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Research Article

Numerical and Experimental Study of Shear Loaded Bolted Joint

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Abstract

In this paper an experimental study on shear loaded bolted joint is presented. Before beginning experimental tests, 3D finite elements simulations are turned for a symmetrical bolted joint to show the assembly behavior and choose suitable parameters. The shear loading is applied by a piston alimented with a hydraulic hand pump. Screws are instrumented with strain gauges to acquire data and analyze stresses applied on bolts. Many experimental tests are conducted. In each one, dimensions and friction factor of contact interface are varied. Results are used to analyze the bolt joint behavior and determine the more significant assembly parameters on screws stresses.

Keywords: *Bolted joint ,Shear loaded , Finite elements modeling , Experimental study ,Contact interface, sliding.*

1. Introduction

Bolts are the most commonly used fasteners in mechanical industry. For this reason they have been the focus of many engineers and researchers. Linear computational models of bolted joints have been developed first by (VDI 2230 recommendations., 2003) for the case of centered and slightly eccentric load. The high eccentrically loaded bolted joint, were then studied by several authors (P. Agatonovic., 1985), (J. Guillot., 1987), (J. Bickford 1995) and (R. Bulatovic and J. Jovanovic., 2000). These are all bent beams models.

The two-bolted joint are studied by (A. Daidié, et Al., 2007) in tension case and by (J. Chakhari et Al., 2008) for the compression case, the developed models are nonlinear. All these studies are available for bolted joints in which loads are perpendicular to the contact area. The stiffness of zones in compression are defined and formulated in references (J. Rasmussen et Al., 1978) and (F. Alkatan et Al., 2007).

An analytical model for eccentrically tension and shear loaded bolted joint has been developed by (M.T. Nasraoui et Al., 2012). This model can't be applied for shear loaded bolted joint case.

(E.W. Kuenzi., 1955) presents a theoretical approach to determine the allowable shear load in one-bolt joint. This model can be used to compute the bolt stresses, but it doesn't show the evolution of the interface state from adhesion until sliding.

Several authors have studied shear loaded bolted joints by three dimensional finite elements simulations, (Z. Yongjie and S. Qin., 2009) and (S. Ruiz et Al., 2007).

In this paper we study a shear loaded bolted joint, in the first place by numerical simulations using ANSYS software and then by an experimental tests. Experimental results will serve to validate the numerical model and to analyze the effect of different parameters on the bolted joint behavior.

2. Problem

We are interested to one-bolted joint where the bolt fixes a beam to a support part, figure1. The beam has a rectangular cross section (bxh). At the end of the beam, a shear load F_T is applied. This force is parallel to the median plane of the assembly and perpendicular to the axis of the screw. The median plane is a symmetry plane for the bolted joint. The contact interface between assembled parts has a friction coefficient f. The other dimensions are shown in Figure 4.

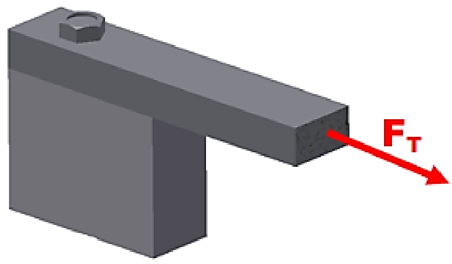

Fig 1. One-bolt joint subjected to a shear load F_T

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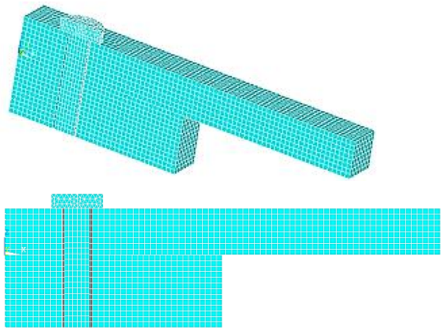


Fig 2. 3D FE model of half-assembly

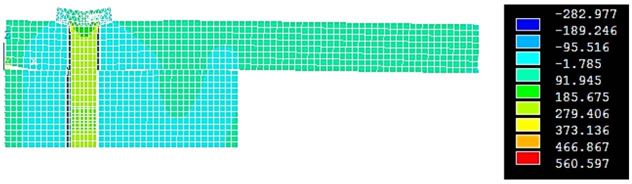


Fig 3. Preloaded joint

3. 3D Finite Elements Simulations

In this modeling, parts are meshed into 3D finite elements. Suitable contact elements are chosen for contact interfaces, Figure 2. The shear loading is applied at the end face of the upper part. The support is fixed on its underside.

Numerical results are taken on the median plane of the bolt. Figure 3 show a preloaded assembly fixed by an M10 bolt under pre-stress σ_0=200 MPa. The simulations are run on ANSYS software.

4. Experimental study

4.1. Test assembly design

Tests on an assembly like in Figure 1 have practical difficulties. It's easier to apply a shear loading on a symmetrical two-bolted joint, Figure 4. A low height hydraulic cylinder is interposed between support parts. A quarter of this assembly corresponds to the bolted joint shown in Figure 1.

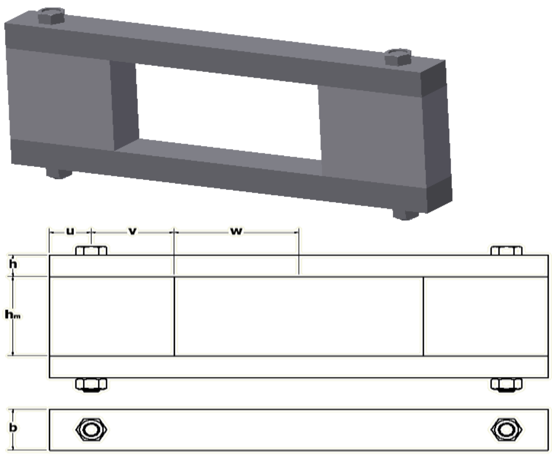


Fig 4. Two-bolted symmetrical test assembly

4.2. Experimental setup

We present here experimental devices used in tests. The two-bolted joint for test is fixed at its bottom side with a clamp, Figure 5. The two bolts are similarly tightened by a torque wrench to be preloaded of 200 MPa stress. We use two identical H M10-100 8.8 quality screws.

Fig 5. Experimental assembly subjected to shear load

Shear loads are applied by a low-height hydraulic cylinder. The cylinder that has a piston diameter of 28.7mm is supplied by a manual hydraulic pump, Figure 6. The pump pressure can reach 700 bars.

Fig 6. Manual hydraulic pump supplying the cylinder

Bolts are instrumented with strain gauges bonded on their reduced diameter portions. On each screw, two diametrically opposed gauges are bonded, Figure 7. Left and right gauges G_L and G_R of each screw are placed in the median plane of the assembly that contains the piston axis. Both bolts are instrumented; this is to check the symmetry of data acquisition. The data acquisition, type national instruments, includes a measurement chassis units, Figure 8, and software "LABVIEW" for data processing.

Fig 7. Bolt instrumented with two strain gauges

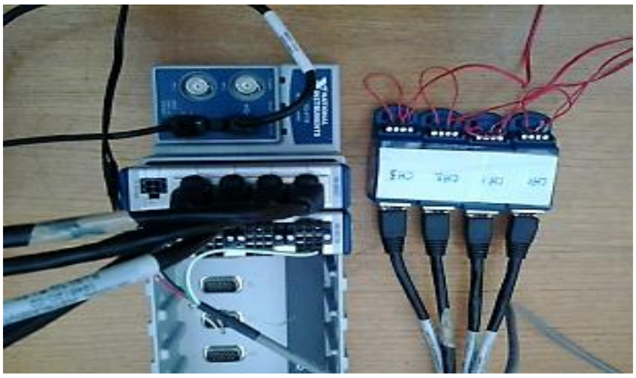


Fig 8. measurement chassis units

4.3. Experimental results

Experimental results correspond to an assembly dimensions given in table 1. The parts are manufactured in carbon steel (E = 210 000 MPa; ν = 0.3). The friction coefficient of machined parts in contact is f=0.2.

Table 1. Joint dimensions in mm.

u	v	W	b	H	h_m
25	50	75	30	16	58

Normal stresses measured by left and right gauges of each screw vary with the shear load F_T as shown in Figure 9. During the test, when the sliding begins, one normal stress increases and the second decreases by increasing F_T, Figure 10.

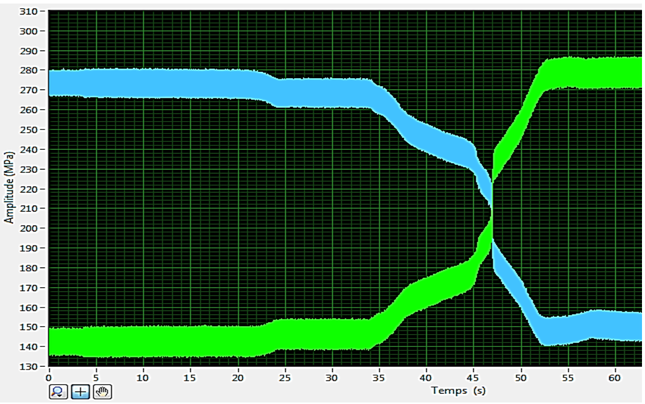


Fig 9. Left and right normal stresses on the bolt

5. Results interpretation

After data acquisition processing, left and right normal stresses curves are plotted function of shear load F_T. The total sliding appears at an accuracy value of F_T. From this time the normal stress increases on one side and decreases on the other one when increasing F_T, Figure 11. The shear load causing sliding depends on different parameters (friction coefficient, contact surface dimensions, preloading).

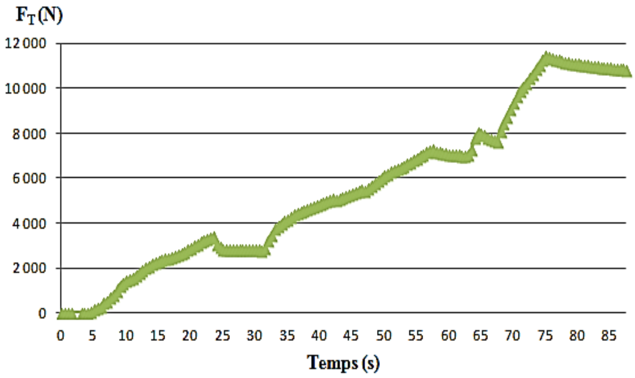


Fig 10. Shear load F_T variation

5.1 Friction coefficient affect

Three identical tests were done on the assembly defined in Table 1, for three different friction coefficients: (1) machined surfaces f_1 = 0.2 (2) polished surface f_2 = 0.12 (3) greased surfaces f_3 = 0.1. The results of these tests are shown in Figure 11. The curves show that the shear load causing the sliding decreases when the friction coefficient decreases.

The bolt pre-stress is 200 MPa, it is the average of the left and right stresses. The deviation of normal stresses from the pre-stress also decreases when decreasing the friction coefficient.

5.2 Numerical simulation to study sliding evolution function of F_T

The distribution of adhesion and sliding zones varies with the shear load F_T. Results obtained by 3D FE simulations, using ANSYS software, are presented in Figure 12. The significant sliding is seen in zones in red color for each loading case.

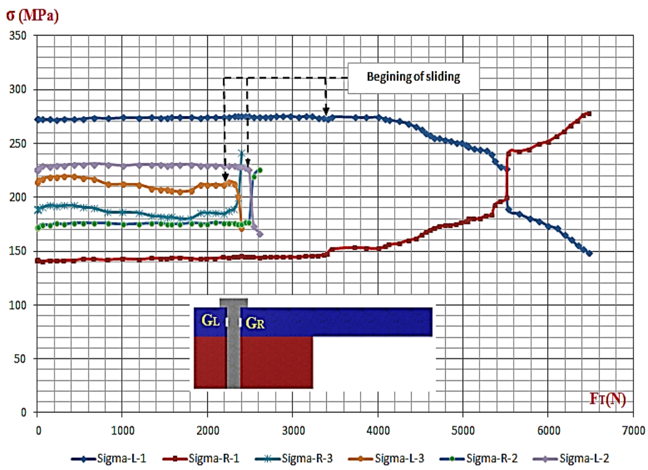


Fig 11. Left and right experimental normal stresses applied on the bolt function of load F_T for three friction coefficients of the contact interface

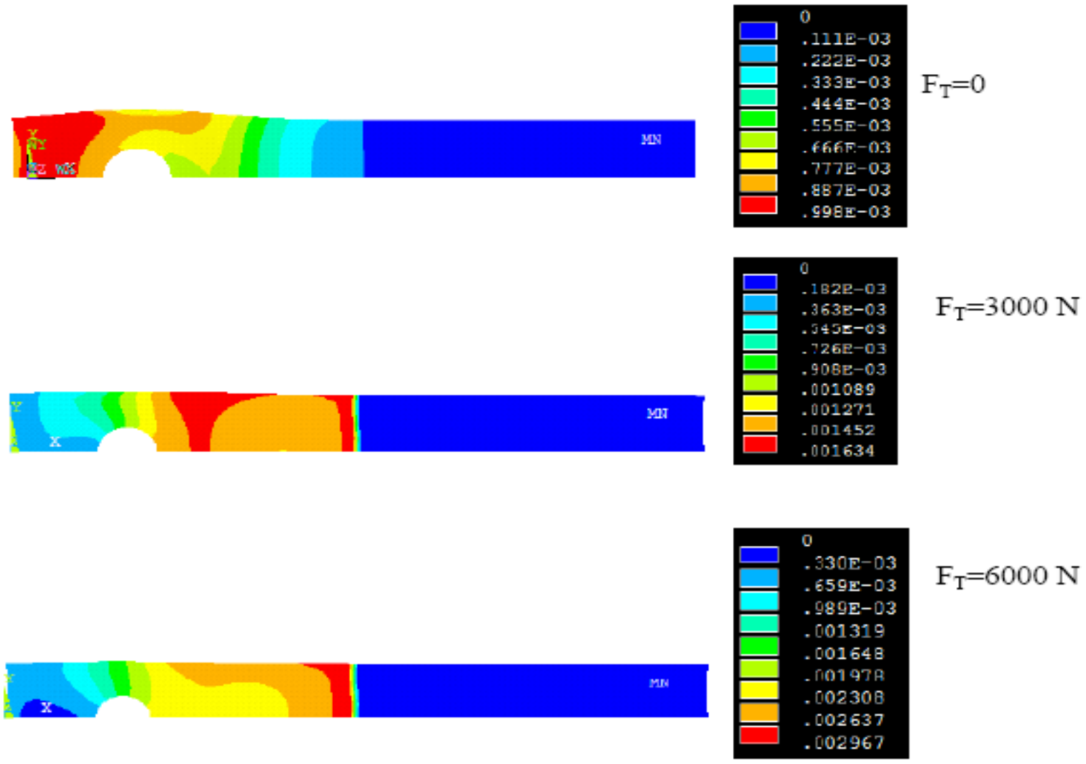


Fig 12. Evolution of sliding zones with shear load F_T

5.3 Contact surface dimensions effect on shear loading limit

A study with experimental design method is done in order to determine contact surface dimensions effect on shear loading limit. Dimensional parameters considered are u, v and b. They define the contact surface between assembled parts. These dimensions are varied as in Table 2 on three levels. A fractional experimental design plan is chosen using the (statistical software BPEW., 1999).

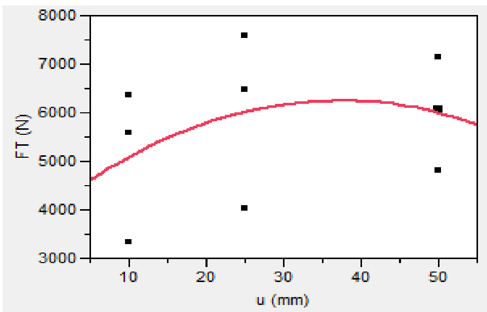
Nine tests are done and variables are taken as in Table 3. For each test the shear load limit F_T is determined after plotting the normal stress curves. Results post-processing is facilitated by the (software JMP., 2007). Shear loading limit F_T vary, independently, function of parameters u, v and b as shown in Figure 13. For every factor, variation of curve is parabolic.

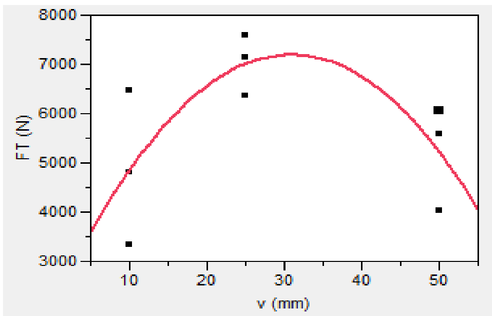
Table2. Factors and levels for a fractional experimental design

Factors	Description	Level 1	Level 2	Level 3
A	u (mm)	10	25	50
B	v (mm)	10	25	50
C	b (mm)	20	30	50

Table3. Expérimental design tests

	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Test 7**	**Test 8**	**Test 9**
u (mm)	10	10	10	25	25	25	50	50	50
v (mm)	10	25	50	10	25	50	10	25	50
b (mm)	30	20	50	20	50	30	50	30	20
F_T (N)	3345	6355	5575	6466	7582	4014	4795	7135	6065





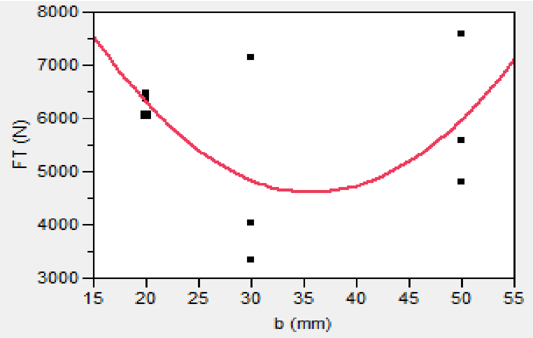


Fig. 13 Contact surface dimensions effects on shear load limit F_T

Conclusion

The force transmission in a shear loaded prismatic bolted joint is provided by adhesion of contact areas under sufficient bolts tightening. If the loading is accidentally higher than expected, the risk of partial or total sliding is possible, especially when the friction coefficient is lower. This result was shown experimentally for one-bolted joint in three contact states: machined, polished and greased.

The shear loading limit that causes a total sliding depends generally on the dimensions of the contact interface, the bolt preloading and the surface finishing of assembled parts, that is to say, the friction coefficient. The study of various parameters effects on the load limit was done through an experimental design.

Numerically, sliding happens locally in the contact interface when the computed sliding displacement value is over than a minimum threshold e.g. 0.001 mm.

In the case of variable or cyclic shear loading, fatigue contact can be generated. Computation of normal and shear stresses for contact faces can serves to study the possibility of defects or cracks apparition on contact area and especially at hole boundary, where there is a stress concentration.

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