COMPARATIVE ANALYSIS OF LOAD CARRYING CAPACITY OF ALUMINIUM AND MILD STEEL BOLTED AND RIVETED JOINTS

V.C Ikeh [1], A. K Oyinlola[2] & J.O Akindapo[3]
[1, 2, 3]Department of Mechanical Engineering, Nigerian Defence Academy, Kaduna
Corresponding Author Email: dacoolvictor@yahoo.com, jacobakindapo@gmail.com

ABSTRACT

A comparative analysis of load carrying capacity of aluminium and mild steel bolted and riveted joints have been investigated in this work. Sample specimens were produced comprising of riveted lap joints, riveted butt joints, bolted lap joints and bolted butt joints from aluminium alloy and mild steel. Experiments were conducted using metallographic examinations, chemical composition analysis, tensile test, and comparative analysis were used to evaluate the results. From the experiments, the results showed that deformations in bolted members were generally smaller than those measured in similar riveted members, with riveted aluminium alloy butt joint having a higher ultimate strength to the Bolted Aluminium Alloy butt joints. The shearing stresses in the rivets and the bearing stresses in the rivets and plates are similar for both joints connections, while the ultimate strength for Bolted Steel Butt joint is greater than that of Riveted Steel Butt joint. However for Lap joint the specimen produced from Aluminium Alloy material, Riveted connection produced a greater strength to the Bolted connection. For Mild steel material, the Bolted Steel Lap Joint showed a higher Load carrying capacity than Riveted Lap joint. The bolt tensions appear to have very little effect on the ultimate strength of bolted joints. The numerical results showed that the Riveted Steel Lap joint yield at 160Nm^{-2}, the Bolted Steel Lap joint yielded at 90Nm^{-2} and strain hardening starts at 115Nm^{-2} and rises linearly until fracture occurs at 350Nm^{-2}. The Riveted Aluminium Lap joint yielded at 23.3Nm^{-2} and plastically deform at a second yield point of 90Nm^{-2}. Strain hardening commences immediately almost linearly till it fractures at the ultimate strength of 158.3Nm^{-2} while the Bolted Aluminium Lap joint yielded and strain hardened at 80Nm^{-2} and fractured at 140Nm^{-2} respectively. The Bolted Steel Butt yielded and strain hardened at 95Nm-^{2} and 160Nm-^{2} respectively and rises linearly until it fractures at 440Nm-^{2}. The strength of the rivets showed a slight increase as connection force increased up to 160Nm^{-2} where the joint deforms plastically. In Bolted Aluminium Butt joints, there was no significant effect on the tensile behaviour of the joint, although, with an increase in the edge distance the strength of the joint increased considerably up to a Load of 133.3Nm^{-2}.

Keywords: Joints**,** Bolted joints, Riveted joints, Comparative analysis, Tensile strength

1.0 INTRODUCTION

The most common types of joints that are used to connect structural parts are bolted and riveted joints. Mechanical joints like bolts or rivets require drilling of holes into the material; this reduces the net cross sectional area of the structure and introduces localized stress concentration thereby reducing the strength of the joint [1].

Rivets press the two parts being joined together and transmit or support shear. The pressure results in friction which is responsible for a considerable part of the load transmitted between two riveted panels. In order to hold up to the maximum possible amount of shear, the rivet requires a smooth surface, A threaded bolt in the other hand is more vulnerable due to the notch effect of the thread[2]. Riveted lap joints are used extensively in the construction of lightweight aircraft fuselage. Typically, the single lap or double joint designs are used to interconnect structural components such as skin panels onto the airframe with single and multiple rows of rivets. These joints are subjected to combined loading from the fuselage pressurisation and bending due to tight loads. The load is transferred from one panel to another through the rivets[3].

Bolts are better at supporting tension loads. Although bolted joints have the advantage that they can be disassembled easily if replacement or repair of parts is needed, they require drilling of matching holes in the parts to be joined and the drilled holes must align accurately during the assembly process. When a threaded fastener is subjected to vibration, the rapid movement causes a lowering of friction against the threads and a subsequent loss of preload. The loss of preload allows the fastener to vibrate loose and could lead to catastrophic consequences for critical applications. To mitigate the problem of unintentional bolt loosening, one must understand what parameters that are critical in the bolted joint that affects this[4].

Riveted lap joints are used extensively in the construction of lightweight aircraft fuselage. Typically, the single lap or double joint designs are used to interconnect structural components such as skin panels onto the airframe with single and multiple rows of rivets. These joints are subjected to combined loading from the fuselage pressurisation and bending due to tight loads. The load is transferred from one panel to another through the rivets. In the case of multiple rivet rows, then the highest load is carried in the first rivet row while the second highest load is carried in the second row and so on. A complete analysis needs to consider the super-position of both the pressure loads and the local rivet loading on the skin (i.e., bearing loads)[5].

Bolted joints are one of the most collective elements in construction, machine design, automobile and air vehicles. They entail of fasteners that capture and join other parts, and are protected with the mating of screw threads. There are two chief types of bolted joint designs. In one method the bolt is stiffened to a calculated clamp load, usually by smearing a measured torque load [6]. The joint will be intended such that the clamp load is never overwhelmed by the forces acting on the joint (and therefore the joined parts see no relative motion).

When a fastener is tightened, it is pushed and the parts being joined are compressed; this can be modelled as a spring-like assemblage that has a non-intuitive dissemination of strain. External forces are intended to act on the secured parts than on the fastener, and the fastener is not subjected to any increased load as the forces acting on the clasped parts do not exceed the clamp load [6].

It is vital that bolted joints holding subassemblies together remain secure. Fasteners used to secure bolts and screws should resist the loosening caused by vibrations and dynamic loads, while keeping the ease of removability during maintenance. When a threaded fastener is subjected to vibration, the rapid movement causes a lowering of friction against the threads and a subsequent loss of preload. The loss of preload allows the fastener to vibrate loose and could lead to catastrophic consequences for critical applications. To mitigate the problem of unintentional bolt loosening, one must understand what parameters are critical in the bolted joint that affects this. [7]

The aircrafts skin is subjected to a lot of stress in flight .The primary purpose of fuselage structure is to support axial and hoop stresses on the body of the aircraft imposed by pressurization forces[8]. For a helicopter in flight apart from the aerodynamic forces acting on the aircraft, it is subjected to a much higher vibration than fixed wing aircrafts, this result to a much higher wear rates on the components especially the different array of bolts on the main rotors and tail rotors assembly. As a result of all these stresses acting on an aircraft there is need to comparatively analyse the riveted joints and bolted joints with a view to improving their serviceability and life span, this will help engineers and technicians in re-enforcing their strength or creating a better continuous air vehicle maintenance program to suit their operations as well as reduce the cost of maintenance and cost associated with the down time for maintenance purposes in addition to a better operational effectiveness.

In the aerospace and automobile industry bolted and riveted joints remain the primary fastening methods although it is the preferred joining technique in many cases; it is still associated with difficulties. In this research work the mechanical properties were evaluated and compared with a view to determining their Strength for aerospace and automobile applications and maintenance.

2.0 MATERIALS AND METHODS

2.1 Materials

The major materials used for the research work are;

(i) Low carbon steel

(ii) Aluminium alloy rod

2.2 Equipment

The following equipment was used for the research work:

1. Portable Hand Drilling machine available at Airforce Institute of Technology, Kaduna
2. Lathe Machine available at Airforce Institute of Technology, Kaduna.
3. Hounsfield Tensometer (Model No 8889) available at University of Nigeria Nsuka, Enugu state.
4. Extensometer (with dial indicator), Blade micrometer.

5. Photographic visual metallurgical microscope (Model number: NJF-120A) available at PRODA Enugu.

2.3 Methods

The following methods were employed in carrying out the experiments: Cut-off (sawing) operations, Drilling operations, Riveting, bolt tensioning, tensile testing and metallographic testing. There operations were carried out in accordance with best practices within the industry.

2.3.1 Preparation of Materials

The work piece chosen for this study was low carbon steel and aluminium alloy rod of 160mm length and breath 20mm. the samples were first polished with smooth sander paper machine and cut to dimensions (160X19X3.2)mm. the samples were subsequently marked out and cut-off with saw ready for drilling using drilling machine to create room for the joining. Those for riveting were riveted using handheld rivet machine while the ones for bolt joining took place using a screw bolt tightening machine. The rivet material is an aluminium/copper alloy while the bolt is a steel of 16mm length and 4mm diameter. The bolt is a pass and tight type while the rivet is the nail type with a cap for riveting (Oscar rivet). Table 1 shows the chemical composition of the mild carbon steel while table 2 gives the chemical composition of the aluminium alloy.

Plate 1 and 2 below, show an already cut out specimen with Mild steel Initial length of 160mm(when joined) , thickness of 2.00mm and breath 20.00mm while for Aluminium Alloy the initial length(Lo) is 160mm(when joined), thickness of 3.00mm and breath 20.00mm.

Plate 1: Samples cut into size

Plate 2: arranging the samples for joining

Plate 3: Riveted and bolted mild steel lap joint   Plate 4: Riveted aluminium alloy lap joint

2.3.2 Metallographic Examination

Metallography examination was conducted on the metal in order to determine the structure of the metal. The procedure involves sectioning of the samples by cut through, embedding it in synthetic resin, grinding and polishing the surface until it is smooth. This allows the observation of very fine structures under the light-microscope with a magnification of up to 1000x.

2.3.3 Sectioning

The sample was cut using Abrasive blade e. g. (MAXCUT Cat. No. MAX-C or MAX-I series) for Aluminium and MAXCUT abrasive blade (cat. No. MAX-D or MAX-E series) for mild carbon steel

2.3.4 Mounting

The sample was mounted using compression mounting with Phenolic or Epoxy compression mounting resins.

2.3.5 Polishing

The Aluminium was polished using P120 or P220 grit ALO paper with water as lubricant and force of 22.2 – 44.4N at a speed of 100/100rpm for a minute while the Mild carbon steel sample was polished using 120 and 240 grit SiC paper with water as lubricant and force of 22.2 – 44.4N at a speed of 200/200rpm for a minute.

2.3.6 Tensile test

Tensile test is used to provide information that will be used in design calculations or to demonstrate that a material complies with the requirements of the appropriate specification - it may therefore be either a quantitative or a qualitative test. The test is made by gripping the ends of a suitably prepared standardised test piece in a tensile test machine and then applying a continually increasing uni-axial load until such time as failure occurs.

The tensile test was carried out in accordance with International standard and ASTM E8.The test process involves placing the test specimen in the testing machine and slowly stretching it until it fractures.

Plate 5: Bolted steel joint undergoing tensile testing

Plate 6: Aluminium alloy lap joint during the test using Hounsfield Tensometer

Plate 7: Mild steel lap joint during the test using Hounsfield Tensometer

3.0 RESULT AND DISCUSSION

3.1 Results

3.1.1 Results of Chemical Composition tests

Table 1 and 2 shows the result of the chemical analysis of the composition of the Materials.

Table 1: Results of Chemical composition of mild carbon steel bar used

Element	C	Mn	Si	P	S	Cu	Fe
% Composition	0.10	0.22	0.16	0.05	0.05	0.001	98.95

Table 2: Chemical composition of aluminium alloy used

Element	Al	Cu	Mg	Mn
% Composition	94.8	3.3	1.5	0.4

Plate 8: Aluminium Alloy, Etched with Reagent

3.1.2 Results of tensile test for Riveted steel Butt joints (RSB)

The results of the Tensile test conducted on Riveted steel Butt Joint is as shown in table 3 below.

Table 3: Result of Tensile Test for Riveted Steel Butt joint (RSB)

Serial	Force(N)	Extension(mm)	Tensile Strength(Nm^{-2})	Strain
1	1600	1.75	40	0.0109
2	2500	3.00	62.5	0.0188
3	4600	4.25	115	0.0266
4	7200	5.50	180	0.0344
5	10,000	7.50	250	0.0469
6	12,400	9.00	310	0.0563
7	14,400	10.25	360	0.0641

3.1.3 Results of Tensile Test for Bolted Steel Butt Joint (BSB)

The results of the tensile test conducted on Bolted Steel Butt Joint (BSB) are as shown in table 4 below,

Table 4: Result of Tensile test for Bolted Steel Butt Joint (BSB)

Serial	Force(N)	Extension(mm)	Tensile Strength(Nm^{-2})	Strain
1	2000	0.50	50	0.0031
2	3800	1.00	95	0.0063
3	6400	3.50	160	0.0219
4	9000	5.00	225	0.0313
5	12000	7.25	300	0.0453
6	14600	8.50	365	0.0531
7	17600	10.00	440	0.0625

3.1.4 Result of Tensile test for Riveted Aluminium Butt Joint (RAB).

The results of the tensile test conducted on Riveted Aluminium Butt Joint (RAB) are as shown in table 5 below;

Table 5: Result of Tensile test for Riveted Aluminium Butt Joints (RAB).

Serial	Force(N)	Extension(mm)	Tensile Strength (Nm^{-2})	Strain
1	1200	0.75	20	0.0047
2	2400	1.00	40	0.0063
3	4800	2.00	80	0.0125
4	7300	3.00	122	0.0188
5	9600	4.00	160	0.025
6	10000	6.25	167	0.0391

3.1.5 Results of Tensile Test for Bolted Aluminium Butt Joint (BAB)

The results of the tensile test conducted on Bolted Aluminium Butt Joint (BAB) are as shown in table 6 below;

Table 6: Result of Tensile test for Bolted Aluminium Butt joint (BAB)

Serial	Force(N)	Extension(mm)	Tensile Strength (Nm^{-2})	Strain
1	1000	0.25	16.7	0.0016
2	2200	0.75	36.7	0.0047
3	3800	1.63	63.3	0.0102
4	5000	2.50	83.3	0.0156
5	7000	3.25	116.6	0.0203
6	8000	3.75	133.3	0.0234
7	9200	5.00	153.3	0.0313

3.1.6 Result of Tensile test for Riveted Steel Lap (RSL) Joint

The results of the tensile test conducted on Riveted Steel Lap (RSL) are as shown in table 7 below;

Table 7: Result of Tensile test for Riveted Steel Lap (RSL) Joint

Serial	Force(N)	Extension(mm)	Tensile Strength (Nm^{-2})	Strain
1	1000	0.25	25	0.0016
2	2600	1.75	65	0.0109
3	4100	3.00	102.5	0.0188
4	5700	4.25	142.5	0.0266
5	6400	6.75	160	0.0422
6	8200	9.50	205	0.0594
7	10,400	11.00	260	0.0688
8	10500	12.0	262.5	0.075

3.1.7 Result of Tensile test for Bolted Steel Lap (BSL) Joint

The results of the tensile test conducted on Bolted Steel Lap (BSL) are as shown in table 8 below;

Table 8: Result of tensile test for Bolted Steel Lap(BSL) joint.

Serial	Force(N)	Extension(mm)	Tensile Strength (Nm^{-2})	Strain
1	600	0.25	15	0.0016
2	1400	0.75	35	0.0047
3	2400	1.50	60	0.0094
4	3600	2.50	90	0.0156
5	4600	3.95	115	0.0247
6	6400	5.50	160	0.0344
7	8000	7.50	200	0.0469
8	9800	9.50	245	0.0594
9	11400	10.00	285	0.0625
10	14000	12.25	350	0.0766

3.1.8 Result of Tensile test for Riveted Aluminium Lap (RAL) Joint

The results of the tensile test conducted on Riveted Aluminium Lap (RAL) are as shown in table 9 below;

Table 9: Result of tensile test for Riveted Aluminium Lap (RAL) joint

Serial	Force(N)	Extension(mm)	Tensile Strength (Nm^{-2})	Strain
1	800	1.50	13.3	0.0094
2	1400	3.00	23.3	0.0188
3	2600	4.50	43.3	0.0281
4	4000	6.25	66.7	0.0391
5	5400	6.50	90	0.0433
6	6800	7.30	113.3	0.0456
7	7600	8.00	126.7	0.05
8	8200	8.40	136.7	0.0525
9	9500	8.50	158.3	0.0531

3.1.9 Result of Tensile test for Bolted Aluminium Lap (BAL) Joint

The results of the tensile test conducted on Bolted Aluminium Lap (BAL) are as shown in table 10 below;

Table 10: Result of Tensile test for Bolted Aluminium Lap (BAL) joint

Serial	Force(N)	Extension(mm)	Tensile Strength (Nm^{-2})	Strain
1	1000	0.50	16.7	0.0031
2	2600	1.00	43.3	0.0063
3	4800	1.50	80	0.0094
4	6400	2.75	106.7	0.0172
5	8000	3.50	133.3	0.0219
6	8400	4.60	140	0.025

3.1.10 Result of Strength and Strain for Riveted Steel Lap (RAL) joint and Bolted Steel Lap (BSL) Joint

The results of the tensile Strength and Strain conducted on Riveted Steel Lap (RAL) joint Bolted Steel Lap (BSL) joint compared are as shown in table 11 below;

Table 11: Result of Strength and Strain for RSL joint and BSL joints compared

	Riveted Steel Lap Joint		Bolted Steel Lap Joint	
Serial	Strength (Nm^{-2})	Strain	Strength (Nm^{-2})	Strain
1	25	0.0016	15	0.0016
2	65	0.0109	35	0.0047
3	102.5	0.0188	60	0.0094
4	142.5	0.0266	90	0.0156
5	160	0.0422	115	0.0247
6	205	0.0594	160	0.0344
7	260	0.0688	200	0.0469
8	262.5	0.075	245	0.0594
9			285	0.0625
10			350	0.0766

3.1.11 Result of Strength and Strain for Riveted Aluminium Lap (RAL) joint and Bolted Aluminium Lap (BAL) Joint

The results of the tensile Strength and Strain conducted on Riveted Aluminium Lap (RAL) joint Bolted Aluminium Lap (BAL) joints compared are as shown in table 12 below;

Table 12: Result of Strength and Strain table for RAL joint and BAL joints compared.

Riveted Aluminium Lap Joint			Bolted Aluminium Lap Joint	
Serial	**Strength (Nm^{-2})**	**Strain**	**Strength (Nm^{-2})**	**Strain**
1	13.3	0.0094	16.7	0.0031
2	23.3	0.0188	43.3	0.0063
3	43.3	0.0281	80	0.0094
4	66.7	0.0391	106.7	0.0172
5	90	0.0433	133.3	0.0219
6	113.3	0.0456	140	0.025
7	126.7	0.05		
8	136.7	0.0525		
9	158.3	0.0531		

3.1.12 Result of Strength and Strain for Riveted Steel Butt (RSB) joint and Bolted Steel Butt (BSB) Joints

The results of the tensile Strength and Strain conducted on Riveted Steel Butt (RAB) joints and Bolted Steel Butt (BSB) joints compared are as shown in table 13 below;

Table 13: Result of Strength and Strain for RSB joint and BSB joint compared

Riveted Steel Butt joint (RSB)			**Bolted Steel Butt Joint (BSB)**	
Serial	**Tensile Strength(Nm^{-2})**	**Strain**	**Tensile Strength(Nm^{-2})**	**Strain**
1	40	0.0109	50	0.0031
2	62.5	0.0188	95	0.0063
3	115	0.0266	160	0.0219
4	180	0.0344	225	0.0313
5	250	0.0469	300	0.0453
6	310	0.0563	365	0.0531
7	360	0.0641	440	0.0625

3.1.13 Result of Strength and Strain for Riveted Aluminium Butt (RAB) joint and Bolted Aluminium Butt (BAB) Joint

The results of the tensile Strength and Strain conducted on Riveted Aluminium Butt (RAB) joint and Bolted Aluminium Butt (BAB) joint compared are as shown in table 14 below;

Table 14: Result of Strength and Strain for RAB joint and BAB joint compared

Riveted Aluminium Butt (RAB) Joint			**Bolted Aluminium Butt joint (BAB)**	
Serial	**Tensile Strength (Nm^{-2})**	**Strain**	**Tensile Strength (Nm^{-2})**	**Strain**
1	20	0.0047	16.7	0.0016
2	40	0.0063	36.7	0.0047
3	80	0.0125	63.3	0.0102
4	122	0.0188	83.3	0.0156
5	160	0.025	116.6	0.0203
6	167	0.0391	133.3	0.0234
7			153.3	0.0313

3.1.14 Result of Strength and Strain for RAL, BAL, RSL, and BSL joints compared

The results of the tensile Strength and Strain conducted on RAL, BAL, RSL and BSL joints compared are as shown in table 15 below;

Table 15: Result of Strength and Strain for RAL, BAL, RSL, and BSL joints compared

RAL			BAL		RSL		BSL	
Serial	Strength	Strain	Strength	Strain	Strength	Strain	Strength	Strain
1	13.3	0.0094	16.7	0.0031	25	0.0016	15	0.0016
2	23.3	0.0188	43.3	0.0063	65	0.0109	35	0.0047
3	43.3	0.0281	80	0.0094	102.5	0.0188	60	0.0094
4	66.7	0.0391	106.7	0.0172	142.5	0.0266	90	0.0156
5	90	0.0433	133.3	0.0219	160	0.0422	115	0.0247
6	113.3	0.0456	140	0.025	205	0.0594	160	0.0344
7	126.7	0.05			260	0.0688	200	0.0469
8	136.7	0.0525			262.5	0.075	245	0.0594
9	158.3	0.0531					285	0.0625
10							350	0.0766

3.1.15 Result of Strength and Strain for RAB, BAB, RSB and BSB joints compared

The results of the tensile Strength and Strain conducted on RAB, BAB, RSB and BSB joints compared are as shown in table 16 below;

Table 16: Result of Strength and Strain for RAB, BAB, RSB and BSB joints compared

RAB			BAB		RSB		BSB	
Serials	Strength	Strain	Strength	Strain	Strength	Strain	Strength	strain
1	20	0.0047	16.7	0.0016	40	0.0109	50	0.0031
2	40	0.0063	36.7	0.0047	62.5	0.0188	95	0.0063
3	80	0.0125	63.3	0.0102	115	0.0266	160	0.0219
4	122	0.0188	83.3	0.0156	180	0.0344	225	0.0313
5	160	0.025	116.6	0.0203	250	0.0469	300	0.0453
6	167	0.0391	133.3	0.0234	310	0.0563	365	0.0531
7			153.3	0.0313	360	0.0641	440	0.0625

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3.1.16 Result of Ultimate Load and Ultimate Strength in shear for all the joints tested

The results of Ultimate Load and Ultimate Strength in shear for all the joints tested are as shown in table 17 below;

Table 17: Ultimate Load and Ultimate Strength in shear

Serial	**Joint description**	**Ultimate load(N)**	**Ultimate strength in shear**
1	RSB	14400	360
2	BSB	17600	440
3	RAB	10000	167
4	BAB	9200	153
5	RSL	10500	263
6	BSL	14000	350
7	RAL	9500	150
8	BAL	8400	140

3.2 DISCUSSIONS OF RESULTS

3.2.1 Tensile Strength of Riveted Steel Lap and Bolted Steel Lap Joints.

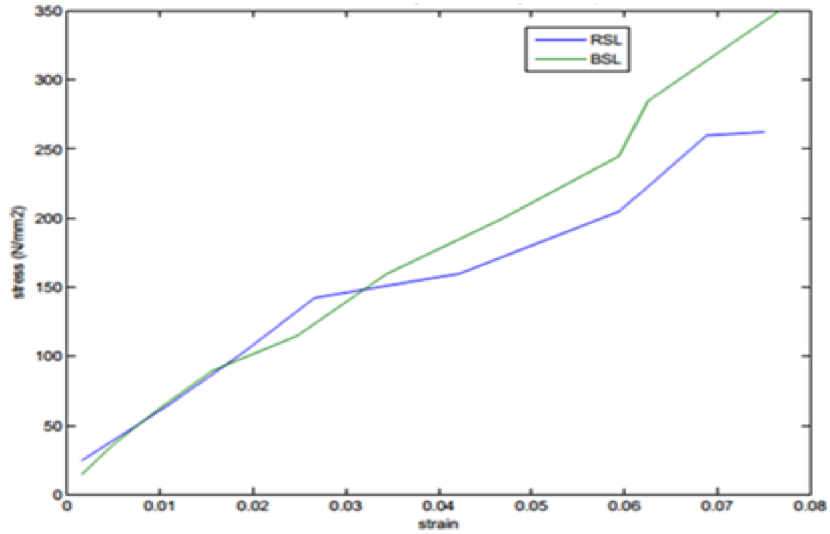

Figure 1: Graph of Strength VS Strain for RSL joint and BSL joints compared

Figure 1 above shows the strength of Riveted Steel Lap and Bolted Steel Lap joints. For Mild steel, the Bolted steel Lap Joint has a higher Load carrying capacity than Riveted Steel Lap joint. The bolt tensions appear to have very little effect on the ultimate strength of bolted joints. However, the load slip characteristics of the joints are greatly affected by the axial tension in the bolts. In general, when the bolt tension is at least 85 percent of the elastic proof load, in joints where rivets are replaced by bolts, slip does not occur until stresses in the plate have reached about equal to or slightly greater than normal working stresses.

Tension tests of driven rivets also show an increase in strength with increasing rivet length (grip). The Riveted steel Lap joint yields at 160Nm^{-2}, the residual clamping force that is present in a driven rivet does not affect the ultimate strength of the rivet. While For Bolted steel lap the tension must be as high as practicable for the greatest resistance to static and fatigue loadings whether the loads are applied as shear loads or tensile loads. The Bolted steel lap joint yield at 90Nm^{-2} and strain hardening starts at 115Nm^{-2}. And it rises linearly until fracture occurs at 350Nm^{-2}.

3.2.2 Tensile Strength of Riveted Aluminium Lap and Bolted Aluminium Lap Joints.

Figure 2 below show the behaviour of Riveted Aluminium Lap and Bolted Aluminium Lap Joints during tensile test.

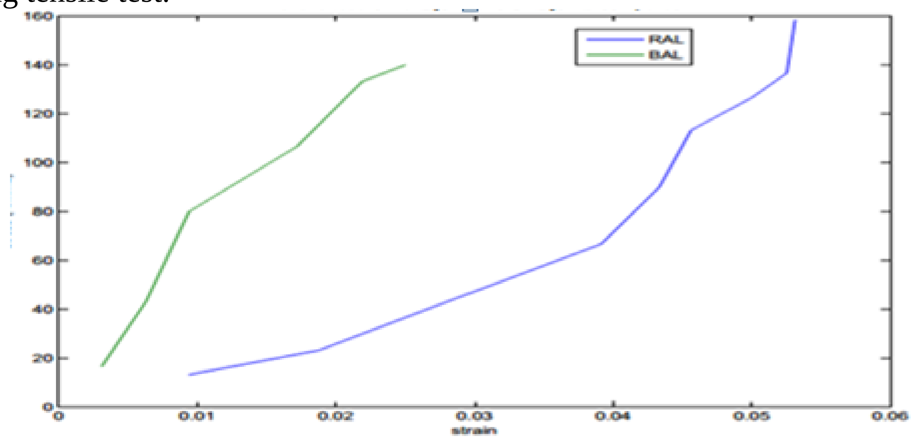

Figure 2: Graph of Strength VS Strain for RAL joint and BAL joints compared

For Aluminium Alloy material, the ultimate strength of RAL is much greater than BAL but the fatigue strength (based on the gross area of the member) of joints assembled with high-strength bolts is known to increase somewhat with an increase in the strength of the plate materials. This increase in fatigue strength is substantially greater than the fatigue strength of riveted members. Because of this superiority in fatigue of the high strength bolt over the rivet, it would appear be desirable to make connections in structures subject to fatigue loadings with high-strength bolts, rather than with rivets.

The ductility of Aluminium alloy material causes the Riveted Aluminium Lap joint to yield at $23.3Nm^{-2}$ and plastically deform till a second yield point of $90Nm^{-2}$. Strain hardening commences immediately almost linearly till it fractures at the ultimate strength of $158.3Nm^{-2}$. The effect of the use of different joint materials on the strength of the bolts under combined tension and shear is negligible. There was no case where there is a fatigue failure for high tensile bolts in the Bolted Aluminium Lap joints, implying that there was no slippage of the joints during the application of load. This is true in spite of the fact that the joints were designed to subject the bolts to unusually severe loading conditions. The Bolted Aluminium Lap joint yielded and strain hardened at $80Nm^{-2}$ and fractured at $140Nm^{-2}$.

3.2.3 Tensile Strength of |Riveted Steel Butt and Bolted Steel Butt joints.

Figure 3 depicted the tensile strength for Riveted Steel Butt and Bolted Steel Butt joints.

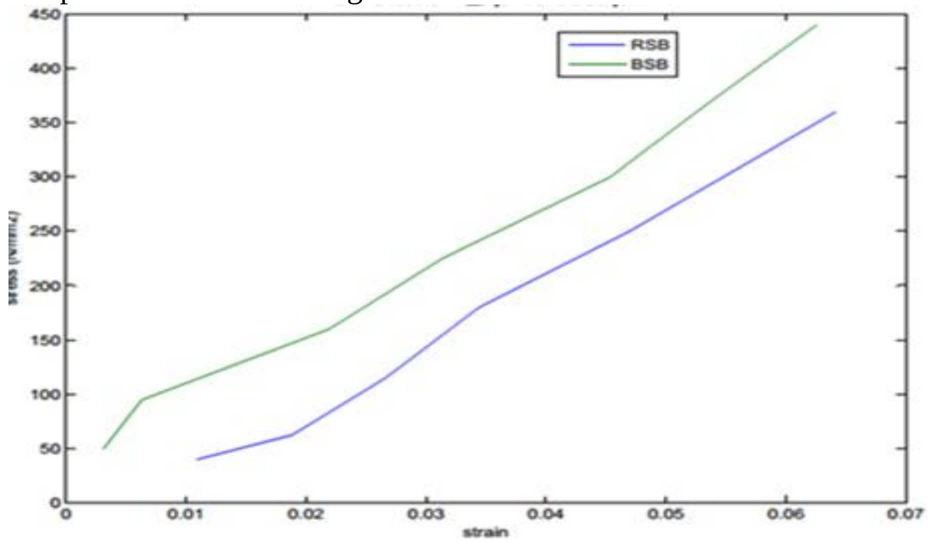

Figure 3: Graph of Strength VS Strain for RSB joint and BSB joints compared

The allowable working stress limits apply to the tensile stresses in the connected plates or members, as well as the shearing stresses in the rivets and the bearing stresses in the rivets and plates are similar for both joints, while the ultimate strength for BSB is greater than RSB. In evaluating the stresses for the design of these tension members, it is generally assumed that the tension is distributed across the width of the connected members, and that the load is equally divided among the rivets. The average ultimate tensile and shearing strengths of riveted structural connections can be evaluated by tests, but the effect of bearing pressure upon the strength or behaviour of such connections has been somewhat elusive.

In Riveted Steel Butt joints, the initial tension in the rivets was equal approximately to the yield point of the rivets. If sufficient ductility exists, this deformation leads to failure of the rivets in shear. Due to this behaviour, the failure modes of riveted connections includes rivet shear, bearing at rivet holes for thinner plates, and failure in tension on net section. For certain force value, the load carrying capacity is less than that for the riveting joints, after reaching this value, the riveting joint start to bend. Further tensile loading causes more bending and plastic deformation. The strength of the riveted material determines the ultimate shear strength of the riveted joints. Tensile tests of Bolted Steel Butt joint conducted showed that the end fasteners have a tendency to fail before all bolts develop their maximum strength; this implies that the load is not distributed evenly on all the bolts. As a result, the average shear stress at first bolt failure was not greatly affected by the joint length. The BSB yielded and strain hardened at 95Nm-^{2} and 160Nm-^{2} respectively and rises linearly until it fractures at 440Nm-^{2}.

3.2.4 Tensile strength characteristics of Riveted Aluminium butt joints and Bolted Aluminium Butt joints.

Figure 4 shows the strength characteristics of Riveted Aluminium Butt (RAB) joints and Bolted Aluminium Butt (BAB) joints.

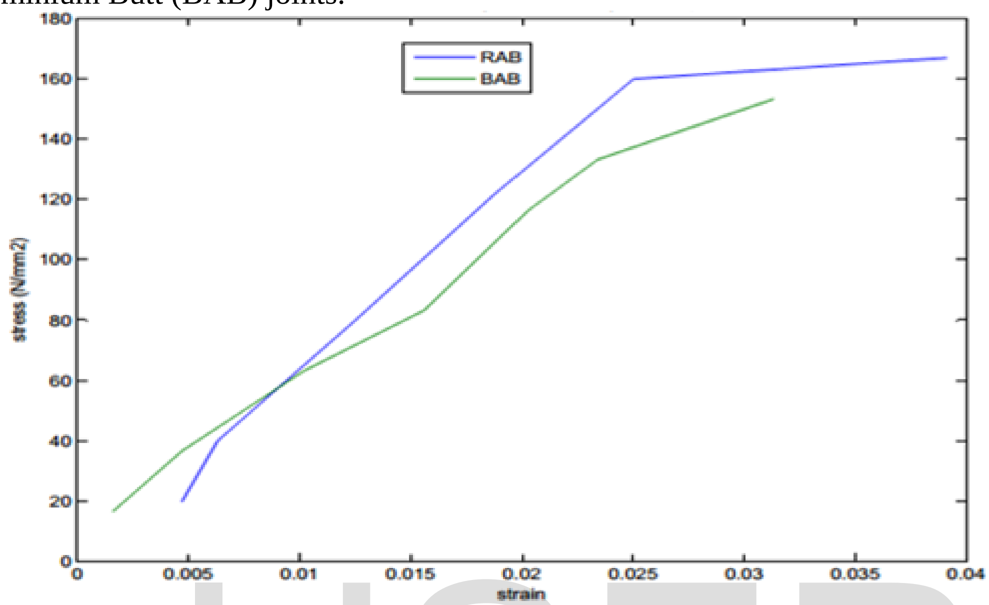

Figure 4: Graph of Strength VS Strain for RAB and BAB joints compared

The unequal distribution of the load at the lower loads did determine the location at which failure would take place. Strains in the sample plates used for the butt-type members were quite low. Deformations in bolted members were generally smaller than those measured in similar riveted members, with Riveted aluminium alloy butt joint having a higher ultimate strength to Bolted aluminium alloy butt joint.
The data for Riveted Aluminium Butt joint showed that some other types of metal alloys had larger rivet shear strengths than typical carbon-steel rivets. The strength of the rivets showed a slight increase as connection force increased up to 160Nm^{-2} where the joint deforms plastically.
In the Bolted Aluminium Butt joints, there was no significant effect on the tensile behaviour of the joint, whereas, with an increase in the edge distance (*e*), the strength of the joint increased considerably up to a Load of 133.3Nm^{-2} where the joint strain hardens and eventually fractured at the ultimate strength of 153.3 Nm^{-2}

3.2.5 Comparism of Tensile Strength of Lap Joints for Aluminium and Steel materials.

Fig 5 shows the tensile strength for various lap joints for Aluminium Riveted and Bolted Riveted joints.

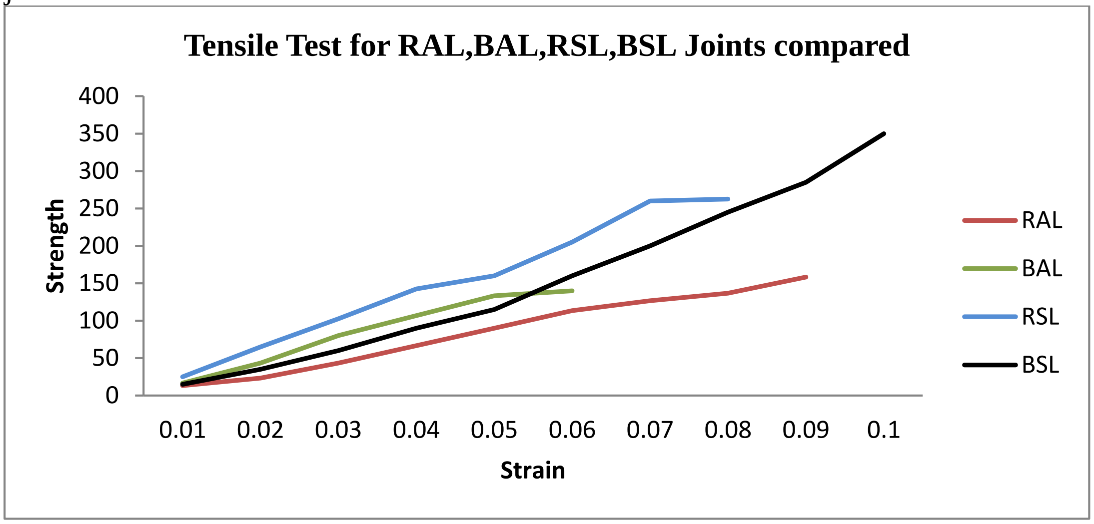

Figure 5: Graph of Strength VS Strain for RAL, BAL, RSL and BSL joints compared

The Riveted steel Lap joint yield at 160Nm^{-2} while the Bolted steel lap joint yielded at 90Nm^{-2} and strain hardening starts at 115Nm^{-2} and rises linearly until fracture occurs at 350Nm^{-2}. The Riveted Aluminium Lap joint yielded at 23.3Nm^{-2} and plastically deform till a second yield point of 90Nm^{-2}. Strain hardening commences immediately almost linearly till it fractures at the ultimate strength of 158.3Nm^{-2} while the Bolted Aluminium Lap joint yielded and strain hardened at 80Nm^{-2} and 140Nm^{-2} respectively. It is obvious from the figure that steel demonstrates superior strength over Aluminium.

3.2.6 Comparism of Tensile Strength of Butt joints for Aluminium and Steel materials.

Figure 6 shows the tensile strength characteristics for butt joints for Aluminium and Steel materials.

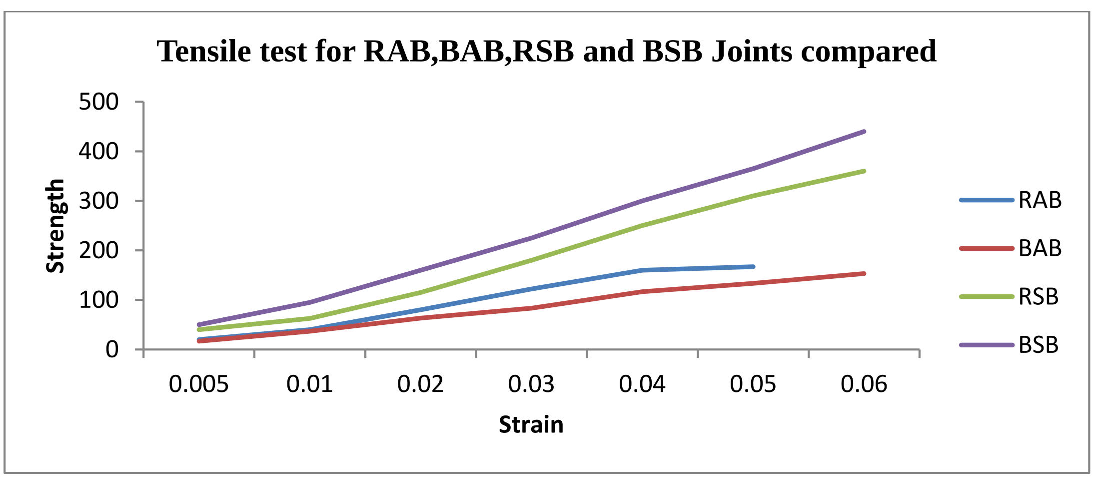

Figure 6: Graph of Strength VS Strain for RAB, BAB, RSB and BSB joints compared

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The Bolted Steel Butt joint yielded and strain hardened at 95Nm-^{2} and 160Nm-^{2} respectively. It rises linearly until it fractures at 440Nm-^{2}. The strength of the rivets showed a slight increase as connection force increased up to 160Nm^{-2} where the joint deforms plastically. In Bolted Aluminium Butt joints, there was no significant effect on the tensile behaviour of the joint, although, with an increase in the edge distance, the strength of the joint increased considerably up to a Load of 133.3Nm^{-2}. Steel material showed superior strength over Aluminium material.

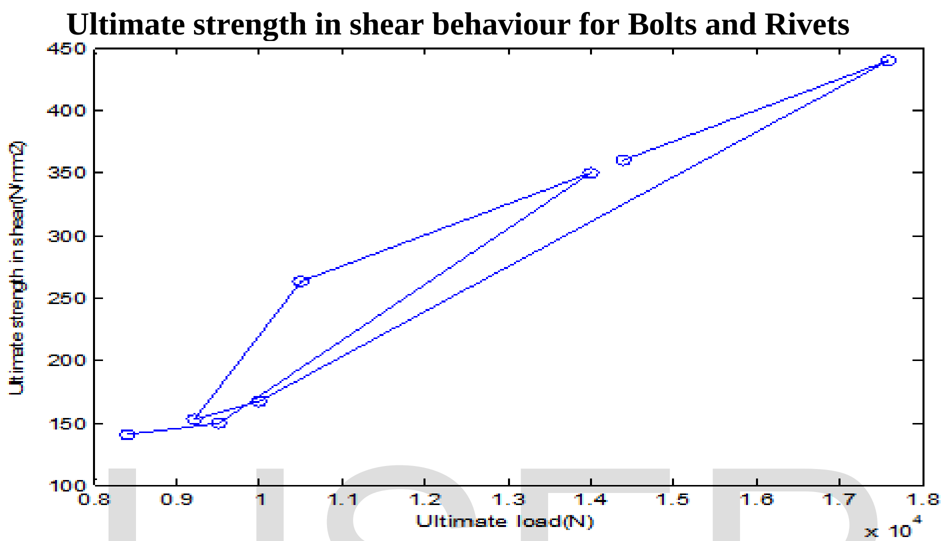

Figure 7: Ultimate Load and Ultimate Strength in shear

The ultimate strength of bolts with the shear planes through the threads was slightly more than 80 percent of that for bolts with the shear planes through the shank, at T-S Load Ratios which were predominantly shear. This value is approximately equal to the relative areas at the shank at the threads. There is increase in efficiency in the riveted joints due mainly to the redistribution of forces in the rivets which depends significantly upon the ductility of the fastener under shearing loads. However, it should be noted that the bolted joints took approximately 50% more load than identical riveted joints.

From the forgoing, both riveted, bolted joint and other fasteners has to be inspected at more frequent interval by maintenance engineers, for early detection of impending failures so that corrective actions can be taken before catastrophic failure occurs. In addition, aircraft operators in temperate regions like Nigeria should apply continuous airworthiness maintenance program in their maintenance production, by replacing time limited spares riveted bolted connections and other fasteners before the stipulated design life to increase their reliance and operational effectiveness.

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4.0 CONCLUSION

The following conclusions can be drawn from this research work:

(i) From the experiment, it could be deduced that bolted and riveted joints have high tensile strength.

(ii) In bolted joints, increase in stress has little or minimal deformation at the initial stage, then tend to show significant changes as the stresses increases, while for riveted steel joint, deformation increases immediately as stress increases.

(iii) In riveted steel butt and bolted steel butt joint, the Stress vs strain curves shows that strain has little or no change at all at the initial stage, and then tend to show significant changes and then deform as the stress increases. The Riveted Steel Lap joint yield at 160Nm^{-2}, the Bolted Steel Lap joint yielded at 90Nm^{-2} and strain hardening starts at 115Nm^{-2} and rises linearly until fracture occurs at 350Nm^{-2}.

(iv) The Riveted Aluminium Lap joint yielded at 23.3Nm^{-2} and plastically deform at a second yield point of 90Nm^{-2}. Strain hardening commences immediately almost linearly till it fractures at the ultimate strength of 158.3Nm^{-2} while the Bolted Aluminium Lap joint yielded and strain hardened at 80Nm^{-2} and fractured at 140Nm^{-2} respectively.

(v) In riveted aluminium and bolted aluminium butt, stress-deformation curves shows that the load has little impact on the strain.

(vi) The Bolted Steel Butt yielded and strain hardened at 95Nm-^{2} and 160Nm-^{2} respectively and rises linearly until it fractures at 440Nm-^{2}. The strength of the rivets Steel Butt showed a slight increase as connection force increased up to 160Nm^{-2} where the joint deforms plastically.

(vii) The type of bolt head had no significant effect on the shear strength or deformation at ultimate load.

(viii) The amount of loads on bolts did not influence the ultimate shear strength of either Lap or Butt joints.

(ix) The shear strength of bolt on Aluminium material is less than the shear strength of bolt on Mild steel.

(x) There was no influence of bolt diameter in ascertaining the shear strength, however, because the bolt shearing area increases faster than the bolt bearing, the deformations at ultimate load are greater.

(xi) The type of connected material had little or no influence on the shear strength and especially there was no noticeable difference in the result between mild steel and low carbon steel. However, the higher the yield points of the connected material, the lower the plate bearing deformations.

(xii) Grip and loading had no significant effect on the shear strength or deformation at ultimate load for either bolted or riveted fastener joints.

(xiii) The actual bolt deformations at ultimate load were not affected by the type of joints.

(xiv) The ductility of a rivet is somewhat greater than that of the high strength bolt and therefore has ability to redistribute the loads more effectively.

(xv) The results have shown that connections assembled with high-strength -steel bolts will perform as well or better than comparable riveted joints, provided the bolted joints are assembled in accordance with the recommendations of the Research Council on Riveted and Bolted Structural Joints.

(xvi) Bolted joints show better fatigue resistance than Riveted Joints; this is because they are free from the local stress, strain concentrations and the varying clamping forces which characterize riveted joints.

(xvii) It was found that clamping force affects the fatigue strength of a joint and that fatigue strengths of bolted joints are greater than those of riveted joints.

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