International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 7, Issue 7, July 2018, ISSN: 2278 -7798

Experimental and Finite element analysis of Stresses due to External forces for Symmetrical and Unsymmetrical Bolted Joints

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Abstract: **-A prior study conducting by the authors the design and behavior of the bolted joints and hopefully with help you become better designers, assemblers, users of such joints or help you analyze and prevent joint failures. The bolt is a mechanism for creating and maintaining a force, the clamping force between joint members. The behaviors and life of the bolted joint depend very much on the magnitude and stability of that clamping force. Due to these factors the bolted joints has been the topic of research for different aspects such as production materials and performance simulation. The main objective of research was to explore predict bolt clamp-up and plate friction for the structural steel and aluminum materials, the three dimensional model of the bolted joint has been developed using modeling software Solid works and FEM Simulation was carried out by using standard commercial software. Experimental work was carried out on Universal Testing machine and specimen of bolted joint was tested to know Maximum load 'KN' on the bolt. Experimental work was conducted to measure maximum load on the bolt before it fails of the bolted joint for validation of the FE model. An idealized study conducted the results from the both simulation and experimental works were then compared and these stresses should not exceed safe permissible values of stresses.**

Keywords:**Bolted Joint; High Strength bolts; Finite element analysis (FEA); UTM (Universal Testing Machine)**

1. Introduction

The bolted joint is one of the most common elements in construction and machine design. The prime reason for selecting bolts as opposed to welding or rivets are that the connection can be easily released allowing disassembly, maintenance and inspection. These joints are primarily used to provide continuity of structure and transfer of internal load from one member to another. The generic similarity between the detailed structural features permits application of the numerous mechanics and design insights and techniques developed for structural joints. Bolted joints are extensively used in many automotive and aeronautical sectors where two members are bolted together. This particular method of fastening is vastly used in many industrial disciplines because it serves as an easy and non-destructive method to join and subsequently disassemble a complex structure. Since, bolted joints constitute an integral part of many structural components; this directly implicates the necessity to investigate the mechanical response of the bolted joints under a variety of loading rates to ensure structural integrity.

There are many different of joints that can be utilized to connect structural parts together. Prevailing as the most dominant in most structures is the method of threaded fastener or bolt. They consist of fasteners that capture and join other parts, and secured with the mating of screw threads. Bolts joints are critical structural regions and must be properly designed so that the desired performance from the overall structures is obtained. Because of large stress concentrations, joints can become a source of weakness if proper design practice is not followed. Accordingly, failures typically occurred at connections and interfaces, rather than within the bulk of the system. To provide a safe and cost effective joint design, it is typical to configure the joint with respect to the geometry and the constitute materials, which effect both strength and failure modes. Bolted Joints come in two flavors, depending on the direction of the external loads or forces acting on the joint. If the line of action of the forces on the joints is more or less parallel to the axes of the bolt, the joint is said to be loaded in tension and is called a tension or tensile joint. If the line of action of the load is more or less perpendicular to the axes of the bolt, the joint loaded in shear and is called a shear joint. The purpose of the bolt or group of bolts in all tensile and in most shear joints is to create a clamping force between two or more things, which we'll call joint members.

1.2. Literature Review

Several workers have addressed the issue of shear force distribution in single lap bolted joints using various methodologies. This research falls in to a variety of categories including simplified bolted joints models for the behavior of different materials plate structure. The easy way method 'Stress analysis of bolted joints' by Rashtrapal B.Teltumade [1]. He narrates the several factors influenced were identified and confirmed with stress distribution results from simulation. Alternatively the method from "3D Finite elements modeling of single bolt connections under static and dynamic tension loading'' by John Davis & co[2] and it shows simulation results for solid bolts under tension loading in as tested physical configurations and results were compared to experimental data. From the previous study of 'Experimental and FE analysis of eccentric loading symmetrical and unsymmetrical bolted Joint with bolt pretension' by Pranav R.Pimpalkar [3].Prior research on simplified modeling of bolt patterns of joints was carried out generic or plate structures by Y Shi, M. Wang[4] 'Analysis on shear behavior of high strength bolts connections', which provides great tool for engineering applications.

In this study and previous research papers to help understanding the bolt connections having high strength bolt, symmetrical and asymmetrical conditions with eccentrically loading conditions and static tension loading. In the extended the modeling in bolt joints stress due to external forces is applied by changing the plate materials. The study contains symmetrical and asymmetrical conditions with the bolt patterns joints. The strength of machine members based upon the mechanical properties of the materials is used. The failure or yielding occurs at a point in the member Maximum Principal Stress or Shear stress in a biaxial stress system reaches a the limiting strength of the material is due to external forces. Comparatively results shows for FE analysis and experimental approach.

2. Objectives and Methodology

The bolted connections can also be classified based on geometry and loading conditions into three types namely, shear connections, tension connections and combined shear and tension connections. Typical shear connections occur as a lap or a butt joint used in the tension members. While the lap joint has a tendency to bend so that the forces tend to become collinear, the butt joint requires cover plates. Since the load acts in the plane of the plates, the load transmission at the point will ultimately be through shearing forces and tension force in the bolts.

1) To carry out the analysis of bolted joint with two different materials of the plate.
2) To check performance to predict maximum load on the bolt before its fails.
3) To comparing the response of symmetric and unsymmetrical bolted joints with different materials of the plates.
4) To check the uniform bolt strength with different plate materials.
5) To verify the predictive capabilities experimental and FE Analysis are compared to bolted joints.

To achieve the comparing analysis of the above mentioned objectives the four models are developed with the symmetric and unsymmetrical bolted joints due to external load.

Model 1: The model was designed with symmetrical bolt pattern with mild steel materials for plates, in contact region between plate and bolt.

Model 2: The model was designed with unsymmetrical bolt pattern with mild steel for plates, in contact region between plate and bolt.

Model 3: The model was designed with symmetrical bolt pattern with aluminum alloy for plates, in contact region between plate and bolt.

Model 4: The model was designed with unsymmetrical bolt pattern with aluminum alloy, in contact region between plate and bolt.

In this analysis of the bolt patterns joints were performed under bi axial stress system reaches the limiting strength of the material in a simple tension test. For numerical analysis FEM is widely used tool in design, the objective of which is to find the maximum principal stress and shear stress theory. Hence FE analysis is carried out by using standard commercial software which then compared with analytical results and hence validated with experimental result for one of the case that has been included for analysis.

3. Experimental Procedure

Experimental work was carried out in machine tools and material testing laboratory. In machine tools lab, the work performed cutting, grinding, drilling and reaming operations have been done is **shown in Fig1.1**.The Tools and equipment are used to complete the operation as **shown in Fig1.2** The plates have been joined by the stainless steel materials M6 bolts (coarse threads) with the help wrench. After completing the bolted joint, the specimen has been tested in material testing with Universal Testing Machine

(UTM) and its specifications are**shown in Fig2.1** and Table1. It is a simple tension test due to external forces tested for loaded bolt joint with symmetric and unsymmetrical conditions with bolt pattern with different plate materials like Mild steel and Aluminum alloy.

Fig-1.1 Operations performed in machine tools lab.

Fig-1.2 Tools and equipment's to complete the Joint.

Fig-2.1 Universal Testing Machine (UTM)

The UTM is used for both tension and compression forces it is named after the fact that it can perform many standard tensile and compression tests on materials, components, and structures." Table 1 shows that specification of the UTM.

Table.1 Specifications of UTM in material test lab.

Model:	UTM-60
MAKE	FIE
Max Capacity	600 KN
Clearance between columns	600mm
Connected load	2.5HP -3¢-440 V

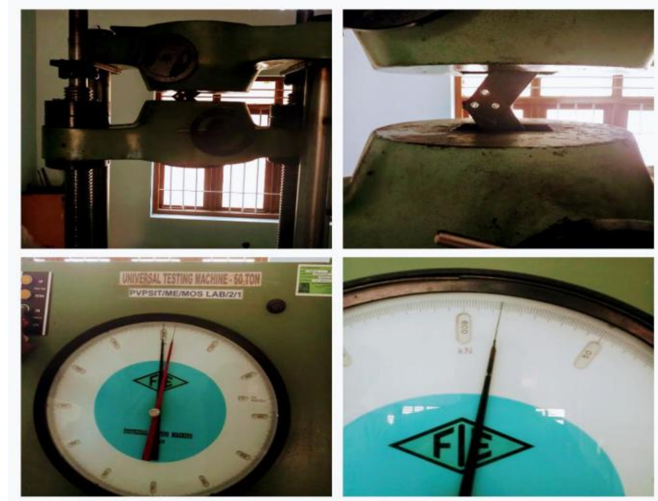

Fig-2.2 Mounting & Loading of Bolted Joint.

The **Fig-2.2** shows that mounted and loading the fixed plates to apply the load as per standard, the bolted joint before it fails Maximum load on the bolt is 14000 N for Unsymmetrical loaded bolted joints with the material is mild steel .Similarly and repeated experiments done UTM for the others models in UTM machine. The bolt carries in the range of load on the bolt13000 N to 14000 N before bolted joint its fails symmetric and unsymmetrical experiments for mild steel and aluminum alloy plates.

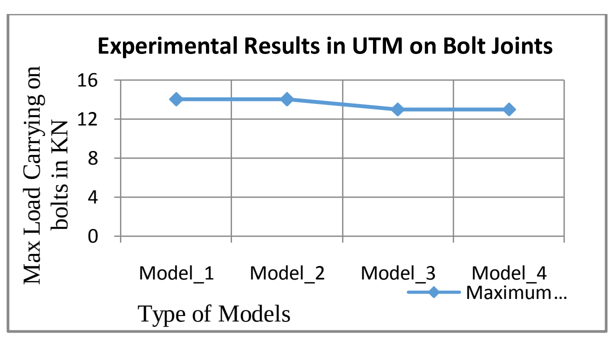

Fig-2.3 Graph Representation failure load bolts on UTM

3.1 Analytical Calculation

Load carrying on the bolt = 13 to 14 KN

M6 bolt (coarse threads) pitch =1mm

Nominal diameter of the bolt (d) = 6mm

Root or core diameter of the thread (d_c) = 4.773mm

Plate dimensions = 137x50x6 mm

Number of bolts used for symmetric (n) = 4 no's

Number of bolts used for unsymmetrical (n) =3 no's

Stresses Due to external force:

1) If the external load applied is taken by the number of bolts, then

$$\sigma_t = P/(\pi/4)*d_c^2*n$$

2) Shearing load carried by the bolts,

$$P_s = (\pi/4)*d^2*n*\tau$$

3) Combined tension and shear stress: When the bolt is subjected to tension and shear loads, then the diameter of the shank of the bolt is obtained from the shear load and that threaded part from the tensile load

Maximum principal Shear Stress,

$$\tau_{max} = ½ \sqrt{(\sigma_t)^2 + 4\tau^2}$$

Maximum principal Tensile Stress,

$$\sigma_{max} = (\sigma_t / 2) + ½ \sqrt{(\sigma_t)^2 + 4\tau^2}$$

Table 2.1 Analytical calculations for Symmetrical and Unsymmetrical for plate materials Mild Steels:

Bolt pattern/Max Stresses	Symmetrical Joint	Unsymmetrical Joint
Max Principal Tensile Stress in 'MPa'	255	340
Max Shear Stress in 'MPa'	**157**	**210**

Table 2.1 shows that the plate have been used Mild steels materials , whereas bolt materials is stainless steel bolts with M6 coarse threads, two models has been developed with symmetrical and unsymmetrical bolt patterns with using above materials. Here, as per experimentally breaking load for bolts symmetrical is 14000 N, the failure is applied on the shank of the bolt from shear load is applied. Breaking stress in maximum shear stress by mathematical calculation has been found symmetrical and unsymmetrical bolt pattern is 156 mpa and 210 mpa for mild steel plates.

Table 2.2 Analytical calculations for Symmetrical and Unsymmetrical for plate materials Aluminum alloy:

Bolt pattern/Max Stress	**Symmetrical Joint**	**Unsymmetrical Joint**
Max Principal Stress in 'Mpa'	**237**	**316**
Max Shear Stress in 'MPa'	147	195

Table 2.2 shows that the plate have been used Mild steels materials , whereas bolt materials is stainless steel bolts with M6 coarse threads, two models has been developed with symmetrical and unsymmetrical bolt patterns with using above materials. Here, as per experimentally breaking load for bolts symmetrical is 13000 N, the failure is applied on the threaded part of the bolt from tensile load is applied. Breaking stress in maximum principal or normal stress by mathematical calculation has been found symmetrical and unsymmetrical bolt pattern is 237 mpa and 316 mpa for aluminum alloy plates.

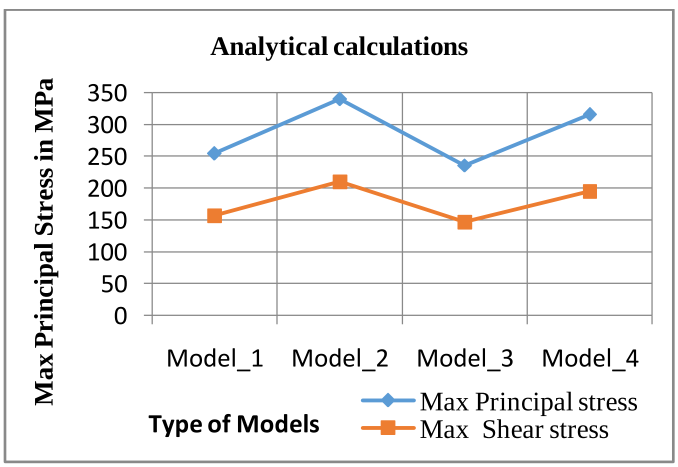

Fig-3.1 Graph Representation analytical calculations for Max Principal and Shear stresses.

4. Finite Element Analysis Using Ansys

ANSYS Mechanical Enterprise is the flagship mechanical engineering software solution that uses finite elementanalysis (FEA) for structural analysis using the ANSYS Mechanical interface. The previous researches study the several bolt pattern configurations were proposed and finite element analysis. The main objective FE analysis on different the experimental loaded factors have to be considered. Here the bolt pattern is symmetrical and unsymmetrical design with two different materials plates one of them mild steel and other one aluminum and its alloy, as well as the bolt material have consider as stainless steel bolts having high strength bolted joints. The mechanical properties for the plates and bolts as follows.

Material Data:

Material type/ Description	Stainless steel for bolts	Mild Steel for plates	Aluminum and its alloys for plates
Modulus of elasticity ‘E’ in GPa	200	200	71
Poisson’s ratio ‘μ’	0.31	0.3	0.33
Proof strength in Mpa	580	-	-
Minimum tensile yield strength ‘S_{yt}in Mpa	207	250	280
Minimum tensile ultimate strength ‘S_{ut}in Mpa	586	460	310

Table 4-1 shows that Materials properties

The step by step procedure has to be follows it shows in below figures.

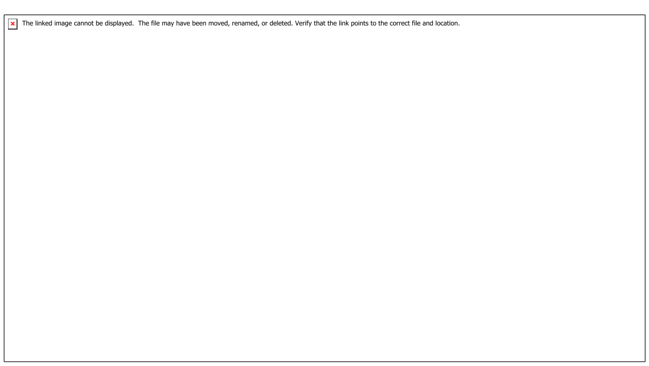

Fig-4.1 Geometrical model of the Specimen

The fig 4.1 shows that the geometrical model developed in Solid works 16.0 and the same geometry have imported finite element analysis in Ansys workbench 14.2.

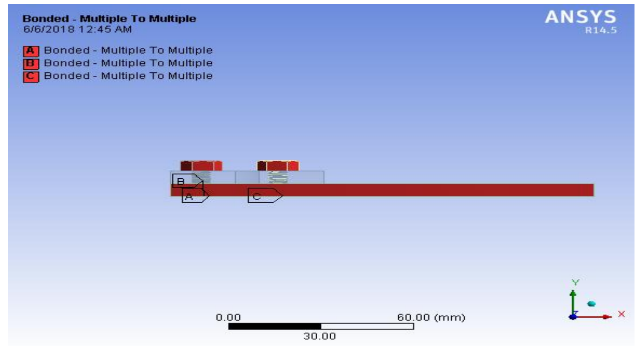

Fig-4.2 Contact Region (Bonded Type to Plate and Bolt)

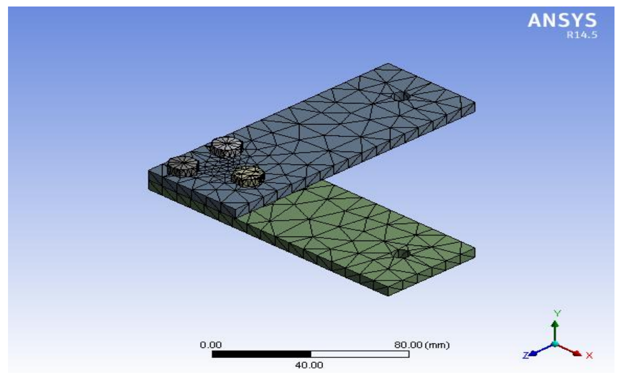

Fig-4.3 Meshing (course mesh type)

The fig 4.1, 4.2 &4.3 shows general set up all the other models shows the model 1, model 2, model 3 and model 4 but the properties of the materials have to be changed as per our requirement.

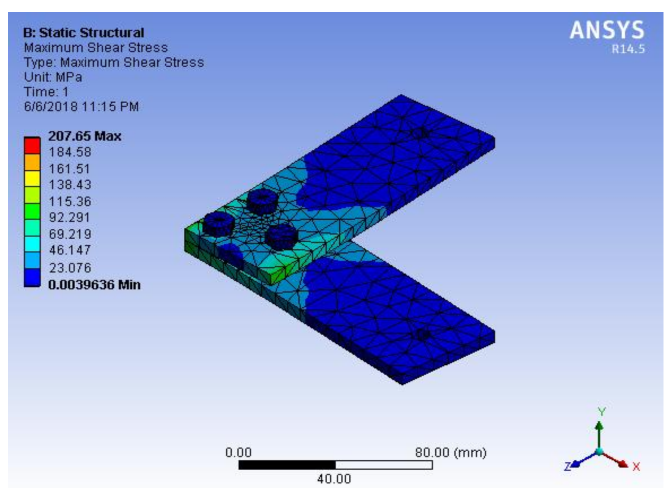

Fig-4.4 Maximum Shear Stress for Mild Steel.

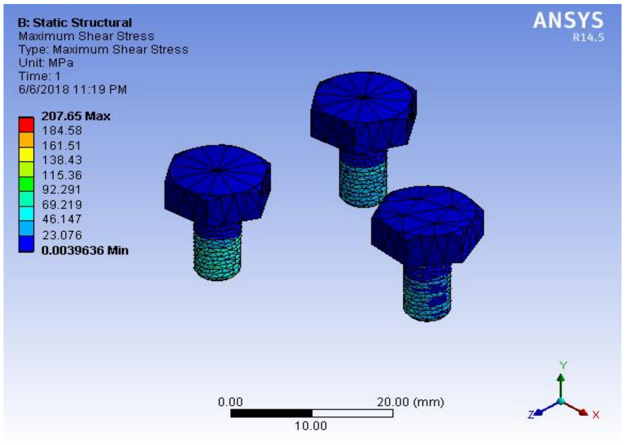

Fig-4.5 Maximum Shear Stress on Unsymmetrical Bolts.

The Fig-4.5 shows that comparatively analysis for mild steel plate's unsymmetrical bolts, in analytical calculations the value of maximum shear stress is 210 Mpa and during FE analysis, value obtained is in the range of 184 Mpa to 207 Mpa which validated. Same procedure is applied for model-1, model-3 and model-4 FE analysis and results as follows.

FE analysis for symmetrical and unsymmetrical for bolts stresses due to external forces:

Max Principal /Descriptions Models	Max Shear Stress in Mpa	Max Tensile stress in MPa
Symmetrical –mild steels plates	**157**	219
Unsymmetrically – mild steels plates	**207**	306
Symmetrical – aluminum alloy plates	203	**232**
Un Symmetrical – aluminum alloy plates	292	**303**

5. RESULTS

For the experimental and FE analysis stresses due to external forces, induced in a bolt pattern when it is subject to an external load, when you consider the mild steels and aluminum alloy plates with high strengthen bolts like stainless steel. The bolt connection for both materials have analytical calculation and FE analysis the maximum shear stress theory failure from range **157 Mpa to 203 Mpa** for symmetrical bolted joints, whereas Unsymmetrical bolted joints the maximum shear stress is in the range **207 Mpa to 292 Mpa** for the mild steel and aluminum alloys. This is validated for materials are close agreement for bolt connections.

Similarly, The bolt connection for both materials have analytical calculation and FE analysis the maximum principal or normal stress theory failurerange from **232 Mpa to 255 Mpa** for symmetrical bolt joint, whereas Unsymmetrical Bolt joints the maximum principal or normal stress is in the range **303 Mpa to 340 Mpa**for the mild steel and aluminum alloys.. This is validated for materials are close agreement for bolt connections.

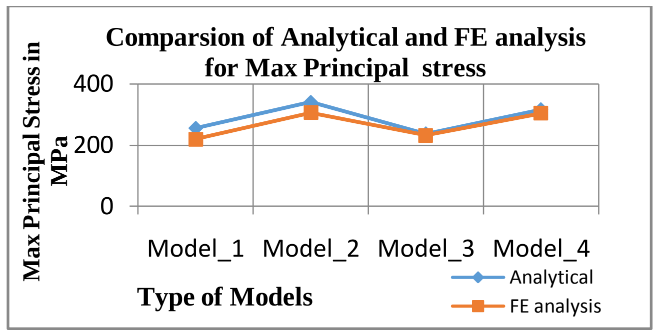

Fig-5.1 Graph Representation Max Principal stresses for Different models

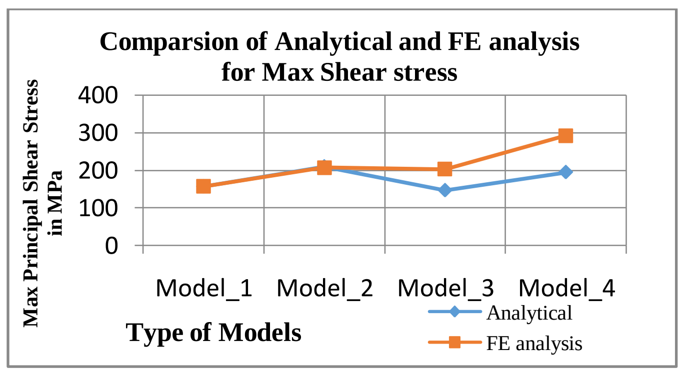

Fig-5.2 Graph Representation Max Principal Shear stresses for Different models

6. CONCLUSION

The results obtained from analytical and FE Analysis are compared for different models under combined shear and tension stress. The experimental determination of biaxial stress system reaches the limiting strength of the material in a simple tension test loaded is 14000 N for symmetrical and unsymmetrical bolted joints stress due to external force for mild steel materials. For the mild materials, which are relatively strong in tension but weak in shear, The comparatively results for symmetrical and unsymmetrical bolted joints for mild steel materials are obtained in analytical calculations and FE analysis obtained to Max Shear and Principal stress theories is the range from 157-210 Mpa and 219 Mpa-340 Mpa.

The experimental determination of biaxial stress system reaches the limiting strength of the material in a simple tension test loaded is 13000 N for symmetrical and unsymmetrical bolted joints stress due to external force for aluminum alloy materials. For the aluminum alloy, unique and unbeatable combination of properties making its use versatile, The comparatively results for symmetrical and unsymmetrical bolted joints for aluminum alloy materials are obtained in analytical calculations and FE analysisobtained to Max Shear and Principal stress theories is 147-292 Mpa and 232 -316 Mpa.

It is observed that, when the bolt subjected to tension and shear loads, as in case of couplings or bearing, then the diameter of the shank of the bolt is obtained from the shear load and that of threaded part from the tensile load. Stresses due to combined load should be checked for the above principal stresses. Thus the experimental and FE analysis of stresses due to external forces for symmetrical and unsymmetrical bolted joints are within safe permissible values of stresses.

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