-28 SCREWS WITH VARIOUS LOCKING DEVICES

[Tightening torque = 94 in-lb]

Locking device	Averaged breakaway torque, in-lb						
	Before cycling	After one cycle	After five cycles	At -275°F	Control screw	After dynamic loading	After static loading
			A-286 stainless steel				
Heli-Coil	85.0	86.0	84.0	138.3	65.0	76.0	72.6
Spiralock	94.3	72.3	88.5	112.5	70.0	78.4	66.2
Loctite 242	114.5	101.3	103.8	169.8	98.0	81.8	86.0
Crest	76.0	79.8	98.5	>233	73.0	81.4	76.0
Epoxy	104.5	109.5	117.3	117.0	88.0	124.4	117.5
No device	78.0	81.0	71.5	143.3	72.0	78.4	72.8
			PH 13-8 Mo stainless steel				
Heli-Coil	74.3	73.0	69.0	107.0	51.0	70.2	74.6
Spiralock	83.5	72.8	67.8	67.8	64.0	68.2	60.0
Loctite 242	104.8	78.8	84.8	185.8	37.0	84.2	79.4
Crest	75.0	77.0	86.5	>223	60.0	74.4	74.6
Epoxy	112.5	125.0	124.3	117.0	89.0	128.6	111.2
No device	81.5	59.8	70.5	128.3	56.0	74.2	70.2
			Nitronic 40 stainless steel				
Heli-Coil	82.3	81.3	79.8	112.5	(a)	68.6	72.8
Spiralock	92.8	87.0	84.3	91.8	80.0	85.4	70.4
Loctite 242	110.8	98.5	94.0	175.8	87.0	79.0	78.0
Crest	77.8	80.8	85.8	>231	84.0	72.4	77.2
Epoxy	115.5	120.3	117.3	109.3	107.0	113.0	116.6
No device	81.0	81.3	75.8	121.0	67.0	78.4	74.8
			18 Ni grade 200 maraging steel				
Heli-Coil	87.0	89.5	88.8	138.8	79.0	80.8	74.2
Spiralock	90.0	83.8	81.0	93.0	85.0	73.4	69.6
Loctite 242	107.8	92.5	91.8	162.8	87.0	87.6	74.8
Crest	74.0	83.3	91.5	>249	70.0	78.6	76.6
Epoxy	107.3	108.5	113.5	111.8	115.0	112.4	104.0
No device	83.8	84.5	67.8	136.5	71.0	80.0	74.8
			6061-T6 aluminum				
Heli-Coil	79.5	76.3	77.3	94.8	72.0	75.0	67.8
Spiralock	78.8	78.0	79.3	107.0	75.0	65.4	41.4
Loctite 242	77.8	86.3	78.5	171.5	57.0	83.6	66.4
Crest	76.8	91.3	83.8	>250	75.0	78.2	77.6
Epoxy	105.5	96.5	94.3	143.5	99.0	96.2	87.8
No device	82.3	85.0	72.3	108.5	76.0	71.8	75.2

[a]Screw too loose to read.

TABLE VI.- AVERAGED BREAKAWAY TORQUE VALUES FOR SPECIAL A-286 2-56 SCREWS WITH VARIOUS LOCKING DEVICES

[Tightening torque = 2.7 in-lb]

Locking device	Averaged breakaway torque, in-lb						
	Before cycling	After one cycle	After five cycles	At -275°F	Control screw	After dynamic loading	After static loading
A-286 stainless steel							
Heli-Coil	2.07	1.85	1.98	2.56	2.05	2.15	(a)
Spiralock	1.76	1.89	1.91	3.45	1.50	2.12	1.84
Loctite 222	3.41	2.88	2.63	(b)	2.50	3.17	2.96
Crest	3.27	3.06	3.03	(b)	2.30	2.53	3.24
Epoxy	2.74	2.53	2.79	4.11	2.25	2.45	2.31
No device	2.24	2.28	2.42	3.07	2.25	1.92	1.77
PH 13-8 Mo stainless steel							
Heli-Coil	1.94	1.42	1.44	2.31	0.90	1.75	(a)
Spiralock	1.89	1.19	1.61	2.67	.70	1.93	1.71
Loctite 222	3.18	2.39	2.88	(b)	3.30	2.87	2.62
Crest	3.28	2.96	3.21	(b)	1.70	2.40	2.88
Epoxy	2.93	2.28	2.48	(c)	1.60	3.19	2.71
No device	2.22	.74	1.61	2.83	.30	1.77	1.84
Nitronic 40 stainless steel							
Heli-Coil	1.94	2.01	1.98	3.83	1.80	2.04	(a)
Spiralock	1.74	1.77	1.85	3.68	1.60	1.98	1.93
Loctite 222	2.81	2.83	2.92	(b)	3.20	3.51	2.76
Crest	3.14	3.13	3.58	(b)	2.80	2.97	3.15
Epoxy	2.49	2.68	2.34	3.75	1.70	3.14	2.47
No device	2.39	2.21	2.16	2.82	2.15	1.51	1.87
18 Ni grade 200 maraging steel							
Heli-Coil	1.88	1.84	1.76	2.54	1.65	1.91	(a)
Spiralock	2.30	1.83	1.65	2.50	.95	1.87	1.47
Loctite 222	3.01	2.98	3.01	(b)	2.65	3.08	2.72
Crest	3.46	2.60	2.68	(b)	1.28	3.37	3.24
Epoxy	2.74	1.30	2.43	(c)	1.60	3.23	2.64
No device	2.16	.49	1.31	2.98	1.75	1.99	1.99
6061-T6 aluminum							
Heli-Coil	1.75	1.81	1.90	2.58	1.95	2.18	1.78
Spiralock	1.75	1.63	1.88	2.57	1.90	2.08	1.66
Loctite 222	2.86	2.69	2.93	(b)	2.75	3.29	2.51
Crest	2.83	2.87	2.76	(b)	3.12	3.07	2.84
Epoxy	2.56	2.12	2.31	3.94	2.25	2.81	3.16
No device	1.93	1.74	1.71	2.26	1.75	2.30	2.27

[a]Screws were too loose to read breakaway torque values.

[b]Screws could not be turned at this temperature. (Wrench torque limit ≈ 7 in-lb.)

[c]Sockets in screw head were stripped.

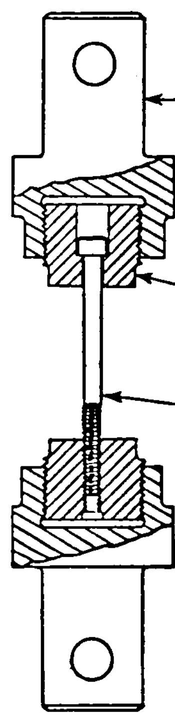
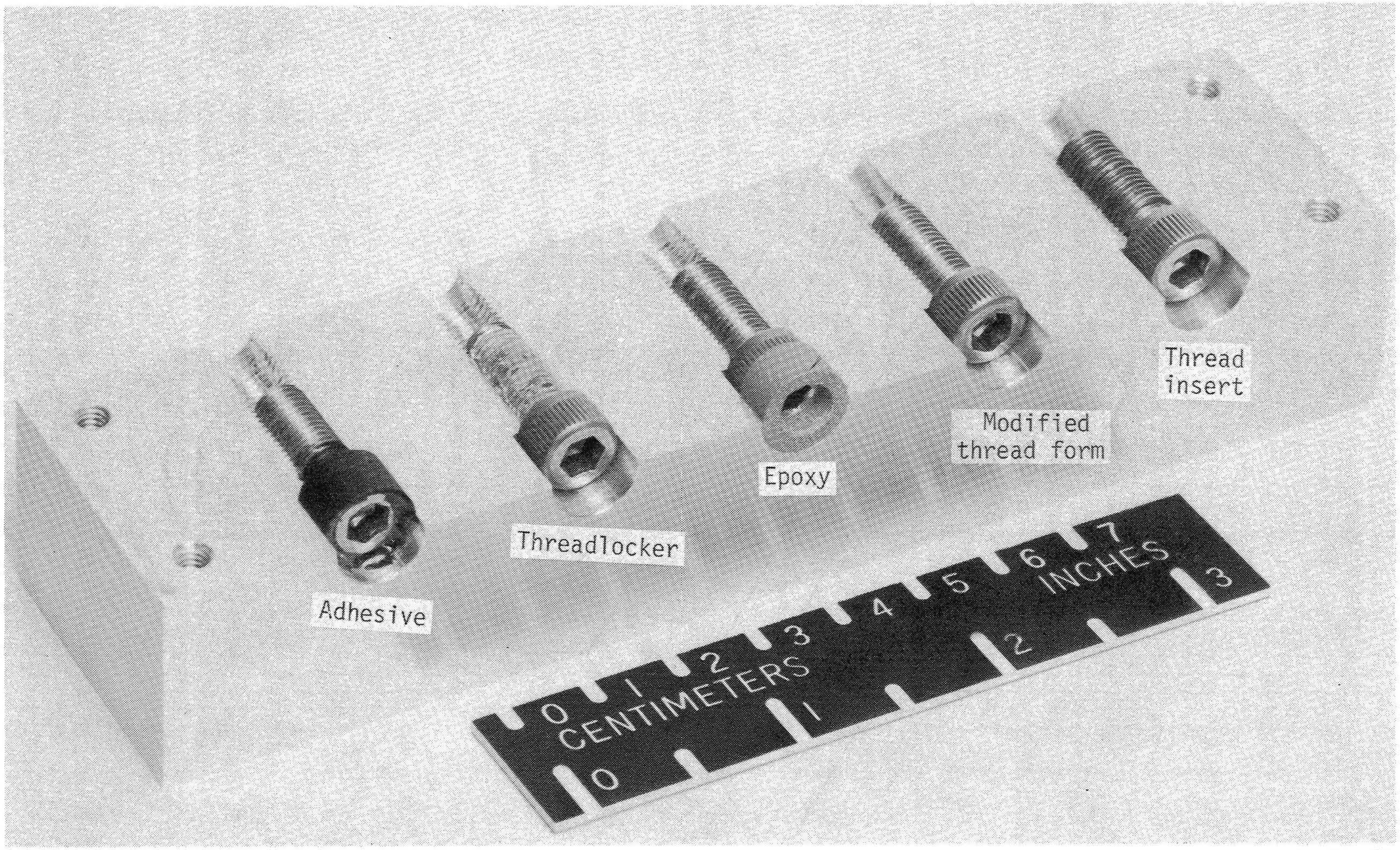
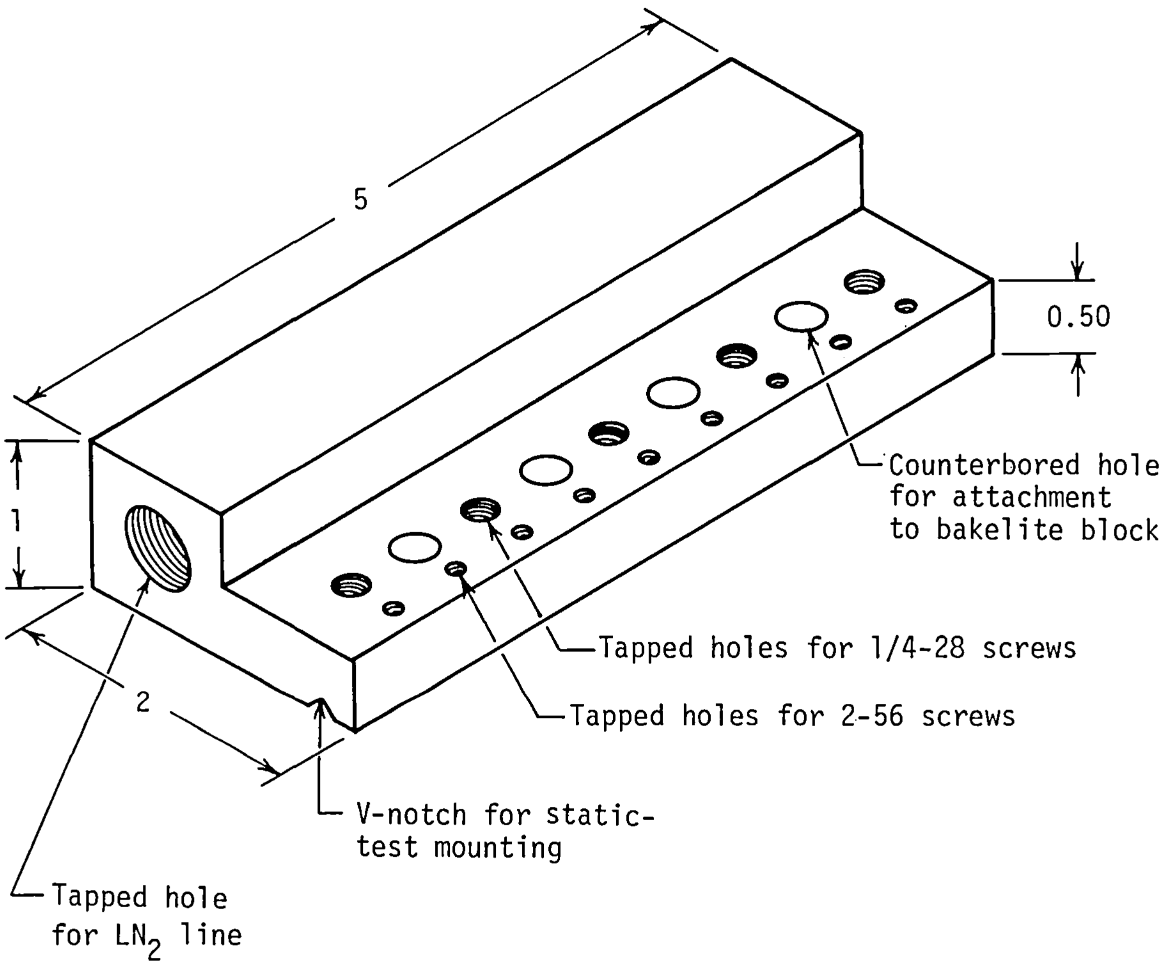


Figure 1.- Typical A-286 screw pull test setup.



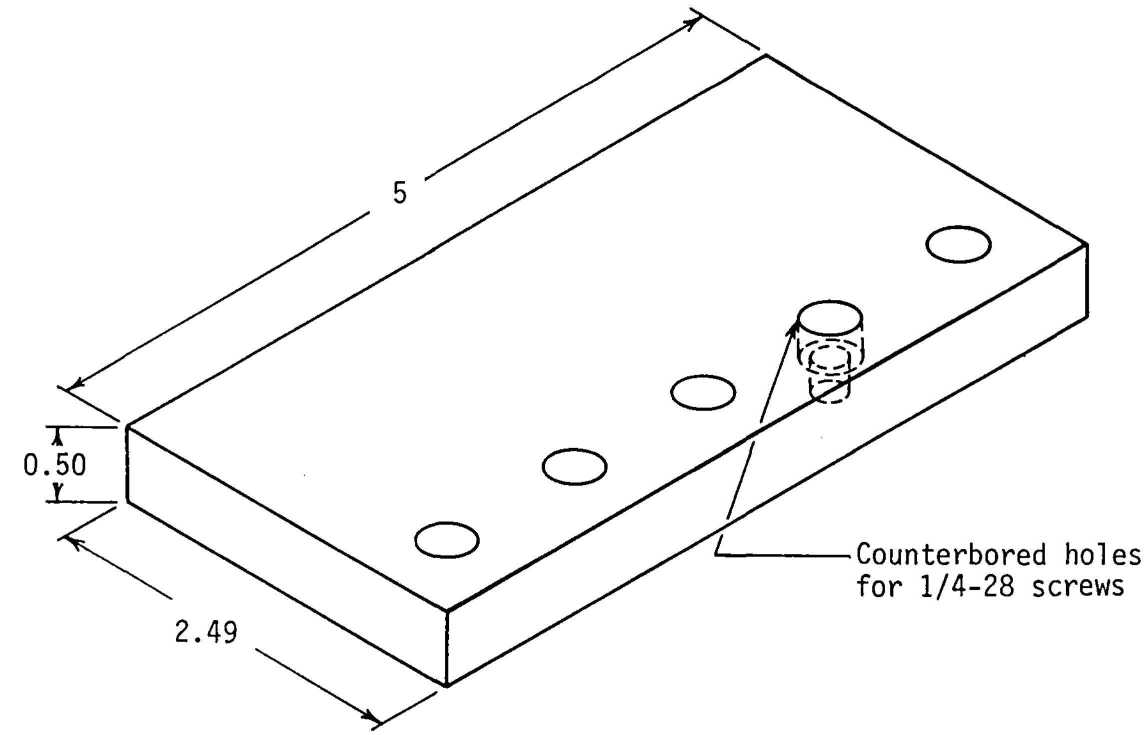
L-84-58

Figure 2.- Cutaway specimen showing five retention devices used with 1/4-28 screw.

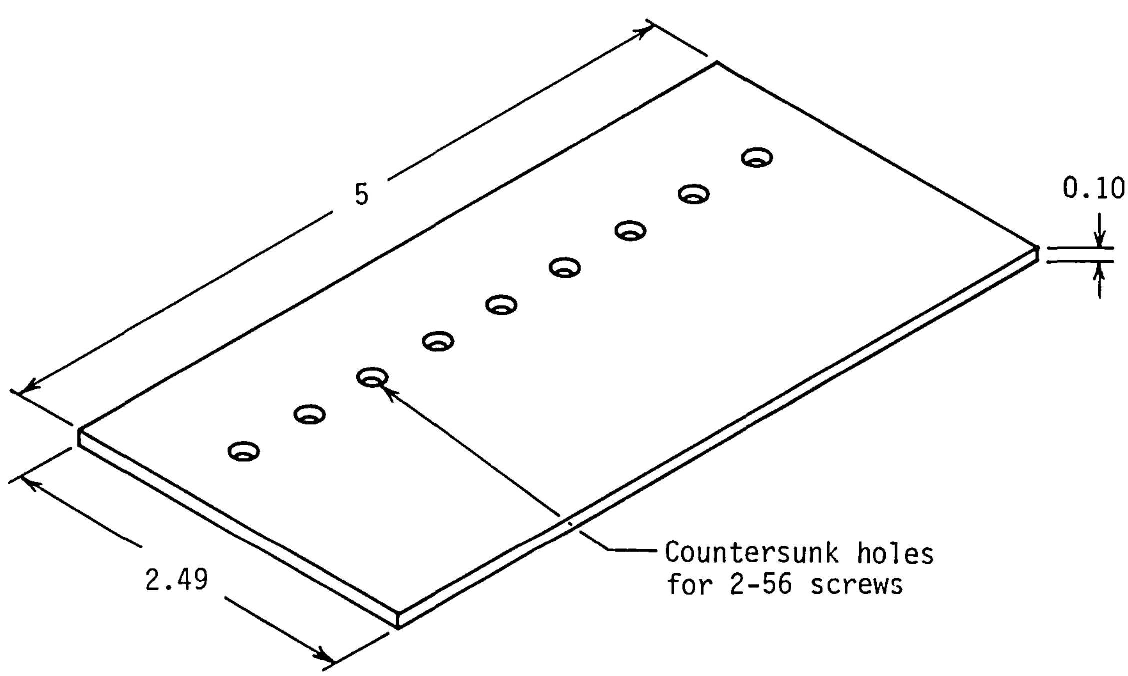


(a) Specimen base.

Figure 3.- Test specimen parts. Dimensions in inches.

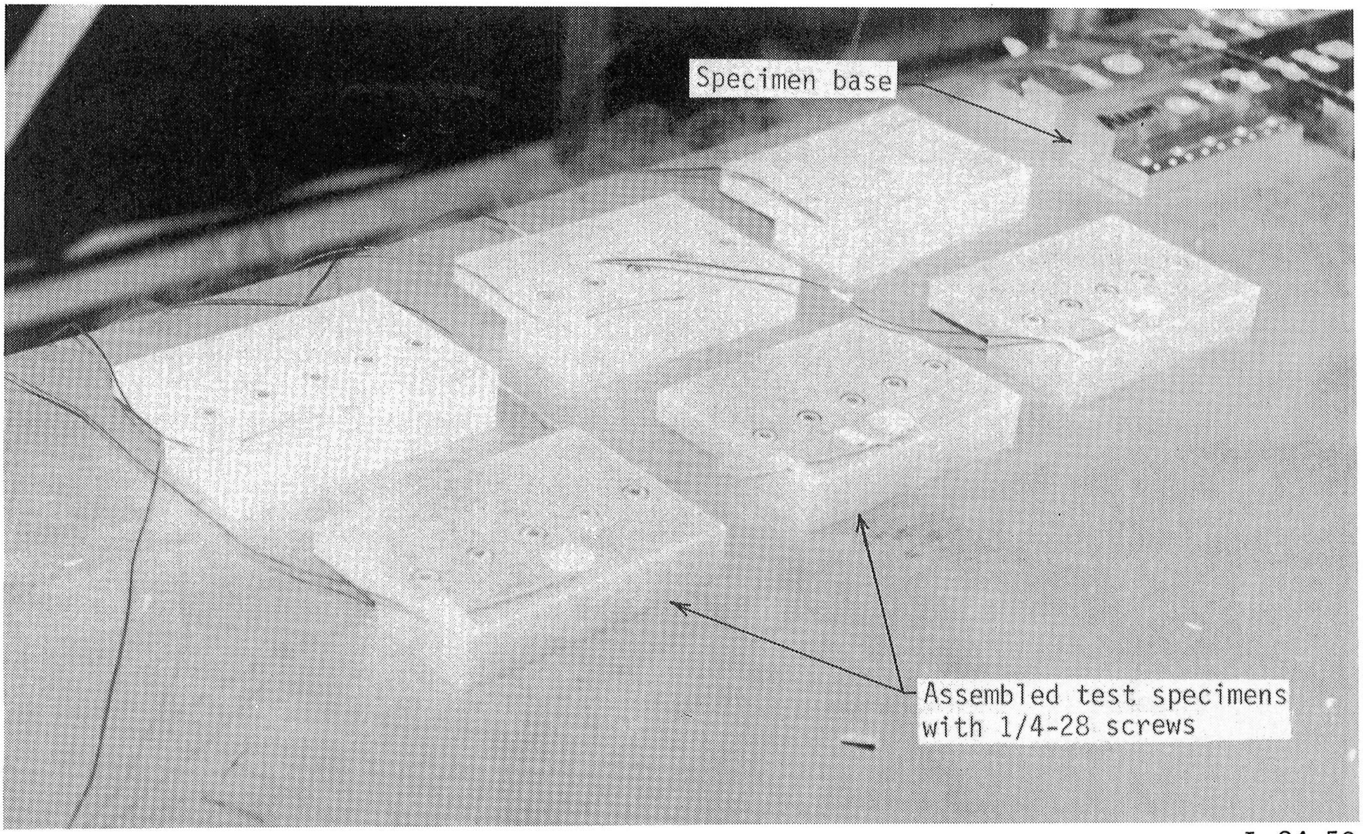


(b) Specimen part A.



(c) Specimen part B.

Figure 3.- Concluded.



L-84-59

Figure 4.- Assembled test pieces.

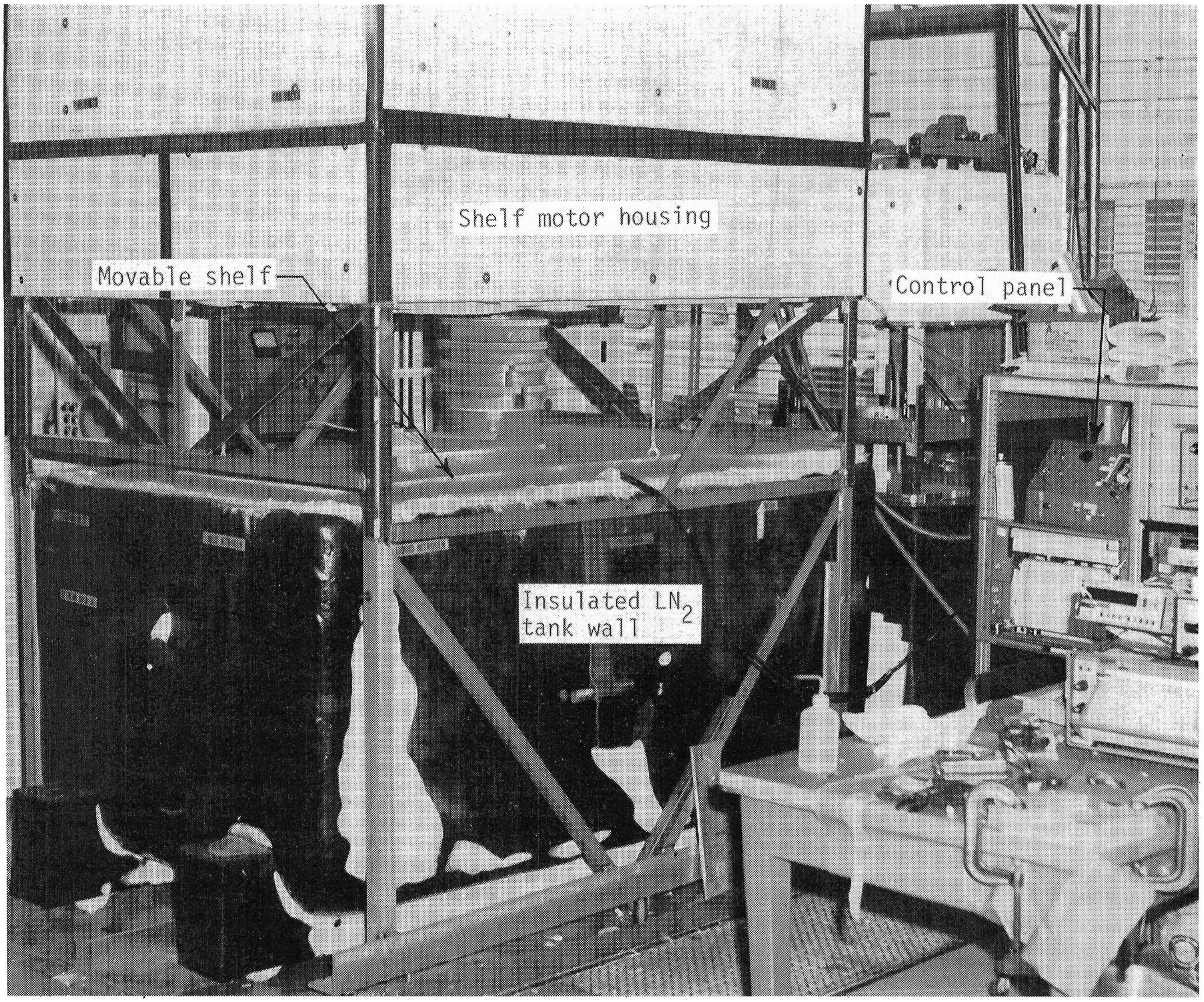


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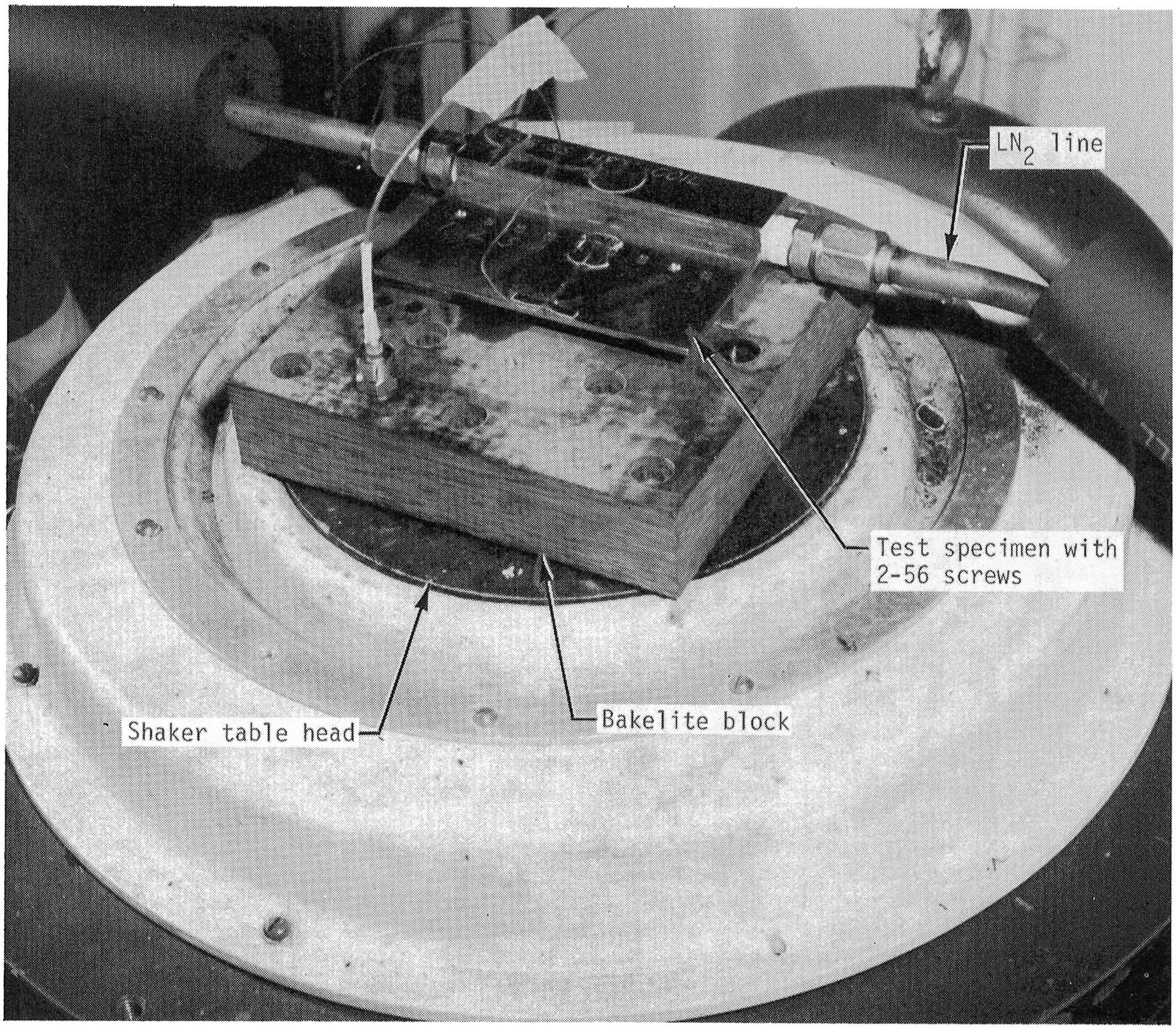
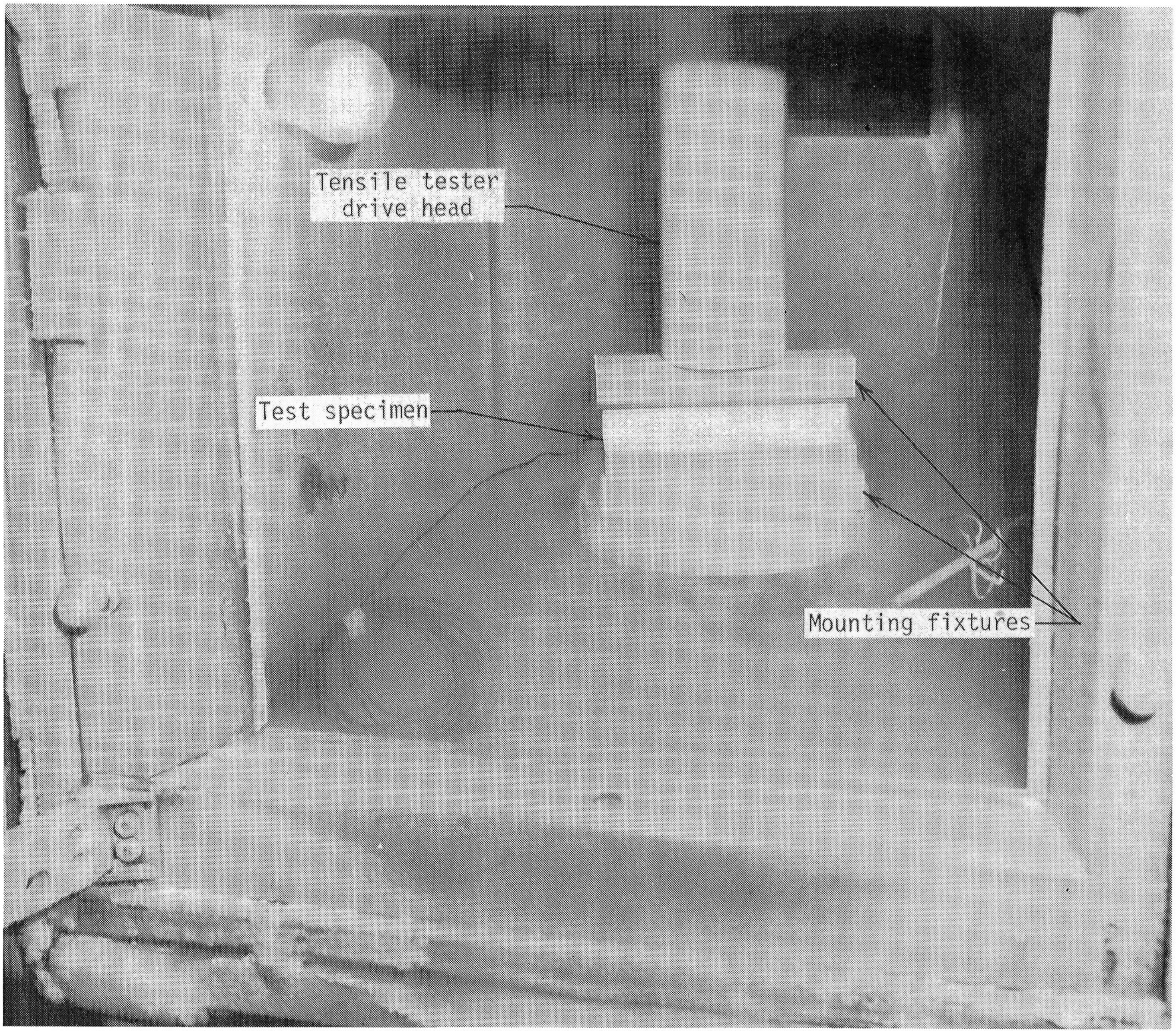
Figure 5.- Liquid nitrogen "soak" tank.



L-84-61

Figure 6.- Test specimen mounted on shaker table.



L-84-62

Figure 7.- Tensile tester with specimen installed.

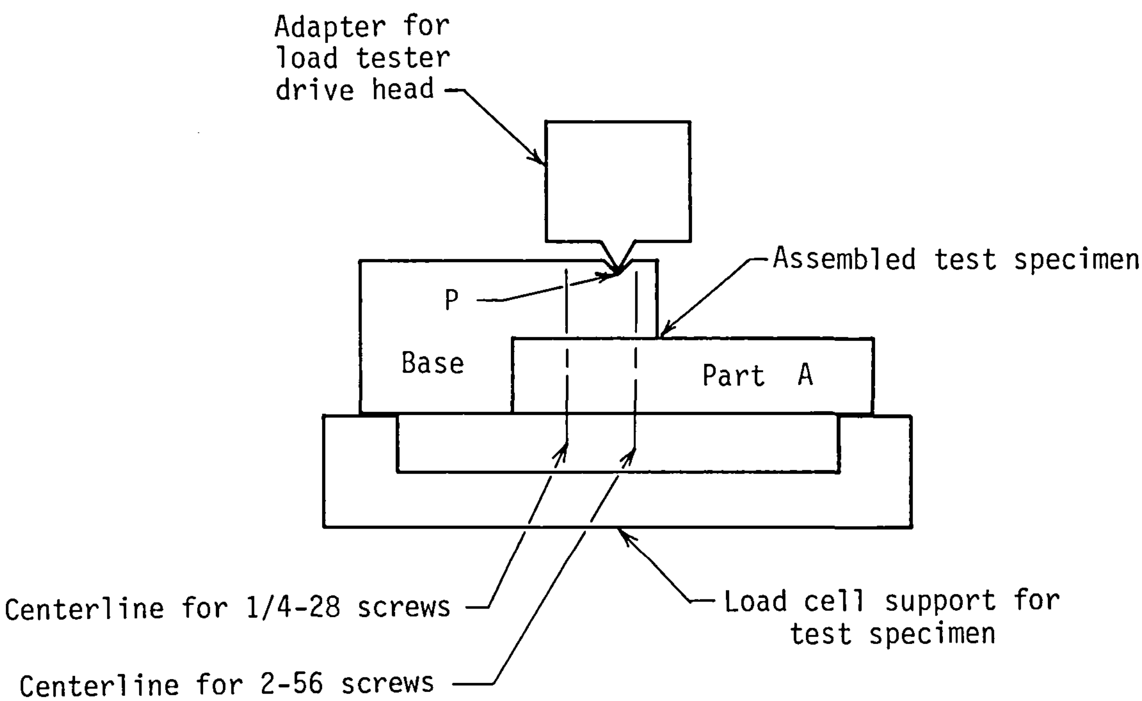


Figure 8.- Static-loading test setup.

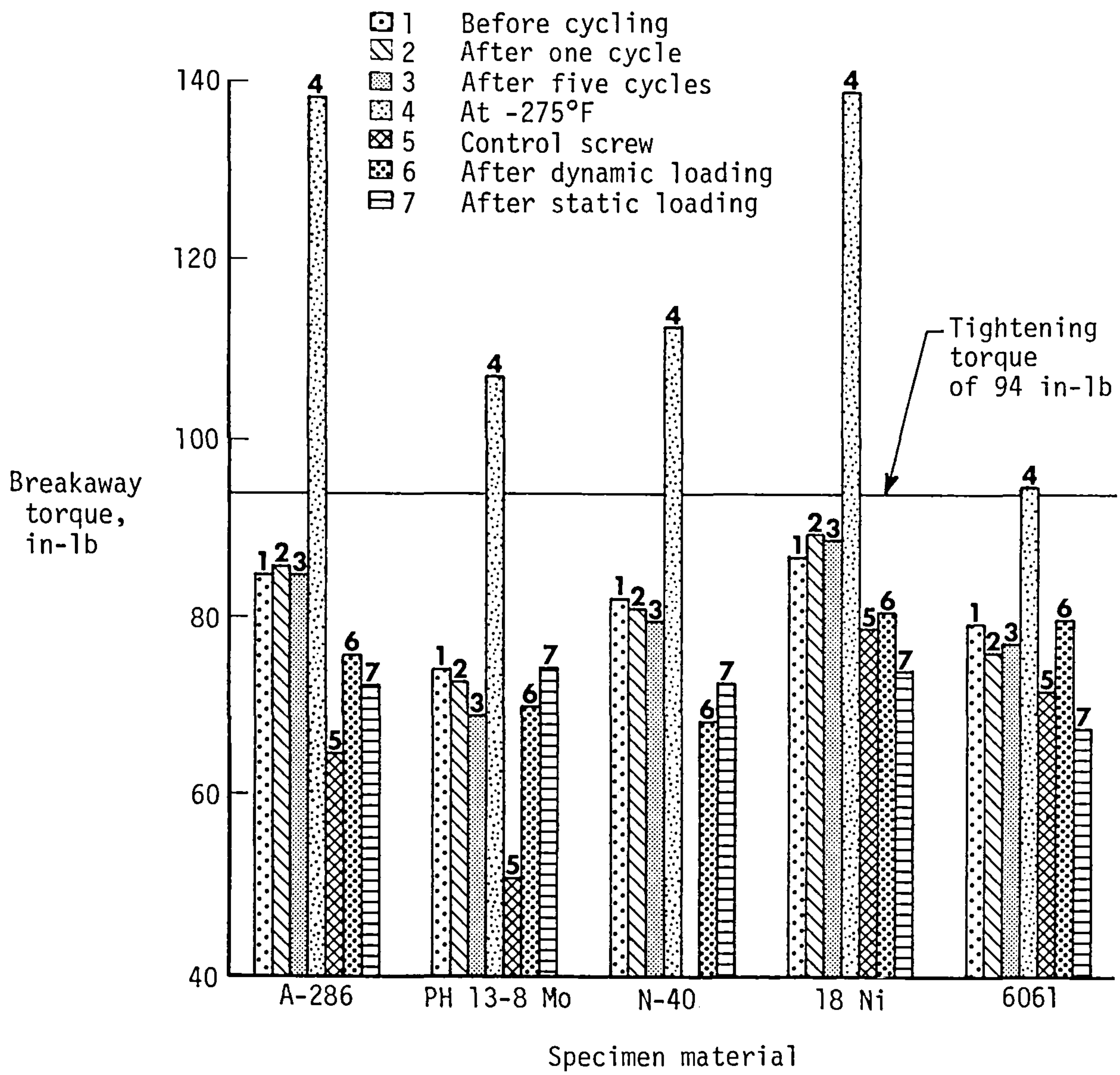


Figure 9.- Breakaway torque versus specimen material for self-locking Heli-Coil thread inserts used with 1/4-28 screws.

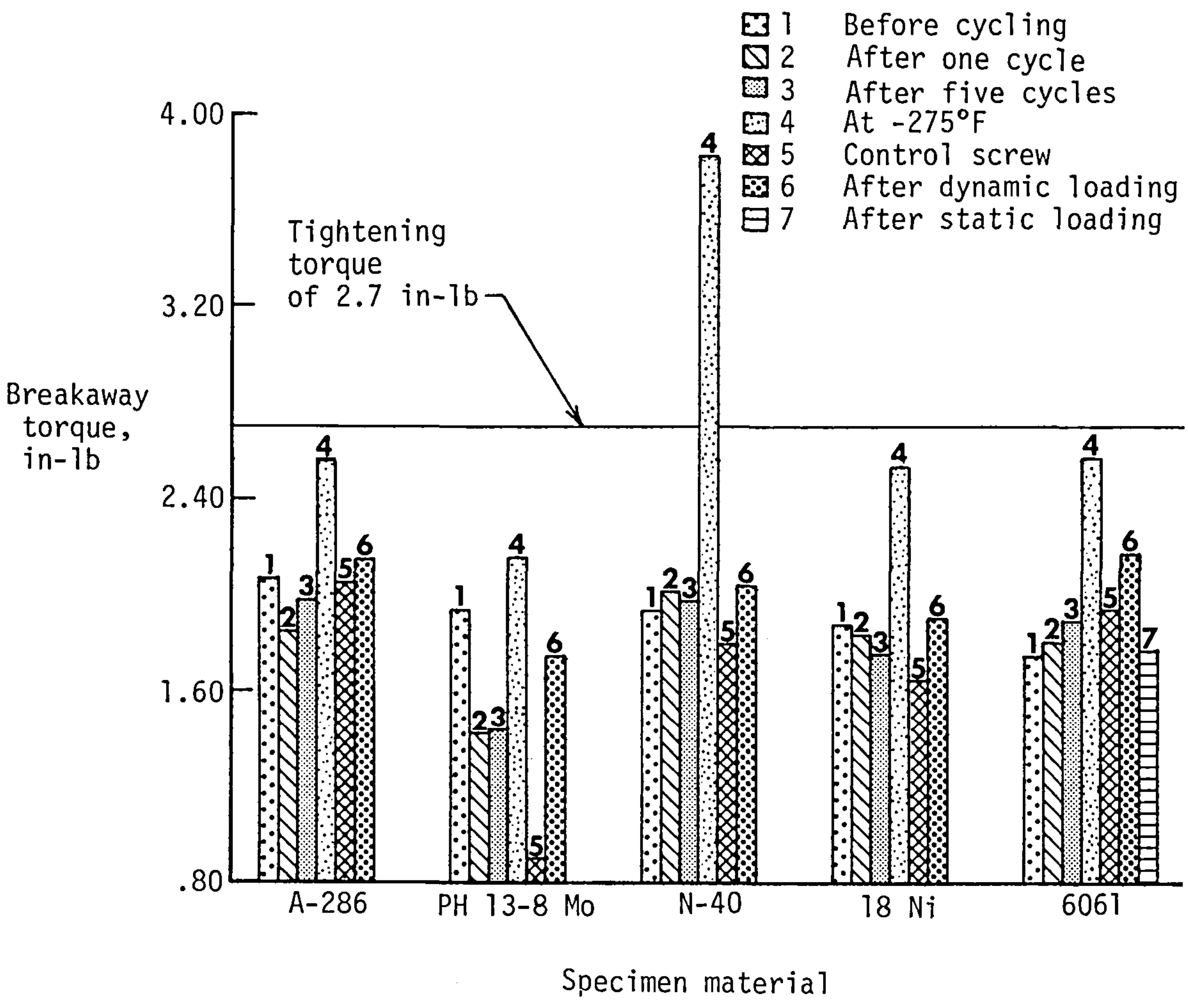
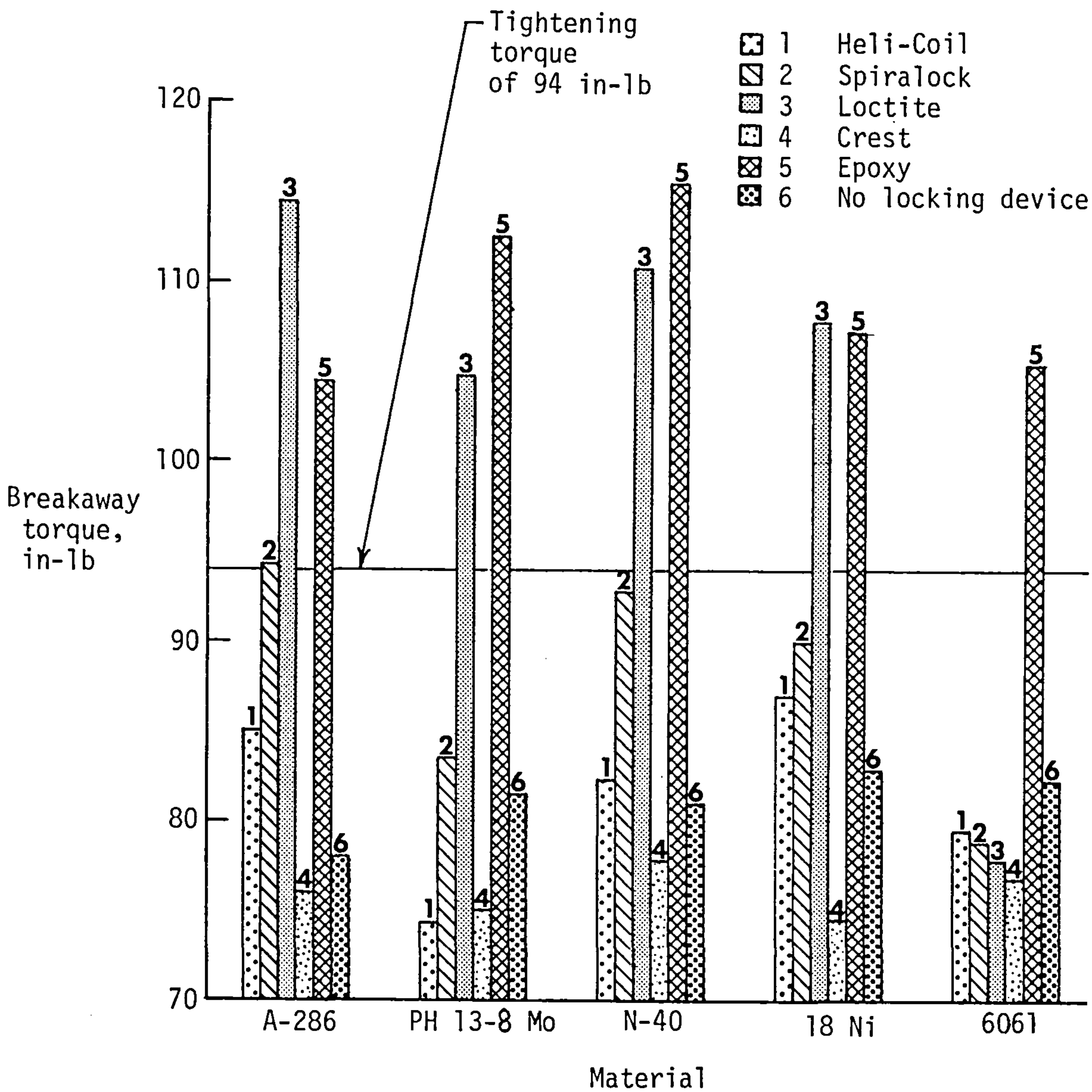
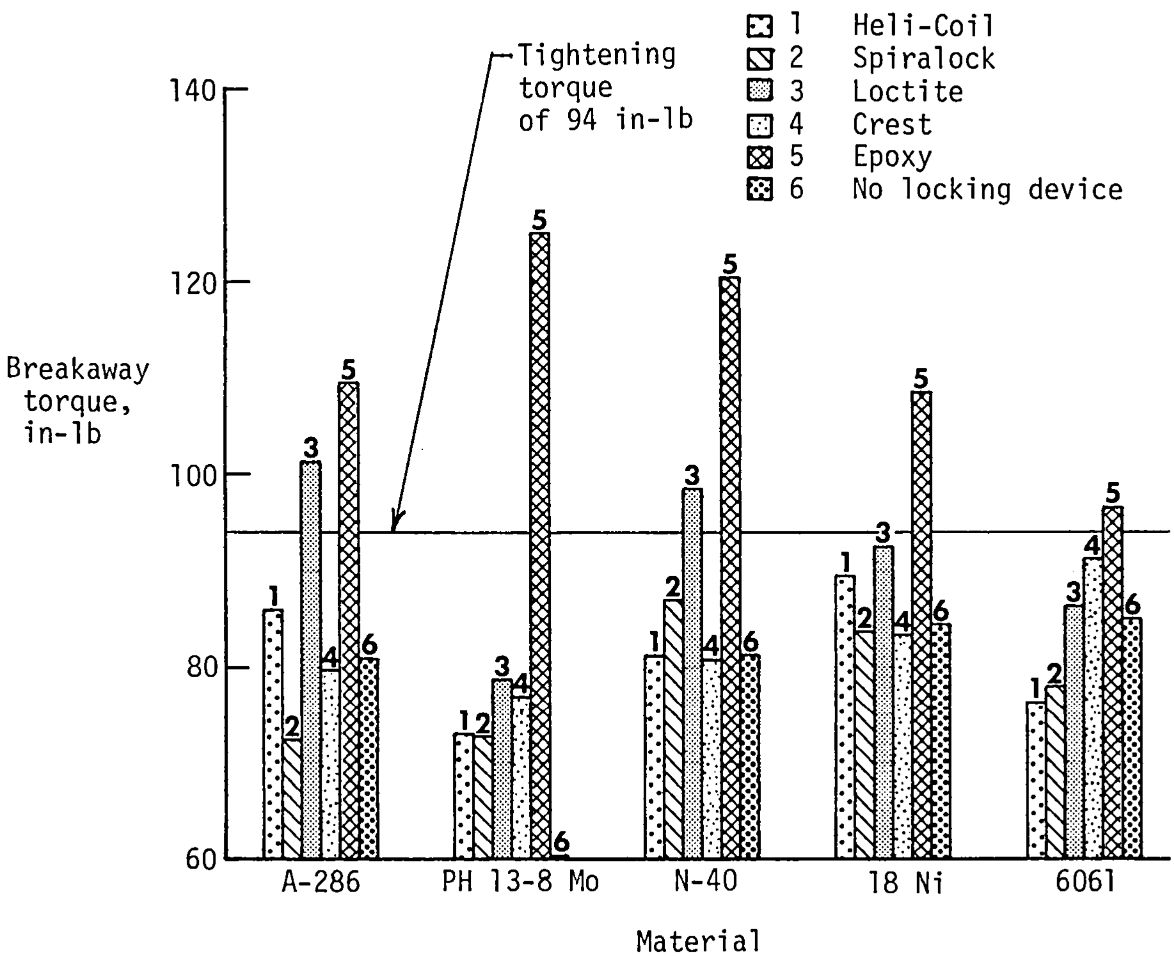


Figure 10.- Breakaway torque versus specimen material for self-locking Heli-Coil thread inserts used with 2-56 screws.



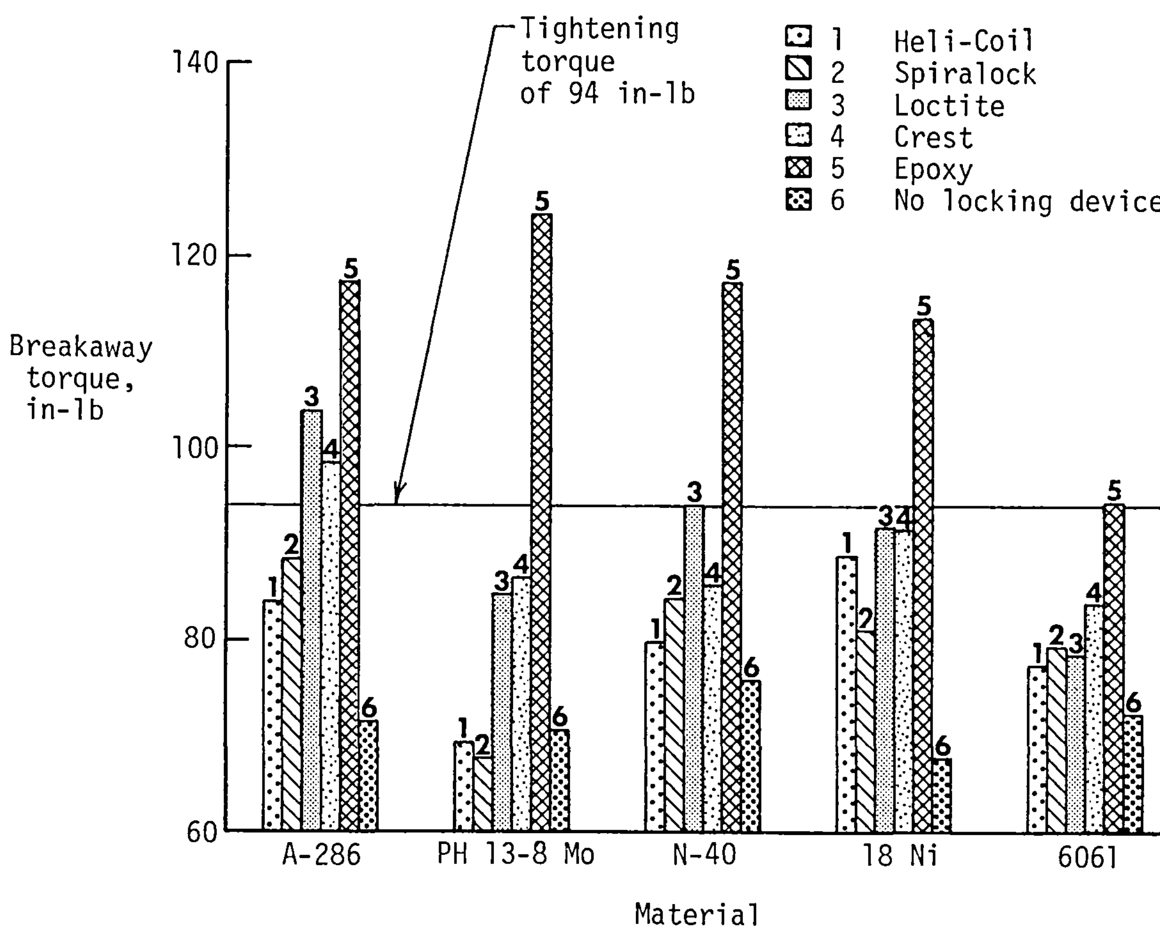
(a) Before cycling.

Figure 11.- Breakaway torque versus specimen material for 1/4-28 screws with various retention devices.



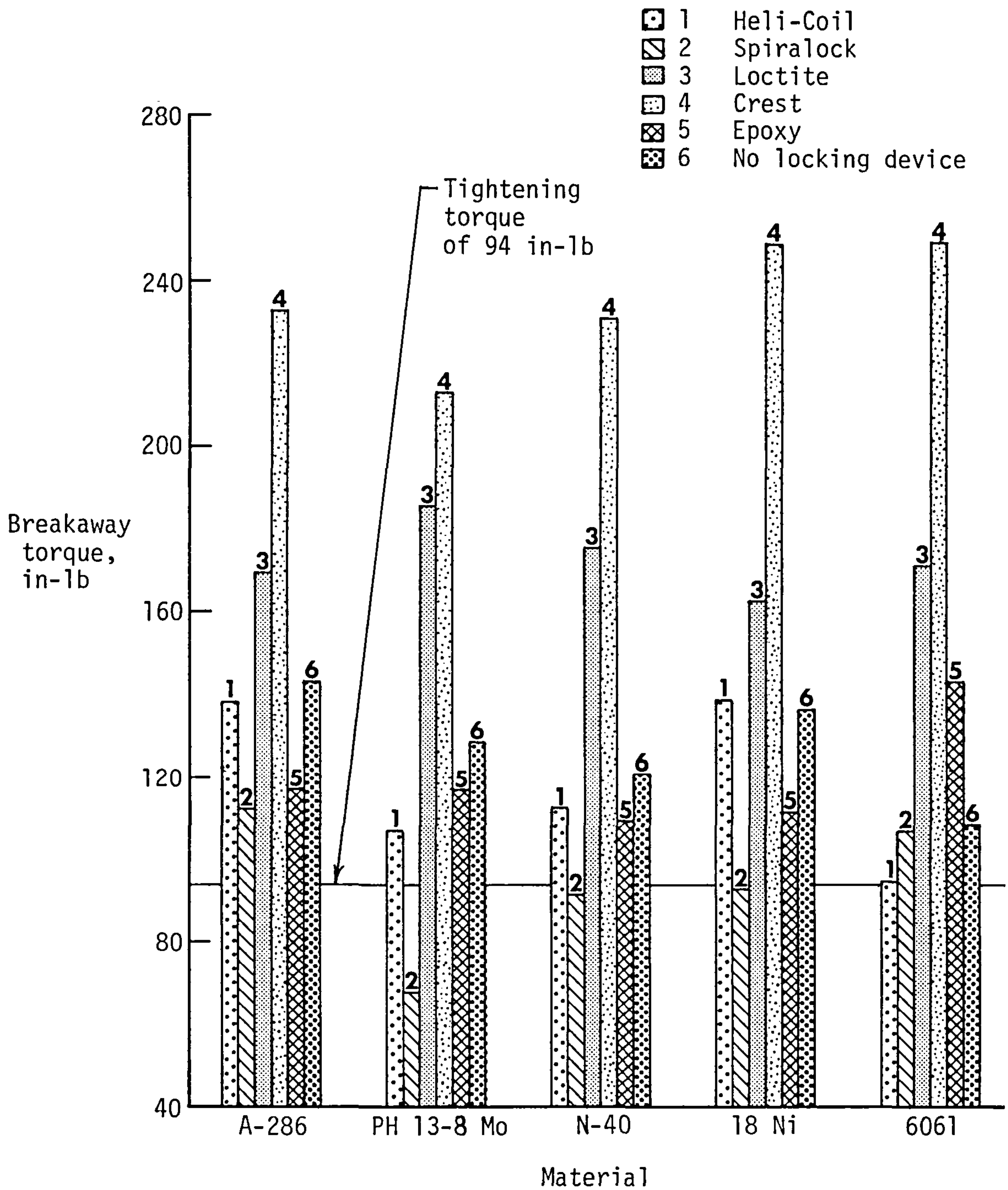
(b) After one cycle.

Figure 11.- Continued.



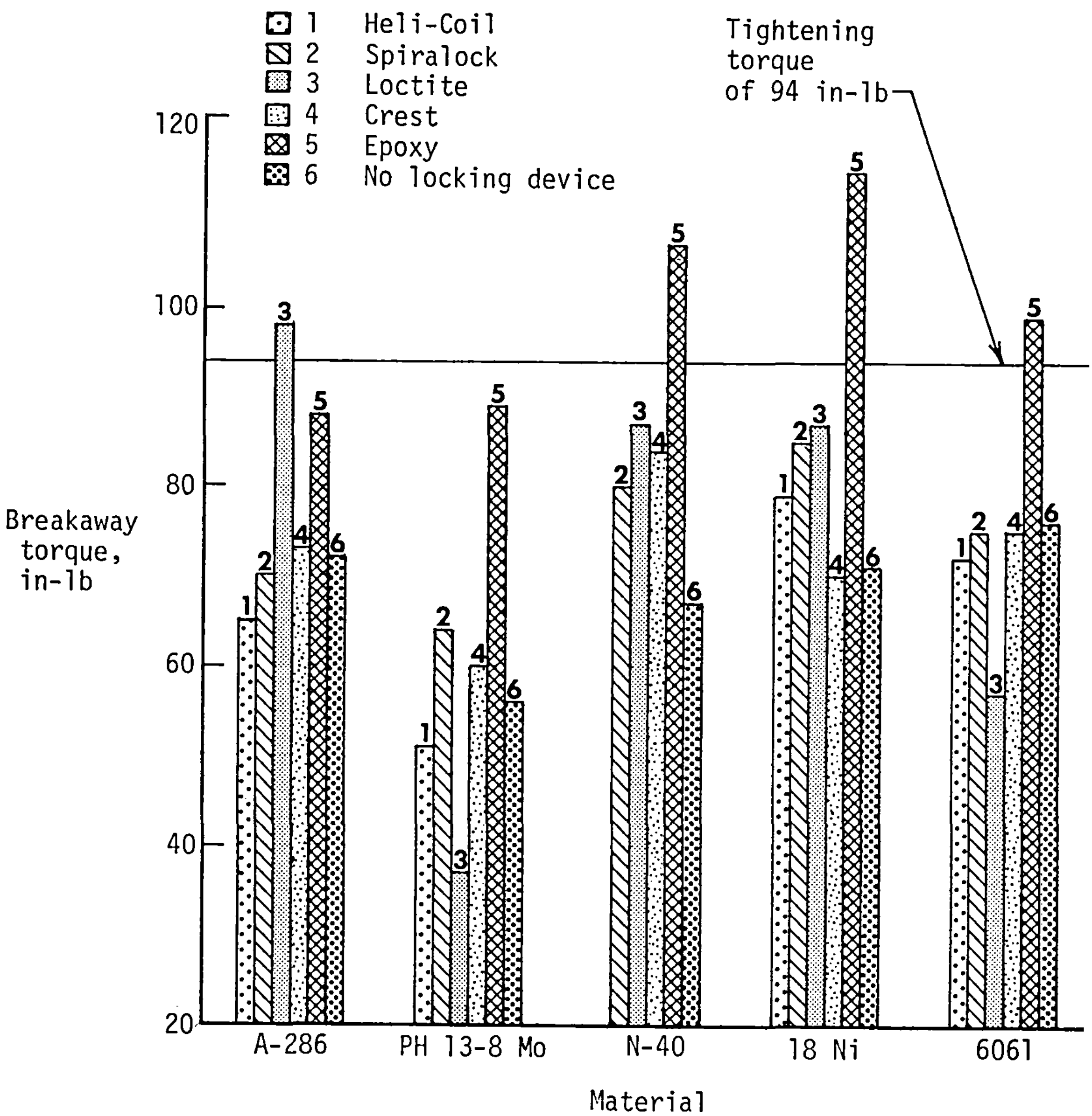
(c) After five cycles.

Figure 11.- Continued.



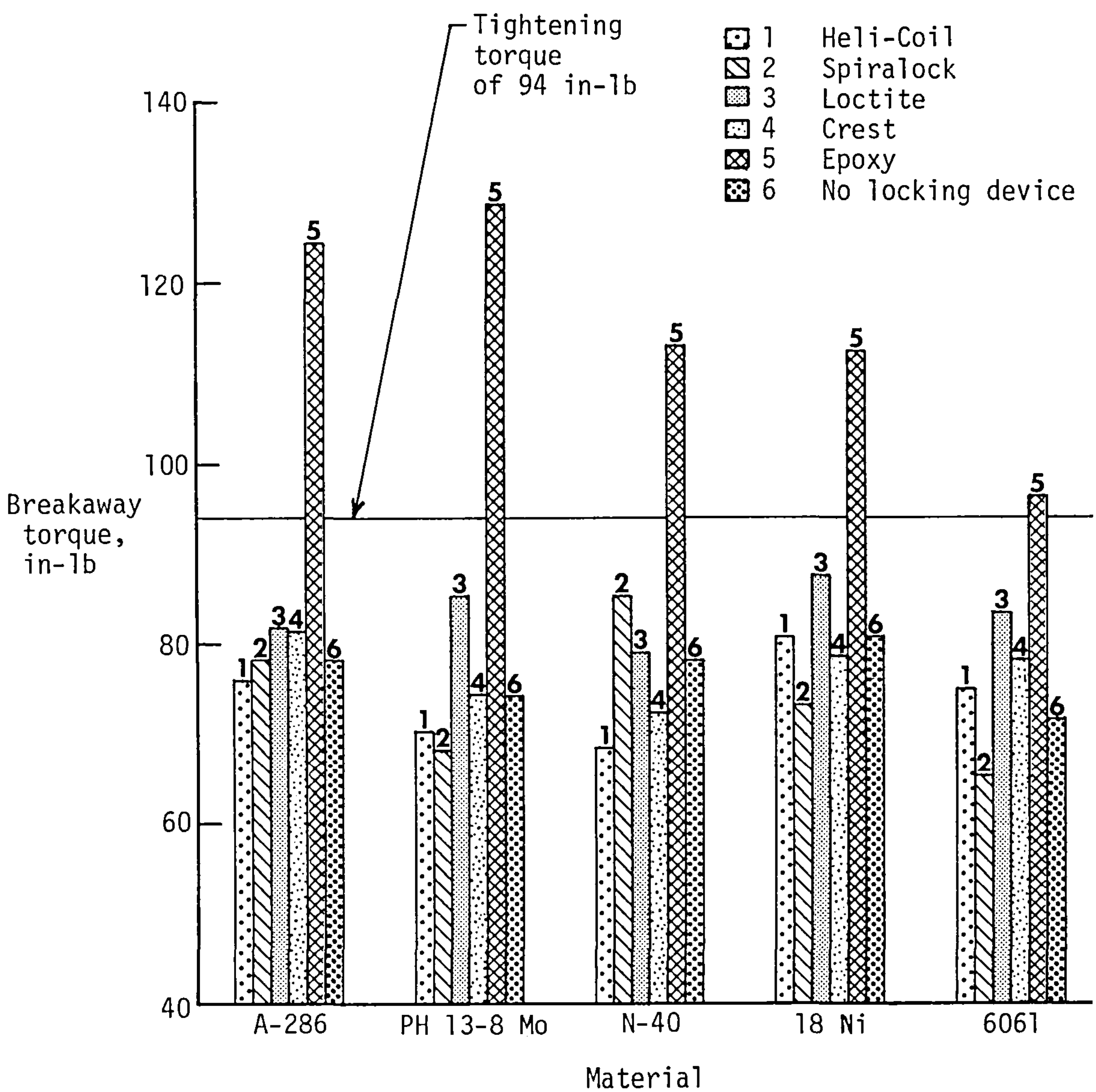
(d) At -275°F.

Figure 11.- Continued.



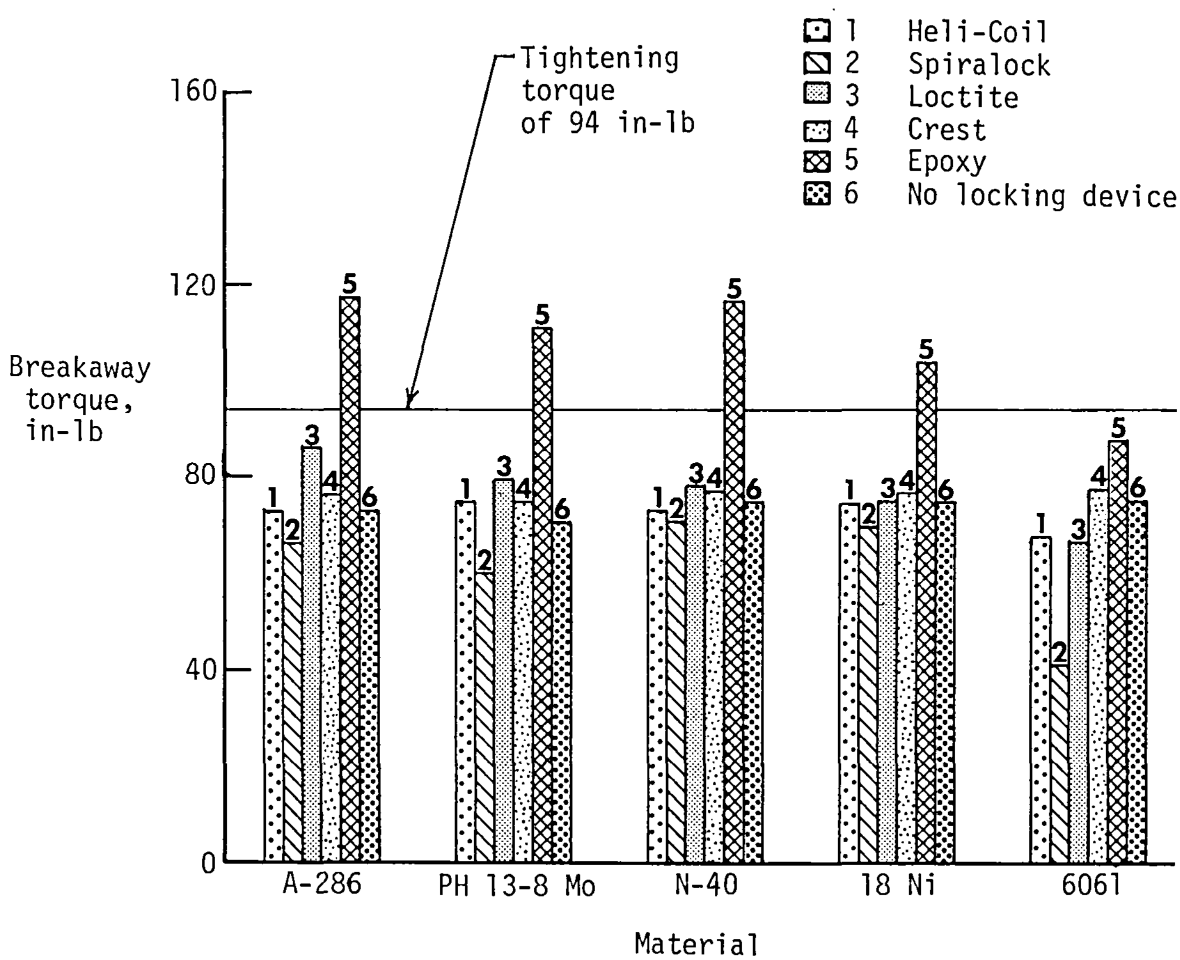
(e) Control screw.

Figure 11.- Continued.



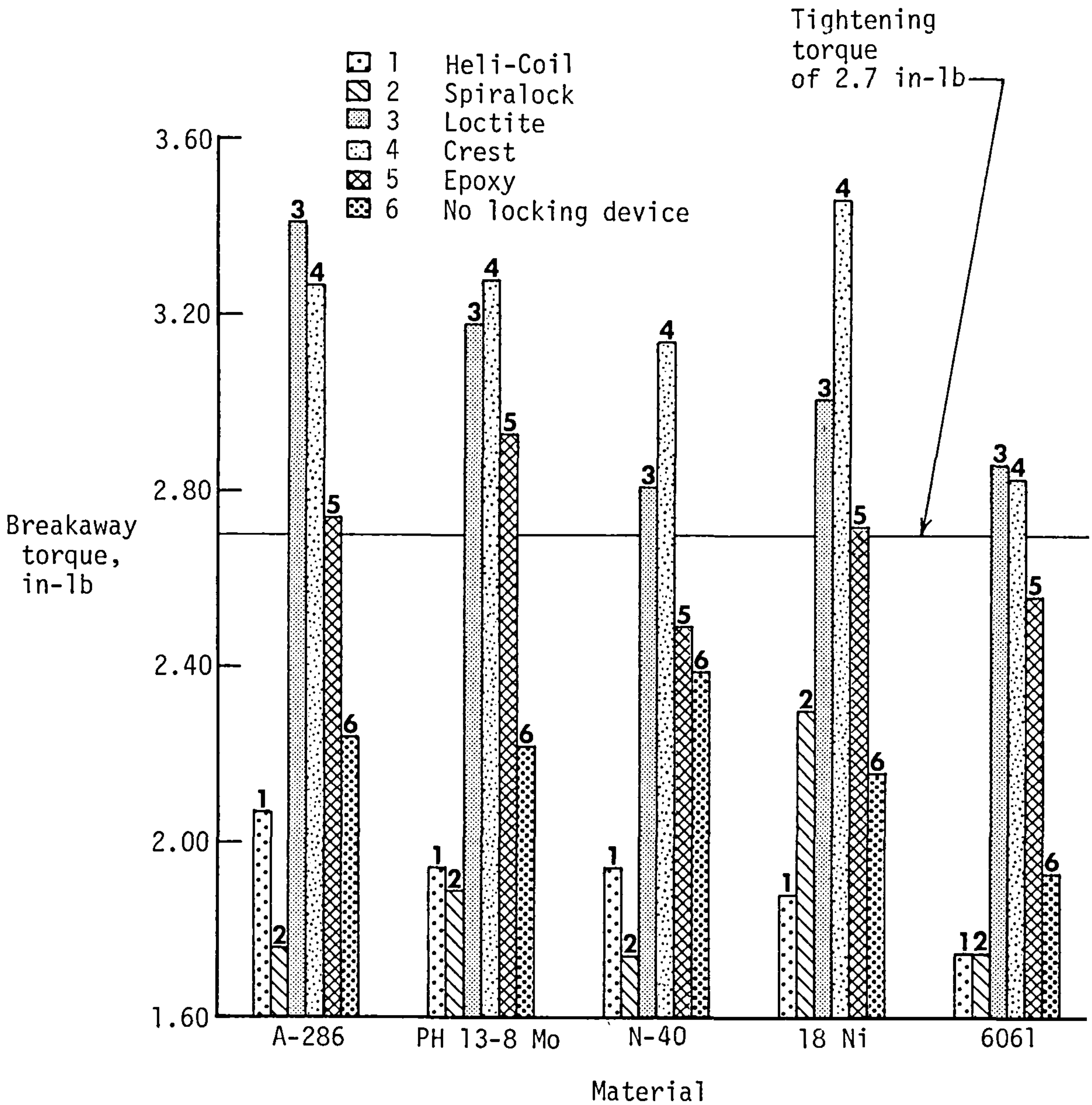
(f) After dynamic loading.

Figure 11.- Continued.



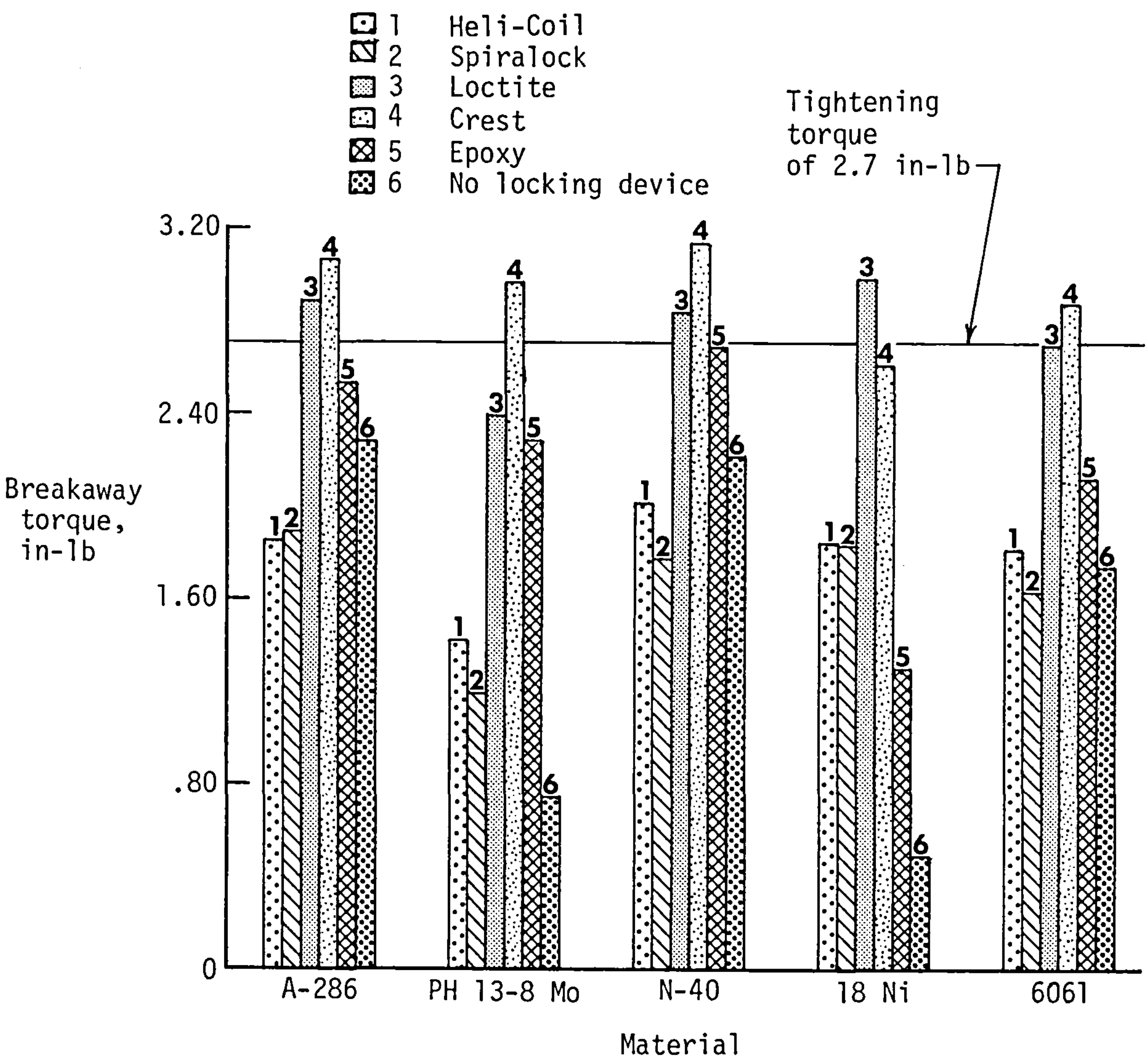
(g) After static loading.

Figure 11.- Concluded.



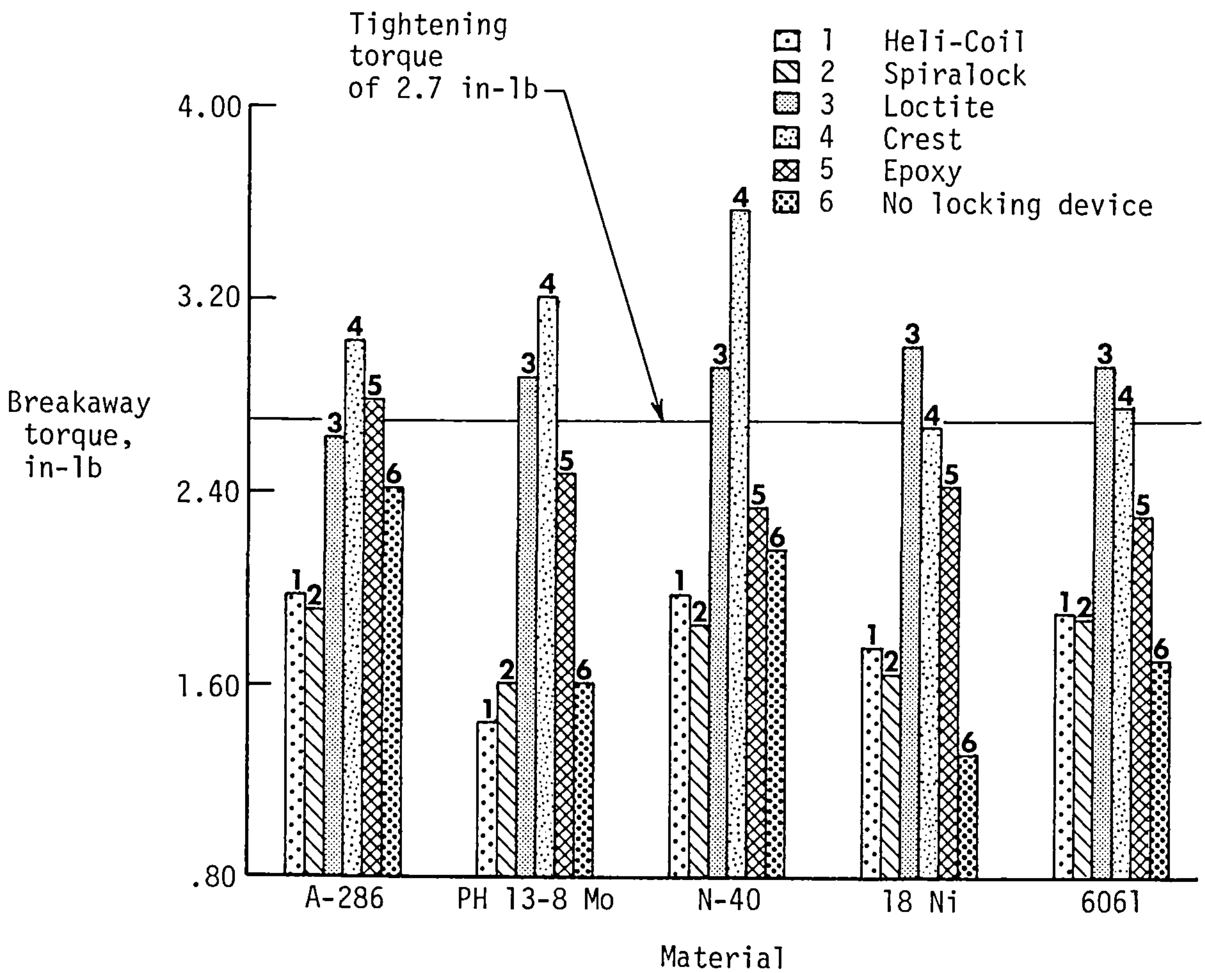
(a) Before cycling.

Figure 12.- Breakaway torque versus specimen material for 2-56 screws with various retention devices.



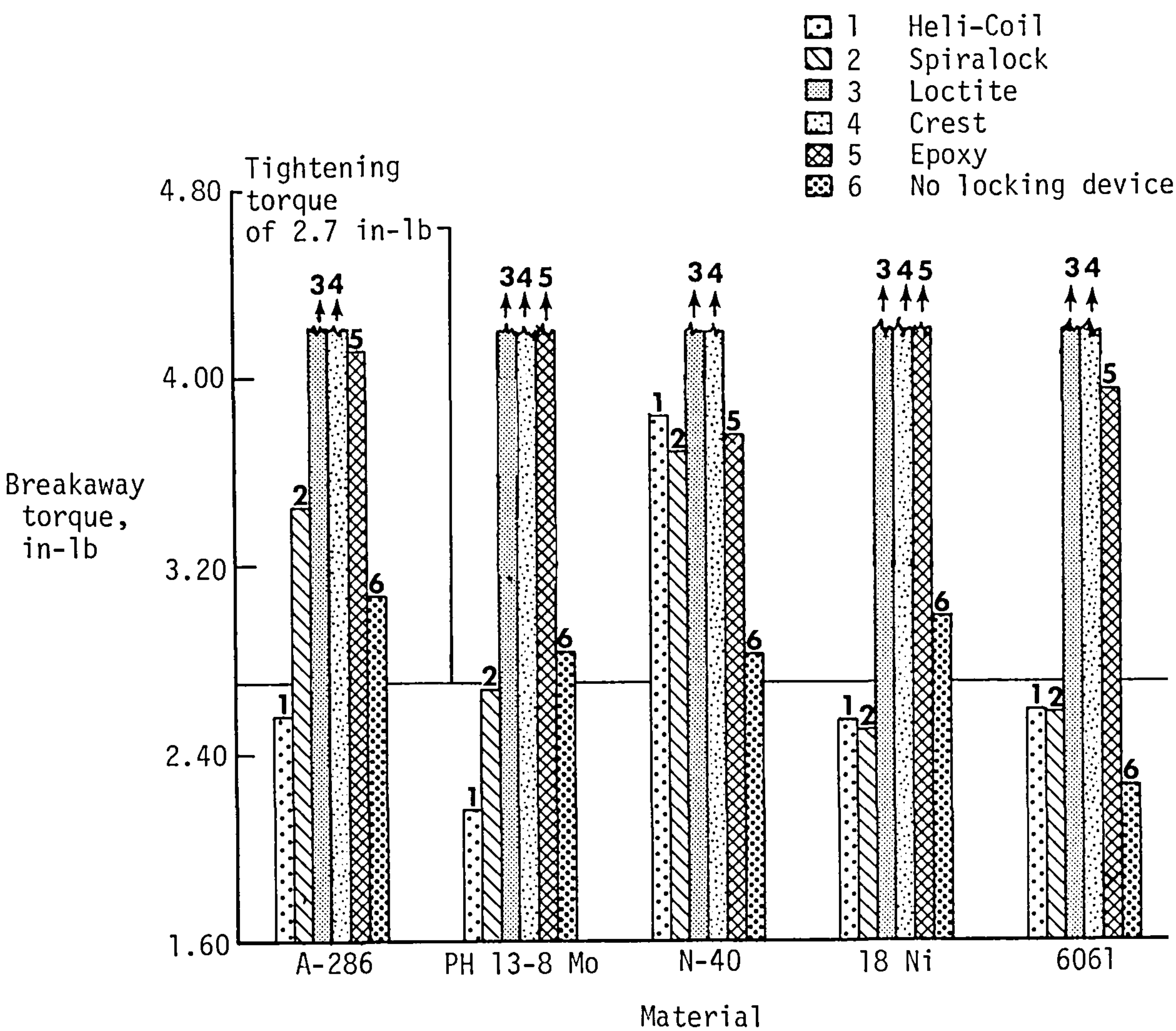
(b) After one cycle.

Figure 12.- Continued.



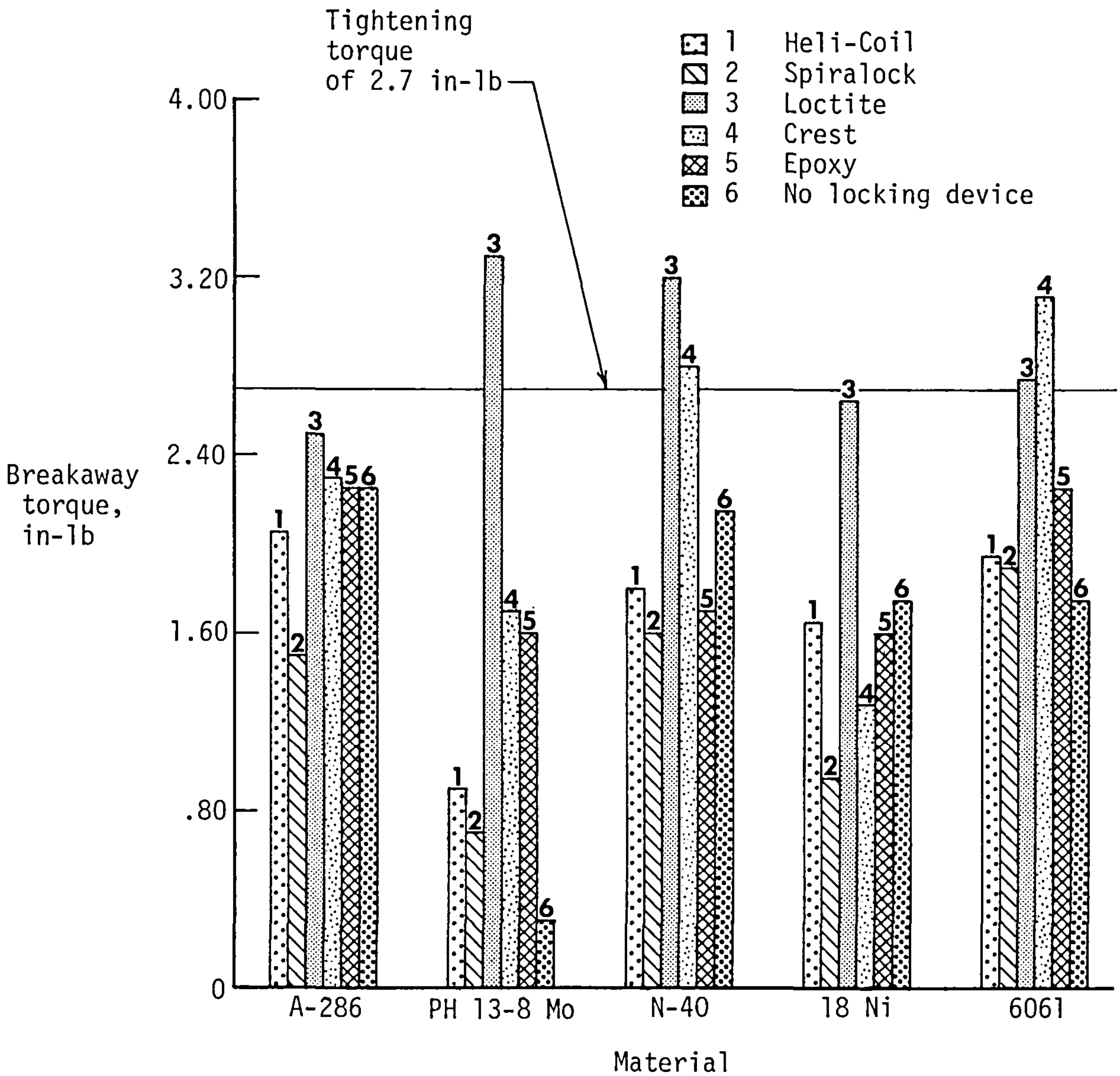
(c) After five cycles.

Figure 12.- Continued.



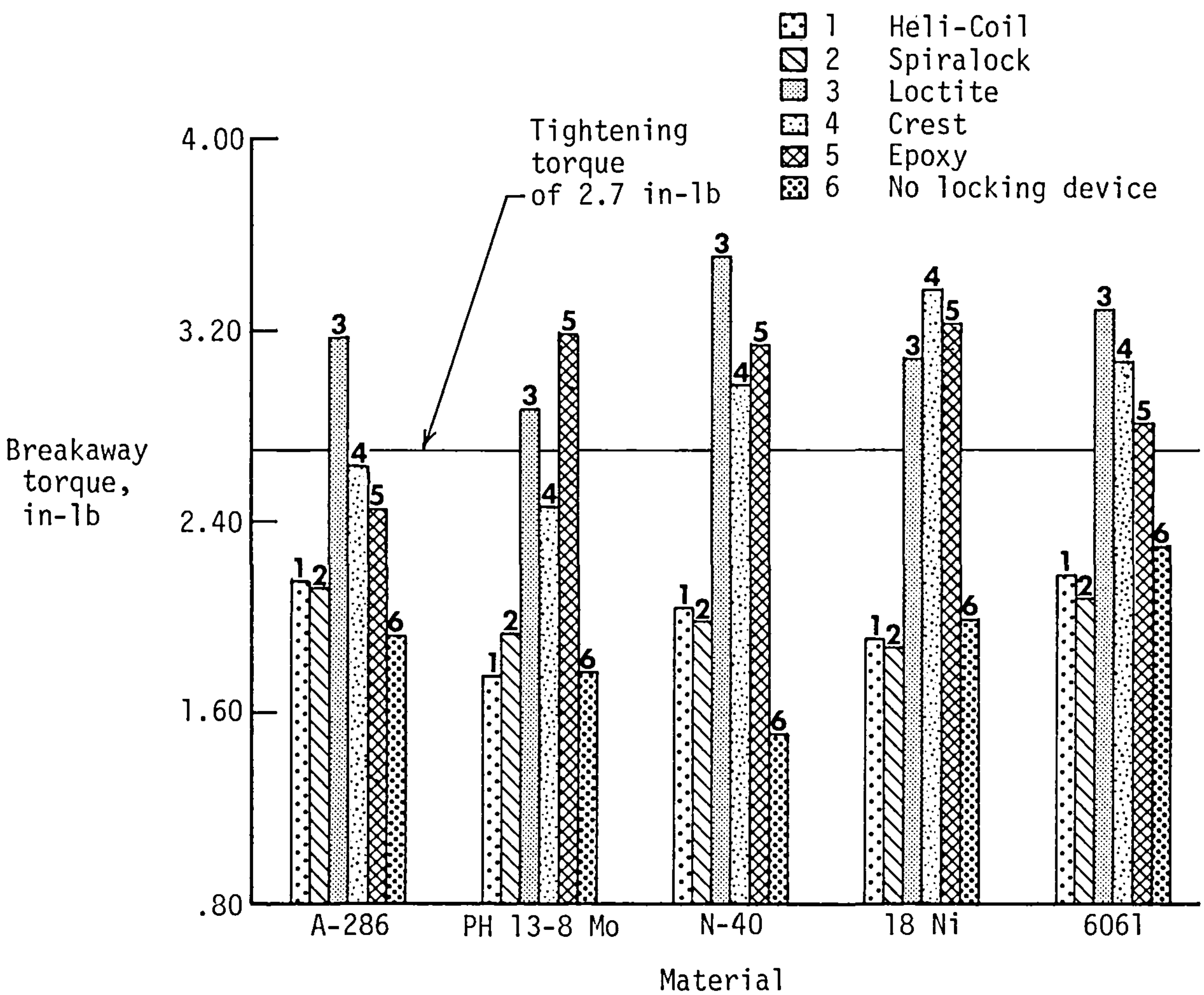
(d) At -275°F. Arrow (↑) indicates screws could not be turned at this temperature. (Wrench torque limit ≈ 7 in-lb.)

Figure 12.- Continued.



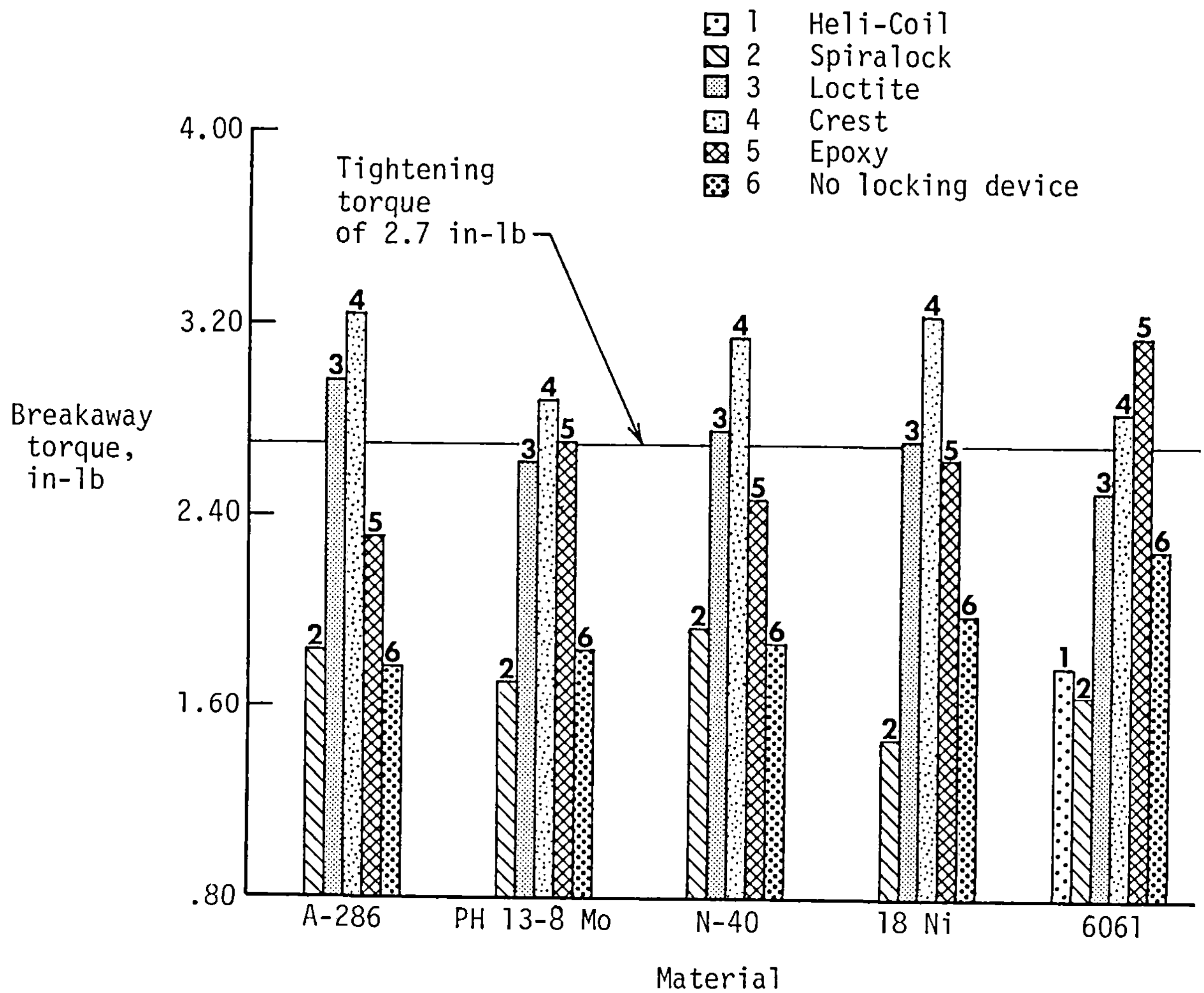
(e) Control screw.

Figure 12.- Continued.



(f) After dynamic loading.

Figure 12.- Continued.



(g) After static loading.

Figure 12.- Concluded.

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15. Supplementary Notes

16. Abstract

This paper presents the results of a fastener load and retention systems test program, which was carried out as a part of the cryogenic models technology development activities at the NASA Langley Research Center. A-286 stainless steel screws were tested to determine the tensile load capability and failure mode of various screw sizes and types at both cryogenic and room temperatures. Additionally, five fastener retention systems were tested by using A-286 screws with specimens made from the primary metallic alloys that are currently used for cryogenic models. The locking-system effectiveness was examined by simple no-load cycling to cryogenic temperatures (-275°F) as well as by dynamic and static loading at cryogenic temperatures. In general, most systems were found to be effective retention devices. There are some differences between the various devices with respect to ease of application, cleanup, and reuse. Also results of tests at -275°F imply that the cold temperatures act to improve screw retention. The improved retention is probably the result of differential thermal contraction and/or increased friction (thread-binding effects). The data in this paper are provided for use in selecting screw sizes, types, and locking devices for model systems to be tested in cryogenic wind tunnels.

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