



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0749

STRENGTH TEST OF RIVETED OVERLAP JOINTS

Gabriel Rodrigues Felix

Luiz Henrique Jorge Machado

Juliana Primo Basílio de Souza

Universidade Federal de Minas Gerais

gabrielrodriguesfelix@gmail.com

luizhenriquejmachado@gmail.com

juliana_basilio@demec.ufmg.br

Abstract. *This paper presents an analysis about the influence of the types of rivets and their methods of application in the strength of overlap riveted joints. For the evaluation of this influence, riveted joints made of 2024 T3 aluminum alloy plates were manufactured and submitted to tensile-shear tests to obtaining force-displacement diagrams according to ASTM E8 standard test method. It was observed that, among the rivets tested, the countersunk rivet presented the highest strength and the RIVNUT[®] rivet the lowest, based on their ultimate load capacity. Additionally, the dimpling process in the installation of countersunk rivets increased the strength of the joint in about 20%. This process also had great contribution for the alignment between the rivet factory head and the aluminum plate.*

Keywords: rivet, joint strength, fastener, overlap joint

1. INTRODUCTION

Rivets are the main fasteners used on aeronautical structures and they are present mainly in the aircraft's wing and fuselage fastening coating panels, stiffeners and other components to the main structure. There is a large variety of rivets, in addition to different techniques of installing these fasteners on the structure.

Holleman (1943) performed a group of tensile tests of 2024 aluminum alloy plate specimens to observe their behavior for different sizes and quantities of holes. Based on the results, guidelines were proposed for designing riveted aeronautical joints. Among these recommendations, it is possible to highlight the importance to avoid installing rivets near the border of the plates (distances around 2.5 times the diameter are recommended); avoid misalignment of rivets from different rows (specially in the rows closest to the border); and keeping the smallest spacing between rows without compromising in the shear strength of the joint. This prevents the buckling of the region between the rows.

According to Miller (1937), the strength of the joint is related to the sheet thickness and its material properties, the rivet's size, and the distance between the rivet's hole to the edge of the plates. By increasing the distance between the hole and the edge, the resistance of the joint is increased until it reaches a limit value, from which there is no increase in resistance. In addition, using high tool pressures in the riveting process, higher resistance values are achieved through better filling of the hole by the rivet, even if the tool causes little damage to the plate.

In the same way of Miller's findings, the finite element 3D model proposed by Rans *et al.* (2007) had shown that the force applied during the rivets installation process is directly proportional to the number of residual stress regions, resulting in a better filling of the rivet in the hole, and thus in a higher ultimate stress value for the joint. Despite this, an optimal installation force could not be determined.

McKinley (1965) states that the best configuration for conducting strength tests is the double shear setup (Fig. 1(a)). In this setup, the rivet is sheared in two planes. Therefore, twice the tensile force applied in the plates is necessary for the same shear stress level of the single shear configuration (Fig. 1(b)). Moreover, the double shear setup also eliminates off-plane strains and indirect bending stress caused by the flexing of the rivet due to the force applied out of its centroid by the plates (Fig. 1(c)). These secondary effects reduce the strength of single shear joints (Kulak *et al.* (2001)).

In accordance with Kulak *et al.* (2001), among the test variables studied there were the rivet length, rivet diameter, rivet application process, and rivet manufacturing process. These variables have no significant influence on the strength of the rivet by themselves. However, long rivets tend to show a decrease in their strength when sheared. The longer the rivet's length, the more deformation and energy dissipation there will be. Thus, the sole parameter capable to influence the strength of the rivet seems to be its length. This is different from the rivet-plate assembly, where all variables cited above have significant influence on the strength of the joint.

Based on the physical analysis of rivet fixation and on riveted plate tensile tests, Mucha and Witkowski (2015) report

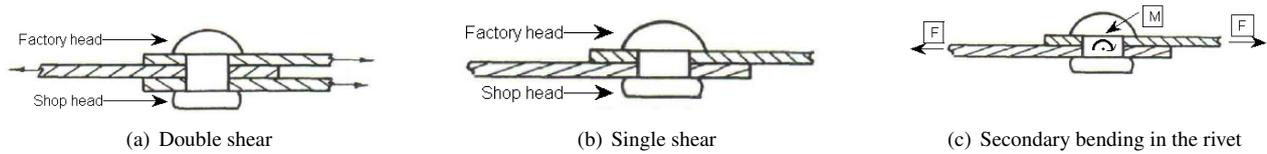


Figure 1. Types of joints. Font: Modified from McKinley (1965)

that joints fastened by blind rivets have lower strength than solid rivets. Two main factors are responsible for this: the gap between the rivet and the wall of the hole, and the fact that blind rivets are commonly hollow. The former causes a leaning of the rivet through the hole, generating secondary stress to the sheet structure. The latter decreases the rivet's bending moment of inertia and cross-sectional area, hence decreasing its strength in bending, shear and tensile loading.

Figure 2(a) shows that when the rivet leans inside the hole, it only touches its edges, causing a concentration of stress on this location. This is visible by the buckling of the region near the surface of the hole, as shown in Fig. 2(c).

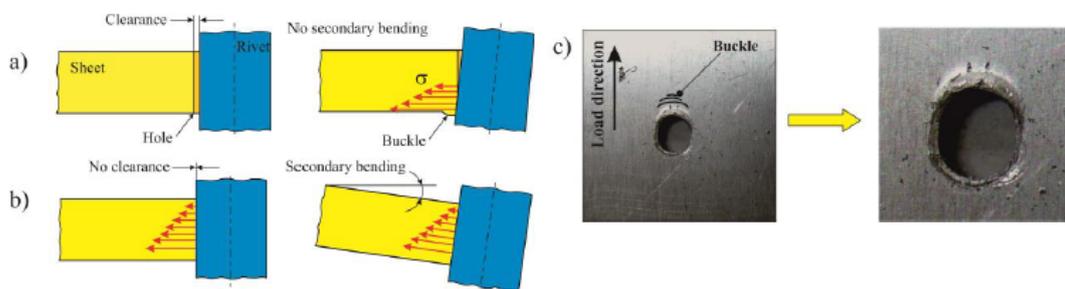


Figure 2. Influence of the rivet in the hole surface: a) with clearance, b) without clearance, c) buckle deformation of the sheet. Font: Mucha and Witkowski (2015)

Mucha and Witkowski (2015) also state that the strength of the plates are higher than the strength of the rivet. Therefore, the strength of the joint in tensile load of the sheets should be limited by the lower strength of the rivet. The thickness of the plates and both the diameter and length of the rivet are the main parameters governing this limited strength. Thus, the maximum load capacity of the joint can be calculated from the shear strength of the rivet.

The objective of the present study is to evaluate the influence of rivet types and their installation methods on the strength of the joint and on the quality of the assembly. These fastening components are mostly subjected to shear stress. Considering this, this study will be done by means of shear tests of the rivets by a tensile test in specimens made of aluminum alloy plates overlapped and fastened by different types of rivets and set up techniques.

2. METHODOLOGY

For evaluating the influence of rivet types and their installation methods on the strength of the joint, double shear specimens were manufactured to be submitted to tensile tests. The plates, when pulled, would transfer a shear load to the rivet. The specimens were manufactured in accordance with ASTM E8 standard testing methods and with the geometry of the testing machine holding jaws, as shown in Fig. 3.

There were two types of rivet available in the local market: solid rivets and blind rivets. In the first group there were 3/32", 5/32" and 1/8" round head rivets; 3/32" and 1/8" countersunk rivets; and a 1/8" Braille rivet. The second group consists in 5/32" RIVNUT[®] rivet, and 1/8" for either Braille and Cherry rivets.

Double shear specimens were composed by three 150x30x0.635 mm rectangular 2024 T3 Alclad aluminum alloy sheets fastened by a rivet. The rivet was positioned in a distance of 10 mm from the borders of the plate. This distance, as can be seen in Fig. 4, is more than 2.5 times the diameter of all rivets used, as recommended by aircraft repair handbooks. After riveting the aluminum sheets, the final dimensions of the specimens were 130x30x1.905 mm.

In the manufacturing process, the aluminum plates were cut with an industrial metal sheet cutter. The solid rivets were installed with a pneumatic compression riveter. This choice was made once the use of pneumatic riveting hammer proved to result in unsatisfactory fixation of the rivet and damage of both the rivet heads. Those problems are attributed to difficulties to control the direction of the application force. Cherry rivets required a rivet gun for their installation, while a hand nut rivet tool was used for setting up the RIVNUT[®].

A Shimadzu MWG-100kN universal testing machine (Japan), shown in Fig. 5, was used for the static tensile shear test of the joints. In each test, the machine records the applied force and displacements in the specimens. The crosshead speed used was set at 10 mm/s, as proposed by Mucha and Witkowski (2015).

Dimpling the plates where countersunk rivets are applied is a factor that has a high influence in the fixing quality of

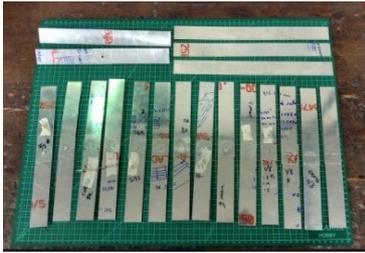


Figure 3. Specimens. Font: The author



Figure 4. Riveted joint - Round head rivet. Font: The author



Figure 5. Specimen positioned in the test machine. Font: The author

the joint, since it promotes a better filling of the hole and since, for better aerodynamic behavior, this type of rivet must have its head leveled with the surface of the top plate.

In this context, for evaluating the influence of the application techniques in the strength of the joint, the countersunk rivet joint specimens were submitted to two different types of dimpling: top plate dimpling and dimpling of all three plates. A total of nineteen (19) specimens were manufactured as can be seen in Fig. 3. Three of them were single plates (without joints) with the same length of the others for test control purposes. Table 1 shows the configurations.

Table 1. Specimen characteristics

Specimen	diameter (in)	Type	Specimen	diameter (in)	Type
1 ⁽¹⁾	-	Control	11	1/8"	Round head
2 ⁽¹⁾	-	Control	12	1/8"	Countersunk Cherry
3 ⁽¹⁾	-	Control	13	1/8"	Round head Cherry
4	3/32"	Round head	14	1/8"	Braille
5	3/32"	Round head	15	1/8"	Braille
6 ⁽³⁾	3/32"	Countersunk	16	5/32"	Round head
7 ⁽²⁾	3/32"	Countersunk	17	5/32"	Round head
8 ⁽³⁾	1/8"	Countersunk	18	5/32"	RIVNUT [®]
9 ⁽²⁾	1/8"	Countersunk	19	5/32"	RIVNUT [®]
10	1/8"	Round head			

⁽¹⁾ Control specimen; ⁽²⁾ Top plate dimpled; ⁽³⁾ All three plates dimpled

3. RESULTS AND DISCUSSION

Figures 6 and 7 present the force-displacement diagrams for each test. Figure 6(a) shows the results for the three control specimens. Figures 6(b), 7(a) and 7(b) present the joint's force-displacement curves for each rivet diameter: 3/32", 1/8" and 5/32", respectively.

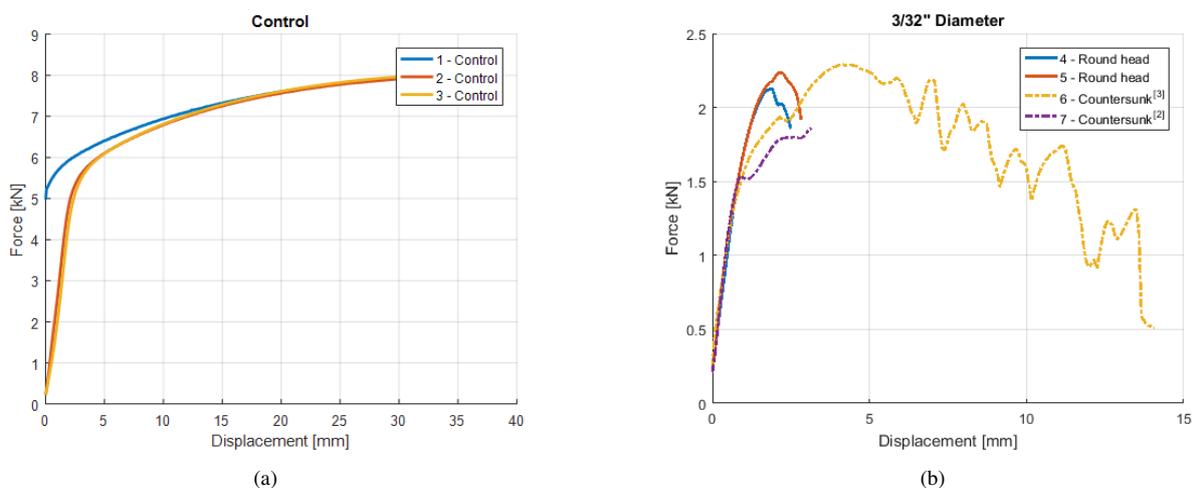


Figure 6. Force-displacement diagrams. Legends numbered in accordance with Tab. 1

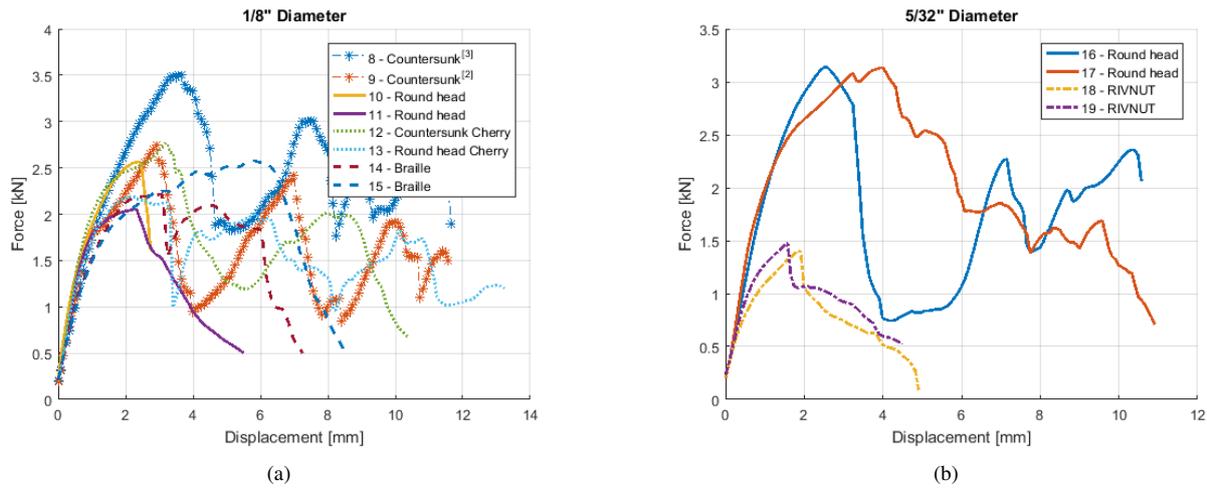


Figure 7. Force-displacement diagrams. Legends numbered in accordance with Tab. 1

It can be noticed by Figures 6 and 7 that some joints presented fabrication problems that resulted in a decrease in the joint mechanical resistance. It was observed, during the tensile-shear tests, the tearing of the rivet rather than the rupture of the sheet, which is characterized as a non-acceptable manufacturing defect for aircraft structural joints. In this way, the results of the tests 11, and 15 they were despised.

Table 2 presents the values of ultimate tensile force F_{ult} , ultimate shear stress τ_{ult} and ultimate compression stress σ_{ult} for the specimens without fabrication problems.

Table 2. Ultimate tensile force (F_{ult}), shear stress (τ_{ult}) and compression stress (σ_{ult}) results

Specimen	F_{ult} (N)	τ_{ult} (MPa)	σ_{ult} (MPa)	Specimen	F_{ult} (N)	τ_{ult} (MPa)	σ_{ult} (MPa)
1 ⁽¹⁾	8048	-	47,79	10	2566	159,53	89,26
2 ⁽¹⁾	7995	-	47,48	12	2578	160,27	89,68
3 ⁽¹⁾	8005	-	47,54	13	2214	137,64	77,02
4	2236	247,13	103,71	14	2766	171,96	96,22
5	2127	235,09	98,66	16	3142	125,02	87,44
6 ⁽³⁾	2290	253,1	106,22	17	3133	124,66	87,19
7 ⁽²⁾	1859	205,46	86,23	18	1479	58,85	41,16
8 ⁽³⁾	3503	217,78	121,86	19	1396	55,55	38,85
9 ⁽²⁾	2750	170,97	95,66				

It is possible to observe, from Tab. 2, that shear and compression stresses are not good parameters for comparison between tests of joints fastened with different rivet diameters. For tests of rivets with the same diameter, the only parameter that varies is the force, and consequently the stress. That allows stress as a comparison parameter. However, for tests of different diameters, there are two variable parameters: the force and the diameter itself, both of these directly affect the stress levels. Thus, the best parameter for comparing tests of different rivet diameters is the tensile force applied on the plates.

In all tests, the compression stress were smaller than the shear stress because of how these stresses are calculated. For compression stress, the reference area used is the side area of the rivet which is in contact with the internal wall of the hole, whereas for the shear stress the reference area is given by the cross-sectional area of the rivet. The double shear configuration causes the rivet to be sheared in two planes, so the area used to calculate the tension is the one corresponding to twice the cross-sectional area. For compression, the reference area is half the lateral area of the rivet, which is greater than the shear reference area, represented by the red areas in contact with the internal wall of the plates, as shown in Fig. 8.

In Tab. 2, for either 3/32" and 1/8" diameters, countersunk rivet provided the best joint strength. This is due to its better fixation and filling of the hole. In addition, the dimpling of the plates had indeed an outstanding influence in the joint strength. In the tests of countersunk rivets for both diameters, the specimens in which all three plates were dimpled had greater load capacity than those in which only the top plate was dimpled. This increase in strength was about 17% and 27% for the 3/32" and 1/8" diameters, respectively.

It was also observed the types of failure which occurred in each specimen. It was seen that fourteen (14) joints failed by ripping of the plate (Fig. 9), and the other two (2) presented the fabrication problems described previously.

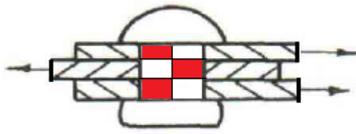


Figure 8. Rivet area under compression. Font: Modified from McKinley (1965)



Figure 9. Ripping of the hole. Font: The author

Also, a sawtooth behavior of the force is observed after the ultimate force point. This is very clear for the countersunk rivet in Fig. 6(b) and it relates to the ripping failure of the plate hole, as seen in Fig. 9. As the material around the plate's rivet hole presented plastic deformation, the force decreased, until the joint stabilized and the loading rise back again, causing the plastic deformation of the plate and restarting the cycle.

RIVNUT[®] presented the lower strength of all rivets tested, despite the greatest diameter. Its maximum strength was approximately 60% of the average of the other 5\32" round head rivets. This behavior is due the fixation of the rivet that compromised the strength of the joint, since the application of the RIVNUT[®] was made using a tool with it was not able to deform its shop head efficiently, causing looseness on the joint. Furthermore, the hollowness of RIVNUT[®] blind rivet decreases its strength when compared to solid rivets, as previously mentioned.

The other types of rivet: round head, Cherry, and Braille had a similar performance to each other. For the diameters of: 3/32" round head resisted an average of 2100 N; 1/8" round head, Cherry and Braille resisted an average of 2400 N; 5/32" round head an average of 3100 N, while RIVNUT[®], resisted about 50% of the latter value.

Comparing the results obtained with all the riveted specimens to the control plates, it was observed that the riveted joints presented the lowest measured strength. The resistance loss reaches 82% of the force for the RIVNUT[®] and 56% in for countersunk rivets. The discontinuity of the plate in riveted joints and the lower strength of the rivet in relation to the plate are the main factors that weakens the joint.

4. CONCLUSION

The objective of this study was to evaluate the influence of rivet types and their installation methods on the strength of the joint and on the quality of the assembly.

It was noticed that, for a more accurate comparison of joints made with rivets of different diameters, the analysis of the strength of the joint must be made in terms of tensile force rather than the shear and compression stresses in the rivets.

Finally, aluminum plate joints riveted by countersunk rivets have the greatest strength among all rivets analyzed, and the dimpling of plates that received countersunk rivets contributed greatly to increase the joint strength. Furthermore, specimens where all aluminum sheets were dimpled had the best surface quality, in which the rivet shop head remained perfectly leveled with the plates.

5. ACKNOWLEDGEMENTS

The authors would like to thank to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) that financed in part this study - Finance Code 001.

Also, the authors sincerely would like to thank to the Fibraer Indústria Aeronáutica Ltda. for supplying the aluminum sheets, rivets, tools and labour for manufacturing the specimens; and professor Haroldo Béria Campos for providing the UFMG Automation and Machining Laboratory infrastructure for the experiments and assistance in the testing process.

6. REFERENCES

- Holleman, C.H., 1943. "Tension joints in aircraft structures". *Journal of Aeronautical Sciences*.
- Kulak, G.L., Fisher, J.W. and Struik, J.H.A., 2001. *Guide to Design Criteria for Bolted and Riveted Joints*. American Institute of Steel Construction, Inc., Chicago, 2nd edition.
- McKinley, L.E., 1965. "Structural riveting for aircraft". *Sport Aviation*.
- Miller, R.A., 1937. "The bearing strength of steel and aluminum allow sheet in riveted or bolted joints". *Journal of Aeronautical Sciences*.
- Mucha, J. and Witkowski, W., 2015. "The structure of the strength of riveted joints determined in the lap joint tensile shear test". *Acta Mechanica et Automatica*, Vol. 9, No. 1.
- Rans, C., Straznický, P.V. and Alderliesten, R., 2007. "Riveting process induced residual stresses around solid rivets in mechanical joints". *Journal of Aircraft*, Vol. 44, No. 1.