Experimental Investigation on Loads Shared by Rivets in Different Joint Orientation

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***Abstract* - Bolted and riveted joints are important for machines and structure for the satisfactory performance. When such joints are used the plate or other member being joined will be weakened because of the holes needed to be drilled. The strength reduction depends on the diameter of drilled hole. Larger the diameter of holes drilled, greater will be the strength reduction. In the conventional design, irrespective of arrangement of bolts or rivets all bolts/rivets are considered to share same amount of load. During this work experimental investigation is carried out to estimate load shared by each rivets in different rivet arrangement.**

This paper presents the experimental results of loads shared by rivets in different joints. Experiments are conducted on four type of symmetric butt joint of different rivet orientation that is 0° 30° 60° and 90° from the horizontal axis. Test specimens are made of aluminium plates fastened by 6 mild steel rivets. Between each pair of rivets a pre-tensioned aluminium strip is fixed firmly and on the centre of the strip strain gauge is mounted and this specimen subjected to tensile load. By using the strain obtained from the strip load taken by each pair of rivet is determined. Results obtained for different rivet arrangements are compared. It is observed that load carried by each pair of rivets depends on rivet arrangement. Rivet closer to the central axis of plate take up more load and the rivets farther away takes up less load. This reduction in load carried depends on orientation arrangement of rivets. That is, when the rivets are arranged in 0° orientation (perpendicular to loading axis), all rivets share equal amount of load. Further when orientation angle are changed from 0° to 30°, it observed that there is a 4-5% difference in load distribution among the rivets, also as the angle increases to 60° and 90°, it observed that there is difference of 7-8% and 11- 12% of load distribution respectively.

***Keyword* - Rivets, Joints, Load Distribution, Aluminium plates, Hole Orientation**

I. INTRODUCTION

Joints or Connections form an important part of any structure and are designed more conservatively than the members connected themselves. This is because, connections are more complex than members to analyse, and the discrepancy between analysis and actual behaviour can be large. Further, in case of overloading, it is preferred that the failure be confined to an individual member rather than in joints, which could affect other members.

In recent years the need for more rational means of design and analysis of connections has been emphasized by the exact requirement of modern structural construction. Improved method for predicting joint strength offers a means of reducing weight if they are adopted to make more efficient use of all connectors within a joint. From the production point of view, Jenkins [1] has shown that approximately 50% of total cost of all metal airplane frame is due to connecting the various components of the structure and that the cost of riveting and bolting constitutes between 80% and 90% of the total cost of connection. These conditions suggest a promising field for investigation, and it has been shown that [1] all bolts in the bolted joint do not carry equal load. Niklewicz .J et al. [6] has explained the method for the approximate determination of a multiple array joint loaded in tension, and explains that the method can be used as an approximation for design purposes for a strip that is designed to a fail in net tension. The present work deals with the problem of load distribution among the bolts of symmetrical butt joint by calculating exact load taken by each individual rivet or bolt. Accordingly it is possible to reduce the size of rivet/bolt. i.e. when number of rivets/bolts of same size are used in a structure, by calculating the exact load carried by each individual rivet/bolt. The idea here is to replace the rivet/bolt which carries the lesser amount of load by a smaller size rivet/bolt. By doing this weight and cost of the structure reduces. And also in the same way the hole size decreases. Hence the strength of structure also increases. Because of this, reduction in plate strength due to large size holes can be reduced.

II. EXPERIMENTAL WORK

Material used:

- Aluminium plate of dimension 1000mm×70mm having a Young's modulus of 70GPa, Poisson's ratio of 0.33, and average thickness of 6.2mm are used to prepare plates of required dimensions.
- Aluminium strips of cross section 0.5mm×24.5mm are used as strain sensing elements.
- Mild steel plates of 24.5mm×24.5mm and having a thickness of 2.5mm are used as end grippers for aluminium strip.

- Mild steel of 8mm diameter and length 100mm are used to prepare riveted pins of required dimensions.
- Foil type strain gage of resistance 350Ω and gage factor 2 are used to mount on aluminium strip.

Fabrication:

Preparation of Model: Aluminium plates of dimension 1000mm×70mm having an average thickness of 6.2mm are cut into two middle plates of 250mm length each and two cover plates of 200mm. Then both the middle and covering plates are assembled and constrained in all directions using C-clamp, six holes of diameter 8mm in the required orientation are then drilled using drilling machine having a drill bit of 8mmΦ. Rivets of dimension 8mmΦ and length 22mm are machined from the 100mm long mild steel rod using turning operation, such that these rivets are push fitted into the holes of plate assembly. The picture of experimental set up for different orientation of holes along with rivets for all the four setup that is for 0, 30, 60, and 90 degree are shown in figures 1 to 4 respectively.

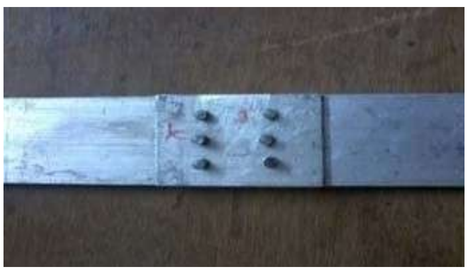


Fig.1.Rivets arranged perpendicular to the loading axis (0˚)

Fig.2. Rivets arranged at 30˚ from the horizontal axis

Fig.3.Rivets arranged at 60˚ from the horizontal axis

Fig.4.Rivets arranged at 90˚ from the horizontal axis

Preparation of Strip:

Aluminium strips of cross section 24.5mm×0.5mm with varying length are prepared. At the ends of each strip a plate of mild steel having dimension 24.5mm×24.5mm×2.5mm are bonded using proper adhesives and purpose of the end plates is to fix the thin aluminium strip in to the rivets and also to avoid the wrinkles which may form when strip gets loaded and this may damages the strain gauge that are mounted at the centre of each strip.

Strip loading data:

As the tensile load is applied at the end of the middle plate of the specimen, because of applied load rivets start gradually moving apart. As this happens rivets transfers the small quantity of load to the thin aluminium strip thus loading the aluminium strips. So it is very much essential to calculate the amount of load to be transferred to the strip and how much load it would carry without failing the strip. To know the maximum allowable load on the strip, a tensile test is conducted only on the aluminium strip in the UTM and it is found that this aluminium strip can sustain the load up to 110 kg. When 1000kg of load is applied to the specimen a small quantity of load is transferred to the strip, for this load the maximum strain obtained in this study is 880μ and by using this strain, the theoretically calculated percentage of load transferred to the strip is about 6.2% which is small quantity of load compared to the applied load.

Experimental procedure:

The experimental setup for determining the load distribution on rivets subjected to tensile load using universal testing machine (UTM) is shown in figure (5).

Fig.5.Experimental setup

Figure.5 shows the experimental setup of riveted butt joints to determine the load carrying capacity of individual rivets. Between the each pair of rivets, aluminium strips are fixed firmly and on the centre of strip, a strain gauge is mounted. Before mounting the strain gauge, aluminium strip is slightly pre-tensioned so that a small quantity of load gets transferred to the strip. The prepared specimen is then mounted on a specimen holder of UTM. The leads of the strain gauge, mounted on strips are then connected to strain meter in order to get the strain. The specimen is then subjected to gradual tensile load up to 1000 kg, for each 100 kg increment of loading, strain on each strip are recorded using strain meter. Because of the applied load each pair of rivet transfers the small quantity of load on to strip, which gives strain and is depends on load taken by that pair of rivets.

From the obtained experimental strain, load distributed on each rivet are calculated using the formulas (1 and 2) below:

$$P=P_1+P_2+P_3 \quad (1)$$

$$P=K\,[€_1+€_2+€_3] \quad (2)$$

Where, P – Total load

P_1, P_2, P_3 – Load at individual pair of rivets,

$€_1$, $€_2$, $€_3$ – Strain at first, second and third strip respectively.

and $K = P/\,[€_1+€_2+€_3]$ N/µ.s

The value of K is depends on the arrangement of rivets. By calculating the K, load on each individual rivets can be calculated by using the formula.

$$P_1= K\,€_1 \quad (3)$$
$$P_2= K\,€_2 \quad (4)$$
$$P_3= K\,€_3 \quad (5)$$

The above procedure is repeated for all the four setups (0˚, 30˚, 60˚, 90˚) and the load distribution on the rivets calculated.

The experimental setup of four specimens subjected to tensile load is shown in figures 6 through 9 below.

Fig.6.Rivets are arranged along the loading axis (90˚)

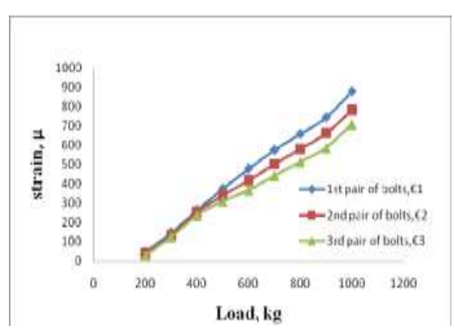
Fig.7. Rivets are arranged perpendicular to the loading axis (0˚)

Fig.8. Rivets are arranged in 30˚ from the horizontal axis

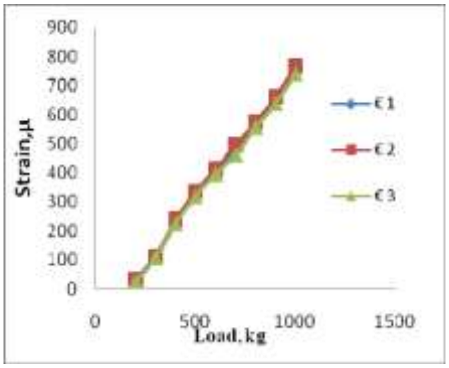
Fig.9. Rivets are arranged in 60˚ from the horizontal axis

III. RESULTS AND DISCUSSIONS

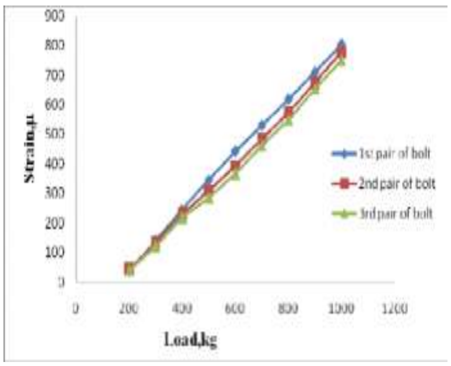
Detailed experimentation is conducted to determine the load carrying capacity of individual rivets in riveted butt joint when it is subjected to tensile load. The experimental data i.e. strains can be used to calculate the load taken by each pair of rivets. To study the load sharing trend of the individual rivets when they were placed at different angular orientations, strain experienced by the strip for different pairs of rivets is obtained. Strain is plotted against the load for the four different cases i.e. 90˚, 0˚, 30˚ and 60˚ rivet orientations as shown in figures 10(a) through figure 10(d) respectively.



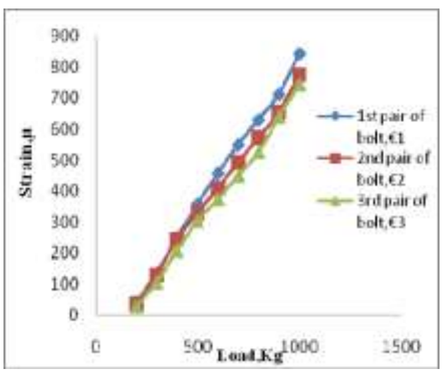
(a) Load v/s strain for 90˚ orientation



(b) Load v/s strain for 0˚ orientation



(c) Load v/s strain for 30˚ orientation



(d) Load v/s strain for 60˚ orientation

From the results presented in the figure 10(a), when rivets are arranged along the loading axis (90˚) at a distance of 20, 50, 80 mm from each side of centre axis (interface between the two middle plates are taken as centre axis), graph shows that as the rivet distance increases from the centre strains gradually decreases i.e. €1 > €2 > €3. So it is clear that first pair of rivets which experience more strain take more loads and it gradually decreases as the distance increases from the central axis. The percentage of load shared by individual pair of rivet is calculated, and is given by 37.19%, 33.09% and 29.7% for inner, second and third (outermost) pair respectively.

Figure 10(b) show the graph plotted against load and strain for 0˚ orientation. When all the rivets are arranged in horizontal axis (0˚) at a distance of 20mm in each side of centre axis (interface between the two middle plates are taken as centre axis), in this condition all the strains, €1, €2, €3 values are almost same so all the three curves converged to single. This indicates that when all the rivets are arranged in perpendicular to loading axis, total load is shared equally among all rivets.

Results plotted in the figure 10(c) and 10(d) shows strain values when rivets are arranged in 30˚ and 60˚ orientations respectively. When these results are compared with the rivets arranged in horizontal axis that is 0˚, it is observed that for 30˚ orientation there is a small deviation in all the three curves obtained from inner, middle and outer pair of rivets whereas for 60˚ orientation of rivets deviation in curves are more when compare with 0˚ and 30˚. But the rate of deviation of curves in case of 90˚ orientation of rivets is maximum when it compared with remaining three orientations (0˚, 30˚ and 60˚) as shown in figure 10(a). This indicates that in the case of 30˚, there is a small difference in the load distribution among the three pairs of rivets and for 60˚ difference in load distribution are comparatively more and it is maximum in case of 90˚ orientation.

For the comparative study among the four different setup, only the strain €-1 of all four setup is plotted against load. Similarly €-2, €-3 and €-4 as shown in the fig.11 (a) to 11(c) respectively.

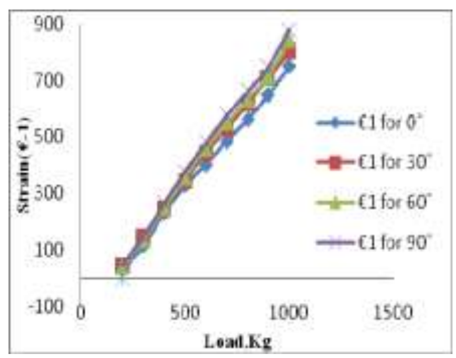


Fig.11(a) Load v/s €1 of 0˚, 30˚, 60˚ and 90˚

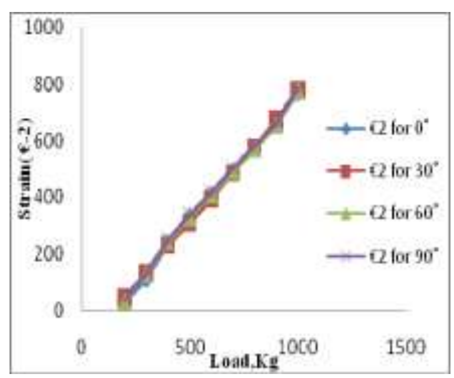


Fig.11 (b) Load v/s €2 of 0˚, 30˚, 60˚ and 90˚

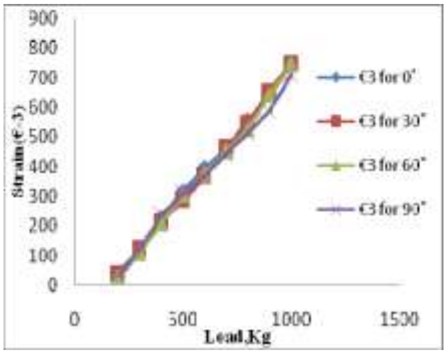


Fig.11(c) Load v/s €3 of 0˚, 30˚, 60˚ and 90˚

Figure 11(a) is the plot of load v/s €1 of all the four setup, 0˚, 30˚, 60˚ and 90˚. This graph shows that for the same load there is a difference in the €1 among all the four setup, here €1 for 0˚ is the minimum and the €1 for 90˚ is maximum and remaining is in between these two i.e. €1-90˚ > €1-60˚ > €1-30˚ > €1-0˚. From this it is clear that as the rivet orientation angle changes from 0˚ to 90˚, €1 increases and hence load at the first pair of the rivet increases. Figure 11(b) all the four strain values €2- 90˚, €2-60˚, €2-30˚, and €2-0˚ are almost equal and the curves are converged to single. This indicates that as the angle of orientation changes from 0˚ to 90˚, there is no change in the load at the middle pair of the rivets. Similarly in Figure 11(c), at the higher load, as the rivet angle changes from 0˚ to 90˚ €3 shows almost decreasing trend and hence load at the last pair of rivets decreases.

IV. CONCLUSION

During this research work experimental investigation has been carried out on riveted joints to study the load shared by different rivets for different arrangement of the rivets. Rivets were arranged on the horizontal plane (0˚) and at 30˚, 60˚ and 90˚ to the horizontal plane and in each of the case, load shared by each pair of rivets i.e. innermost pair, middle pair and the outermost pair is obtained by measuring the strains induced in a thin aluminium strip mounted between each of this pair. For these different experiments, strain levels indicate the percentage of loads shared by each rivet. Following observations are made.

Load carried by all rivets are same when all the rivets are in horizontal plane.

Percentage of load carried by each rivet pair is different when line of rivets makes some angle with horizontal plane.

Line of rivet coincides with line of loading (90˚). In this case, innermost pair of rivets shares the maximum load i.e.37.19%, middle pair slightly lesser i.e. 33.09%, and the outermost pair shares least amount of load that is about 29.7%.The same way other arrangements also show different percentage of loads carried by different rivet pairs. From this study it is clear that when rivets are arranged in the line coinciding with line of loading it is not necessary to use same size of rivets. The rivets sizes can be proportionally smaller. This reduces the weight of rivets used as well as increases the strength of plate and this is important from the design consideration.

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