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Study of Different Factors Affecting T Bolt Failure of Band Clamp

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***Abstract*— This paper describes study of hydrogen embrittlement and thread form of T bolt of the band clamp. Hydrogen embrittlement is the very critical phenomenon which can cause the catastrophic failure of the bolt. Threads are available in various forms. The assembly of different bolt and nut having different thread forms can cause interference effect which can cause the failure of bolt. In this paper hydrogen embrittlement phenomenon, mechanism and different testing method are discussed and compatibility of UN and UNJ thread forms are examined by CATIA modeling.**

Keywords*— Hydrogen Embrittlement, Thread grade, UN, UNJ, Interferance.

I. INTRODUCTION

Mechanical joints are part of machine which are used to connect one or more components to each other. Mechanical joints may be permanent or temporary type as per requirement of the machine/ part. Mechanical joints are designed in such a way that it can allow the restrict moment between the two or more parts in one or more directions. Pin joint, ball joint, knuckle joint, cotter joint, welded joint, bolted joint etc. are some of types of the mechanical joints.

The band clamp is used for joining two parts by Marmon joint or assembling the any part on another cylindrical part. The band clamps consists of circular strap with Bolt assembled in it. Tension is provided on the T bolt by means of nut which provides force that holds the ends together. T-Bolt band clamps are specially designed clamps to provide connections without leaks. They are mainly used to form butt joints. T bolt band clamps are used for multiple applications like automobile, heavy truck, duct connection, irrigation, railway, tractor, pneumatic connections etc.

Different parameters can be responsible for the failure of T bolt. These parameters should be examined properly to predict the failure mode of T bolt. Some of these are listed below.

1. Insufficient Preload
2. Stripping failure
3. Fatigue failure
4. Material Defect
5. Improper mechanical properties
6. Improper manufacturing process
7. Corrosion
8. Hydrogen Embrittlement etc.

Failure caused due to any of these factors can lead to heavy loss of the parts. To predict and prevent the failure of the bolt it is necessary to study the different failure modes and correct them before causing any heavy losses. In further discussion, effect of Hydrogen Embrittlement, thread grade is briefed.

II. HYDROGEN EMBRITTLEMENT

Hydrogen Embrittlement is the failure process which takes place in the presence of hydrogen in metal and residual or applied tensile stresses on part. Hydrogen is the lightest element in the periodic table and at ambient pressure and temperature it is a gas with two atoms, H_2. In air, the hydrogen content is very low, but water contains 11 % hydrogen and the Earth's crust contains 0.14% hydrogen, mostly as crystalline water, but also as oil and hydrocarbons. This hydrogen present in the environment can react with metal and form hydrogen embrittlement. Hydrogen can also enter into the material lattice during various manufacturing processes like Hydrogen phosphating, pickling, electroplating, casting, carbonizing, surface cleaning, electrochemical machining, welding, hot roll forming, heat treatments etc.

- Three necessary conditions for HE-
1. Tensile stress
2. Material susceptibility
3. Corrosive Environment

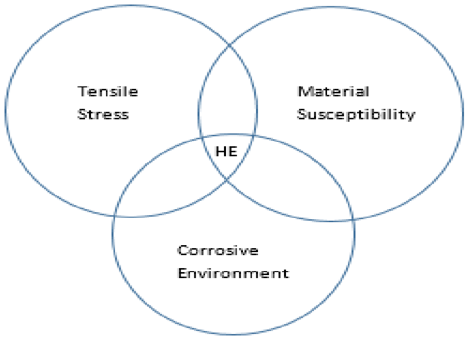

Fig 1. Conditions for Hydrogen Embrittlement

1. ***Mechanisms*** –

Many scientist proposed different mechanisms for the hydrogen embrittlement. The researchers are still working on it.

Variety of mechanisms can cause the hydrogen embrittlement like hydride formation and fracture, Hydrogen Enhanced decohesion, hydrogen enhanced localized plasticity.

1. Hydride formation and fracture –

This mechanism is based on the formation and fracture of hydrides at the crack tip formed in the material. This is the series of repeated process involving (i) hydrogen diffusion ahead of the crack tip at the high hydrostatic stress region. (ii)

Nucleation and growth of hydride phase (iii) cleavage formation in hydride (iv) crack arrest at hydride matrix interface.
Hydride mechanism requires some favorable conditions to occur such as temperature and strain rate such that the hydrogen as sufficient time to diffuse in the metal and temperature where hydride phase is stable.

2. Hydrogen Enhanced Decohesion (HEDE) -
Hydrogen is the first element of the periodic table and lightest amongst all. Atomic number of hydrogen is 1 and electronic configuration is $1s^1$, iron have atomic number 26 and electronic configuration is [Ar] $4s^2$ $3d^6$. When the hydrogen comes in the contact with iron in the metal it donate its electron to the unfilled 3d shell of iron. Due to this donation the interatomic bond in the irons gets weak. Decohesion is weakening of the interatomic which results in the sequential tensile separation of the atoms when a critical crack-tip-opening displacement (CTOD) is reached. Decohesion at grain boundaries occurs ahead of crack tip due to trapped hydrogen and impurities at sites which results in weakening of bond.

3. Hydrogen Enhanced Localized Plasticity (HELP) –
This mechanism states that speed of dislocation enhances near the crack tip due to the accumulation of the hydrogen. Dislocation behaves as carrier of plastic deformation in the metal lattice. Local dislocation movement is possible at relatively low tensile stress due to the presence of hydrogen. Active energy and activation area required for the location can be decreased by the effect of hydrogen.

2. ***Factors affecting Hydrogen Embrittlement*** -
The various material properties and external factors can vary the intensity of the hydrogen embrittlement.
Factors affecting the hydrogen embrittlement in the materials are listed below.

1. Hardness –
Material having hardness more than 32 HRC is more susceptible to Hydrogen Embrittlement.

2. Temperature –
HE gradually diminishes when the temperature is higher than 100°C.

3. Microstructure –
Martensitic structure is more susceptible to Hydrogen Embrittlement as compared to austenite and perlite.

4. Strength-
High strength steels are more susceptible to Hydrogen Embrittlement.

5. Crystal Structure-
Rates of hydrogen diffusion in pure metals at ambient temperatures depend especially on the crystal structure, with hydrogen-diffusion coefficients, D, generally 4 to 5 orders of magnitude higher for body-centred cubic (bcc) metals compared with face-centred cubic (fcc) and hexagonal close-packed (hcp) metals at 20°C.

6. Hydrogen Concentration –
As hydrogen concentration increases in the metal lattice or at the grain boundaries. The pressure exerted by it increases which increases the susceptibility of hydrogen embrittlement cracking in metal.

3. ***Different techniques and tools to measure Hydrogen Embrittlement*** –

- Temperature desorption spectroscopy –

This measures the amount of desorbed hydrogen in the material by controlled and limited heating. When the heat is supplied to the material then the hydrogen absorb the thermal energy and release itself. The quantity of hydrogen is measured by quadrupole mass spectroscopy. [1]

- Microstructural analysis –

Microstructural analysis plays an important role in the evaluation of Hydrogen Embrittlement susceptibility of a material and alloy. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are analytical technique for determining the internal microstructure of a material and effect of presence of hydrogen in microstructure and characteristic of material. [1]

- Hydrogen microprint technique –

This technique is used to know the path of diffusible hydrogen in metal. This technique can be applied to different material such as low carbon steel, high strength steel and austenite steel. In this process, the surface of hydrogen charged material is covered with thin layer of AgBr gel. After the reaction, metallic form of silver ion has created and leaves a track where hydrogen contact happened. Silver particles are present on this location and the excess unreacted gel is take off from that place. SEM examination of the sample is carried where the silver is present. [1]

4. ***ASTM standard for heat treatment to reduce risk of hydrogen embrittlement***

ASTM B850 - Post coating treatment of steel for reducing the risk of hydrogen Embrittlement
This standard describes the heat treatment procedure for coated metals to reduce the risk of hydrogen embrittlement.
The different temperature ranges and timings are specified according to the tensile strength of the steel.

Class	Tensile strength MPA	Temperature ^{0}C	Time H
ER -0	Not Applicable		
ER-1	1701 to 1800	190-220	Min 22
ER-2	1601	190-220	Min 20
ER-3	1501	190-220	Min 18
ER-4	1401	190-220	Min 16
ER-5	1301	190-220	Min 14
ER-6	1201	190-220	Min 12
ER-7	1525 or greater	177-205	Min 12
ER-8	1101	190-220	Min 10
ER-9	1000	190-220	Min 8
ER-10	1250	177-205	Min 8
ER-11	1450	190-220	Min 6
ER-12	1000	177-205	Min 4
ER-13	1000	440-480	Min 1
ER-14	Surface hardened parts <1401	130-160	Min 8
ER-15	Surface hardened parts 1401 to 1800 plated with cadmium, tin, zinc, or their alloys	130-160	Min 8
ER-16	Surface hardened parts<1401 plated with cadmium, tin, zinc, or their alloys	130-160	Min 16

Table 1.1 Conditions for Hydrogen De-embrittlement

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5. ***ASTM standards for testing of Hydrogen Embrittlement/ different parameters causing Hydrogen Embrittlement–***

ASTM Standard	Description
F606/606M	This test gives the testing method for various mechanical properties like tensile properties, hardness. It also gives the embrittlement testing method by using washer, hardened plate and wedge.
F1624	This test method gives the threshold stress value of the steel by using incremental step loading method. By keeping the stress value below threshold stress value embrittlement can be avoided.
F519 -18	This test method gives acceptance criteria for coating and plating processes that can cause hydrogen embrittlement in steels. Subsequent exposure to chemicals encountered in service environments, such as fluids, cleaning treatments or maintenance chemicals that come in contact with the plated/coated or bare surface of the steel, can also be evaluated by this test.
G38 – 01	In this method the specimen is kept in the desired environmental condition under stress and the timing of failure is calculated. This gives the predicted serviceability period for the specimen.
G41	This test method gives the information about susceptibility of material to the corrosion cracking when the material is exposed to salt environment.

Table 1.2 ASTM standards for HE testing

6. ***Hydrogen Embrittlement testing of T bolt as per ASTM F606/ F606 M***

Procedure as per standard –

1. The T bolt is installed in the test fixture with the bolt head positioned against wedge assembled with Nut and washer.
2. The thickness of plate was maintained in such a way that, after installation and tightening, a minimum of three full threads of the test fastener was in the grip.
3. Wedge was of hardness 45 HRC, thickness equal to one half the nominal fastener diameter (i.e. 0.125 inch), and angle should be 6°.
4. The T bolt was tensioned to 75 % of their specified minimum ultimate tensile strength.
5. The assembly kept in this tightened state for not less than 48 h, after which the test fastener was visually examined for embrittlement-induced failure, such as missing head.
6. The joint was then disassembled, and the test fastener visually examined using a 24X power magnification for evidence of embrittlement failure, such as transverse cracks in the shank, threads or at the junction of head to shank.
7. While disassembling the retightening torque was measured.
8. Torque Calculation -
   Tensile strength = 100 ksi [6]
   Stress area = 0.7854 * (D – 0.9382 / n)^2
   = 0.03681 inch^2
   Ultimate tensile strength = 100*1000 * 0.03681
   = 3681 lb
   Preload = 0.75 * 3681 = 2760.75 lb
   Torque = 0.25 * 2760.75 * 0.25 = 172.5469 lb inch = 19.4952 Nm

Experimental set up –

Fig. 1.2 Experimental set-up for HE testing

Observations and Conclusion –

1. Visual examination for crack is carried under 24X no cracks were observed.
2. No failure at head is observed
3. Torque applied was 22 Nm and retention torque was 21.5 Nm (Greater than the 90% of initial torque)

Hydrogen Embrittlement test is passed by given lot of bolts.

III. THREAD FORM

Thread structure convert the rotational motion of the nut to the linear motion. Threads of the bolts holds the nut on the bolt by providing required friction between them. Basic terminology of thread is described by thread Pitch, lead, minor diameter, major diameter, root radius, addendum, dedendum, helix angle, lead angle, flank angle, axial thickness. Threads are mainly differentiated due to different thread grades, thread forms, thread fits.

Thread form determines the way in which the male and females fits together. Unified Thread Standards (UTS) is dominated thread fits. UN, UNR and UNJ are different thread form standards used in UTS.
In further discussion, UN and UNJ thread forms are discussed in the details.
Unified (UN) standard includes-
UNC – Unified Coarse
UNF – Unified Fine
UNEF – Unified Extra Fine
Above standard only differ in the number of threads per inch. Coarse have least number of threads per inch and extra fine have largest number as compared to others.

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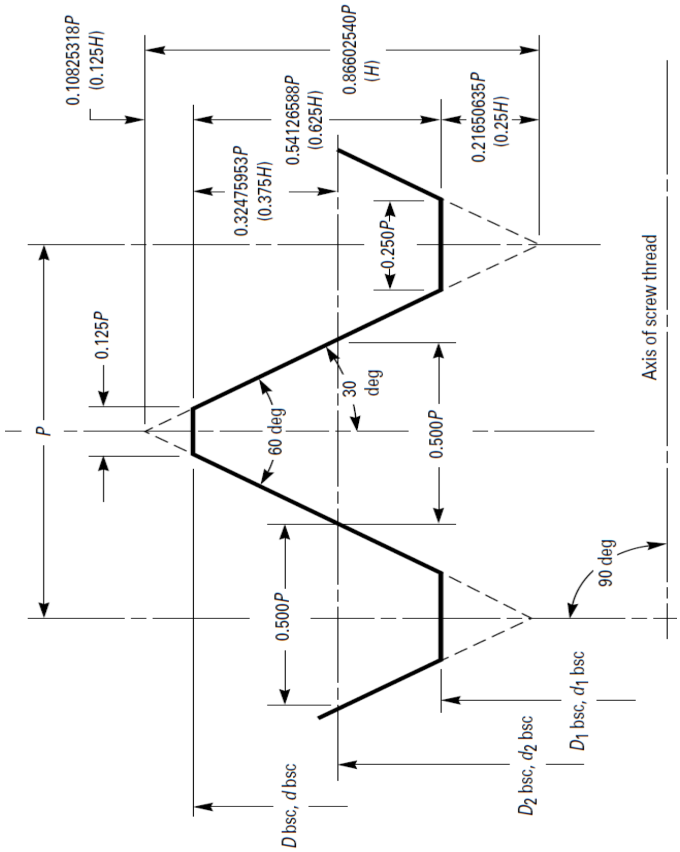

Fie. 2.1 UN Basic Thread structure [14]

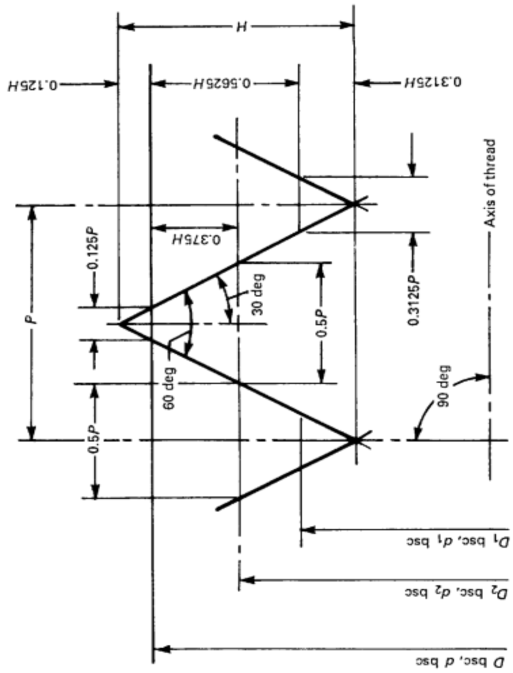

Fig. 2.2 UNJ Basic Thread structure [14]

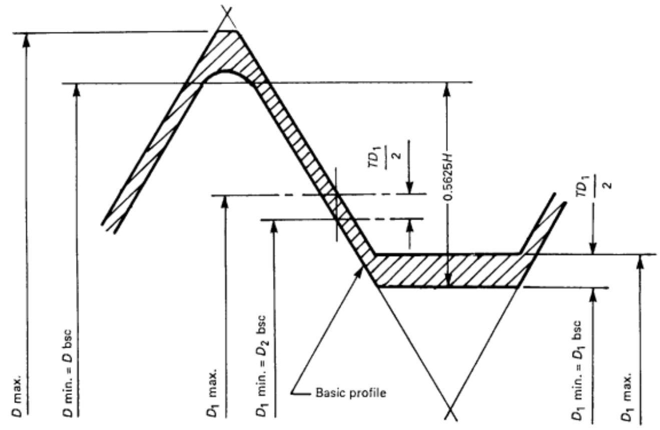

Fig. 2.3 Internal UNJ Thread design and tolerences [14]

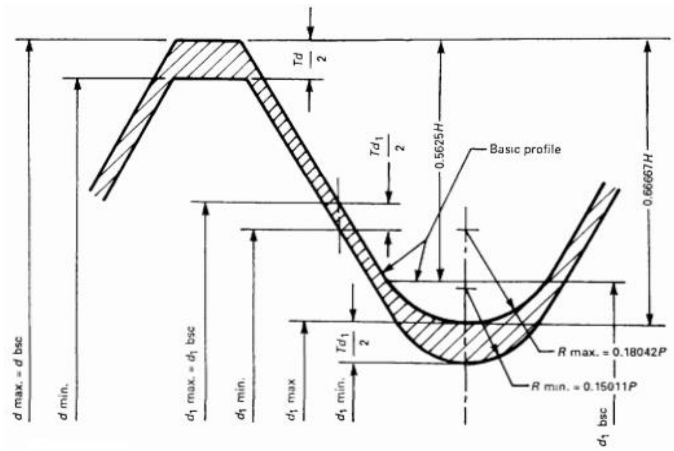

Fig 2.4 External UNJ thread design and tolerances [14]

Formulas for thread form

Angle of thread,

$2\alpha = 60^{\circ}$

Half angle of thread

$\alpha = 30^{\circ}$

Pitch of thread,

$P = 1/n$

Where, n = threads per inch

Height of sharp V thread,

H = 0.866025P

Height of UN internal thread and external thread

hs = 0.54127 p

Height of UNJ external thread

hej = 0.57753 p or 0.6667 H

Height of UNJ internal thread,

hij = 0.5625 H

Flat at the thread of external thread

Fes = 0.125 p

Truncation of external thread crest

fes = 0.10825 p or 0.125 H

Truncation of UNJ external thread

fej = 0.10825 p

Basic flat at the crest of internal thread and root of external thread

Fcn = 0.25 P

Truncation of internal thread Crest

fcn = 0.21651 p

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Flat at root of internal thread
Frn = 0.125 p
Truncation of internal thread root
frn = 0. 10825 p
UNJ thread Series have controlled root radius of 0.15011P to 0.18042P on external threads and 0 to 0.072P on internal Threads.

¼ - **28** thread

P = 1/n = 1/28
H = 0.86605 p = 0.0391'
Major Diameter = ¼

Allowance Formula –

1. Allowance for 1A and 2A = 0. 3 times pitch diameter tolerance of 2A
2. Allowance for 3A = No allowance

Tolerance Formula –

1. Major Diameter (External Thread)
   i. Class 1A, 2A = 0.090 *P^2/3
   ii. Class 3A = 0.060* P^2/3
2. Pitch Diameter (External Thread)
   i. Class 1A = 1.5* Class 2A pitch diameter tolerance
   ii. Class 2A = 0.0015*D ^ 1/3 + 0.0015*Le + 0.015* P^2/3
   iii. Class 3A = 0.750* Class 2A pitch diameter tolerance
3. Pitch Diameter (Internal Thread)
   i. Class 1 B = 1.950 * Class 2A pitch diameter tolerance
   ii. Class 2B = 1.300 * Class 2A pitch diameter tolerance
   iii. Class 3B = 0.975 * Class 2A pitch diameter tolerance
4. Minor Diameter (Internal Threads)
   i. Class 1B, 2B = 0.25*P – 0.4*P^2
   ii. Class 3B = [0.05*P^2/3 + 0.03* P/D] – 0.02

Allowance and tolerance for ¼ - 28 for different thread fits

Nominal size	Basic major diameter	Threads/ inch	Allowance Classes 1A, 2A
¼	0.25	28	0.0010

Table 2.1 Allowance table

Tolerances -

Tolerances					
Major diameter External Thread		Pitch diameter			
1A, 2A	3A	1A	1B	2A	2B
0.0098	0.0065	0.0050	0.0065	0.0033	0.0043

Tolerances			
Pitch Diameter		Minor diameter internal threads	
3A	3B	1B, 2B	3B
0.0025	0.0032	0.0084	0.0077

Table 2.2 Tolerance Table

Dimensions of T bolt [12]–

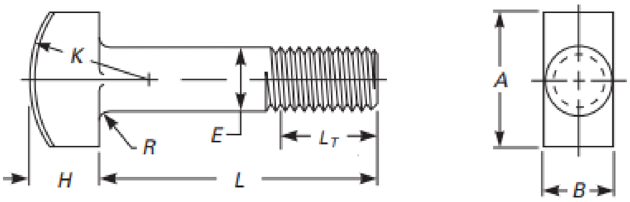

Fig. 2.4 T bolt dimensions

Basic bolt diameter , D		Body Diameter , E		Head length, A	
		Max	Min	Max	Min
1/4	0.250	0.260	0.237	0.500	0.488

Head width, B		Head Height H		Basic Head Radius K	Fillet Rad., R
Max	Min	Max	Min		
0.280	0.245	0.204	0.172	0.438	0.031

Table 2.3 T bolt dimensions

Nut Dimensions [13]–

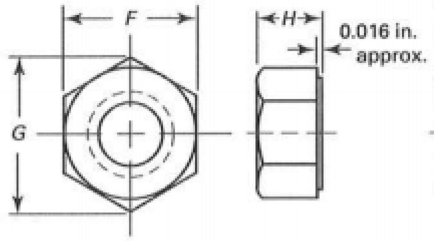

Fig. 2.5 Nut Dimensioning

Nominal Size	Basic Major Diameter of thread	Width across flat, F		Width across corners, G	
		Min	Max	Min	Max
¼	0.2500	0.488	0.50	0.556	0.577

Thickness		
Basic	Min	Max
15/64	0.218	0.250

Table 2.4 Nut Dimensions

The T bolts and hex nuts are designed in CATIA with UN and UNJ threads and assembled.
The results were taken by performing different combinations on nut and bolt. Combinations described are

1. UN Bolt and UN nut
2. UN Bolt and UNJ nut
3. UNJ Bolt and UN nut
4. UNJ Bolt and UNJ nut

CATIA modeling of Assembly of T bolt and NUT -

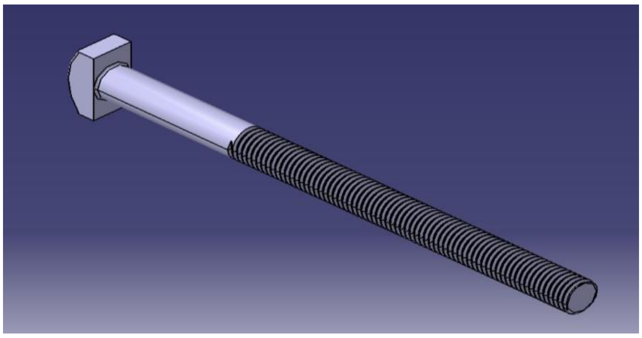

Fig 2.6 CATIA model of T bolt

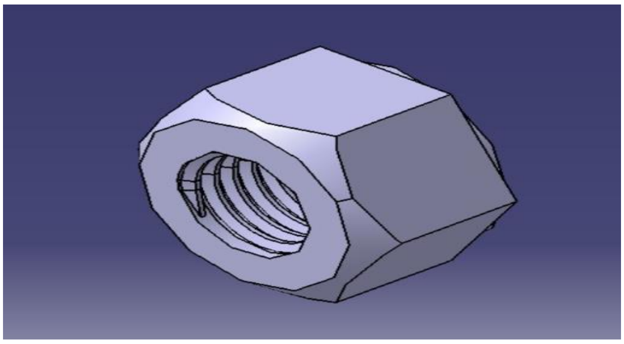

Fig 2.7 CATIA model of Hex lock Nut

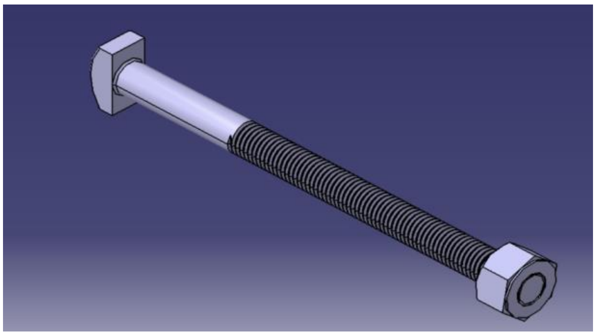

Fig. 2.7 CATIA model of Assembly

1. Bolt of UN thread form and Nut of UNJ thread form -

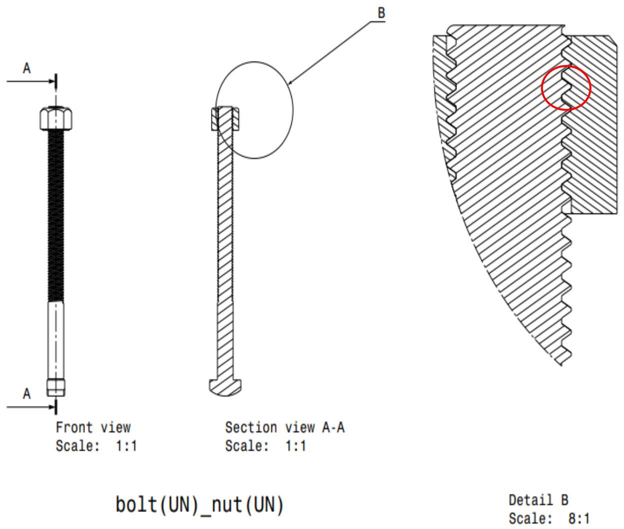

Fig. 2.8 Sectional View

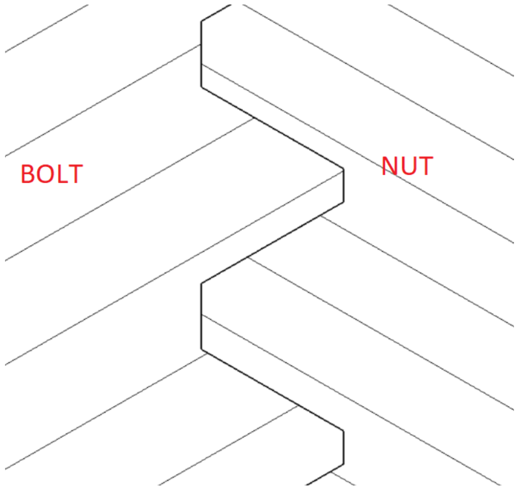

Fig. 2.9 Detailed View

2. Bolt of UNJ thread form and Nut of UN thread form

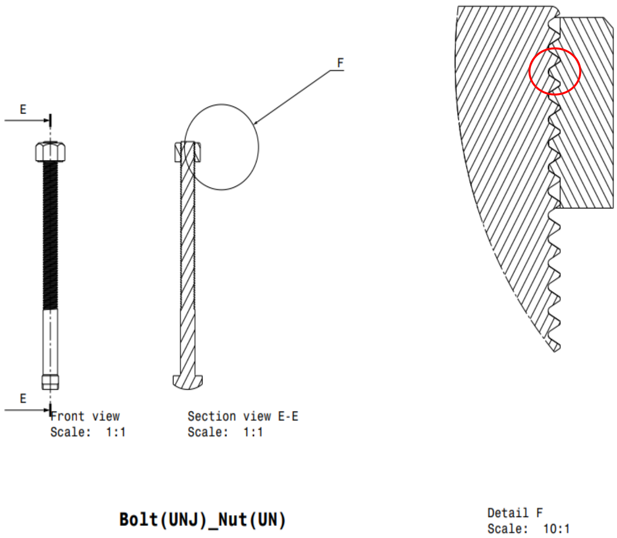

Fig. 2.10 Sectional View

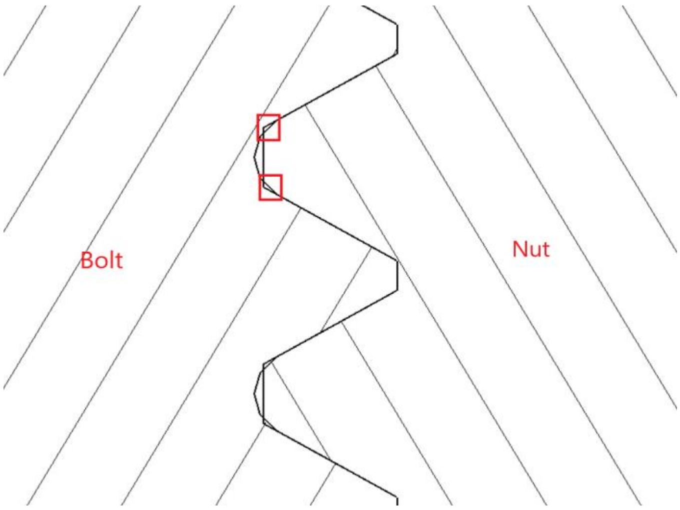

Fig. 2.11 Detailed View

Note – Interference is shown using red rectangles.

3. Bolt of UN thread form and Nut of UNJ thread form

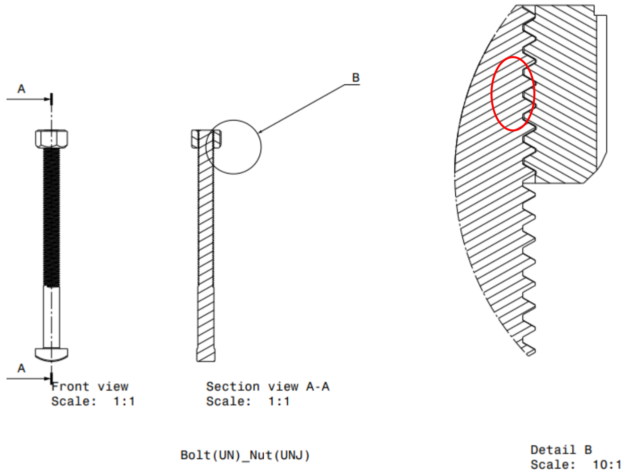

Fig 2.12 Sectional View

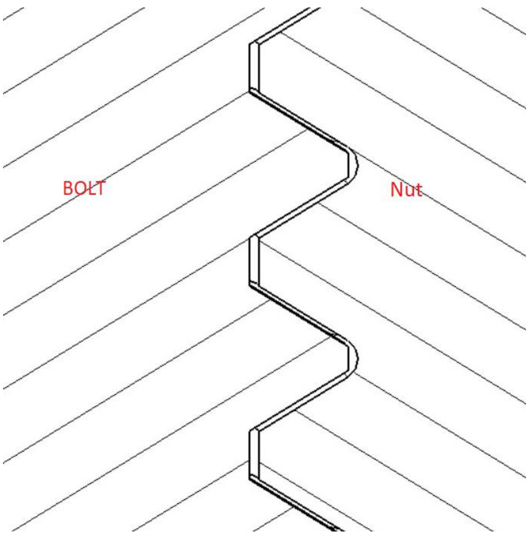

Fig. 2.13 Detailed View

4. Bolt of UN thread form and Nut UNJ thread form

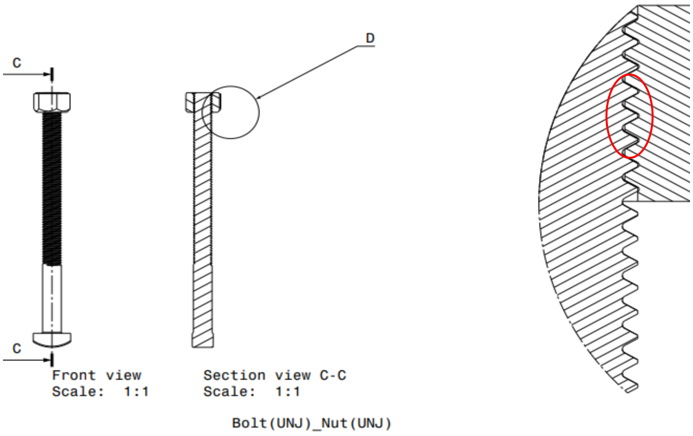

Fig. 2.14 Sectional View

Detailed View

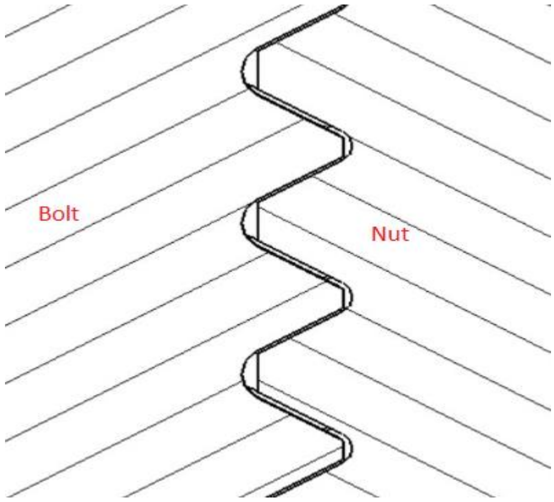

Fig. 2.15 Detailed View

Observation –

UN Bolt and UN nut – No interference
UNJ Bolt and UNJ nut – No interference
UNJ Bolt and UN nut – Interference problem
UN Bolt and UNJ nut - No interference

Conclusion –

It is recommended that UNJ thread form bolt should not be assembled with UN thread form nut.

IV. CONCLUSION

1. Hydrogen Embrittlement can cause catastrophic failure in the bolt. Use of different preventative measure and testing methods can reduce this risk.
2. The T bolt tested by ASTM F606/ F606M standard for hydrogen embrittlement passed the test.
3. Bolt of UNJ thread form assembled with Nut of UN thread form causes the interference problem. Hence assembly of them should be avoided.

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