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A Single Lap $AlCu_4Mg$ Riveted Joint Plate Material Structural Analysis for Bending-Shearing-Squeezing Forces under Airflow and External Loads in Computational Engineering Design

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A rivet is a cylindrical rod (shank) with a tapered tail and a head. Rivets are used in many design applications such as joining together two or more plates. The full understanding of these joints is essential in many areas, e.g. automobile and aviation industries and marine applications, mainly for leak proof joints like oil tanks, boilers etc. However, the riveted joints studies have been so far poorly comprehended and necessitate more research. The aim of this research is to establish and analyze 3D computational models of single riveted joints based on elastic-plastic properties. The static stress under bending/shearing and squeezing forces of rivet material with PA25 alloy ($AlCu_4Mg$) according to EN 1301-2:1997 ductile fracture conditions were analyzed for residual tensional load and airflow in the riveted connection by the finite element method. This paper proposes a hybrid simulated analysis of bending/shearing and squeezing forces combined simultaneously for riveting process. In addition to this, the external loading and airflow simulations were also carried out to find residual stress solutions. The effects of riveting operation parameters i.e. material type, head die design, impact force, and geometric parameters under BSSF of plates for rivets were investigated under airflow conditions. The ANSYS explicit finite element analysis of riveting process was realistic approach to simulate hundreds of rivets before the riveted joint system realization to prevent service and work safety hazardous.

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1. Introduction

Riveting is a type of connection that depends on the material and shape parameters. The quality of rivet joint is changed by geometrical and manufacturing process parameters i.e. rivets diameter-pitch, rivets squeeze force and plate thickness [1–3]. The researches in literature about rivet are mainly focused on the rivet fatigue performance and crack issues [5] and the residual stresses about the riveted joint [4]. The squeezing forces that were proved to be experimentally and numerically have the most significant role in riveting process [6]. To increase fatigue resistance of riveted joints and to model large aircraft assembly finite element (FE) was applied for assembly variation analysis [7]. Regarding the research presented in this article, hybrid riveting analysis for a new FE method was proposed considering bending and shearing forces while squeeze force applied to shank head and plate to increase the strength of the structured monolithic body. The next section explains this new concept as numerical and simulation method for riveting related to bending/shearing and squeezing forces (BSSF) under airflow loading conditions on single riveting model as shown in Fig. 1.

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2. Material and methods: experimental procedure

The main goal of this research was the analysis of the material deformation behavior of the composite joint contained of two plates and rivets under airflow. The ANSYS program for simulation was employed to compute the strengths occurred during airflow in a rivet specimen. This static loaded rivet was applied airflow with velocity of 300 m/s is given in Fig. 2. Simulation The FE numerical investigation consists of 3D modeling of the composite plates, the rivets under the effect of airflow. The experiments carried out for single lap rivet

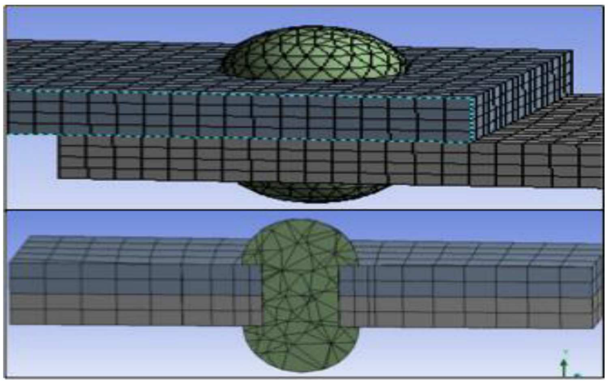

Fig. 1. Single lab rivet model.

joint were accomplished by numerical outcomes as well as airflow tests for under airflow pressure to observe the behavior of the material as displayed in Fig. 3. To provide a better comprehension of the stress-related deformation progression after riveting and elastic recovery, a series of asymmetric models are simulated for the rivet under temperature as shown in Fig. 4.

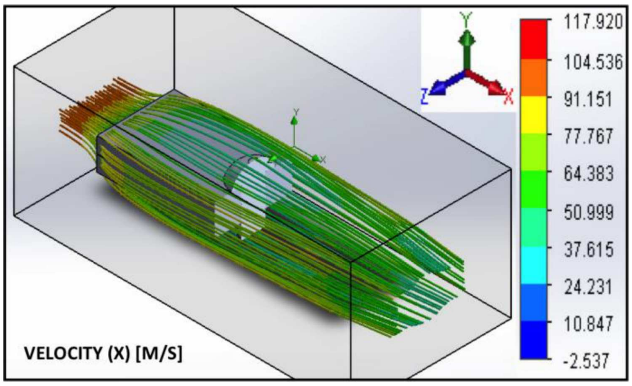

Fig. 2. Rivets under airflow of velocity.

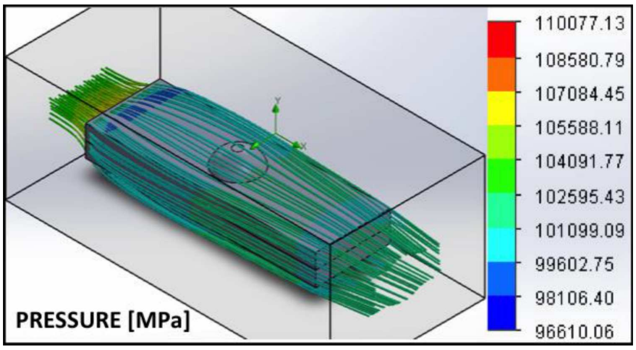

Fig. 3. Rivets under airflow of pressure.

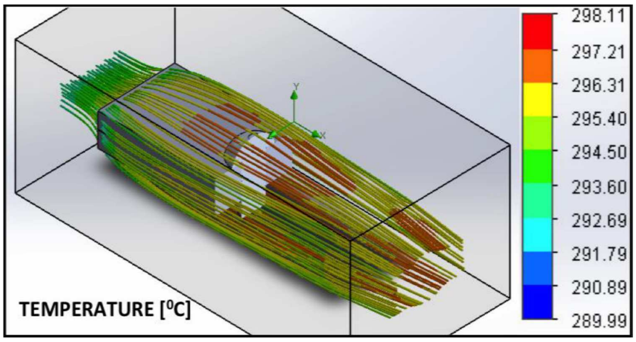

Fig. 4. Rivet under temperature.

The structural performance of the riveting process included the strength of a riveted joint under static loading as exhibited in Fig. 5a. The isotropic hardening process in forming the rivet caused the von Mises yield criterion to maximum level. Composite plates and rivets were deformed to large deformation before crack occurred as given in Fig. 5b. A displacement (based destruction deformation) parameter is added to the main computational equation. In the ANSYS simulation program and experimental study, it was tried to understand the deformation and rivet safety which can be occurred by evaluating the tensile strength of the stress distribution due to the effect on rivet by finite element analysis given in Fig. 6a. The single rivet case fatigue model was analyzed as shown in Fig. 6b.

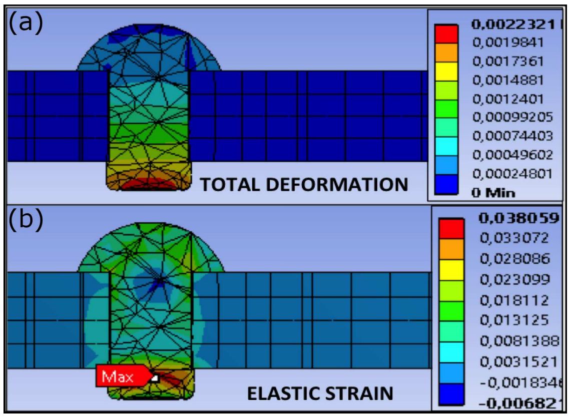

Fig. 5. The stress distribution of rivets: deformation (a), strain (b).

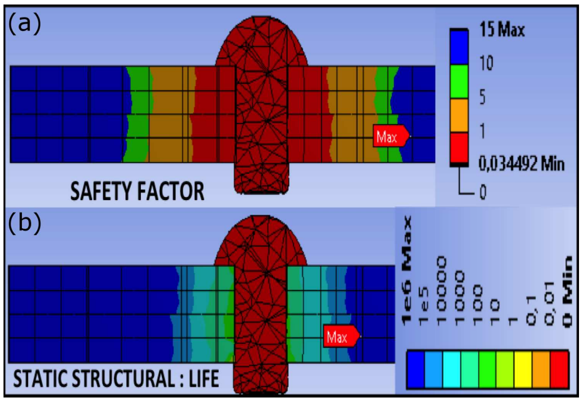

Fig. 6. Rivet safety and fatigue analysis model: safety (a), lifetime (b).

Displacement caused by BSSF forces with maximum 950 N for sheared riveted joint. The conditions of equilibrium boundary were adapted to BSSF model. The residual stresses occurred in rivet were computed by FE ANSYS constitutive code. The von Mises equivalent strain ε_v is given by

$$\varepsilon_v = \left\{ \frac{2}{9}\left[(\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_y - (\varepsilon_z)^2 + (\varepsilon_z - (\varepsilon_x)^2 \right] + \frac{1}{3}\left(\gamma_x^2 y + \gamma_y^2 z + \gamma_z^2 x \right) \right\}^{\frac{1}{2}}, \quad (1)$$

and octahedral shear stress τ_o is given by

$$\tau_o = \frac{1}{3}\Big[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6\left(\tau_y^2 z + 6\tau_z^2 x + \tau_x^2 y \right) \Big]^{\frac{1}{2}}. \quad (2)$$

Equations (1), (2) are developed to observe strain and stress level during squeezing forces applied, and solid element invariants are defined there.

This research produced a static stress model to simulate multiple parameters based on plasticity model of von Mises, which include material hardening and strain rate knowledge. As a result of the analysis, large deformation was observed in the two holes region and at the progressively reduced stress level far from the hole. This resulted in unequal expansion in the rivet hole along. The greatest expansion caused by the squeeze force occurred in the hole on the free surface of the top plate. The largest von Mises stress value of around 850 MPa was obtained in this experimental simulation study.

The circumferential direction of the stress distribution at the contact surface of the two plates was at the rivet diameter from the center of the rivet. Near the rivet head under bending force maximum value was 400 MPa and rivet zone was at the value of 340 MPa bending forces. Computational simulations of the rivet joint process under airflow show that the rivet head and near rivet zone is different from each other. Depending on the bending forces of the rivet under airflow, different stress values were observed locally. In the case of loading shearing forces with 174 MPa, the distance is clearly visible due to the friction forces in the squeezing formation of the rivet head. The rivet head under shearing forces found at the value of 102 MPa. Therefore, the results of the analysis depended on how accurate the friction level is during the riveting process.

3. Results and discussion

The higher the squeezing and the clamping force the better the filling of the rivet hole generated on the plates. It has been observed that the rivet body has a higher radial expansion and a larger size of the driven head better filled the inside of the plates. Residual tensile strength in the fracture deformation of the rivets due to the compressing process produced radial stress. Resistance stress, radial compressive stress, and compressive and tangential compressive stress resulting from the riveting process are occurred in the hole area. The other part of the research generated data for airflow effect on the rivet during serving. The analysis of the result related to airflow provided that residual tensile strength may cause breakage of the rivet.

4. Conclusion

The hybrid analysis of bending and shearing and squeezing forces combined simultaneously of single lap riveting model for finite element simulations of load distributions in plate joints was successfully implemented. The simulation was accomplished accurately acquisition of the physical boundary information of a riveted joint. A considerable parameter research revealed that near the rivet head under bending and shearing forces applied for riveting was managed successfully to calculate load distributions.

Acknowledgments

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