

FEA of Double Shear Lug Joint by Varying Material Combinations

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Abstract: Lug joint arrangement are mostly used in aeronautical and mechanical structures. Lug joints are generally used to connect major structure components for transfer of loads and they often subjected to repeated load spectra. Lug and thin joints have been designed based on theoretical strength of materials models. In this study, geometry was determined and analysed using theoretical Strength of material calculations. The ultimate loads and allowable stresses by using different materials (Inconel718, Waspaloy, Stellite6, 2024T351 plate, 7075T651 plate, Mg Bronze, 4130 steel) in the current lug joint geometry are calculated by strength of material calculations. From calculations we determined the allowable limiting loads for those different materials in the double shear lug joint. The von mises stresses are induced for different material combinations of lug joint is obtained in FEA software by applying the allowable loads of those material combinations from the design procedure. The induced von mises stress from FEA is less than the ultimate stresses of respective materials. It is suggested the highest allowable limiting load of a double shear lug joint by using different materials in the geometry under allowable stresses.

Keywords: Lug joint, limiting load, Inconel718, Waspaloy, Stellite6, 2024T351 plate, 7075T651 plate, Mg Bronze, 4130 steel

1. Introduction

Lugs are connector types of elements widely used as a structural supporter for pin connectors. Generally lug joints are classified as single shear lug joint, double shear lug joint and multi shear lug joints. Lug joints are mainly used for bearing loads on structural supports, lifting heavy loads and dragging the lug. The application area of lugs are in aeronautical industry and in infrastructure industry. due to precision elements used in aeronautical industry design complications must be so accurate. for that analysis part be take place using FEA software is used to resolve.

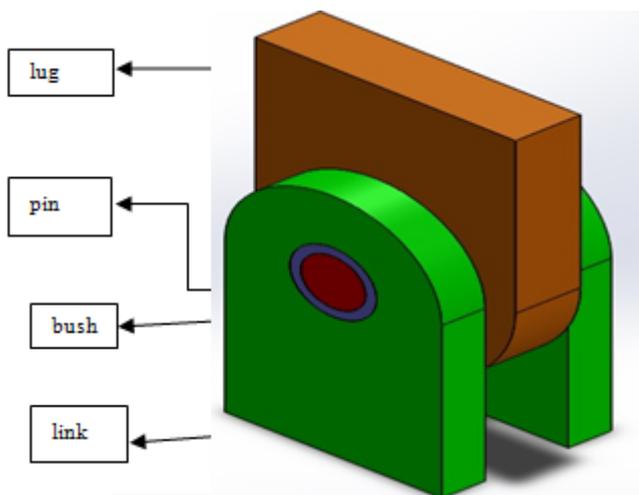


Figure 1: Double Shear Lug joint

2. Literature Review

Early aerospace lug analysis, developed in the 1950's at Lockheed Aircraft Corporation by F.P. Cozzone, M.A.Melcon, and F.M Hoblit and summarized in Reference 2 and 3, addressed prior anticonservative assumptions, such as incomplete evaluation of the effect of stress concentration

and pin adequacy. Margin of safety and limiting load for single material combination of lug joints are summarized by Stenman in reference [5]. Stenman use ABAQUS for modelling and ANSYS for analysis. Where as in this present work modelling did by SOLID WORKS and analysis by ANSYS. This paper will expand to calculated limiting loads for different material combinations and analysed whether the calculated limiting load is safe for our design by using ANSYS for cross verification

3. Calculation of Ultimate Loads and Ultimate Stress for a Uniformly Loaded Lug-Link-Bush-Pin

(INCONEL718-Waspaloy-Stellite6-INCONEL718) and FEA of Lug joint

The Below Tabulated Material Properties are taken from reference [4]

	Units	Lug	Link	Brushing	Pin
Material		INCONEL718	Waspaloy	Stellite6	INCONEL718
Temperature	°F	1000	1000	1000	1000
F_{tu}	Ksi	160	147		160
F_{ty}	Ksi	134	101		134
F_{cy}	Ksi			67.3	
F_{su}	Ksi				99
E	psi	25.4E6	26.9E6	28.5E6	25.4E6
e_u		0.211	0.207		0.211
D	in	1	1	1	
D_p	in			0.75	0.75
e	in	1.25	1.5		
a	in	0.75	1		
w	in	2.5	3		
t_{lug}	in	0.5		0.5	
t_{link}	in	0.75		0.75	
g	in	0.1	0.1	0.1	
h_1	in	0.110			
h_2	in	0.0825			
h_3	in	0.110			
h_4	in	0.0825			

Lugs must be analyzed for bearing and net-section strength while pins are analyzed for shear and bending load. See

Figure 2 below for an overview of basic lug geometry

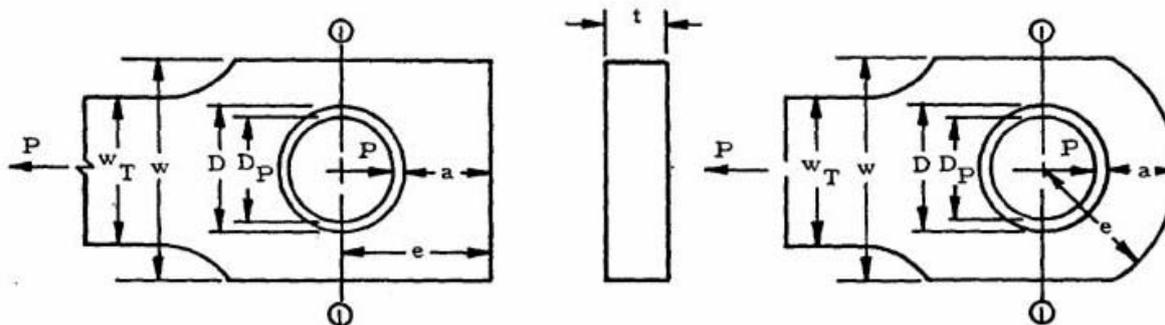


Figure 2: Lug Geometry for Uniform Axial Loading [5]

The design Procedure and calculations are performed from the reference [5]

3.1 Lug Bushing Under Axial Load

a) Lug Bearing Strength

$$e_1/d_1 = 1.25/1.00 = 1.25 : K_{I1} = 1.46$$

$$F_{beul} = k * (a/D) * F_{tul} = 1.46 * (0.75/1.00) * 160 * 10^3 = 175.2 * 10^3 \text{ psi}$$

$$F_{beyl} = k * (a/D) * F_{tyx} = 1.46 * (0.75/1.00) * 134 * 10^3 = 146.7 * 10^3 \text{ psi}$$

$$P_{beul} = 1.304 * F_{bey} * D * t = 1.304 * 146.73 * 10^3 * 0.5 = 95.667 \text{ lbs}$$

b) Lug Net Section tension strength:

$$D/w_1 = (1.0/2.5) = 0.4; F_{ty}/F_{tu} = (134/160) = 0.8375$$

$$F_{tu}/E * e_u = (160 * 10^3) / (25.4 * 10^6 * 0.211) = 0.0298$$

$$K_n = \text{Net Tension stress Co-efficient} = 0.871$$

$$F_{nul} = K_n * F_{tu} = 0.871 * 160 * 10^3 = 139.36 * 10^3 \text{ psi}$$

$$F_{nyl} = K_n * F_{ty} = 0.871 * 134 * 10^3 = 116.714 * 10^3 \text{ psi}$$

$$P_{nul} = F_{nul} * (w-D) * t = 139.36 * 10^3 * (2.5 - 1) * 0.5 = 104.52 * 10^3 \text{ lbs}$$

c) Lug Design Strength

Here the allowable design ultimate load for the lug is lower or equal of the values obtained from P_{nul} or P_{beul}

$$P_{ul} = P_{brul} = 95667 \text{ lbs}$$

d) Bushing Design Strength

$$F_{bsuB} = 1.304 * F_{cyB} = 1.304 * 67.3 * 10^3 = 87.75 * 10^3 \text{ psi}$$

$$P_{ubl} = 1.304 * F_{cyB} * D_p * t = 1.304 * 67.3 * 10^3 * 0.75 * 0.5 = 32.909 * 10^3 \text{ lbs}$$

e) Combined Lug-Bushing Design Strength

Here the allowable lug-bushing ultimate load for the lug is lower or equal of the values obtained from

$$P_{uLB1} = P_{uB} = 32.909 * 10^3 \text{ lbs}$$

3.2 Link & Bushing Under Axial Load

$$F_{tux} = 147 * 10^3 \text{ psi}; 1.304 * F_{ty} = 1.304 * 101 * 10^3 = 131.7 \text{ psi}$$

a) Link Bearing Strength

$$e_2/D = 1.5/1.0 = 1.5 : K_2 = 1.33$$

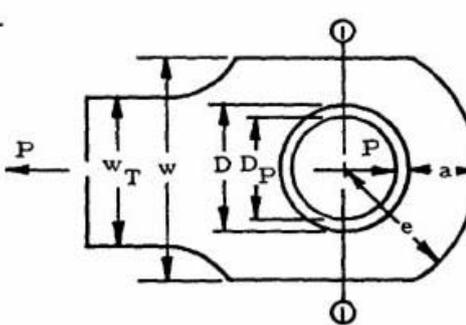
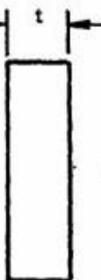
$$F_{beiL} = K * F_{tux} = 1.33 * 147 * 10^3 = 195.51 * 10^3 \text{ psi}$$

$$F_{bet2} = K * F_{ly2} = 1.33 * 101 * 10^3 = 134.33 * 10^3 \text{ psi}$$

$$P_{beul} = 1.304 * F_{bey2} * D * t = 1.304 * 134.33 * 10^3 * 1.00 * 0.75 = 131.37 * 10^3 \text{ lbs}$$

b) Link net-Section Tension strength

$$D/w_2 = (1.00/3.00) = 0.333; t_{dy}/t_{tx} = 101/147 = 0.687$$



c) Link-design strength

$$E_{tv}/(E * e_u) = (147 * 10^3 / (26.9 * 10^6 * 0.207)) = 0.0263;$$

$$K_2 = 0.67$$

$$F_{nu2} = K_n * F_{tu} = 0.67 * 147 * 10^3 = 98.49 * 10^3 \text{ psi}$$

$$F_{ny2} = K_n * F_{ly} = 0.67 * 101 * 10^3 = 67.67 * 10^3 \text{ psi}$$

$$P_{nu2} = 1.304 * F_{ny2} * (w-D) * t = 1.304 * 67.67 * 10^3 * (3 - 1) * 0.75 = 132.36 * 10^3 \text{ lbs}$$

Here the allowable design ultimate load for the lug is lower or equal of the values obtained from P_{nu2} or P_{beu2}

$$P_{uL2} = P_{beu2} = 13.37 * 10^3 \text{ lbs}$$

d) Bushing Strength

$$F_{bsuB} = 1.304 * F_{cyB} = 1.304 * 67.3 * 10^3 = 87.75 * 10^3 \text{ psi}$$

$$P_{uB2} = 1.304 * F_{cyB} * D_p * t = 1.304 * 67.3 * 10^3 * 0.75 * 0.75 = 49.464 * 10^3 \text{ lbs}$$

e) Combined Link- Bushing Design Strength

Here the allowable lug-bushing ultimate load for the lug is lower or equal of the values obtained from P_{uB1} or P_{beul}

$$P_{uLB} = P_{uB2} = 49.364 * 10^3 \text{ lbs}$$

3.3 Joint Analysis

a) Link-Bush Strength

$$P_{uLB} = P_{uB2} = 49.364 * 10^3 \text{ lbs}$$

b) Pin Shear Strength

$$P_{usp} = 1.571 * D_p^2 * F_{sup} = 1.571 * 0.75^2 * 99 * 10^3 = 87.48 * 10^3 \text{ lbs}$$

c) Pin Bending Strength

$$P_{ubp} = (0.1963 * K_{bp} * D_p^3 * F_{iup}) / (t_1/2 + t_2/4 + g)$$

$$= (0.1963 * 1.56 * 0.75^3 * 160 * 10^3) / (0.5/2 + 0.75/4 + 0.10)$$

$$= 38.456 * 10^3 \text{ lbs}$$

Since P_{ubp} is less than both P_{uLB} and P_{usp} , the pin is relatively weak pin which deflects sufficiently under load to shift the bearing loads towards shear faces of lugs. the new value of pin bending strength is as below

$$P_{ubmax} = 2c \sqrt{(P_{ubd}/c * (t_1/2 + t_2/4 + g) + g^2) - 2cg}$$

Where $c = (P_{uLB1} * D_{UXD2}) / (P_{uLB1} * t_2 + D_{uLB2} * t_1)$

$$= (32.909 * 10^3 * 49.364 * 10^3) / (32.909 * 10^3 * 0.75 + 49.364 * 10^3 * 0.5) = 32.910 * 10^3 \text{ lbs/inch}$$

$$P_{ubmax} = 2 * 32.910 * 10^3 * \sqrt{(38.456 * 10^3 / 32.910 * 10^3)^2 * (0.5/2 + 0.75/4 + 0.10) + 0.1^2 - (2 * 32.910 * 10^3 * 0.1^2)} = 37.384 * 10^3 \text{ lbs}$$

The balanced widths are

$$t_1 = b_1 = (P_{ubmax} * t_1) / (2 * P_{uLB2}) = (37.384 * 10^3 * 0.5) / (2 * 32.909 * 10^3) = 0.283 \text{ in}$$

$$t_2=2b_2=(P_{ubmax} * t_2)/P_{uLB_2}= 37.384 \times 10^3 \times 0.75 / (49.364 \times 10^3) = 0.5678 \text{ in}$$

Therefore, the same value of P_{uLBmax} would be obtained if the thickness of lug and link reduced to above balanced widths which their thickness reduces to the current geometry.

3.4 Joint Strength

$$P_{all}=P_{ubmax}=37.384 \times 10^3 \text{ lbs}$$

Material	Inconel718-Waspaloy -stellite6-Inconel718	2024T351 plate-7075T651plate-Mg bronze-4130 steel	2024T351 plate-7075T651plate-Mg bronze- Inconel718
Load in lbs	37384	37900	37900

3.5 Lug Strength under transverse

$$F_{bevl}=K_{tex} * F_{tx}$$

$$h_{av}=6/(3/n_1+1/n_2+1/n_3+1/n_4)=6/(3/0.110$$

$$+1/0.0825+1/0.110+1/0.0825) = 0.099$$

$$n_{av}/D = 0.099/1 * N = 0.99$$

$$K_{rev}=0.51$$

2024T351 plate-7075T651plate-stellite6 -4130 steel	2024T351 plate-2024T351plate-Mg bronze-4130 steel	Inconel718-Waspaloy -Mg Bronze - Inconel718
26848.84	37900	36056

$$F_{bw}=K_{rev} * F_{tx}=0.51 \times 160 \times 10^3 = 81.6 \times 10^3 \text{ psi}$$

$$F_{bey}=K_{tey} * F_{ty}=0.51 \times 134 \times 10^3 = 68.34 \times 10^3 \text{ psi}$$

$$P_{twl}=1.304 * F_{beyl} * D * T = 1.304 \times 68.34 \times 10^3 \times 1 \times 0.5 = 44.55 \times 10^3 \text{ lbs}$$

3.6) Link Strength under transverse load

$$F_{bry}=k_{ty} * F_{ty}=0.51 \times 101 \times 10^3 = 51.51 \times 10^3$$

$$P_{tex}=1.304 * F_{ty} * D * t = 1.304 \times 101 \times 10^3 \times 0.75 \times 10^3 = 50.37 \times 10^3 \text{ lbs}$$

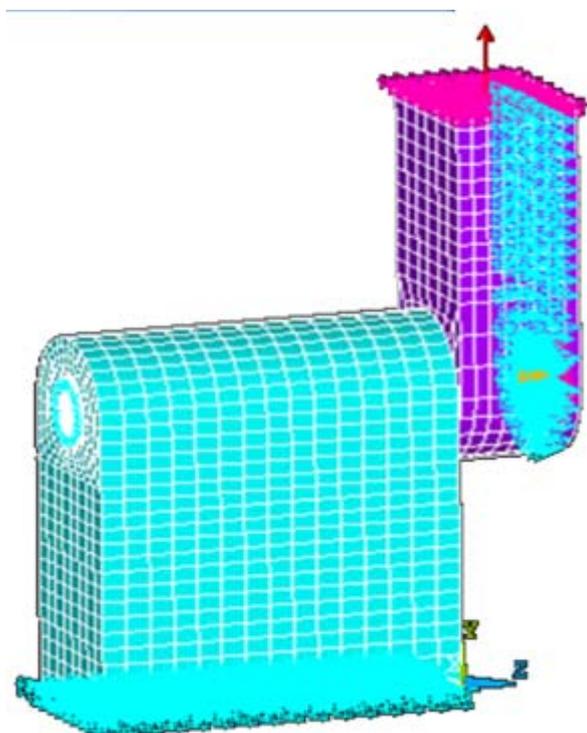


Figure 3: FEA model of LUG JOINT after applying boundary conditions

4. Results & Discussions

From the calculations the following results are obtained

Table-a Allowable Limiting Load of Lug-Link-Bush-Pin

From the above table it is observed that Allowable limiting load of the Double shear Lug joint is 37900 lbs. and all the values for the different combinations are almost nearer values except one combination i.e. (2024T351 plate-2024T351plate-Mg bronze-4130 steel). It is observed that the values for the three combinations are same even though changing of material in lug and link happened also that is just because of not changing material combination of bush and pin. The following are the vonmises stresses of Inconel718-Waspaloy -stellite6- Inconel718 for limiting load 166292N

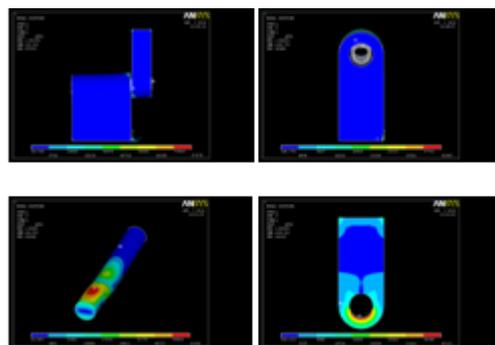


Figure 4: Vonmises stress of double shear lug joint, Lug, Pin, Link

From the above figure it was understood that different colours show the range of stress distribution across the sections of Lug joint. Blue colour indicates minimum stress and Red colour indicates maximum stress. Induced stress is less than allowable stress at Limiting load. So the design is safe. The following are the vonmises stresses of 2024T351 plate-7075T651plate-Mg bronze-4130 steel for limiting load 168587 N

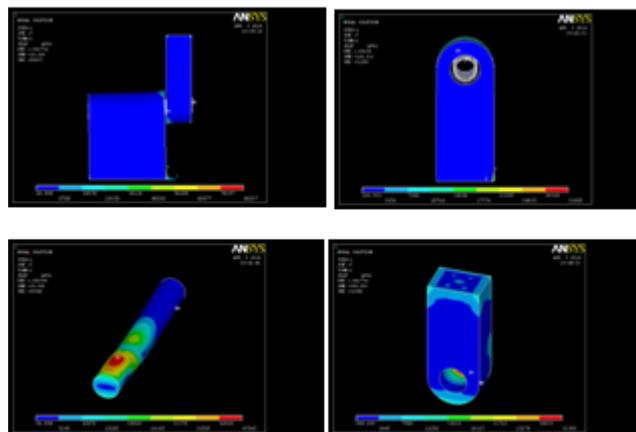


Figure 5: Vonmises stress of double shear lug joint, Lug, Pin, Link

From the above figure it was understood that different colours show the range of stress distribution across the sections of Lug joint. Blue colour indicates minimum stress and Red colour indicates maximum stress. Induced stress is less than allowable stress at Limiting load. So the design is safe. The following are

the vonmises stresses 2024T351 plate-7075T651plate-Mg bronze- Inconel718for limiting load 168587 N

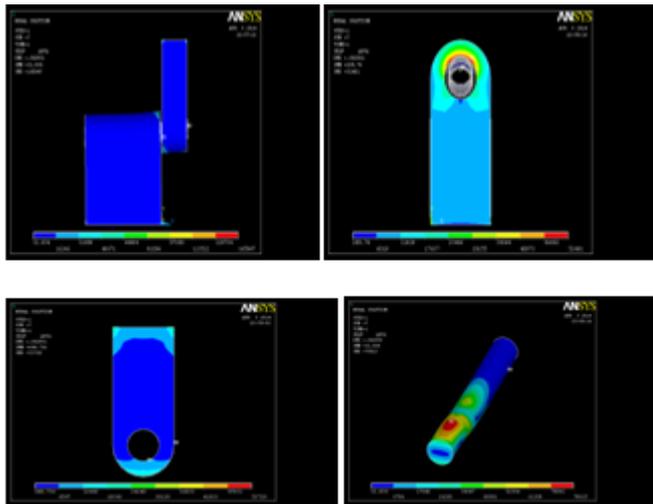


Figure 6: Vonmises stress of double shear lug joint, Lug,Pin,Link

From the above figure it was understood that different colours show the range of stress distribution across the sections of Lug joint. Blue colour indicates minimum stress and Red colour indicates maximum stress. Induced stress is less than allowable stress at Limiting load. So the design is safe. The following are the vonamises stresses of Inconel718- Waspaloy -Mg Bronze - Inconel718 for limiting load 160385 N

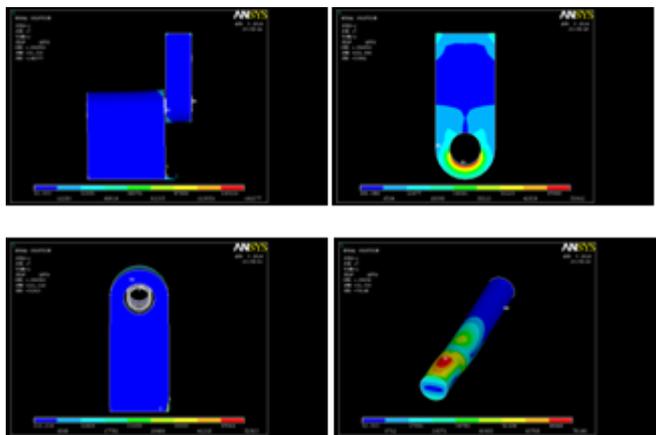


Figure 7: Vonmises stress of double shear lug joint, Lug,Pin,Link

From the above figure it was understood that different colours show the range of stress distribution across the sections of Lug joint. Blue colour indicates minimum stress and Red colour indicates maximum stress. Induced stress is less than allowable stress at Limiting load. So the design is safe. The following are the vonamises stresses of 2024T351 plate-2024T351plate-Mg bronze-4130 steel for limiting load 168587 N

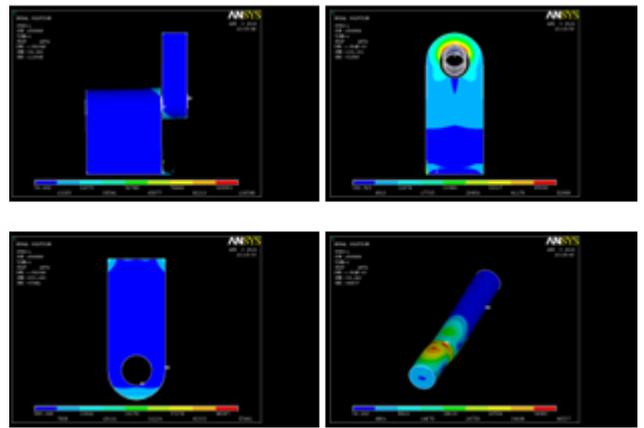


Figure 8: Vonmises stress of double shear lug joint, Lug,Pin,Link

From the above figure it was understood that different colours show the range of stress distribution across the sections of Lug joint. Blue colour indicates minimum stress and Red colour indicates maximum stress. Induced stress is less than allowable stress at Limiting load . So the design is safe. The following are the vonamises stresses of Inconel718- Waspaloy -Mg Bronze - Inconel718 for limiting load 160385 N

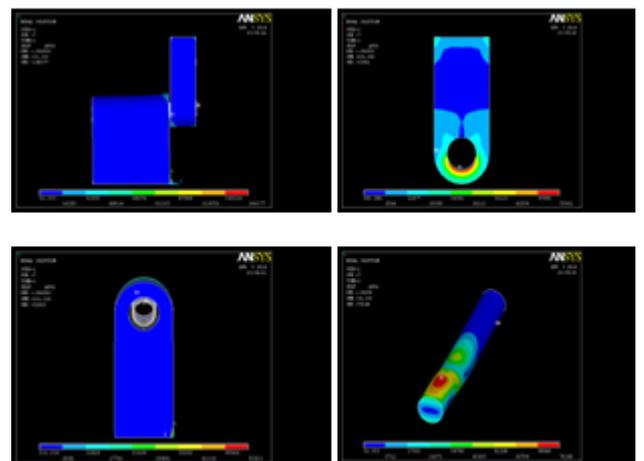


Figure 9: Vonmises stress of double shear lug joint, Lug,Pin,Link

From the above figure it was understood that different colours show the range of stress distribution across the sections of Lug joint. Blue colour indicates minimum stress and Red colour indicates maximum stress. Induced stress is less than allowable stress at Limiting load. So the design is safe

5. Conclusions

- 1) From the results it is observed that the limiting load is same even though changing of material in lug and link happened also that is just because of not changing material combination of bush and pin, by changing the material combinations of pin and bush the limiting load varying depends on the material properties .So choosing more strength material for pin and bush than lug and link.
- 2) 2)The allowable limiting load for three combinations is maximum i.e. (2024T351 plate-7075T651plate-Mg bronze-4130 steel),(2024T351 plate-7075T651plate-Mg bronze- Inconel718),(2024T351 plate-2024T351plate-Mg bronze-4130 steel) is 37900lbs.On cost basis Inconel718

and 7075T651 is high than 2024T351, So this combination is better suit for 2024T351 plate-2024T351plate-Mg bronze-4130 steel is better suit for the geometry in strength wise as well as cost wise.

6. Acknowledgment

The authors are thankful Friends and Family members who support, guide and encouraged us for completion of work.

7. Nomenclature

F_{beu} = Lug Ultimate Bearing Stress (psi)
 F_{bey} = Lug Yield Bearing Stress (psi)
 F_{tu} = Ultimate Tensile Strength (psi)
 F_{ty} = Yield Tensile Strength (psi)
 F_{beu} = Allowable Ultimate Bearing Stress (psi)
 F_{bey} = Allowable Yield Bearing Stress (psi)
 F_{tu} = Ultimate Tensile Stress (psi)
 F_{nu} = Allowable Lug Net-Section Tensile Ultimate Stress (psi)
 F_{ny} = Allowable Lug Net-Section Tensile Yield Stress (psi)
 F_{bey} = Allowable Bearing Yield Stress for Bushings (psi)
 F_{cyb}, = Bushing Compressive Yield Stress (psi)
 F_{beub}, = Allowable Bearing Ultimate Stress for Bushings (psi)
 F_{su,p} = Ultimate Shear Stress of Pin Material
 F_{tu,p} = Pin Ultimate Tensile Strength (psi)
 P_{nu} = Allowable Lug Net-Section Ultimate Load (lb)
 P_{u,B} = Allowable Bushing Ultimate Load (lb)
 P_{u,LB} = Allowable Lug/Bushing Ultimate Load (lb)
 P_{us,p} = Pin Ultimate Shear Load (lb)
 P_{ub,p} = Pin Ultimate Bending Load (lb)
 P_{ub,p,max} = Balanced Design Pin Ultimate Bending Load (lb)
 P_{all} = Allowable Joint Ultimate Load (lb)
 K₁ = Allowable Load Coefficient
 K_n = Net-Section Stress Coefficient
 k_{bp} = Plastic Bending Coefficient for the Pin
 a = Distance from the Edge of the Hole to the edge of the Lug (in)
 b = Effective bearing Width (in)
 D = Hole Diameter (in)
 D_p = Pin Diameter (in)
 E = Modulus of Elasticity (psi)
 e = Edge Distance (in)
 g = Gap between Lug and Link (in)
 h_{1..h4} = Edge Distances in Transversely Loaded Lug (in)
 h_{av} = Effective Edge Distance in Transversely Loaded Lug (in)
 t_{lug} = Lug Thickness (in)
 t_{link} = Link Thickness (in)
 w_{lug} = Lug Width (in)
 w_{link} = Link Width (in)
 ε = Strain (in/in)

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