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Analysis for Effect of Slight Pitch Difference on the Fatigue Life of Bolt

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Abstract- **In this work fatigue failure is examine for bolt with nut connections, when a slight pitch difference is established between bolt and nut. To improve the fatigue life, there are three types of slight pitch difference processed on the specimens and results are discussed in terms of FEM analysis. Taking into consideration the standard dimension bolt and nut connection having pitch difference of (α) =0 µm, the bolt fracture does not happen at the No. 1 thread by introducing a slight pitch difference of (α) =5 µm and pitch difference (α) =15 µm, is observed. Furthermore, it is having been discovered that the fatigue life of bolt can be increase by introducing some slight pitch differences. The effect of bolt-nut connection with slight pitch difference, on the fatigue failure of bolt is discovered.**

Index terms - Bolt-Nut Connection, Pitch Difference, Finite Element Method, Fatigue life.

I. INTRODUCTION

Bolt and nut connections are one of the common mechanical elements. In general, bolt-nut connections have the advantages like it can easily connect and also easily disengaged; they set easily while making necessary adjustment and can also set with high precision with fastening tools. Threads have as wedge effect that they also used for very thick members which can be fastened tightly. Because of these advantages, surprisingly very large amount of numbers of bolt-nut connections are used in a every variety of machines and structures, such as machine tools, transportation equipment, steel towers, bridges, etc. The maximum times of these nut and bolt connections are undergone to repeated loads which come to the phenomenon for fatigue that is cause for the early failure in bolts. For bolt there are parameters as root radius, thread pitch, material and thread angle which can be influence the performance life of bolt. Bolts and nuts are manufactured in different number of types like fine and coarse threads. The question which here arises is which root number of thread pitch, yields a higher fatigue life and load carrying capacity, for standard steel bolts fitted with nuts having standard dimension. For the selection of this particular parameter for the research study is that most other parameters such as fillet radius, height of threads and depth are directly proportional to the pitch. Fatigue failure of bolt is always of concern, which sometimes leads to severe accidents. Fig.1 shows a giant bolt (called tie rod – outside diameter of thread =478 mm) failed after using 3 years in 1975, Japan. The experiment on the surface having fractured reported that the failure is attributable for crack due to fatigue which initiated at the thread root and propagated.

The main cause for the fatigue failure of bolt is the uneven load sharing among the bolt thread. The first loaded

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thread carries more load than all the subsequent threads are seen in Figure 2. The high stress concentration exists at thread roots.

A. Problem Statement

Currently fatigue failure in bolt is observed due to effect of pitch difference in nut and bolt connection. Find the solution to increase the fatigue life of bolt to avoid the crack in first engagement of thread by using suitable pitch difference.

Figure 1: Bolt failed due to the fatigue fracture.[4]

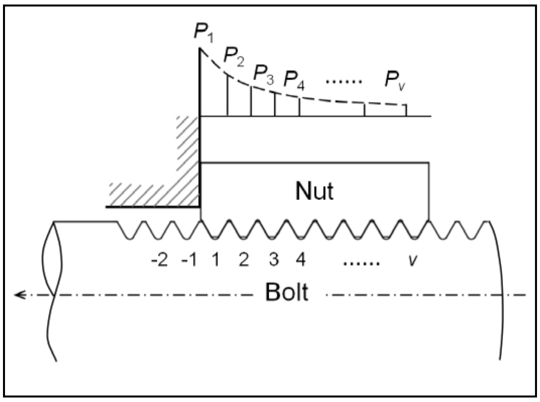


Figure 2: Load distribution on bolt threads.[1]

B. Objective

In this work, the effect of pitch differences of bolt on the improvement of fatigue life will be discussed systematically. The main objective of this seminar is to develop a type of bolt-nut connection which can realize fatigue strength improvement without raising the cost.

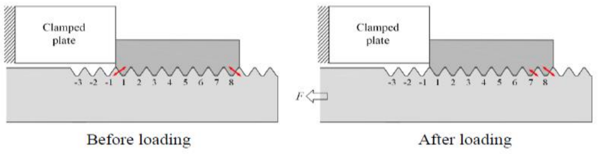
The objectives are summarized as follows:

1) To study using Finite Element Analysis to describe the effect of pitch difference on stress state at each threads of bolt.

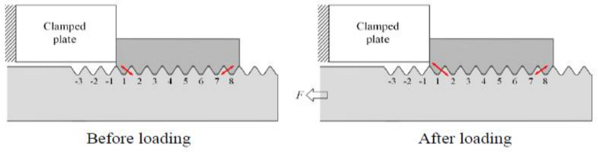
2) Discussing the pitch difference which can realize the increase of fatigue life.

C. Effect of Contact between Bolt and Nut on Stress Value

If the pitch of nut is larger than of the pitch of bolt, at No.1 thread left side surface contact before the loading is changed to no contact after the application of loading, as seen from figure Here the contact is removed means the crack failure is not obtained on No. 1 thread as compare to standard Nut and Bolt Connection. However, considering that the value of nut pitch which is smaller than value of bolt pitch, at No. 1 thread the right-side contact of nut and bolt is same for before loading and after application of loading. Here the value of maximum stress concentration at thread No.1 of bolt can be decreased only by introducing larger nut pitch.



(a) The nut pitch is larger than the bolt pitch



(b) The nut pitch is smaller than the bolt pitch

Figure 3: Contact between bolt and nut before and after the loading. [1]

For this research work the M20 bolt with pitch 2.5 mm with length 150mm is taken. The geometry of specimen used is shown in figure 4.

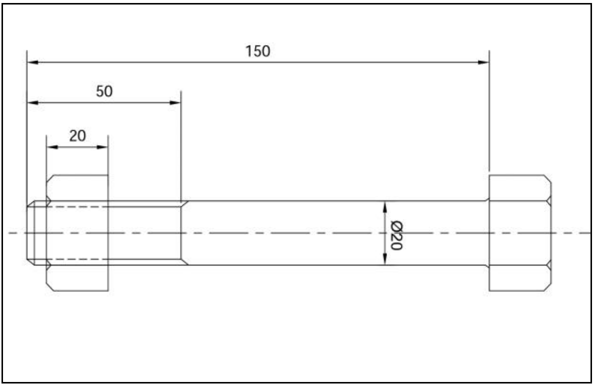


Figure 4: Bolt and Nut Specimen used for FEA Analysis (dimensions in mm).

Literature review carried out in the area of analysis on bolt to find its fatigue life in context to the present work is presented and cited.

Nao-Aki *et.al* introduces that pitch difference having slight variation between a bolt and nut is affecting on fatigue failure. Fatigue testing is done using three pitch differences by varied stress amplitudes. It is found that the life of fatigue for the bolt can be increase while some pitch difference is taken in the account. Here the criteria for fatigue failure are discussed in terms of variation of pitch difference. They also showed that how importance of pitch difference affecting fatigue limits. They show that the fatigue life can be increase while some pitch difference is considered [1].

Dragoni found that slight pitch on the fatigue value of strength of ISO steel bolts which are used for analysis. It can have studied boundary element analysis and cross-comparison with theory and photo elasticity, the load capacity of the bolt is ultimately related to a comprehensive stress concentration dependency. In the work of plotting the function of nominal diameter verses the thread pitch of bolt for the steel bolts. It concludes endurance phenomenon for load lightly increases if the value of pitch is decreased for small diameter bolts of low value of grade steel. Conversely, the value of endurance load increases with the pitch large bolts of high value of grade steel [2].

Chen *et.al* focused on fatigue failure, for bolt and nut connections, while pitch difference is introduced between the connection of bolt and nut. For improvement the fatigue life, there are three types of pitch difference are produced on the specimens which are compared with experimental results and discussed in terms of FEM analysis [3].

Sano et.al focused on the work done by them to increase the fatigue life of nut and bolt, they can vary some pitch differences. They also discussed the loosening experiment and relation between the prevailing torque and clamping force [4].

Wahabb et.al introduces the slight pitch difference between the bolt and nut engagement in order to study its effect on the fatigue performance. They considered that the pitch of nut was some microns greater than the pitch of the bolt. Fatigue experiment was done for three types of specimens with different measurement of pitch differences. The plot of S-N curves for the fatigue life shows that it was extended by 1.5 times which compare with the standard connection [5].

Majzoobi *et.al* found the stress, various factor of stress concentration in the bolt and fatigue strength / endurance limit by analytically and correlate with the experimentally. They compared results standard of ISO having coarse threaded bolts and with the comparatively fine dimension threaded bolts. Which shows have coarse thread are preferred. Here the reason for preferring coarse thread is that the value of pitch difference is more compare to fine threads. The condition of loading is same for both type of coarse and also fine threads. For the comparison which is made on the basis of parameter of core diameter. The conclusion that for the same stress, which the fatigue life for both ISO as well as unified bolts, for 100 unified bolts, comes low as the nominal bolt diameter increases within the range tested [6].

II. FINITE ELEMENT ANALYSIS

To analyzed the effect of the pitch difference on the stress at the bolt threads, the elastic and plastic finite element analyses were performed for $\alpha = 0$ micron, $\alpha = 5$ micron and $\alpha = 15$ micron by using ANSYS Workbench. Herein standard M20 bolt and nut body are modeled in contact.

A. Material Properties

For this work the material is chosen as mild steel.
The Material Properties for mild steel are as follows:
Density – 7.8 x 10^{-6} Kg/mm^3
Young’s Modulus – 210 GPa
Poisson’s Ratio – 0.3
Yield Strength – 640 MPa
Ultimate Strength – 800 MPa

B. Geometry of Bolt and Nut Thread

At first, draw the geometry sketch of standard M20 × 2.5 mm bolt as per the dimensions given in figure 4 in design modeler of ANSYS workbench as shown in figure 5. Since here the axisymmetric model considered for two-dimensional analysis, convert sketches to 2D surface i.e. nut and bolt. Conversion is done for the reason to mesh model using 2D element during meshing.

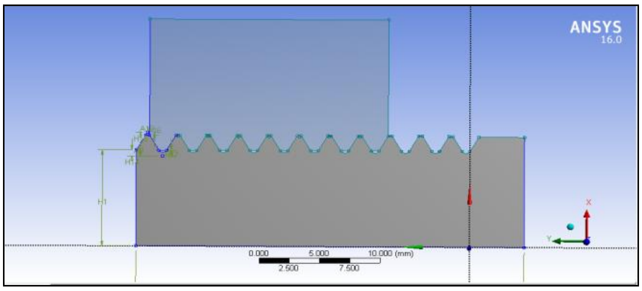


Figure 5: Create the 2D element and add material.

C. Meshing

For getting accurate results at particular node, mesh is created at the root of bolt thread with the size of 0.01 mm×0.01 mm, and 4-noded linear quad elements are made on surface. Here the axisymmetric solid element is used as shown in figure 6.

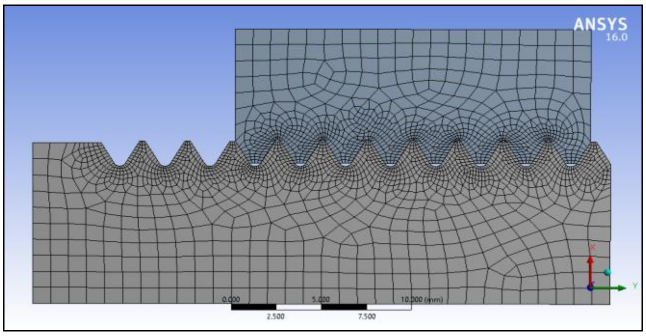
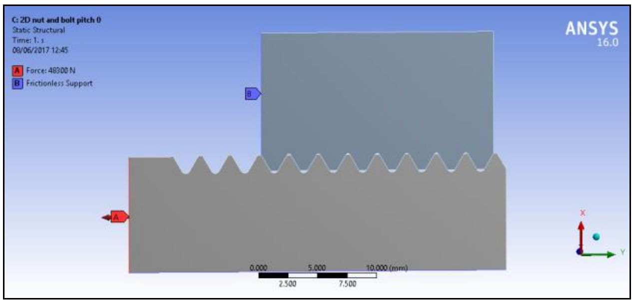


Figure 6: Meshing

D. Standard Boundary Condition

In the tightening process, the accumulated pitch difference causes the axial force between the bolt threads engaged with the nut thread. In this modeling, Frictionless support gives on the nut inner portion and bolt bottom portion, pretension force act on the bolt is 30 ±18.3kN as shown in Figure 7.


C: 2D nut and bolt pitch 0
Static Structural
Time: 1. s
08/06/2017 12:45

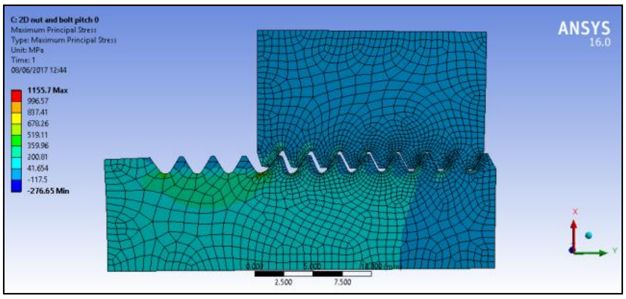
A Force: 48300 N
B Frictionless Support

Figure 7: Boundary Conditions

III. RESULT AND DISCUSSION

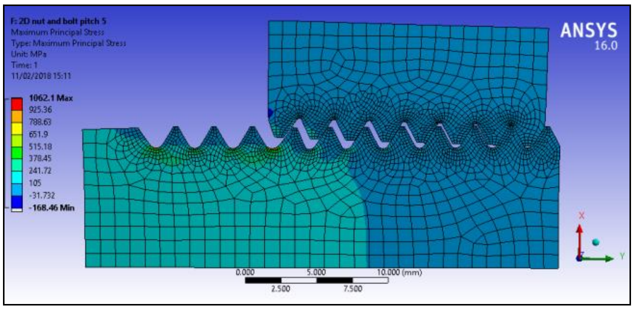
A. Maximum Principal Stress

An axisymmetric model of nut and bolt has been analyzed as per the given boundary condition in Ansys workbench to find maximum principal stress when α is equal to 0 µm, 5 µm, 15µm and contour plots are shown in figure 8, 9, 10 respectively.


C: 2D nut and bolt pitch 0
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
08/06/2017 12:44

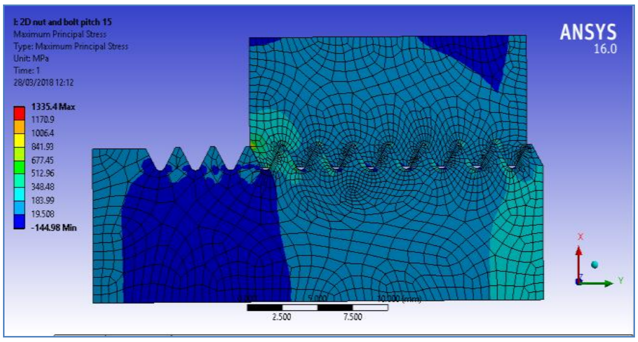
1155.7 Max
996.57
837.41
678.26
519.11
359.96
200.81
41.654
-117.5
-276.65 Min

Figure 8: For Model when α=0µm.


F: 2D nut and bolt pitch 5
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
11/02/2018 15:11

1062.1 Max
925.36
788.63
651.9
515.18
378.45
241.72
105
-31.732
-168.46 Min

Figure 9: For Model when α=5µm.


I: 2D nut and bolt pitch 15
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
28/03/2018 12:12

1335.4 Max
1170.9
1006.4
841.93
677.45
512.96
348.48
183.99
19.508
-144.98 Min

Figure 10: For Model when α=15µm.

B. Minimum Principal Stress

Also, an axisymmetric model of nut and bolt has been analyzed as per the given boundary condition in Ansys workbench to find minimum principal stress when α is equal to 0 µm, 5 µm, 15µm and contour plots are shown in figure 11, 12, 13 respectively.

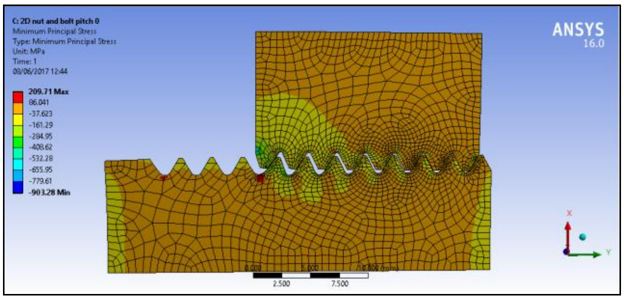


Figure 11: For model when α=0µm.

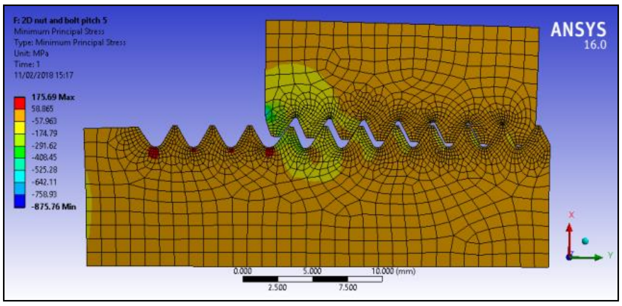


Figure 12: For model when α=5µm.

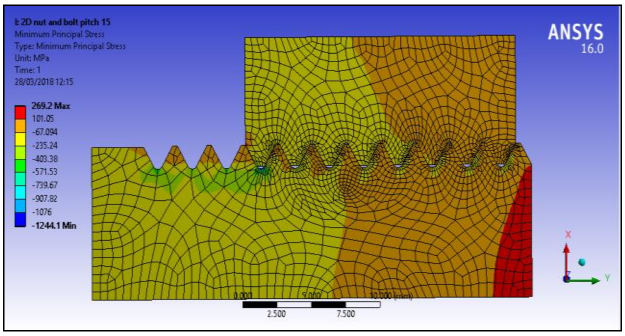


Figure 13: For model when α=15µm.

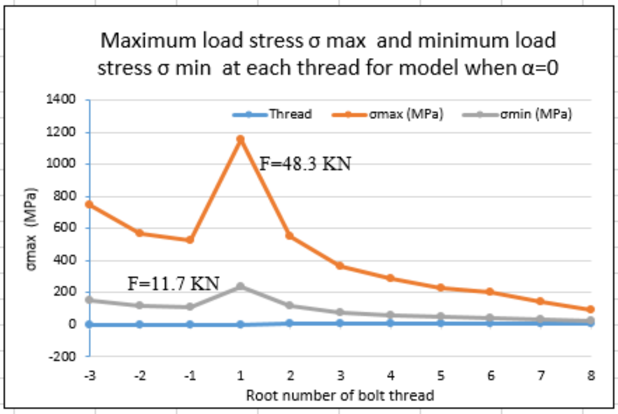


Figure 14: Location of maximum and minimum load stress at each thread for model when α=0

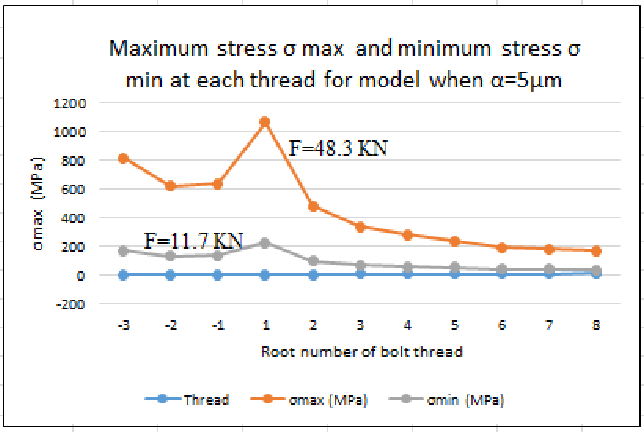


Figure 15: Location of maximum and minimum load stress at each thread for model when α=5

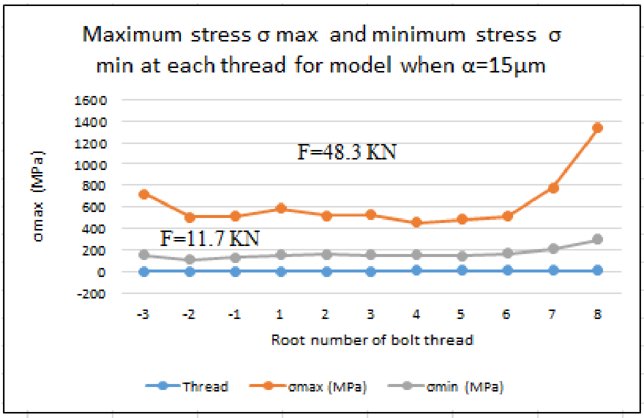


Figure 16: Location of maximum and minimum load stress at each thread for model when α=15

Figure 14 to 16 shows the value of maximum stresses at each root of bolt thread under varying loads, i.e. F_{min}=30-18.3 kN and F_{max}=30+18.3 kN.

C. Investigate the Result by Stress Concentration

The stress concentration at No. 1 is extremely predominant because the finial crack happens at this thread. The stress concentration at No.-3 to No.-1 threads can be controlled and reduced by because of no contact. For No. 7 or No. 8 threads, for example, the crack propagated at threads which not mean fracture is final because hence other threads carry the load. The stress concentration for No.1 thread will be encountered in this work. Here the reason is that finial fracture can control for occurring at this thread.

The value of stress concentration at each root of bolt thread is examined by using stress concentration factor K_t which is defined by,

$$K_t = \frac{\sigma_{t_{\max}}}{\sigma_n} \qquad (1)$$

$$\sigma_n = \frac{F}{A} \qquad (2)$$

Where $\sigma_{t\max}$ is the maximum tangential stress appearing at each bolt root, and σ_n is the total bolt axial force F divided by the bolt cross section A_R as shown in figure 17.

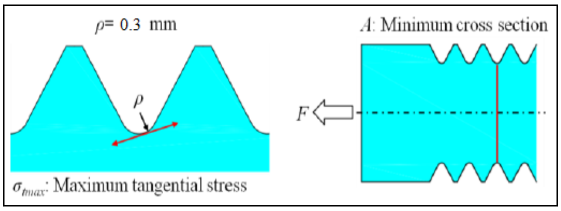


Figure 17: Tangential and normal stress for value of Kt. [3]

The K_t of each bolt root is indicated in figure 18 and shows the comparison of the stress concentration factor K_t for α=0 μm, α=5 μm and α=15 μm. It is found that when α=5μm is introduced; the stress concentration at root No. 1 reduces significantly. However, for the roots No. 7 and No. 8 it increases very high when α=15 μm.

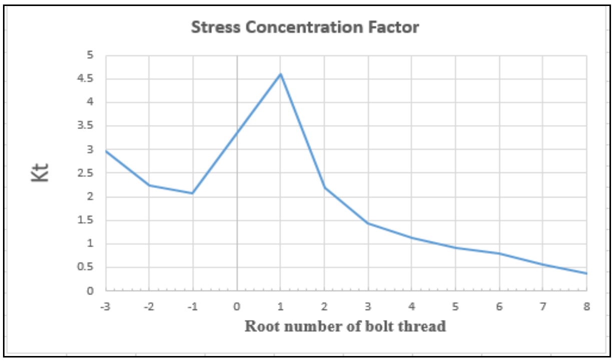


Figure 18: Stress Concentration α=0μm

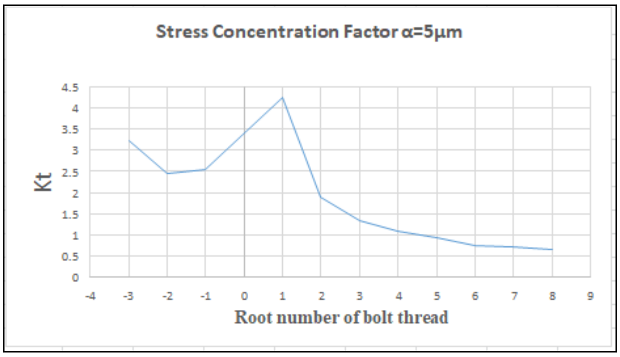


Figure 19: Stress Concentration α=5μm

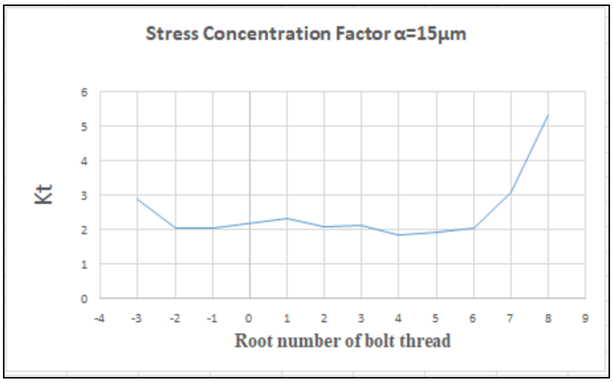


Figure 20: Stress Concentration α=15μm

D. Mean Stress and Stress Amplitude for Root of Bolt Thread

The endurance limit diagrams for α=0 μm, α=5 μm and α=15 μm are obtained as seen in Figure 21, based on the results of Figure 25. Herein, mean stress σ_m and stress amplitude σ_a are define by

$$\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} \qquad (3)$$

$$\sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2} \qquad (4)$$

Where $\sigma_{\max}$ is the maximum stress of each thread which comes under maximum load F=30+18.3 kN, and $\sigma_{\min}$ is the maximum stress of each thread under the minimum load F=30-18.3 kN. For the bolt-nut connection with α=0, the bolt thread No. 1 has the maximum stress amplitude as shown in Figure 21. For α=5 μm in Figure 22, it is seen that stress amplitude as well as the mean stress for thread No. 1 decreases significantly. Compared with α=0 μm, the difference of each thread is condition of severe becomes smaller, which rshows the load is not shared among the bolt threads is improved. For α=15 μm in Figure 23, the large stresses appear at threads No. 7 and No. 8 instead of thread No. 1. From Figure 10, it is that when the pitch difference is large enough, threads No. 7 and No. 8 become the most dangerous threads instead of thread No. 1 although the some fracture at No. 7 and No. 8 which not mean that final bolt fracture. Here the reason for that is other threads may carry and distribute the load.

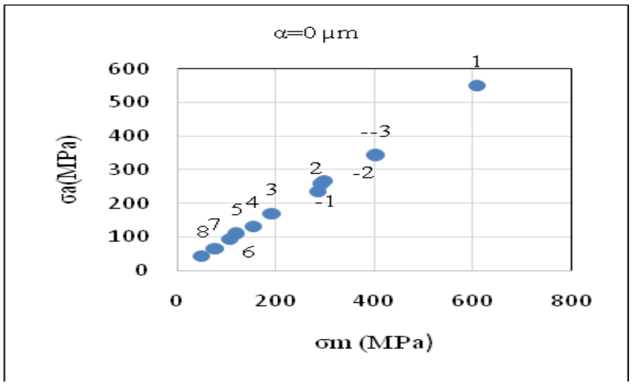


Figure 21: Stress Amplitude Vs Mean Stress for α=0 μm.

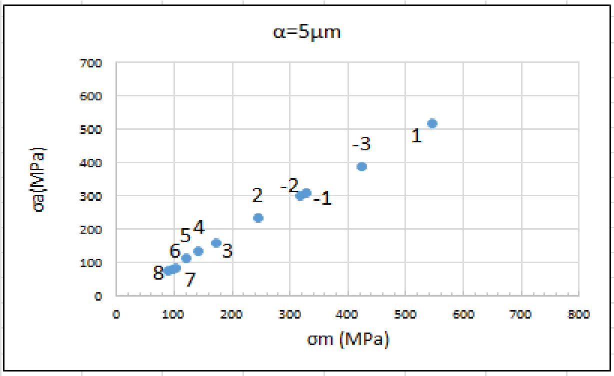


Figure 22: Stress Amplitude Vs Mean Stress for α=5 μm.

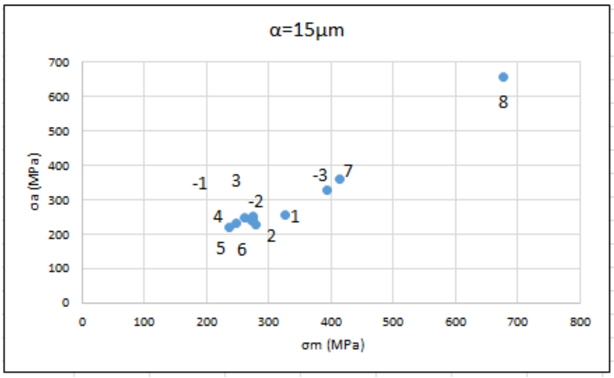


Figure 23: Stress Amplitude Vs Mean Stress for α=15 μm.

IV. CONCLUSIONS

In this work, the study of bolt-nut connections with slight pitch difference was considered using FEM analysis for three specimens. According to that FEM result shows that stress states for each root threads of bolt were presented. The observations from work are as follows:

For the standard bolt and nut connection α=0 μm, the fatigue fracture happens at the No. 1 thread, while for α=5 μm the stress is low at the No. 1 Thread compare to α=0 μm, and for α=15 μm the maximum stress is generated in the no. 8 thread. For *α*=15 μm, instead of No. 1 thread, maximum stress occurs at No. 7 and also No. 8 threads although the fracture at No. 7 and No. 8 threads which not mean the finial bolt fracture. From the results for this work show that the values of stress amplitude and average stress for No. 1 root thread of bolt can be decreased by establishing a suitable value of pitch difference.

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