FAILURES OF FASTENERS

Harish V Umarji[1], Laxmanrao S Patil[2], Naveen V Kalasapur[3], Vaibhav K Sattur[4]

Department of Mechanical Engineering, KLE Institute of Technology, Hubli, Karnataka, India

ABSTRACT

This paper focused on the overview of failure analysis of high tensile fasteners. An industrial fastener comprises a very wide range of items like nuts and bolts, washers, studs, nails etc. Nuts and bolts are used for fastening purpose in industries where the replacement of pieces and the parts is necessary. Although, fastener is a low-cost class C item, but fastener failure is undesirable as is the first item that gets the blame when there is a failure, aftereffects of fastener failure are cumbersome which cause financial loss to machine & process. Hence, the cause of failure is understood & eliminated.

Keyword: - *Hydrogen Embrittlement, Fastener failure, Fasteners plating & baking, Zinc passivation*

1. INTRODUCTION

A "fastener is a hardware device that mechanically joins or affixes two or more objects together. In general, fasteners are used to create non-permanent joints; that is, joints that can be removed or dismantled without damaging the joining components".
Nuts and Bolts are most commonly used items in the family of industrial fasteners and their demand is fast increasing due to expansion of industries in the country. Bolt is a piece of metal rod whose one end is upset and at the other end threading is done. Nut is a device which rolls on bolt threads. In nuts, internal threading is done while bolts bear external thread. Screw, demonstrate their true merit in the movements, assembly etc, of wooden components. Screws are most popular as fasteners which assemble or join parts together to be made into a complete unit.
Although the fastener is the first item that gets the blame when there is a failure, our experience is that the fastener will meet the specs it was intended to meet most of the time. At that point putting experienced engineers and equipment to work can save significant time in analysing the situation and preventing future failures.
Historical Background on Screw Threads. It is considered by some that the screw thread was invented in about 400BC by Archytas of Tarentum (428 BC - 350 BC). Archytas is sometimes called the founder of mechanics and was a contemporary of Plato.

1.1 Brief History

Let us begin with the screw, a fastener that keeps the roof over our heads and the floor under our feet. The screw thread is believed to have been invented around 400 BCE, by Archytas of Tarentum, a Greek philosopher sometimes called "the father of mechanics.
Ex: Permanent Fasteners such as Welding, temporary fasteners such as Screws, Bolts, etc.
In General, Fasteners, can be divided into 2 main categories;
Non-Permanent and Permanent Fasteners.
Non-Permanent Fasteners: They enable parts to be assembled and disassembled repeatedly, they can further be divided into 2 groups:
General Fasteners: Such as keys, pins, retaining rings, Etc. (Associated with shafts)
Permanent Fasteners: This kind of fastening may not be removed easily, removing will damage the surface.
Ex: Welding, Soldering, Riveting (Removal would mean destroying them), brazing, forge welding, etc.
Threaded Fasteners: Bolts, Screws, Studs, Setscrews, etc. These are the most widely used fasteners since they can be easily removed then reused.

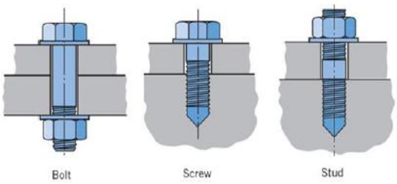


Fig-1: Threaded Fasteners

2.TERMINOLOGIES IN THREADED FASTENERS:

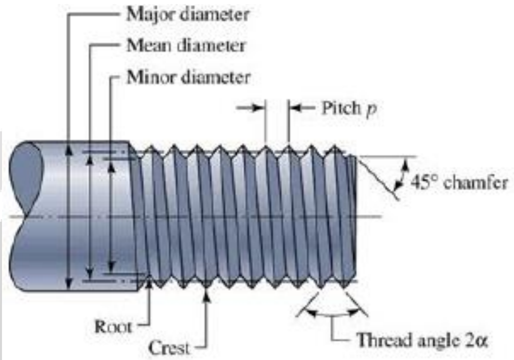


Fig-2: Fastener Terminology

Major Diameter (D, d): The largest diameter of the screw thread.
Minor Diameter (D_1, d_1): Also called root diameter, is the smallest diameter of the screw thread.
Mean diameter (D_2, d_2): Also called pitch diameter, the average diameter of the screw thread.
Pitch (p): The distance between adjacent threads measured parallel to thread axis.
Thread Angle (2α): The angle between the mating faces of two adjacent threads.
All threads are usually right handed unless otherwise is indicated (screws with right handed threads advance forward when the screw is rotated in the direction of the curled right-hand fingers).

2.1 Standards

Metric ISO: There are 2 standard profiles M and MJ where both have a similar geometry, but MJ has a rounded fillet at the root and a larger minor diameter.
Unified ANSI:

- There are 2 standard profiles UN and UNR where the UNR has a filleted root
- Unified threads are specified by the major diameter(inch) and the number of threads per inch

Ex: ¼ - 20 UNC, ¼- Diameter ,20-N, UN- Profile, F- Coarse or Fine

Table gives preferred standard sizes for Metric bolts and screws ISO 262:

- Note that there is Coarse-Pitch and Fine-Pitch where the fine-pitch has better tensile strength.
- If the thread being specified is "coarse" pitch thread, the pitch can be omitted from the designation.

Ex: M10 X 1.5 or M10

Nominal Major Diameter d mm	Coarse Pitch p mm	Fine Pitch p mm	Nominal Major Diameter d mm	Coarse Pitch p mm	Fine Pitch p mm
1.6	0.35		20	2.5	1.5
2	0.40		24	3	2
2.5	0.45		30	3.5	2
3	0.5		36	4	2
3.5	0.6		42	4.5	2
4	0.7		48	5	2
5	0.8		56	5.5	2
6	1		64	6	2
8	1.25	1	72	6	2
10	1.5	1.25	80	6	1.5
12	1.75	1.25	90	6	2
14	2	1.5	100	6	2
16	2	1.5	110		2

Table-1: Standard sizes for Metric Bolts and Screws ISO 262

2.2 External and Internal Threads

- External Threads: External threads are on the outside of a member (threads of bolts and screws). A chamfer on the end of the screw thread makes it easier to engage it into a hole or nut.
  External thread is cut using a die.

- Internal Thread: Internal threads are on the inside of a member (threads of nuts and holes). Usually threaded holes have a chamfer on the side from which the screw will enter to make its engagement easier.
  Internal thread is cut using a tap.

2.3 Types of bolts and Screws

There are many different types of bolts and screws where each is suitable for different types of applications. While bolts have hexagonal heads, there are several head styles that are being used in cap screws. The fig shows some of the common head styles that are used for cap screws.

- All head dimensions are standardised, and they are usually given in tables according to the nominal size

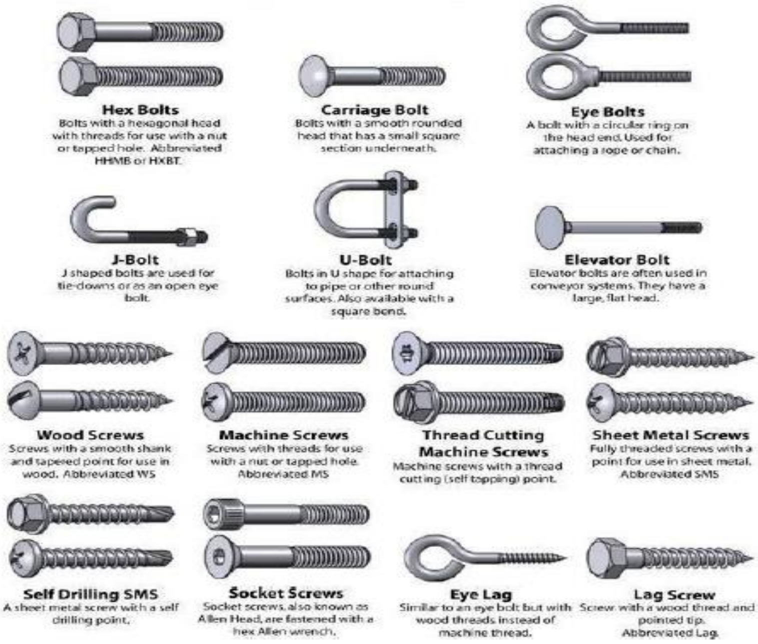
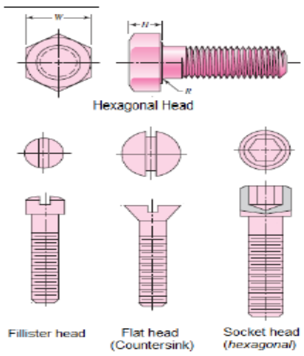


Fig 3: Types of bolts and screws

The table shown gives the standard head dimensions for regular hexagonal head bolts.



Nominal Size, mm	Regular Hexagonal W	H	R_{min}
M5	8	3.58	0.2
M6	10	4.38	0.3
M8	13	5.68	0.4
M10	16	6.85	0.4
M12	18	7.95	0.6
M14	21	9.25	0.6
M16	24	10.75	0.6
M20	30	13.40	0.8
M24	36	15.90	0.8
M30	46	19.75	1.0

Table-2: Standard head dimensions for regular hexagonal head bolts

3.APPLICATION OF FASTENERS

Some of applications of fasteners are as follows:

- Military – Fasteners specially designed to withstand the stress of high temperature, high wear and corrosive environments such as engines, motors, heat exchangers and process equipment. We offer a wide range of diameters, lengths and thread configurations using stainless steel, copper alloys, alloy steels, nickel alloys and exotic alloys.
- Oilfield – Fasteners manufactured using stainless steel, tool alloys, nickel alloys and exotic metals that will perform well in the high stress, corrosive environment found in oilfield and mining applications. Our fasteners are used in drilling rigs, tanks and pumping equipment.
- Turbine & Power Generation – Fasteners used in electrical equipment, turbines, motors, exhaust systems, pumping systems and storage vessels. Nickel alloys, aluminum, steel alloys and stainless steel are used for their strength, high wear and anti-corrosive properties. Copper alloys are used for their conductive properties.
- Chemical Refining – Fasteners manufactured using stainless steel, tool alloys, nickel alloys and exotic metals that will perform well in the high stress, corrosive environment found in chemical processing applications. Our fasteners are used in heat exchangers, exhaust systems, tanks and vessels, and processing equipment.
- Marine – Fasteners that perform well in the harsh marine environment without corroding. Copper alloys are ideal for the marine environment and bronzes perform well in saltwater applications. In addition, stainless steel and aluminum are also popular materials. Our fasteners are used for decks, ramps, bulkheads, tanks and a wide range of products and components.
- Replacement parts – We manufacture replacement fasteners for unique OEM products as well as specialty fasteners that are used in custom products.

4. Failures of Fasteners

4.1 Strength of materials point of view

Failure is the inability to perform the assigned task, failure does not necessarily mean the fracture of the fasteners, there are various causes of failures, some significant causes are discussed below.
Failed pieces have shown vibration in tensile strength, Lab analysis shows that 97% fasteners failed due to Hydrogen Embrittlement, 2% because of Tensile Failure due to over tightening and 1% due to metal corrosion.
The root cause of failure is because of Hydrogen Embrittlement.

TYPES OF FAILURES OF FASTENERS:

- Failure because of Overload

Many accidents can be characterized as an impact with a non-compliant object such as a truck impacting a concrete bridge support. The fine, grey appearance of the fracture surface is consistent with a sudden overload failure.

- Failure from lack of Locking Mechanism

To prevent bolts from loosening over time, various locking mechanisms are employed. They include lock washers, locking nuts, jam nuts, mechanical deformations, wire wrap, cotter pins, metal locks, expansion anchors, helical coils and polymer locking compounds. Machinery that is subject to vibratory environments usually is equipped with some sort of locking mechanism. If the locking mechanism is not applied to the machinery during manufacture, a catastrophic event may result.

- Metal Fatigue

Metal fatigue is the phenomenon characterized by progressive crack growth during cyclic loading. A crack is often initiated at a flaw or stress riser (sharp notch) in a part. Cyclic forces such as vibrations or repeated impact cause the crack to increase in size until the part can no longer sustain the load, and a final fracture occurs

- Failure from Improper Torque

When threaded fasteners are utilized, the amount of tightening or bolt torque is often important. Motor vehicle wheel studs require torques ranging from about 100 ft-lbs for smaller vehicles to over 400 ft-lbs for large trucks. The appropriate torque is required in order to prevent relative flexing of the two parts being fastened and to assure an acceptable mechanical connection. Bolt failures as a result of improper torque have occurred in automobile applications.

- Corrosion Failure

Corrosion of metals can be disastrous to threaded fasteners. Surface and pitting corrosion attacks threaded fasteners as a result of contact with moisture or other corroding media. Since bolts often carry high loads, stress corrosion cracking is another corrosion related failure mode. Corrosion, coupled with forces in a bolt, tends to accelerate cracking.

- Hydrogen Embrittlement (HE)

A permanent loss of ductility in a metal or alloy caused by hydrogen in combination with stress, either externally applied or internal residual stress.

- Galling

If you've ever had the pleasure of installing or removing stainless steel fasteners, you've more than likely experienced galling. Galling is a cold-welding process that results when the threads are in contact under heavy pressure and friction. Or in other words, when fasteners are assembled or disassembled.

4.2 Sample Case of Failure in Industrial Application

A cables and control levers manufacturing company offer a full line of controls and cables for commercial vehicles, industrial machines, construction equipment, boats and special purpose vehicles.

They were having bolt failure directly underneath the head of the fastener. The failure is a delayed failure. The delay is generally from one to 24 hours after installation.

Fastener was under standard load conditions. They were using higher grade fastener with 32+ HRC.

To avoid corrosion Zinc passivated fasteners are used as area of application is in marines.

4.3 Methodology for Failure Analysis

According to the problem identified and the objective of study. The proposed methodology includes the step by step procedure to obtain the solution. This includes understanding process flow of metal plating, sample collection for testing.

Step 1: Understanding field conditions, loads experienced by the fastener, and other factors
Step 2: Collecting sample of both the failed piece(s) and unused parts from the same lot.
Step 3: Lab analysis - Laboratory testing will confirm whether there are any issues with that lot.
Step 4: Understanding & monitoring processes done on fastener – Plating/Galvanizing
Step 5: Finding root cause of failure in process/product selection.
Step 6: Suggesting best possible alternative.
Step 7: Comparing the results obtained with respect to the prior failure rate.
Step 8: Application of best suited process.

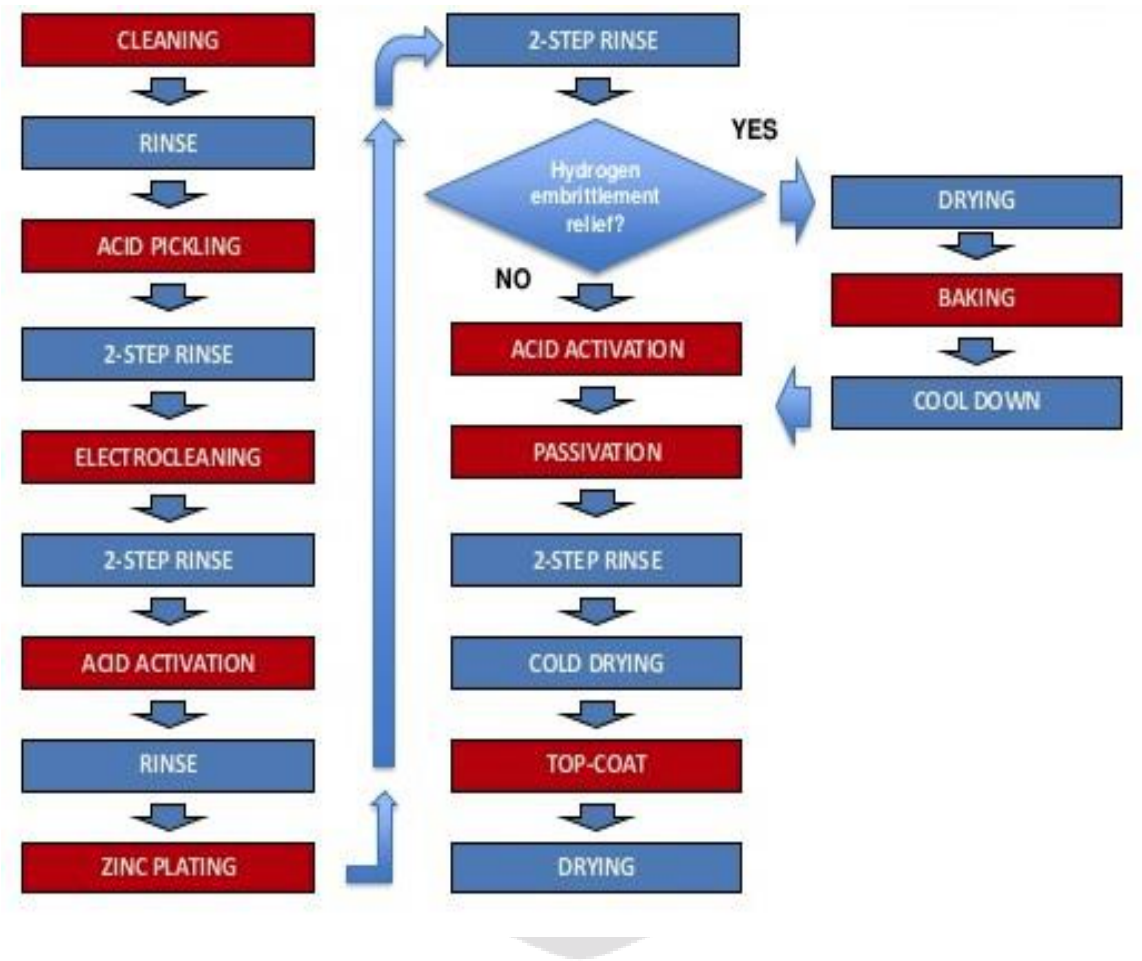


Fig 4: Failure Analysis Methodology

The failures occurred sometime after installation, usually between 1 and 24 hours.
• The part was under design stress when failure occurs.
• Fastener was Zinc passivated to avoid failure due to metal corrosion.
• High tensile grade fastener was used to sustain more tensile strength.

- Sample Selection

A Sample of 100 Pcs. is taken from both the failed piece(s) and unused parts from the same lot for LAB Analysis. LPS has a NABL certified laboratory in plant premises for testing of fasteners.

- LAB Analysis Result

Fastener testing shows following result:

- Unused fasteners meet the appropriate standards. Their material composition & strength was as per manufacturing IS standards.
- Failed pieces have shown variation in tensile strength. LAB analysis shows that 97% fasteners failed due to Hydrogen embrittlement, 2% failed because of tensile failure due to over tightening & 1% due to metal corrosion. The root cause of the failure is because of hydrogen embrittlement.

After analysing the process flow chart & type of fastener used it is found that they were using zinc passivated fastener to avoid metal corrosion. Hydrogen is getting induced in zinc plating (galvanizing) process.

Hydrogen ions, which will later combine to form hydrogen molecules, trapped within grain boundaries promoting enhanced de-cohesion of the steel which caused fastener failure.

4.4 Hydrogen Embrittlement

Hydrogen embrittlement can be described as absorption of hydrogen ions, which will later combine to form hydrogen molecules, trapped within grain boundaries promoting enhanced de-cohesion of the steel, primarily as an intergranular phenomenon. Hydrogen embrittlement is generally associated with high-strength fasteners. Hydrogen embrittled fasteners or parts under stress can fail suddenly without any warning. Hydrogen embrittlement can occur whenever atomic or protonic hydrogen is produced from a reaction, e.g. acid pickling can react iron and hydrochloric acid to diffuse hydrogen in iron.
Hydrogen embrittlement is generally associated with high-strength fasteners made of carbon and alloy steels. Hydrogen embrittled fasteners or parts under stress can fail suddenly without any warning. Hydrogen is the most common element in the world and many acidic and oxidation reactions with steel will liberate hydrogen in various amounts depending on the specific chemical reaction.
Hydrogen embrittlement can occur whenever atomic or protonic hydrogen is produced from a reaction, e.g. acid pickling can react iron and hydrochloric acid to diffuse hydrogen in iron. During acid pickling hydrogen can be diffused into the iron. Electroplating is another process to introduce hydrogen into a metal in both the acid pickle and the plating processes.

Conditions for hydrogen embrittlement failure

Three conditions must be met to cause hydrogen embrittlement failure:

- Steel that is susceptible to hydrogen damage,
- Stress (typically as an applied load), and
- Atomic hydrogen.

If all three of these elements are present in sufficient quantities, and given *time*, hydrogen damage results in crack initiation and growth until the occurrence of fracture. *Time to failure* can vary, depending on the severity of the conditions and the source of hydrogen.

Source of Hydrogen ions

Frequently, hydrogen is introduced to the fastener during the electroplating process. In these cases, the hydrogen is absorbed into the fastener during the acid cleaning or descaling process and is then trapped in the part by the plating. A subsequent baking process is typically employed to remove or displace the trapped hydrogen. Even proper baking is no guarantee of freedom from hydrogen.
Effect of Hydrogen ions

Hydrogen embrittlement failures occur where the stress in the screw or bolt is most highly concentrated when installed in an application. When tension is applied to the fastener, the hydrogen tends to migrate to points of high stress concentration (under the head of the fastener, first engaged thread, etc.). The pressure created by the hydrogen creates and/or extends a preexisting crack which grows under subsequent stress cycles until the bolt breaks.
For example, electroplating provides a source of hydrogen during the cleaning and pickling cycles, but by far the most significant source is cathodic inefficiency. A simple hydrogen bake out cycle can be performed to reduce the risk of hydrogen damage.

Factors That Influence Hydrogen Embrittlement on Parts

The severity and mode of the hydrogen damage depends on:
• A tensile strength > 1050MPa, 1000N/mm2 or
• A hardness > 32 HRC or above (10.9 grade fasteners or above)
• Source of hydrogen—external (gaseous)/internal (dissolved).
• Exposure time.
• Temperature and pressure.
• Presence of solutions or solvents that may undergo some reaction with metals (e.g., acidic solutions).
• Amount of discontinuities in the metal.
• Treatment of exposed surfaces (barrier layers, e.g., oxide layers as hydrogen permeation barrier on metals).
• Final treatment of the metal surface (e.g., galvanic nickel plating).

Methods of Checking Hydrogen Embrittlement

When metals are subjected to pickling processes, the metals are dissolved by the acids and hydrogen is generated. The hydrogen is also generated during electrolytic de-greasing, electrolytic pickling, and electro-plating. This hydrogen is occluded (absorbed) by the base metal, especially steel alloys and makes the steel brittle. This phenomenon is the Hydrogen Embrittlement. Parts with hydrogen embrittlement can break after being subjected to loadings. Here, we'll look delta method to see how much hydrogen embrittlement there is on plated steel.

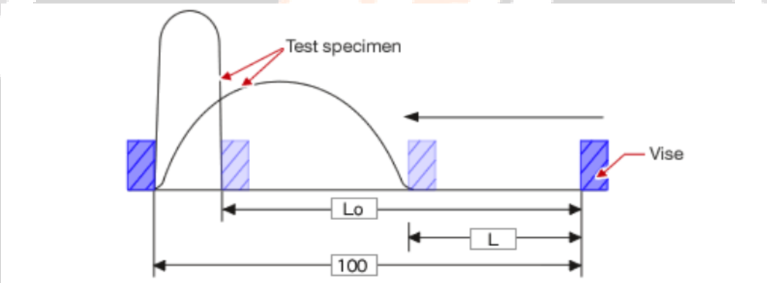


Fig 5: Delta Gage Method

The method uses steel plates made of alloys susceptible to hydrogen embrittlement, press bent in a constant speed vise, and the vise travel distance to the point of breakage is measured. The distance traveled indicates the degradation of flexibility of the test specimen, in turn indicates the extent of the hydrogen embrittlement. It is also called "Slow press-bent destruction method". Fig 5 above shows the measurement principle of the Delta Gage method.

Hydrogen embrittlement rate (%) = $(L_0\text{-}L)\ 100\ /\ L0$
Where,
L_0: Vise travel distance to breaking point for test specimen not pickled (no hydrogen embrittlement) in mm.
L: Vise travel distance to braking point for pickled test specimen with hydrogen embrittlement.

Prevention of Hydrogen Embrittlement

Steps that can be taken to avoid hydrogen embrittlement include reducing hydrogen exposure and susceptibility, baking after plating (mandatory and as soon as practical) and using test methods to determine if a material is suspect. Other options that could help in avoiding hydrogen embrittlement include the use of lower strength steels (not always viable), the avoidance of acid cleaning, the utilization of low hydrogen plating techniques and the reduction of residual and applied stress.

If any of these factors are not present, the chances of the failure being confirmed as hydrogen embrittlement are unlikely.

- Do not electro-plate inch socket head metric property class 12.9 bolts or screws.

- If customers insist on using electro-plated bolts and screws, suggest they consider using a Grade 8 or property class 10.9 part of a slightly larger diameter instead of using the socket head cap screw or property class 12.9 part.

- If the customer insists on using an electro-plated socket head cap screw or property class specify that the parts must be baked at 190 ^{o}C-200 ^{o}C within one hour after plating for at least four hours. Also, conduct one of the recognized hydrogen embrittlement tests on every lot of parts to provide you the opportunity to catch hydrogen embrittlement before it is exhibited in the user’s application.

- If you must electro-plate any type of tapping screw, specify to the heat treater that the core hardness of the screws must not exceed 32 HRC.

ALTERNATIVE SUGGESTED:

Uncoated Fasteners: Fasteners must be oil hardened & oil tempered with minimum or no scale, coming from oil tempering, least possibilities of rusting. But, after discussing with design team they need zinc passivated fasteners for avoiding metal corrosion.

Grade 10.9 (Tensile Strength 1040 N/mm^{2}) and 12.9 (Tensile Strength 1220 N/mm^{2}) grade Fasteners are not recommended for Zinc Plating as they may absorb Hydrogen during the coating process, which then causes embrittlement of the bolts.

Baking Parts (Hydrogen De-embrittlement) after coating will reduce the risk of failure, but this process can never be assumed to be 100% effective.

Solution: If electroplating is still desired, ensure that the plater uses the proper procedures and bakes the fasteners correctly based on the Hardness of the fastener. For the requirement of Plating on Fasteners, we suggested Grade 8.8. In general, if the hardness of the fastener is less than 32 HRC, there will probably be little difficulty with hydrogen embrittlement. However, if the fastener has hardness above 32 HRC, problems are more likely to occur.

Result: Usage of uncoated fasteners is one of the best cost-effective engineering solution however zinc passivation to be given up to some extent due to working condition.

Low grade fastener for Zinc passivation reduced the fastener failure by Approximately 98%, rest 2% failure is found because of :-

• Tightening methods
• Thread lubrication
• Corrosion
• Galling

5.FAILURES FROM FINITE ELEMENT POINT OF VIEW

(Includes Experimental Investigation)

Experimental Investigation:

Namely two types of Experimental work have been conducted:

- Tensile testing for thread failure load calculation

- Thread loosening performance of test rig.

- Tensile testing for thread failure load calculation

Thread failure testing used for determination of proof load limits applied on nut bolt assembly. Proof load is the maximum safe load that can be applied to a fastener without inducing permanent deformation, as with yield. For that tensile test of nut bolt assembly is taken to determine the maximum proof load and breaking load. Tensile test is better than compressive testing for shearing the threaded fasteners. The tensile test is done on Universal testing machine having capacity of 40 tonnes. The free body diagram for load application.

The maximum load carried by first threads while the loads are reduced one by one on remaining. The engaged threads are failing first and the maximum load for thread failure is obtained in load vs deflection curve. The bolts of M8, M10, M12, M16, and M20 and pitches are 1.25, 1.5, 1.75, 2 and 2.5 respectively are used for the tensile test.

- Tensile test results

The load vs deflection curves of nut bolt assembly of M8 x 1.25, M10 x1.5, M12 x 1.75, M16 x 2, and M20 x 2.5
as shown in graphs given below. The tensile stress area is used as shown table 1.1 as input to the UT machine. The behavior of curve initially a straight line, that shows maximum load sustained by threads before failure known as proof load. As load increases beyond the limits of ultimate tensile, the threads fail at breaking load. The purpose of this test is to decide the limits of proof load for applying the pretension load on nut bolt assembly without thread failure. Pretension load on assembly must be less than proof load for thread. If the pretension load exceeds the value of proof load, the thread failure occurs due to shearing between engaged threads of nut and bolt.
The values of tensile loads, proof loads and breaking loads are obtained from tensile tests of different sizes of nut bolt assemblies as shown in table, the comparison of load deflections curves of various dimensions of nut bolt tensile test as follows

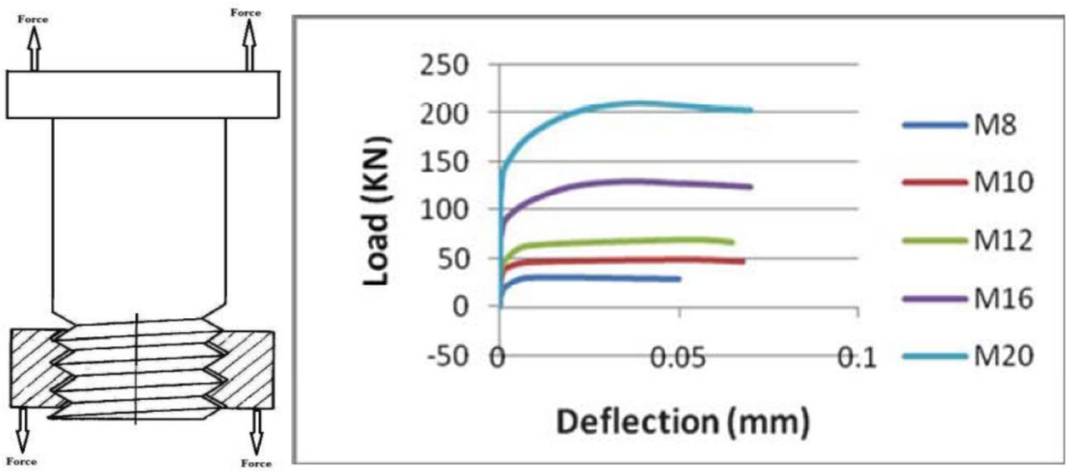


Fig 6: Tensile test results

- Thread loosening performance of test rig

The most widely used apparatus for experimental study of loosening performance of nut bolt assembly under dynamic shear load. The transverse vibration test apparatus developed by Junker. Similar model of manually operated test rig is fabricated as shown in Fig 6. It consists of two plates having thickness 10mm each with center holes for assembly of different diameters of nut bolts. The lower plate is fixed to the fixed base foundation while the upper movable plate is sliding over lower plate. In between these two plates rollers are inserted for reducing friction between them. The movable plate is connected to connecting rod which is also connected to eccentric shaft which produces the oscillations. The eccentric shaft is rotate on bearing supports. The big pulley is mounted on the eccentric shaft while small pulley is mounted on motor shaft. Both pulleys are connected by belt. The motor rotates at 1440 rpm reduced to 600 rpm to eccentric shaft in order to 600 oscillations per minute to the movable plate.
The torque wrench is used to apply preload calculated for different dimensions of bolts. The bolt is inserting in two plate of test rig and nut is tight. The preload is applied on bolt head, and then the machine is start. Check the loosening performance of nut with bolt at various stages during the rotation of machine. Lamps the top movable plate to the rigid fixed base through a threaded insert. Roller bearings are placed between the top plate and the fixed base to prevent galling. The top plate is subjected to a cyclic shear load through an arm connected to an eccentric.

The influence of the type of slip on loosening is illustrated in Fig 6. Which shows a typical Preload versus No. of cycles plot of loosening obtained using the transverse vibration test apparatus. The loosening rate shows a drastic increase as soon as head slip changes from localized to complete slip.

Size	Pitch	Area of Root of Thread	Tensile Stress Area of Thread	Proof Load	Breaking Load
	mm	mm^2	mm^2	KN	KN
M8	1.25	32.84	36.6	21.5	29.4
M10	1.5	52.29	58	34	46.6
M12	1.75	76.24	84.3	49.2	67.6
M16	2	144.12	157	91.3	125
M20	2.5	225.18	245	147.3	203.2

Table 3: Test Results

Fig 7: Test Rig

Material Definitions

The next step after modeling is Analysis is the. IGES format file is imported in Ansys workbench. The Contact regions are automatically defined in ANSYS which involved bonded type of interactions within plate and bolt, nut and bolt, plate and nut and plate with bolt. The next task is assigning the materials for plate is mild steel is assign with density 7850 Kg/m3, and for nut and bolt mild steel with density 7850 Kg/m3 are assign. Proper assignment of various material properties plays an important role in analysis. Another most important part of analysis is the meshing. Figure 8 Shows the meshed generated for M16 nut bolt assembly. Coarse mesh with hexahedral elements is used for meshing.

The number of nodes and elements for various models are shown in table.

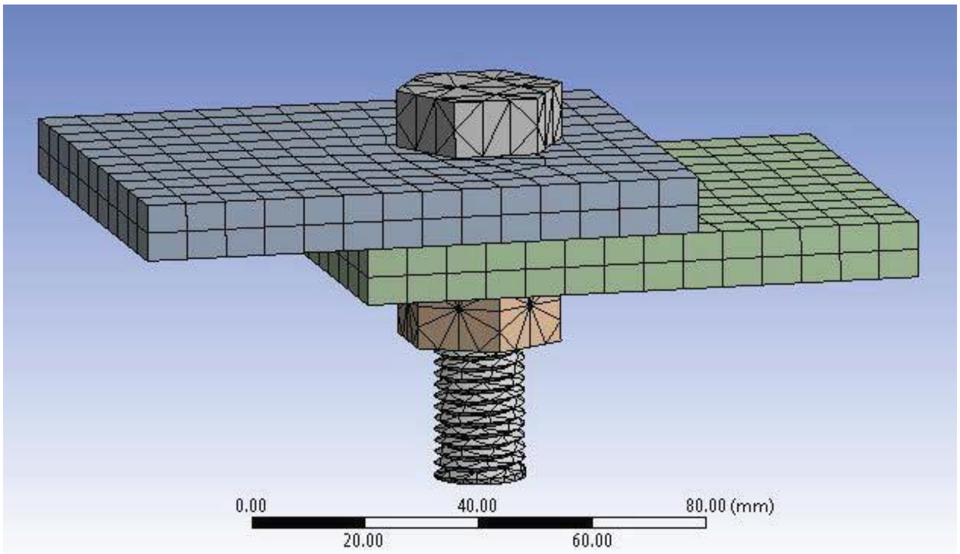


Fig 8: ANSYS Model

Sr.No.	Designation	Nodes	Elements
1	M8	9460	3147
2	M10	10079	3697
3	M12	9432	3374
4	M16	9039	3145
5	M20	9451	3401

Table 4: Nodes and Elements for Various Models

Boundary Conditions

As explained earlier preprocessor, processor and post processor are the three main steps of any CAE analysis. Modeling and meshing comes under preprocessor. Next step i.e. processor is applying boundary conditions such as loads and supports which implies the physical condition of the problem for which the problem will be simulated. Figure 9 shows the boundary conditions applied for the model

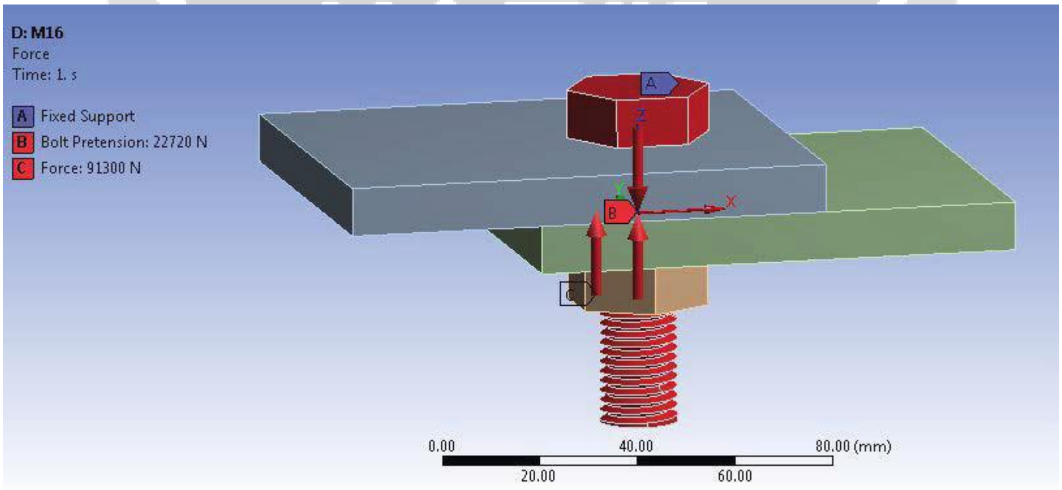


Fig 9: Load Simulation

Three boundary conditions are applied for each of nut and bolt assembly. The top surface of the nut is applied as fixed support. The bolt pretension load is applied for bolt body and force is applied to the nut surface which indicated the amount of force required to tight the nut. According to the experimental procedure different pretension loads and force is applied to different nuts and bolts table shows the different values of loads for different nut and bolt.

Sr.No.	Designation	Pretension Load (KN)	Tensile Force (KN)
1	M8	11.36	21.5
2	M10	14.20	34
3	M12	17.40	49.2
4	M16	22.72	91.3
5	M20	28.40	141.3

Table 5: Values of Loads

Solutions

Finally, all the required data for analysis is provided in Ansys. Preprocessor and processor are defined now next step is the solution. As the problem is not dependent on time a static analysis is performed for getting desired results and stress and deformation. Stress tool is selected for results with von-misses stress and deformation is selected for analyzing the amount of deformation for given loading conditions. As the numerical method is same for all the nuts and bolts of designation M8, M10, M12, and M16 the sequence of method for analysis is same except the magnitude of force and bolt pretension. Hence, results for stress and deformation are evaluated for the specified boundary conditions. The contours and animations are obtained after successful completion of solution process in order to get insight on bolt performance at different loading conditions.

Result and Discussion

Result for Stress in M16 bolt

Figure show the pretension load applied at 22.72 KN in M16 Nut and Bolt 143.58 MPa stress value is obtained.

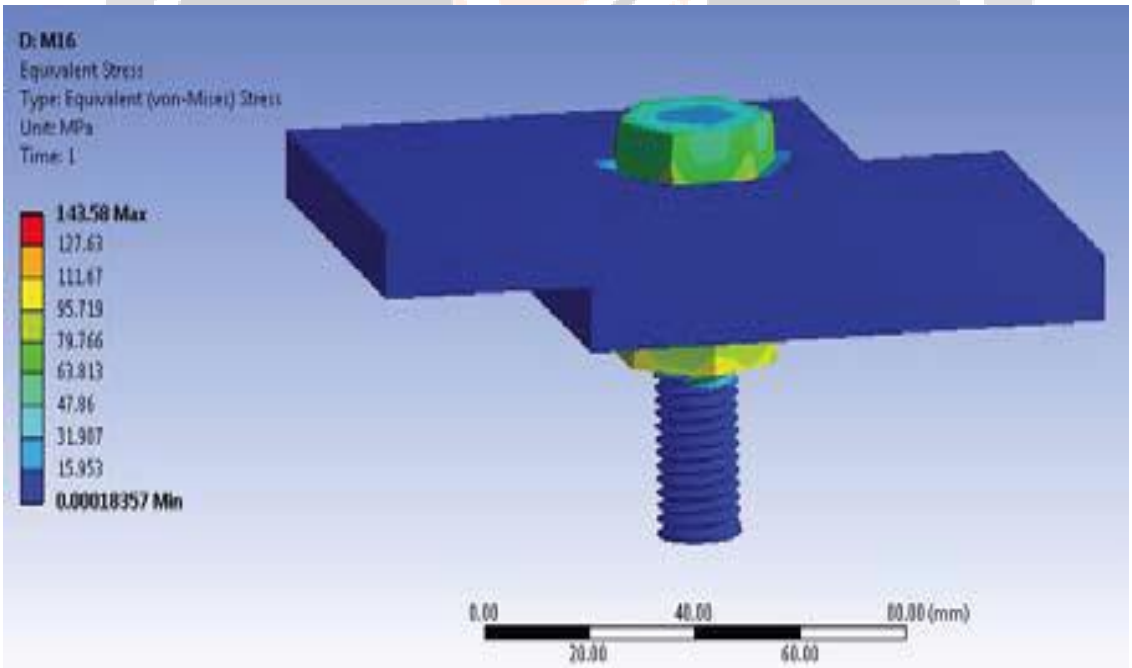


Fig 10: Result for Stress in M16 Bolt

Result for Deformation in M16 bolts

Fig shows the pretension load applied at 22.72 KN in M16 Nut and Bolt 2.82 mm deformation value is Obtained.

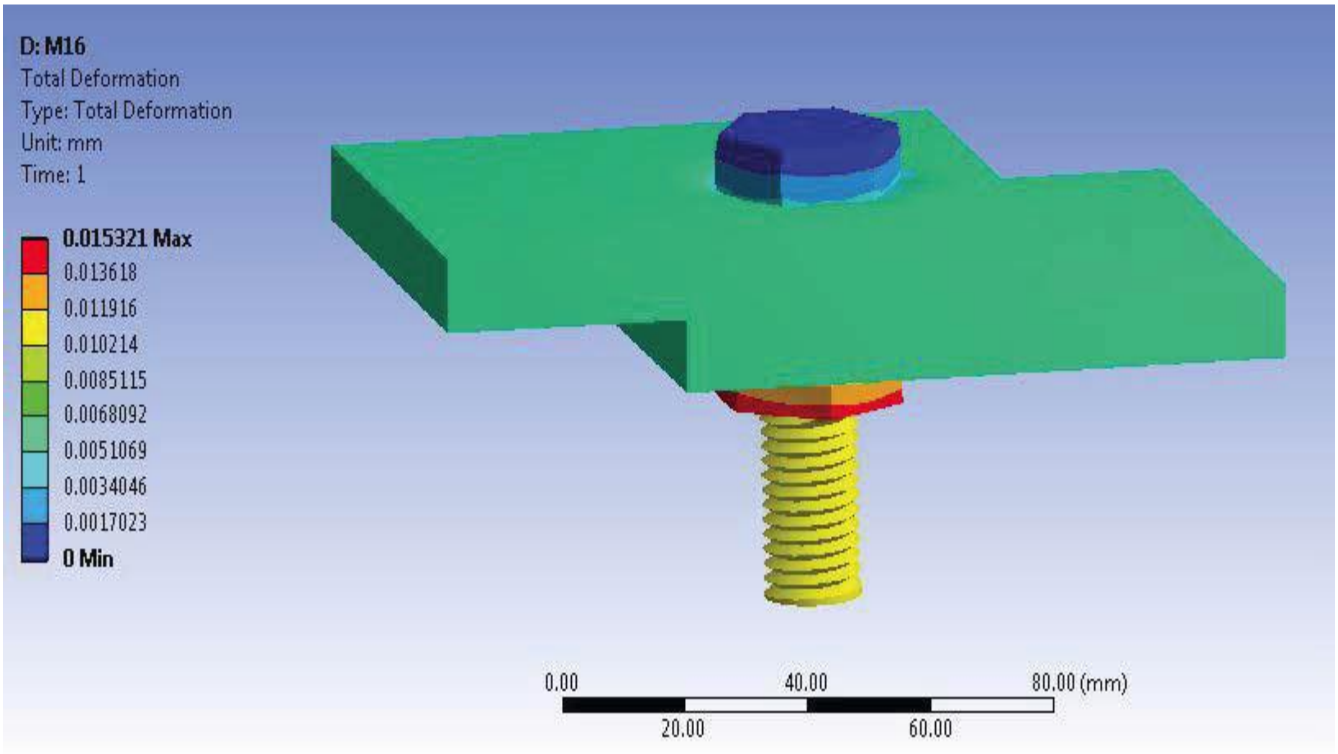


Fig 11: Result for Deformation in M16 bolts

Simulations of different fasteners assembly

Bolt Size	Pitch	Maximum Stress N/mm^2	Maximum Deformation in mm
M8	1.25	307.32	0.92
M10	1.5	240.65	1.87
M12	1.75	198.23	2.04
M16	2.0	143.58	2.82
M20	2.5	111.87	2.98

Table 6: Simulations

6. CONCLUSION

Hydrogen embrittlement remained as the only probable cause of the failure observed. Unlike stress corrosion cracking and quenching cracks, cracks caused by hydrogen embrittlement usually do not branch neither show oxidized surfaces. Typical features of hydrogen embrittlement were observed on the fracture surfaces of both bolts. Bolts had been Zinc electroplated, which is one way to introduce hydrogen into metals, and baking treatment.

If any of these factors are not present, the chances of the failure being confirmed as hydrogen embrittlement are unlikely. Unhardened fasteners or those of Grade 5 or Property Class 8.8 or lower do not fail due to hydrogen embrittlement. Parts that are cleaned by mechanical processes instead of acid are highly unlikely to fail due to hydrogen embrittlement. Failures that occur while parts are being installed are not due to hydrogen embrittlement.

7.REFERENCES

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