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Influence of Hole Chamfer Size on Strength of Blind Riveted Joints

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ABSTRACT

This work presents results of the strength analysis of a single lap riveted joints. In experimental investigations, performed in this paper, the blind rivet was considered. Blind riveted joints are very popular and often used in many branches as aerospace or automotive. In scientific publications is a research gap related to the strength analysis and failure mechanisms of the blind riveted joints. There are many geometrical parameters of riveted joints that have influence on strength parameters of the joint. One of them is the size of the chamfer located on the edge of the rivet hole. In this analysis a four different sizes of the hole chamfer were examined. The investigated specimens (sheets and the rivet) were made out of aluminium alloy. The tests of the blind rivet joints were performed with the use of Zwick-Roell tension machine. As a results of experimental investigations, the ultimate shear load diagrams of joints were obtained. Obtained shear load diagrams showed influence of the hole chamfer size on destructive force of joint. Moreover, for a few joints the static test was interrupted before the damage of rivet. Next, the joints were covered by the epoxy resin. After that, the joints in advanced stage of rivet deformation were cut and magnified using an optical microscope. Analysis of the rivet axial sections at various stages of deformation is an interesting task from the research point of view. Results obtained in this work contribute to a better understanding of the failure process of blind rivets.

Keywords: blind rivet, failure phenomenon, shearing test, lap blind joint, chamfer size.

INTRODUCTION

Riveted joints are one of the oldest methods of sheet joining. The most popular rivets are the solid and the blind rivets. Both of them are used in every branch of industry, including aviation. Blind rivets were developed to overcome the disadvantages of solid rivets and at the same time retain the advantages of these rivets. Blind rivets have been used in aviation (since the production of DC-3 airctraft) for joining of thin-walled, closed structures that are difficult to access. The advantages of blind rivets are low cost and uncomplicated riveting process. Blind rivet during riveting process is expanded and fills the gap between the hole and external rivet surface what prevents any relative motion of joined components. Morover the formed head compress the parts together (reduction of corrosion process) [6].

In most publications the blind rivets are compared to the other types of rivets or a different type of connectios (adhesive joints, bolted joints). The publications related to the load capacity and strength of bling riveted joints are not often published. Mucha and Witkowski [9] conducted a shear test for four types of riveted joints. The authors tested also the strength of joints with different combinations of steel and aluminum sheets. It was concluded that the joints of steel sheets have the highest load capacity, and the aluminum ones the lowest. It was found that joints with: the blind rivets, the blind hermetic rivets and the rivets for closing up have a similar load capacity and the maximum strength of joints is mainly influenced by the sheet metal factor. In another article, Mucha [8] compared the blind riveted joints with joints made with the ClinchRivet joints. The shear test showed that the strength of the ClinchRivet joint is 72% higher than the blind rivet joints. The author investigated also the influence of temperature during shearing of the blind rivet joint and it proved that the temperature have an influence on the load capacity of joint. Pittaa et al. [10] analyzed the blind riveted joints and hybrid joints (riveted and bonded) of metal-metal and metal-composite configurations. The authors concluded that the joints with adhesive bond showed nearly 5 times higher average strength than pure riveted joints. Rudawska et al. [11] analyzed the strength of specially shaped rivet joints and adhesive steel sheets with steel fixtures and polymer. In this publication the steel and aluminum blind rivets were analyzed. The experiment showed that the joints with the use of steel blind rivets were stronger than those made of aluminum blind rivets.

Another group of publications is related to experimental static and fatigue strength analysys of riveted joints compared to the results of numerical simulation. Sadowski et al. [12] analyzed the results of shear and fatigue tests for three types of connections: rivet joint, adhesive joint, and hybrid (adhesive and rivet - including blind rivet). The static tests of joints was made with the use of the Aramis system in oreder to joint deformation analysis. The authors created a numerical model of joints using the ABAQUS software and compared the experimental results to the numerical ones. The analysis showed that hybrid joints (using adhesive and rivet) have the highest static strength.

In research publications the new methods of riveting as self-piercing riveting (SPR) was described. These papers presented simulation of riveting process, strength tests, and numerical analysis of SPR joints. Weiming Yan et al. [15] described the results of strength tests of self-piercing rivets. In this analysis the number of rivets, the rivet spacing, and the thickness of the sheets were considered. The influence of riveting parameters on the shear curve was also analyzed. The results concluded that the orientation of the rivets has a significant influence on the shearing strength of SPR joints. Weiming Yana et al. [14] presented the results of strength tests with various sheet thicknesses and rivet lengths. The experiment showed that these parameters have a significant influence on the shear strength of the joint and a great effect on the failure mode of the joint.

Some authors, such as Rezwanul Haque and Yvonne Durandet [5], have studied the mechanical properties of self-piercing riveted joints of steel sheets in shear and cross-tension test. It was concluded that higher strength of joints was always observed during the shear loading than in the cross-tension test. In publication [13] authors examined the strength of riveted joints with a blind rivet for single-row and five-row lap joint, additionally. Moreover for a single-row joint the geometric parameter as size of the hole chamfer was considered. The shear curves obtained in investigarions showed that the size of the hole chamfer has a significant influence on the load capacity of a single joint. Adam Lipski et al. in work [7] presented the analysis of influence of the rivet hole sizing process on the fatigue life of the joint. Obtained results confirmed the positive effect of hole sizing on the fatigue life of joints. Yiwei Chen and Xujing Yang in publication [4] presented results of an experimental analysis of riveted joints, hybrid joints, and bonded joints. In investigations were the mechanical tests and analysis of the failure process of joints were performed. It was found that higher load is transferred by the hybrid joints.

A literature review performed by the authors of this work showed that there is a limited number of research works related to the strength analysis of blind riveted joints. For many years, the research works were performed in order to increase the strength and fatigue life of riveted joints. Performed investigations were mainly based on the experimental tests because the analytical description of phenomena occurring in riveting or shear processes is very complex. Based on the literature review, it appears that there is a research gap in analysis of the strength, destructive load, and the damage phenomena of the blind riveted joints. Moreover, the influence of geometrical parameters of blind riveted joints on its strength was not often described in the research works.

In this study, an experimental strength analysis of the single lap blind riveted joints was performed. The main aim of this work is to determine the influence of the chamfer size on both the destructive force and the shape of shear diagrams of blind riveted joints. An additional goal of this work is analysis of blind rivet deformation during the various load phases of the joint.

MATERIALS AND METHOD

Preparation of joints

There are many kinds of blind rivets used in automotive and aviation industries. One of them is the blind rivet presented in Figure 1. It

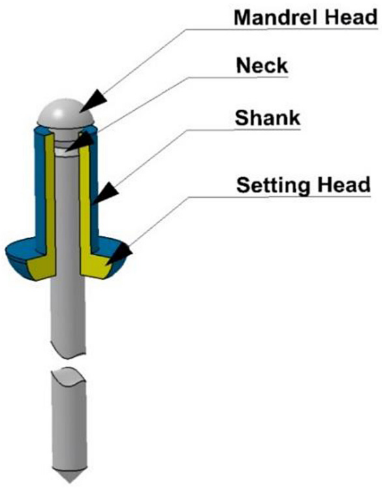


Fig. 1. Geometry of blind rivet

consists of: the shank, setting head, and mandrel. The setting head should be made out of alloy susceptible to plastic deformation. The material of the mandrel is usually more brittle. In the top part of the mandrel is located the neck. During the riveting process, the mandrel moves down and in consequence, the upset head is created (Fig. 2). The high stress value in neck of the mandrel (due to stress concentration) causes that in the final part of riveting process the mandrel is broken. The riveting force (maximum force applied to the mandrel) depends on material of mandrel and geometry of the neck. The riveting force has an influence on many parameters as: initial stress in riveted joint or static and fatigue strength of joint. For one series of rivets with the same geometry there is observed a small fluctuation of riveting force. It enables repeatability of the riveting process using a simple tool as manual riveter or pneumatic blind rivet gun.

An another factor which has impact on strength of the joint is size of the chamfer located on the corner of the rivet hole. The chamfer size f is shown in Figure 2. In order to check the influence of the chamfer size on both the strength of the joint and also the shape of shear diagrams of joints the following chamfer sizes (f dimension in Figure 2) were considered: 0, 0.1 mm, 0.3 mm, 0.5 mm. These joints had the following symbols: A0, A01, A03 and A05 (Table 1). For every type of connection, 10 tests were conducted for appropriate repeatability of results.

The dimensions of the metal sheets used in the tests are given in Figure 3. In order to eliminate the eccentricity of load, the additional shim plates were fixed to the sheets. Specified combinations of selected geometric parameters of joints and size of hole chamfer for considered specimens were presented in Table 1. The lap joints used in the strength tests were made using the pneumatic blind rivet gun.

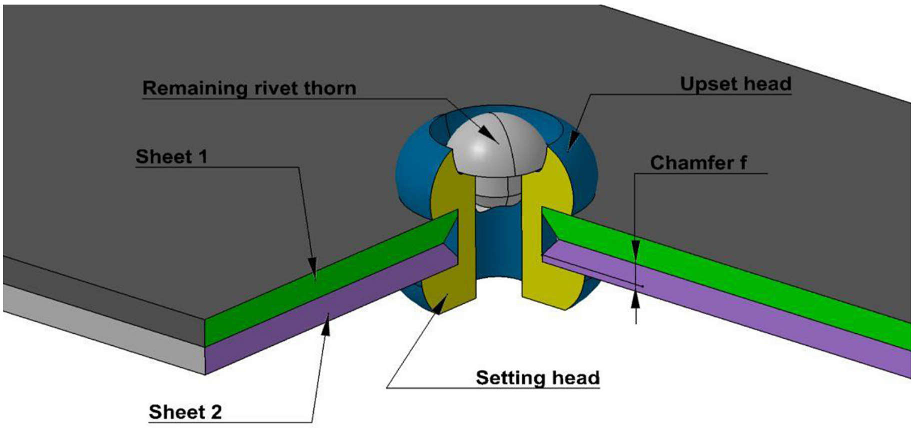


Fig. 2. Geometry of joint

Table 1. Geometry of joints used in experimental analysis

Working symbol of joint	Width of sheet b, mm	Size of hole chamfer f, mm
A0	30	0
A01	30	0.1
A03	30	0.3
A05	30	0.5

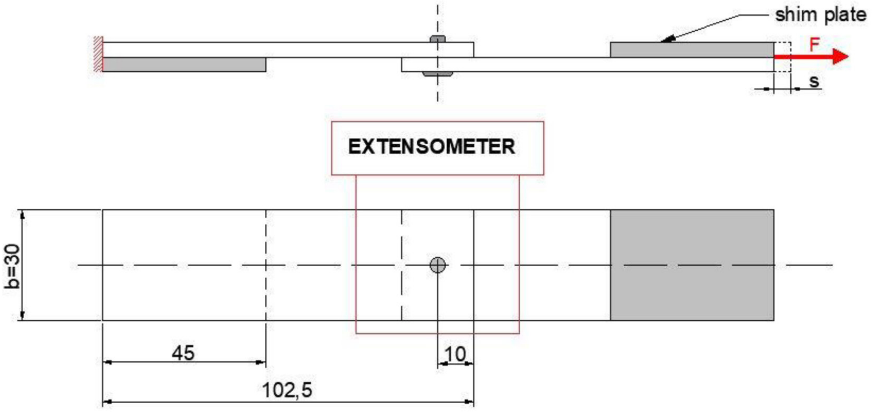


Fig. 3. Geometry, load and boundary conditions of joints used in experimental analysis [3]

Table 2. Mechanical properties of EN AW2017A and EN AW5251 aluminium alloy [1, 2]

Element	Material name (Aluminum alloy)	Young modulus, E GPa	Yield stress, $R_{p0.2}$ MPa	Ultimate tensile strength UTS, MPa
Rivet	EN AW - 2017A	179	288	440
Sheets	EN AW - 5251	70	140	240

Table 3. Chemical composition of EN AW2017A and EN AW5251 aluminum alloy [1, 2]

Material	Values in weight percentages (%)							
	Ti	Si	Fe	Cu	Mn	Mg	Cr	Zn
EN AW - 2017A	0.04	0.64	0.4	4.2	0.62	0.76	0.05	0.18
EN AW - 5251	0.15	0.4	0.5	0.15	0.1–0.5	1.7–2.4	0.15	0.15

MATERIALS

The sheets (joined elements) used in presented investigation were made out of EN AW2017A aluminum alloy. The thickness of sheets was 1 mm. The mechanical properties and chemical composition of the sheet material are given in Tables 2 and 3. The blind rivet used for joining of sheets was made out of EN AW5251 aluminum alloy (Tabs 2-3).

The static strength tests of the lap joints were carried out in accordance with guideline ISO 12996 standard [3]. The shear tests were performed with the use of Zwick-Roell tension machine equipped with an extensometer. View of specimen (single lap riveted joint) fixed to the grips of tension machine is presented in Figure 4. Static tests of joints were performed for the traverse speed of 4 mm/min. It enables to create the shear diagram for investigated riveted joint.

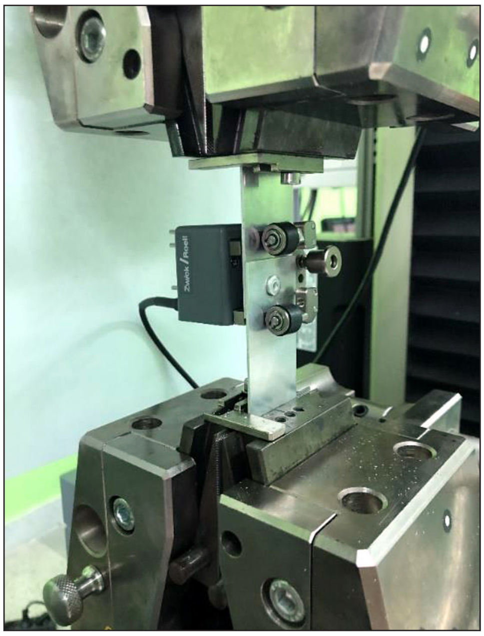


Fig. 4. View of specimen (single lap riveted joint) fixed to the grips of tension machine

RESULTS AND ANALYSIS

After preformation of all static tests of specimens, the results were subjected to the quantitative analysis. Obtained results of investigations showed that the size of hole chamfer has significant influence on both the strength and also the geometrical parameters of blind riveted joints. In next part of the chapter, the shear diagrams for the two extreme chamfer sizes (A0 and A05) will be presented.

During the shear test of the joints the actual force F (acting on the sheet edge) and the sheet displacement s were monitored and recorded. It enabled to create the shear curves for the blind riveted joints. Figure 5 presents the shear diagram for A0 joint (Table 1). As seen from this figure, for the joint with size of hole chamfer f = 0 mm the maximum force (955 N) is achieved at sheet displacement s = 1.1 mm. The destruction of joint occurred at displacement s = 1.63 mm.

Figure 6 presents the shear diagram for A05 joint. Obtained results showed that the maximum force for the joint with chamfer f = 0.5 mm increased to the value of 1181 N. The joint A05 was damaged at displacement s = 2.87 mm. The results of investigation showed that both the maximum force and the displacement at rivet (joint) destruction depend on the chamfer size.

In next part of the work the fractures of the rivets will be analysed. Figures 7a and 7b present the fracture of rivet installed in the joint A0. As seen from this figures on left part of the rivet fracture the smooth zone is observed. This zone with large number of the parallel lines was created by displacement of rigid hole corner of sheet. It caused the plastic shear of the left part of blind rivet. The total failure of rivet occurs when the plastic strain in shear plane of the rivet achieves a critical value, related to the coherence forces of the material. The brittle (rough) fracture area (Fig. 7a, 7b) is visible in the right part of fracture. The brittle fracture zone for the joint A0 achieves about 75% or the total fracture area. In the case of joint with chamfer f = 0.5 mm (Fig. 7 c, d) the brittle fracture zone is smaller (about 60% of the total fracture area). Moreover, for the joint A05 (Fig. 7c) the folds of material are visible in the right part of the rivet fracture.

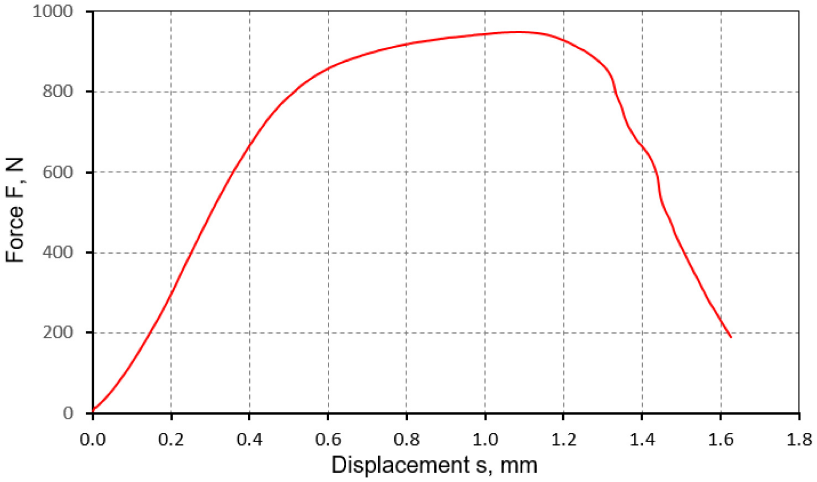


Fig. 5. Shear curve for joint A0 with size of hole chamfer f = 0 mm

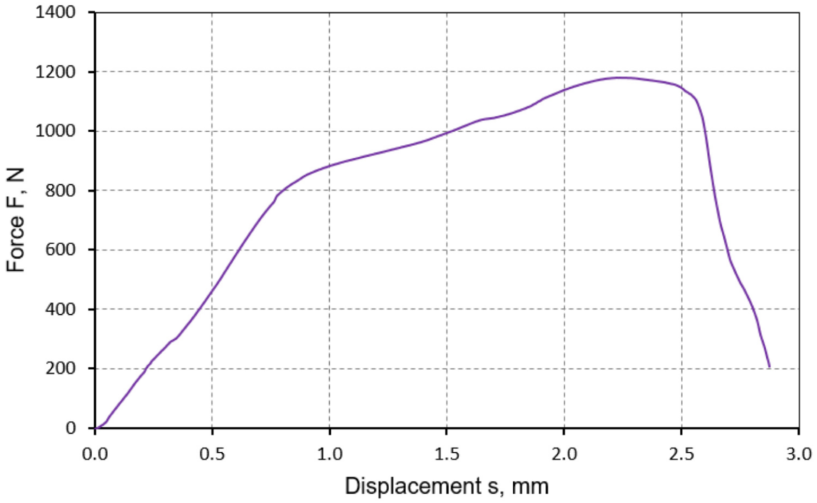
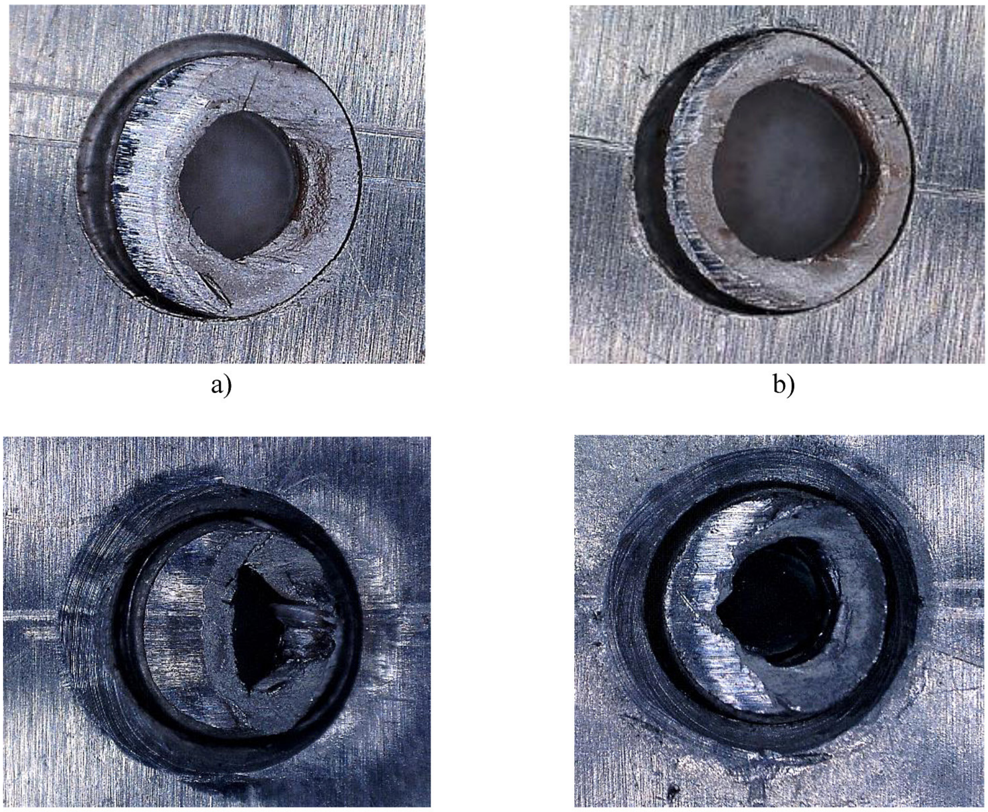
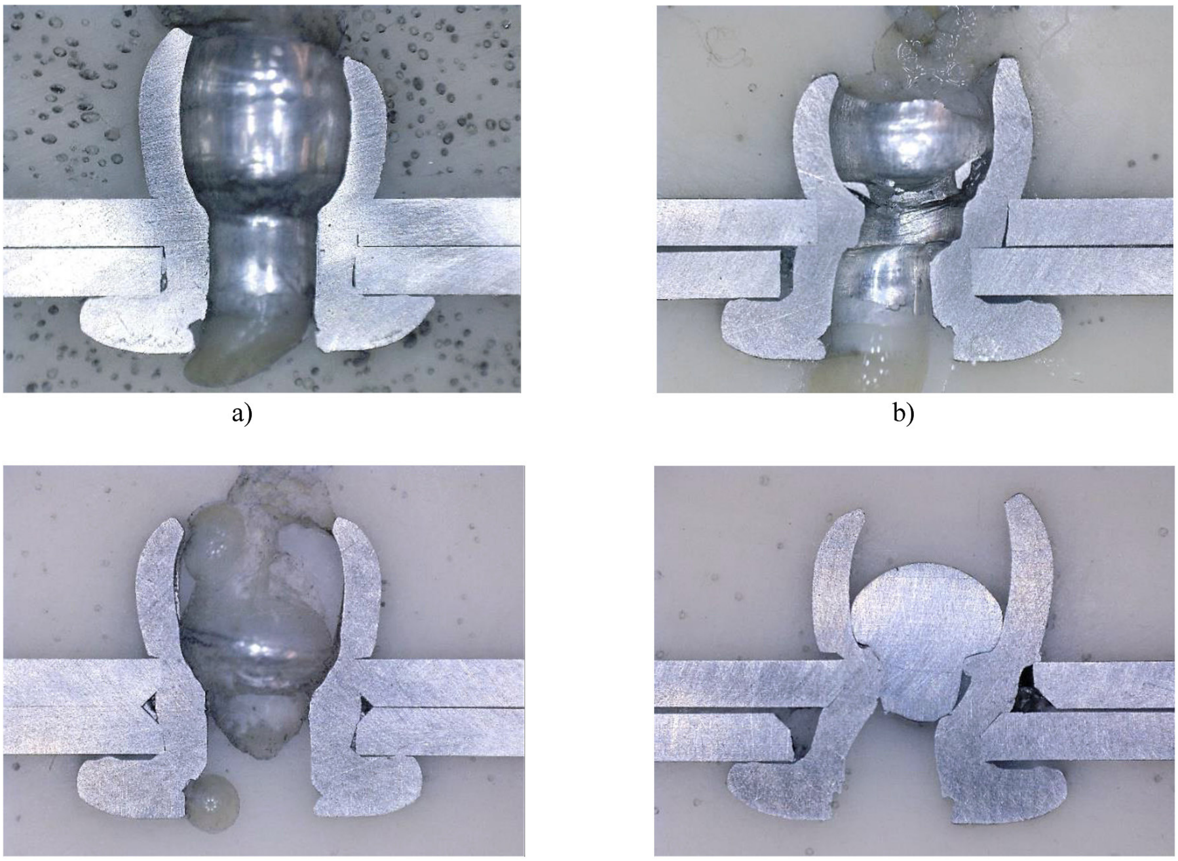


Fig. 6. Shear curve for joint A05 with size of hole chamfer f = 0.5 mm



a) b) c) d)

Fig. 7. View of damaged rivet in joint: with 0 mm chamfer (a, b) and with 0.5 mm chamfer (c, d)



a) b) c) d)

Fig. 8. Axial section of the joints: A0, F = 500 N (a); A0, F = 900 N (b); A05, F = 500 N (c); A05, F = 1100 N (d).

In a few cases, the shear process of the rivet was interrupted at different stages of loading. Next, the joints were covered by the epoxy resin. After hardening of resin, the joints were cut and polished. The results of mentioned above operations, shown in Figure 8 are interesting from the research point of view.

Figure 8a presents axial section of the joint A0 (chamfer f = 0 mm). There is visible a formed rivet head created by the mandrel. At preliminary stage of loading (for F = 500 N) there is observed a small sheets displacement. At this load the rivet deformation is also not observed. Similar small deformation of the joint components is visible for the joint with chamfer f = 0.5 mm laded by force F = 500 N.

When the force is close to the maximum value (in this case F = 900 N, Fig. 8b), there is visible the rivet deformation, caused mainly by the shear process. The internal cylindrical surface of rivet (preliminary smooth) was deformed (shifted) as a reason of local high shear stress. Moreover, at advanced stage of loading the gap between the joined materials is observed (Fig. 8b).

A quite different shape of deformed rivet is observed for the specimen A05 (hole with chamfer f = 0.5 mm, Fig. 8d). At high load F = 1100 N (which is a bit smaller than the maximum force) the rivet is strongly bend. Moreover the shift of section is not observed on internal cylindrical surface of the rivet. Results of performed observations indicated that after increase of the chamfer size a larger bending deformation (and also the bending stress) occurs in the blind rivet before its destruction.

In order to compare the obtained results a shear curves for all considered joints were presented in Figure 9. As seen from this figure, a large difference between the curve A0 and the other curves is visible. For the joint A0 (f = 0 mm) the maximum force (955 N) is the smallest (and is observed at displacement s = 1.1 mm). The maximum force for joints A01, A03 and A05 equals adequately: 1050 N (increase at 10% in reference to A0 joint), 1145 N (increase at 20%) and 1181 N (increase at 24%). The displacement of sheets at which the maximum forces are observed for joints A01, A03 and A05 are in the range of 2.1 mm to 2.25 mm.

Results of performed investigations showed that the joint A0 (with chamfer f = 0 mm) has the lowest destructive force and could be indicated as the worst from the strength point of view. In general, increase of the chamfer size causes increase of destructive force of the joint.

CONCLUSIONS

The main goal of the study was to determine the influence of hole chamfer size on destructive force of the joint. In order to solve this problem the experimental analysis of the single lap riveted joints was performed. In investigations the joints with different size of the chamfer of rivet hole were considered. The main results of performed experimental analysis were: shear diagrams, fractures of joints after destructive tests and the axial sections of joints with the blind rivet at different stages of deformation. All obtained results helps in explanation of the failure phenomenon of blind

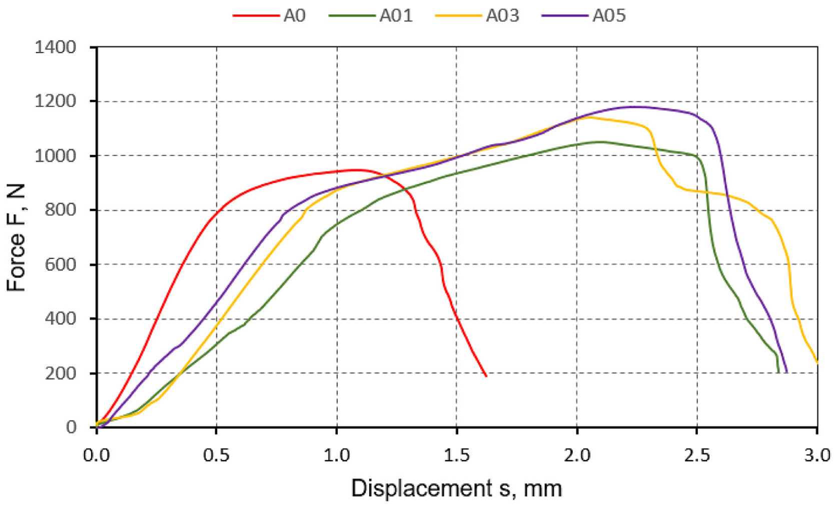


Fig. 9. Shear curves for single lap blind riveted joints with different size of hole chamfer

rivets. Results of this work can be used during design of riveted joints with the use of blind rivets.

As results of performed investigations, the following conclusions were formulated:

1. The size of hole chamfer has a significant influence on strength of single lap riveted joints.
2. The highest destructive force (F = 1181 N) was observed for the joint with hole chamfer f = 0.5 mm. This value is about 24% higher then maximum force for reference joint A0 without chamfer (955 N).
3. Destruction of joint A0 was observed at displacement s = 1.63 mm. Increase of the chamfer size to the value higher than 0.1 mm caused growth of displacement (need to rivet damage) to the value about 2.8–3 mm.
4. Observation of both the rivet fractures and the axial sections of joints showed that the rivet in joint A0 (without chamfer) was damaged as a result of shear process. After increase of the chamfer size the blind rivet is also subjected to bending. As a result of more complex stress state in the rivet (combination of shear and bending in advanced stage of deformation) the increase of destructive force of joint is observed.

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