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Analysis of Adhesively Bonded Riveted Joints

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Abstract. This paper represents the analysis and modeling of adhesively bonded single lap riveted joints. The present work aimed at recommending appropriate configuration and characterization of these joints for maximum utilization.

The present study includes the effectiveness of bond line thickness, the bonded layer configuration, and the situation of dissimilar thickness joints. The finite-element technique was used throughout the analysis of the present work. The present work showed that riveted bonded joint (bonded at overlap area and rivet body) is superior in strengthening to the riveted joints. Riveted bonded joint seems to strengthen and balances the stresses of dissimilar thickness joints.

Introduction

Bonding of metals is becoming increasingly important, both in absolute terms and relative to mechanical fastening. Applications of adhesive bonding are found in the assembly of many products including aircraft, cars, trucks, and office furniture. This is because adhesive bonding offers more uniform distribution of stresses, increased fatigue life, weights savings, reduction of corrosion between dissimilar materials, added to the ability to join small and delicate parts [1-3]. In machine tool manufacturing, adhesives are used for cementing gear wheels, joining elements of hydrostatic bearings and transmissions with load bearing surfaces [1-3]. In electrical and electric industry adhesives are used in variety of ways. These range from holding microcircuits to bonding coils in mammoth electric generators. In addition, mechanical fastening adhesives are required in electrical applications to seal and protect substrate and conduct or insulate heat and electricity [4].

Bonded structure can be of two types based on either purely adhesive or on adhesive/mechanical connection. The purely adhesive connections include shaft-pinion joints, laminated metal-metal joints and three-layer honeycomb structures. The bonded mechanical types include bonded-welded, bonded-riveted and bonded-screwed connections [3-10]. The combined connections (bonded-welded, bonded-riveted and bonded-screwed) ensure high fatigue strength of the structures. The single lap riveted joint is an important part of an aircraft structure and rivets are used extensively for joining plates together. During the riveting process, the protruding end of the shank is formed and the shank is deformed ahead and expanded laterally in order to fill the fastener hole.

Very few research works have been carried out on the analysis of adhesively bonded riveted joints. Hoffer [11] determined the load-bearing capacity of a riveted joint by statistically testing the joints and evaluating the joint failure type. Larson [12] investigated the effect of clamping forces and grip on the fatigue strength of rivets in butt joints. Wyly and Scott [13] observed that the drifting of holes during erection can produce initial cracks that can consequently lead to fatigue failures in riveted bridges. Schvechkov [14] studied experimentally the effects of adhesive mechanical properties along with the geometry of butted sheets on the point of failure and cycle longevity on rivet-bonded joints. Ekval [15] developed a simple finite element model for stress analysis to determine the local stress and strain, at the fatigue critical location of the test specimen due to a spectrum of applied loads. Fung [16] built a finite element model for snap and countersink riveted single joints, and were able to examine the interactions between rivets and jointed members for these two types of joints. The stress concentration factors around the joints were also determined. In the present work, the finite element technique is adopted to study the effect of adhesive orientation, type and thickness on the stresses developed in riveted-bonded joints.

Finite Element Modeling and Boundary Conditions

Four different bonded layer orientation in bonded-riveted joints were considered in the present work and the considered orientation are listed as follows:

1. A single lap riveted model,
2. A single lap riveted-bonded model (bonded at overlap area only),
3. A single lap riveted-bonded model (bonded at overlap area and rivet-body),
4. A single lap riveted-bonded model (bonded at overlap area, rivet-body and rivet-cap-head).

Figure 1 shows the configuration, dimensions, constraints and loading conditions for each model.

The finite-element meshes of these models were generated using four-node-tetrahedral elements through the ***GID*** preprocessing program [17]. The FE computation was carried out using ***Tochnog*** FE program [18], which is an internal module inside the ***GID*** program. ***GID*** is widely used for generating data and results visualization in a number of linear and non-linear problems in structural engineering mechanics, using the finite element method. In ***Tochnog*** have different FE modules to solve different engineering problems, e.g. structure and thermal modules. The program can be used to model 3D problems and run under Linux operating system. Furthermore, the program can be used to model friction and contact boundary surfaces. The program was used to model FE model and friction boundary surfaces between rivet body and strip joints in the 3D FE model of the rivet-bonded joints given in current work.

The following assumptions and boundary conditions were considered throughout the idealization process:

1. The problem is 3-D-FE model. A friction contact surfaces between rivet body and joint strips was specified having friction factor of 0.1 [14]. To save the computation time, half model was considered. Furthermore, elastic-plastic FE model was considered in current analysis.
2. The adhesive layer is isotropic, i.e. stresses on the micro-scale, such as those caused by flows in the adhesive, were neglected (in case of incorporating adhesive layer in the joint).
3. The restrained points as well as the applied load (position and value) were kept constant to enable fair comparison between the data to be made.

The applied load was taken to be the relatively small value of 500 N, as the displacement and accordingly the stresses are assumed proportional to the load in ***Tochnog*** program. The riveted-bonded FE mesh was modeled using 682 nodes and 1,962 tetrahedral elements (it is worth noting that different refine meshes were used in the current study to insure FE results were conversed). Figure 2 shows one of the FE mesh used in current study. The material properties used throughout the present work are given in Table 1.

Table 1. Material properties of adherends and adhesive used

Material	**Young's modulus (N/mm^2)**	**Possion's ratio**	**Shear modulus (Gpa)**
Adhesive	$2.5x\ 10^3$	0.38	0.905
Steel	$2.0x\ 10^5$	0.30	78.1

Stress Developed in a Single Lap Riveted Joints

The predicted normal stresses ($\sigma_{x)}$, (σ_y) and the shear stress (τ_{xy}) through the mid-layer of the overlap area of the riveted joint are shown in Fig. 3. From the figure it can be observed that the normal stresses are normally distributed throughout the rivet body area while highly concentrated at the far ends of the rivet body. The predicted major and minor principal stresses (σ_1 and σ_2) through the mid-layer area are shown in Fig. 4. From the figure it can be observed that the major principal stresses are highly concentrated in the riveted area toward the far ends of the rivet, when compared with the minor principal stress.

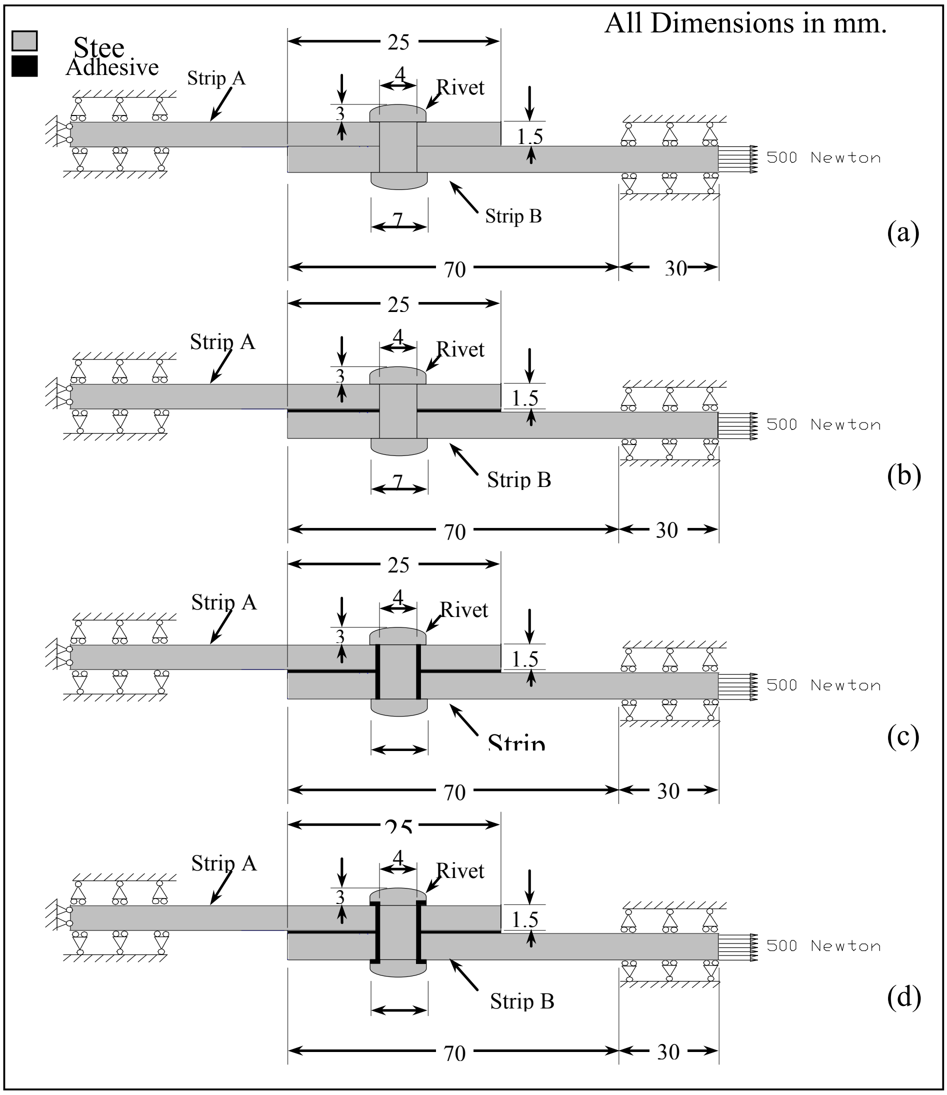

Fig. 1. Assigned constraint and boundary conditions on FE models of; a) a single lap riveted joint, b) a single lap riveted-bonded (bonded at overlap area only), c) a single lap riveted-bonded model (bonded at overlap area and rivet-body), and d) a single lap riveted-bonded model (bonded at overlap area, rivet-body and rivet-cap-head).

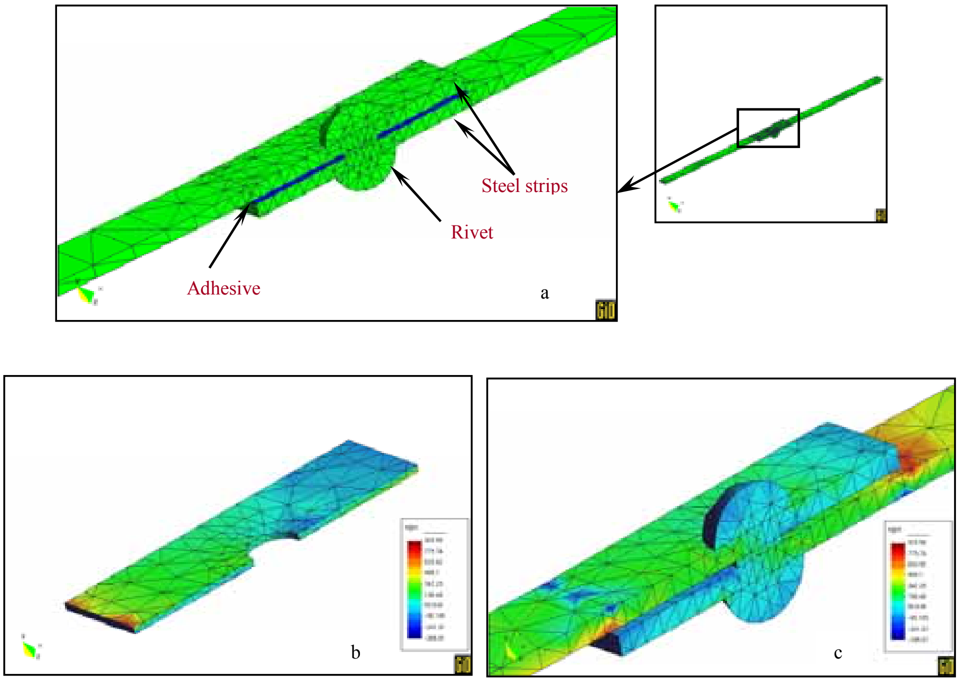

Fig. 2. The 3D FE model; (a) FE mesh (half model) for riveted-bonded joint, (b) normal stress (S_x) contours developed in adhesive layer, and (c) normal stress (S_x) developed in strips and rivet structure.

Effect of Bonded Layer Configuration on the Stresses Developed in Riveted-bonded Joints

Figure 5 shows the principal stresses (σ_1) through the mid-layer of the overlap area of the riveted-bonded joint, while Fig. 6 shows minor principal stresses developed in these joints. These figures show that the stresses are concentrated at the free ends of the overlapped area and at the far ends of the rivet body. These figures show that the riveted-bonded (rivet-body and overlap area) has the lowest stress level at the far ends of the rivet ends, when compared with those bonded (at the overlap area) and those bonded (at overlap area, rivet-body and cap).

Effect of Bondline Thickness on the Stresses Developed in Riveted Bonded Joints

Figure 7 shows the major principal stress (σ_1) developed through the mid-layer of the overlap area of the riveted-bonded joint (overlap area and rivet-body) for three joints having different bond-line thickness (0.1, 0.2 and 0.5 mm). Although, the adhesive thickness should be kept as low as possible to restrict its deformation, from these figures it can be observed that increasing the bond-line thickness decreases the developed stresses and consequently strengthening riveted bonded joints.

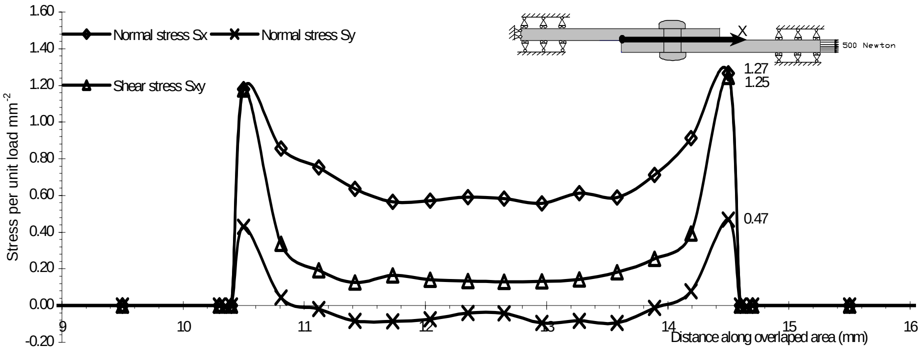

Fig. 3. Normal and shear stresses (Sx, Sy and Sxy) developed along the mid-layer of overlaped riveted joint.

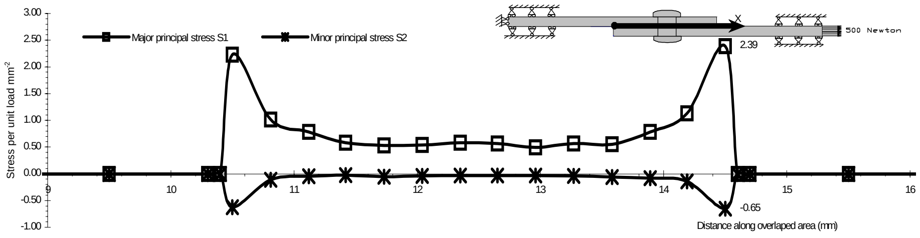

Fig. 4. Major and minor principal stresses (S1 and S2) developed along the mid-layer of overlaped riveted joint.

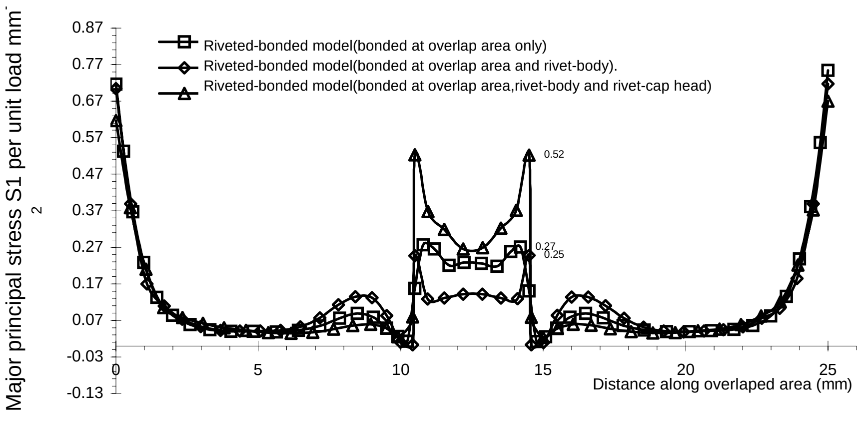

Fig. 5. Major principal stress S_1 distribution along the overlaped mid-layer of rivet-bonded joints.

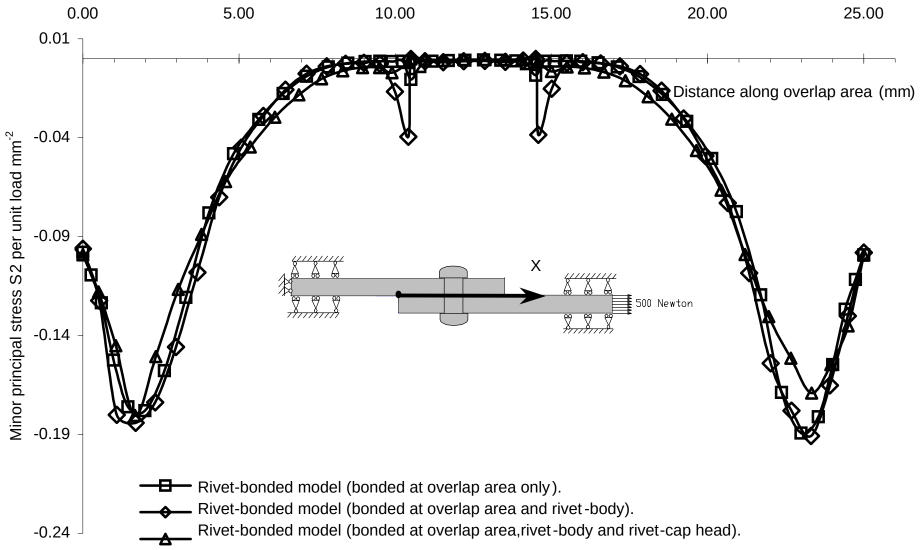

Fig. 6. Minor principal stress S2 distribution along the overlaped mid-layer of rivet-bonded joints.

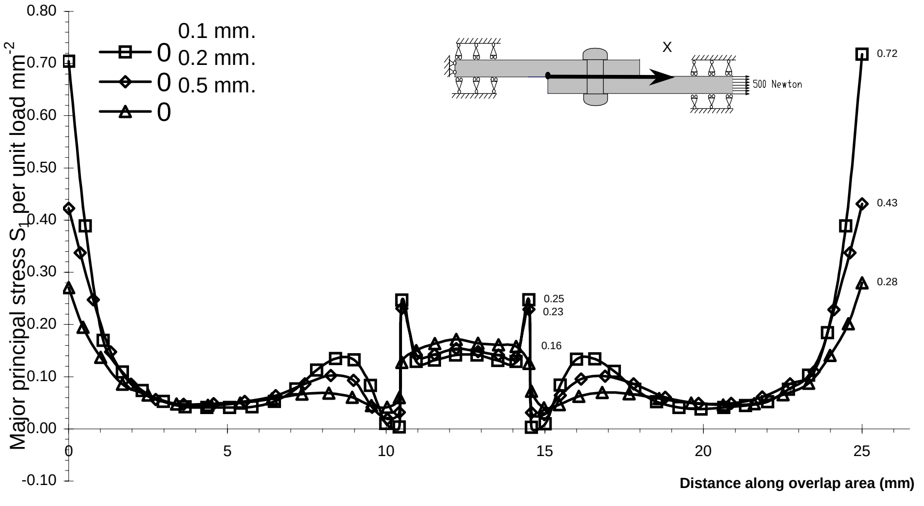

Fig. 7. Major principal stress S1 distribution along the overlapped mid-layer for riveted-bonded joints having different bond-line thickness.

Dissimilar Strip Thickness of Riveted Joints

Figures 8 and 9 show the major and minor principal stresses developed in dissimilar thickness joints. The figures show that the stresses are more concentrated towards the thinner part of the joint. From these figures it can be seen that riveted-bonded joints strengthen and balances the stresses developed in dissimilar thickness boned-riveted joints.

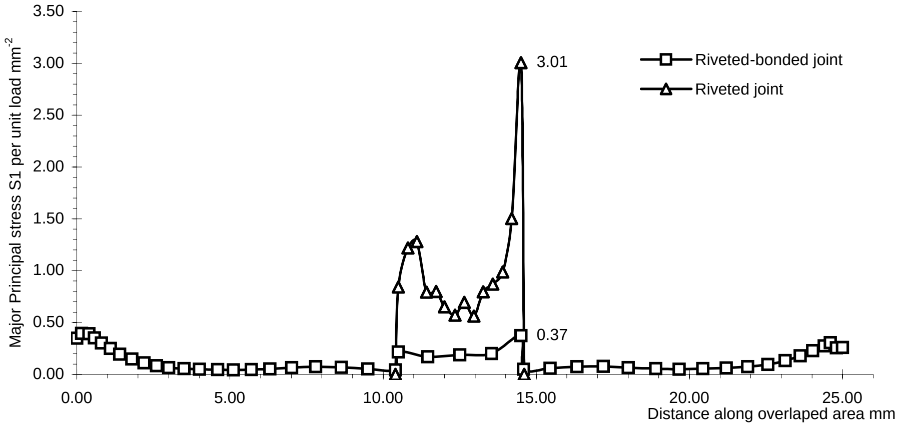

Fig. 8. Major principal stress distribution along the overlaped area for riveted and riveted-bonded joints for dissimilar strip thickness (1.5-2.0 mm).

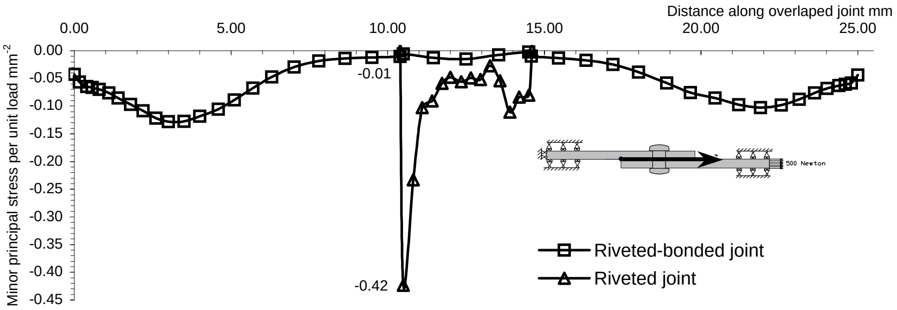

Fig. 9. Minor principal stress distribution along the overlaped area for riveted and riveted-bonded joints for dissimilar strip thickness (1.5-2.0 mm).

Conclusion

Within the range of the present work, the following can be concluded:

1. Increasing the bond-line thickness decreases the developed stresses and consequently strengthening riveted bonded joints.
2. Riveted bonded joints (bonded at overlap area and rivet body) is superior in strengthening to riveted joints.
3. Riveted-bonded joints balances the stresses developed in dissimilar thickness riveted joints.

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دراسة وتحليل الوصلات المبرشمة والمدعمة بالمواد اللصقة

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ملخص البحث. تعنى هذه الورقة بدراسة وتحليل الوصلات المبرشمة والمدعمة بالمواد اللاصقة. وللإستفادة القصوى من هذه الوصلات يهدف هذا البحث إلى تقصي متانة هذه الوصلات عند تغير أوضاع تصنيعها, وتغير أوضاع عمليات اللصق, وتقليل الإجهادات المتولدة في الوصلات غير المتماثلة السمك. لقد تمت عمليات التحليل باستخدام الحاسب الآلي وأسلوب العناصر الدقيقة. لقد أوصي باستخدام الوصلات المبرشمة و المدعمة بالمواد اللصقة بين منطقة التماس وعلى جسم البرشام.