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Enhancing the Dynamical Behaviour of Bolted Joints under Alternating Thermal Loads using Finite Element Method

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ABSTRACT

The behaviour of the local sliding between the threads and bearing surfaces when subjected to Alternating thermal loads is usually non-linear; this gradually accumulates with the thermal cycle, causing the threaded fasteners to loosen. In this paper, finite element analysis uses to assess the behavior of the dissimilar bolted joint (medium Steel carbon grade 8.8 with Aluminum Alloy 6061-T6) under Alternating thermal load using three different bolt diameters (12mm,16mm, and 20mm) with changing in parameters thread angle and thread pitch to find the maximum preload losses and later attempt to reduce the preload loss by redesigning the thread bolt and nut. Eight novel anti-loosening structures have been redesigned metric thread to withstand losing preload. All these structures can impede the alternate slippage that occurs on the thread surface under the effect of Alternating thermal load. The results show that preload loss is directly proportional to the bolt diameter. The bolt thread redesign for the 20mm diameter resulted in an improvement of preload losses by 14.36%. In the case of the 16mm and 12mm bolts, the resultant losses improved by 14.96% and 4.41%, respectively. Based on the study of the process by which the bolt loosened, it was proposed that the key to preventing local slippage accumulation and sustained loosening was to inhibit the slippage or relative motion occurring on the thread surface. Thus, several novel thread structures were designed to reduce the phenomena of loosening based on the above findings. Finally, their superior anti-loosening abilities were validated by the FEA method.

keyword: Bolted joint, Preload, Alternating thermal, Novel Stricture

1.Introduction

A bolted joint is used to transfer the internal load in structure from member to member. Welded joints use in applications specifically pressurized tanks, space structures. Most applications use bolted joints with the same types of materials; some unique applications require a combination of different types of materials (e.g., steel bolt with aluminum nut). However, current design standards and guidelines do not allow for using preloaded steel bolts with aluminum nut connections, mainly because of a lack of knowledge on the preload loss to be expected in these connections, and this limits the application field of this type of structure [1]. Ying Lia et al. [2] found that the relaxation behavior of bolted joints affected by axial vibration is similar to that of connections excited by transverse cyclic loads, which can be divided into two stages. Andreas Wettstein et al [3]. friction and frictional variances were investigated precise impact tightening can develop by control and designed method of tightening processes. K. Ding et al [4] study the effect of bolt tightness loss on the integrity of bonded-bolt joints under axial stress field. The tension on the bolted connection must be maintained to draw the joint rod tighter and prevent the joint from losing structural integrity under bending. Nao-Aki Noda et al [5]. have studied the effect of a slight pitch difference between a bolt and a nut. The fatigue life was improved when a pitch difference α= α small. Jianhua Liu et al. [6]. have Investigated the dynamic behavior of bolted connections under torsional excitation. The shape of the hysteresis curve is affected by the angular magnitude at small angular amplitudes, no slippage between contact threads occurs, and at high angular amplitudes, slippage between contact threads occurs at the beginning of the test. The hysteresis curve versus applied twist angle at small angular amplitudes is parallelogram-shaped, while at high angular amplitudes it is a parallel hexagon. Dean Chen et al [7]. have Studied the tightening behaviour of bolted joints with non-parallel bearing surfaces. Bending moments of non-parallel bearing surfaces appear as an excess of the integral of the thread contact force, resulting in additional contact and lateral pressure in the mating thread. By increasing the friction torque, the clamping force deviation will increase. At the non-parallel joint, the clamping force deviation and the additional friction torque did not increase, the same parallel joint increased the bending moment additional torque and the preload deviation almost proportionally with the increase of the inclination angle of the bolted joint. Daiyang Gao et al [8]. detected that the random vibration loading affected axial-connected bolts of the thin-walled cylinder. the shear strength on nut and fatigue fracture of the bolt are effects in bolt connections. Jianhua Liu et al [9]. have Investigated the self-loosening of bolted joints excited by the dynamic axial load with three types of coating (Polytetrafluoroethylene (PTEF), Molybdenum Disulfide (MoS2), and Titanium nitride (TiN)). MoS2 coating on the bolt shows a better result in anti-loosening performance than others. The MoS2 coated on the bolt thread root both the preload and the anti-loosening performance show greater results than the uncoated bolt. Khaleed Hussain et al. [10] have investigated the stress in engaged threads of bolt M12 are maximum in first engaged and minimum in last thread. Sami Daouk et al. [11]. have Studied the dynamic behaviour of a bolted joint under heavy loadings. The stiffness of the bolted joint plummets when the loading level increases. The resonance frequency and modal damping are effects by loading level. U.A. Khashaba et al [12]. have Studied the Effect of washer size and tightening torque on the performance of bolted joints in composite structures. The slope of load-displacement diagrams of bolted joints (stiffness) that under the same tightening torque increases with decreasing washer size. Guangwu Yang et al. [13] have studied the lessening life of bolts under vibration found that low frequency affects in bolt loosening. Yangjie Zuo et al [14]. Preloaded bolts are used for joints where the load is reversed, a high-stress range is generated, or the adjacent components need to be prevented from slipping. Hao Gong et al [15] have Studied the lwan model in thread surface and bearing surface to represent the nonlinear local slippage behavior with different novel anti-loosening structures by using FEM. The preload in the novel thread structures shows better anti-loosening abilities than the metric thread. During the tightening process, preload (or initial load) emerges, elongating the bolt and compressing the joint members Figure.1. This study investigates the relationship between bolt joint diameter and its effect on preload losses under Alternating thermal load and investigates ways of improving these losses.

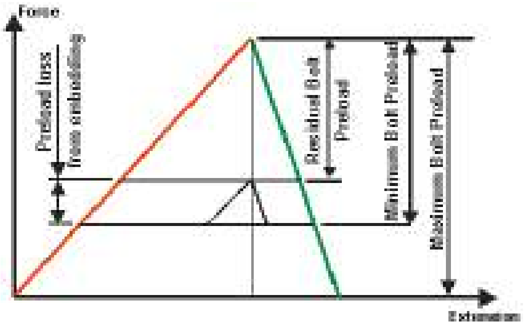


Figure 1. The Effect of Preload Variation and Embedding [16]

2. Finite Element modelling

Finite Element Analysis (FEA) is used to assess the bolted joint structure, as shown in Figure.2. The models will study by 2D-section Axisymmetric, FEA which is performed using the commercial software Ansys 2020R2(Workbench)®.

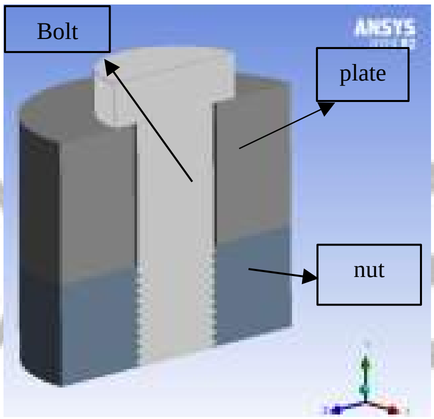


Figure 2. 3D section of bolted joint

2.1. Dimensional data and material properties

The properties of the material in the bolt are medium carbon steel grade 8.8 and in the nut is aluminum alloy 6061-T6. The corresponding size data of the bolt are shown in Table.1, Table.2, Table.3, and Table.4. The calculation formulas of bolt size are [17]:

$$A_n = \frac{\pi}{4} d_{nom}^2 \qquad (1)$$

$$A_t = \frac{\pi}{4}(d_{nom} - 0.9382P)^2 \qquad (2)$$

$$d_m = d_{nom} - 1.08253175P \qquad (3)$$

$$d_p = d_{nom} - 0.64951905P \qquad (4)$$

A_n: Nominal Area (mm^2), A_t: Tensile Stress Area (mm^2), d_{nom}: Nominal (Major) Diameter (mm), d_m: Minor Diameter (mm), dp: Pitch Diameter (mm), and P: Pitch (mm).

2.1.1. Dimensional data

Table 1: The bolt dimensional data at thread pitch 2mm.

d_{nom} (mm)	12	16	20
P (mm)	2	2	2
d_m (mm)	9.835	13.83	17.83
d_p (mm)	10.70	14.7	18.7
A_n (mm^2)	113.04	200.96	314
A_t (mm^2)	80.493	156.67	258

Table 2: The bolt dimensional data at thread pitch 1.5mm.

d_{nom} (mm)	12	16	20
P (mm)	1.5	1.5	1.5
d_m (mm)	10.376	14.376	18.38
d_p (mm)	11.026	15.03	19.03
A_n (mm^2)	113.04	200.96	314
A_t (mm^2)	88.126	167.25	271.5

Table 3: The bolt dimensional data at thread pitch 1mm.

d_{nom} (mm)	12	16	20
P (mm)	1	1	1
d_m (mm)	10.92	14.92	18.92
d_p (mm)	11.35	15.35	19.35
A_n (mm^2)	113.04	200.96	314
A_t (mm^2)	96.1	178.17	285.4

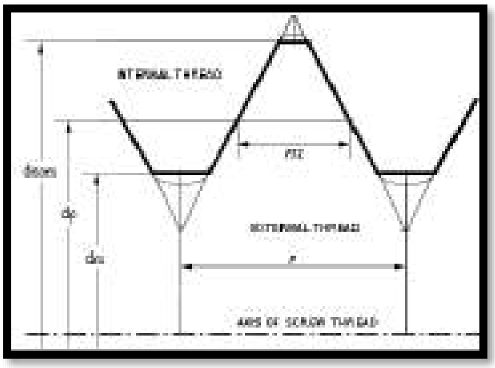


Figure 3. Dimensional of bolted join

2.1.2. Material properties

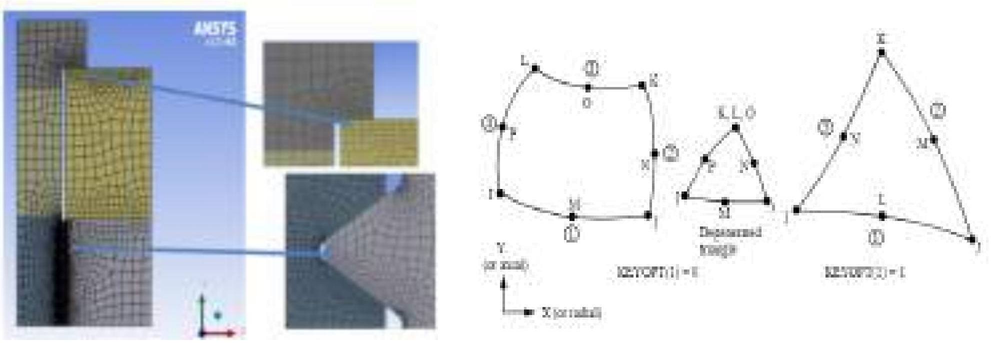
Table 4: Material properties of bolt and nut [18,19].

		Bolt grad 8.8	Nut AA6061-T6
Ys	MPa	640	278
T_m	MPa	1412	883
T_U	MPa	800	380
v	--	0.3	0.33

YS: Yield Strength, T_m: Tangent Modulus, T_U: Ultimate Strength, and v: Poisson’s ratio.

2.2. Mesh sensitivity studies

The model has two contact interfaces as shown in Figure.4A the threaded interface between the nut and bolt and the bearing interface between the bolt and plate. The element order type used in Finite element meshes of bolted joints, as shown in Figure.4B is Plane183. Plane183 is a higher-order 2-d have 8-node when KEYOPT (1) = 0, or 6-node when KEYOPT (1) = 1 element. Plane183 has quadratic displacement behavior. The number degrees of freedom are x-axis and y-axis when KEYOPT (3) ≠ 6, and x-axis, y-axis, and rotary when KEYOPT (3) = 6. The mesh sensitivity graph presented in Figure.5. Clearly illustrates the independent mesh model when the mesh size increases to 9,000-elements or more.



(A) **(B)**

Figure 4. (A)- 2D section mech in bolted joint at the contact area between head of bolt and plate & thread, (B)- PLANE183 Geometry

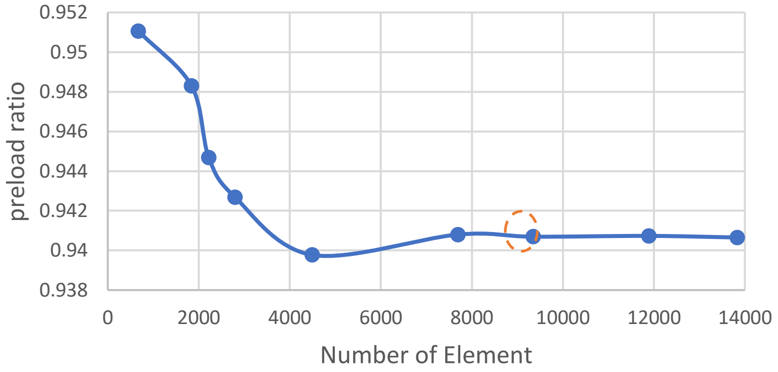


Figure 5. Mesh sensitivity graph

2.3. Boundary conditions and loading procedure

Figure.6 shows the bounder condition in bolted joint use in the 2D-section axisymmetric model the input preload (A). (B), (D) are the supports (B) are free at the y-axis and fixed at the x-axis, (D) are free at the x-axis and fixed at the y-axis. (C) the external thermal load add-in model. The finite element analysis procedure included three steps: Step1: Adjustment of the bolted joint by (1e-003mm). Step 2: add preload for bolt shown in Table.5. Step 3: locking the bolt and applying the external thermal load adds on all model bolt, nut, and plates. Contact and target surfaces are meshed by the CONTA172 and TARGE169 elements. A value of friction coefficient 0.15 is assigned to all sliding interfaces from the stander based on VDI 2230-Part1 [20].

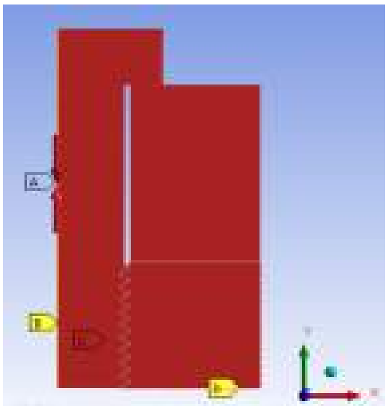


Figure 6. Boundary condition on the structure

Table 5: The parameters used for assessment bolted joint.

Diameter(mm)/preload(N)	Temperature (C)	Thread pitch	Thread angle	Cycle
12mm/25144 N	150/25/-20	1	55	30
16mm/47280 N	200/25/-50	1.5	60	
20mm/75000 N	250/25/-80	2	65	

2.3.1. Thermal Effects

When a structure is subjected to temperature variations, the bolted joint can expand or contract. If a bolted joint is used with different materials, the growth or contraction of the elements can vary thanks to deviating coefficients of thermal load. If deformations at intervals a bolted joint area unit restricted, thermal stresses area unit introduced in joints with preloaded bolts, deformations area unit prevented by the clamping of the preloaded bolt. This may result in a rise of the bolt force or loss of preload. After, the friction resistance of the joint is going to be affected [18].

Table 6: Coefficients of thermal expansion for medium Steel carbon grade 8.8 and Aluminum Alloy 6061-T6 [18,19].

Coefficients of thermal expansion		
α_T[C^-1]	Carbon steel grad 8.8 ISO898	Aluminum Alloy 6061-T6
	1.2E-05	2.5E-05

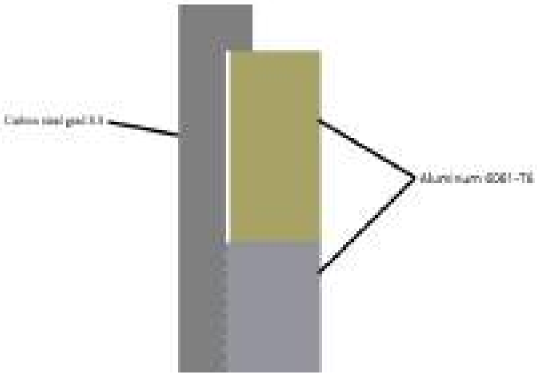
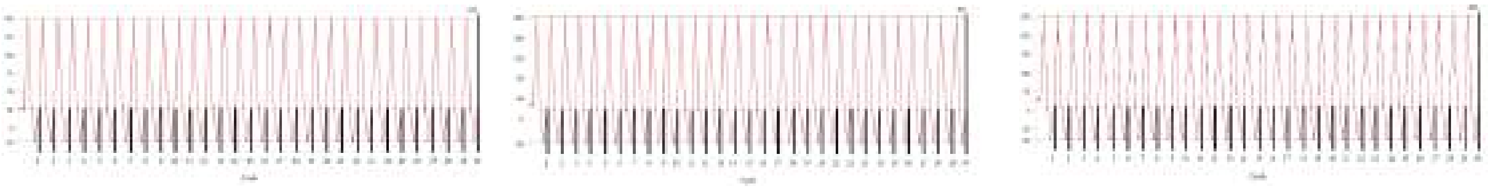


Figure 7. 2D Section of bolted joint with materials Steel Carbon grade 8.8 vs. Aluminum Alloy 6061-T6.

2.3.2. Thermal Range

It is clear from several studies that aluminum alloys are excellent mechanical properties such as strength and ductility at cryogenic temperatures. The deformation results of aluminum alloys show that the strength and toughness of the alloys significantly improve with decreasing temperature. Typically, treatment below -80°C is called cryogenic [21-22]. Most of aluminum alloys are not suitable for temperature above 227 C [23]



(a) (b) (c)

Figure 8. Alternating Thermal Load (a) -20^{o}C to 150^{o}C /30-cycles, (b) -50^{o}C to 200^{o}C /30-cycles, and (c)-80^{o}C to 250^{o}C /30-cycles

2.4. Model verification

The experimental results of the specimens under thermal load 20^{o}C to 60^{o}C reported by Oybek [24], are verified in this study by using FEM. The results of specimens on FEM are close to the experiment results. Figure.9 show that at temperatures 20^{o}C to 60^{o}C and preload 5kN, 10kN, and 15kN the bolt preload goes up sharply while the temperature of the joint increases. When the temperature reaches the peak point of 60^{o}C, the bolt tension makes up 153.89% at 5kN, 126.86% at 10kN, and 117.83% at 15kN. In the cooling process, the preload drops dramatically to 92.95% at 5kN, and 95.02% at 10kN, and 96.25% at 15kN at the end of the process.

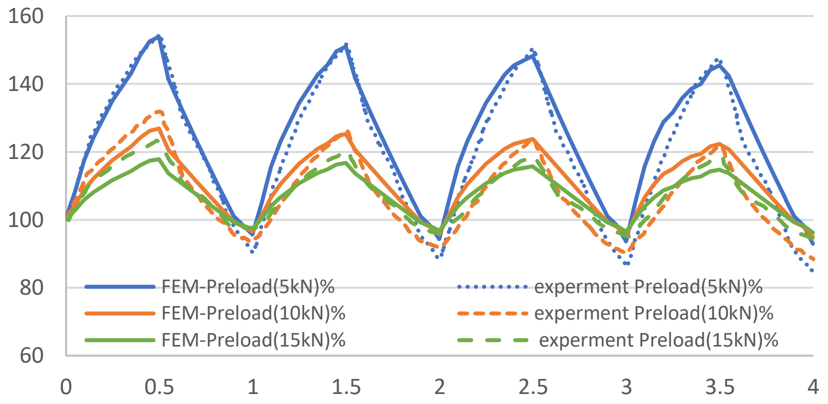
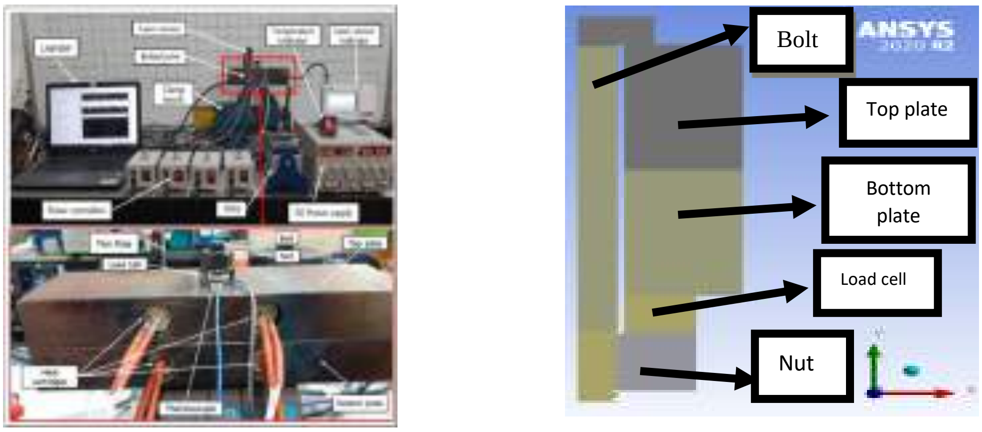


Figure 9. The comparison of experimental results and FEM of different bolt preload under temperature from 20^{o}C to 60^{o}C.



(a) (b)

Figure 10. Verification model between (a) experiments [33] and (b) FEM.

3.Assessment of Bolted Joint under Alternating Thermal Load

The bolted joint is assessed by changing the bolt parameters thread angle (55^{o},60^{o}, and 65^{o}), thread pitch (2mm, 1.5mm, and 1mm), and the bolt diameter (12mm, 16mm, and 20mm) with Alternating thermal Load ($150^{o}C/25^{o}C/-20^{o}C$) -($200^{o}C/25^{o}C/-50^{o}C$) -($250^{o}C/25^{o}C/-80^{o}C$) as shown in Table 5. The material is shown in Table 4, and Figure 7.

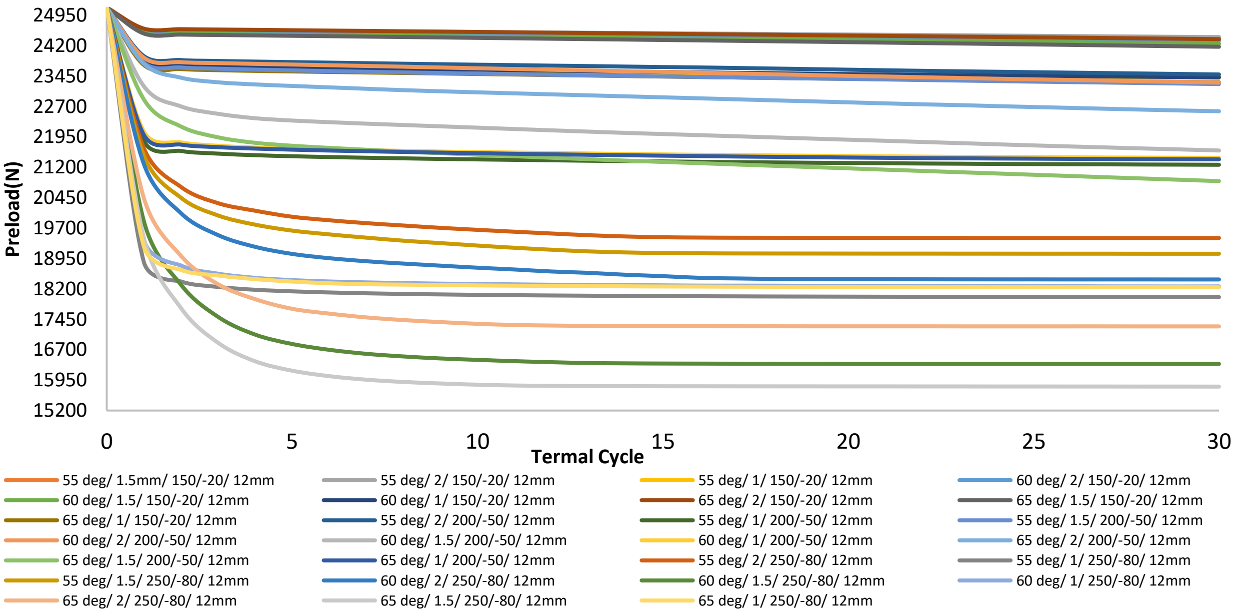


Figure 11. Preload vs cycle of bolted joint Diameter 12mm

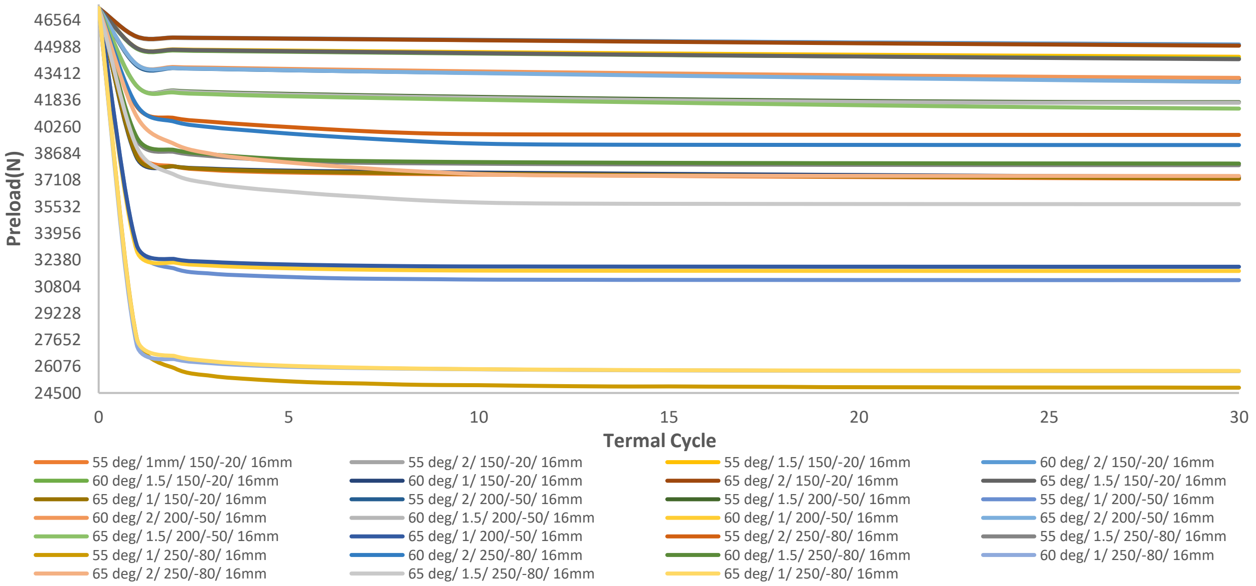


Figure 12. Preload vs cycle of bolted joint Diameter 16mm

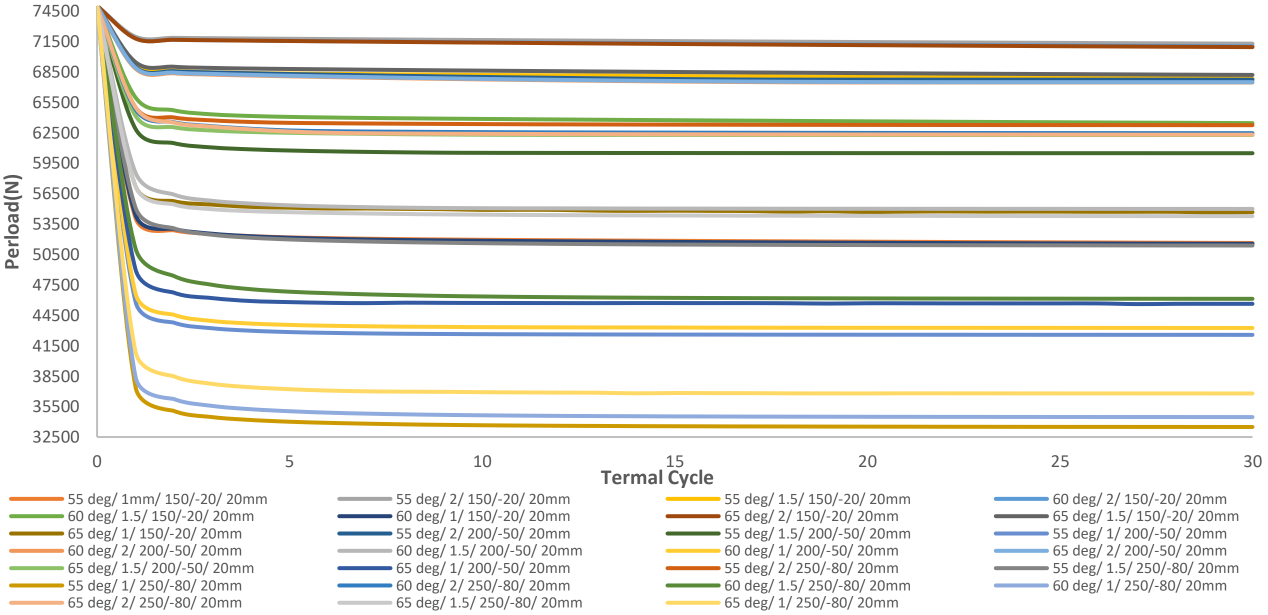


Figure 13. Preload vs cycle of bolted joint Diameter 20mm

The alternating thermal load cycles are shown in Figure.8a, Figure.8b, and Figure.8c the thermal cycle starts from 25^o before high temperature and ends in 25^o after low temperature (i.e., $25^oC/150^oC$ /$25^oC/-20^oC/25^oC$). The results of assessment bolted joint diameters (12mm, 16mm, and 20mm) are shown in Figure.11, Figure.12, and Figure.13. The local sliding between the threads and bearing surfaces when subjected to alternating thermal loads is non-linear; this gradually accumulates with the thermal cycle, causing the threaded fasteners to loosen.

Table 7: losing in preload at temperature rang 150°/25°/-20° after 30 cycles.

150°C/-20°C	55°/2mm	55°/1.5mm	55°/1mm	60°/2mm	60°/1.5mm	60°/1mm	65°/2mm	65°/1.5mm	65°/1mm
12mm	2.90%	3.22%	6.90%	3.23%	3.54%	6.84%	3.10%	3.85%	7.33%
16mm	4.55%	6.10%	21.38%	4.57%	6.33%	21.13%	4.71%	6.41%	21.30%
20mm	4.96%	9.56%	31.16%	5.32%	15.41%	31.22%	5.42%	9.10%	27.15%

Table 8: losing in preload at temperature rang 200°/25°/-50° after 30 cycles.

200°C/-50°C	55°/2mm	55°/1.5mm	55°/1mm	60°/2mm	60°/1.5mm	60°/1mm	65°/2mm	65°/1.5mm	65°/1mm
12mm	6.57%	7.51%	15.43%	7.37%	14.03%	14.75%	10.18%	17.03%	14.90%
16mm	8.90%	11.77%	34.06%	8.74%	11.85%	32.91%	9.25%	12.58%	32.38%
20mm	9.70%	19.37%	43.24%	10.08%	26.69%	42.29%	10.03%	16.97%	39.16%

Table 9: losing in preload at temperature rang 250°/25°/-80° after 30 cycles.

250°C/-80°C	55°/2mm	55°/1.5mm	55°/1mm	60°/2mm	60°/1.5mm	60°/1mm	65°/2mm	65°/1.5mm	65°/1mm
12mm	22.61%	24.16%	28.42%	26.69%	34.97%	27.36%	31.29%	37.20%	27.45%
16mm	15.88%	19.67%	47.52%	17.15%	19.46%	45.45%	21.02%	24.55%	45.42%
20mm	15.70%	31.50%	55.34%	16.73%	38.51%	54.01%	16.93%	27.64%	50.94%

Table.7 shows the loss in bolted joint diameters (12mm, 16mm, and 20mm) at a temperature range 150°C/25°C/-20°C after 30 cycles. Table.8 shows the presence of a loss in bolted joint diameters (12mm, 16mm, and 20mm) at temperature range 200°C/25°C/-50°C after 30 cycles. Table.9 shows the presence of a loss in bolted joint diameters (12mm, 16mm, and 20mm) at temperature range 250°C/25°C/-80°C after 30 cycles. The worst bolt show at diameter 12mm with parameters angle 65° and pith 1.5mm at the temperature range 250°C/25°C/-80°C, for diameter 16mm (angle 55° and pith 1 mm) at the temperature range 250°C/25°C/-80°C, and diameter 20mm (angle 55° and pith 1 mm) at the temperature range 250°C/25°C/-80°C.

4. Redesign of Improved Bolted joint models

Novel anti-loosening structures redesign the bolt thread to resist the preload loss, as shown in Figure.14a. The first and second structures are designed trapezoid shapes with angles 60°, 80° as shown in Figures.14b, c. The third structure is designed triangular-grooved shapes with angle 135°, as shown in Figure.14d. In the fourth structure is designed step-grooved shapes angle as shown in Figure.14g. The fifth is designed triangular in mid of the thread area, as shown in Figure.14h. The sixth and seventh structures are designed triangular with angles 35° and 20°, as shown in Figures.14k, j. The eighth structure is designed triangular at the right side of the thread area as shown in Figure.14i. The upper angle of all structures is increased by (9°). All these structures can impede the alternate slippage that occurs on the thread surface under the effect of alternating thermal load.

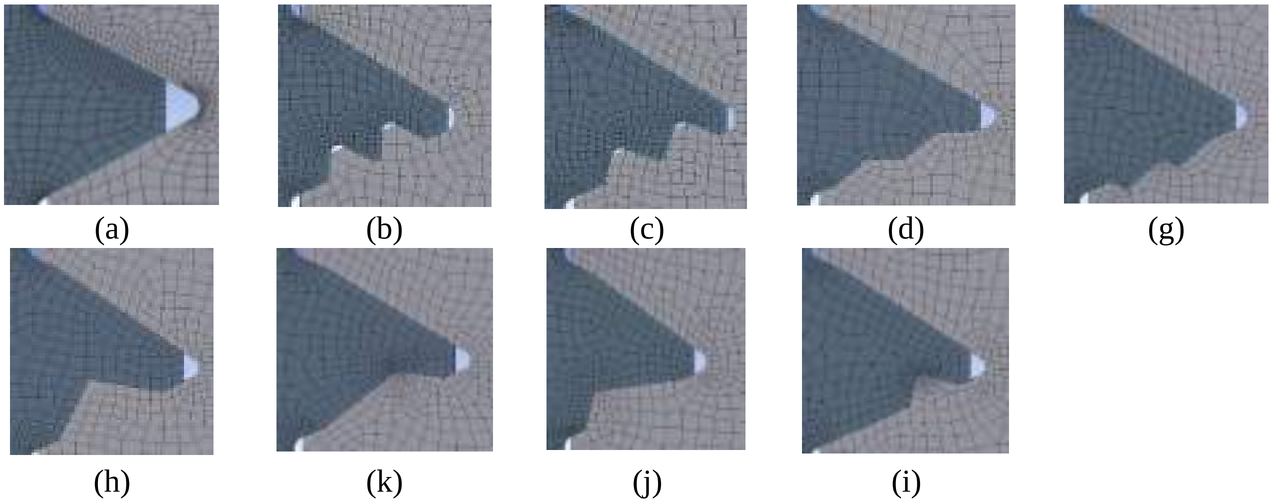


Figure 14. Two-dimensional finite-element models of different thread connection structures. (a) bolted joint, (b) the first novel anti-loosening structure, (c) the second novel anti-loosening structure, (d) the third novel anti-loosening structure, (g) the fourth novel anti-loosening structure, (h) the fifth novel anti-loosening structure, (k) the sixth novel anti-loosening structure, (j) the seventh novel anti-loosening structure, and (i) the eighth novel anti-loosening structure.

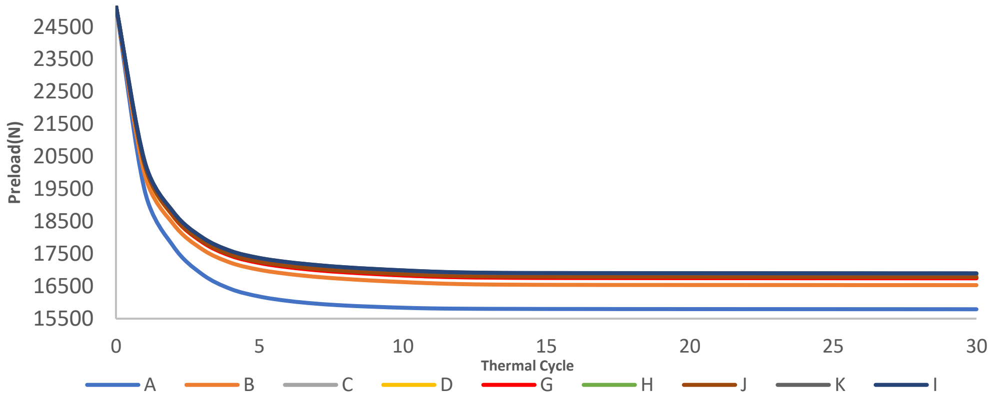


Figure 15. Changes in preloads for Bolt (12mm) with an increase in thermal cycles modelled by FEM

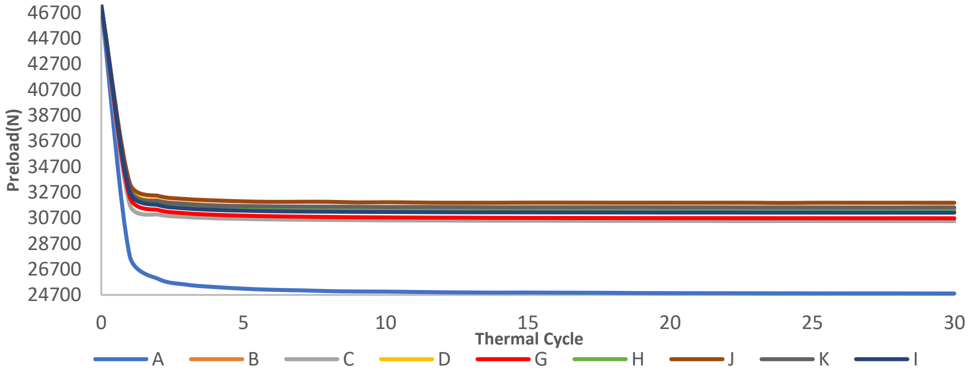


Figure 16. Changes in preloads for Bolt (16mm) with an increase in thermal cycles modelled by FEM

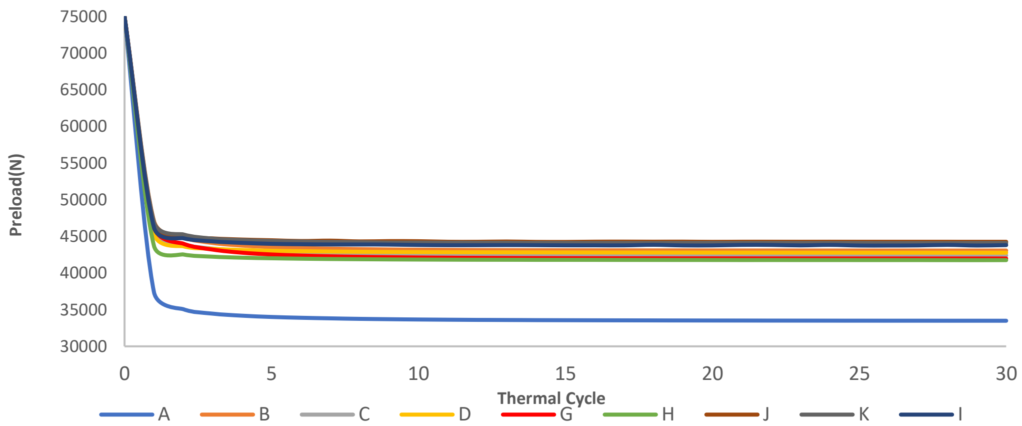


Figure 17. Changes in preloads for Bolt (20mm) with an increase in thermal cycles modelled by FEM

Table 10:- Preload loss compared between metric thread structure with novel anti-loosening structures for bolt for bolt 12mm.

Model	A	B	C	D	G	H	I	J	K	Q
Losing%	37.20%	37.07%	37.04%	37.09%	35.19%	33.95%	37.02%	37.06%	37.07%	36.05%
Development%	----	0.13%	0.16%	0.11%	2.01%	3.25%	0.18%	0.14%	0.13%	1.15%

Table 11:- Preload loss compared between metric thread structure with novel anti-loosening structures for bolt for bolt 16mm.

Model	A	B	C	D	G	H	I	J	K	Q
Losing%	47.52%	47.05%	45.98%	47.24%	40.87%	37.17%	47.06%	46.43%	46.22%	44.96%
Development%	----	0.47%	1.54%	0.28%	6.65%	10.35%	0.46%	1.09%	1.30%	2.56%

Table 12:- Preload loss compared between metric thread structure with novel anti-loosening structures for bolt for bolt 20mm.

Model	A	B	C	D	G	H	I	J	K	Q
Losing%	55.34%	54.57%	53.61%	54.82%	47.02%	44.73%	54.34%	54.04%	54.28%	50.64%
Development%	----	0.78%	1.73%	0.53%	8.33%	10.62%	1.01%	1.30%	1.07%	4.71%

After assessment, the bolted joint diameters (12mm, 16mm, and 20mm) with changing in parameters. Figure.15, Figure.16, and Figure.17. Shown the improvement of Novel anti-loosening structures for metric thread bolted joint. Table 10, Table 11, and Table 12 shown the percentage of losing in bolted joint at diameters 12mm, 16mm, and 20mm with the improvement of Novel anti-loosening structures.

5. Discussion

5.1 Effect thermal load on Preload losing for bolt

Figure.18 shows the preload loss in the bolted joint is affected by the increase in bolt size because of the tension stress and temperature on the bolt. The different percentage of preload losing at temperature (150^{o}C/-20^{o}C) between bolt 12mm and 16mm is 14.48% between bolt 16mm and 20mm 9.78%. At temperature (200°C/-50°C) between bolt 12mm and 16mm is 18.63% and between bolt 16mm and 20mm 9.18%. At (250°C/-80°C), between bolt 12mm and 16mm is 19.1% and between bolt 16mm and 20mm 7.82%. At elevated temperatures, if a metal part is subjected to tensile stress, creep will occur, increasing the length of the part. The amount of deformation that a part will experience depends on the amount of stress, the characteristics of the metal, and the time the part is exposed to high temperatures increase in loss of preload.

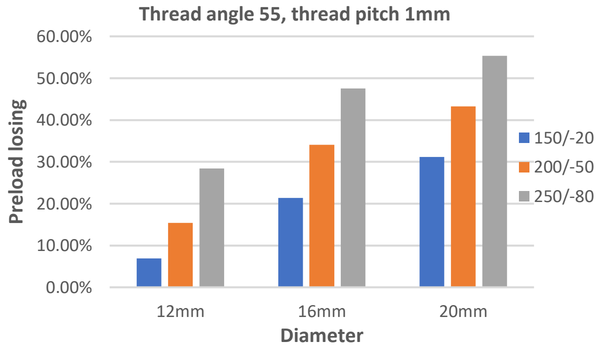
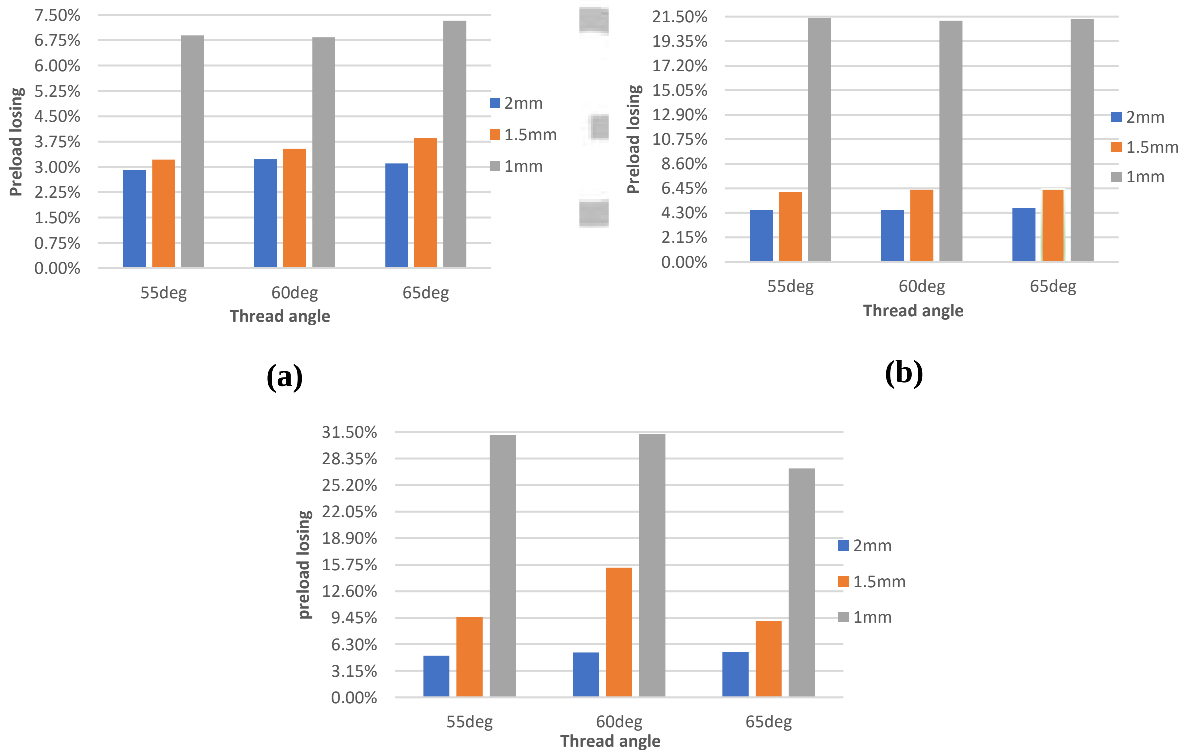


Figure 18. Preload losing in bolted joint (55°/1mm) diameter (12mm, 16mm, and 20mm) with the increase in temperature. (150/-20, 200/-50, and 250/-80)



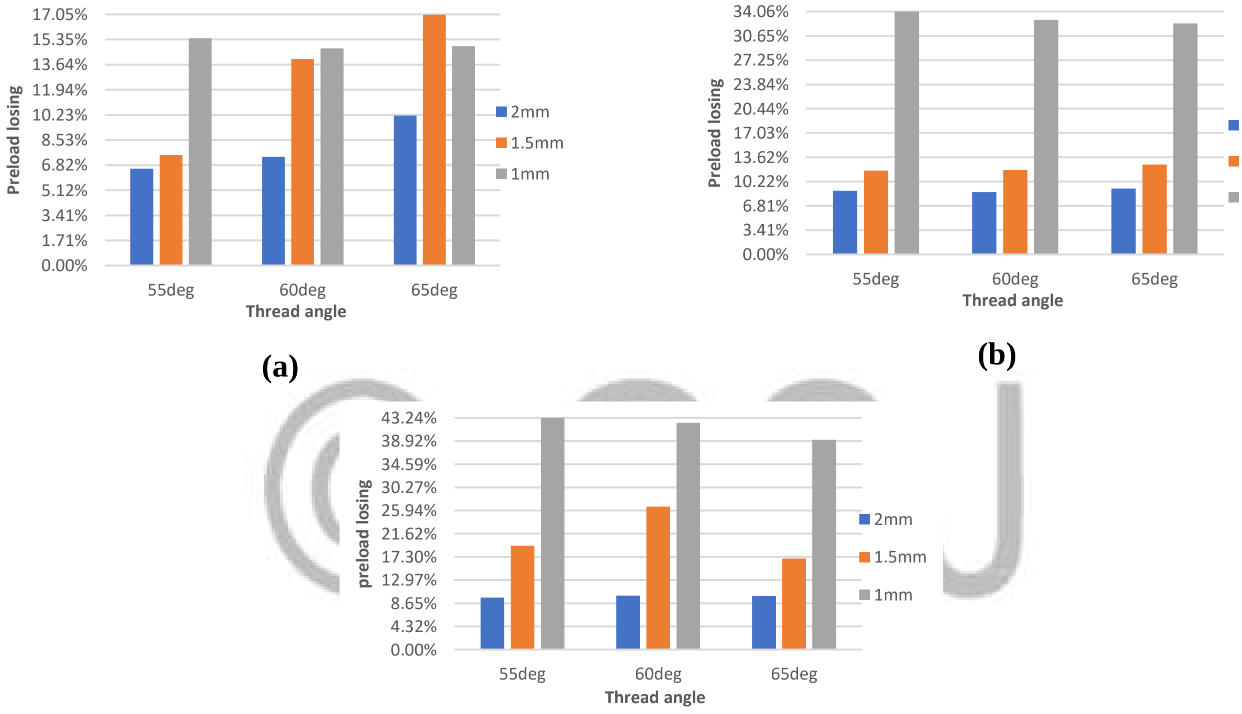
(a) **(b)**

(c)

Figure 19. Preload losing with pitch and angle of thread at Alternating thermal load 150°/25°/-20° (a) bolt 12mm, (b) bolt 16mm, and (c) bolt 20mm.

Figure.19a, Figure.19b, and Figure.19c shows the preload loss in bolted joints at Alternating thermal load (150°C/25°C/-20°C). The result shows the effect of thread angle and pitch in bolt 12mm at angle

55^o - pitch 2 mm is given lower preload losing followed by angle 65^o - pitch 2 mm, angle 55^o - pitch 1.5 mm, angle 60^o - pitch 2 mm, angle 60^o - pitch 1.5mm, angle 65^o - pitch 1.5 mm, angle 60^o - pitch 1mm, angle 55^o - pitch 1mm, and angle 65^o - pitch 1mm. A bolt 16mm angle 55^o - pitch 2 mm is given lower preload loss followed by angle 60^o - pitch 2 mm, angle 65^o - pitch 2 mm, angle 55^o - pitch 1.5 mm, angle 60^o - pitch 1.5mm, angle 65^o - pitch 1.5 mm, angle 60^o - pitch 1mm, angle 65^o - pitch 1mm, and angle 55^o - pitch 1mm. In bolt 20mm angle 55^o - pitch 2 mm is given lower preload losing followed by angle 60^o - pitch 2 mm, angle 65^o - pitch 2 mm, angle 65^o - pitch 1.5 mm, angle 55^o - pitch 1.5mm, angle 60^o - pitch 1.5 mm, angle 65^o - pitch 1 mm, angle 55^o - pitch 1mm, and angle 60^o - pitch 1mm.

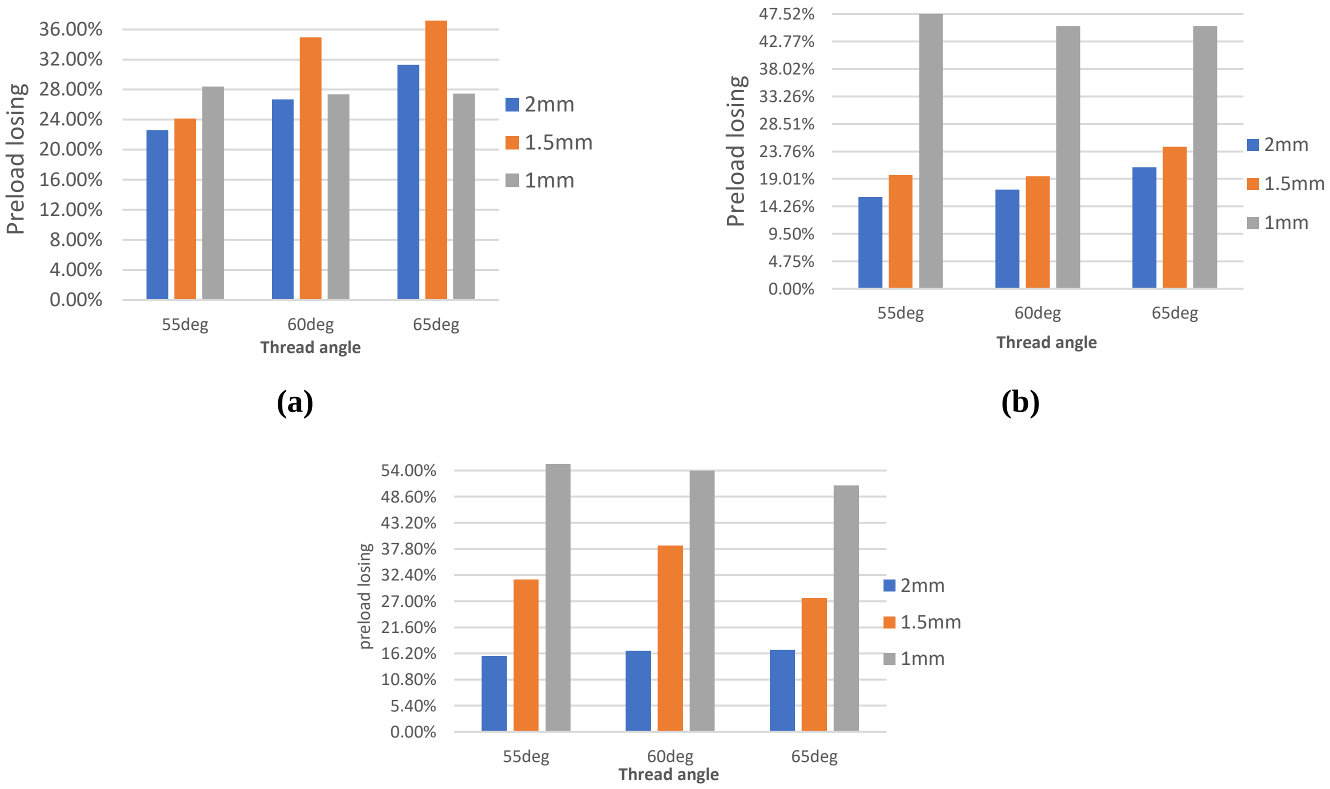


(a) **(b)**

(c)

Figure 20. Preload losing with pitch and angle of thread at Alternating thermal load $200^{O}/25^{O}/-50^{O}$ (a) bolt 12mm, (b) bolt 16mm, and (c) bolt 20mm.

Figure.20a, Figure.20b, and Figure.20c shows the preload losing in bolted joint at Alternating thermal load ($200^oC/25^oC/-50^oC$). The result shows the effect of thread angle and pitch in bolt 12mm at angle 55^o pitch 2 mm is given lower preload losing followed by angle 60^o pitch 2 mm, angle 55^o pitch 1.5 mm, angle 65^o pitch 2 mm, angle 60^o pitch 1.5mm, angle 60^o pitch 1 mm, angle 65^o pitch 1mm, angle 55^o pitch 1mm, and angle 65^o pitch 1.5mm. A bolt 16mm angle 60^o pitch 2 mm is given lower preload losing followed by angle 55^o pitch 2 mm, angle 65^o pitch 2 mm, angle 55^o pitch 1.5 mm, angle 60^o pitch 1.5mm, angle 65^o pitch 1.5 mm, angle 65^o pitch 1mm, angle 60^o pitch 1mm, and angle 55^o pitch 1mm. In bolt 20mm angle 55^o pitch 2 mm is given lower preload losing followed by angle 65^o pitch 2 mm, angle 60^o pitch 2 mm, angle 65^o pitch 1.5 mm, angle 55^o pitch 1.5mm, angle 60^o pitch 1.5 mm, angle 65^o pitch 1 mm, angle 60^o pitch 1mm, and angle 55^o pitch 1mm.



(a) **(b)**

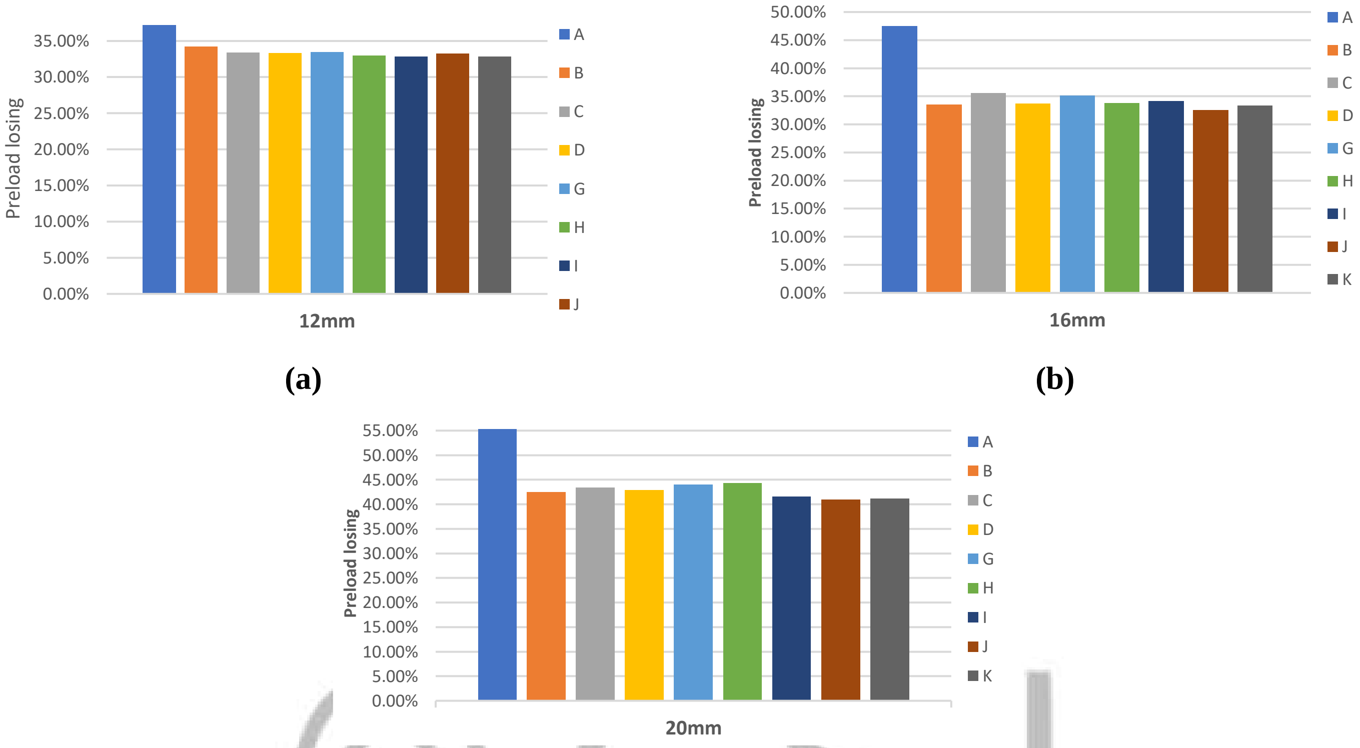
(c)

Figure 21. Preload losing with pitch and angle of thread at Alternating thermal load $250^{O}/25^{O}/-80^{O}$ (a) bolt 12mm, (b) bolt 16mm, and (c) bolt 20mm.

Figure.21a, Figure.21b, and Figure.21c shows the preload losing in bolted joint at Alternating thermal load (250^{o}C/25^{o}C/-80^{o}C). The result shows the effect of thread angle and pitch in bolt 12mm at angle 55^{o} pitch 2 mm is given lower preload losing followed by angle 55^{o} pitch 1.5mm, angle 60^{o} pitch 2mm, angle 60^{o} pitch 1 mm, angle 65^{o} pitch 1mm, angle 55^{o} pitch 1mm, angle 65^{o} pitch 2mm, angle 60^{o} pitch 1.5mm, and angle 65^{o} pitch 1.5mm.A bolt 16mm angle 55^{o} pitch 2mm is given lower preload losing followed by angle 60^{o} pitch 2 mm, angle 60^{o} pitch 1.5mm, angle 55^{o} pitch 1.5 mm, angle 65^{o} pitch 2mm, angle 65^{o} pitch 1.5 mm, angle 65^{o} pitch 1mm, angle 60^{o} pitch 1mm, and angle 55^{o} pitch 1mm. In bolt 20mm angle 55^{o} pitch 2 mm is given lower preload losing followed by angle 60^{o} pitch 2 mm, angle 65^{o} pitch 2 mm, angle 65^{o} pitch 1.5 mm, angle 55^{o} pitch 1.5mm, angle 60^{o} pitch 1.5 mm, angle 65^{o} pitch 1 mm, angle 60^{o} pitch 1mm, and angle 55^{o} pitch 1mm.

5.2 Validation of anti-loosening ability of novel structures

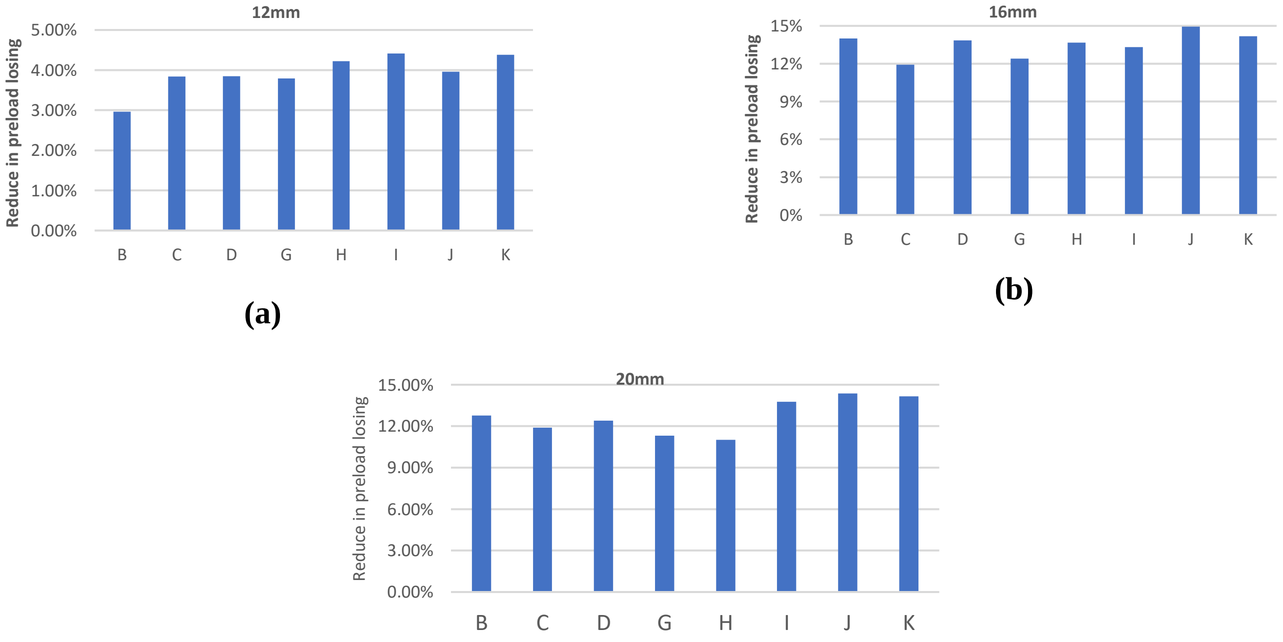
As shown in Figure.14 the novel anti-loosening structures are used to improve metric threaded bolt structure. Figure.22a, Figure.22b, and Figure.22c compare metric thread bolt structure with novel anti-loosening structures. The preload in the novel anti-loosening structures 12mm bolt reduces the preload loss by 4.41% shown in Figure.23a. As shown in Figure.23b the preload at 16mm bolt, the novel anti-loosening structures are reducing the preload loss by 14.96%. Figure.23c shows the preload at 20mm bolt, the novel anti-loosening structures are reducing the preload loss by 14.36%. Whereas the preload in the metric thread bolted joint decreases steadily. It indicates that the novel thread structures indeed have better anti-loosening abilities compared with the metric threaded bolt.



(a) (b)

(c)

Figure 22. Compare metric thread bolt structure (A) with novel anti-loosening structures (B, C, D, G, H, I, J, and K) (a) bolt 12mm angle 65°-thrid pitch 1.5mm (b) bolt 16mm angle 55°-thrid pitch 1mm (c) bolt 20mm angle 55°-thrid pitch 1mm



(a) (b)

(c)

Figure 23. Reduce in preload losing by using novel anti-loosening structures (B, C, D, G, H, I, J, and K) (a) bolt 12mm (b) bolt 16mm (c) bolt 20mm.

6.Conclusions and Recommendation

The objectives of the research have been successfully achieved.

1) FE model is developed to simulate the bolted joint under thermal load.
2) It is found that the Losses are directly proportional to the bolted joint diameter.
3) By studying closely, the mechanisms of loosening, the design is a redesign, test, and shown to have improved the performance of the bolted joint.

In this study, bolted joint assessment and improvement by cyclic Alternating thermal load by three diameters 12mm, 16mm, and 20mm with different parameters thread angles and thread pitch.

The results show an increase in bolt diameter and alternating thermal load will increase the preload loss in the bolt. The thread angle and thread pitch show the different results in bolt at temperature (150^{o}C/-20^{o}C) the thread angle 55^{o} and thread pitch 2mm in bolt 12mm, 16mm, and 20mm show low preload loss. At temperature (200^{o}C/-50^{o}C) in bolt 12mm and bolt 20mm the thread angle 55^{o} and thread pitch 2mm, 16mm thread angle 60^{o} thread pitch 2mm show low preload loss. At temperature (250^{o}C/-80^{o}C) in bolt 12mm, 16mm, and 20mm the thread angle 55^{o} and thread pitch 2mm show low preload loss.

Based on the loosening mechanism, a method to reduce the loosening effect is proposed, and several new improved structures are designed based on this idea. Finally, their superior performance is verified by the FEA method.

Recommendations for future work include the following:

1) The study can be followed by experimentation work to confirm the results given by the FEA model.
2) Further study can include investigating the behaviour of the stress concentration in the bolt.

References

[1]- den Otter, C., & Maljaars, J. (2020). Preload loss of stainless steel bolts in aluminium plated slip resistant connections. Thin-Walled Structures, 157, 106984.

[2]- Li, Y., Liu, Z., Wang, Y., Cai, L., & Zheng, M. (2020). Experimental study on behavior of time-related preload relaxation for bolted joints subjected to vibration in different directions. Tribology International, 142, 106005.

[3]- Wettstein, A., Kretschmer, T., & Matthiesen, S. (2020). Investigation of dynamic friction during impact tightening of bolted joints. Tribology International, 146, 106251.

[4]- Ding, K., & Dhanasekar, M. (2007). Flexural behaviour of bonded-bolted butt joints due to bolt looseness. Advances in Engineering Software, 38(8-9), 598-606.

[5]- Noda, N. A., Chen, X., Sano, Y., Wahab, M. A., Maruyama, H., Fujisawa, R., & Takase, Y. (2016). Effect of pitch difference between the bolt–nut connections upon the anti-loosening performance and fatigue life. Materials & Design, 96, 476-489.

[6]- Liu, J., Ouyang, H., Feng, Z., Cai, Z., Mo, J., Peng, J., & Zhu, M. (2019). Dynamic behaviour of a bolted joint subjected to torsional excitation. Tribology International, 140, 105877.

[7]- Chen, D., Ma, Y., Hou, B., Liu, R., & Zhang, W. (2019). Tightening behavior of bolted joint with non-parallel bearing surface. International Journal of Mechanical Sciences, 153, 240-253.

[8]- Gao, D., Yao, W., & Wu, T. (2019). Failure analysis on the axial-connected bolts of the thin-walled cylinder under random vibration loading. Engineering Failure Analysis, 105, 756-765.

[9]- Liu, J., Ouyang, H., Feng, Z., Cai, Z., Liu, X., & Zhu, M. (2017). Study on self-loosening of bolted joints excited by dynamic axial load. Tribology international, 115, 432-451.

[10]- Khaleed, H. M., Samad, Z., Suhaib, S., Uthman, A. R., Jagirdar, S. A., Badruddin, I. A., ... & Quadir, G. A. (2008). Analysis of stress concentration factor in bolted joint using finite element method. International Journal of Mechanical and Materials Engineering, 3(1), 38-45.

[11]- Daouk, S., Louf, F., Cluzel, C., Dorival, O., Champaney, L., & Audebert, S. (2017). Study of the dynamic behavior of a bolted joint under heavy loadings. Journal of Sound and Vibration, 392, 307-324.

[12]- Khashaba, U. A., Sallam, H. E. M., Al-Shorbagy, A. E., & Seif, M. A. (2006). Effect of washer size and tightening torque on the performance of bolted joints in composite structures. Composite structures, 73(3), 310-317.

[13]- Yang, G., Che, C., Xiao, S., Yang, B., Zhu, T., & Jiang, S. (2019). Experimental study and life prediction of bolt loosening life under variable amplitude vibration. Shock and Vibration, 2019.

[14]- Zuo, Y., Cao, Z., Zheng, G., & Zhang, Q. (2020). Damage behavior investigation of CFRP/Ti bolted joint during interference fit bolt dynamic installation progress. Engineering Failure Analysis, 111, 104454.

[15]- Gong, H., Liu, J., & Ding, X. (2020). Thorough understanding on the mechanism of vibration-induced loosening of threaded fasteners based on modified Iwan model. Journal of Sound and Vibration, 473, 115238.

[16]-Bill Eccles. Bolt science. September (2021). Back to Basics - Why Bolt Preload is Important. https://www.boltscience.com/pages/basics2.htm.

[17]- Budynas, R. G., & Nisbett, J. K. (2011). Shigley's mechanical engineering design (Vol. 9). New York: McGraw-Hill.

[18]- van Hove, I. B. D., & van Loon, J. J. Preload loss of stainless (steel) bolts in aluminium/steel joints.

[19]-ASM Aerospace Specification Metals Inc. (2001). Aluminum 6061-T6; 6061-T651. https://www.aerospacemetals.com/

[20]-C.Junker, J.Newnharn. (1988). Systematic Calculation of High Duty Bolted Joints Joints with One Cylindrical Bolt. Verein Deutscher Ingenieure, 624.078.2 (083.132).

[21]- Yuan, S., Cheng, W., & Liu, W. (2021). Cryogenic formability of a solution-treated aluminum alloy sheet at low temperatures. Journal of Materials Processing Technology, 298, 117295. https://doi.org/10.1016/j.jmatprotec.2021.117295

[22]-S. Harsha, S.M. Dasharath: Effect of cryogenic heat treatment & ageing on ultra-fine-grained aluminium–lithium alloy- A review, Materials Today: Proceedings 45 (2021) 338–348. https://doi.org/10.1016/j.matpr.2020.10.1009

[23]- Lee, J. A. (2003, March). Cast aluminum alloy for high temperature applications. In Automotive alloys The 132nd TMS Annual Meeting & Exhibition.

[24]- Eraliev, O. M. U., Zhang, Y. H., Lee, K. H., & Lee, C. H. (2021). Experimental investigation on self-loosening of a bolted joint under cyclical temperature changes. Advances in Mechanical Engineering, 13(8), 16878140211039428.