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Effect of Bolt Behaviour on the Performance of a Bolted Joint

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Abstract: For proper bolted joint's performance, it is known that the higher the pre-load the better the joint will be. In order to achieve proper pre-load and to utilise proper strength of the bolt to increase the joint strength and joint sealing, bolt quality is of prime importance. It is realized that selection of the proper quality bolt is not given enough importance, which results in poor performance of the bolted joints. Due to the improper bolt selection, overloading of the bolts can cause the gasket crushing and flange yielding in a gasketed joint, especially for the large diameter flanges where hammering and flogging applications are adopted. This paper discusses the need of a good quality bolt using detailed experimental study and highlights the effect of surface treatment on bolts; different makes of bolts, use of different number of nuts and washers, use of different nuts, number of tightening on the same bolt, use of lock nuts and use of proper tooling in detail.

Key words: Bolts · Bolted · Joint · Performance · Surface treatment · Lubricant · Tightening

INTRODUCTION

Due to the flexibility of the gasket, present in the gasketed joints, it is not easy to get the proper pre-load in the joint. The limitation of avoiding the flanges and pipe to yield, limits the applied pre-load value in the bolts. Overloading of the bolts can cause the gasket crushing and flange yielding [1-19]. However higher preload up-to 80% and more is recommended for the non-gasketed joints for better joint strength and sealing [1, 18-33]. It becomes important, especially for the large diameter flanges where hammering and flogging methodologies are adopted. It is therefore concluded that bolt plays a key role in the performance of the bolted joint [11, 34-41]. During experiments, a calibration unit developed for the measurement of force felt by the bolt is shown in Figure 1a. Calibration unit consists of an aluminium cylinder equipped with strain gauges arranged in a Wheatstone full bridge circuit. An amplifier for better result recording and plotting was attached after its calibration with the device. Spectra software package was used to make the full bridge circuit to record the results. M12 bolts as per ISO-898 grade 8.8 and 10.9 [26] and unknown marking with different surface treatment, nuts and washers of different thickness and geometry were arranged from different sources to study their effect on preload and joint's performance. One bolt from each set was placed in the calibration device and was torque up using calibrated electronic torque wrench. Bolts were pre-loaded up-to at least minimum 80% of their yield strength. Bolts were also tested above the proof load but less than the minimum ultimate tensile strength of the bolts to see their strength. Pre-load was applied in increments of 10kN and after each stage torque was recorded from the calibrated electronic torque wrench.

To study the importance of surface treatment of bolts i.e. use of different lubricants, Molykote 321R (used as Anti-friction lubricant), Hydraulic oil for grinders, Wax-emulsion gleitmo 1952 V, unknown surface treatment by one supplier, Bright Zinc without any lubricant, Loctite 7063 (used for cleaning, or used as anti-grease or anti-oil lubricant), PTFE tape, CASTROL

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Table 1: Properties of the bolts tested

Bolt Dia.(mm)	Property Class	Stress Area (mm^2)	Min. Yield Strength	Proof Load (kN)	Min. UT Load (kN)	Pre-load (kN)
M12	10.9	84.3	900	70.0	87.7	81.43
M12	8.8	84.3	640	48.9	67.4	57.91

(a) (b)

Fig. 1: (a) Calibration unit, (b) Experimental setup

(a) (b)

Fig. 2: (a) Bolts, Nuts and washers used during tests, (b) Torque Wrenches used

(a) (b) (c)

Fig. 3: (a,b) Bolts, Nuts and Washers with different dimensions but same standard mentioned (c) Different Surface Treatments (lubricants) used on bolts

EPEX Hydraulic Oil (80W/90) and Copper Slip were applied on the bolts. Experimental setup is show in Figure 1b, different bolts, nuts and washers, tools and lubricants used are shown in Figure 2 and Figure 3. Properties of the bolts tested are given in Table 1.

RESULTS AND DISCUSSION

Bolts with Different Surface Treatments and Makes For First Tightening I.e. Using for the First Time: In this study, all the bolts were brand new (virgin) and were tested for the first time. The difference of surface treatment and make from the applied torque is obvious from results plotted in Figure 4a. Similarly the feel during torquing was observed different for different bolts. For all the bolts of grade 10.9, surface treated by the Supplie-2, torque applied was found more than the double up-to a pre-load of 20kN and after that it was found about 4 times more. A great effort was applied to achieve the required pre-load, whereas on the other hand for the bolts surface treated by Supplier-1, the required pre-load of 81 Nm was achieved very easily. Applied torque was recorded up-to

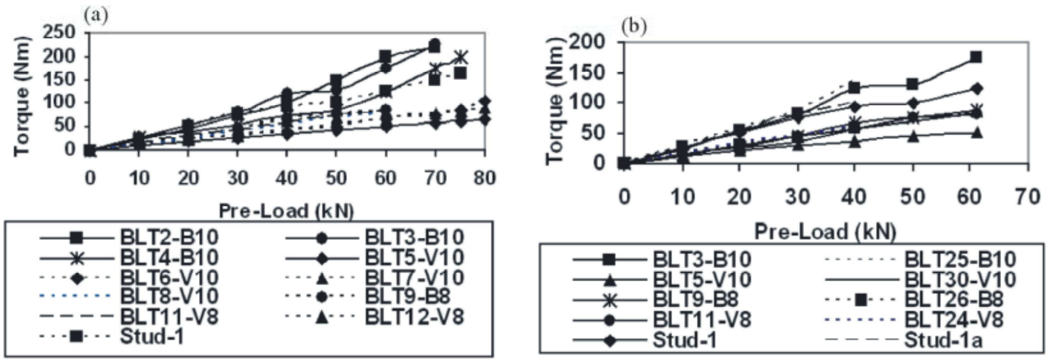

Fig. 4: Torque Vs Pre-load for: (a) Bolts of grade 8.8 and 10.9 with different surface treatments, (b) Bolts tested for one and more times with different surface treatments

about 120Nm using the electronic torque wrench, whereas beyond this torque value, another calibrated torque wrench was used to torque the bolts as high as possible but less than the value of the ultimate tensile load.

The applied torque for the bolts of grade 8.8 surface treated by both suppliers was found almost the same. Whereas, the effort applied was found little bit higher for the bolts arranged from the Supplier-2. In addition, for the same make, same quality and same surface treatment, for some of the bolts, torque recorded was observed different. This variation is less for bolts surface treated by the Supplier-1, but is obvious for the bolts surface treated by the Supplier-2. Comparing results of the bolts of grade 8.8 and 10.9, surface treated by the Supplier-1, torque for the bolt of grade 10.9 was observed comparatively less. Some of the bolts surface treated by Supplier-2, were observed yielding at a torque of about 200Nm. Stud-1, from unknown manufacturer but surface treated by the Supplier-1 was observed yielding at a torque of about 150Nm and is concluded due to the overload as its property class and grade was not known. In actual joint, the torque applied also depends upon the flatness and finish of the clamped surfaces.

For More than One Tightening: This study was performed to examine the effect of repeated usage of the same bolt with the same surface treatment. Results in Figure 4b, shows that the bolt for the second tightening needs almost the same torque to get the same pre-load. A small variation in the torque during tightening bolts of grade 10.9, whereas, no variation for bolts of grade 8.8 was observed. Surface treatment was observed reduced from the shiny surface of threads. Regarding bolt quality, some of the bolts arranged were marked as FS 8.8, were tested in the joint and were damaged/worn after the first and at the most after the second tightening.

Same Bolt with Different Lubricants

For First Tightening: This study was performed to observe the effect of different lubricants or fluids to which the bolt can be exposed during joint assembly, joint maintenance or during leakage of fluid from the joint on the bolt behaviour. In the industrial places where grease, hydraulic oil or other fluids are present mostly and the hands of the technician exposed to such things can be considered to affect the bolt threads. During the present work, almost all the bolts were exposed to the hydraulic oil and glycol due to the leakage and during test rig filling and this was not considered important. All the bolts were torqued up to the same average pre-load using calibrated electronic torque wrench. Bolts of grade 8.8 and 10.9 were used with different lubricants which were surface treated by the Suppliers 1&2. On each of the bolt with original surface treatment different lubricants were applied one by one and for each lubricant the bolt was cleaned using cleaning spray Loctite 7063 to remove the effect of the previous lubricant. This was done due to the limited number of bolts available. Results with the applied lubricants and tightened for the first time is presented in Figure 5a-c.

From the results, the difference is obvious for different lubricants applied. For each bolt with original surface treatment e.g. BLT8-V10-1, torque applied found was less as compared with the lubricant applied. Purpose of this study was not to highlight the type of the lubricant, which should be used, but was to highlight their effect. In Figure 5a, the bolt (BLT8-V10-OO1) was just touched with the hydraulic oil during handling and the effect of oil on the original surface treatment can be

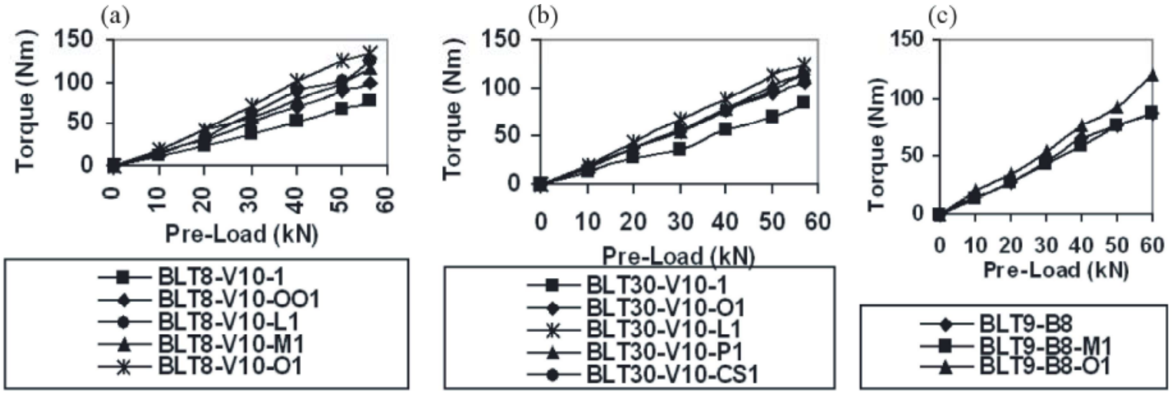

Fig. 5: Torque variation Vs Preload in bolts of grade 8.8 and 10.9 using different Lubricants during first tightening.

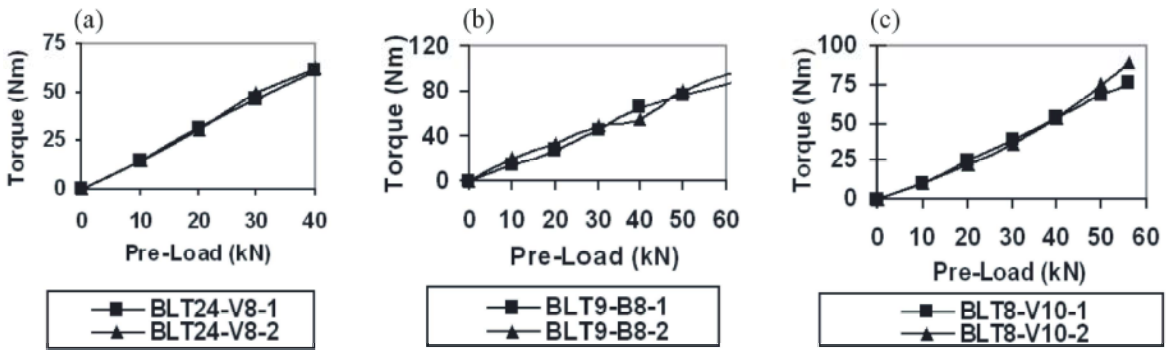

Fig. 6: Torque variation Vs Preload in bolts of grade 8.8 and 10.9 with original surface treatment for more than one tightening.

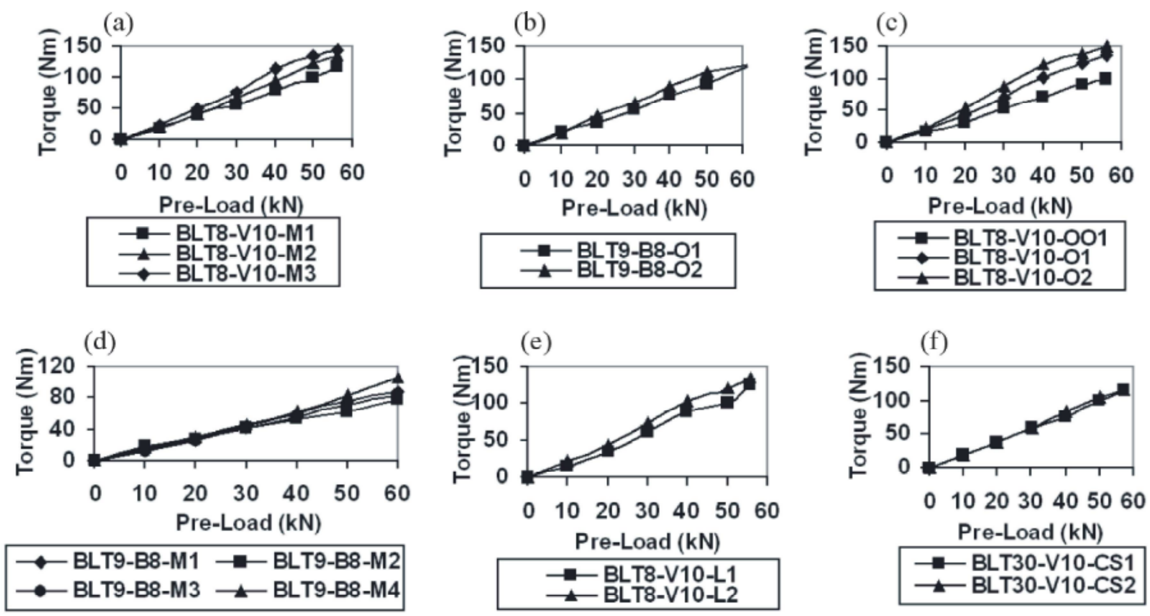

Fig. 7: Torque variation using same lubricants but for more than one tightening on the same bolt.

seen obviously. This effect increases or decreases with different lubricants [10,13,16]. Lubricants and other treatments like hydraulic oil for grinding, Molykote 321R, Loctite 7063 for cleaning, PTFE tape and copper slip and Castrol EPX hydraulic oil were applied on the threads of the bolts and similar results were observed.

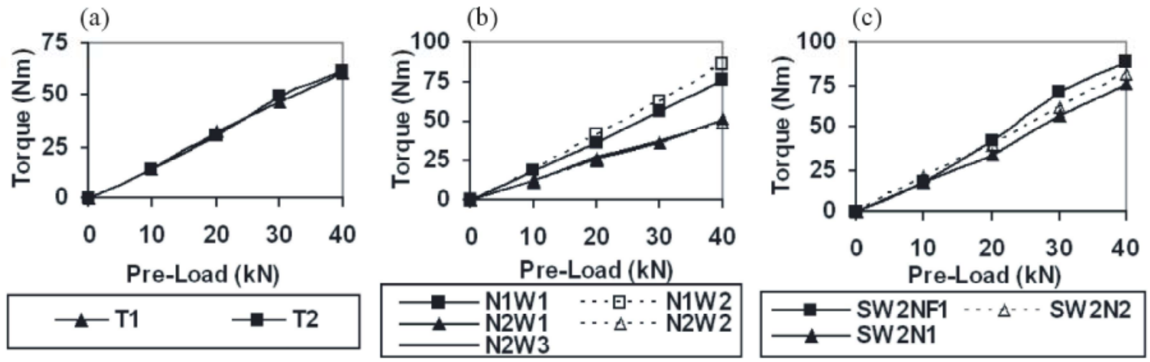

Fig. 8: Preload Vs Torque variation using same bolt (Bolt 24) of grade 8.8 arranged from supplier-1: (a) For two tightening with no washer, (b) for one tightening but with different number of nuts and washers, (c) for one tightening but with different number of nuts and sturdy washers

For More than One Tightening: Results with the original surface treatment on the bolts for two and three tightening show almost the same behaviour and are plotted in Figure 6a, b and c. From the results of Figure 7a-f, for number of tightening for the same applied lubricant, torque required for the second and third tightening is observed greater to get the same pre-load value. This was concluded due to the removal of the lubricant from the threads of the bolt and increased friction. It is also interesting to note that even the cleaning spary Loctite 7063 effects the torque applied and changes the friction on threads.

Bolts with Different Nut and Washer Combinations for One and More than One Tightening: Results for all the different combinations of nuts and washers and for one and more tightening are plotted in Figure 8a-c. It is clear that for more than one tightening, torque slightly increases with each combination. Using one nut and two thin hard washers one under the bolt head and one under nut requires comparatively less torque than with one thick washer under the bolt head. Using a thick washer of improper flat surface increases the torque required to get the required pre-load. This is observed an important consideration for a bolt to be properly pre-loaded and to avoid the surfaces and bolt threads from damage. This consideration can also be applied to the surfaces, which are not perfectly flat. Results using two thick washers and one thin washer were found almost the same. Summarising, the use of the washer on both the sides under bolt head and nut is recommended to utilise the high strength properties of the bolt. In addition washers of flat surfaces are also recommended.

Proper Tooling and Fastener Dimensions: At the start of experiments, no consideration was given to the tooling required for the bolts. However, later it was found that some bolts are of metric dimensions and some are of others. Even for the same metric dimensions, nut and bolt head of different dimensions were observed e.g. for M12 bolt some were observed of 18-mm and some of 19-mm. Different tools available in the lab i.e. conventional torque wrenches, open ring spanners, long handle spanner, electronic calibrated torque wrench were used to highlight the importance of proper tooling to get a required higher pre-load (Figure 2b). Using conventional ring or open spanners it was found very difficult to tighten the bolts and using these tools the bolt head and nut hexagonal geometry was damaged. Sometimes experiments were stopped because of the unavailability of the proper spanner due to the varying dimension of bolt head or nut. This was also found that the bolts marked with the same marking have large variation in their quality, geometry, surface finish and even visibility. Even the bolts used in this study were of very good quality, proper surface treated but still torque variation is obvious from the results. Quality of fasteners can not be guaranteed from unknown manufacturers or suppliers.

CONCLUSIONS

In the light of results and observation, following conclusions and recommendations are made;

- Proper bolt surface treatment, preferably dry lubricant should be used to get the required higher pre-load without damaging the flange and the bolt.

- New or virgin bolts with original surface treatment should be used i.e. without the effect of any lubricant, as this increases the resistance for the applied torque.
- High strength, good quality bolts are recommended. Bolts of grade 8.8 as they were found in good behaviour for both the suppliers but for grade 10.9, a great effort during tightening was realised after reusing the bolts several times.
- Use of bolts, nuts, washers of proper quality and geometry with proper tooling to get the proper required pre-load is recommended.
- Nuts and washers should be of high quality with properly flat and perpendicular surfaces to have proper contact and avoid pre-load loss
- Tightening speed should also be controlled as was noted during experiments and more than one passes should be adopted with proper sequence.
- The joint surfaces in contact should be ensured against any deformation during manufacturing or welding as it can affect the proper pre-loading of the joints.
- Joint should be pre-loaded high enough to compensate for the pre-load loss.
- Re-tighten the bolts after a few minutes to several hours and even after proof testing.
- Proper training of the fitter for bolt and joint pre-loading is important.
- Use proper tooling to get proper higher pre-load, matching with the dimensions of the bolts and nuts. Ring spanners are recommended instead of open spanners.
- For the optimized performance of a flange joint, it is important to consider flange joint as a unit with all the accessories including bolt, nut, washers, flanges and required tooling to get the effectiveness of the joint.

Nomenclature:

BLT	Bolt number
V	Bolt arranged from Supplier-1
B	Bolt arranged from Supplier-2
8	Bolt as per ISO-898, property class 8.8
10	Bolt as per ISO-898, property class 10.9
LN	with Lock-nut (Nyloc)
OO1	Surface treatment by Supplier-1 mixed with Hydraulic Oil lubricant
NL	No lubricant used (without lubricant)
M1~M4	With lubricant Molykote 321R
O1~O2	With lubricant Hydraulic Oil for grinder for one or more tightening
L1~2	Cleaned with Loctite 7063 for one or more tightening
CS1~2	with lubricant Copper slip for one or more tightening
P1~2	with PTFE tape for one or more tightening
T1~2	Number of tightening (one or more)
N1~2	Number of nuts (one or more)
W1~2	Number of washers (one or more)
SW1~2	Number of sturdy/thick washers (one or more)
CAS1~2	CASTROL EPX hydraulic oil

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