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THE EFFECT OF RIVET GUN OPERATING PRESSURE AND HOLE CLEARANCE ON RIVET SHEAR STRENGTH IN SHEET METAL RIVETING PROCESS

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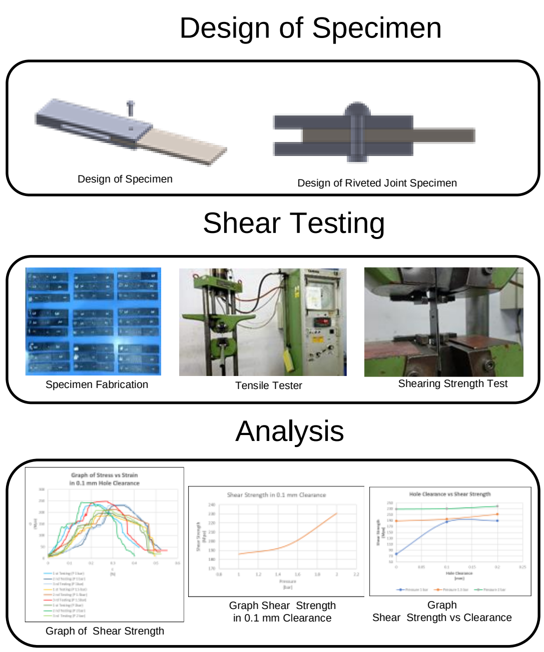
Graphical abstract



Abstract

Several parameters related to the riveting process and the quality or result of the rivets are squeeze force, rivet length, rivet diameter, and hole clearance. This riveting experiment uses a semi-automatic riveting tool to set riveting parameters. The parameter set is the operating pressure of the rivet gun with a semi-automatic riveting tool, while the drilling process on sheet metal makes the hole clearance. The results of riveting using an automatic rivet tool show that the operating pressure of the rivet gun and the hole clearance have a direct effect on the shear strength of the rivets; the higher the operating pressure of the rivet gun and the greater the hole clearance will increase the shear strength of the rivets. This rise in the rivet's shear strength is because, during the riveting process, the rivets experience strain hardening when pounded using a rivet gun.

Keywords: Rivet gun pressure, hole clearance, shear strength, rivets, sheet metal

1.0 INTRODUCTION

Sheet metal is an essential material in aircraft manufacturing industry that is usually joined using a method called riveting [1]. Rivet various materials making it a choice aircraft maintenance and production [2].

Rivet failure can cause death and aircraft accidents [3]. Damages on metal joints due to rivet failure can be fatal. For example, the 1998 crash of Aloha Airlines 243 was attributed in the investigation to damage to one of the rivet holes that affected the entire joint. Failure of rivet joints in airframes causes induced stress, thermal fatigue, and vibration [4]. Induce stress is the stress that occurs when an airplane is operating which can be controlled to minimize the risk of rivet joint failure [3], [5].

The use of rivets improves the crashworthiness and fatigue performance of an aircraft, and it is more corrosion resistant when compared to spot welded joints [6], [7], [8]. Cheraghi mentioned a number of parameters related to the riveting process that affect the quality of rivets, namely squeeze force, rivet length, rivet diameter, and rivet hole diameter tolerance [3]. When analyzing how various factors in riveting, such as squeezing force, impact force, rivet structure, countersunk hole design, countersunk diameter, plate thickness, and clamping force, influence the overall integrity of the riveted connection. The simulation illustrates the correlation between riveting parameters and the fluctuation pattern in the quality of rivet connections. The research findings unveiled that the utilization of squeezing force plays a pivotal role in determining the effectiveness of rivet joints [3].

Riveting process involves multiple sequential steps, the selection of an appropriate rivet type, the creation of holes, the determination of the rivet length, the adjustment of the operating pressure of the rivet, and finally, the actual riveting of the selected rivet. Certain procedures are typically known as riveting parameters.

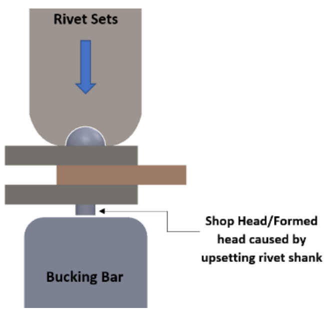


Figure 1.1 Riveting operation

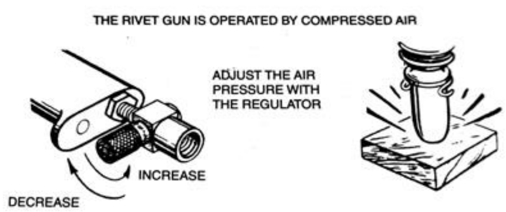


Figure 1.2 Adjusting air pressure [9]

Figure 1.1 illustrates riveting operation, while Figure 1.2 shows how to adjust the operating pressure of the rivet gun. Assuming that the rivet gun operates at the right pressure and the riveting duration is properly controlled, adhering to predetermined standards will yield the best possible riveting outcomes [10], [9]. Figure 1.3 below illustrates the standardization of rivet sizes.

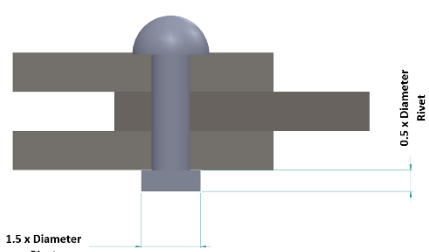


Figure 1.3 The standardized shape of the shop head rivet [9]

The classification of rivet connections by pressing in DIN standards (DIN 8593-0:2003, 2003a; DIN 8593-5:2003, 2003b). Other international standards, such as DIN EN ISO 14272 (2002), EN1993-1-8 (2005), and ISO/DIS 12996 (2013) include information on specimen dimensions, testing circumstances, and joint failures which provide a comprehensive list of the characteristics associated with lap joints. Addition, the ISO 2013 standard precisely outlines the structural analysis pertaining to joints [11], [12].

Another notable observation in the study pertains to the tendency of a plate to bend when two sheets of metal are joined using rivets. This bending effect can impact the measurement of shear strength, resulting in impure readings provided an explanation for this phenomenon as shown in Figures 1.4.

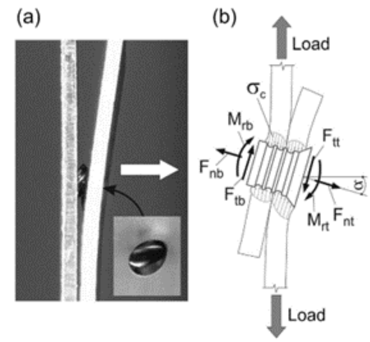


Figure 1.4 (a) SEM of single shear riveting, (b) force and moment projection [13]

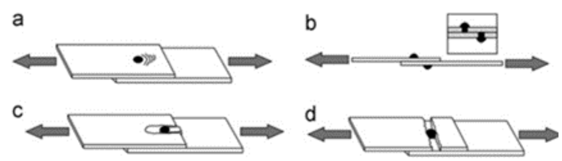


Figure 1.5 Fracture phenomenon in shear testing [13]

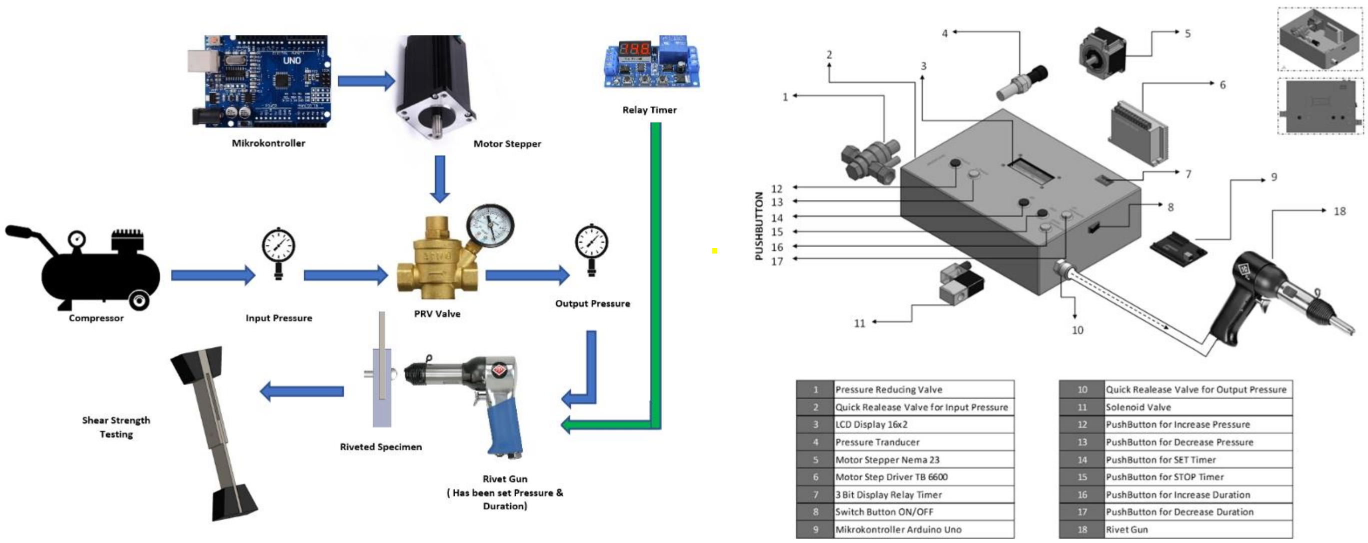
As previously indicated in Figures 1.4, (a) the picture is a photograph of a specimen performing shear testing. The test findings indicate that the sheet metal has undergone deformation in a direction that is not parallel to the shear plane. This occurrence is referred to as the single shear phenomenon, which leads to the rivets peeling off. it is essential to conduct specific calculations when performing a shear test on rivets using the single shear test method. This is necessary because the resulting fracture is not purely a shear phenomenon but rather a combination of shear forces see Figure 1.4 (b) [14].

Figure 1.5 illustrates various fracture events in the shear test of the rivet connection, (a) demonstrates the state of the rivet where it is not fully displaced, (b) shows the perfect displacement of the riveted specimen during tensile testing, (c) displays the condition of the specimen when the sheet metal tears as wide as the rivet diameter due to the rivet material's greater strength compared to the sheet metal, (d) illustrates the test condition where the sheet metal breaks in the shear plane because the sheet metal material is susceptible to brittleness.

In regards to the research background and literature review, this experiment was conducted to determine the shear strength of rivets resulting from the riveting based on rivet gun operating pressure and hole clearance.

2.0 METHODOLOGY

This research was performed to design and implement an autonomous system capable of regulating the air pressure applied to the rivet gun [15]. This enabled the determination and regulation of the operating pressure parameters of the rivet gun. The controlling system employed in this study consisted of an Arduino Uno microcontroller. To measure the air pressure output, a DC 5V pressure transducer sensor was utilized. Both of these components were supplied with a direct current (DC) voltage of 5 volts. The schematic presented in Figure 2.1 offered a comprehensive depiction of the riveting process with a semi-automatic tool.



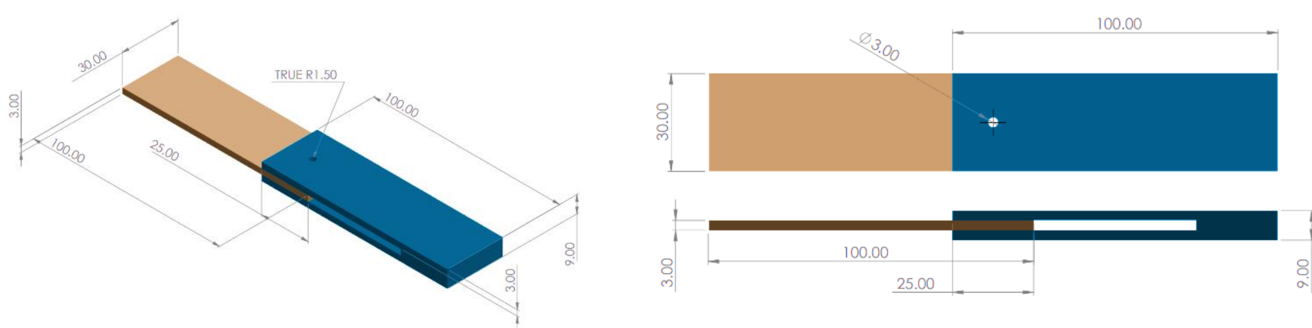
(a) (b)

Figure 2.1 Schematic representation of the experimental workplan showing of (a) riveting process until destructive shear strength testing, (b) component of Semi-automatic riveting system

The specimen utilized for evaluating the shear strength of rivets is illustrated in Figure 2.2 In this research, solid rivet 3mm diameter of Aluminum 1100/plain series rivet was used to connect low carbon steel that possesses comparable properties to the AISI 1012 standard or exhibits a strength minimum of 370 MPa. The material properties of AISI 1012 are shown in Table 1 [16][17]. This Experimental testing reference to ASTM D1002 Test Method for Apparent Shear Strength of Single Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading.

Table 1 Material properties of AISI 1012 series of steel

Material Properties of AISI 1012 Steel					
Material	**Hardness, Brinell**	**Tensile Strength, Ultimate (MPa)**	**Tensile Strength, Yield (MPa)**	**Shear Modulus (GPa)**	**Modulus of Elasticity (GPa)**
AISI 1012	105	370	310	80	205



(a) (b)

Figure 2.2 Shear testing specimen (a) isometric view, (b) top and front view

Different variations used in this research are presented in Table 2.

Table 2 Table of riveting parameters variation

Variation	
Pressure (MPa)	**Hole Clearance (mm)**
0.1	0
0.15	0.1
0.2	0.2

The drill bit was used to make holes or hole clearance where specimens were made with as many as three pieces as testing and replication were carried out three times. See Figure 2.3.

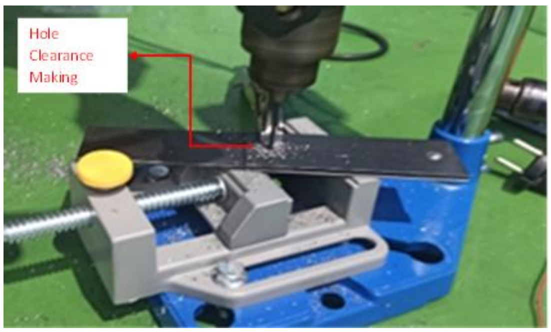


Figure 2.3 Hole clearance making

Figure 2.4 illustrates the specimen making using a semi-automatic riveting tool that has been made, where the rivet gun's operating pressure and riveting duration can be adjusted. The following is a specimen of the riveting results with the rivet gun operating pressure parameters and hole clearance.

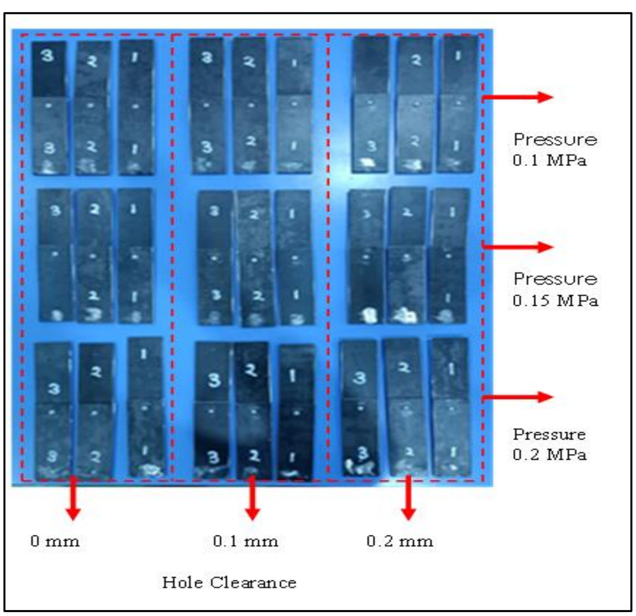


Figure 2.4 Shear test specimen

The specimen will thereafter be subjected to the tensile testing machine produced by Tarno Grocky with maximum capacity load of 100 kN and 0.0869 mm/s crosshead speed that applied to specimen as shown in the following Figure 2.5.

Figure 2.6 depicts the procedure of conducting shear tests on specimens that have been joined together using rivets.

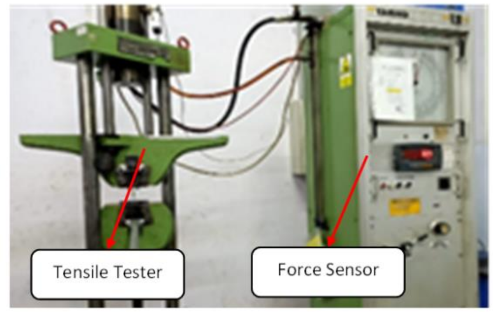


Figure 2.5 Tarno Grocky Tensile Testing Machine

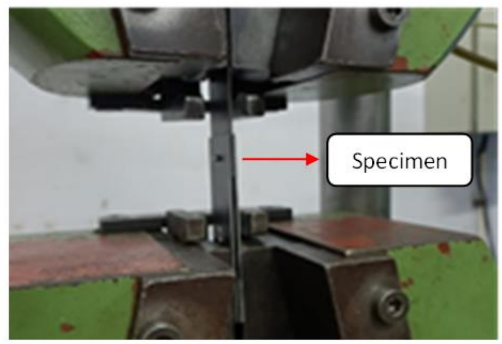


Figure 2.6 Testing specimens with a Tarno Grocky tensile testing machine

It was necessary to generate a graphical representation of the test data following the completion of the shear test. This was done to determine the characteristics of shear strength exhibited by the rivets produced as a result of the riveting process. Relevant information regarding the material parameters of plain type rivets within the 1100 series can be found in Table 3 [18].

Table 3 Material properties of 1100 series rivets

Material Properties of Rivet				
Material	**Head Marking**	**AN430 Round Head**	**AN470 Universal Head**	**Shear Strength (MPa)**
1100	Plain 			68.94

After analyzing the results of the shearing, the shear strength was measured to determine the character of the shear strength of the rivets sheared using the predetermined parameters.

Then, tensile testing process measured several variables that include mass (F) and length increase (ΔL). Hence, to determine the plotting of the stress (σ) strain (ε) graph, formula was used.

$$\sigma = \frac{F}{A}$$

Then $$\sigma = \frac{4F}{\pi D^2} \quad (1)$$

Where :
σ = Stress (MPa)
F = Tensile Force (N)
D = Rivet Diameter (mm)

In scenarios involving specific constructions, where rivets or fastening bolts are subjected to double shear loads, certain adjustments are made. In such cases, the cross-sectional areas responsible for bearing the shear load are effectively doubled. This modification ensures that the rivet or bolt experiences a shear stress denoted as σ = F / 2A.

$$\sigma = \frac{F}{2A}$$

then $$\sigma = \frac{4F}{2\pi D^2}$$

then $$\sigma = \frac{2F}{\pi D^2} \quad (2)$$

while ε is the elongation or length increase of the specimen, which can be formulated with the following formula:

$$\varepsilon = \frac{\Delta L}{Lo} \quad (3)$$

Where:
ε = Strain (%)
ΔL = Specimen length increase (mm)
L_0 = Initial specimen length (mm)

3.0 RESULTS AND DISCUSSION

The diameter of the shop head and shop height of the rivet specimen were measured to determine the deformation of the rivet. From the measurement results, data plotting was then presented in a graph to identify the trend.

Figure 3.1, illustrates the dimensions of both the shop head diameter and the shop height pertaining to riveting outcomes. These outcomes are evaluated against the criteria outlined in the Standard Aircraft Handbook [9] to determine the quality of riveting, see Figure 3.2.

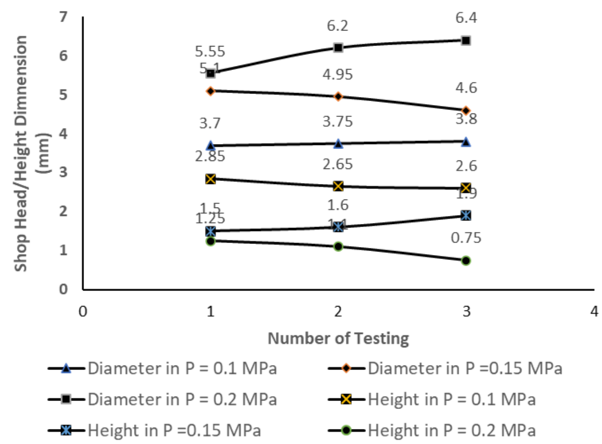


Figure 3.1 Shop head and shop height distribution chart

Among the various parameters considered, the optimal riveting results are achieved when employing a rivet gun operating at a pressure of 0.15 MPa and maintaining a hole clearance of 0.2 mm. These values align with the established riveting standards as follows.

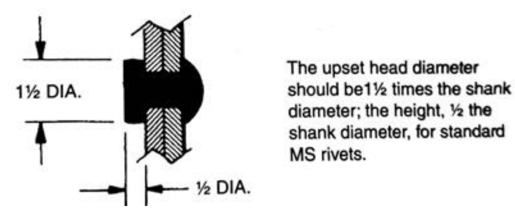


Figure 3.2 Shop head and shop standart

$$D_{SH} = 1.5 \times D_r$$
$$H_{SH} = 0.5 \times D_r \quad (4)$$

Where :
D_{SH} = Shop head diameter
H_{SH} = Height of shop head
D_r = Rivet Diameter

Therefore, the optimal size of rivets with a diameter of 3 mm is

D_{SH} = 1.5 x 3 H_{SH} = 0.5 x 3
D_{SH} = 4.5 mm H_{SH} = 1.5 mm

3.1 Effect of Rivet Gun's Pressure on Rivet Shear Strength

According to literature findings, the primary factor influencing the shear strength of rivets, as demonstrated in this study, is the squeeze force, represented by the rivet gun pressure. Typically, the operator has control over the operating pressure of the rivet gun by adjusting the valve on the tool, allowing precise regulation of the air pressure supplied to the rivet gun [19].

The experimental results conducted in this study are depicted in the accompanying graph, illustrating the shear strength test data for the rivets.

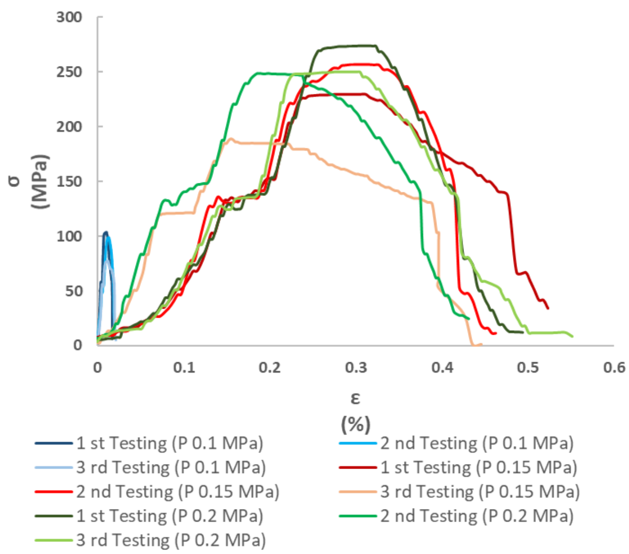


Figure 3.3 Stress vs strain graph at pressures of 0.1, 0.15, and 0.2 MPa at 0 mm hole clearance

Figure 3.3 illustrates the results of a tensile test conducted on a riveting specimen, evaluating its resistance to tensile forces. The graph portrays a distinct behavior observed during testing, with reference to its source available at a specified location. This phenomenon encompasses the variability witnessed in the disconnection of rivet connections and the occurrence of the Ultimate Tensile Strength (UTS) phenomenon across various tests. Both instances serve as illustrations of this particular phenomenon, underscoring the need for a revised calculation to determine the stress magnitude associated with UTS.

Table 4 Rivet shear strength table

Variation		**Shear Strength (MPa)**		
Pressure (MPa)	**Hole Clearance (mm)**	**1st Test**	**2nd Test**	**3rd Test**
0.1	0	103.76	98.76	77.12
0.15	0	229.65	257.09	189.14
0.2	0	273.75	248.92	250.23

After summarizing the Ultimate Tensile Strength (UTS) value and identifying the lowest UTS value from the tensile testing, the analysis reveals that the riveting process under specific conditions generates the highest shear stress. This occurs when the rivet gun operates at a pressure of 0.2 MPa with a hole clearance of 0 mm, specifically during the second test, which yields the minimum shear stress value of 248.92 Mpa, see Tabe 4.

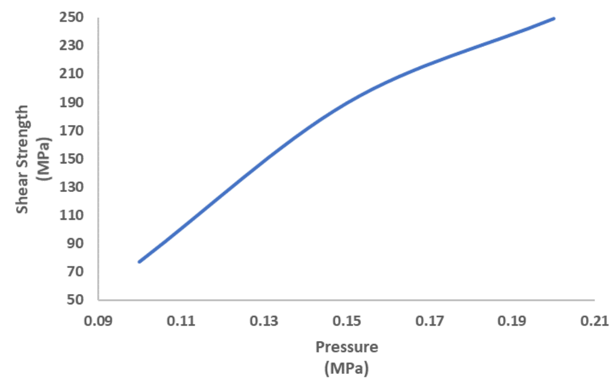


Figure 3.4 Stress vs strain graph at pressures of 0.1, 0.15, and 0.2 MPa at 0 mm hole clearance

Figure 3.4 illustrates a positive correlation between the operating pressure of the rivet gun and the corresponding increase in shear strength of rivets. The optimal shear strength of rivets is achieved at a pressure of 0.2 MPa s with final shear strength of 248.92 MPa. Based on the trend, a positive correlation between the operating pressure of the rivet gun and the shear strength of the rivet was found [20], [21].

The enhancement in rivet shear strength that was directly proportional to the increase in rivet gun operating pressure, can be attributed to the strain hardening phenomenon that takes place when the rivet set collided with the rivet shop head [22]. During the process of shop head riveting development, dislocations were observed to undergo motion and engage in interactions with other dislocations. The interplay among dislocations in the material elevate its density, hence impeding the mobility of dislocations. The challenge related to the mobility of dislocations is directly correlated with the shear strength displayed by rivet materials [23].

The findings mentioned bear a resemblance to a study conducted by A. Manes, as documented in the scholarly article titled "Effect of riveting process parameters on the local stress field of a T-joint." This research concluded that the predominant factor influencing the shear strength of rivets is the pressure or squeezing force applied during the riveting process [19].

A tensile test was conducted on the riveting specimen which results are shown in Figure 3.5. A discernible pattern in testing, wherein the disconnection of the rivet connection or the ultimate tensile strength (UTS) phenomena exhibits varying tendencies throughout different tests. This assertion is substantiated by the observation that this phenomenon is visually represented in the chart. In regards to this, it is imperative to reevaluate the ultimate tensile strength (UTS) value.

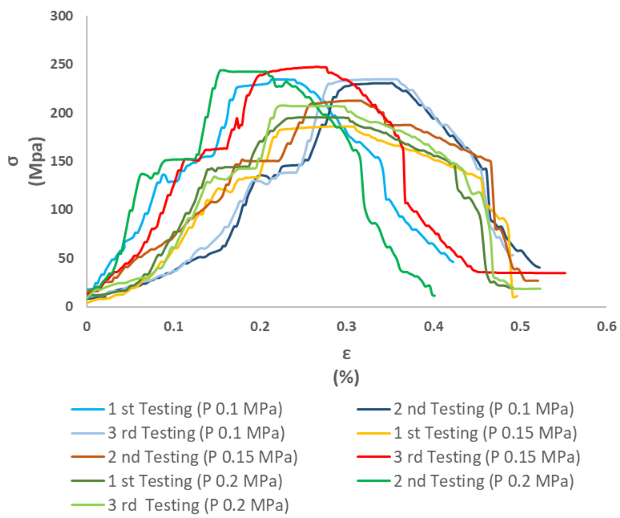


Figure 3.5 Stress vs strain graph at pressures of 0.1, 0.15, and 0.2 MPa at hole clearance of 0.1 mm

Table 5 Rivet shear strength table

Variation		Shear Strength (MPa)		
Pressure (MPa)	**Hole Clearance (mm)**	**1st Test**	**2nd Test**	**3rd Test**
0.1	0.1	185.87	212.66	247.94
0.15	0.1	195.67	244.02	208.09
0.2	0.1	234.87	230.63	234.55

After summarizing the Ultimate Tensile Strength (UTS) value and selecting the lowest UTS value from the tensile testing process for safety factor consideration, it becomes evident that the highest shear stress value is achieved through the riveting process utilizing a pressure parameter of 0.2 MPa with a hole clearance of 0.1 mm. This scenario specifically occurs during the second test, resulting in a minimum shear stress value of 230.63 Mpa, see Table 5.

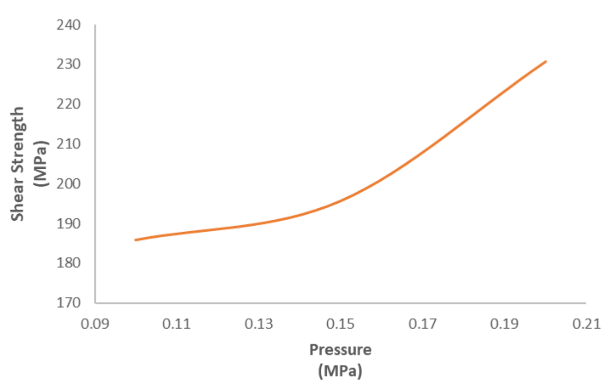


Figure 3.6 Rivet gun pressure vs shear strength graph at hole clearance 0.1 mm

The shear strength of rivets exhibits a positive correlation with the operating pressure of the rivet gun, as illustrated in Figure 3.6. Riveting operations at a pressure of 0.2 MPa in shear strength of 230.63 MPa. This value represents the upper limit of shear strength attainable with the use of rivets. A notable rise in the shear strength of the rivet as the operational pressure of the rivet gun is elevated was confirmed [24], [21].

The shear strength of rivets exhibits increases when subjected to higher operating pressures exerted by the rivet gun. The occurrence is attributed to the strain hardening that ensues when the rivet set and the rivet shop head come into contact [22]. This phenomenon occurs as a consequence of the collision that transpires between the two entities. During the production of shop head rivets, dislocations exhibit mobility and engage in inter-dislocation interactions. This is a routine aspect of the production procedure. The interaction between dislocations leads to an increase in material density, hence impeding the mobility of dislocations inside the material. A direct correlation exists between the shear strength of the material on the fasteners and the level of difficulty encountered in facilitating dislocation motion [23], [25], [26].

The results of the tensile strength test conducted on the rivets are shown in the following figure. The experiments, conducted with a hole clearance of 0.2 mm resulted in the following findings.

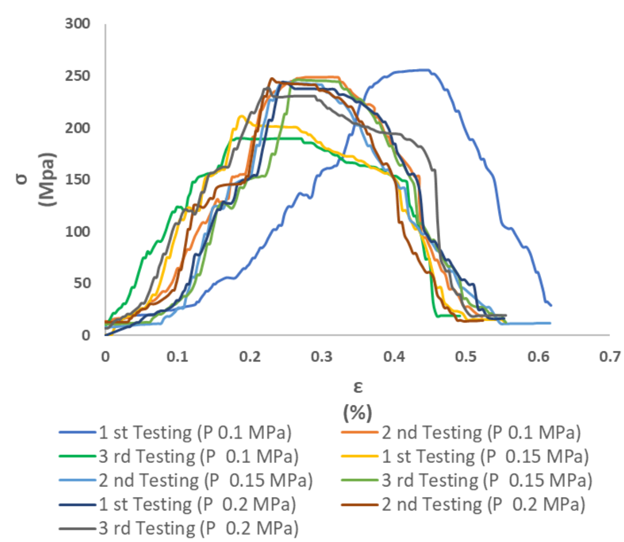


Figure 3.7 Stress vs strain graph at pressures of 1, 1.5, and 2 MPa at hole clearance of 0.2 mm

The tensile testing resulted from the riveting specimen is shown in Figure 3.7, specifying the separation of rivets or the manifestation of ultimate shear strength (UTS). Distinct patterns in various testing scenarios were found, thereby, it is essential to assess the stress value associated with UTS.

Table 6 Rivet shear strength table

Variation		Shear Strength (MPa)		
Pressure (MPa)	Hole Clearance (mm)	1st Test	2nd Test	3rd Test
0.1	0.2	255.78	249.25	189.79
0.15	0.2	211.68	244.35	245.98
0.2	0.2	244.02	247.29	238.79

After conducting a thorough examination of the Ultimate Tensile Strength (UTS) values, the next step involved choosing the tensile testing procedure with the lowest UTS value as the basis for calculating the safety factor. This experimental investigation aimed to assess the influence of various pressure parameters on the riveting process. Notably, it was observed that when the pressure parameter was set to 0.2 MPa and the hole clearance was maintained at 0.2 mm, the highest shear stress value was achieved. This phenomenon was particularly pronounced in the third test, where the minimum shear stress value reached 238.79 Mpa, see Table 6

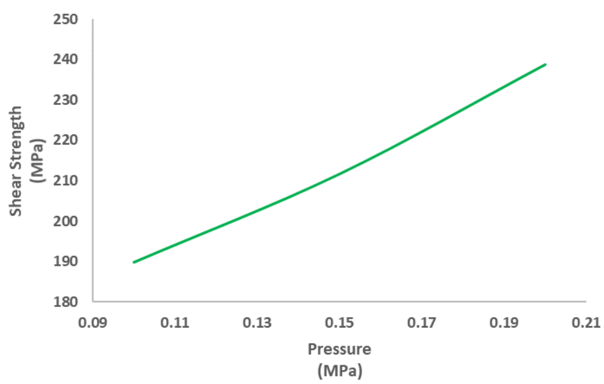


Figure 3.8 Rivet gun pressure vs. shear strength graph at 0.2 mm hole clearance

Based on Figure 3.8, the operating pressure of the rivet gun positively correlates with the shear strength of the rivet. The rivet shear strength reaches its highest value of 238.79 MPa when subjected to a rivet gun pressure of 0.2 MPa. This result aligns with the ones of the other research [24], [21].

The rivet shear strength significantly improves from strain hardening during the contact between the rivet set and the shop head. During the process of shop head rivet creation, dislocations exhibit movement and interact with each other, resulting in an increase in material density and a corresponding increase in the difficulty of dislocation movement. The shear strength of rivet materials corresponds to the challenges associated with dislocation motion [23], [26], [27], [28].

3.2 Effect of Hole Clearance on Rivet Shear Strength

According to academic research findings, it is evident that hole clearance plays a pivotal role in influencing the shear strength of rivets. The importance of hole clearance lies in its capacity to affect the magnitude of shear stress applied to the rivet. In the context of sheet metal drilling, it is customary to establish hole clearance after the drilling process is completed. This gap between the rivet's body and the sheet metal hole is commonly referred to as "hole clearance" [19]. It is essential to note that measurements of this clearance should be conducted in millimeters.

The results of the shear strength experiments conducted on the rivets are presented in the Table 7. The conclusions drawn in this paper are grounded in the outcomes derived from a series of meticulously executed experiments.

Table 7 Rivet shear strength table

Variation		Shear Strength (MPa)		
Hole Clearance (mm)	Pressure (MPa)	1st Test	2nd Test	3rd Test
0	0.1	103.76	98.76	77.12
1	0.1	185.87	212.66	247.94
0.2	0.1	255.78	249.25	189.79
0	0.15	229.65	257.09	189.14
0.1	0.15	195.67	244.02	208.09
0.2	0.15	211.68	244.35	245.98
0	0.2	273.75	228.92	250.23
0.1	0.2	234.87	230.63	234.55
0.2	0.2	244.02	247.29	238.79

After reviewing the Ultimate Tensile Strength (UTS) values, minimum UTS value was selected from the tensile testing procedure to calculate the safety factor to identify the lowest shear stress value within the parameters of a 0 mm hole clearance and a pressure of 1 MPa. In the second test, a minimum shear stress value of 98.76 MPa was gained. The UTS value ascertains the safety factor. Upon comparing various techniques, it became evident that the riveting process exhibited the highest shear stress values. This was most pronounced when employing a hole clearance parameter of 0.2 mm and a pressure of 2 MPa. The minimum shear stress value of 238.79 MPa was found in the third test, representing the peak measurement of shear stress attained in the study.

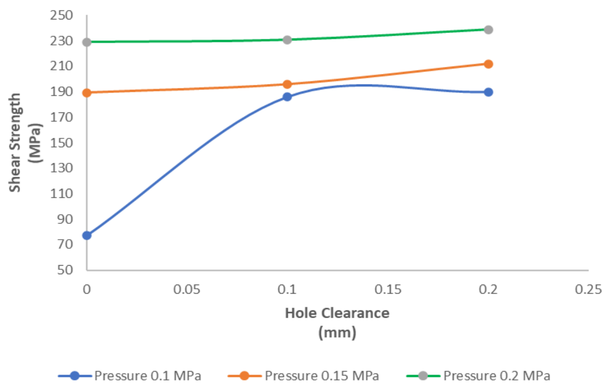


Figure 3.9 Hole clearance vs shear strength graph

Figure 3.9 demonstrates the augmentation in the pressure exerted on the hole clearance dimension which leads to a corresponding enhancement in the shear strength of rivets. The highest potential shear strength of rivets of 238.79 MPa is achieved when riveting is done with a hole clearance of 0.2 millimeters 2 MPa pressure can be inferred from the trend that a significant enhancement is reached as the hole clearance increases [24], [21].

The highest increase in shear strength occurred at the pressure of 1 MPa with a hole clearance ranging from 0 mm to 0.1 mm. The hole clearance increases the shear strength due to the residual tension experienced by the rivet material throughout the riveting process from the force during the riveting process. The term "residual stress" pertains to the internal stress that remains within a material subsequent to undergoing a process, such as thermal treatment or deformation. Under some conditions, residual stress can enhance the mechanical strength of a material, specifically in terms of its compressive strength attributed to the induction of internal compression inside the material [22], [29], [25], [27], [29].

The riveting process at different pressures of 0.15 and 0.2 MPa in this research resulted in distinct outcomes across varied hole clearance variations as shown in Figure 3.8. Shear strength showed increasing trend across the tests; nevertheless, the observed differences across the tests were not statistically significant. This phenomenon occurs due to the plastic deformation of the rivet material caused by the aforementioned factors, rendering it incapable of bearing further residual stress which creates an issue to address [27], [28], [30], [31].

4.0 CONCLUSION

Based on the results of this experiment, can be drawn into conclusion that riveting parameters significantly affect the shear strength of rivets. On the other hand, increases in the pressure put on rivet gun followed by increases in the shear strength of the rivets from the strain.

A significant enhancement in rivet shear strength occurs when the rivet pressure is 0.1 MPa within the range of hole clearance between 0 mm and 0.1mm. Similarly, increases in rivet shear strength are primarily manifested at rivet pressure parameter of 1 MPa. Extra pressure, hole clearance parameter and the enlargement of hole clearance dimensions, indicate that the enhancement in shear strength of rivets is not as substantial as previously believed.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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