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Experimental Evaluation of Contact Stresses in a Clevis-Type Pin-Lug Joint Using Strain Rosettes

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Abstract - *Clevis-type pin-lug joints are commonly used for load transmission in mechanical and structural components. Although these joints have a simple configuration, high stress concentration develops near the pin-hole interface due to localized contact between the pin and the lug, which significantly affects joint strength and durability. In this work, an experimental investigation was carried out on an Aluminium 6061 clevis-type pin-lug joint using three-element strain rosettes. Surface strains near the pin-hole region were measured for different applied loads and hole diameters and converted into principal stresses and equivalent Von Mises stress using plane stress relationships. Finite element analysis using ANSYS was performed to simulate stress distribution. The results show that principal and Von Mises stresses increase almost linearly with load, and larger hole diameters produce higher stress due to increased clearance. Numerical results are close to experimental observations. This combined approach supports improved design of pin-connected components.*

Key Words: Clevis Joint, Contact Stress, Strain Rosette, Aluminum 6061, Finite Element Analysis, Pin-Lug Joint, Bearing Stress

1. INTRODUCTION

Mechanical joints utilizing pin-lug or clevis-style connections are essential components in various engineering applications such as aerospace, marine, industrial, and automotive systems. These joints are widely adopted due to their simple geometry, ease of assembly, and efficient load transmission. However, the stress developed near the pin-hole interface is highly non-uniform due to localized contact between the pin and the hole.

The applied load is transferred only through a limited contact region, depending on factors such as clearance, material properties, plate thickness, and loading direction. As a result, high localized stresses develop near the contact zone, which are usually higher than those predicted by nominal bearing stress formulas. Under repeated loading conditions, these regions may experience wear, deformation, and crack initiation, leading to structural failure.

Conventional analytical methods generally assume uniform pressure distribution over the contact area, which is rarely valid in practical joints, especially under clearance-fit and thin plate conditions. Therefore, experimental investigation is necessary to study the real stress behaviour in pin-loaded joints. Strain gauge rosettes provide accurate strain measurements near stress concentration zones without significantly altering the stress field.

In this study, an experimental and numerical investigation is carried out on Aluminium 6061 clevis-type pin-lug joints using strain rosettes and finite element analysis. The objective is to analyse contact stress development near the pin-hole interface and to examine the influence of clearance on localized stress behaviour.

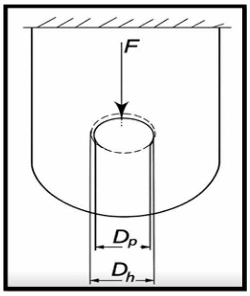

Fig -1: Schematic representation of a pin-lug joint showing applied load and pin hole contact

2. Literature Review

Several researchers have investigated the stress behaviour of pin-connected joints and plates with circular holes under different loading conditions. The presence of a hole in a structural member leads to stress concentration, which significantly reduces the load-carrying capacity of the component.

Aradhye and Kulkarni studied stress concentration in isotropic and orthotropic plates with circular holes using strain gauge rosettes and experimental techniques. Their results indicated that strain rosettes are effective tools for evaluating localized stress fields around holes. Kaw and others analysed composite and metallic joints and reported that clearance and contact conditions play a major role in stress distribution.

Previous studies have also shown that conventional analytical methods based on uniform bearing pressure assumptions are inadequate for predicting actual stress distribution in pin-lug joints. Finite element analysis has been widely used to simulate contact behaviour and stress concentration in such joints. However, experimental validation is necessary to ensure the accuracy of numerical models.

From the literature, it is observed that limited work is available on combined experimental and numerical investigation of thin Aluminium 6061 clevis joints using strain rosettes. Therefore, the present study focuses on analyzing contact stress behaviour through experimental measurements and finite element simulation.

3. METHODOLOGY

The present investigation involves both experimental testing and finite element analysis of a clevis-type pin-lug joint made of Aluminium 6061-T6. The methodology adopted in this study is divided into specimen preparation, experimental setup, strain measurement, stress calculation, and simulation.

3.1 Specimen Preparation

The clevis-type lug specimens were fabricated from Aluminium 6061 plate of thickness 3.4 mm. Holes of different diameters were drilled at the center of the specimens to study the effect of clearance on contact stress behaviour. The specimen was welded to a flat plate which would be used to hold the specimen with the help of c clamp during loading.

3.2 Experimental Setup

The experimental setup consists of a loading frame, clevis joint assembly, loading pan, c clamp and weight set. The specimen was mounted vertically, and load was applied gradually through dead weights. Proper alignment was ensured to avoid eccentric loading.

Fig -3: Experimental test setup with loading arrangement

3.3 Strain Measurement

Three- element strain gauge rosettes (BF350, 350Ω) with gauge orientations -45°, 90° and +45°. They were bonded near the pin-hole interface where high stress is expected. Surface preparation was carried by fine sanding and acetone cleaning to ensure proper bonding of strain gauges. The strain gauges were connected to a digital strain indicator, and strain readings were recorded for each load increment.

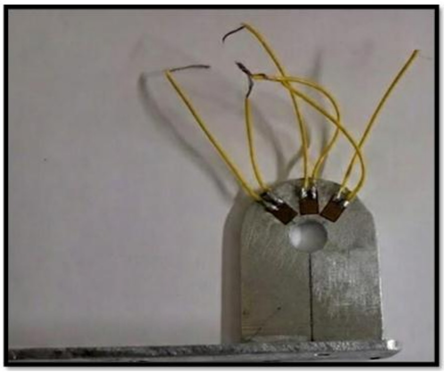

Fig -2: Specimen with bonded strain rosettes

3.4 Stress Calculation

The measured strain values were converted into stress components using plane stress relations. Principal stresses, maximum shear stress, and equivalent Von Mises stress were calculated using standard stress transformation equations. These values were used to analyse the contact stress behaviour near the pin-hole interface. For -45°/90°/+45° configuration the directions are denoted as ε_1 , ε_2 and ε_3, respectively.

The normal and shear stresses in the x-y coordinates are calculated by the following plane stress equations:

$$\sigma_x = \frac{E}{1-\nu^2}(\varepsilon_1 + \nu\varepsilon_3)$$

$$\sigma_y = \frac{E}{1-\nu^2}(\varepsilon_3 + \nu\varepsilon_1)$$

$$\tau_{xy} = G\left(\varepsilon_2 - \frac{\varepsilon_1+\varepsilon_3}{2}\right)$$

where:

σ_x , σ_y = Normal stresses
τ_{xy} = In-plane shear stress
ε_1, ε_2, ε_3 = Measured strains

3.4.1 Principal Stress Transformation

The principal stresses are calculated using the following relation:

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

where:
σ_1 = maximum principal stress
σ_2 = minimum principal stress

Since the lug plate is relatively thin, the out-of-plane stress component was neglected ($\sigma_3 = 0$). Based on this assumption, the equivalent von Mises stress was calculated using:

$$\sigma_{vm} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2}$$

3.5 Finite Element Analysis

Solid works were used for model creation and ANSYS Workbench was used for 3D simulation of pin-lug assembly. SOLID186 hexahedral elements and wedge 15 elements were used with mesh refinement at pin-hole interface (0.2 mm element size). CONTA174 contact and TARGE170 target elements defined at pin-hole boundary. Frictionless boundary condition. Fixed support at lug base and the pin was fixed in x and z direction to prevent rigid body motion. The tensile load was applied in matching with experimental conditions.

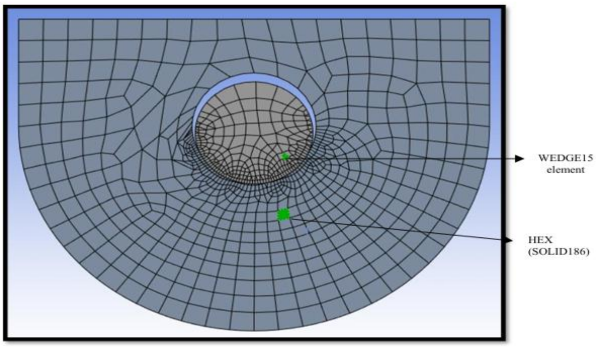

Fig -4: FEA model with mesh refinement at contact region

4. RESULTS AND DISCUSSION

The strain values measured experimentally were converted into stress components, principal stresses, and Von Mises stress using the relations discussed in Section 3.4. The experimental strain readings for the three specimens A, B, and C with hole diameters of 10 mm, 10.5 mm, and 11 mm, respectively, are presented in Tables 1-3.

Table -1: Experimental strain values for Specimen A (10 mm hole)

Load (kg)	ε_1 (-45°) in με	ε_2 (90°) in με	ε_3 (+45°) in με
2	17	11	4
4	36	20	10
6	52	32	15
8	73	41	21
10	91	49	25
12	108	59	29

Table -2: Experimental strain values for Specimen B (10.5 mm hole)

Load (kg)	ε_1 (-45°) in με	ε_2 (90°) in με	ε_3 (+45°) in με
2	20	12	6
4	41	23	11
6	60	35	17
8	81	46	23
10	100	57	28
12	120	68	34

Table -3: Experimental strain values for Specimen C (11 mm hole)

Load (kg)	ε_1 (-45°) in με	ε_2 (90°) in με	ε_3 (+45°) in με
2	22	13	7
4	42	25	13
6	65	38	20
8	88	50	26
10	111	62	33
12	130	75	40

Tables 1-3 show the variation of strain in - 45°, 90°, and +45° directions with applied load for the three specimens. It is observed that strain increases almost linearly with increasing load, indicating elastic behaviour of the material within the applied load range. This trend confirms that the specimens deform elastically and no permanent deformation occurs under the tested conditions. Maximum stress was observed near the loading direction at the edge of the hole due to localized bearing contact between the pin and lug. Minor variations among the specimens are attributed to manufacturing tolerances and experimental uncertainties.

Table -4: Principal stress values for Specimens A, B and C

Load (kg)	Specimen A		Specimen B		Specimen C	
	σ_1 (MPa)	σ_2 (MPa)	σ_1 (MPa)	σ_2 (MPa)	σ_1 (MPa)	σ_2 (MPa)
2	1.43	-0.64	1.67	-0.81	1.89	-0.93
4	3.03	-1.37	3.45	-1.69	3.63	-1.89
6	4.48	-2.27	5.03	-2.53	5.52	-2.76
8	6.18	-3.37	6.82	-3.52	7.43	-3.81
10	7.67	-4.25	8.41	-4.38	9.36	-4.76
12	9.11	-4.99	10.10	-5.26	11.29	-5.78

The principal stresses were calculated from the measured strain values using the stress transformation equations is shown in Table - 4. The variation of maximum principal stress (σ_1) and minimum principal stress (σ_2) with applied load shows an almost linear trend for all three specimens.

For Specimen A, σ_1 increased steadily with load and reached its maximum value at 12 kg. Similar trends were observed for Specimens B and C, with higher stress values for larger hole diameters. The increase in principal stresses with hole diameter is mainly due to increased clearance and reduced contact area. The results indicate that maximum tensile stress occurs near the loading direction at the edge of the hole, while compressive stress develops on the opposite side.

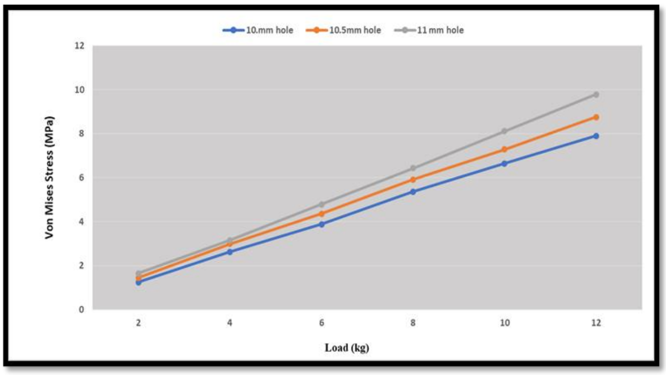

Fig -5: Variation of Von Mises stresses (σ_{vm}) with load

Fig. 5 shows the variation of Von Mises stress with applied load for the three specimens. It is observed that Von Mises stress increases almost linearly with increasing load, indicating elastic behaviour within the tested range. At higher load levels, Specimens B and C exhibit higher stress values compared to Specimen A due to increased hole diameter and clearance. The reduced contact area results in localized bearing stress and higher stress concentration.

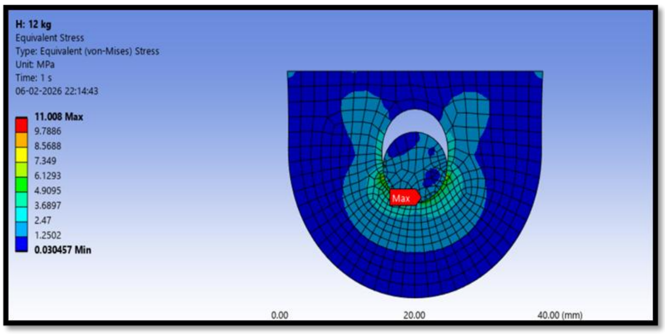

Fig. 6: Von Mises Stress Distribution from Finite Element Analysis For 12 kg load

The Von Mises stress contour obtained from finite element analysis is shown in Fig. 6. High stress concentration is observed near the pin-hole contact region, particularly along the loading direction. The maximum stress occurs at the edge of the hole where direct contact with the pin takes place.

Table -5: Variation of equivalent (Von Mises) stress for different hole diameters with load

Load (kg)	Equivalent (von mises) Stress (in MPa)		
	10.0 mm	10.5 mm	11.0 mm
2	1.83	2.02	2.22
4	3.70	4.28	4.44
6	5.50	6.42	6.66
8	7.34	8.56	8.88
10	9.17	10.70	11.10
12	11.00	12.84	13.32

Table 5 presents the variation of equivalent (Von Mises) stress for different hole diameters under applied loading. It is observed that Von Mises stress increases with increasing load for all specimens. For a given load, specimens with larger hole diameters exhibit higher stress values due to increased clearance and reduced contact area. This confirms the influence of hole diameter on stress concentration in pin-lug joints.

4.1 Comparison of Experimental and Numerical Results

To validate the finite element model, the experimental Von Mises stress values were compared with the corresponding numerical results obtained from ANSYS. Since Aluminium 6061 is a ductile material, Von Mises stress was considered as the primary criterion for comparison between experimental and numerical results. The comparison Experimental and FEA Von Mises Stress is presented in Table 6.

Table -6: comparison Experimental and FEA Von Mises Stress

Load (kg)	Specimen A		Specimen B		Specimen C	
	Exp	FEA	Exp	FEA	Exp	FEA
2	1.24	1.83	1.45	2.02	1.64	2.22
4	2.63	3.70	2.99	4.28	3.15	4.44
6	3.88	5.50	4.36	6.42	4.78	6.66
8	5.36	7.34	5.91	8.56	6.43	8.88
10	6.65	9.17	7.29	10.70	8.11	11.10
12	7.90	11.00	8.75	12.84	9.78	13.32

From Table 6, it is observed that the finite element results are in close agreement with experimental values for all three specimens. The deviation between experimental and numerical Von Mises stress values is within acceptable limits, indicating good correlation.

The minor differences between experimental and FEA results may be attributed to idealized boundary conditions, simplifications in contact modelling, material property variations, and experimental alignment errors. Overall, the comparison confirms that the developed finite element model is reliable for predicting contact stress behaviour in clevis-type pin-lug joints.

5. CONCLUSIONS

An experimental and numerical investigation was carried out to analyse the contact stress behaviour in Aluminium 6061 clevis-type pin-lug joints using strain rosettes and finite element analysis. The experimental results show that strain, principal stresses, and Von Mises stress increase almost linearly with applied load within the elastic range. Maximum stress concentration occurs near the loading direction at the edge of the hole due to localized bearing contact between the pin and lug. Specimens with larger hole diameters exhibit higher stress levels because of increased clearance and reduced contact area.

Finite element analysis predicts stress distribution patterns that are in good agreement with experimental observations. The comparison between experimental and numerical results confirms the validity of the developed finite element model. The combined experimental and numerical approach adopted in this study provides useful guidelines for improving the design and durability of pin-connected components subjected to static loading. The results of this work can assist engineers in minimizing stress concentration and enhancing joint performance.

REFERENCES

[1] V. G. Aradhye and S. S. Kulkarni, “Use of Strain Gauge Rosette to Investigate Stress Concentration in Isotropic and Orthotropic Plate with Circular Hole,” International Research Journal of Engineering and Technology (IRJET), vol. 2, no. 7, pp. 958–962, 2015.

[2] D. B. Kawadkar, D. V. Bhope, and S. D. Khamankar, “Evaluation of Stress Concentration in Plate with Cutout and its Experimental Verification,” International Journal of Engineering Research and Applications (IJERA), vol. 2, no. 5, pp. 566–571, 2012.

[3] M. D. Jagtap, B. D. Gaikwad, P. M. Pawar, and B. P. Ronge, “Use of Strain Gages to Analyze the Behaviour of Roller Conveyor Chain Strip,” in Proc. IRF Int. Conf., Mar. 2015, pp. 35–38.

[4] N. F. Knight Jr., “Bearing-Load Modeling and Analysis Study for Mechanically Connected Structures,” NASA Contractor Rep. NASA/CR-2006-214529, Dec. 2006.

[5] Y. Li, R. Huang, S. Zhao, and J. Wang, “Contact pressure analysis of pin-loaded lug with clearance,” Advances in Mechanical Engineering, vol. 14, no. 6, 2022.

[6] T. Hong, F. Ding, F. Chen, H. Zhang, Q. Zeng, and J. Wang, “Mechanical Properties of 6061 Aluminium Alloy under Cyclic Tensile Loading,” Crystals, vol. 13, no. 8, pp. 1–17, 2023.

[7] P. Sathyaprakash, V. Kulkarni, and K. S. Vishwanath, “Finite Element Analysis of Lug Joint,” SSRN Electronic Journal, 2022.

[8] R. Prasad, “Overview of Strain Gauge and its Various Applications,” International Journal of Engineering and Applied Sciences (IJEAS), vol. 10, no. 9, Sep. 2023.

[9] L. S. Srinath, Experimental Stress Analysis, 2nd ed. New Delhi, India: Tata McGraw-Hill, 2006.

[10] S. Singh, Applied Stress Analysis: A Textbook for Engineering Students, 4th ed. Delhi, India: Khanna Publishers, 2000.