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Use of Anaerobic Adhesive for Prevailing Torque Locking Feature on Threaded Product

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by

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DEDICATION

I would like to dedicate this thesis to my family and friends. I would like to especially dedicate it too my mother and father, Elsa and Mario Hernandez, for their encouragement and support throughout my educational career. My brother, Michael R. Hernandez, which has motivated me when I needed it most.

I also dedicate this thesis to Anayamille Alvarado, for being by my side through most of my educational career and ensuring I do my best at everything I do.

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ABSTRACT

The purpose of this research is to determine if anaerobic adhesive can be used as a prevailing torque locking feature. Maintaining preload in critical joints is the usual standard that anaerobic adhesives are held to in aerospace and other industry. To test if anaerobic adhesive can be used as a prevailing torque locking feature a test procedure was developed and implemented to measure the removal torque of threaded fasteners after an allotted cure time. In total, 191 threaded fasteners of different material and coatings were tested in the unseated and seated states with various strengths and varieties of anaerobic adhesive. A series of three tests were conducted: initial use, reuse with no added anaerobic adhesive, and a third test with added product to the bolt and nut to see how removal torque would behave in these conditions. It was found that using anaerobic adhesive as a prevailing torque locking feature is viable in many cases. No published work to date analyzes anaerobic adhesive at the standard of a prevailing torque locking feature.

CHAPTER 1: INTRODUCTION AND BACKGROUND

The loosening of threaded fasteners in critical applications is a major concern still today though there are many devices and standards that help prevent threaded fasteners from disassembling. The two most common devices used on threaded fasteners are mechanical locking features and prevailing torque locking features. A mechanical locking feature is one that employs non-friction methods to hold the threaded fastener together to maintain preload [1]. This type of locking feature usually involves a cotter pin or safety wire. A prevailing torque locking feature is one that relies on friction but independent of preload to resist disassembly of a threaded fastener [1]. Some examples of prevailing torque locking features are deformed thread nuts and nylon lock nuts. Another form of providing a locking feature to threaded fasteners is with thread locking anaerobic adhesives. Thread locking anaerobic adhesives are single component anaerobic adhesives that consist of a resin that hardens to a solid in the presence of metal ions and absence of oxygen [2]. As an anaerobic adhesive cures the gap between the threads become completely filled. In filling the gaps, thread friction increases causing it to work as a locking feature.

A potential issue with using an anaerobic adhesive is that curing is not always guaranteed since curing can be affected by the type of material the threaded fastener is made of or coated with. Knowing the material of the threaded fastener is important for the reason the anaerobic adhesive performs differently between active and inactive metals. Inactive metals are low in metal ions which are necessary to promote curing with anaerobic adhesives. With inactive metals it is necessary to apply an activator to the threads to improve anaerobic adhesive curing [2].

Inactive metals consist of stainless steel, zinc, magnesium, cadmium, anodized aluminum and passivated titanium [3].

Recently, a method to validate if sufficient curing has occurred has been developed but is not yet commonly used in practice [4]. This method uses a test removal torque that is slightly less than the breakaway torque so the locking is not destroyed. Before the development of this method there was no direct way to assess that the anaerobic adhesive has cured.

The aerospace industry has preferred using prevailing torque locking features for the reason that they can be easily validated during installation and there are standards and specifications associated with prevailing torque locking features [5, 6, 7, 8, 9, 10]. Another reason is uncured anaerobic adhesives can off-gas which can contaminate other components in space applications.

When anaerobic adhesive is used in the aerospace industry it is held to the same standard as a mechanical locking feature which is to maintain preload on joints [1]. What if anaerobic adhesive is not held to the standard as a thread locker for preload critical joints but to the standard of a prevailing torque locking feature? Some work using anaerobic adhesive as a prevailing torque locking feature has been performed [11, 12] but no published research currently exist. Anaerobic adhesive was used to repair the worn prevailing torque locking features in inserts on the windshield of a space shuttle [11, 12]. Using anaerobic adhesive to repair the locking feature was chosen over replacing inserts in the shuttles structure because replacing the inserts would have damaged or destroyed the structure.

The purpose of this research is to test if using anaerobic adhesive can be used as a prevailing torque locking feature. This was done by testing a variety of non-aerospace and aerospace threaded fastener with a variety of anaerobic adhesives. The threaded fasteners will be tested in the unseated and seated state. Unseated state means that the threaded fastener does not contain any preload or better said does not clamp the components. As for the seated state, the fasteners will be preloaded to a designated torque. A procedure for preparing the threaded fasteners for testing and how to test the threaded fasteners will be defined for repeatability of the data collected. After the data is collected, presented results are discussed to assess if anaerobic adhesive can be used as a prevailing locking feature within the specification.

CHAPTER 2: TESTING

The goal of this study is to see if an anaerobic adhesive can be used as an in specification prevailing torque locking feature. This is determined by testing a variety of aerospace and non-aerospace grade threaded fasteners in the unseated and seated state. For both testing states the re-use of anaerobic adhesive is explored. The same threaded fastener is tested twice in reuse. For the first reuse the hex nut is completely removed and then placed at the same location where it previously cured at. For the second reuse the nut is completely removed but anaerobic adhesive is added to the cap screw and hex nut. The reasoning behind testing the reuse of threaded fasteners containing anaerobic adhesive is to comprehend the effects of the adhesive under these conditions.

2.1 Materials

2.1.1 Threaded Fasteners

All threaded fasteners used consist of ¼-28 thread size with differing root radii. For the non-aerospace grade fasteners the thread type is ¼-28 UNF, while for the aerospace grade fastener the thread type is ¼-28 UNJF which has a rounded root radius. The nuts used are plain hex nuts for the reason that they resemble lock nuts with worn prevailing torque locking feature. By using plain hex nuts this gives the ability to explore anaerobic adhesive as repair method for worn mechanical prevailing torque locking features, as well as, using plain hex nuts with anaerobic adhesive as a prevailing torque locking feature. The advantage of using just a plain hex nut with anaerobic adhesive as a prevailing torque locking feature is the reduced cost of materials during assembly and also the ability to reuse the threaded fastener by just adding anaerobic adhesive. In total 191 cap screws, 191 hex nuts, and 174 flat washers were tested. The specifications for these products are provided in the following subsections.

2.1.1.1 Plain Grade 8

The specifications for the plain grade 8 threaded fasteners are provided in Tables 1-3. When referring to the cap screws, hex nuts, and flat washers as plain, it is describing that the products are as-manufactured which are black in color.

2.1.1.1.1 Cap Screws

Table 1 Plain grade 8 cap screw specifications.

Plain Grade 8 Cap Screw	
Manufacturer	Nucor Fasteners
Material Properties	Covered in SAE J429
Dimension and Tolerances	Meets ASME (ANSI) B18.2.1
Coating Type	Plain
Thread Type	¼ -28 UNF
Thread Length	1-¼ inches
Lot #	270002A

2.1.1.1.2 Hex Nuts

Table 2 Plain grade 8 hex nut specifications.

Plain Grade 8 Hex Nut	
Manufacturer	Fabory
Material Properties	Covered in SAE J995
Dimension and Tolerances	Meets ASME (ANSI) B18.2.2
Coating Type	Plain
Thread Type	¼ -28 UNF
Lot #	n08051758

2.1.1.1.3 Flat Washers

Table 3 USS steel flat washer specifications.

USS Steel Flat Washer	
Manufacturer	Fabory
Material Properties	Covered in ASME B18.22.1
Dimension and Tolerances	Meets ASME (ANSI) B18.22.1
Coating Type	Plain
Lot #	2013071701

2.1.1.2 Yellow-Zinc Grade 8

The coating on the caps screws, hex nuts, and flat washers are yellow-zinc. Yellow-zinc is the most common type of finish found on threaded product. Plating the threaded fasteners with this type of coating provides resistance to corrosion. Tables 4-6 provides the specifications for the yellow-zinc grade 8 products.

2.1.1.2.1 Cap Screws

Table 4 Yellow-Zinc grade 8 cap screw specifications.

Yellow-Zinc Grade 8 Cap Screw	
Manufacturer	Brighton Best
Material Properties	Covered in SAE J429
Dimension and Tolerances	Meets ASME (ANSI) B18.2.1
Coating Type	ASTM F1941 FeZn5C
Thread Type	¼ -28 UNF
Thread Length	1-¼ inches
Lot #	686987

2.1.1.2.2 Hex Nuts

Table 5 Yellow-Zinc grade 8 hex nut specifications.

Yellow-Zinc Grade 8 Hex Nut	
Manufacturer	Fabory
Material Properties	Covered in SAE J995
Dimension and Tolerances	Meets ASME (ANSI) B18.2.2
Coating Type	Yellow Zinc Plating
Thread type	¼ -28 UNF
Lot #	GD213094842

2.1.1.2.3 Flat Washers

Table 6 Yellow-Zinc grade 8 flat washer specifications.

Yellow-Zinc Grade 8 Flat Washer	
Manufacturer	Master Products
Material Properties	Covered in ASTM F436
Dimension and Tolerances	Meets ASME (ANSI) B18.2.2
Coating Type	Yellow Zinc Plating ASTM F436
Lot #	68096-01

2.1.1.3 A-286

A-286 is a very common stainless steel used for aerospace threaded fasteners. The caps screws, hex nuts, and flat washers contain a passivate finish. The passivate finish enhances stainless steels natural ability to resist corrosion. In Tables 7-9 the specifications for the cap screws, hex nuts, and flat washers are given.

2.1.1.3.1 Cap Screws

Table 7 A-286 cap screw specifications.

A-286 Cap Screw	
Vendor	Aerolyusa
Manufacturer	3V Fasteners
Part #	NAS1004-1A
Material Properties	AMS 5731L
Heat Treatment	AMS 2759/3D
Dimension and Tolerances	Meets MIL-S-8879
Coating Type	Passivate AMS 2700B Met. I TY II
Thread type	¼ -28 UNJF-3A
Mfg Lot #	42863

2.1.1.3.2 Hex Nuts

Table 8 A-286 hex nut specifications.

A-286 Hex Nut	
Vendor	Aerolyusa
Manufacturer	Automatic Screw Machine
Part #	MS9356-10
Material Properties	AMS 5737P
Heat Treatment	AMS5737P
Dimension and Tolerances	Meets MIL-S-8879
Coating Type	Passivate per specification
Thread type	¼ -28 UNJF-3B
Mfg Lot #	11648

2.1.1.3.3 Flat Washers

Table 9 A-286 flat washer specifications.

A-286 Flat Washer	
Vendor	Aerolyusa
Manufacturer	Anillo Industries
Part #	NAS1149E0432R
Material Properties	AMS 5525 Rev. J
Heat Treatment	AMS2759
Dimension and Tolerances	NAS1149E0432R
Coating Type	Passivate AMS-2700 Met. I TY VI

2.1.2 Anaerobic Adhesive

Low and medium strength anaerobic adhesives are used in this work for the reason that high strength anaerobic adhesive exceeds the prevailing torque range of 3.5-30 in-lb. During preliminary testing it was found that Loctite 290, which is a medium strength wicking grade, also consistently exceeds the prevailing torque range of 3.5-30 in-lbs., so further studies were not performed with this grade of Loctite.

Three different types of Loctite were used during testing which include Loctite 222MS, Loctite 242, Loctite 243 as shown in Tables 10-12.

Loctite 222MS when uncured is purple in color. It is consider a low strength anaerobic adhesive meant to be used on small fasteners up to ¼ of an inch in thread size. For more information refer to the technical data sheet referenced [13].

Table 10 Loctite 222MS specifications.

Loctite 222MS	
Color	Purple liquid
Strength	Low Strength
Bolt Size	Small fasteners up to ¼ inch.
Standards & Specifications	MIL-S-46163A

Loctite 242 when uncured is blue in color. This type of adhesive is meant for fasteners ¼ to ¾ of an inch thread size. Loctite 242 is suited for plated surfaces and when cured prevents leakage from shock and vibrations. For more information that is not listed in Table 11 refer to the technical data sheet [14].

Table 11 Loctite 242 specifications.

Loctite 242	
Color	Blue liquid
Strength	Medium Strength
Bolt Size	¼ to ¾ of an inch
Standards & Specifications	MIL-S-46163A

The difference between Loctite 242 to Loctite 243 is that Loctite 243 is referred to as a primer less anaerobic adhesive that has the capability to work on passive substrates which is advantageous when working with A-286 [15].

Table 12 Loctite 243 specifications.

Loctite 243	
Color	Blue liquid
Strength	Medium Strength
Bolt Size	¼ to ¾ of an inch

2.2 Equipment

2.2.1 Ultrasonic Cleaner

The test specimens are cleaned using an ultrasonic cleaner containing methyl ethyl ketone (MEK). The ultrasonic cleaner used for the experiment is manufactured by Fisher Scientific. The input voltage and frequency rated on the cleaner is 117 volts at an input frequency of 50/60 Hz. The frequency at which the ultrasonic cleaner operates at is 13,000 Hz. Dimensions of the container are 6x5.375x3.5 inches which is sufficient for the size of fixtures and fasteners used.

2.2.2 Torque Wrench

Dial torque wrenches were used for measuring the removal and prevailing torque of the threaded fasteners. By using a dial torque wrench, the variance in prevailing torque during one revolution of the hex nut is observed with ease. For unseated state tests, a torque wrench rated from 0-75 in-lbs. is used for the reason that each tick mark represents 1 in-lb. Another reason for using the 0-75 in-lbs. dial torque wrench for the unseated state is to allow enough range in case the prevailing torque exceeded the allowable amount of 3.5-30 in-lbs. for ¼-28 fasteners. For seated state test however two torque wrenches were utilized since the threaded fasteners are preloaded to 150 in-lbs. The first torque wrench used is rated from 0-250 in-lbs. with each tick mark representing 5 in-lbs. After the removal torque has dropped to the range of the 0-75 in-lbs. dial torque wrench, the 0-250 in-lbs. torque is exchanged for the 0-75 in-lbs. dial torque wrench. The specifications for these two dial torque wrenches are provided in Tables 13 and 14.

Table 13 0-75 in-lbs. dial torque wrench specifications.

0-75 in-lbs. Dial Torque Wrench	
Manufacturer	Proto
Scale Range	0-75 in-lbs.
Scale Accuracy	1.0 in-lbs.
Drive Size	¼ inch

Table 14 0-250 in-lbs. dial torque wrench specifications.

0-250 in-lbs. Dial Torque Wrench	
Manufacturer	Proto
Scale Range	0-250 in-lbs.
Scale Accuracy	5 in-lbs.
Drive Size	3/8 inch

2.2.2.1 Calibration of Torque Wrenches

In order to validate the calibration of the torque wrenches, a 0.661 lbs. weight is hung 8.25 inches away from the drive as shown in Figure 1. Using this simple equation:

$$T = F * d$$

where F is the weight and d is the length of the moment arm. One can calculate the torque caused by the mass and compare it to the measured value off the torque wrench.

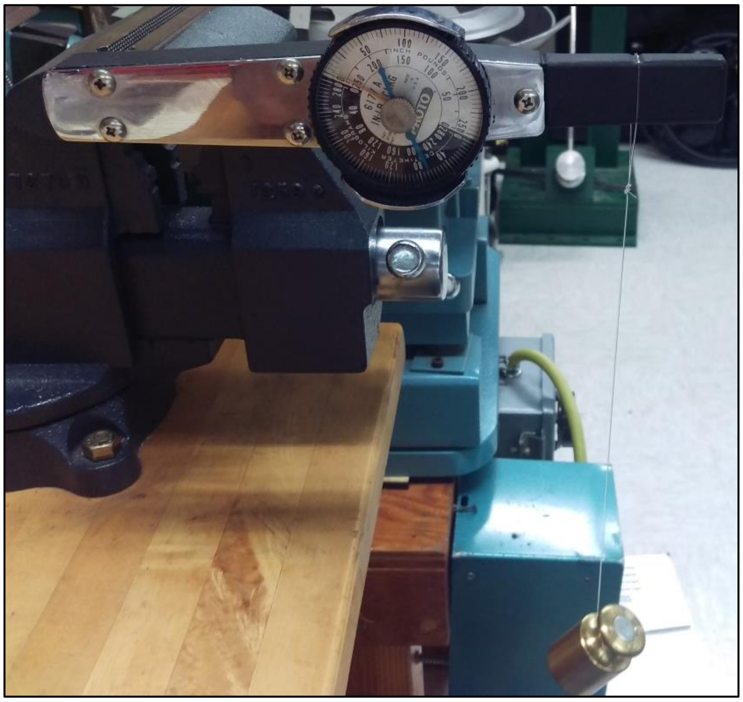

Figure 1 Calibration of torque wrench

The calibration of the torque wrenches is as follows:

1) Lightly clamp the drive of the dial torque wrench using a table vise as shown in Figure 1. Be sure that the drive is squared to the vise before clamping onto it.
2) Attach fishing string to the weight.

3) Make a large enough noose, at the other end of the fishing string, so that the dial torque wrench's handle fits inside the noose.
4) Hang the weight to a known distance.
5) Measure the reading off the dial torque wrench and compare to theoretical value.

The results from calibrating the torque wrenches are listed in Table 15. The procedure for calibration was performed at the beginning and at intermittent times throughout testing. Every time the calibration procedure was performed the same measured values occurred.

Table 15 Calibration verification of torque wrenches.

Calibration Verification		
Torque Wrench	Calculated Value	Measured Value
0-75 in-lbs. Torque Wrench	5.45 in-lbs.	5.5 in-lbs.
0-250 in-lbs. Torque Wrench	5.45 in-lbs.	5 in-lbs.

2.2.3 Fixtures

2.2.3.1 Unseated State Fixture

No fixtures were manufactured for the unseated state tests. A 6 inch Craftsman table vise is used to clamp the test specimens for the unseated state.

2.2.3.2 Seated State Fixtures

For the seated state tests, fixtures were made so that multiple test specimens can be preloaded at once. The fixtures are made out of 304 stainless steel because of its ability to resist corrosion. Figures 2-4 illustrate all dimensions and tolerances for the fixtures. The test fixtures through holes are oversized to eliminate contact between the fasteners and the through holes, which can affect the torque measurements.

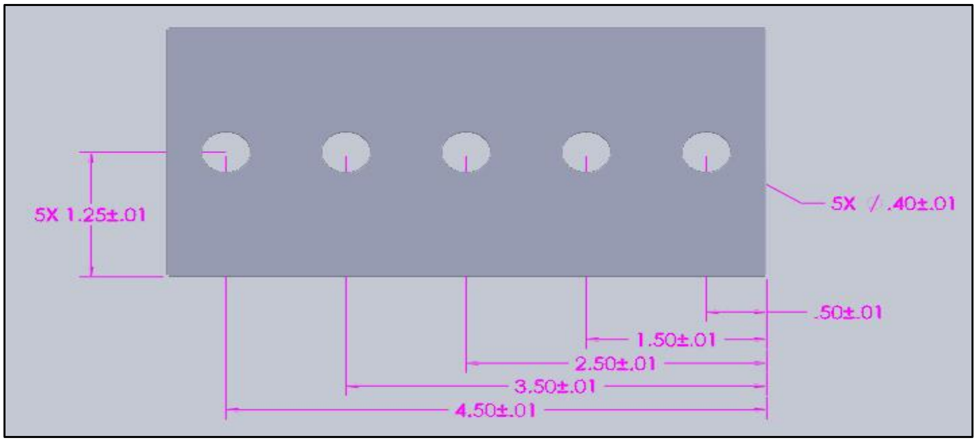

Figure 2 Top view for seated state fixtures.

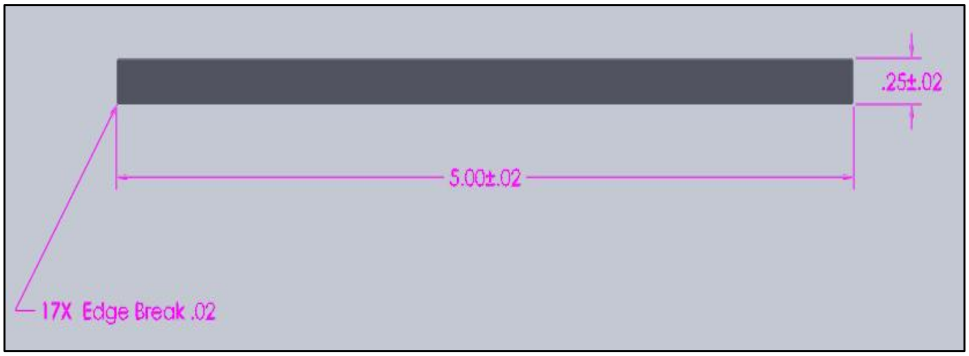

Figure 3 Front view of seated state fixtures.

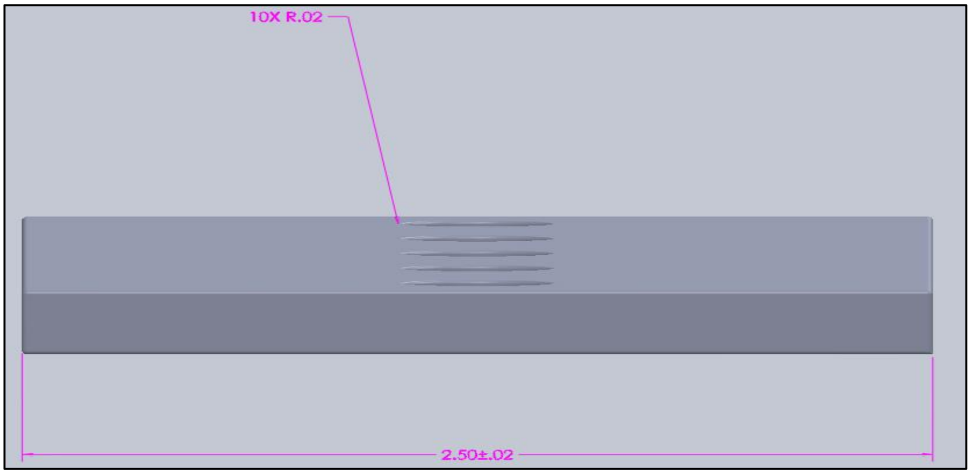

Figure 4 Side view of seated state fixtures.

2.3 Preparing the Test Specimen

2.3.1 Inspection Process

Before any anaerobic adhesive is applied to the threaded fastener the tolerances are inspected to ensure consistency between threaded fasteners. Any threaded fastener that was not within tolerance was not used for the experiment. This was determined by assembling the cap screw and hex nut. If during the assembly the hex nut is not freely mating with cap screw the combination is considered to be out of tolerance due to thread size being undersized or burrs on the threads. Another issue that can occur is having the thread size oversized. This is determined by mating a cap screw with a hex nut and applying a moment perpendicular to the direction of the threads. If the hex nut moves a significant amount, compared to the average amount, the threads are considered to be oversized. After the threaded fasteners have been inspected the next step is to clean the cap screws and hex nuts.

2.3.2 Cleaning Process

All cap screw, hex nuts, flat washers, and fixtures are cleaned to remove contaminates and lubricants. This ensures consistency between test specimens. The cleaning process differs between the unseated and seated state.

2.3.2.1 Cleaning Process for Unseated State Tests

1) Place the cap screws and hex nuts in the ultrasonic cleaner containing MEK.
2) Turn on the ultrasonic cleaner
3) After 5 minutes turn off the ultrasonic cleaner
4) Remove the cap screws and hex nuts using tongs
5) Place the cap screws and hex nuts on a lint free paper towel or cloth.
6) Leave the test specimens to air dry for 5 minutes.

2.3.2.2 Cleaning Process for Seated State Tests

2.3.2.2.1 Cleaning Process of Fixture for Seated State

1) Place the fixtures in the ultrasonic cleaner containing MEK.
2) Turn on the ultrasonic cleaner.
3) After 5 minutes turn off the ultrasonic cleaner.
4) Remove fixtures using tongs. Be sure to firmly hold the fixture to prevent the MEK from splashing out of the ultrasonic cleaner.
5) Place fixtures on a lint free paper towel or cloth.
6) Leave the fixtures to air dry for 5 minutes.
7) If the fixtures contain remnants from the cured anaerobic adhesive, lap the fixtures using a 120 grit Emory cloth or higher until, contaminates (e.g., cured Loctite) are removed.
8) Repeat steps 1 thru 6 to remove debris introduced after lapping.

2.3.2.2.2 Cleaning Process of Threaded Fasteners for Seated State

1) Place the cap screw, hex nuts, and flat washers in the ultrasonic cleaner containing MEK.
2) Turn on the ultrasonic cleaner.
3) After 5 minutes turn off the ultrasonic cleaner.
4) Remove the cap screw, hex nuts, and flat washers using tongs.
5) Place the cap screw, hex nuts, and flat washers on a lint free paper towel or cloth.
6) Leave the test specimens to air dry for 5 minutes.

2.4 Unseated State Test Procedure

After all the threaded fasteners that are going to be tested have been inspected and cleaned, the following step is to apply the adhesive to the cap screw and hex nut. Assemble the cap screw and hex nut containing adhesive and let threaded fastener cure for a sufficient amount of time. Once the curing time has been reached, testing of the threaded fastener is achieved by holding the head of the cap screw on a bench vise. A torque wrench is used to record prevailing torque data from the fastener.

2.4.1 Initial Unseated State

2.4.1.1 Preparation of Test Specimens for Initial Unseated State

1) Apply anaerobic adhesive to the cap screw until the threads are filled. Apply from the start of the threads to about a ¼ of inch up the thread. Two drops of adhesive is usually sufficient to fill the threads.
2) Apply anaerobic adhesive to the hex nut until the gaps between the threads are filled. One drop of anaerobic adhesive is sufficient to fill the threads.
3) Assemble the cap screw and hex nut that contains anaerobic adhesive until three full threads are exposed. Be sure adhesive is visible where the hex nut is placed to cure.
4) Let the assembly cure for 48 hours on a lint free paper towel or cloth without any interruptions.
5) After the curing time has been reached lightly wipe any excess adhesive from the threads of the cap screw with a lint free paper towel or cloth. Be sure to not disrupt the hex nuts position or contaminate the threaded fastener.

2.4.1.2 Test Procedure for Initial Unseated State

1) Clamp the threaded fastener using a table vise as shown in Figure 5. Clamp the head of the cap screw so that the torque wrench can be applied to the hex nut.

Figure 5 Threaded fastener clamped on table vise.

2) Use a 0-75 in-lb. dial type torque wrench with 7/16 socket.
3) Apply a torque in the counter-clockwise direction, to the nut, gradually until motion is initiated. Record the breakaway torque at the instant of motion without stopping rotation.
4) Keep applying the torque gradually and continuously while recording the torques at 2-5, 90,180, 270, and 360 degrees relative to the position where the torque was first applied. If necessary one can stop to record the data but when the torque is re-applied be sure to rotate at the same rate.

2.4.2 Reuse of the Unseated State

Once the initial unseated testing has been performed the next step is to prepare the test specimen for reuse in the unseated state. This is done simply by removing the hex nut completely from the cap screw and then reassembling the hex nut to the same location where it was cured at for the initial unseated state.

2.4.2.1 Preparation of Test Specimens for Reuse of the Unseated State

1) Remove the hex nut completely from the cap screw.
2) Place the hex nut exactly the same manner it was removed onto the threads of the cap screw.

3) Fasten the hex nut to the location where it was fastened too in the initial unseated state. It should be fastened until approximately three full threads are exposed from the hex nut.

4) Let the assembly cure for 48 hours on a lint free paper towel or cloth without any interruptions.

2.4.2.2 Test Procedure for Reuse of the Unseated State

1) Clamp the threaded fastener using a table vise as shown in Figure 1. Clamp the head of the cap screw so that the torque wrench can be applied to the hex nut.

2) Use a 0-75 in-lb. dial type torque wrench with 7/16 socket.

3) Apply a torque in the counter-clockwise direction, to the nut, gradually until motion is initiated. Record the breakaway torque at the instant of motion without stopping rotation.

4) Keep applying the torque gradually and continuously while recording the torques at 2-5, 90,180, 270, and 360 degrees relative to the position where the torque was first applied. If necessary one can stop to record the data but when the torque is re-applied be sure to rotate at the same rate.

2.4.3 Reuse of the Unseated State Adding Anaerobic Adhesive

The preparation of the reuse with adding anaerobic adhesive for the unseated state is similar to that of the reuse for the unseated state. The only difference is when the hex nut is completely removed, anaerobic adhesive is added to the hex nut and cap screw. Once the adhesive has been added, the hex nut is placed in the same location where it previously was cured at.

2.4.3.1 Preparation of Test Specimens for Reuse of Unseated State Adding Anaerobic Adhesive

1) Remove the hex nut completely from the cap screw.
2) Add 2 drop of anaerobic adhesive to the cap screw. Apply from the start of the threads to about a ¼ inch up the thread.
3) Add 1 drop of anaerobic adhesive to the hex nut.
4) Place the hex nut exactly the same manner it was removed onto the threads of the cap screw.
5) Fasten the hex nut to the location where it was previously cured at. It should be fastened until approximately three full threads are exposed from the hex nut.
6) Let the assembly cure for 48 hours on a lint free paper towel or cloth without any interruptions.

2.4.3.2 Test Procedure for Reuse of Unseated State Adding Anaerobic Adhesive

1) Clamp the threaded fastener using a table vise as shown in Figure 1. Clamp the head of the cap screw so that the torque wrench can be applied to the hex nut.
2) Use a 0-75 in-lb. dial type torque wrench with 7/16 socket.
3) Apply a torque in the counter-clockwise direction, to the nut, gradually until motion is initiated. Record the breakaway torque at the instant of motion without stopping rotation.
4) Keep applying the torque gradually and continuously while recording the torques at 2-5, 90,180, 270, and 360 degrees relative to the position where the torque was first applied. If necessary one can stop to record the data but when the torque is re-applied be sure to rotate at the same rate.

2.5 Seated State Procedure

Once the test specimens and fixtures have been inspected and cleaned, the following step is to apply molybdenum disulfide (MoS_2) to both sides of the flat washers. The reason for applying MoS_2 is to prevent galling from occurring. After the flat washers are placed under the head of the cap screws and the partial assembly is inserted into the fixtures. At the other end of the fixture, where the threads are exposed, insert the flat washers coated with MoS_2. Now anaerobic adhesive is applied to the threads of the caps screws and hex nuts and fastened to a designated preload. Once it is sufficiently cured, testing of the threaded fastener is achieved by holding the head of the cap screw on a table vise and using a torque wrench to record prevailing torque data.

2.5.1 Initial Seated State

2.5.1.1 Preparation of Test Specimens for Initial Seated State

1) Place the flat washers at a location where it is safe to apply MoS_2.
2) Spray MoS_2 to the surface of the flat washer until the entire surface is coated. Spray from about 16 inches away from the surface.
3) Let the MoS_2 dry until it has a dark opaque finish. The drying process can be accelerated using a heat gun from approximately two feet away until the same dark opaque finish occurs.
4) Once dried flip the flat washer to the surface not containing MoS_2.
5) Spray MoS2 to the surface of the flat washer until the entire surface is coated. Spray from about 16 inches away from the surface.

6) Let the MoS2 dry until it has a dark opaque finish. The drying process can be accelerated using a heat gun from approximately two feet away until the same dark opaque finish occurs.

7) Grip the fixture using a table vise so that the bolt holes are parallel to the ground as shown in Figure 6.

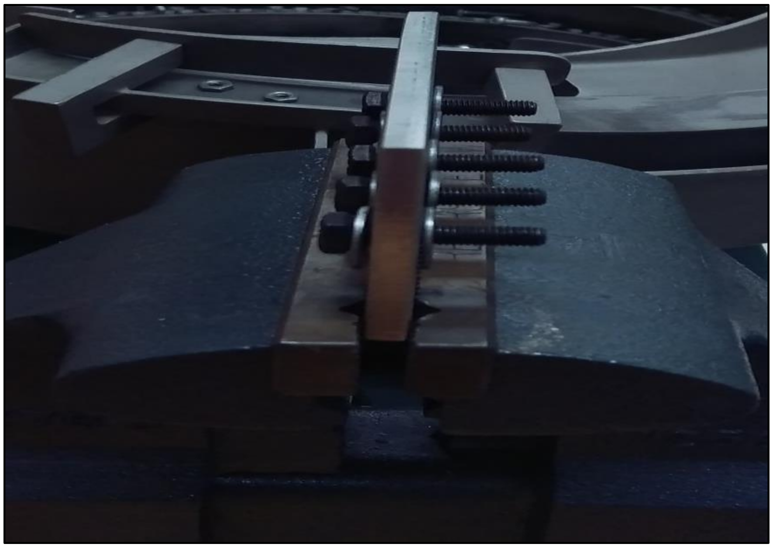

Figure 6 Seated state fixture fastener install.

8) Place a flat washer containing MoS_2 on a cap screw.

9) Insert the cap screw and flat washer with MoS_2 into the fixture.

10) Insert a flat washer containing MoS_2 on the other side of the fixture where the cap screw threads are exposed.

11) Apply anaerobic adhesive to the cap screw until the threads are filled. Apply from the start of the threads until 0.100 of an inch before the fixture. Two or three drops of adhesive is usually sufficient to fill the threads.

12) Apply anaerobic adhesive to the hex nut until the gaps between the threads are filled. One drop of anaerobic adhesive is sufficient to fill the threads.

13) Assemble the hex nut to the cap screw until hand tight. Be sure that the cap screw is centered to the hole on the fixture. If multiple test specimens can be loaded to the same fixture, repeat steps 8-13 until fixture is completely loaded.

14) Unload the fixture, containing the test specimens, from the table vise.

15) Clamp the head of the cap screw using the table vise as shown in Figure 7.

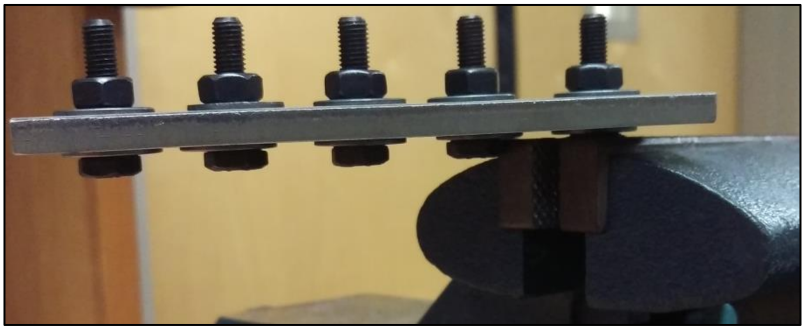

Figure 7 Clamping the head of the cap screw with a table vise.

16) Using a dial torque wrench rated for 0-250 in-lbs. with a 7/16 socket, preload the threaded fastener until 150 in-lbs. which corresponds to a preload of about 3636 lbs. Once you reach specified torque, hold at the specified torque for five seconds.

17) Relieve the hex nut from the torque. Re-apply and hold to the specified torque for an additional 10 seconds. (Note: The hex nut usually turns during the first couple of seconds of the reapplication of the torque.)

18) For multiple test specimens on one fixture repeat steps 15-17.

19) Once the threaded fastener is preloaded let the assemblies cure for 48 hours without disturbances.

20) After the curing time has been reached lightly wipe any excess adhesive from the threads of the cap screw with a lint free paper towel or cloth. Be sure to not disrupt the hex nuts position or contaminate the threaded fastener.

2.5.1.2 Test Procedure for Initial Seated State

1) Clamp the head of the cap screw using a table vise as shown in Figure 7.
2) Use a dial torque wrench rated for 0-250 in-lbs. with 7/16 socket.
3) Apply a torque in the counter-clockwise direction, to the nut, gradually until motion is initiated. Record the breakaway torque at the instant of motion without stopping rotation.
4) Keep applying the torque gradually and continuously and while recording the torque at 2-5 degrees. Once the removal torque is less than 75 in-lbs., switch to the dial torque wrench rated for 0-75 in-lbs. for accurate readings. This should occur at approximately 60 degrees.
5) Using the dial torque wrench rated for 0-75 in-lbs., apply the torque gradually and continuously while recording the torques at 90,180, 270, and 360 degrees relative to the position where the torque was first applied. If necessary one can stop to record the data but when the torque is re-applied be sure to rotate at the same rate.

2.5.2 Re-Use of the Seated State

Once the initial seated testing has occurred, the step that follows is to prepare the test specimen for the re-use in the seated state. The first step is to remove the hex nut completely from the cap screw. Then reassemble the hex nut to the cap screw and preload to the designated torque.

2.5.2.1 Preparation of Test Specimens for Re-Use of the Seated State

1) Clamp the head of the cap screw using the table vise as shown in Figure 7.
2) Remove the hex nut completely from the cap screw.
3) Assemble the hex nut to the cap screw until hand tight. Be sure that the cap screw is centered to the hole on the fixture.

4) Using a dial torque wrench rated for 0-250 in-lbs. with a 7/16 socket, preload the threaded fastener until 150 in-lbs. which corresponds to a preload of about 3636 lbs. Once you reach specified torque, hold at the specified torque for five seconds.
5) Relieve the hex nut from the torque. Re-apply and hold to the specified torque for an additional 10 seconds.
6) For multiple specimens on one fixture repeat steps 1-5.
7) Once the threaded fastener is preloaded let the assemblies cure for 48 hours without disturbances.

2.5.2.2 Test Procedure for Re-Use of the Seated State

1) Clamp the head of the cap screw using a table vise as shown in Figure 7.
2) Use a dial torque wrench rated for 0-250 in-lbs. with 7/16 socket.
3) Apply a torque in the counter-clockwise direction, to the nut, gradually until motion is initiated. Record the breakaway torque at the instant of motion without stopping rotation.
4) Keep applying the torque gradually and continuously and while recording the torque at 2-5 degrees. Once the removal torque is less than 75 in-lbs., switch to the dial torque wrench rated for 0-75 in-lbs. for accurate readings. This should occur at approximately 60 degrees.
5) Using the dial torque wrench rated for 0-75 in-lb., apply the torque gradually and continuously while recording the torques at 90,180, 270, and 360 degrees relative to the position where the torque was first applied. If necessary one can stop to record the data but when the torque is re-applied be sure to rotate at the same rate.

2.5.3 Reuse of the Seated State Adding Anaerobic Adhesive

The preparation of the reuse with adding anaerobic adhesive for the seated state is similar to that of the reuse of the seated state. The only difference is when the hex nut is completely removed; anaerobic adhesive is added to the hex nut and cap screw. Then the cap screw and hex nut are reassembled and preloaded to the designated amount.

2.5.3.1 Preparation of Test Specimens for Reuse of the Seated State Adding Anaerobic Adhesive

1) Clamp the head of the cap screw using the table vise as shown in Figure 7.
2) Remove the hex nut completely from the cap screw.
3) Apply anaerobic adhesive to the cap screw until the threads are filled. Apply from the start of the threads until 0.100 of inches before the fixture. Two drops of adhesive is usually sufficient to fill the threads.
4) Apply anaerobic adhesive to the hex nut until the gaps between the threads are filled. One drop of anaerobic adhesive is sufficient to fill the threads.
5) Assemble the hex nut to the cap screw until hand tight. Be sure that the cap screw is centered to the hole on the fixture.
6) Using a dial torque wrench rated for 0-250 in-lbs. with a 7/16 socket, preload the threaded fastener until 150 in-lbs. which corresponds to a preload of about 3636 lbs. Once you reach specified torque, hold at the specified torque for five seconds.
7) Relieve the hex nut from the torque. Re-apply and hold to the specified torque for an additional 10 seconds.
8) For multiple specimens on one fixture repeat steps 1-7.

9) Once the threaded fastener is preloaded let the assemblies cure for 48 hours without disturbances.

2.5.3.2 Test Procedure for Reuse of the Seated State Adding Anaerobic Adhesive

1) Clamp the head of the cap screw using a table vise as shown in Figure 7.
2) Use a dial torque wrench rated for 0-250 in-lb. with 7/16 socket.
3) Apply a torque in the counter-clockwise direction, to the nut, gradually until motion is initiated. Record the breakaway torque at the instant of motion without stopping rotation.
4) Keep applying the torque gradually and continuously and while recording the torque at 2-5 degrees. Once the removal torque is less than 75 in-lbs., switch to the dial torque wrench rated for 0-75 in-lbs. for accurate readings. This should occur at approximately 60 degrees.
5) Using the dial torque wrench rated for 0-75 in-lbs., apply the torque gradually and continuously while recording the torques at 90,180, 270, and 360 degrees relative to the position where the torque was first applied. If necessary one can stop to record the data but when the torque is re-applied be sure to rotate at the same rate.

2.6 Test Matrix

Combinations of three fastener materials/coatings and three anaerobic adhesives were tested. Preliminary tests with 5 specimens of plain grade 8 and 5 specimens of yellow-zinc grade 8 showed typical removal torque variation of about 5 through 7 in-lbs. for a given removal angle. Since the prevailing torque locking feature specification range is 3.5 through 30 in-lbs., a sample size of 5 specimens was determined to be reasonable. All test configurations have at least 5 specimens but most test configurations contain 10. 191 specimens were tested each that underwent cure times of 48 hours for the initial use, reuse without adding anaerobic adhesive, and reuse applying additional anaerobic adhesive to the threads.

Table 16 Test matrix.

Test Number	Fastener Type	Test Type	Adhesive Type
1	Plain grade 8	Unseated	Loctite 290
2	Plain grade 8	Unseated	Loctite 290
3	Plain grade 8	Unseated	Loctite 290
4	Plain grade 8	Unseated	Loctite 290
5	Plain grade 8	Unseated	Loctite 290
6	Yellow-zinc grade 8	Unseated	Loctite 290
7	Yellow-zinc grade 8	Unseated	Loctite 290
8	Yellow-zinc grade 8	Unseated	Loctite 290
9	Yellow-zinc grade 8	Unseated	Loctite 290
10	Yellow-zinc grade 8	Unseated	Loctite 290
11	Plain grade 8	Unseated	Loctite 222MS
12	Plain grade 8	Unseated	Loctite 222MS
13	Plain grade 8	Unseated	Loctite 222MS
14	Plain grade 8	Unseated	Loctite 222MS
15	Plain grade 8	Unseated	Loctite 222MS
16	Yellow-zinc grade 8	Unseated	Loctite 222MS
17	Yellow-zinc grade 8	Unseated	Loctite 222MS
18	Yellow-zinc grade 8	Unseated	Loctite 222MS
19	Yellow-zinc grade 8	Unseated	Loctite 222MS
20	Yellow-zinc grade 8	Unseated	Loctite 222MS
21	A-286	Unseated	Loctite 222MS
22	A-286	Unseated	Loctite 242
23	A-286	Unseated	Loctite 243
24	A-286	Unseated	Loctite 290
25	Plain grade 8	Unseated	Loctite 242
26	Plain grade 8	Unseated	Loctite 242
27	Plain grade 8	Unseated	Loctite 242
28	Plain grade 8	Unseated	Loctite 242
29	Plain grade 8	Unseated	Loctite 242
30	Yellow-zinc grade 8	Unseated	Loctite 242
31	Yellow-zinc grade 8	Unseated	Loctite 242
32	Yellow-zinc grade 8	Unseated	Loctite 242
33	Yellow-zinc grade 8	Unseated	Loctite 242
34	Yellow-zinc grade 8	Unseated	Loctite 242
35	Plain grade 8	Unseated	Loctite 243
36	Plain grade 8	Unseated	Loctite 243
37	Plain grade 8	Unseated	Loctite 243
38	Plain grade 8	Unseated	Loctite 243

Table 16 (Continued)

Test Number	Fastener Type	Test Type	Adhesive Type
39	Plain grade 8	Unseated	Loctite 243
40	Yellow-zinc grade 8	Unseated	Loctite 243
41	Yellow-zinc grade 8	Unseated	Loctite 243
42	Yellow-zinc grade 8	Unseated	Loctite 243
43	Yellow-zinc grade 8	Unseated	Loctite 243
44	Yellow-zinc grade 8	Unseated	Loctite 243
45	A-286	Unseated	Loctite 222MS
46	A-286	Unseated	Loctite 242
47	A-286	Unseated	Loctite 243
48	Plain grade 8	Unseated	Loctite 222MS
49	Plain grade 8	Unseated	Loctite 222MS
50	Plain grade 8	Unseated	Loctite 222MS
51	Plain grade 8	Unseated	Loctite 222MS
52	Plain grade 8	Unseated	Loctite 222MS
53	Plain grade 8	Unseated	Loctite 242
54	Plain grade 8	Unseated	Loctite 242
55	Plain grade 8	Unseated	Loctite 242
56	Plain grade 8	Unseated	Loctite 242
57	Plain grade 8	Unseated	Loctite 242
58	Plain grade 8	Unseated	Loctite 243
59	Plain grade 8	Unseated	Loctite 243
60	Plain grade 8	Unseated	Loctite 243
61	Plain grade 8	Unseated	Loctite 243
62	Plain grade 8	Unseated	Loctite 243
63	Yellow-zinc grade 8	Unseated	Loctite 222MS
64	Yellow-zinc grade 8	Unseated	Loctite 222MS
65	Yellow-zinc grade 8	Unseated	Loctite 222MS
66	Yellow-zinc grade 8	Unseated	Loctite 222MS
67	Yellow-zinc grade 8	Unseated	Loctite 222MS
68	Yellow-zinc grade 8	Unseated	Loctite 242
69	Yellow-zinc grade 8	Unseated	Loctite 242
70	Yellow-zinc grade 8	Unseated	Loctite 242
71	Yellow-zinc grade 8	Unseated	Loctite 242
72	Yellow-zinc grade 8	Unseated	Loctite 242
73	Yellow-zinc grade 8	Unseated	Loctite 243
74	Yellow-zinc grade 8	Unseated	Loctite 243
75	Yellow-zinc grade 8	Unseated	Loctite 243
76	Yellow-zinc grade 8	Unseated	Loctite 243
77	Yellow-zinc grade 8	Unseated	Loctite 243
78	Plain grade 8	Seated	Loctite 242
79	Plain grade 8	Seated	Loctite 242
80	Plain grade 8	Seated	Loctite 242

Table 16 (Continued)

Test Number	Fastener Type	Test Type	Adhesive Type
81	Plain grade 8	Seated	Loctite 242
82	Plain grade 8	Seated	Loctite 242
83	Plain grade 8	Seated	Loctite 243
84	Plain grade 8	Seated	Loctite 243
85	Plain grade 8	Seated	Loctite 243
86	Plain grade 8	Seated	Loctite 243
87	Plain grade 8	Seated	Loctite 243
88	Plain grade 8	Seated	Loctite 222MS
89	Plain grade 8	Seated	Loctite 222MS
90	Plain grade 8	Seated	Loctite 222MS
91	Plain grade 8	Seated	Loctite 222MS
92	Plain grade 8	Seated	Loctite 222MS
93	A-286	Unseated	Loctite 222MS
94	A-286	Unseated	Loctite 222MS
95	A-286	Unseated	Loctite 222MS
96	A-286	Unseated	Loctite 222MS
97	A-286	Unseated	Loctite 222MS
98	A-286	Unseated	Loctite 222MS
99	A-286	Unseated	Loctite 222MS
100	A-286	Unseated	Loctite 222MS
101	A-286	Unseated	Loctite 242
102	A-286	Unseated	Loctite 242
103	A-286	Unseated	Loctite 242
104	A-286	Unseated	Loctite 242
105	A-286	Unseated	Loctite 242
106	A-286	Unseated	Loctite 242
107	A-286	Unseated	Loctite 242
108	A-286	Unseated	Loctite 242
109	A-286	Unseated	Loctite 243
110	A-286	Unseated	Loctite 243
111	A-286	Unseated	Loctite 243
112	A-286	Unseated	Loctite 243
113	A-286	Unseated	Loctite 243
114	A-286	Unseated	Loctite 243
115	A-286	Unseated	Loctite 243
116	A-286	Unseated	Loctite 243
117	Plain grade 8	Seated	Loctite 222MS
118	Plain grade 8	Seated	Loctite 222MS
119	Plain grade 8	Seated	Loctite 222MS
120	Plain grade 8	Seated	Loctite 222MS
121	Plain grade 8	Seated	Loctite 222MS
122	Plain grade 8	Seated	Loctite 242

Table 16 (Continued)

Test Number	Fastener Type	Test Type	Adhesive Type
123	Plain grade 8	Seated	Loctite 242
124	Plain grade 8	Seated	Loctite 242
125	Plain grade 8	Seated	Loctite 242
126	Plain grade 8	Seated	Loctite 242
127	Plain grade 8	Seated	Loctite 243
128	Plain grade 8	Seated	Loctite 243
129	Plain grade 8	Seated	Loctite 243
130	Plain grade 8	Seated	Loctite 243
131	Plain grade 8	Seated	Loctite 243
132	A-286	Seated	Loctite 222MS
133	A-286	Seated	Loctite 222MS
134	A-286	Seated	Loctite 222MS
135	A-286	Seated	Loctite 222MS
136	A-286	Seated	Loctite 222MS
137	A-286	Seated	Loctite 242
138	A-286	Seated	Loctite 242
139	A-286	Seated	Loctite 242
140	A-286	Seated	Loctite 242
141	A-286	Seated	Loctite 242
142	A-286	Seated	Loctite 243
143	A-286	Seated	Loctite 243
144	A-286	Seated	Loctite 243
145	A-286	Seated	Loctite 243
146	A-286	Seated	Loctite 243
147	A-286	Seated	Loctite 222MS
148	A-286	Seated	Loctite 222MS
149	A-286	Seated	Loctite 222MS
150	A-286	Seated	Loctite 222MS
151	A-286	Seated	Loctite 222MS
152	A-286	Seated	Loctite 242
153	A-286	Seated	Loctite 242
154	A-286	Seated	Loctite 242
155	A-286	Seated	Loctite 242
156	A-286	Seated	Loctite 242
157	A-286	Seated	Loctite 243
158	A-286	Seated	Loctite 243
159	A-286	Seated	Loctite 243
160	A-286	Seated	Loctite 243
161	A-286	Seated	Loctite 243
162	Yellow-zinc grade 8	Seated	Loctite 222MS
163	Yellow-zinc grade 8	Seated	Loctite 222MS
164	Yellow-zinc grade 8	Seated	Loctite 222MS

Table 16 (Continued)

Test Number	Fastener Type	Test Type	Adhesive Type
165	Yellow-zinc grade 8	Seated	Loctite 222MS
166	Yellow-zinc grade 8	Seated	Loctite 222MS
167	Yellow-zinc grade 8	Seated	Loctite 242
168	Yellow-zinc grade 8	Seated	Loctite 242
169	Yellow-zinc grade 8	Seated	Loctite 242
170	Yellow-zinc grade 8	Seated	Loctite 242
171	Yellow-zinc grade 8	Seated	Loctite 242
172	Yellow-zinc grade 8	Seated	Loctite 243
173	Yellow-zinc grade 8	Seated	Loctite 243
174	Yellow-zinc grade 8	Seated	Loctite 243
175	Yellow-zinc grade 8	Seated	Loctite 243
176	Yellow-zinc grade 8	Seated	Loctite 243
177	Yellow-zinc grade 8	Seated	Loctite 222MS
178	Yellow-zinc grade 8	Seated	Loctite 222MS
179	Yellow-zinc grade 8	Seated	Loctite 222MS
180	Yellow-zinc grade 8	Seated	Loctite 222MS
181	Yellow-zinc grade 8	Seated	Loctite 222MS
182	Yellow-zinc grade 8	Seated	Loctite 242
183	Yellow-zinc grade 8	Seated	Loctite 242
184	Yellow-zinc grade 8	Seated	Loctite 242
185	Yellow-zinc grade 8	Seated	Loctite 242
186	Yellow-zinc grade 8	Seated	Loctite 242
187	Yellow-zinc grade 8	Seated	Loctite 243
188	Yellow-zinc grade 8	Seated	Loctite 243
189	Yellow-zinc grade 8	Seated	Loctite 243
190	Yellow-zinc grade 8	Seated	Loctite 243
191	Yellow-zinc grade 8	Seated	Loctite 243

CHAPTER 3: RESULTS

The results presented in this chapter show the measured removal torques at the various removal angles in degrees. Testing was performed on different combinations of threaded fastener material, anaerobic adhesive, and loading configurations as defined in Chapter 2. This was done to understand how the anaerobic adhesive behaves with that fastener and test material conditions.

The plots are organized with the removal angle on the horizontal axis and the removal torque on the vertical axis. The acceptable range of prevailing torque for ¼ -28 thread size is 3.5-30 in-lbs. per specifications [5-10]. At the limits of acceptable prevailing torque, horizontal dashed lines are plotted in all test result figures.

During the acquisition of the data with the 0-75 in-lbs. torque wrench, if the dial on the torque wrench is between increments it is rounded to the nearest integer. Rounding eliminates trying to find the exact number while constantly rotating the torque wrench during removal. The only time this was not applied was if the increment was between 3 and 4 in-lbs. If the dial is at 3.5 in-lbs. it was rounded down to 3 in-lbs. for the reason that the calibration value is off by .05 in-lbs. This is not implemented for the 0-250 in-lbs. due to the fact that the scale accuracy is 5 in-lbs. between each increment and the values measured using this torque wrench are usually in the hundreds.

The values shown in the graphs were recorded at the instant that the torque wrench has reached that point relative to the starting point. This means that if a maximum value occurred between two measured angles and the value changed before reaching the next measured angle it will not be represented in the plots. While measuring a test specimen however, the maximum removal torque values are recorded. What is true for most cases was that either the maximum removal torque is represented at a measured angle or that highest removal torque value is under the maximum removal torque at a measured angle by no more than 2 in-lb.

3.1 Results for Unseated State

This section presents 27 removal torque vs. removal angle plots for the unseated tests. Each plot includes data from 5 to 10 test fasteners. Note that many data points overlap such that the number of test measurements appears lower than 5 or 10

3.1.1 Unseated Plain Grade 8

Nine plots are generated for unseated plain grade 8 configuration. These plots include initial removal, reuse of the threaded fastener without adding additional anaerobic adhesive, and reuse with adding additional anaerobic adhesive for the three different types of Loctite. Remember a plain threaded fastener is one that is not coated and is received as manufactured. As received indicates that the fasteners are received with residual oil which is removed in the cleaning process.

3.1.1.1 Unseated Plain Grade 8 Loctite 222MS

All the removal torque measurements were within the specification of 3.5 to 30 in-lbs. for the plain grade 8 coated with low strength Loctite 222MS as shown in Figure 8.

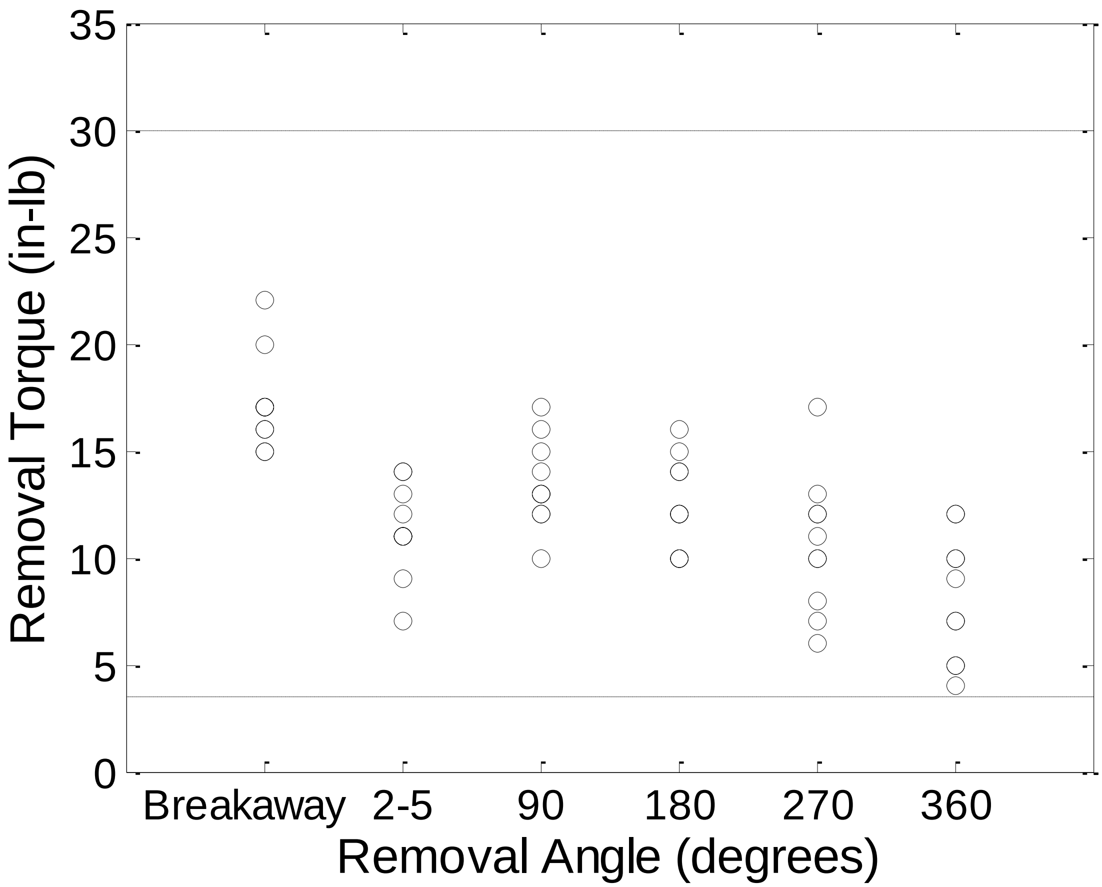

Figure 8 Initial unseated plain grade 8 Loctite 222MS.

When reusing the plain grade 8 threaded fasteners with Loctite 222MS most of the test specimens failed after 270 degrees as shown in Figure 9. One of the test specimens (#12) failed from the start of the experiment. Another test specimen (#14) failed after breakaway and two test specimens (#15&#48) failed at 90, 180, 270, and 360 degrees.

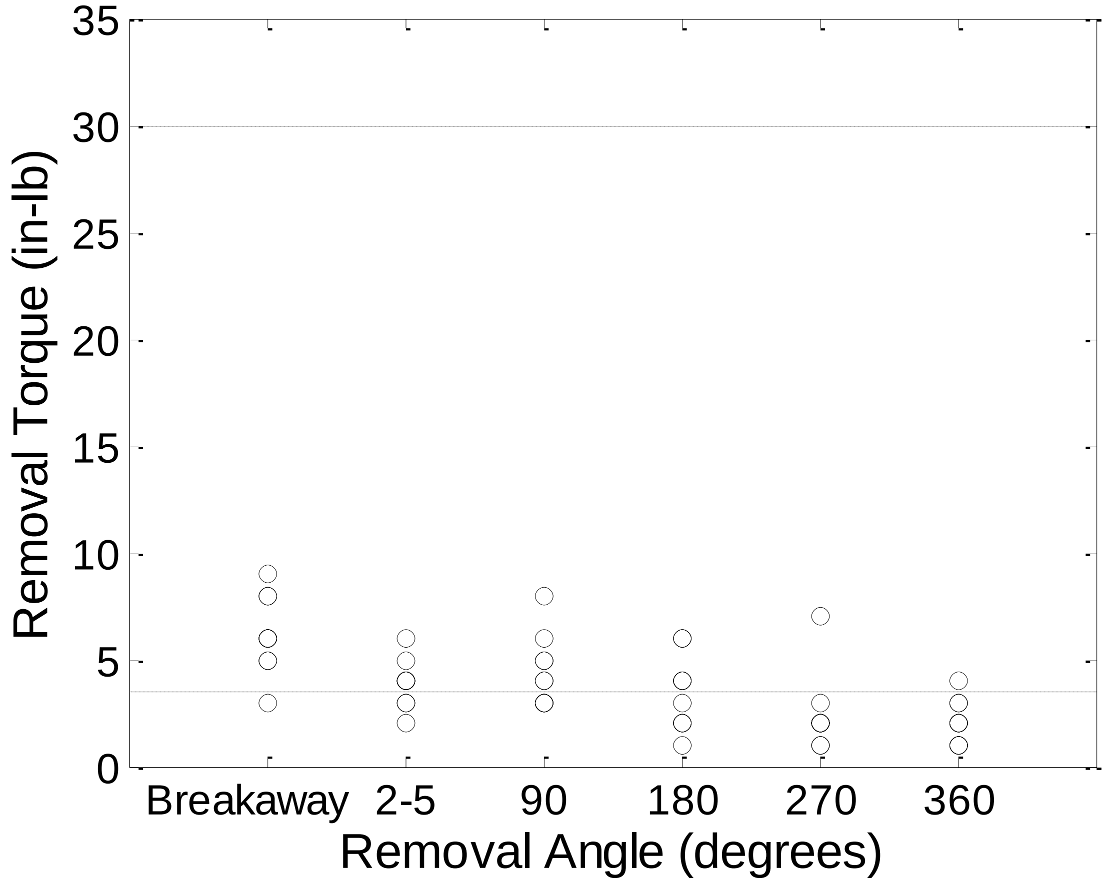

Figure 9 Unseated plain grade 8 Loctite 222MS reuse.

Only five threaded fasteners were tested for the reuse adding anaerobic adhesive. One fastener specimen (#51) failed as illustrated in Figure 10. The specimen failed at 270 and 360 degrees. The rest of the threaded fasteners had a tight spread initially when widening after 180 degrees. Initially, for some threaded fasteners, there were low values of removal torque and then values increased progressively. The most probable cause for the values to increase is as the hex nut was being loosened the anaerobic adhesive binds up in the threads increasing the friction.

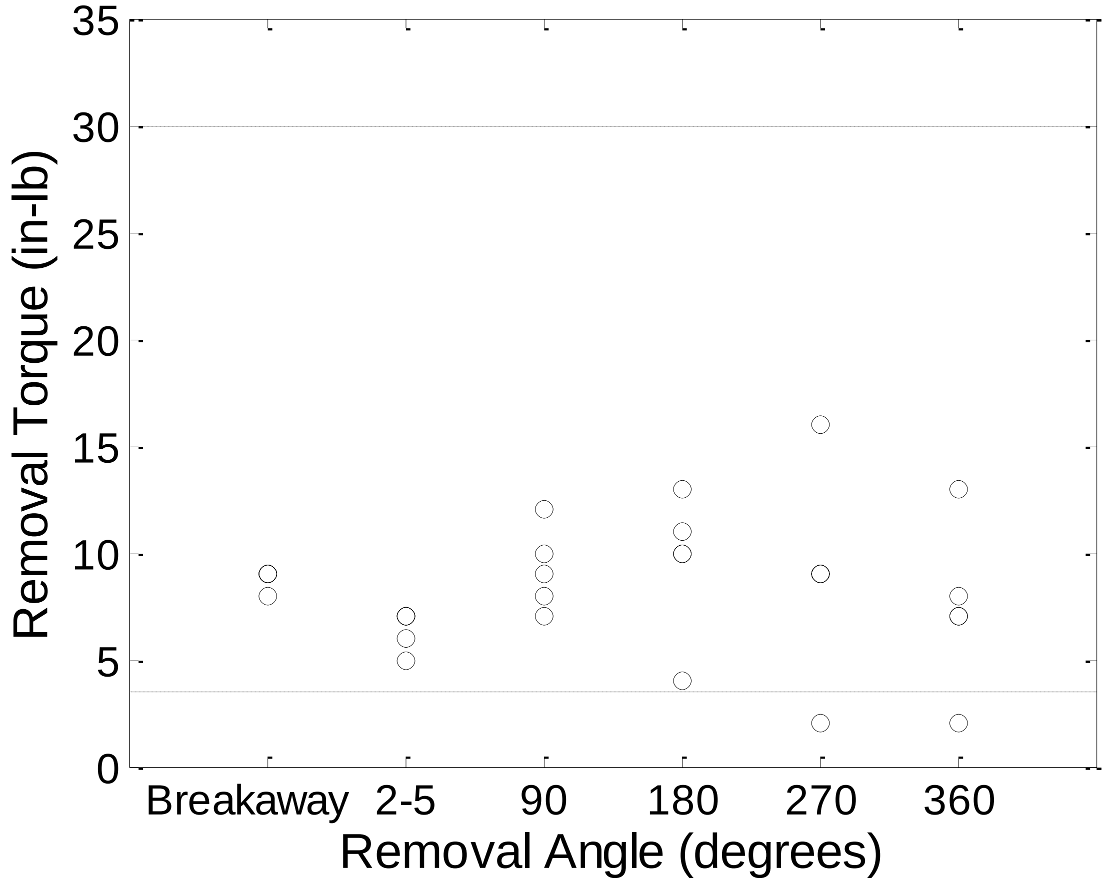

Figure 10 Unseated plain grade 8 Loctite 222MS reuse adding anaerobic adhesive.

3.1.1.2 Unseated Plain Grade 8 Loctite 242

For this testing configuration Loctite 242 is used. Loctite 242 is a medium strength anaerobic adhesive.

Only one test specimen (#51) failed during this configuration which is shown in Figure 11. The specimen exceeded the upper bound of 30 in-lbs. at 90. 180, 270, and 360 degrees. The reasoning for this is that the adhesive became bound up in the threads causing a higher friction force.

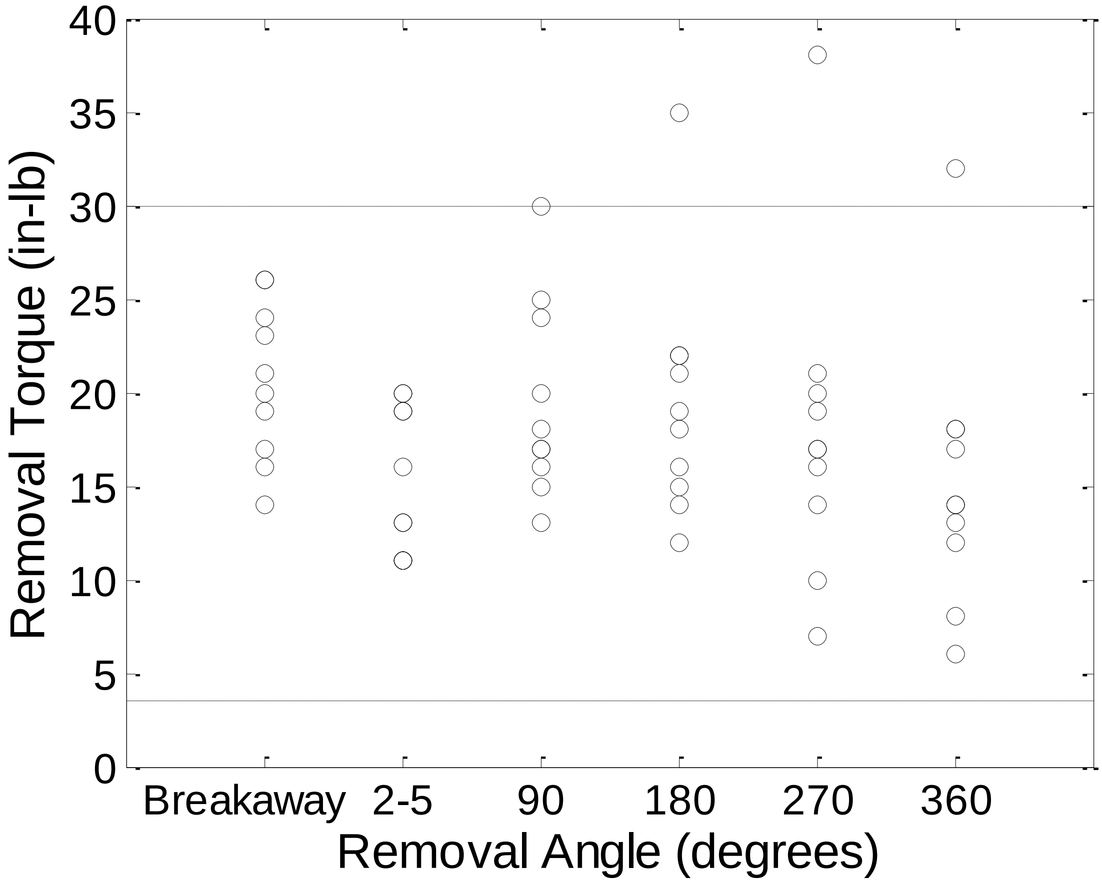

Figure 11 Initial unseated plain grade 8 Loctite 242

Shown in Figure 12, two test specimens did not have a removal torque in the specified range during the experiment (#54&56). One specimen (#54) failed to be within specification at 90, 180, 270, and 360 degrees. A specimen showed (#56) zero removal torque which from a visual inspection there was no anaerobic adhesive on the threads of the cap screw.

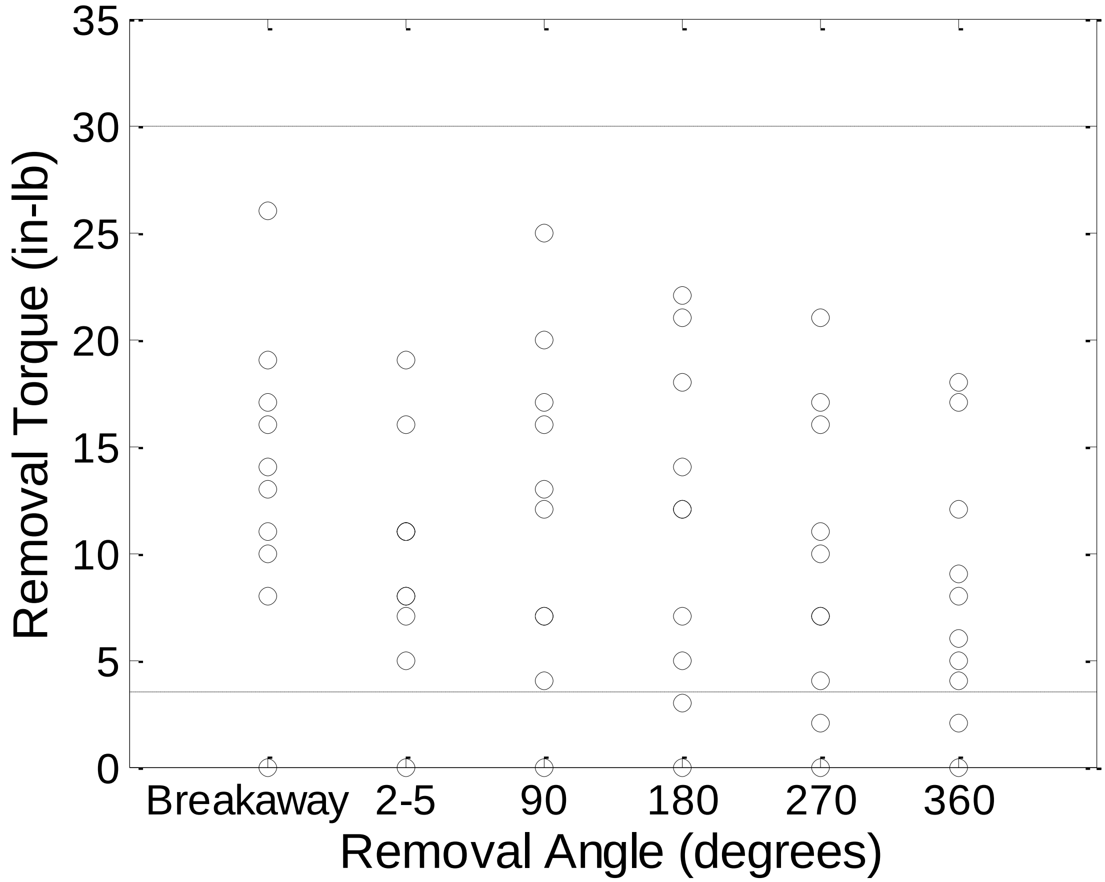

Figure 12 Unseated plain grade 8 Loctite 242 reuse.

As shown in Figure 13, a specimen (#55) failed by exceeding the upper limit of removal torque at 270 degrees. However the same specimen dropped back down to tolerance at 360 degrees. What seemed to happen is that the cured anaerobic adhesive broke down and built up in the threads during the loosening of the hex nut. Once the removal angle was passed 270 degrees the buildup stayed on the cap screw freeing up the hex nut.

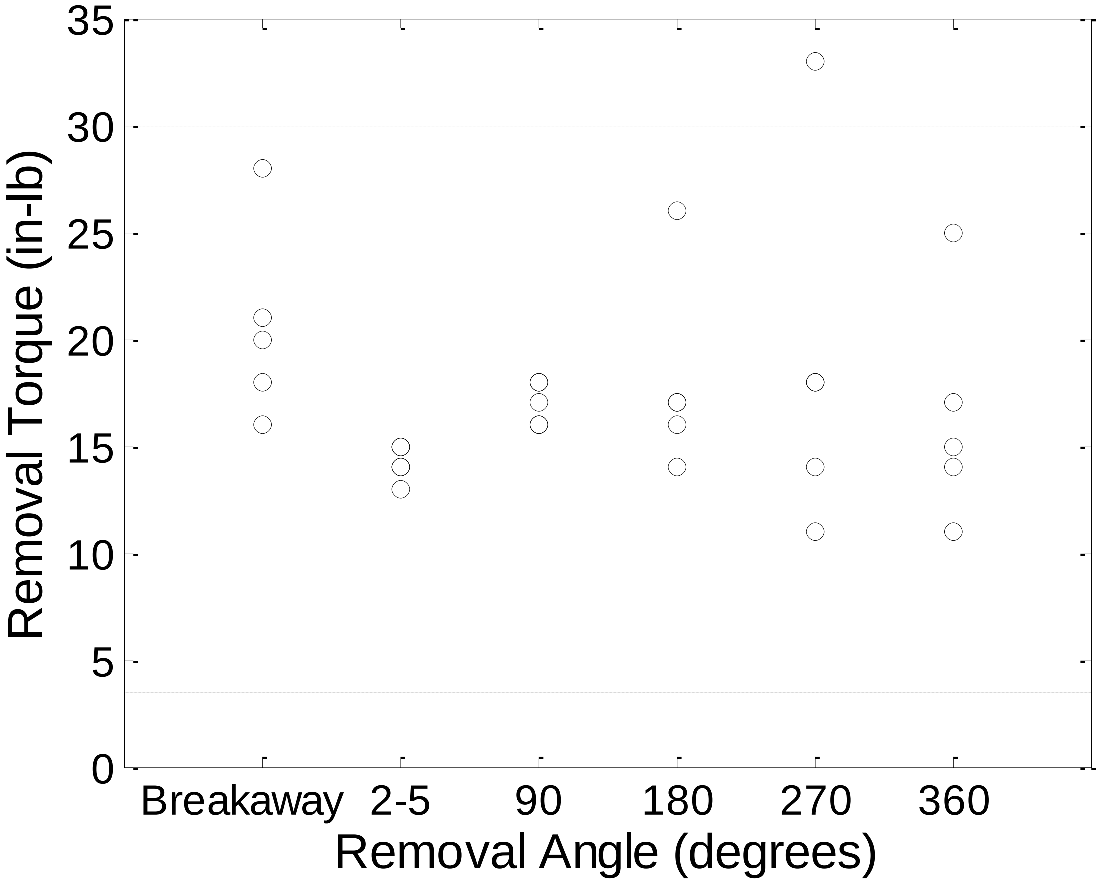

Figure 13 Unseated plain grade 8 Loctite 242 reuse adding anaerobic adhesive.

3.1.1.3 Unseated Plain Grade 8 Loctite 243

Similar to the previous test configuration, a medium strength anaerobic adhesive is coated on the threaded fasteners. The difference is Loctite 243 primer less anaerobic adhesive. It has the capabilities of curing on inactive metals. Also Loctite 243 is designed to be used in high temperatures and is oil tolerant.

Almost all the specimen exceeded the 30 in-lbs. limit at breakaway as shown in Figure 14. At 2-5, 90, 180, 270, and 360 degrees all the test specimens were within tolerance.

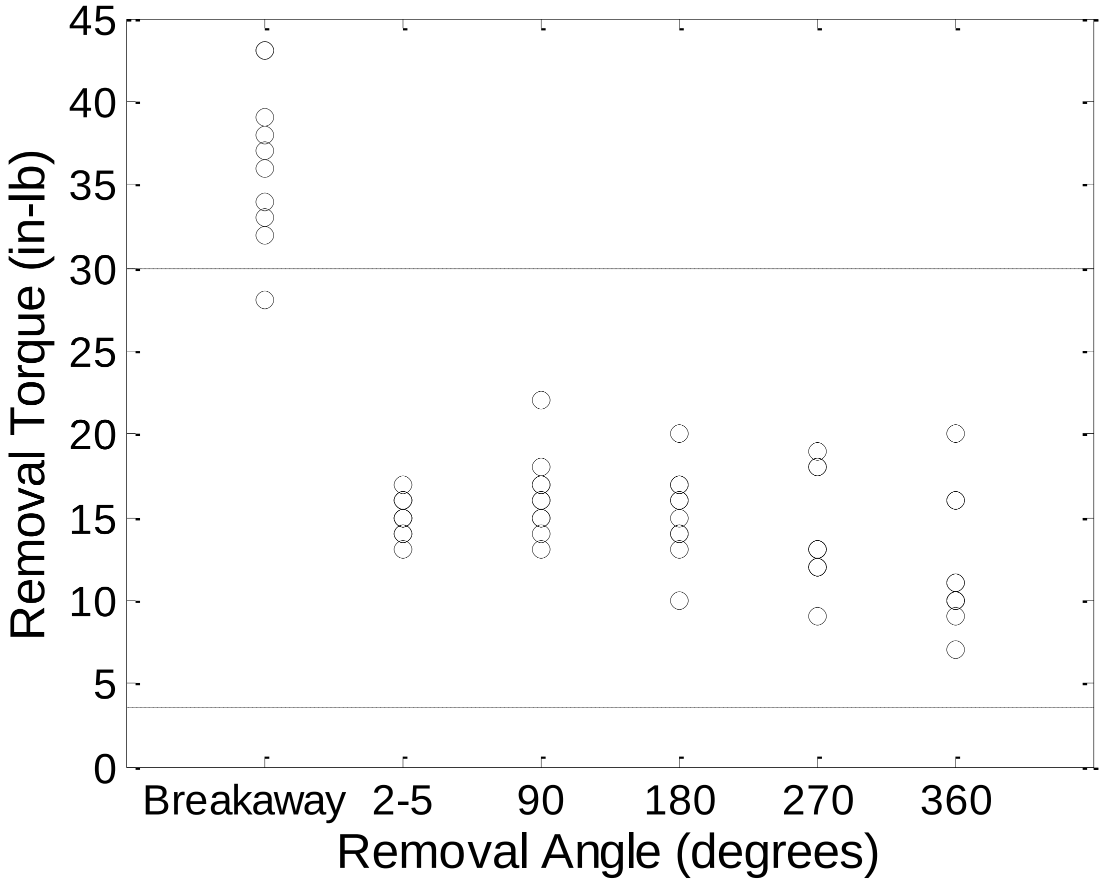

Figure 14 Initial unseated plain grade 8 Loctite 243.

As demonstrated in Figure 15 most of the test specimens failed after breakaway. This was due to the fact that when the hex nut is being removed from the cap screw the cured anaerobic adhesive flakes off as small particles leaving no residue on the threads.

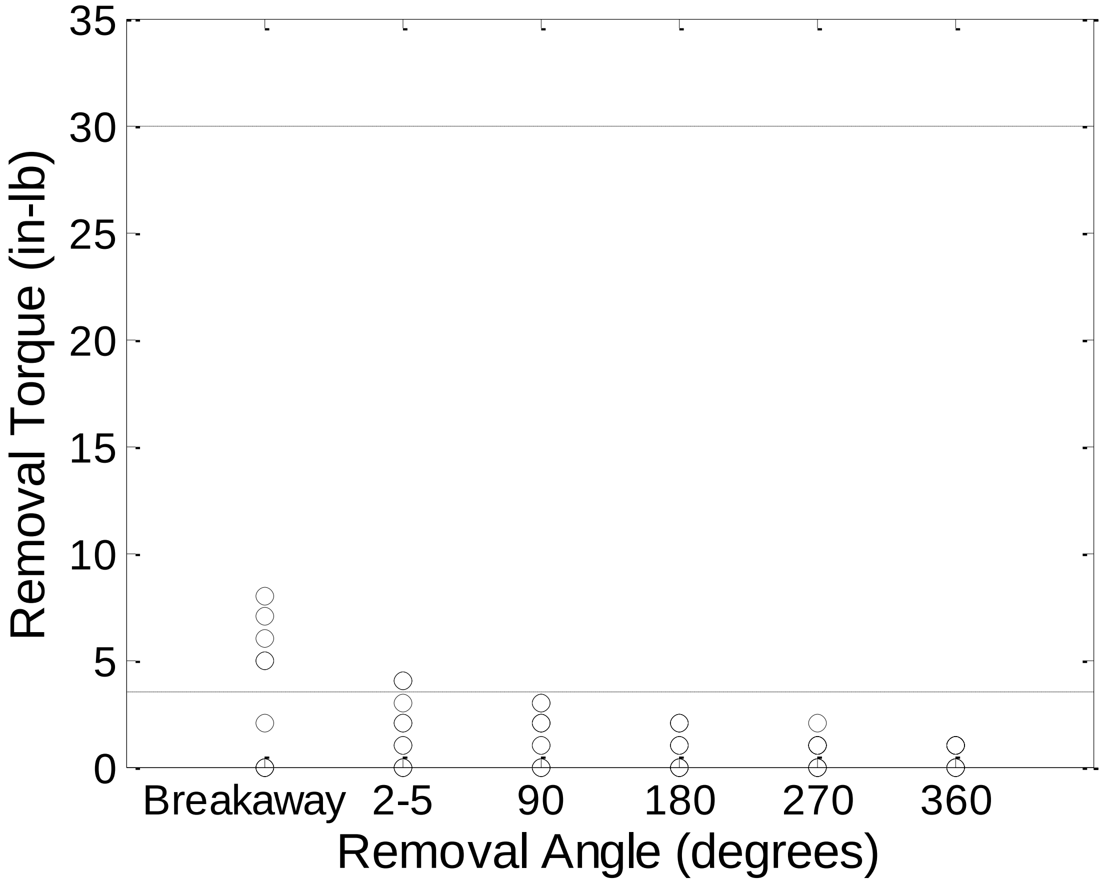

Figure 15 Unseated plain grade 8 Loctite 243 reuse.

When additional Loctite 243 is applied to the threads of the cap screw and hex nut, the results differ as shown in Figure 16. All of the threaded fasteners were within the specification of 3.5 to 30 in-lbs. At breakaway, 2-5, and 180 degrees the range of the data was very close with the majority of the data point overlaying each other.

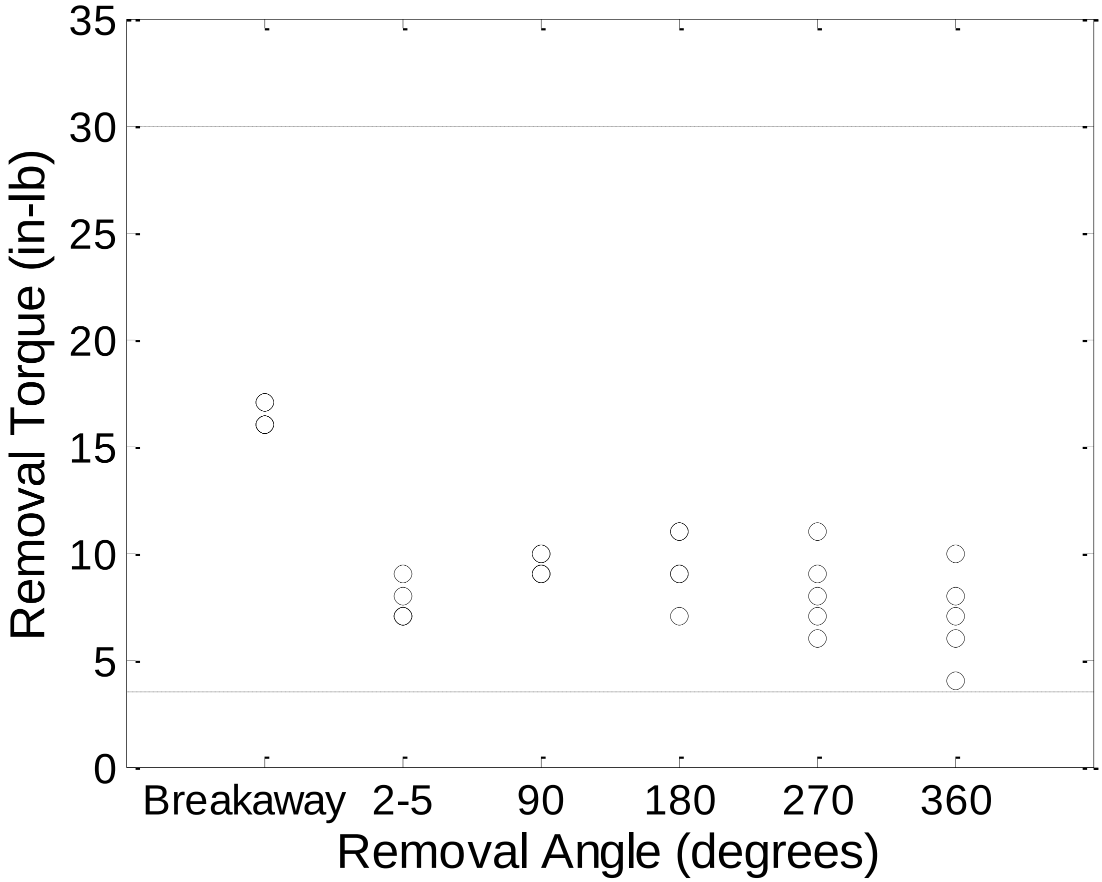

Figure 16 Unseated plain grade 8 Loctite 243 reuse adding anaerobic adhesive.

3.1.2 Unseated Yellow-Zinc Grade 8

This section contains 9 plots for yellow-zinc grade 8 threaded fasteners. These plots include initial removal, reuse of the threaded fastener without adding additional anaerobic adhesive, and reuse with adding additional anaerobic adhesive for the three different types of Loctite.

Yellow-zinc plating is the most common type of plating on threaded fasteners. The purpose of plating a threaded fastener is to increase corrosion resistance.

3.1.2.1 Unseated Yellow-Zinc Grade 8 Loctite 222MS

Loctite 222MS is a low strength anaerobic adhesive.

In Figure 17 a test specimen (#16) that failed needs to be ignored for the reason that it was an operator error. The torque wrench was not zeroed causing the data points to be shifted down. The results of the specimen were left to illustrate that it still followed the same pattern as the other test specimens.

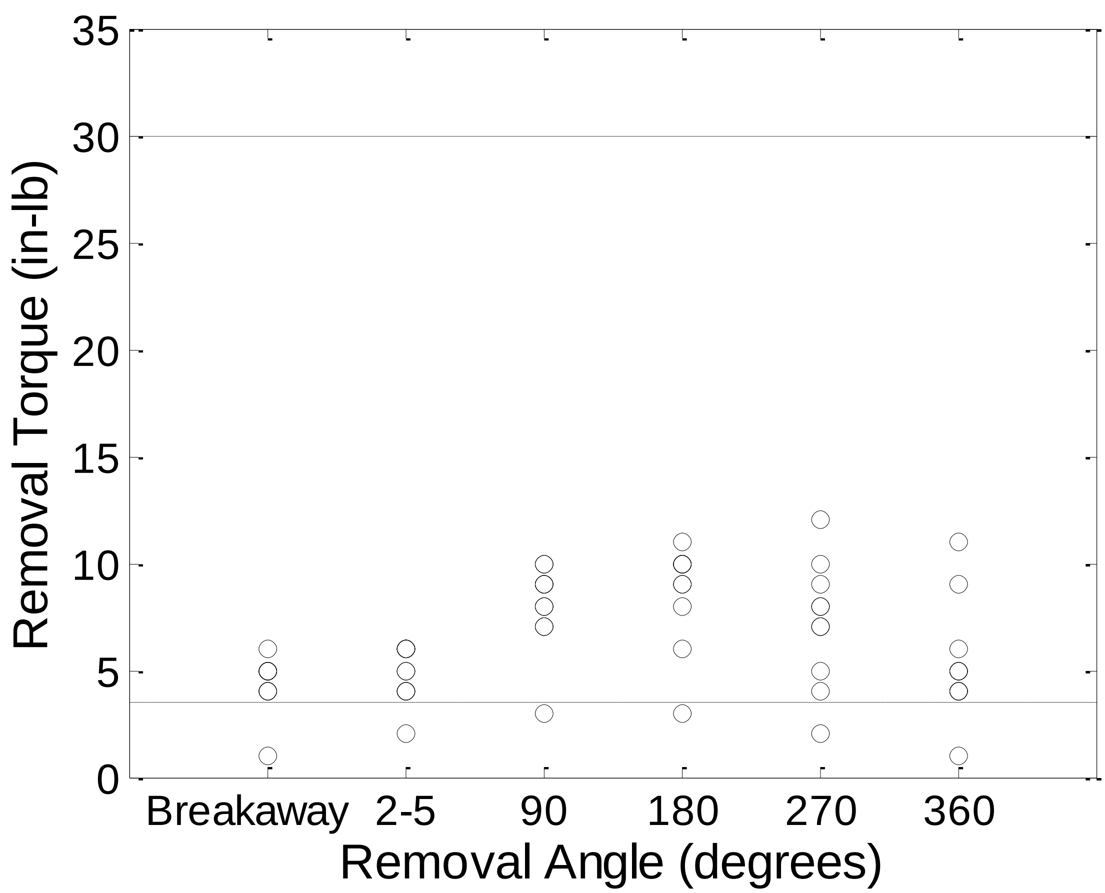

Figure 17 Initial unseated yellow-zinc grade 8 Loctite 222MS.

Only one test specimen (#66) passed as shown in Figure 18. The same behavior was experienced here as in the reuse of plain grade threaded fasteners.

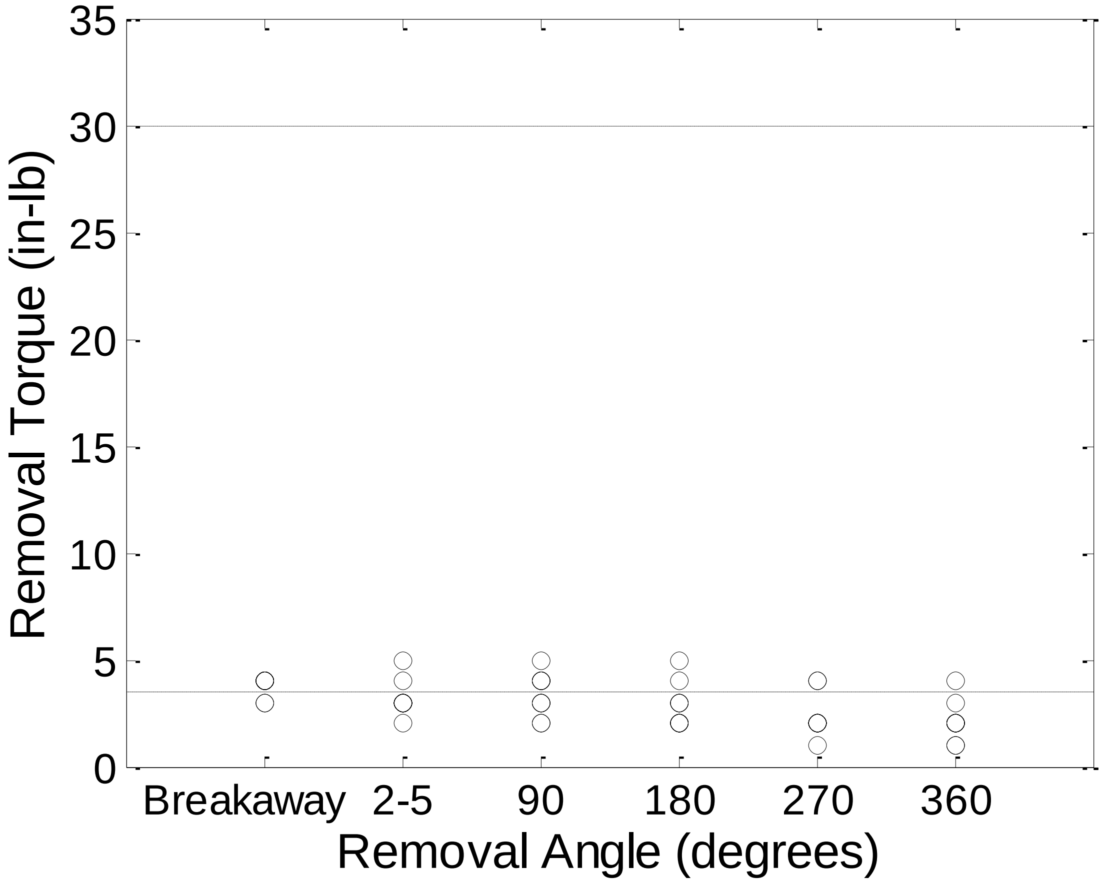

Figure 18 Unseated yellow-zinc grade 8 Loctite 222MS reuse.

As shown in Figure 19 one threaded fastener failed at 360 degrees. Even though a failure did occur the specimen was within specification through more than ¾ of the removal angle.

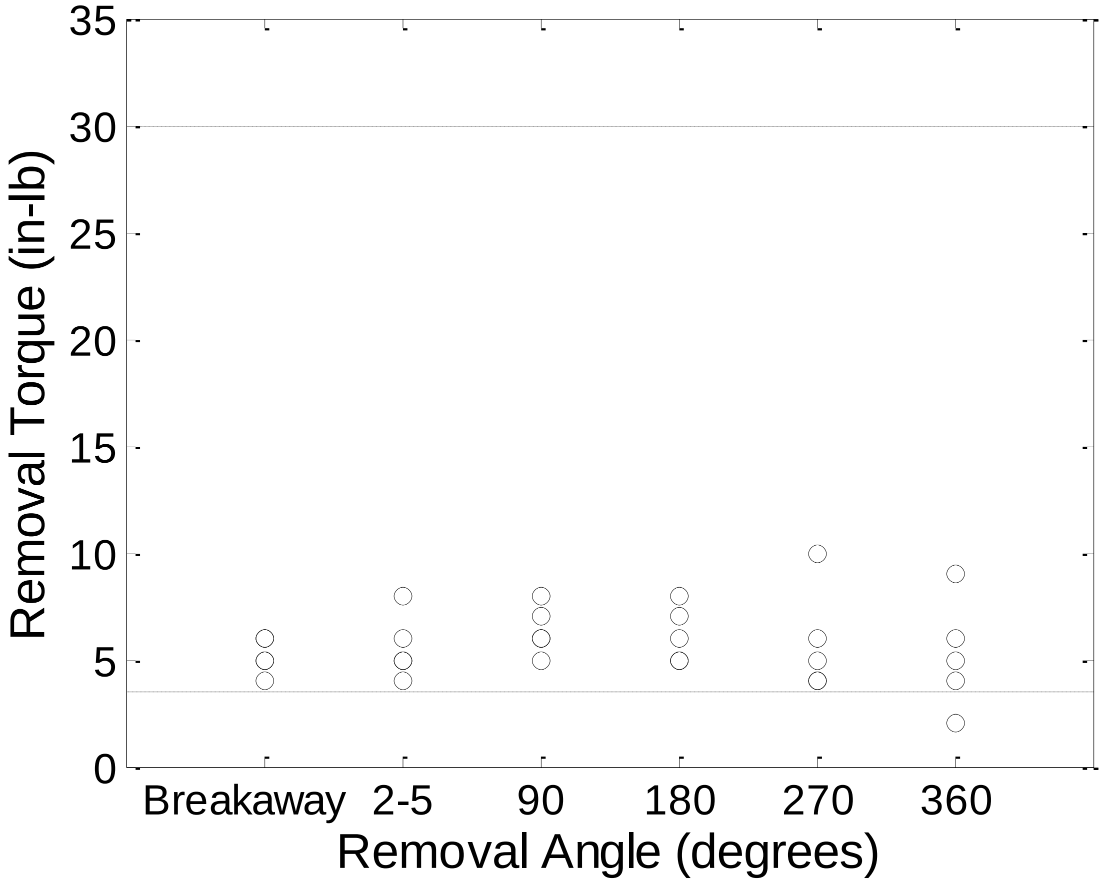

Figure 19 Unseated yellow-zinc grade 8 Loctite 222MS reuse adding anaerobic adhesive.

3.1.2.2 Unseated Yellow-Zinc Grade 8 Loctite 242

The anaerobic adhesive used for this configuration is a medium strength anaerobic adhesive.

All of the threaded fasteners were within tolerance for this test configuration as shown in Figure 20. Note how there is an increase in the removal torque at 90 degrees and 180 degrees and a decay after that measured angle.

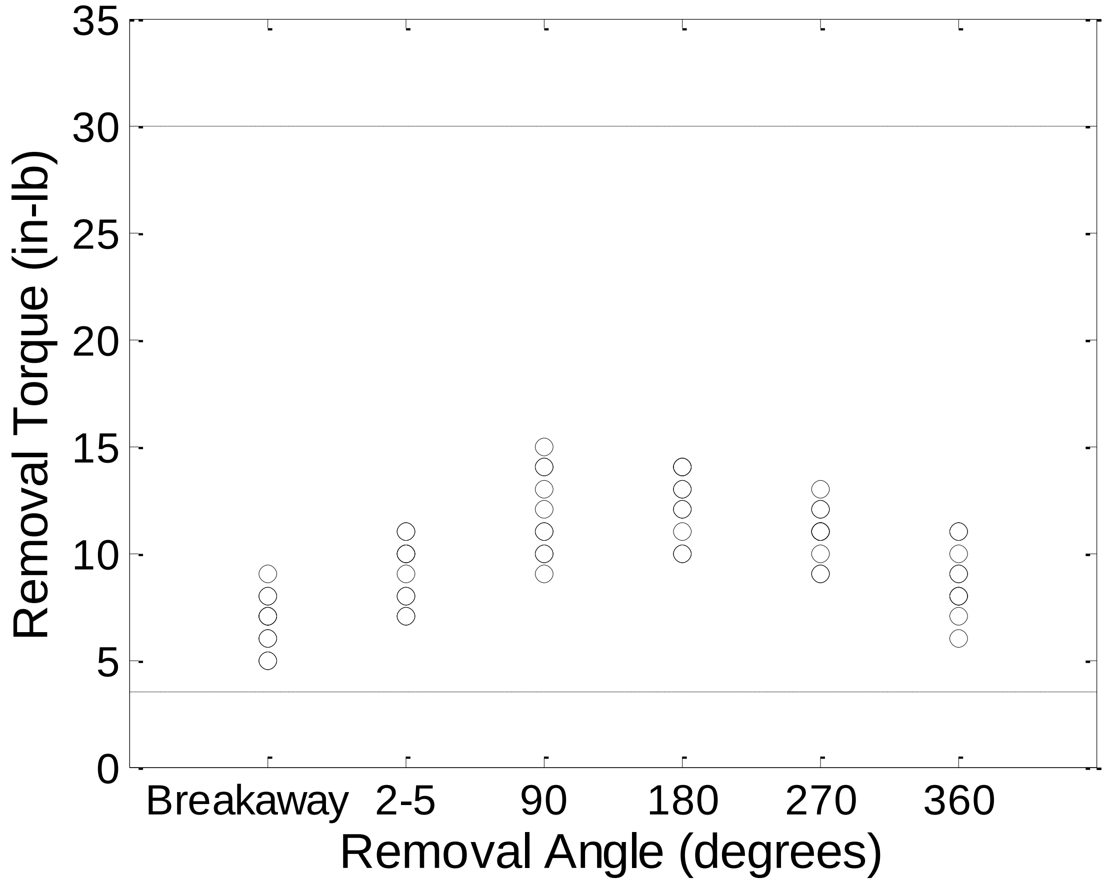

Figure 20 Initial unseated yellow-zinc grade 8 Loctite 242.

Three test specimens (#30, 34, and 68) were the only ones to pass as shown in Figure 21. Majority of the specimens started to fail at 180 degrees. This seems to be a common behavior for the reuse of anaerobic adhesive. This happens because the anaerobic adhesive is degraded when the hex nut was completely removed from the cap screw.

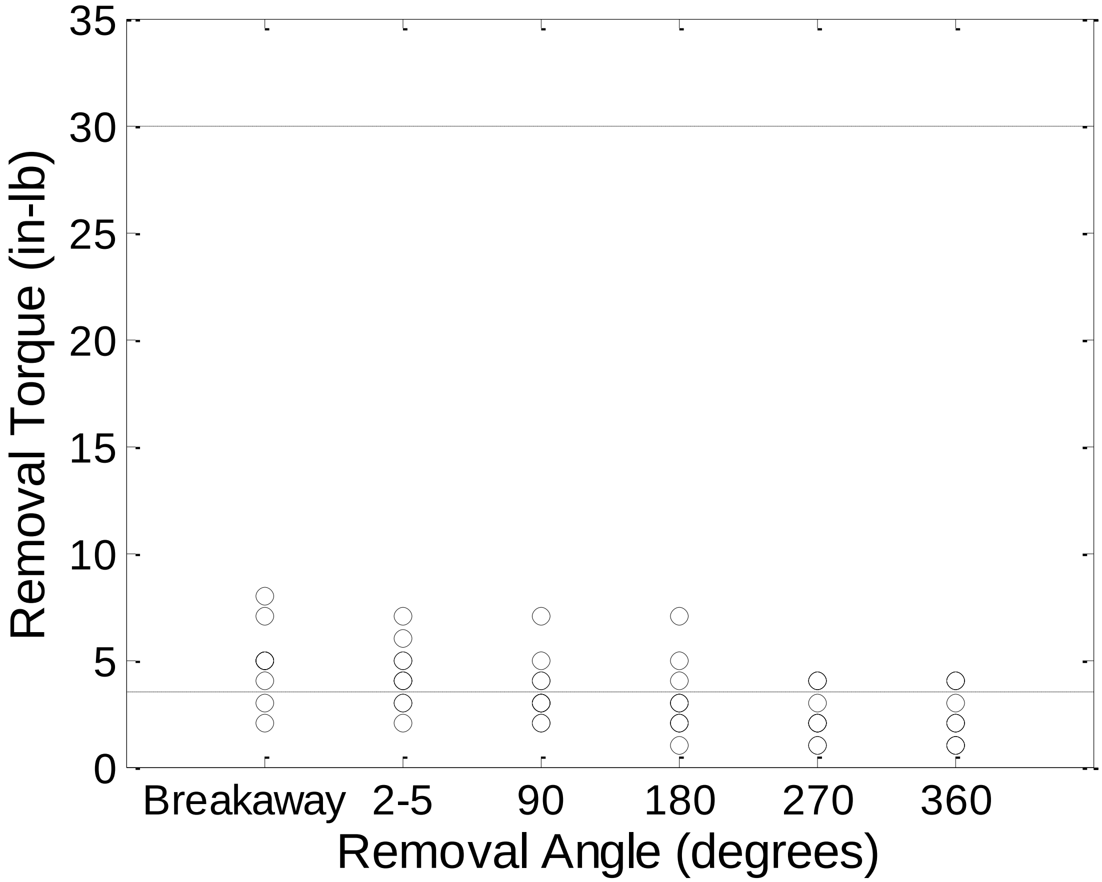

Figure 21 Unseated yellow-zinc grade 8 Loctite 242 reuse.

All of the test specimens meet the specification for prevailing torque in Figure 22. At the breakaway removal angle the spread in the data is very close and it widens as the hex nut is moved throughout the removal angles.

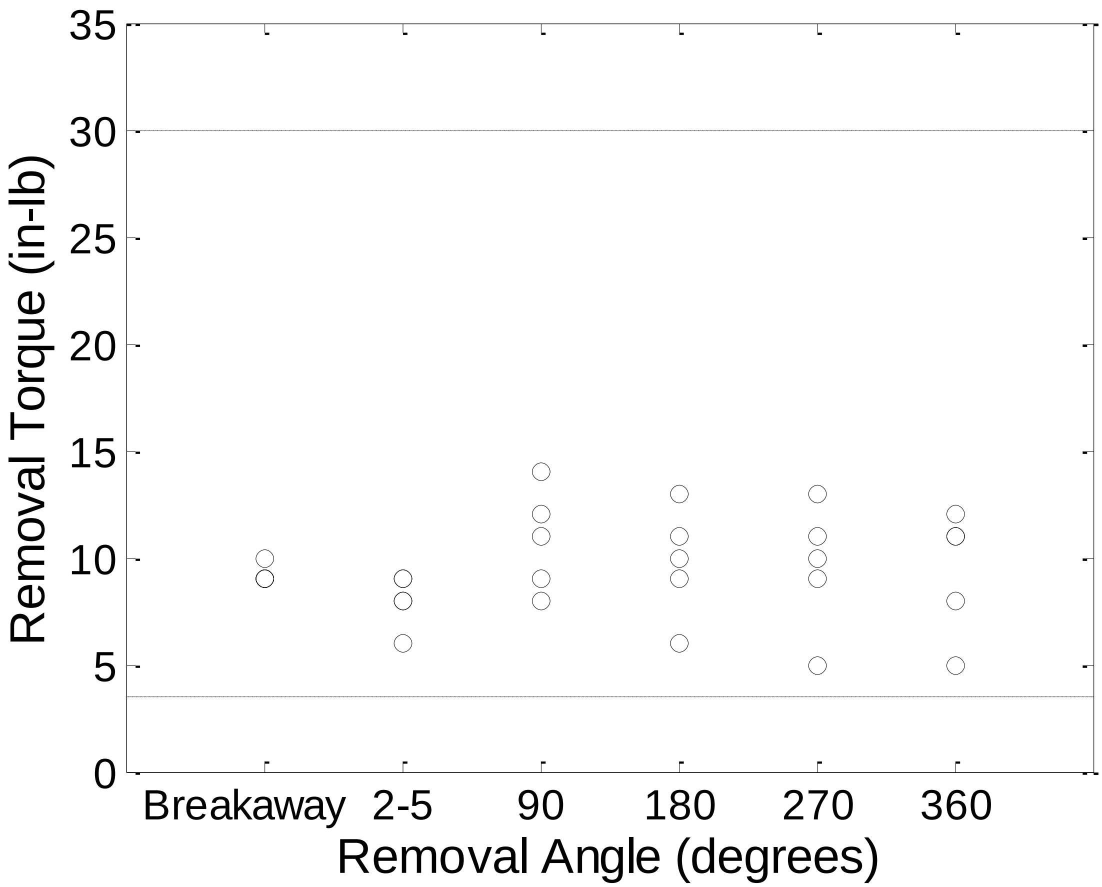

Figure 22 Unseated yellow-zinc grade 8 Loctite 242 reuse adding anaerobic adhesive.

3.1.2.3 Unseated Yellow-Zinc Grade 8 Loctite 243

Loctite 243 is a medium strength anaerobic adhesive that does not require a primer if used with an inactive metal.

All of the test specimens passed the requirement of 3.5 to 30 in-lbs. as shown in Figure 23. At the breakaway removal angle, the removal torque was much higher than the rest of the data at the different removal angles

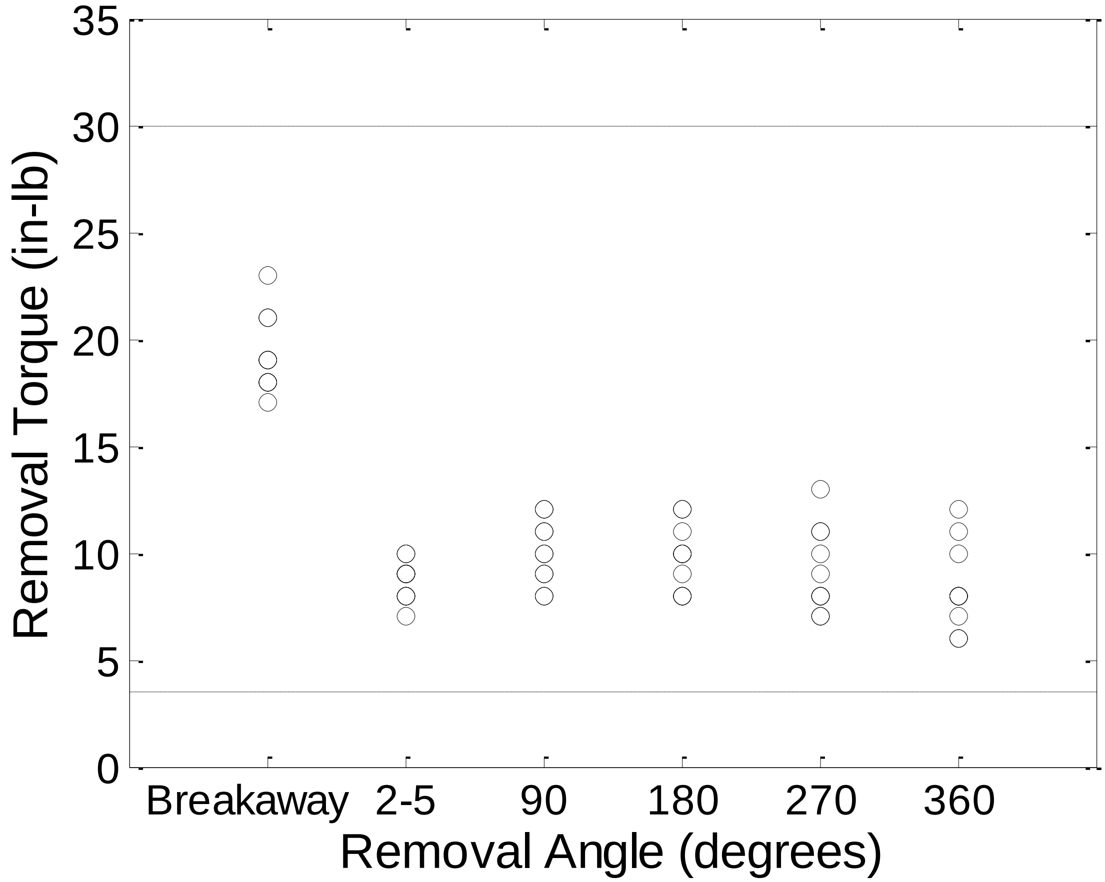

Figure 23 Initial unseated yellow-zinc grade 8 Loctite 243.

All the specimens failed as shown in Figure 24. Like before, the cured anaerobic adhesive flakes off during the removal of the hex nut leaving the threads bare.

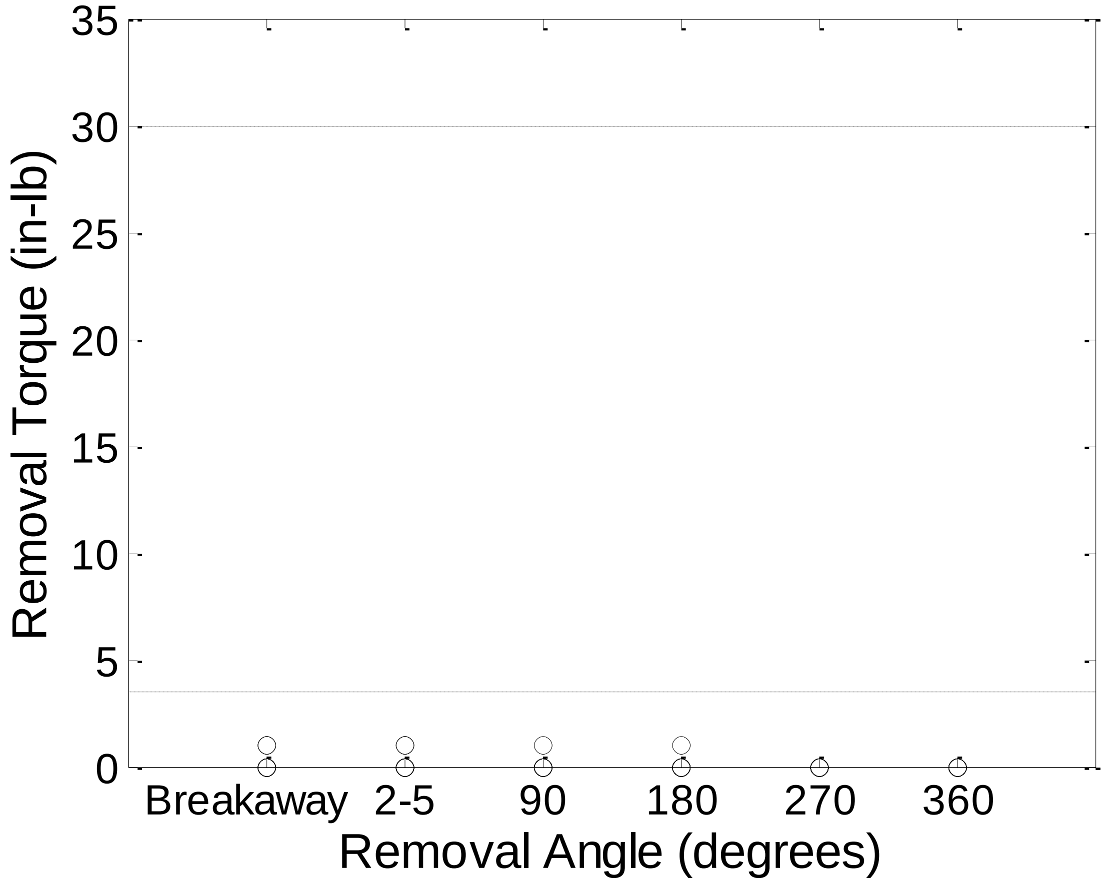

Figure 24 Unseated yellow-zinc grade 8 Loctite 243 reuse.

All specimens were within tolerance for this configuration shown in Figure 25. The same higher removal torque is displayed at the breakaway removal angle. The spread of the data is tight for 2/3 of the data and widens at 270 degrees and 360 degrees.

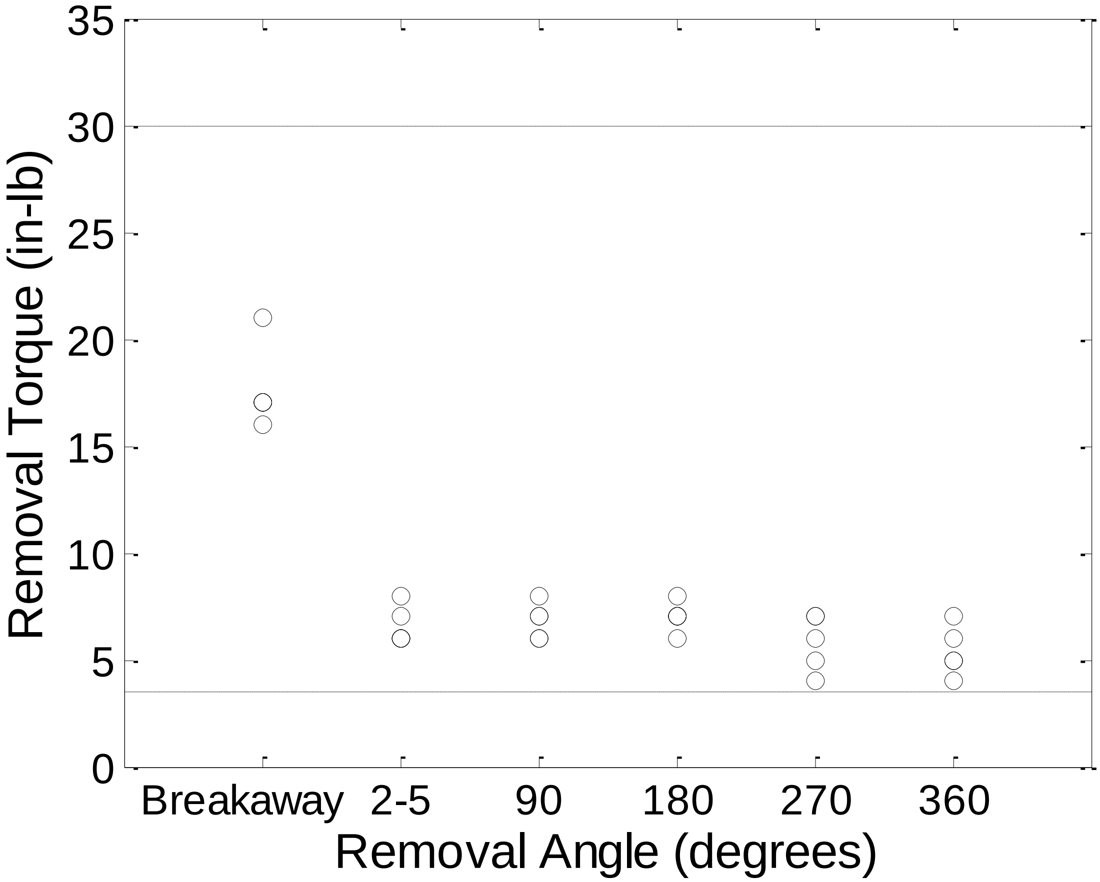

Figure 25 Unseated yellow-zinc grade 8 Loctite 243 reuse adding anaerobic adhesive.

3.1.3 Unseated A-286

A-286 is an inactive metal used in many aerospace threaded fasteners. Anaerobic adhesives have trouble curing with inactive metals unless a primer/activator is used. The finish on the A-286 threaded fasteners tested is a passivate finish.

For unseated A-286, 9 plots were generated. These plots include initial removal, reuse of the threaded fastener without adding additional anaerobic adhesive, and reuse with adding additional anaerobic adhesive for the three different types of Loctite.

3.1.3.1 Unseated A-286 Loctite 222MS

The anaerobic adhesive with the A-286 did not cure resulting in what is shown in Figure 26. In the technical data sheet for Loctite 222MS it recommends the use of an activator when applying the anaerobic adhesive to an inactive metal to promote curing [13].

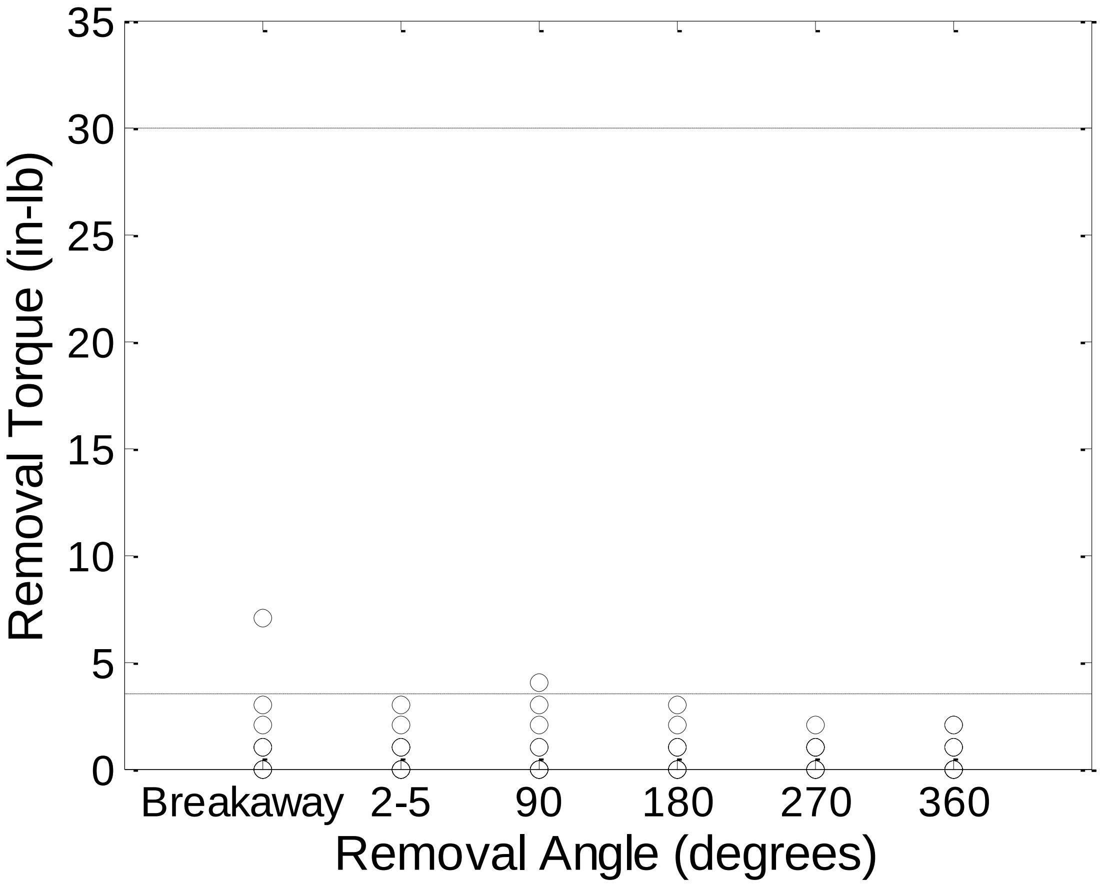

Figure 26 Initial unseated A-286 Loctite 222MS.

A surprising turn of events occurred when reusing the A-286 threaded fasteners without adding any additional anaerobic adhesive as shown in figure 27. Two specimens (#96, 99) showed a value of zero for prevailing torque. Another specimen (#93) failed at 2-5, 90, 180, 270, and 360 degrees. One specimen (#100) failed at 360 degrees.

A possible explanation for why some curing occurred with the reuse of A-286 without adding anaerobic adhesive is, Loctite anaerobic adhesive works by forming polymer chains that attach to imperfections in the metal [2]. A passivate finish, which is found on the A-286 fasteners tested, creates an oxide film that is very uniform and smooth [16]. The smooth surface finish affects the curing of the anaerobic adhesive making it difficult for the polymer chains to attach to the surface. Also since oxygen is absorbed by the surface of the A-286 during passivation, there is still oxygen present when the hex nut was fastened to the cap screw even though the air voids between the threads are removed by the anaerobic adhesive. This explains why in the initial test minimal curing of the specimen's occurred. When fasteners were then set up for the reuse, a film of anaerobic adhesive is coated on the threads of the cap screw and hex nut causing the anaerobic adhesive to form the polymer chains between the films of itself allowing for some curing to occur.

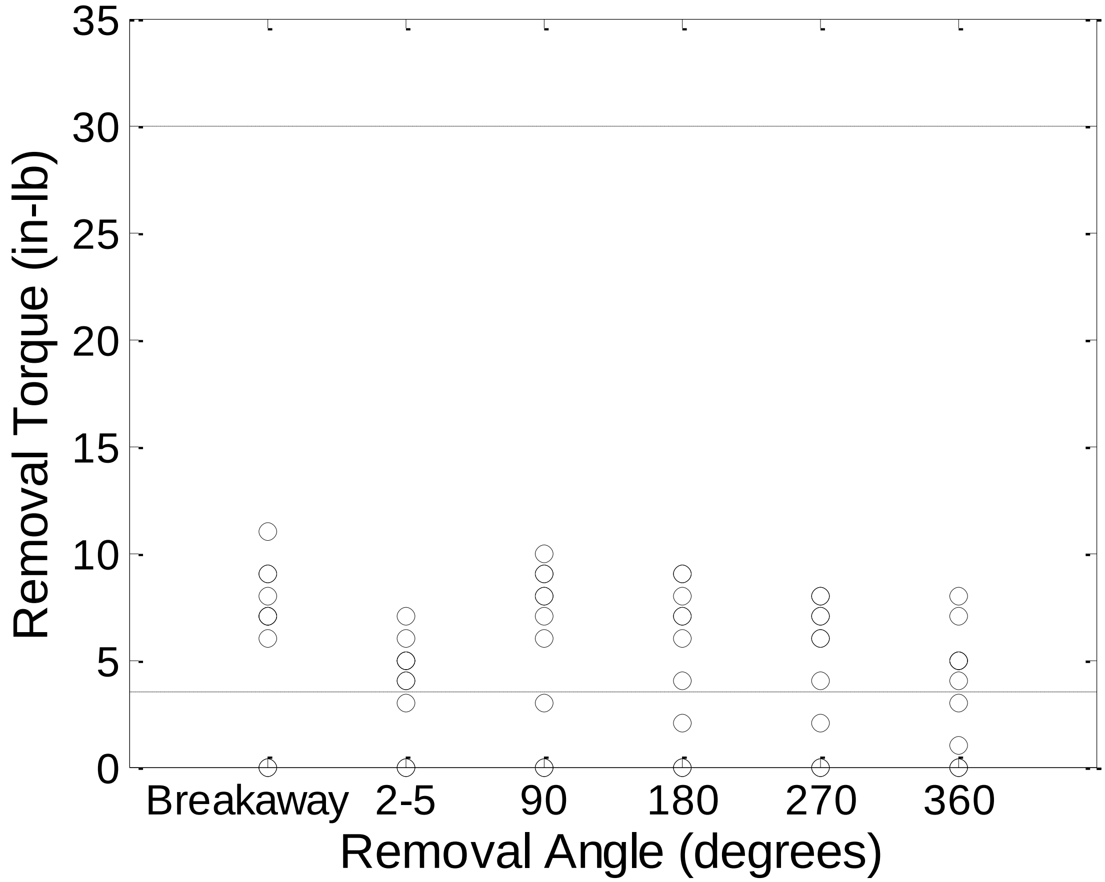

Figure 27 Unseated A-286 Loctite 222MS reuse.

When removing the hex nut completely and adding additional anaerobic adhesive, the only two specimens failed (#96, 99) which showed zero for the readings of prevailing torque as shown in Figure 28. These specimens were the same ones that failed in the reuse of A-286.

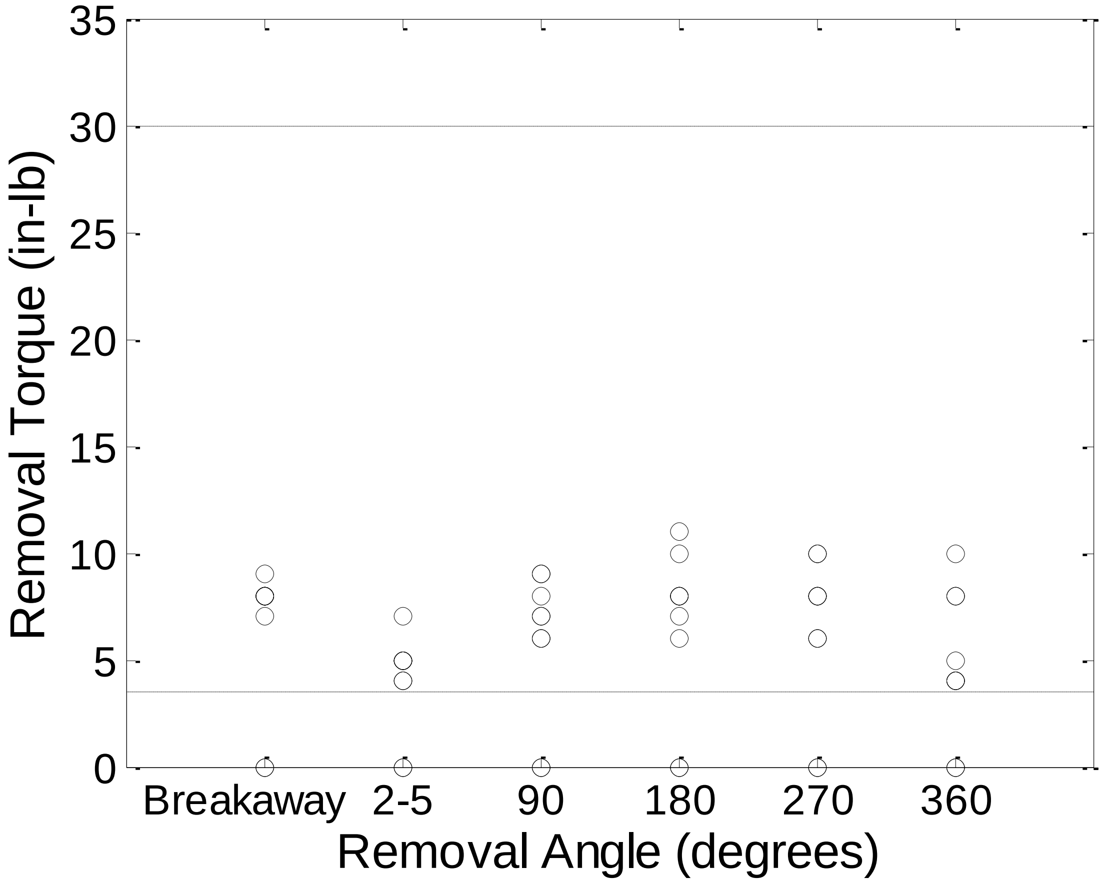

Figure 28 Unseated A-286 Loctite 222MS reuse adding anaerobic adhesive.

3.1.3.2 Unseated A-286 Loctite 242

The same sort of behavior was experienced in Figure 29 as in Figure 26. The anaerobic adhesive did not seem to cure for the same reason as explained earlier even though the anaerobic adhesive used is a medium strength grade.

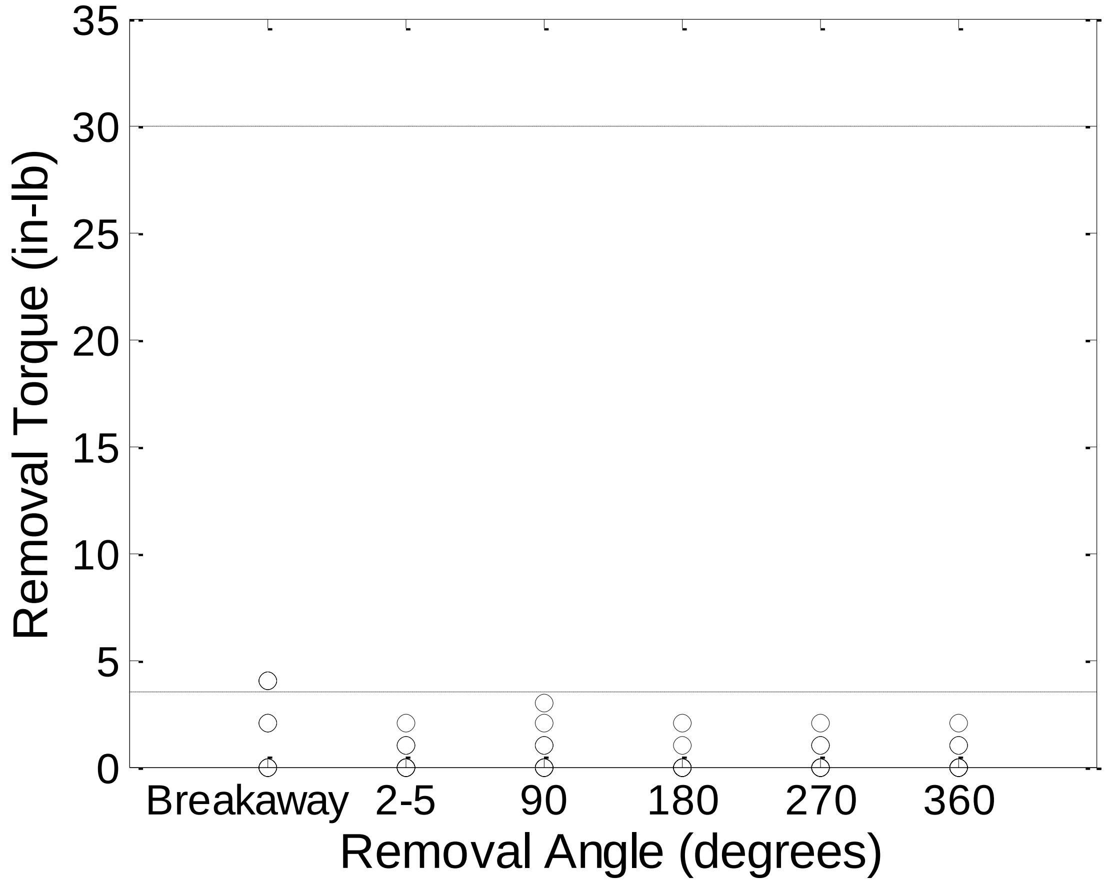

Figure 29 Initial unseated A-286 Loctite 242.

Two specimens (#101, 102) experienced values of zero for the removal torque as shown in Figure 30. The same behavior was experienced as in Figure 27 which is having some of the test specimens within range.

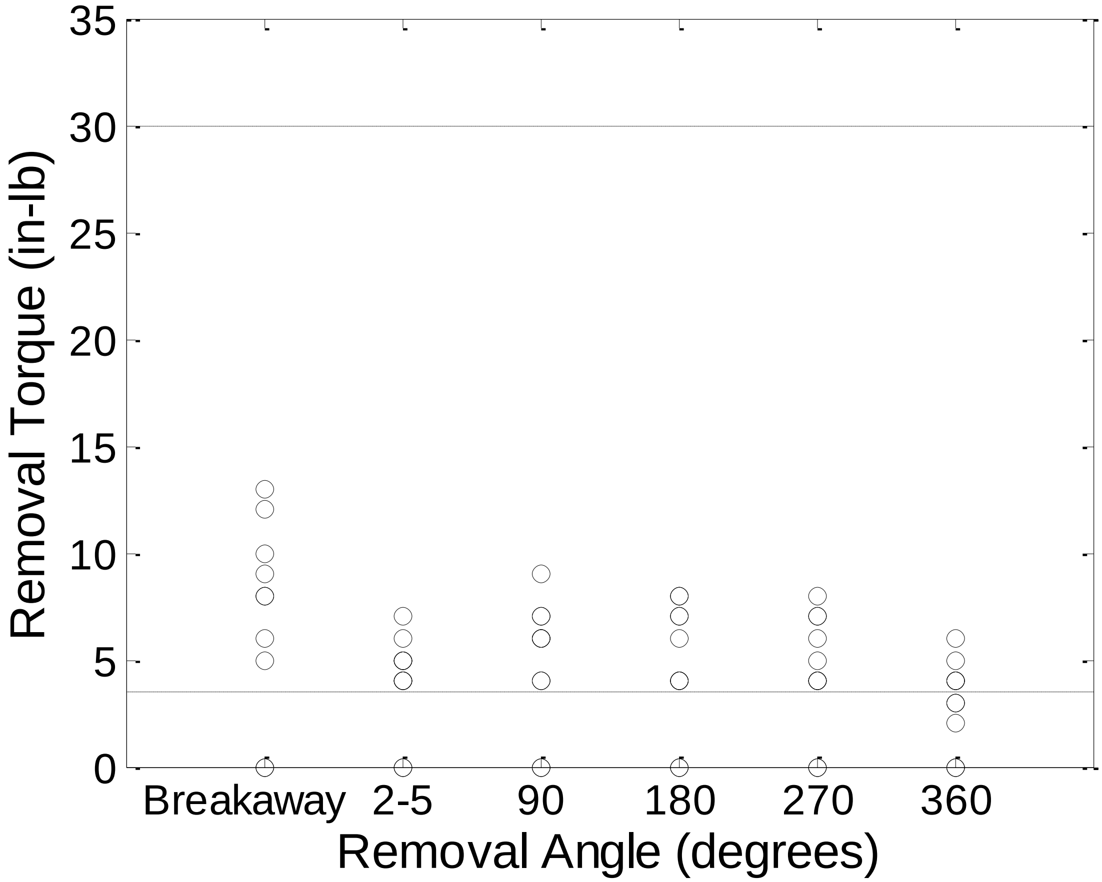

Figure 30 Unseated A-286 Loctite 242 reuse.

The same two specimens (#101, 102) had a reading of zero for the removal torque after the designated curing time as illustrated in Figure 31.

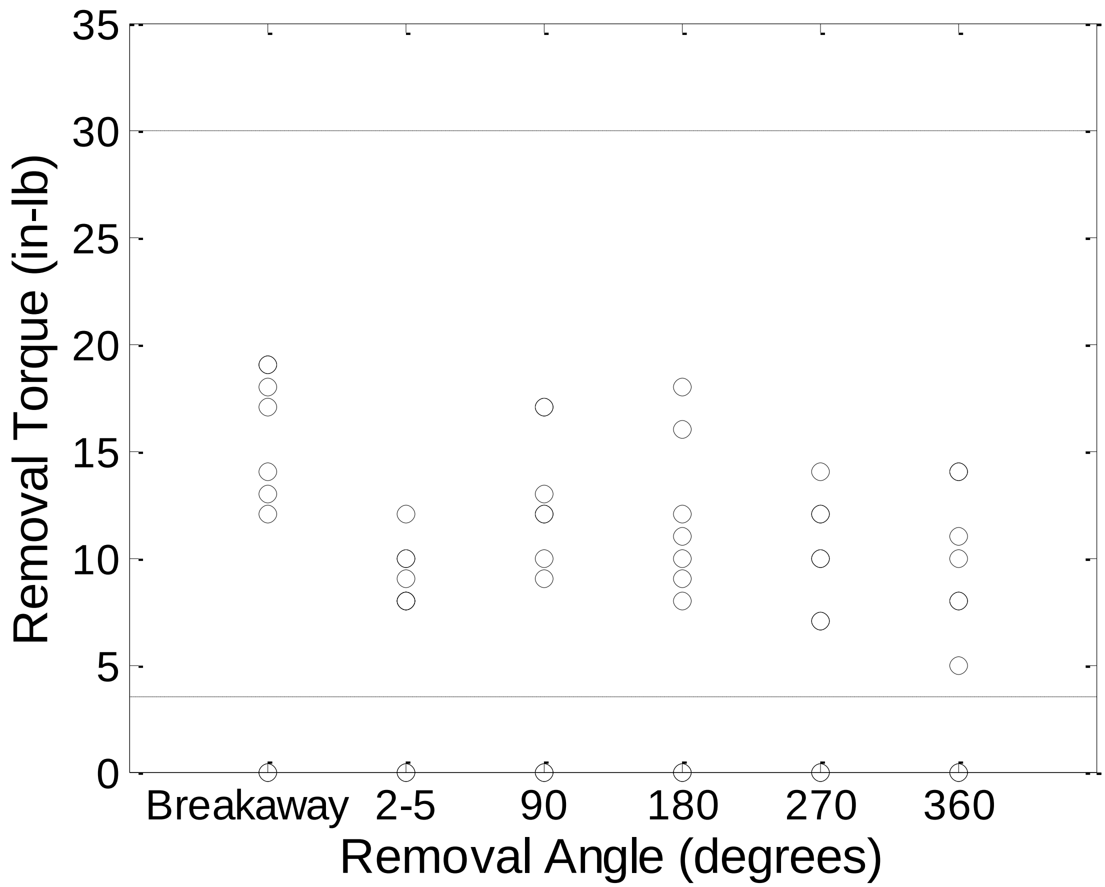

Figure 31 Unseated A-286 Loctite 242 reuse adding anaerobic adhesive.

3.1.3.3 Unseated A-286 Loctite 243

All the test specimens were within tolerance except for one (#115) that exceeded the upper limit by 1 in-lbs. as shown in Figure 32. Since the anaerobic adhesive used is designed to be used with passive substrates, there were no issues with curing [15].

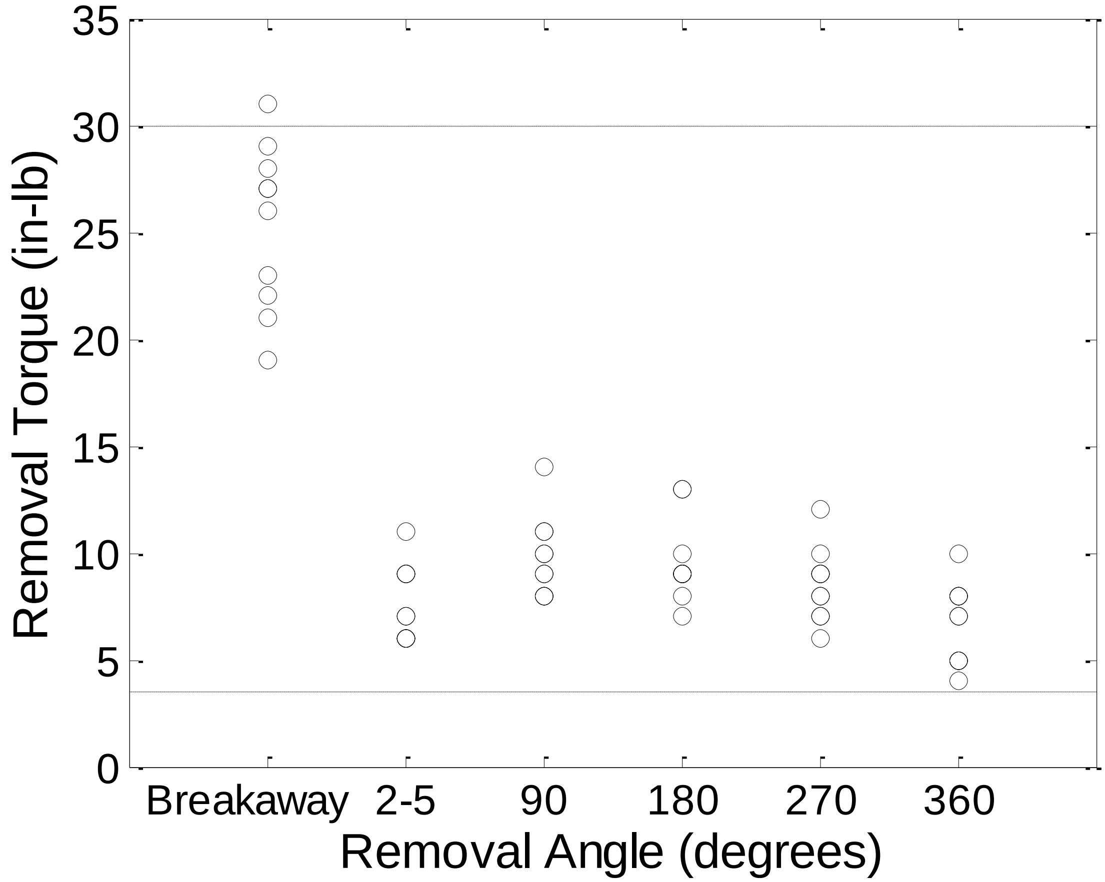

Figure 32 Initial unseated A-286 Loctite 243.

The same issue was experienced with the reuse of Loctite 243 as before, during the removal of the hex nut the adhesive flakes off the threads leaving no cured adhesive behind. This causes for the majority of the specimens to fail as shown in Figure 33.

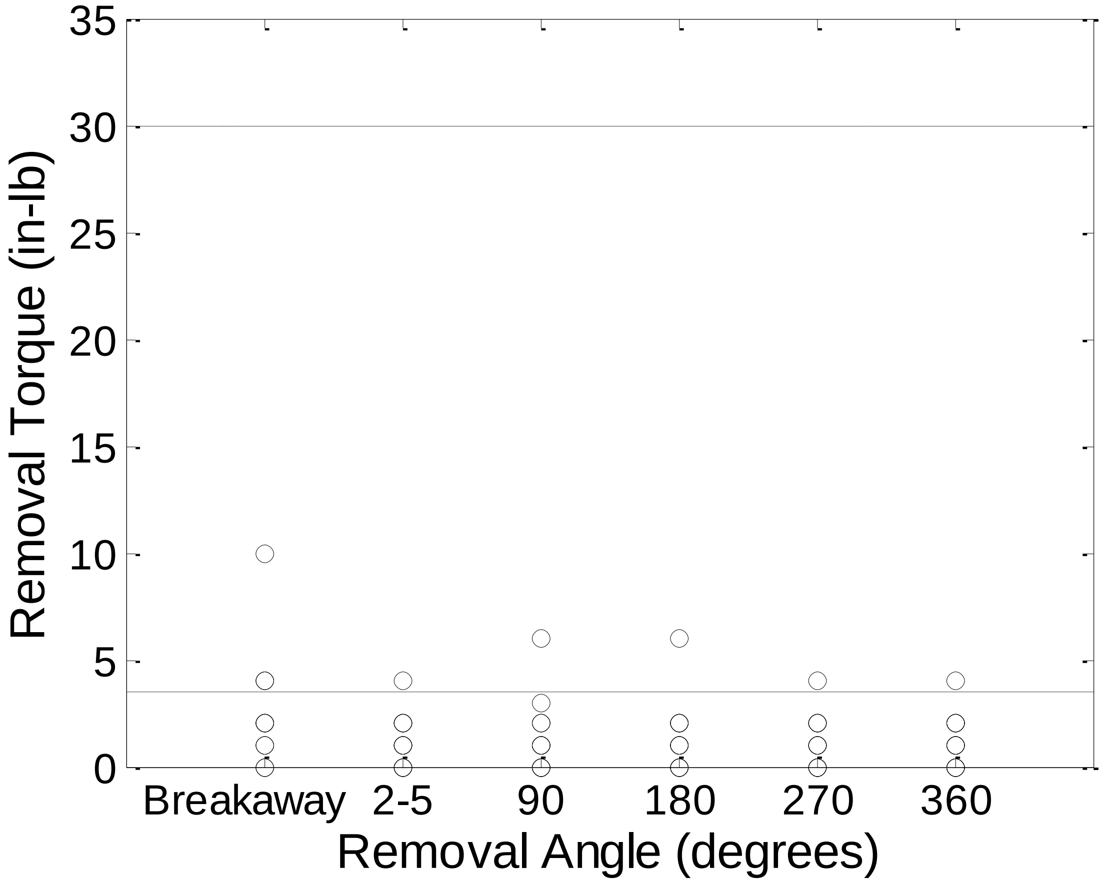

Figure 33 Unseated A-286 Loctite 243 reuse.

All of the threaded fasteners were within the specification for this test configuration shown in Figure 34. Since additional Loctite 243 is coated on the threads the results improved compared to the reuse.

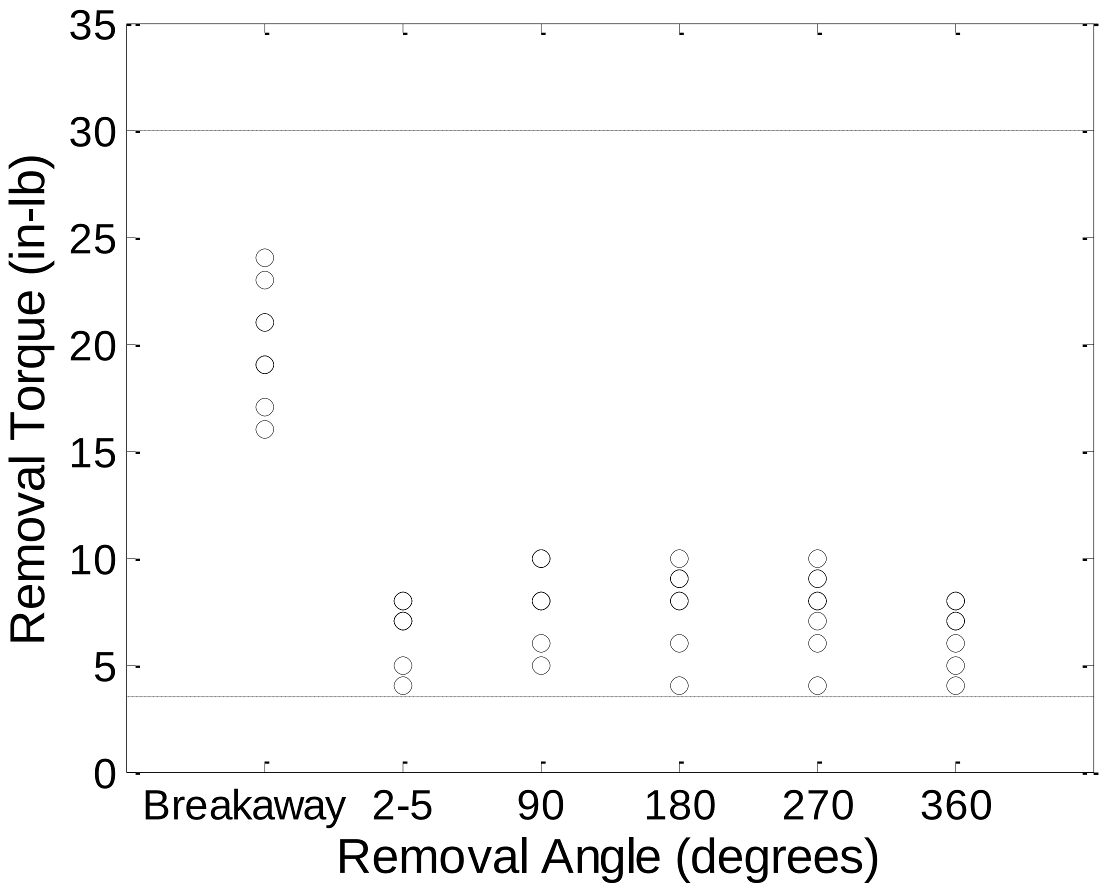

Figure 34 Unseated A-286 Loctite 243 reuse adding anaerobic adhesive.

3.2 Results for Seated State

This section presents 27 removal torque vs. removal angle plots for the seated tests. The threaded fasteners were preloaded to 150 in-lbs. when setting up the test and are left to cure for 48 hours. Each plot includes data from 10 test fasteners. Since preload remains until 90 degrees and some above 90 degrees, only removal torque data for the removal angles 180, 270, and 360 degrees are compared to the 3.5-30 in-lbs. specification.

3.2.1 Seated Plain Grade 8

For seated plain grade 8, 9 plots were generated. These plots include initial removal, reuse of the threaded fastener without adding additional anaerobic adhesive, and reuse with adding additional anaerobic adhesive for the three different types of Loctite. Remember a plain threaded fastener is one that is not coated and is received as manufactured.

3.2.1.1 Seated Plain Grade 8 Loctite 222MS

Two test specimens (#117, 119) went below tolerance at 360 degrees. All other test specimens were with in tolerance as shown in Figure 35.

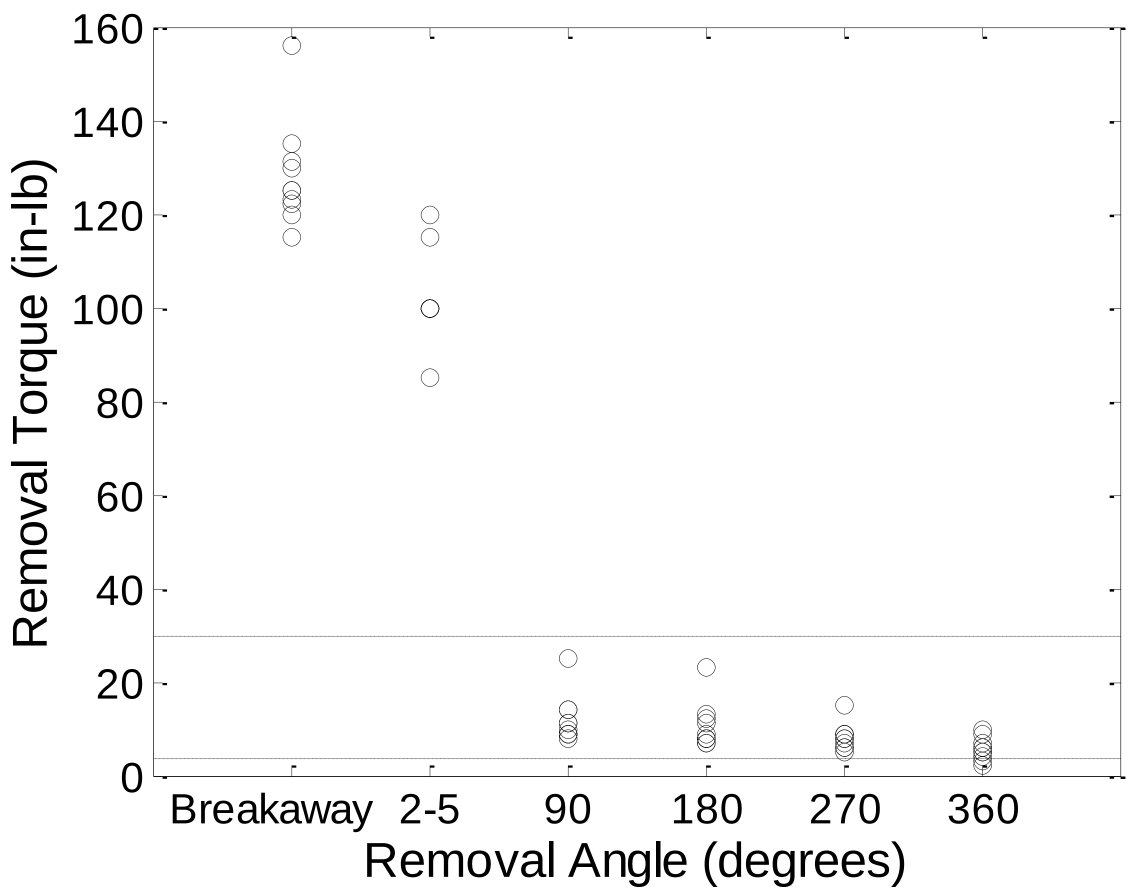

Figure 35 Initial seated plain grade 8 Loctite 222MS.

One specimen was within the tolerance at 90 degrees because the threaded fastener still experienced preload as shown in Figure 36.

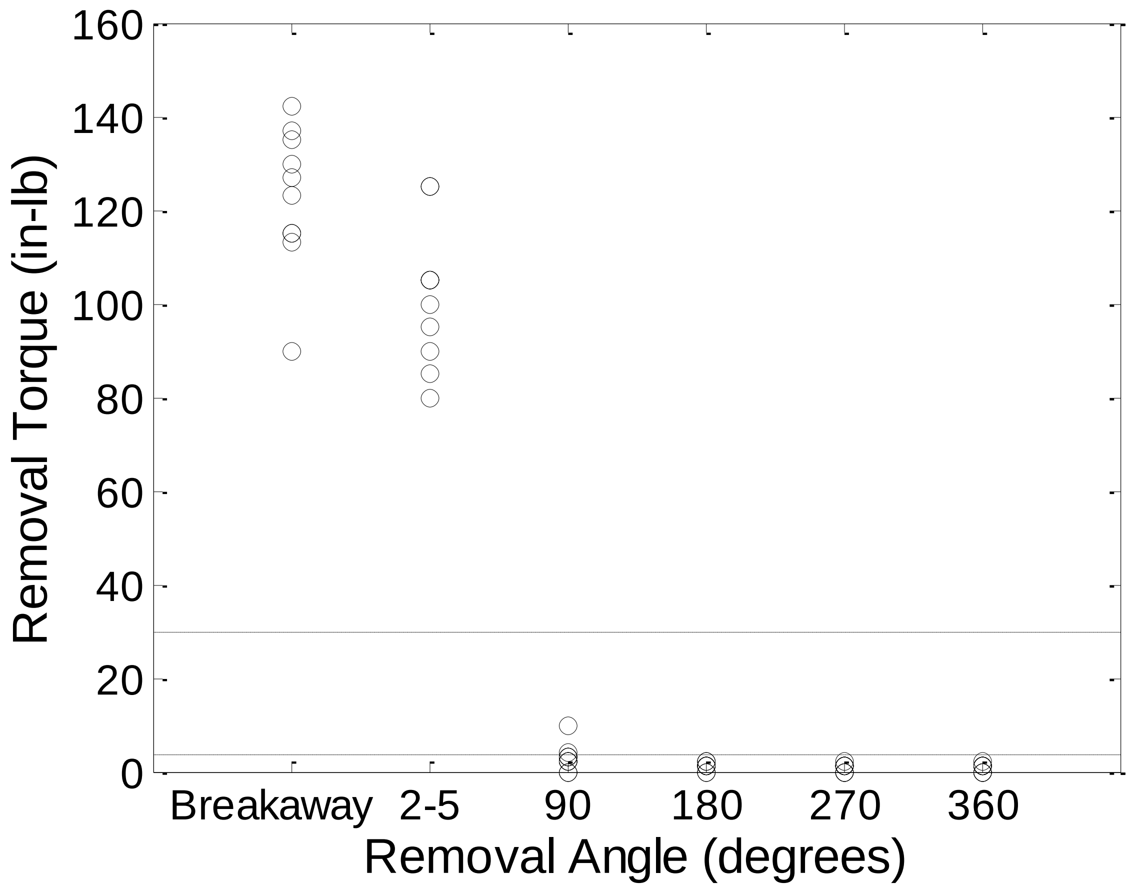

Figure 36 Seated plain grade 8 Loctite 222MS reuse.

In Figure 37, the majority of the test failed at 180, 270, and 360 degrees. Only two fasteners were within tolerance through all of the removal angles.

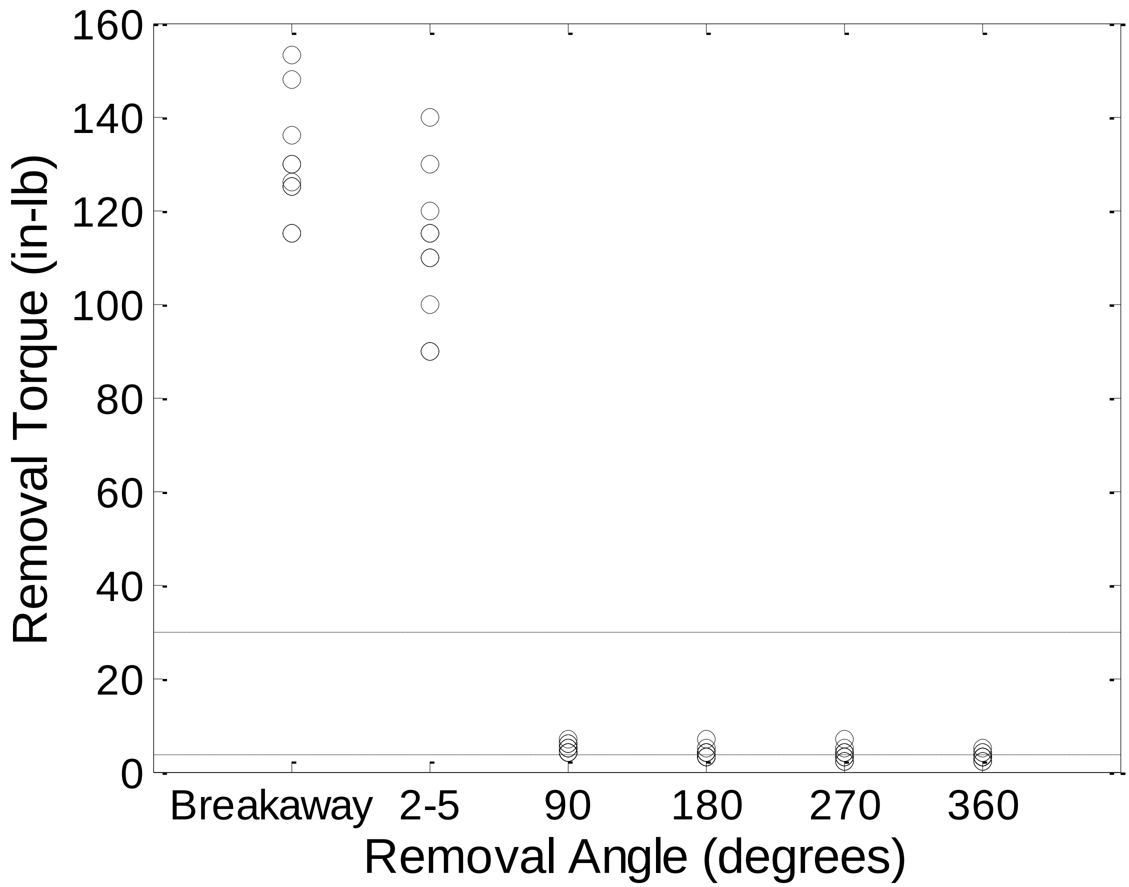

Figure 37 Seated plain grade 8 Loctite 222MS reuse adding anaerobic adhesive.

3.2.1.2 Seated Plain Grade 8 Loctite 242

The anaerobic adhesive used in this test configuration is a blue in color medium strength adhesive for fastener of ¼ to ¾ of an inch in size.

One test specimen (#79) was over the tolerance at 180 degrees by 1 in-lbs. which is shown in Figure 38. The rest of the test specimens were within tolerance throughout all the removal angles.

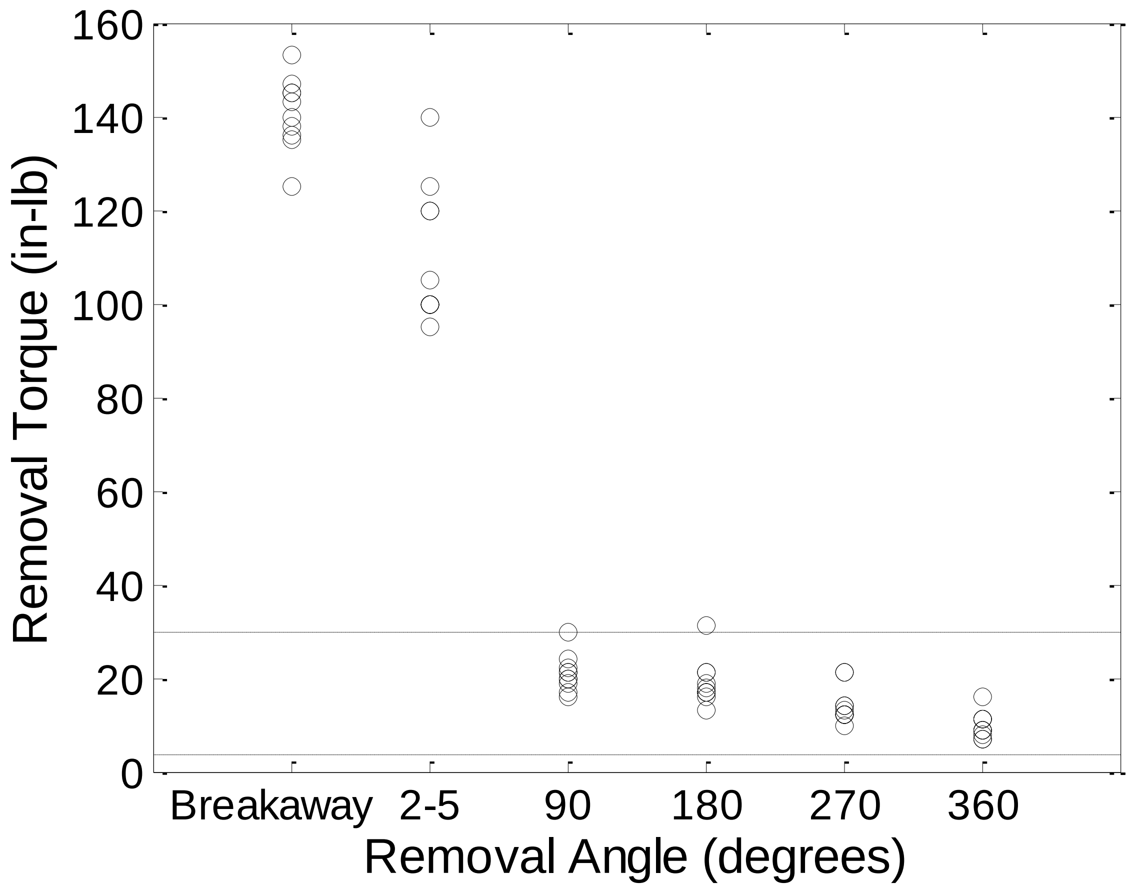

Figure 38 Initial seated plain grade 8 Loctite 242.

The majority of the test specimens failed for this test configuration as shown in Figure 39. The Loctite 242 seemed to act as the Loctite 243 with particles of cured adhesive flaking off the threads leaving the threads bare.

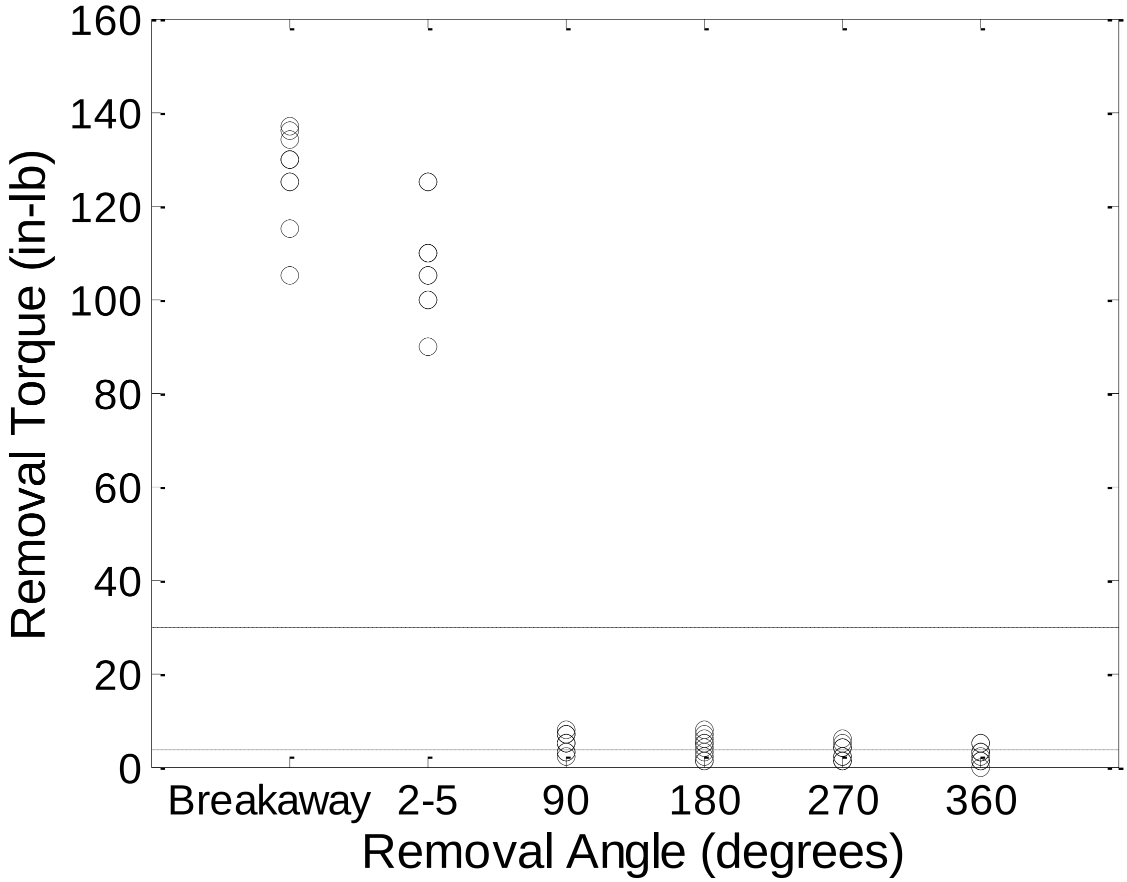

Figure 39 Seated plain grade 8 Loctite 242 reuse.

All specimens are within the bounds of 3.5 to 30 in-lbs. as shown in Figure 40 because additional adhesive was applied to the threads. The spread at after 90 degrees is fairly consistent and becomes tighter towards at 270, and 360 degrees.

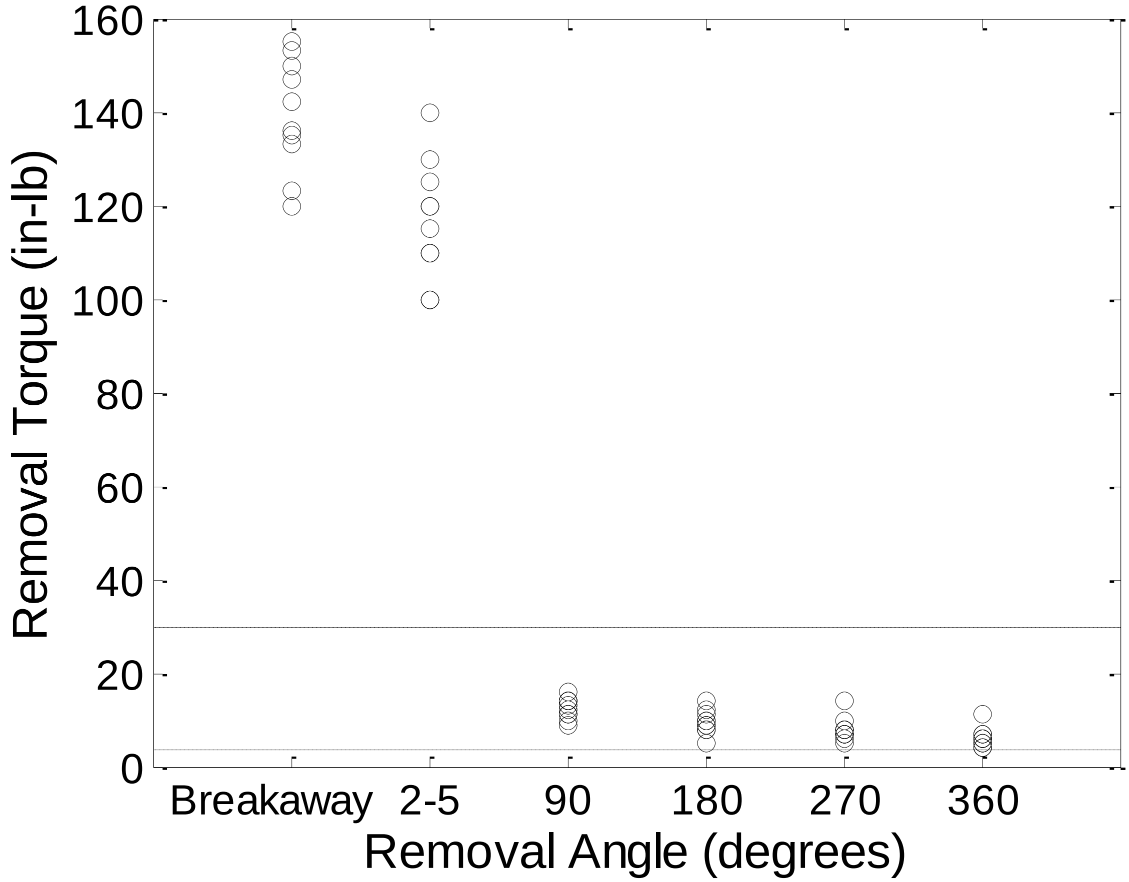

Figure 40 Seated plain grade 8 Loctite 242 reuse adding anaerobic adhesive.

3.2.1.3 Seated Plain Grade 8 Loctite 243

Similar to the previous test configuration, a medium strength anaerobic adhesive was coated on the threaded fasteners. The difference is Loctite 243 is a primer less anaerobic adhesive. It has the capabilities of curing on inactive metals. Also Loctite 243 is designed to be used in high temperatures and is oil tolerant.

All of the specimens were in the range of 3.5 to 30 in-lbs. throughout all of the removal angles as shown in Figure 41. The spread becomes tighter towards the end of the revolution.

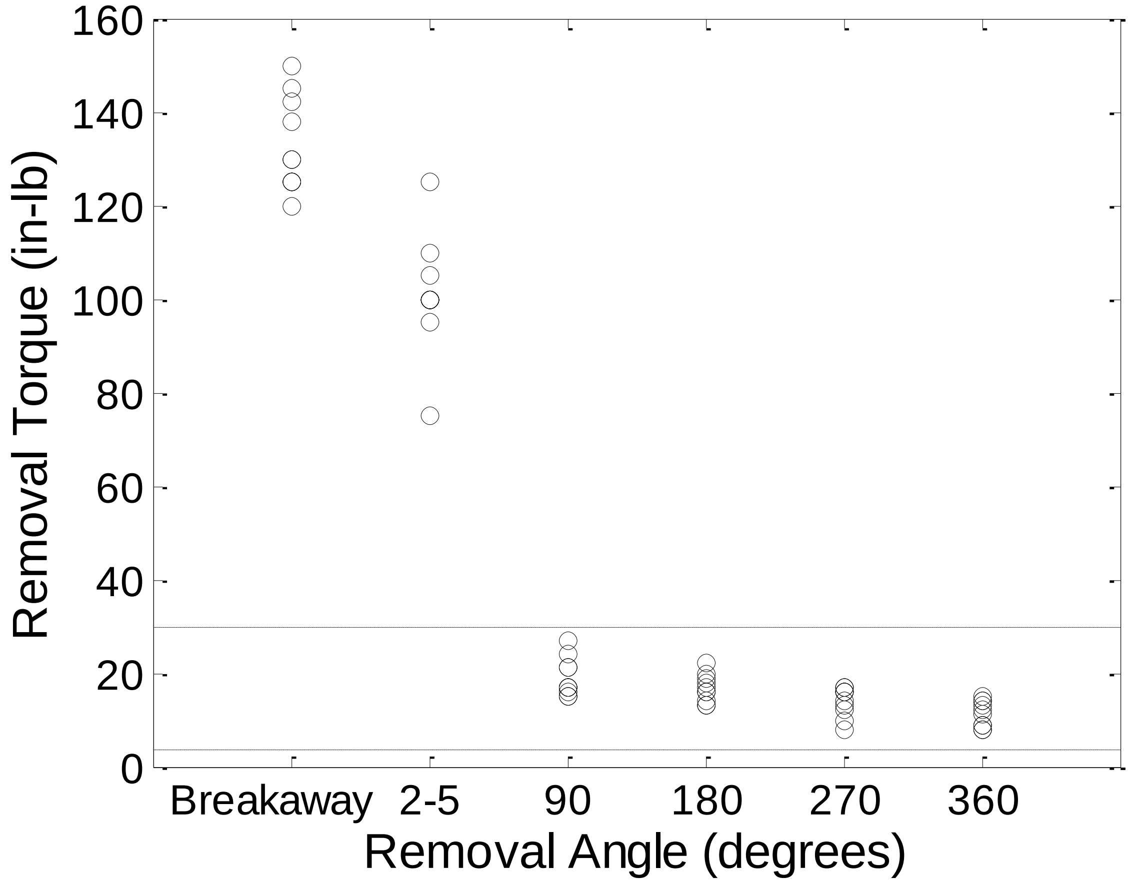

Figure 41 Initial seated plain grade 8 Loctite 243

All test specimen fail due to the fact that during removal of the hex nut the cured anaerobic adhesive flakes off leaving the cap screw and hex nut with small amounts of cured anaerobic adhesive. The results are illustrated in Figure 42.

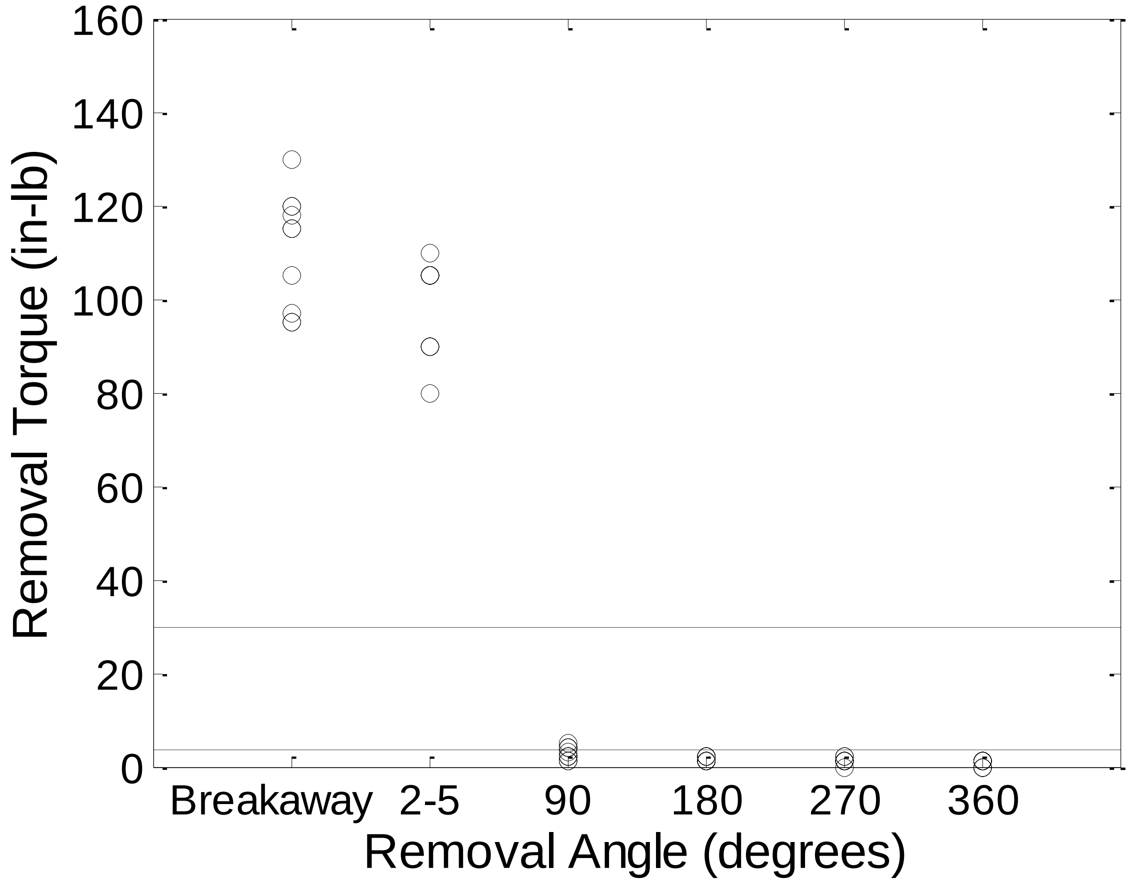

Figure 42 Seated plain grade 8 Loctite 243 reuse.

Only two specimens (#86, 87) fail at 360 degrees as shown in Figure 43. Applying anaerobic adhesive improved the conditions.

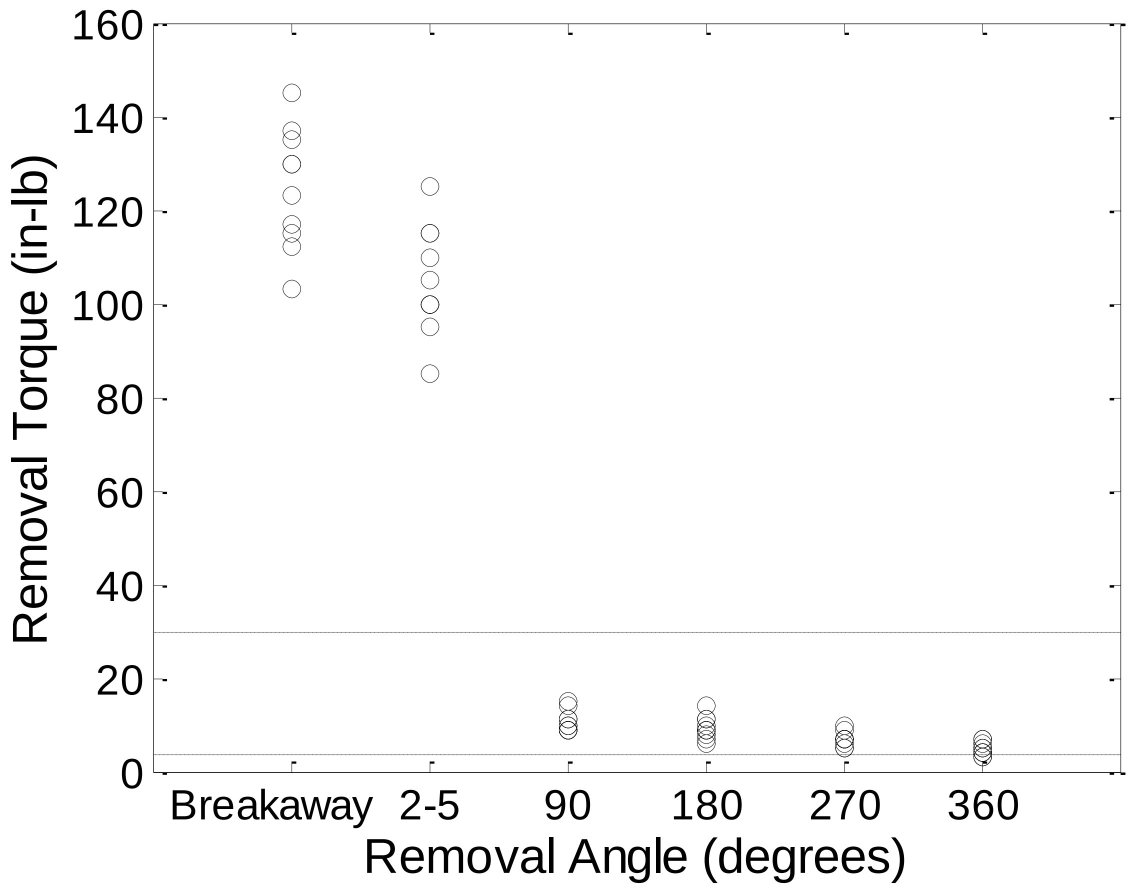

Figure 43 Seated plain grade 8 Loctite 243 reuse adding anaerobic adhesive.

3.2.2 Seated Yellow-Zinc Grade 8

This section contains 9 plots for yellow-zinc grade 8 threaded fasteners. These plots include initial removal, reuse of the threaded fastener without adding additional anaerobic adhesive, and reuse with adding additional anaerobic adhesive for the three different types of Loctite.

Yellow-zinc plating is the most common type of plating on threaded fasteners. The purpose of plating a threaded fastener is to increase corrosion resistance.

3.2.2.1 Seated Yellow-Zinc Grade 8 Loctite 222MS

Only two specimens failed at 360 degrees as shown in Figure 44. The results for the seated state compare well to those of the unseated state, of course ignoring the preload.

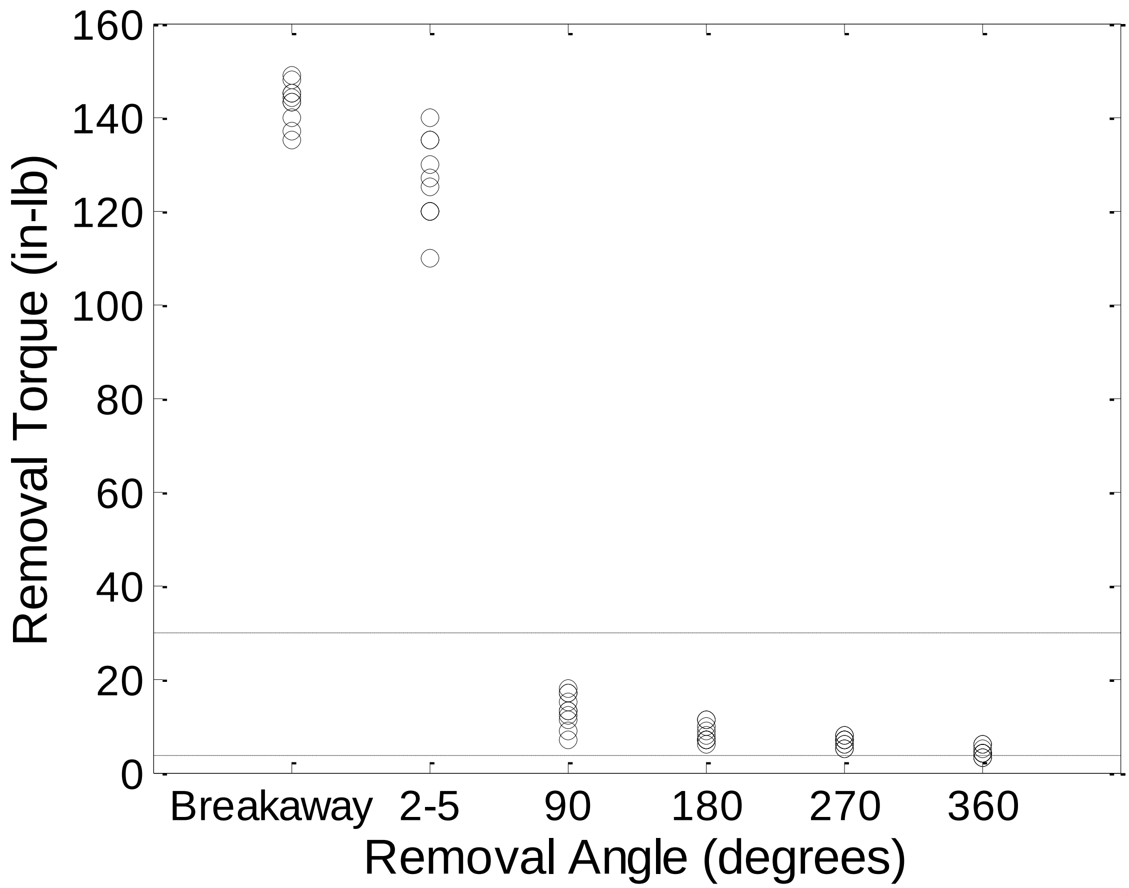

Figure 44 Initial seated yellow-zinc grade 8 Loctite 222MS.

One threaded fastener (#163) was within tolerance throughout all removal angles. The majority of the specimens failed at 270 and 360 degrees illustrated in Figure 45.

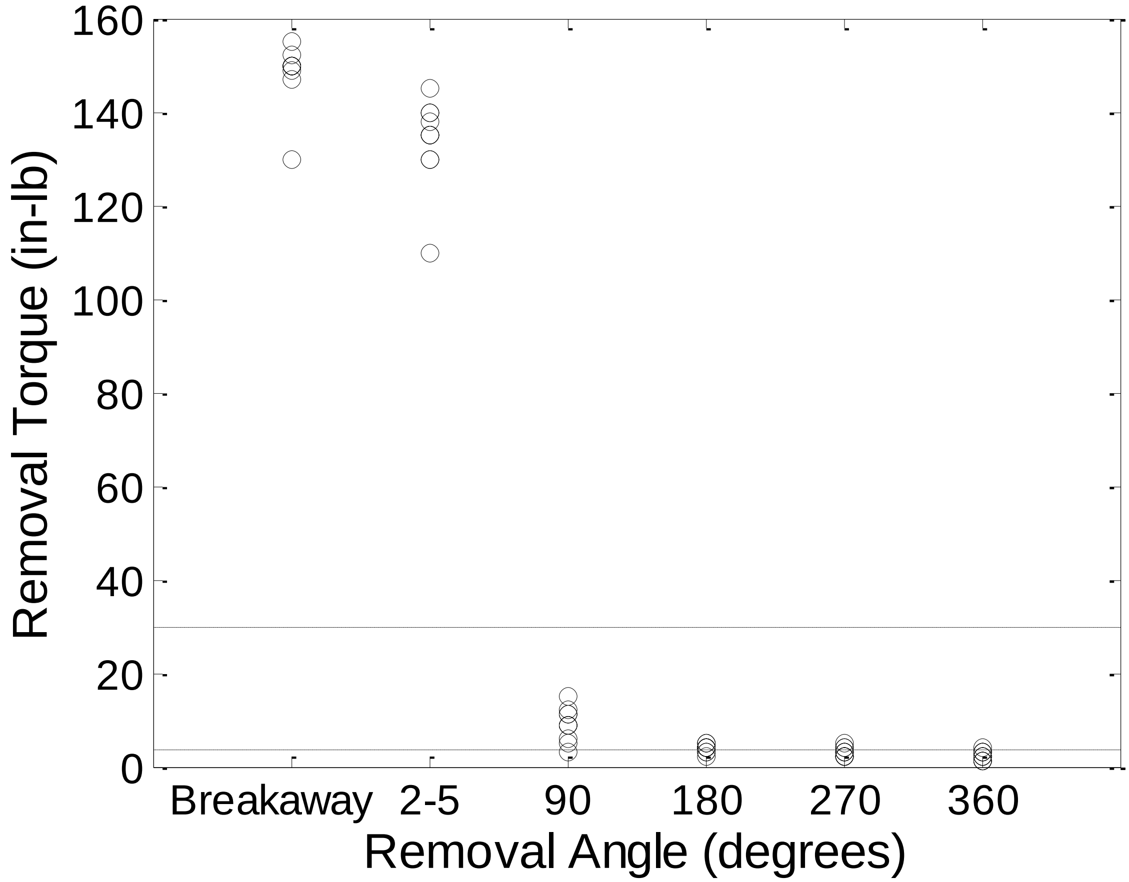

Figure 45 Seated yellow-zinc grade 8 Loctite 222MS reuse.

Four test specimens were within tolerance during all removal angles. The test specimens that were not within tolerance failed at 360 degrees as shown in Figure 46.

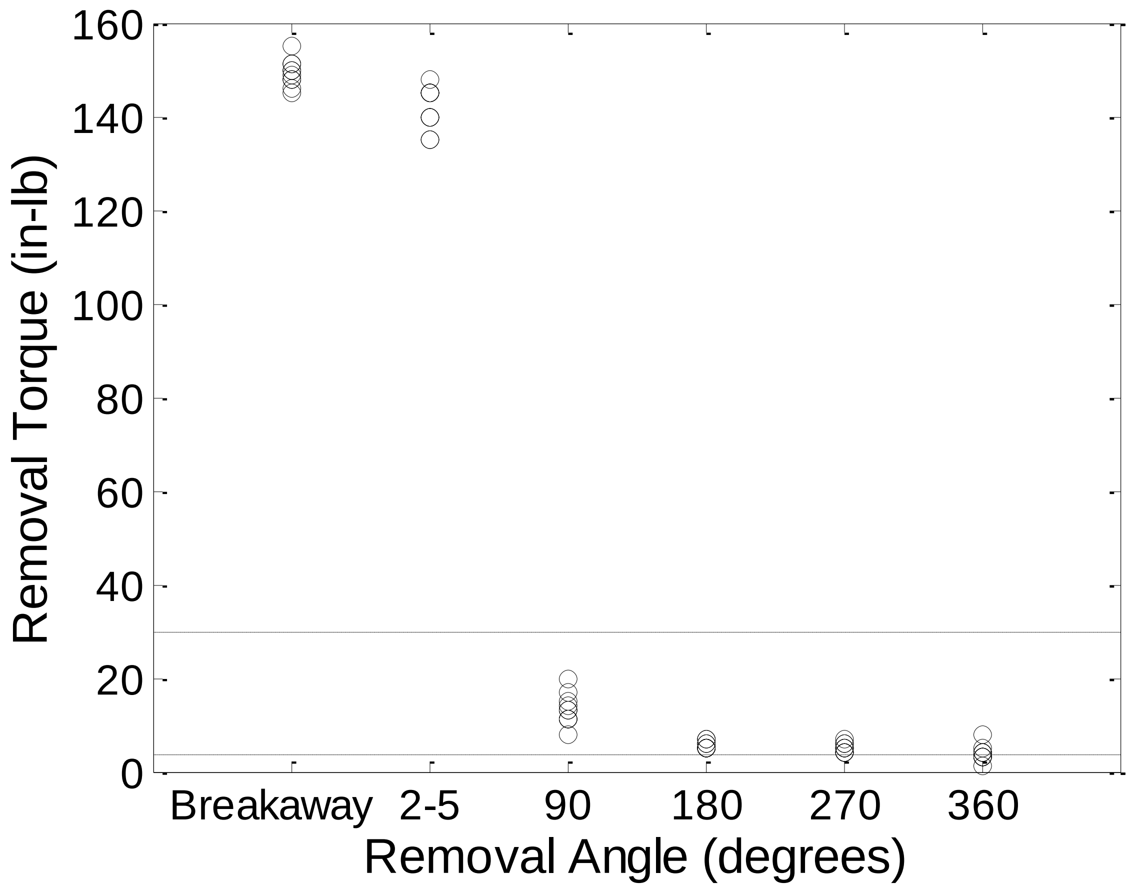

Figure 46 Seated yellow-zinc grade 8 Loctite 222MS reuse adding anaerobic adhesive.

3.2.2.2 Seated Yellow-Zinc Grade 8 Loctite 242

Loctite 242 is a medium strength anaerobic adhesive that is suited for plated surfaces.

Referring to Figure 47, all of the specimens were within tolerance once the entire preload has been disengaged. The spread of the data is consistent through most of the removal angles.

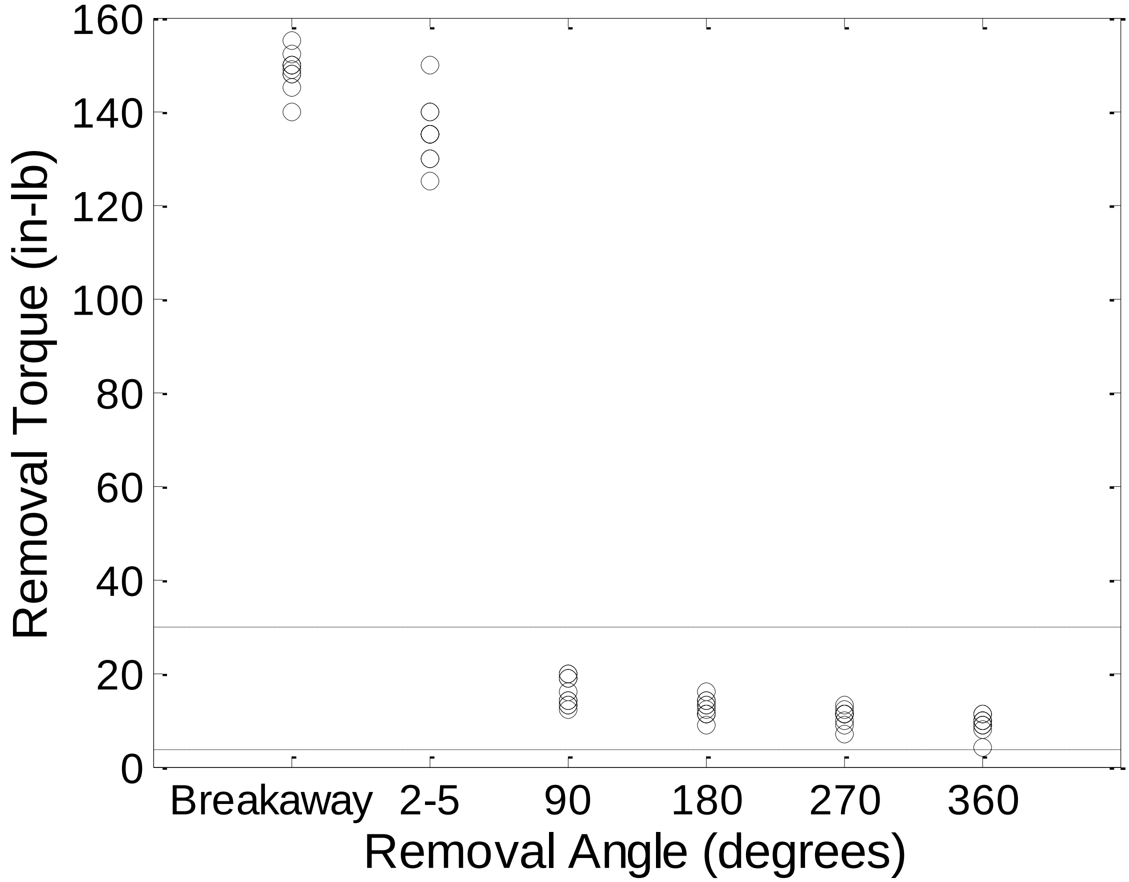

Figure 47 Initial seated yellow-zinc grade 8 Loctite 242.

Two specimens (#168, 182) were the only two that were within tolerance during all removal angles. The majority failed at the removal angle of 360 degrees as shown in figure 48. The same behavior was experienced, when the hex nut was being removed from the cap screw some of the adhesive deteriorated into small particles.

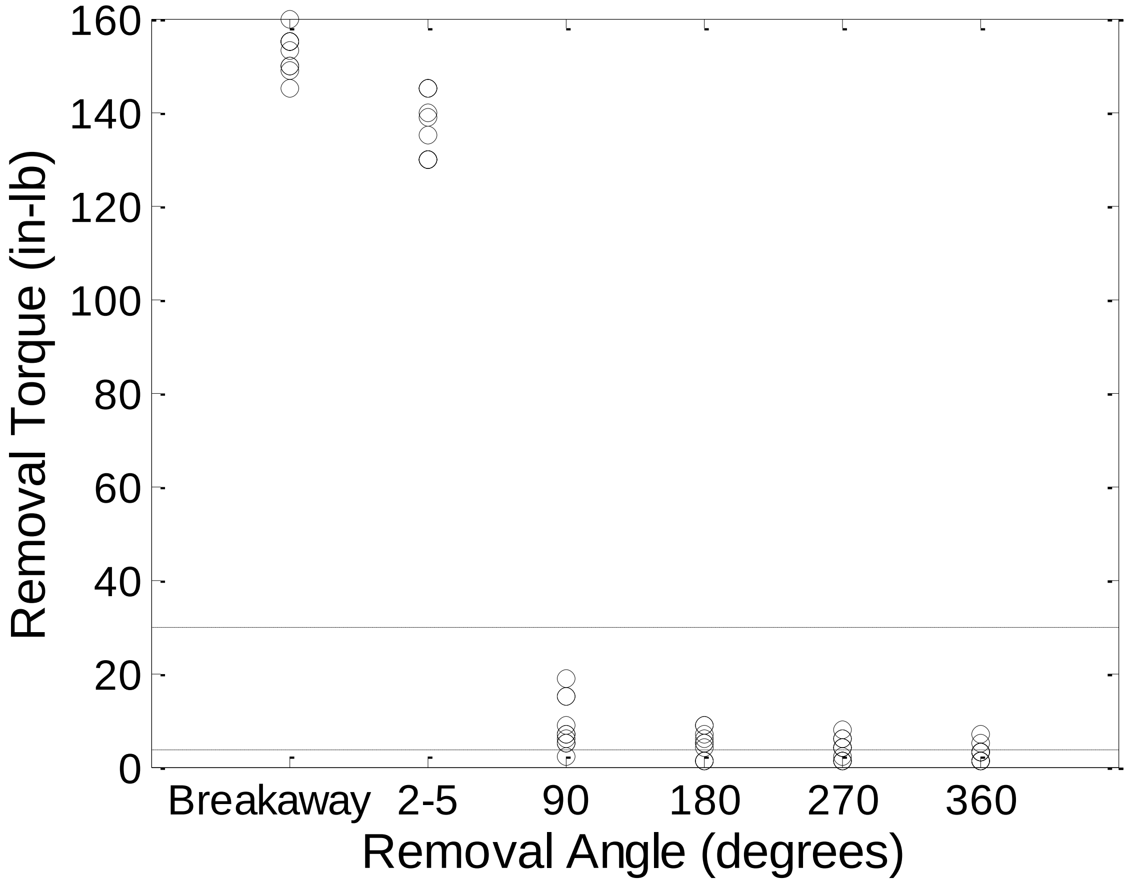

Figure 48 Seated yellow-zinc grade 8 Loctite 242 reuse.

When adhesive was applied to the specimens for a second time all of the fasteners were within tolerance as shown in Figure 49.

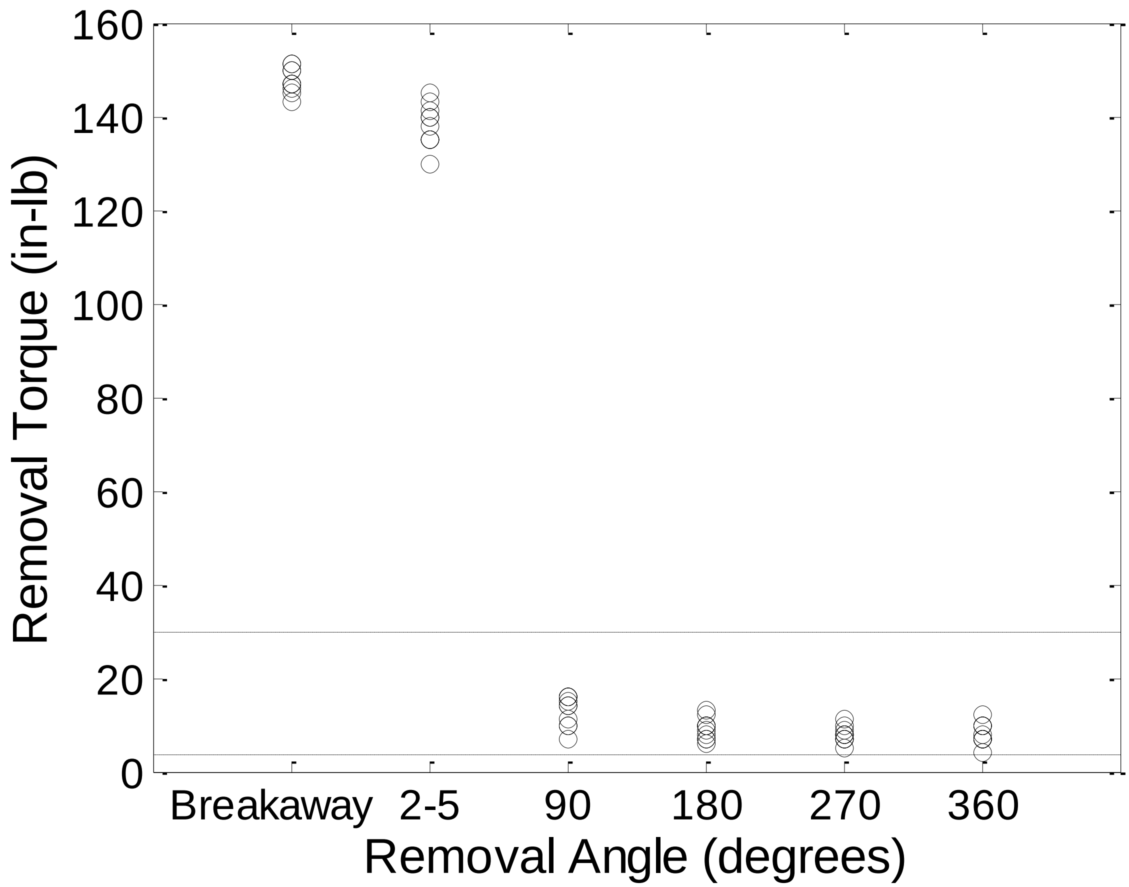

Figure 49 Seated yellow-zinc grade 8 Loctite 242 reuse adding anaerobic adhesive.

3.2.2.3 Seated Yellow-Zinc Grade 8 Loctite 243

Loctite 243 is a medium strength anaerobic adhesive that does not require a primer if used with an inactive metal.

All of the test specimens shown in Figure 50 were within the specification of 3.5 to 30 in-lbs. The range of the data at 270 and 360 degrees is tight illustrating that of the removal torques occurred at the same locations.

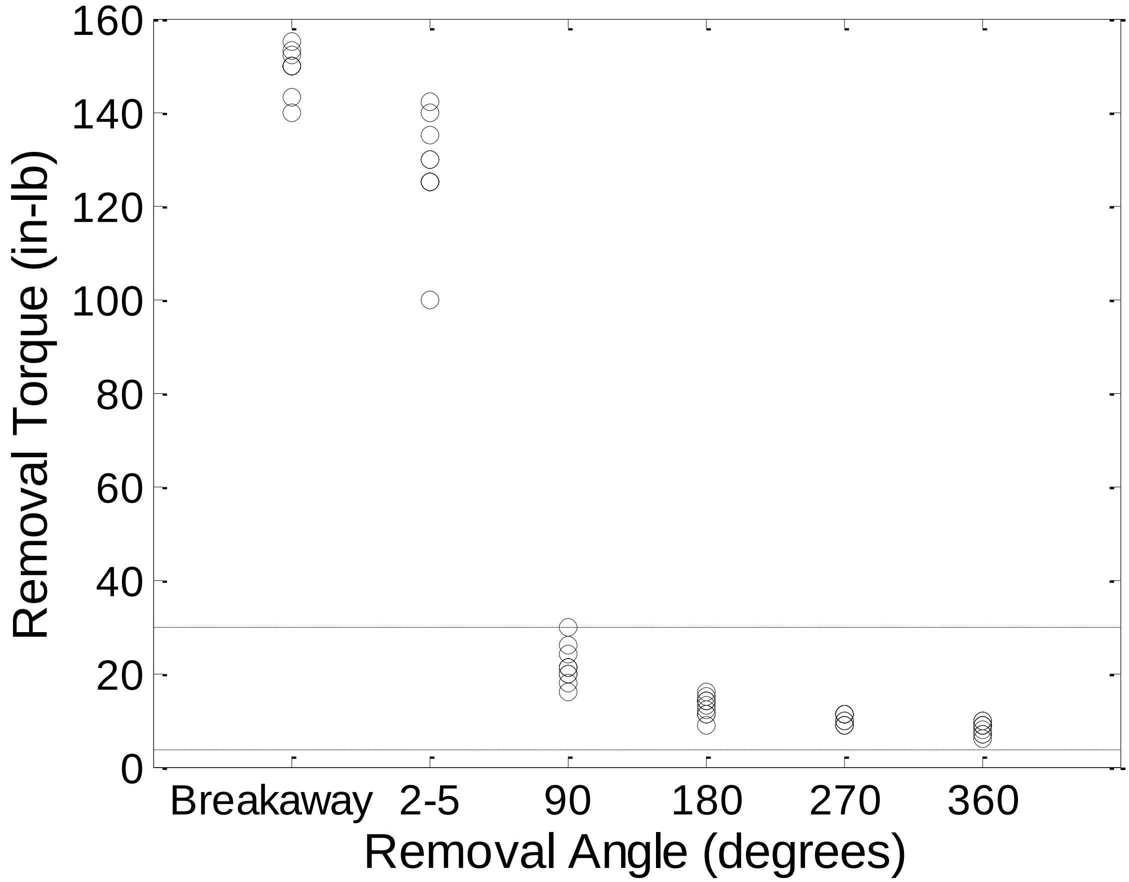

Figure 50 Initial seated yellow-zinc grade 8 Loctite 243.

All the specimens failed as shown in Figure 51. Similar to the same situation as in Figure 24, the cured anaerobic adhesive flakes off during the removal of the hex nut leaving the threads bare.

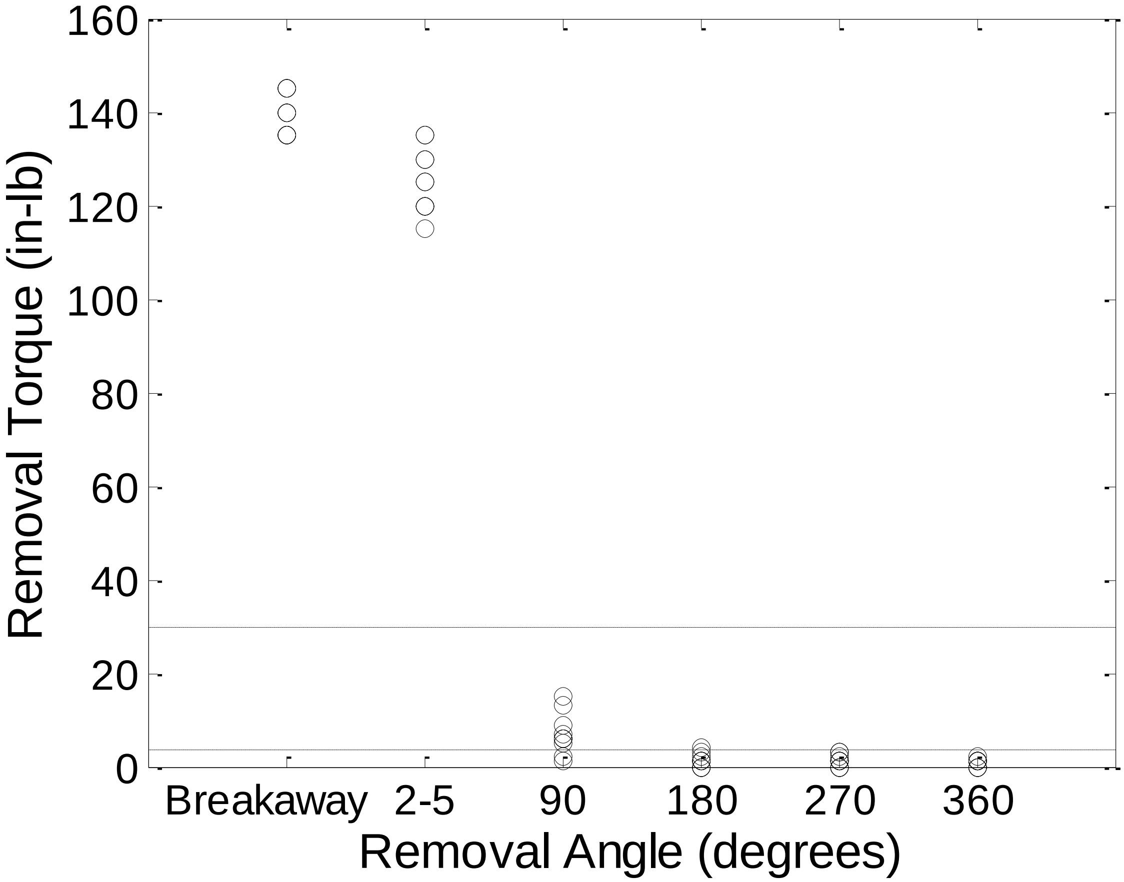

Figure 51 Seated yellow-zinc grade 8 Loctite 243 reuse.

All specimens passed as shown in figure 52. The only issue is that there was still preload at 90 degrees causing the removal torque values to be higher. The range becomes tighter as the degrees in removal angle increase.

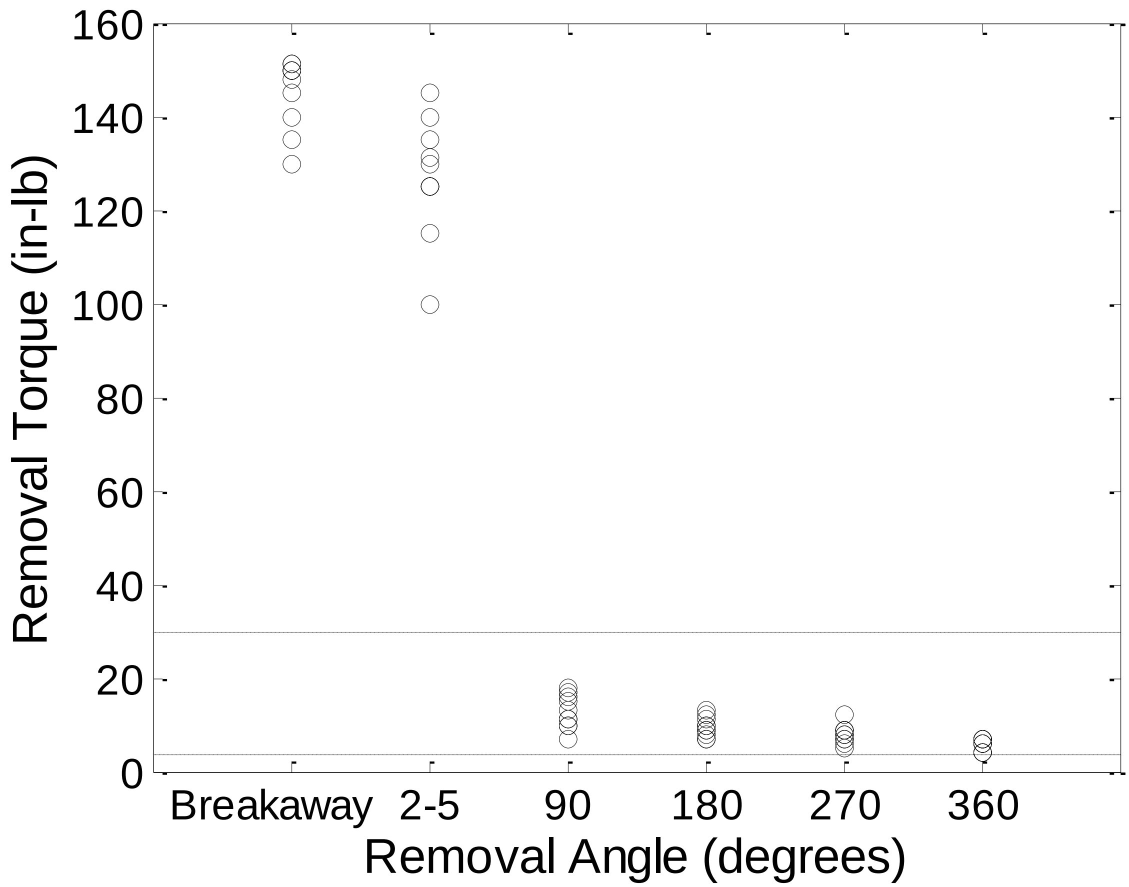

Figure 52 Seated yellow-zinc grade 8 Loctite 243 reuse adding anaerobic adhesive.

All specimens passed as shown in figure 52. The only issue was that there was still preload at 90 degrees causing the removal torque values to be higher.

3.2.3 Seated A-286

A-286 is an inactive metal used in many aerospace threaded fasteners. Anaerobic adhesives have trouble curing with inactive metals unless a primer/activator is used. The finish on the A-286 threaded fasteners tested is a passivate finish.

For seated A-286, 9 plots were generated. These plots include initial removal, reuse of the threaded fastener without adding additional anaerobic adhesive, and reuse with adding additional anaerobic adhesive for the three different types of Loctite.

3.2.3.1 Seated A-286 Loctite 222MS

In the technical data sheet for Loctite 222MS it recommends the use of an activator when applying the anaerobic adhesive to an inactive metal. It is interesting to note that only one specimen (#135) failed at 360 degrees as shown in Figure 53. A hypothesis to why most of them cured is when the fasteners were preloaded it forced the air between the threads to escape.

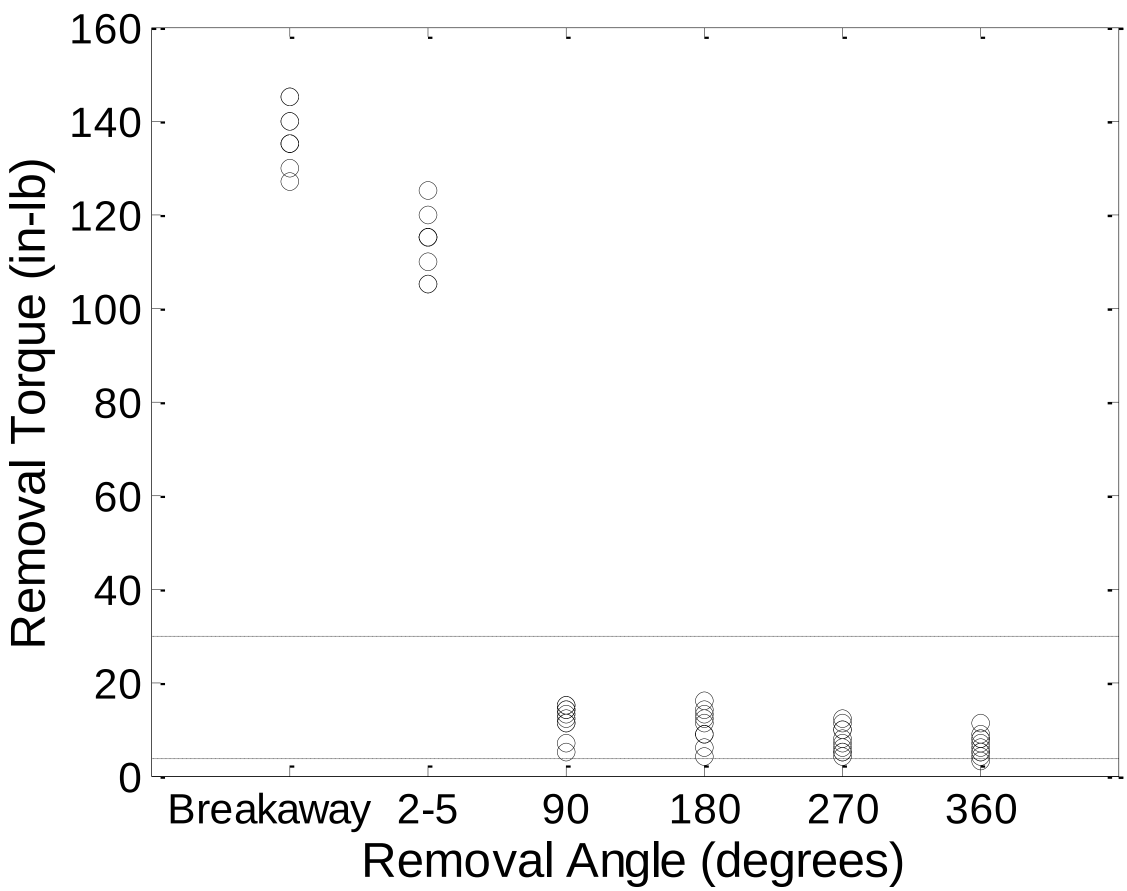

Figure 53 Initial seated A-286 Loctite 222MS.

Only three specimens succeeded in meeting the specification throughout all of the removal angles. This is illustrated in Figure 54.

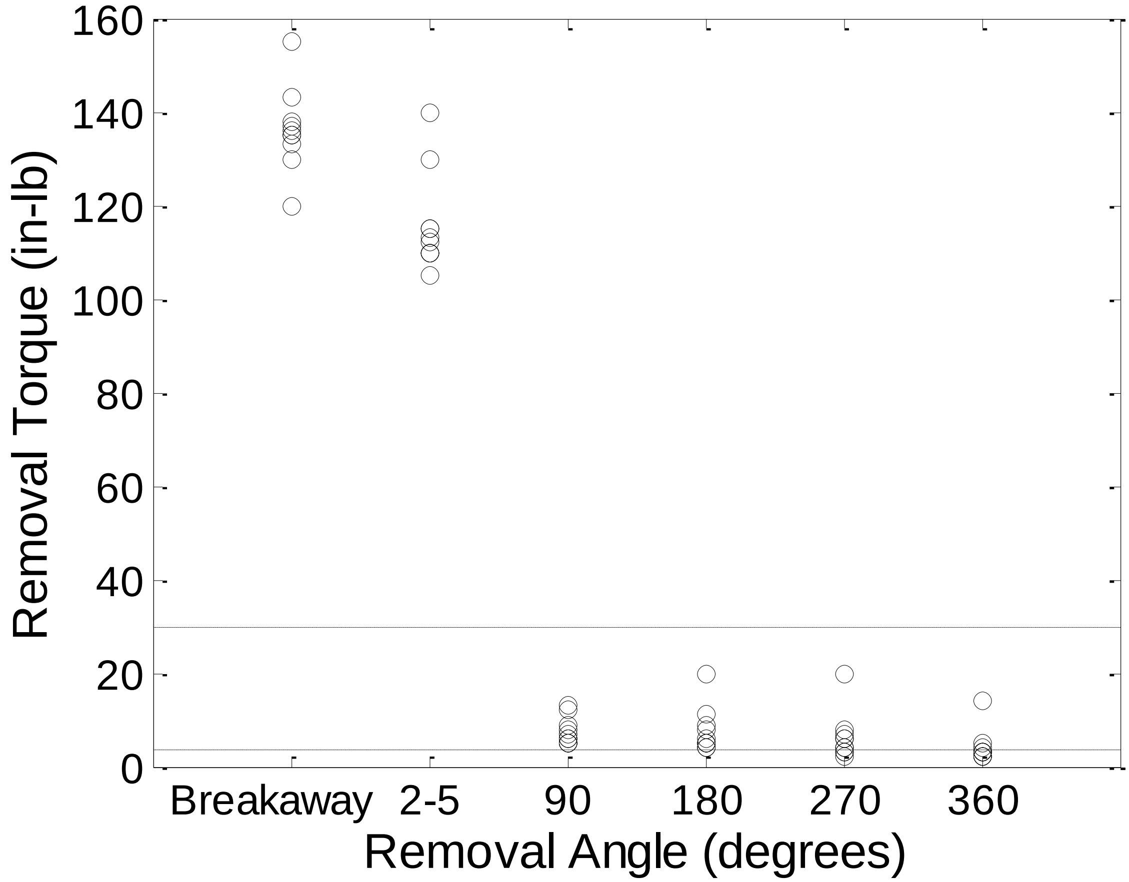

Figure 54 Seated A-286 Loctite 222MS reuse.

When applying additional adhesive to the threads the failure rate reduced to only 30% comparing to 70% failure in reuse. Figure 55 displays these results.

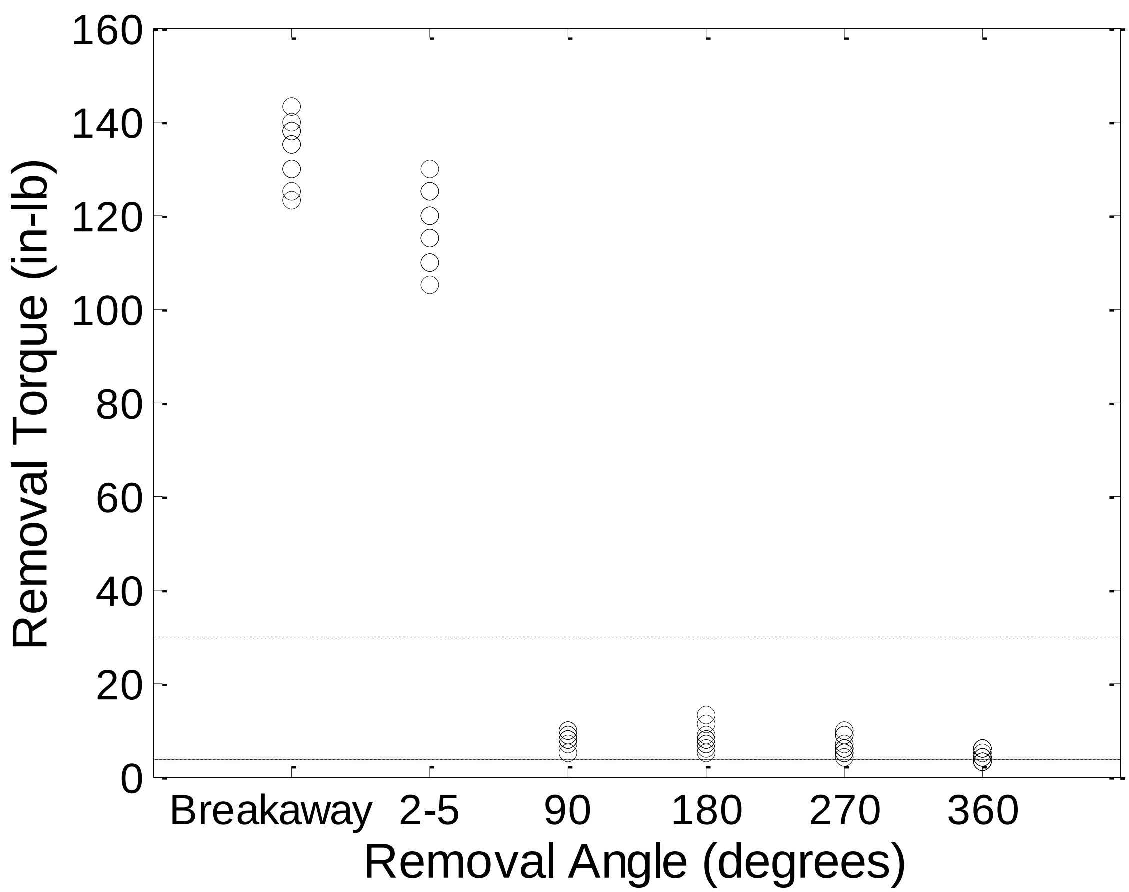

Figure 55 Seated A-286 Loctite 222MS second reuse.

3.2.3.2 Seated A-286 Loctite 242

Loctite 242 is a blue in color medium strength anaerobic adhesive. As mentioned earlier this adhesive can work with plated surface.

All test specimens passed for the initial, reuse, and reuse adding additional anaerobic adhesive as shown in figures 56, 57, and 58. Comparing to the results to unseated A-286 with Loctite 242 they vary drastically. Since the only difference introduced is preload, that is a possible reason why Loctite 242 cured sufficiently.

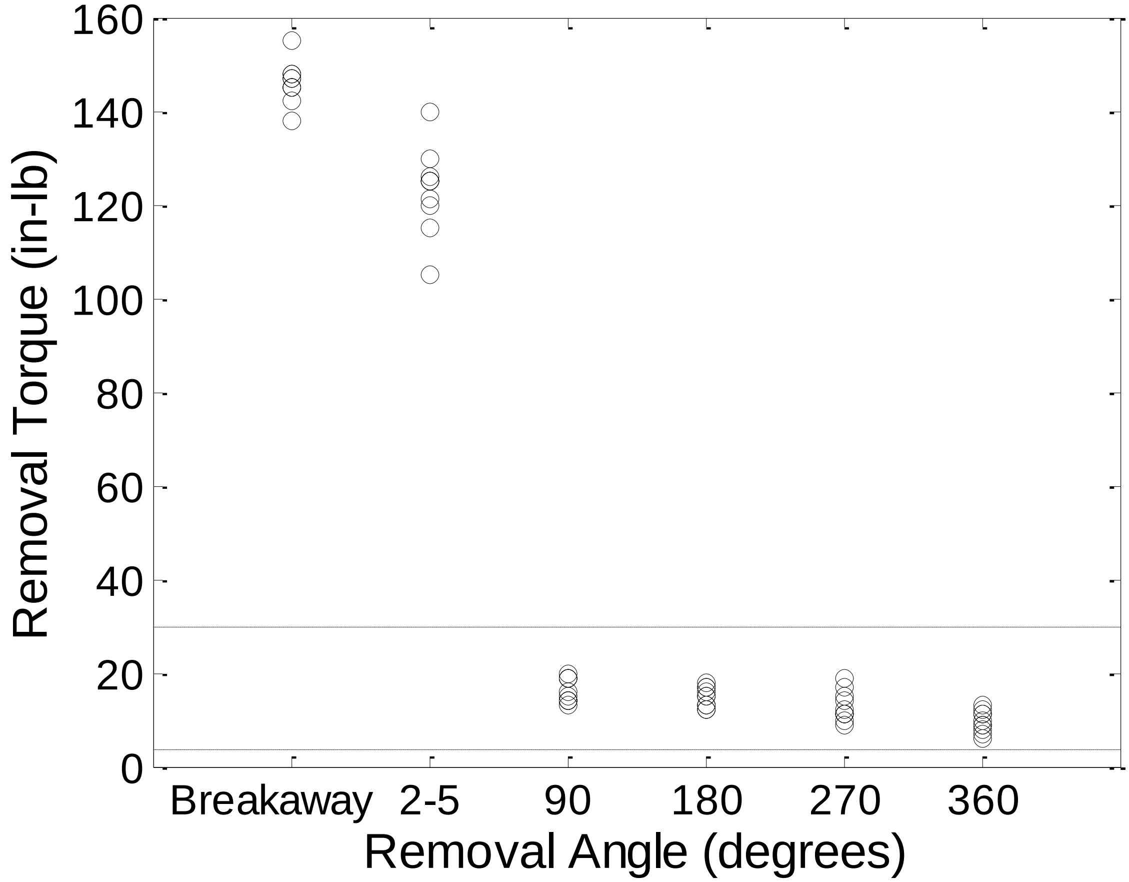

Figure 56 Initial seated A-286 Loctite 242.

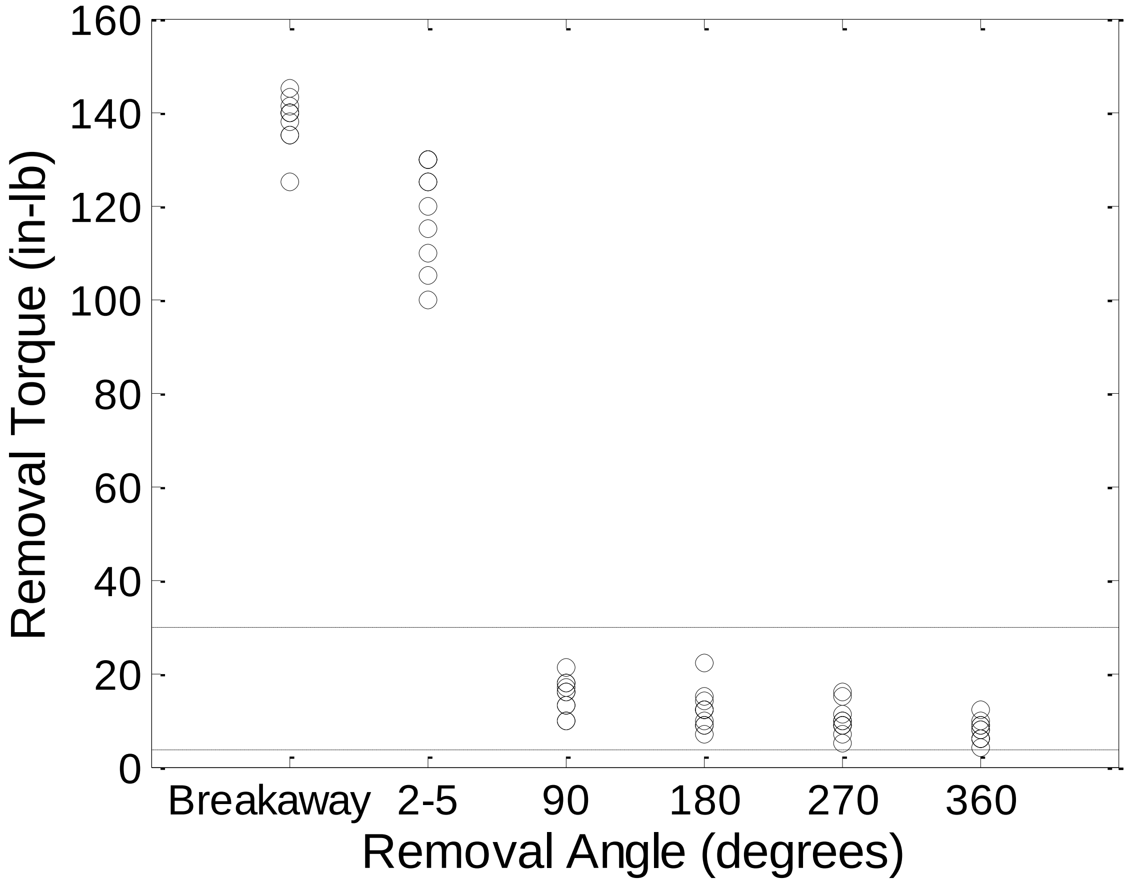

Figure 57 Seated A-286 Loctite 242 reuse.

The spread of the data in Figure 58 is consistent throughout all of the removal angles.

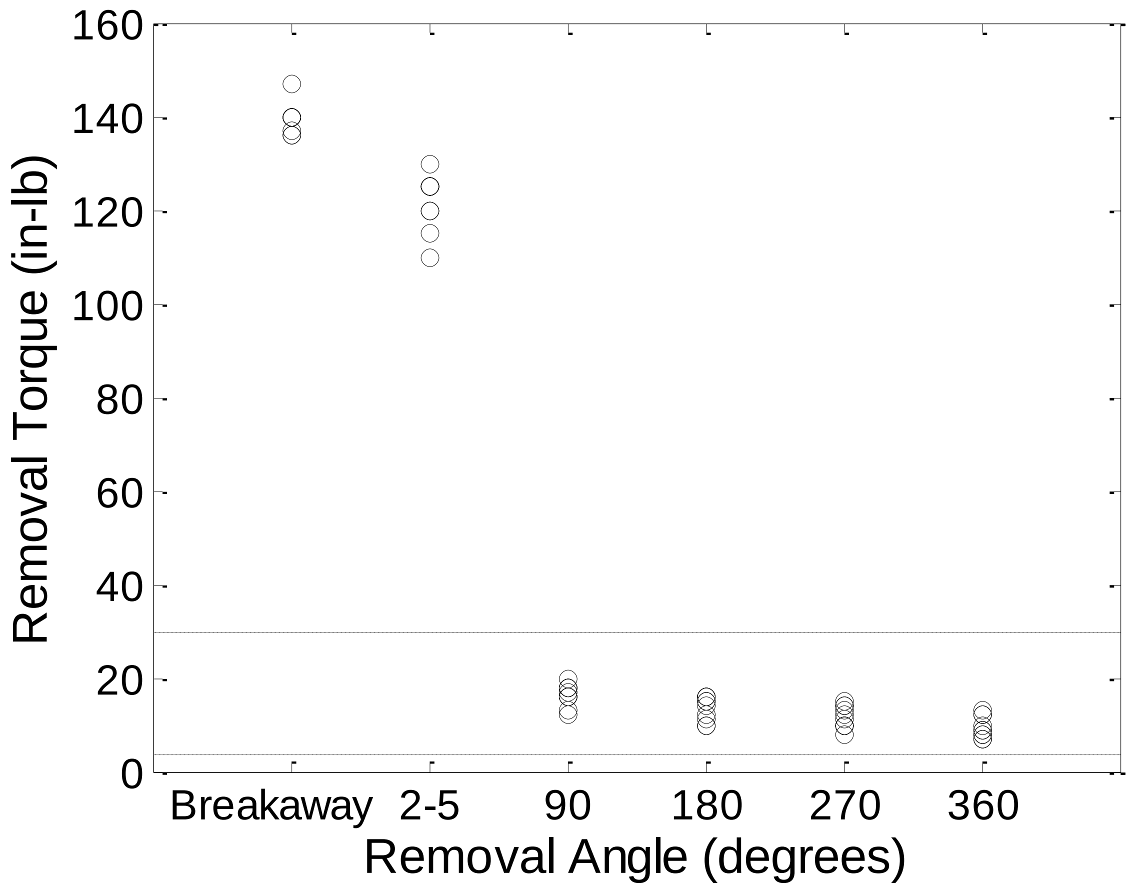

Figure 58 Seated A-286 Loctite 242 reuse adding anaerobic adhesive.

3.2.3.3 Seated A-286 Loctite 243

Since the anaerobic adhesive used is designed for passive substrates, there are no issues with curing.

A threaded fastener (#143) exceeded the range by 1 in-lbs. as shown in Figure 59. The range of the data became tighter towards the end of the hex nuts measurements.

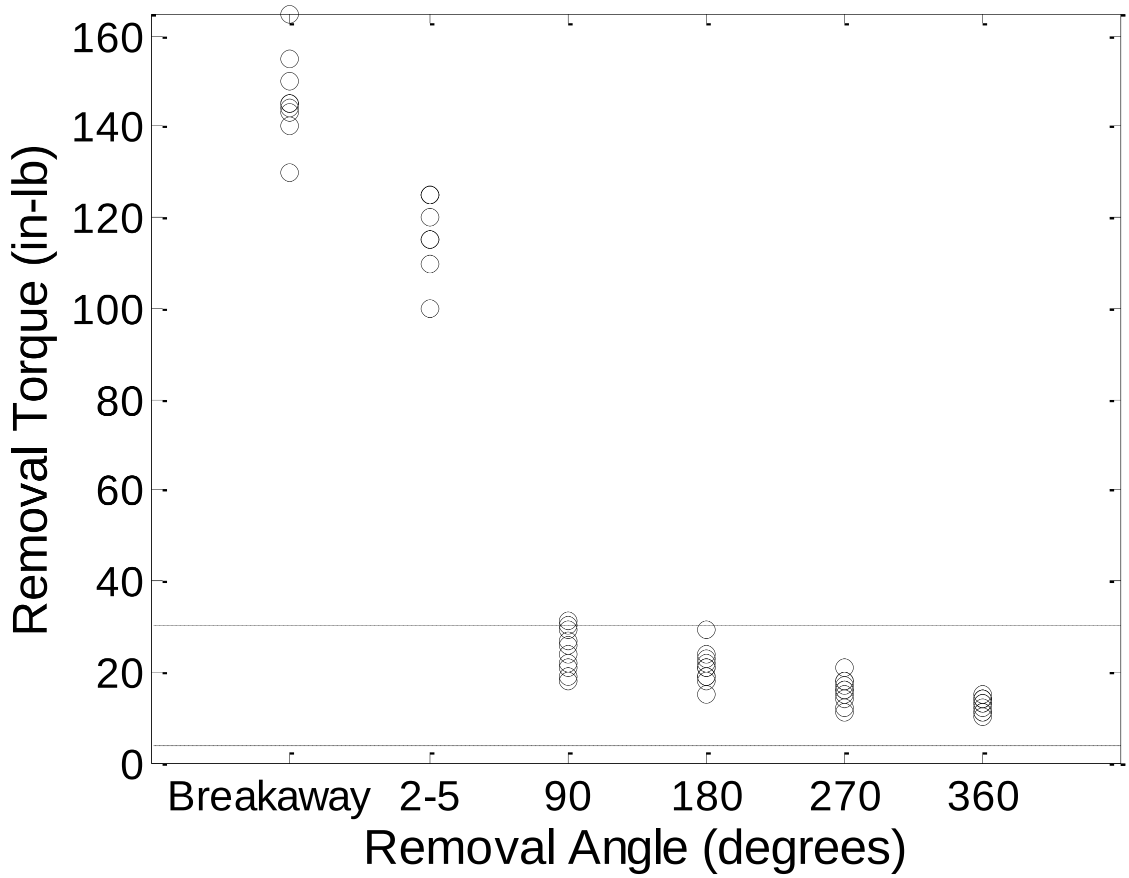

Figure 59 Initial seated A-286 Loctite 243.

The majority of the test specimens failed due to the fact when the hex nut was removed the cured anaerobic adhesive flakes off the threads as illustrated in Figure 60.

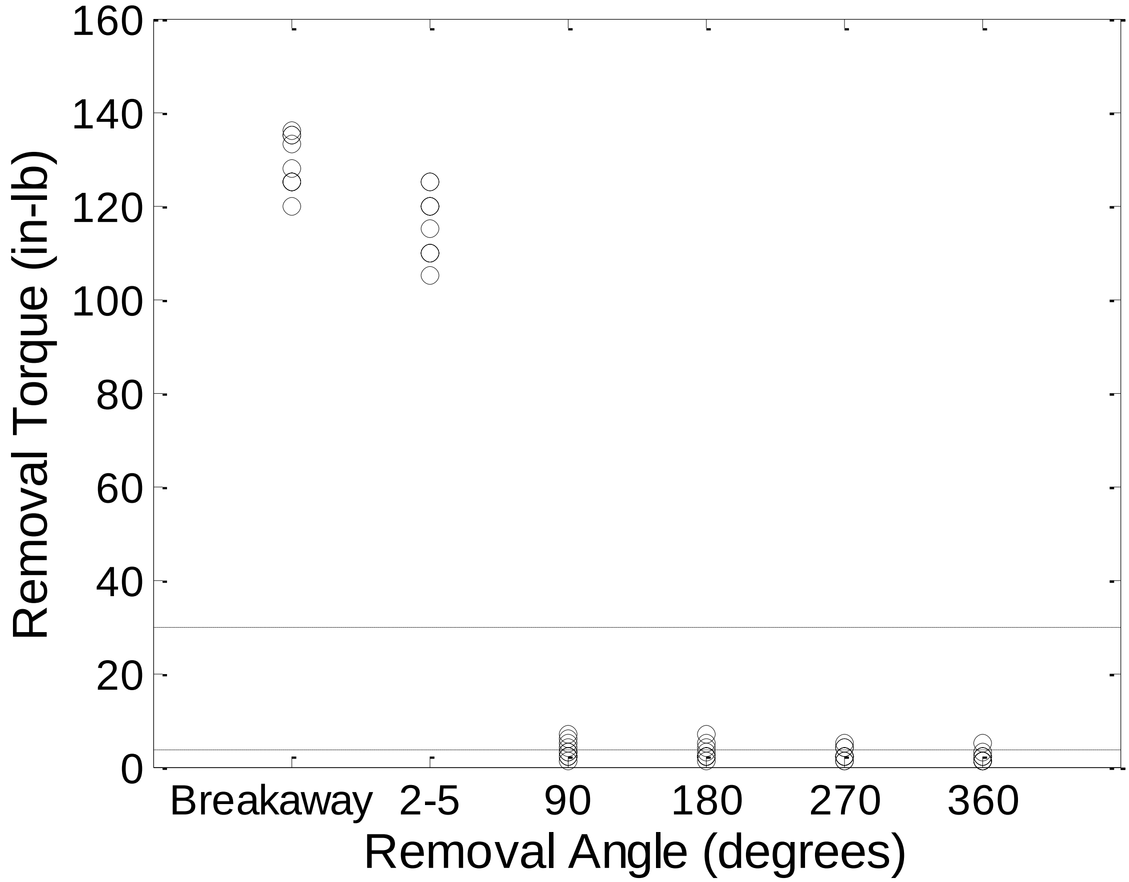

Figure 60 Seated A-286 Loctite 243 reuse.

When applying an additional coat of anaerobic adhesive the results compare to those of Figure 59. In Figure 59 most of the specimens were over 10 in-lbs. with one exceeding the upper bound of 30 in-lbs., while in Figure 61 all the specimens are around the 10 in-lbs. with some test specimens getting close to the 3.5 in-lbs. lower limit at 360 degrees. The range of the data is consistent throughout all of the removal angles.

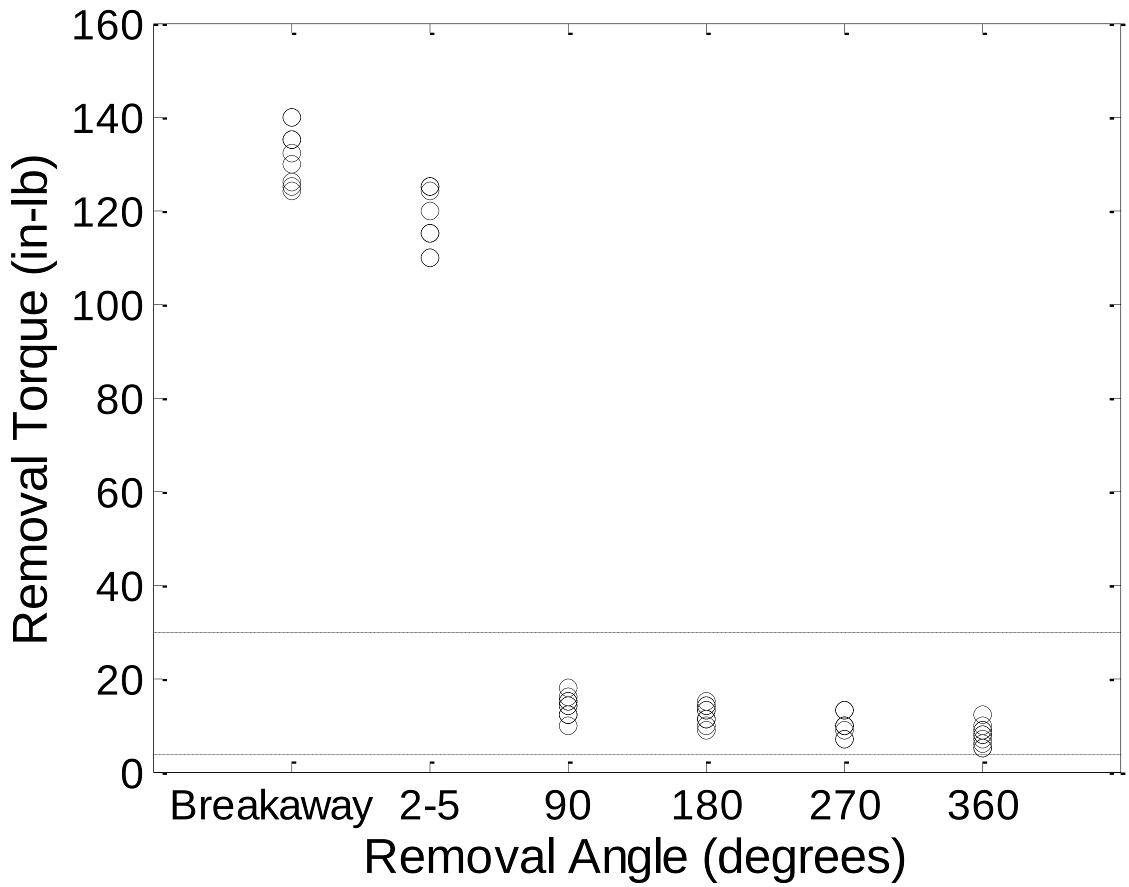

Figure 61 Seated A-286 Loctite 243 reuse adding anaerobic adhesive.

CHAPTER 4: DISCUSSIONS

4.1 Discussions for Unseated State

When tests were conducted on a specimen for the unseated state, it is set up and left to cure for 48 hours. After the allotted time, a torque wrench is applied to the hex nut to record the removal torque at the removal angles desired. Once the data is recorded the hex nut was completely removed and then fastened to the same location where it was initially cured at. This is considered to be the reuse of the threaded fastener. Another 48 hours pass and again a torque wrench was applied to the hex nut and the removal torque is measured for the desired removal angles. Then the hex nut was completely removed, anaerobic adhesive was applied to the threads of the cap screw and hex nut and the hex nut was fastened to the same location where the hex nut initially cured at. This is considered to be a reuse with adding anaerobic adhesive.

4.1.1 Discussions for Unseated Plain Grade 8

Table 17 illustrates the pass rates for unseated plain grade 8 threaded fasteners with Loctite 222MS, 242, and 243. For the initial use of anaerobic adhesive the low strength adhesive Loctite 222MS had all of threaded fasteners within the specification of 3.5 to 30 in-lbs. Loctite 242 and 243 had a lower pass rate due to threaded fasteners exceeding the limit of 30 in-lbs. According to the specification this is considered a failure but maybe advantageous to have threaded fasteners with higher prevailing torque.

When reusing threaded fastener without additional anaerobic adhesive added to the threads there was a lower pass rate as shown in Table 17. What seems to happen is as the hex nut was completely removed from the cap screw the anaerobic adhesive on the threads degrades lowering the friction between the threads. For Loctite 243, visible particles of cured anaerobic adhesive flake off the threads causing them to all fail. Loctite 242 had an 80% pass rate in this configuration.

The configuration where the test specimens are reused and additional anaerobic adhesive was applied to the threads, the amount that are within the specification increased compared to the reuse without additional product as illustrated in Table 17. For Loctite 222MS one specimen fell below the standard of 3.5 in-lbs. compared to Loctite 242 one specimen exceeded the limit of 30 in-lbs. All of the specimens with Loctite 243 passed when reused with additional anaerobic adhesive.

Table 17 Unseated plain grade 8 percent within prevailing torque specification.

Plain Grade 8	Loctite 222MS	Loctite 242	Loctite 243
Initial	100% Pass	90% Pass	10% Pass
Reuse no added Anaerobic Adhesive	10% Pass	80% Pass	0% Pass
Reuse adding Anaerobic Adhesive	80% Pass	80% Pass	100% Pass

4.1.2 Discussions for Unseated Yellow-Zinc Grade 8

The initial unseated state testing for yellow-zinc grade 8 threaded fasteners coated with Loctite 222MS, Loctite 242, and Loctite 243 were all within the specification of 3.5 to 30 in-lbs. as shown in Table 18. There was an operator error when the initial yellow-zinc grade threaded fasteners coated with Loctite 222MS test was performed. For one of the specimens the 0-75 in-lbs. torque wrench was not zeroed causing all of the data points to lower than they actually are. The data was left on the plot to illustrate that the threaded fastener followed the same sort of pattern as the other specimens.

Grade 8 threaded fasteners plated with yellow-zinc should not be reused without adding additional anaerobic adhesive due to the fact that most of the specimens did not pass as illustrated in Table 18. The reason why the majority of the test specimens were under the 3.5 in-lbs. limit is the same as before. Degradation seems to occur when the hex nut was completely removed from the cap screw. With Loctite 243, cured adhesive flakes off leaving the threads free of anaerobic adhesive. It is not recommended to reuse the threaded fastener when additional anaerobic adhesive is not applied to the threads.

When reusing the yellow-zinc grade threaded fasteners and applying additional adhesive the only configuration that did not pass at all of the removal angles was Loctite 222MS shown in Table 18. A specimen did not pass because it fell below the specification of 3.5 in-lbs.

Table 18 Unseated yellow-zinc grade 8 test results.

Yellow-Zinc Grade 8	**Loctite 222MS**	**Loctite 242**	**Loctite 243**
Initial	100% Pass *	100% Pass	100% Pass
Reuse no added Anaerobic Adhesive	10% Pass	30% Pass	0% Pass
Reuse adding Anaerobic Adhesive	80% Pass	100% Pass	100% Pass

*- Omitting specimen due to torque wrench not set to zero.

4.1.3 Discussion for Unseated A-286

In the initial unseated state for A-286 the only configuration that functioned was Loctite 243 as shown in Table 19. The reason why Loctite 222MS and 242 did not function with A-286 was that Loctite anaerobic adhesive works by forming polymer chains that attach to imperfections in the metal [2]. A passivate finish, which is found on the A-286 fasteners tested, creates an oxide film that is very uniform and smooth [16]. The smooth surface finish affects the curing of the anaerobic adhesive making it difficult for the polymer chains to attach to the surface. Also since oxygen is absorbed by the surface of the A-286 during passivation, there is still oxygen present when the hex nut is fastened to the cap screw even though the air voids between the threads are removed by the anaerobic adhesive. Loctite 243 cured and proved 100% pass rate because it is designed to cure on inactive metals.

When Loctite 222MS and Loctite 242 were reused without applying additional anaerobic adhesive to the threads some curing occurred displayed in Table 19. A possible reason why is when the fasteners are set up for the reuse, cured and uncured anaerobic adhesive was still coated on the threads of the cap screw and hex nut. When the hex nut was fastened to the cap screw, cured and uncured anaerobic adhesive was mixed causing the polymer chains to form between the anaerobic adhesives. Another possibility is when the hex nut was removed and fastened to the cap screw, it forces more of the oxygen out of adhesive initiating cure. For Loctite 243, the same issue of the cured adhesive flakes when disassembling the hex nut from the cap screw leaving the threads free from cured adhesive.

When the test specimens are reused and additional anaerobic adhesive was applied to the threads, the amount of test specimens that were within the specification increased illustrated in Table 19. Only two specimens did not pass for Loctite 222MS and Loctite 242. For both cases, the specimens had removal torque values of zero in-lbs. throughout all of the removal angles. The same two specimens had removal torque values of zero in-lbs. in the reuse case without additional anaerobic adhesive for Loctite 222MS and Loctite 242. All A-286 specimens coated with Loctite 243 in the reuse adding anaerobic adhesive passed. This shows that in the unseated state A-286 threaded fasteners with Loctite 243 applied to threads is a viable option.

Table 19 Unseated A-286 test results.

A-286	Loctite 222MS	Loctite 242	Loctite 243
Initial	0% Pass	0% Pass	100% Pass
Reuse no added Anaerobic Adhesive	60% Pass	50% Pass	10% Pass
Reuse adding Anaerobic Adhesive	78% Pass	78% Pass	100% Pass

4.2 Discussions for Seated State

When tests are conducted on a specimen for the seated state, it was set up and left to cure for 48 hours. After the allotted time, a torque wrench was applied to the hex nut to record the removal torque at the removal angles desired. Once the data was recorded the hex nut was completely removed and then fastened to the same preload set when initially cured. This is considered reuse of the threaded fastener. Another 48 hours pass and again a torque wrench was applied to the hex nut and the removal torque was measured for the desired removal angles. Then the hex nut was completely removed and anaerobic adhesive was applied to the threads of the cap screw and hex nut and the hex nut was fastened to the same preload initially cured at. This is considered to be reuse with adding anaerobic adhesive. Only data that did not have preload will be included for the pass rate in Tables 20, 21, and 22. In the upcoming sections the configurations that will be commented on are the ones that did not meet the specification of 3.5-30 in-lbs.

4.2.1 Discussions for Seated Plain Grade 8

In the initial seated testing for plain grade 8 threaded fasteners Loctite 243 demonstrated a 100% pass rate as shown in Table 20. With Loctite 222MS, two specimens fell below specification of 3.5 in-lbs. at 360 degrees. This is still an option as a prevailing torque locking feature due to the fact for most removal angles the specimens were within tolerance. With

Loctite 242 the removal torque was exceeded at 180 degrees. After 180 degrees the specimen was within tolerance. This sort of behavior can be desirable in certain situations.

In the seated state for plain grade 8 threaded fasteners, reuse without adding anaerobic adhesive is not a feasible option as shown in Table 20. With Loctite 242 only two test specimens were within tolerance for all removal angles. For Loctite 222MS one of the test specimens was within tolerance at 90 degrees for the reason that the specimen still had preload. On the other hand, with Loctite 243 all of the specimens did not pass because during removal of the hex nut the cured anaerobic adhesive flakes off leaving the cap screw and hex nut with small amounts of cured anaerobic adhesive.

When reusing plain grade 8 threaded fasteners with additional anaerobic, Loctite 242 passed throughout all removal angles as shown in Table 20. Only two specimens passed with Loctite 222MS compared to 8 specimens when the same configuration was tested in the unseated state. With Loctite 243, 8 specimens passed in the seated state compared to 10 specimens in the unseated state. At 360 degrees is where the two specimens fell below the specification for the reuse with the applying additional Loctite 243 on the seated plain grade 8 threaded fasteners. Since the specimens went below tolerance at the end of the hex nuts revolution, Loctite 243 still can be used as a prevailing torque locking feature if precaution is taken in this configuration tested.

Table 20 Seated plain grade 8 results.

Seated Plain Grade 8	Loctite 222MS	Loctite 242	Loctite 243
Initial	80% Pass	90% Pass	100% Pass
Reuse no added Anaerobic Adhesive	0% Pass	20% Pass	0% Pass
Reuse adding Anaerobic Adhesive	20% Pass	100% Pass	80% Pass

4.2.2 Discussions for Seated Yellow-Zinc Grade 8

All of the test specimens passed for the initial use of Loctite 242 and 243 on yellow-zinc grade 8 threaded fasteners. For the same configuration, two specimens failed with Loctite 222MS at 360 degrees. The results are illustrated in Table 21.

The majority of the test specimens went below the 3.5 in-lbs. limit for the reuse without additional anaerobic adhesive as demonstrated in Table 21. For Loctite 222MS one specimen stayed within the specification of 3.5-30 in-lbs. As for Loctite 242, two specimens stayed within tolerance. All of the specimens tested with Loctite 243 did not pass because the cured adhesive flaked off of the threads.

For the reuse adding anaerobic adhesive, all of the test specimens coated with Loctite 242 and 243 were within the specification as shown in Table 21. Most of the test specimens coated with Loctite 222MS did not pass because they went below the tolerance at 360 degrees.

Table 21 Seated yellow-zinc test results.

Seated Yellow-Zinc Grade 8	Loctite 222MS	Loctite 242	Loctite 243
Initial	80% Pass	100% Pass	100% Pass
Reuse no added Anaerobic Adhesive	10% Pass	20% Pass	0% Pass
Reuse adding Anaerobic Adhesive	40% Pass	100% Pass	100% Pass

4.2.3 Discussions for Seated A-286

In the initial seated state for A-286, the anaerobic adhesives that did not have a 100% pass rate are Loctite 222MS and Loctite 243 shown in Table 22. With Loctite 222MS one threaded fastener failed at 360 degrees because the fastener went below 3.5 in-lbs. For Loctite 243 one threaded fastener failed because it exceeded the upper limit of 30 in-lbs. A possible reason why the test specimen exceeded the limit is when the hex nut is unfastened the cured anaerobic adhesive binds in the threads increasing the friction.

When reusing the A-286 threaded fasteners without adding additional anaerobic adhesive, Loctite 242 had the best results of all of the test specimens being within tolerance. Loctite 222MS had only three specimens within the specification with the majority below the tolerance at 270 and 360 degrees. With Loctite 243 the majority of the specimens went below the tolerance after 270 degrees. The results are shown Table 22.

When the test specimens were reused and additional anaerobic adhesive was applied to the threads, the amount of test specimens that are within the specification increased illustrated in Table 22. A-286 with Loctite 222MS had three specimens below the specification of 3.5 in-lbs. when reused and additional anaerobic adhesive was applied. The rest of the configurations passed as shown in Table 22.

Table 22 Seated A-286 test results.

A-286	**Loctite 222MS**	**Loctite 242**	**Loctite 243**
Initial	90% Pass	100% Pass	90% Pass
Reuse no added Anaerobic Adhesive	30% Pass	100% Pass	10% Pass
Reuse adding Anaerobic Adhesive	70% Pass	100% Pass	100% Pass

4.3 Overall Discussion

After the variety of tests performed with different fastener materials, anaerobic adhesives and configurations, the potential use of anaerobic adhesive as a prevailing torque locking feature is found to be viable. From the test it was determined that when anaerobic adhesive was applied to the threads for the first time and cured, for most of the test configuration, it performs within the specification as a prevailing torque locking feature. Cases that are not within specification under these circumstances are the cases with Loctite 222MS and Loctite 242 in the unseated state with A-286 threaded fastener. Other than these cases, lower pass rates occurred for the initial application of anaerobic adhesives on threaded fasteners happened because the prevailing torque exceeded the specification of 3.5-30 in-lbs. which was still a failure to the specification but it illustrates that anaerobic adhesive has the capability of being used as a prevailing torque locking feature.

In very limited cases, reusing the initial anaerobic adhesive applied to the threaded fastener functions. The hypotheses why this configuration does not function is that the anaerobic adhesive was degraded when disassembled.

When reusing a threaded fastener and applying additional adhesive to the threads, a higher success rate was experienced with Loctite 242 and 243. In fact, removal torque vs. removal angle results were found to be nearly identical to the initial use. A possible reason why these anaerobic adhesives work in reuse with applying additional adhesive is that the adhesive already applied to the threads is bonded to the imperfections on the metal. The recently applied anaerobic adhesive bonds with adhesive originally on the threads, causing a sufficient amount of friction to meet the specification. For the lower strength Loctite 222MS it could be the bonds between itself is not strong enough to increase the friction to meet specification.

For convenience, Table 23 illustrates the configurations tested that resulted in 100% pass rates. Table 24 shows the configuration that did not pass due to the prevailing torque exceeding the 30 in-lbs. limit. These results reveal using anaerobic adhesive as a prevailing torque locking feature is a viable option. Test like the ones performed here should be implemented for the specific threaded fasteners, anaerobic adhesive, and joint configurations desired to be used.

Table 23 Configurations with 100% pass rate.

Fastener Material	Anaerobic Adhesive	Configuration
Plain Grade 8	Loctite 222MS	Unseated Initial use
Plain Grade 8	Loctite 243	Unseated reuse adding anaerobic adhesive
Yellow-Zinc Grade 8	Loctite 222MS	Unseated Initial use
Yellow-Zinc Grade 8	Loctite 242	Unseated Initial use
Yellow-Zinc Grade 8	Loctite 243	Unseated Initial use
Yellow-Zinc Grade 8	Loctite 242	Unseated reuse adding anaerobic adhesive
Yellow-Zinc Grade 8	Loctite 243	Unseated reuse adding anaerobic adhesive
A-286	Loctite 243	Unseated initial use
A-286	Loctite 243	Unseated reuse adding anaerobic adhesive
Plain Grade 8	Loctite 243	Seated Initial use
Plain Grade 8	Loctite 242	Seated reuse adding anaerobic adhesive
Yellow-Zinc Grade 8	Loctite 242	Seated Initial use
Yellow-Zinc Grade 8	Loctite 243	Seated initial use
Yellow-Zinc Grade 8	Loctite 242	Seated reuse adding anaerobic adhesive
Yellow-Zinc Grade 8	Loctite 243	Seated reuse adding anaerobic adhesive
A-286	Loctite 242	Seated Initial use
A-286	Loctite 242	Seated reuse without adding anaerobic adhesive
A-286	Loctite 242	Seated reuse adding anaerobic adhesive
A-286	Loctite 243	Seated reuse adding anaerobic adhesive

Table 24 Configurations that exceeded the specifications.

Fastener Material	Anaerobic Adhesive	Configuration
Plain Grade 8	Loctite 242	Unseated initial use
Plain Grade 8	Loctite 242	Unseated reuse adding anaerobic adhesive
Plain Grade 8	Loctite 243	Unseated initial use
A-286	Loctite 243	Unseated initial use
Plain Grade 8	Loctite 242	Seated initial use
A-286	Loctite 243	Seated initial use

CHAPTER 5: CONCLUSIONS

This thesis entitles if anaerobic adhesive can be used as a prevailing torque locking feature. A variety of threaded fasteners and anaerobic adhesives were tested in the unseated and seated state. A test procedure was developed for the unseated and seated states that resulted in repeatable data. Threaded fasteners with anaerobic adhesive applied were tested in three different scenarios. The first scenario was the initial use of anaerobic adhesive on a threaded fastener with 48 hour cure time. Next was to reuse the same threaded fastener after complete disassembly without applying additional anaerobic adhesive and a 48 hour cure time. For the last scenario reuse after complete disassembly but with additional anaerobic adhesive applied to the same threaded fastener and a 48 hour cure time. The main conclusions of this work is:

- Using anaerobic adhesive as a prevailing torque locking feature is a viable approach.
- Using anaerobic adhesive as a prevailing torque locking feature is not guaranteed to provide prevailing torque values within the specification for any combination of threaded fastener and adhesive. It is recommended to follow the test procedure developed to ensure if the combination of threaded fastener, adhesive, and joint configuration wanted to be used meets the specification.
- Anaerobic adhesive provides some prevailing torque even after the complete disassembly of the hex nut from the cap screw and reusing the thread fastener without applying additional adhesive and letting it cure for 48 hours.

- Reuse after complete disassembly and applying additional anaerobic adhesive and curing for 48 hours provides almost identical removal torque vs. removal angle data as initial test.

One of the advantages of using anaerobic adhesive as a prevailing torque locking feature is the reduced cost of materials. Another advantage of using an anaerobic adhesive is when first applied as a liquid to the threads, the adhesive acts as a lubricant which achieves a more accurate preload compared to prevailing torque locking features. Also if the idea of reusing the same threaded fastener with the same adhesive is not desired, anaerobic adhesive can be cleaned from the threads and can be reused with all new adhesive.

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