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ENGINEERING ANALYSIS OF MS20426AD4-6 ALUMINUM ALLOY RIVETED JOINT PLATES UNDER AIRFLOW ON AIRCRAFTS BY COMPUTATIONAL FLUID DYNAMICS MODELING

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Abstract: Rivets are used in many design applications such as joining together two plates. A full understanding of these joints is essential in most of automobile, aviation and marine applications and mostly for leak proof joints like oil tanks, boilers etc. The aim of this research is to construct and analyze 3D computational models of single riveted joints based on elastic-plastic properties. The static stress under bending/shearing and squeezing forces (BSSF) of rivet material with PA25 alloy (MS20426AD4-6, EN 1301-2:1997) ductile fracture conditions were analyzed for residual tensional load and airflow in the riveted connection by the Computational Fluid Dynamics modeling and finite element method. This paper proposes a hybrid analysis of BSSF combined simultaneously for riveting process. In addition 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 FE 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.
Keywords: rivet design, aluminum alloy, bending-shearing-squeezing stress, finite element

INTRODUCTION

Fasteners are divided into three classes according to an overview, shape-bound elements, force-bound elements and material-bound elements. In another respect, fasteners are divided into two classes, detachable elements and undetachable elements. Rivets are located within the undetachable fasteners elements. The rivets are widely used in aircraft and other products. Industrial rivets are of four basic types: tubular, blind, split and solid. The most general aviation aircraft fastener is the solid rivet. They have high strength virtue of the fact that they fill the entire hole with solid aluminum, strain hardened by the driving process. The air frame of an aircraft has approximately 2.5 million fasteners costing about US$800 thousand. Riveting depends on the material and shape parameters. The quality of rivet joint is changed by geometrical and manufacturing process parameters i.e. rivet diameter-pitch, rivet squeeze force and plate thickness [1-3]. The researches in literature about rivet are mainly focused on the rivet's 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 FE was applied for assembly variation analysis [7]. To obtain crack growth behavior the orthogonal arrays of the Taguchi method are selected in mixed level design mode in which one factor with two levels and six factors with four levels for finite element simulation are examined by Nejad et al. [8].

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 stresses occurred during airflow in a rivet specimen. This static loaded rivet was applied airflow with velocity of 300 m/sec is given in Figure 2, maximum shear stresses as shown in Figure 1.

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 BSSF under airflow loading conditions on single riveting model under maximum shear stresses as shown in Figure 1.

The simulation process consists of 3D modeling of composite plates, rivets exposed to airflow, FE numerical analysis of the system and finally their outcomes. As shown in Figure 3, air flow tests were performed under pressure to convert the behavior of the material into numerical outputs in a single lap rivet joint. Material properties change with temperature. In the elastic deformation of the riveted two-plate system, the airflow affects the heat transfer in the system and thus the temperature distribution. In addition to the stress and elastic deformation behaviors in the defined asymmetric system, the temperature distribution is also included in the study, Figure 4.

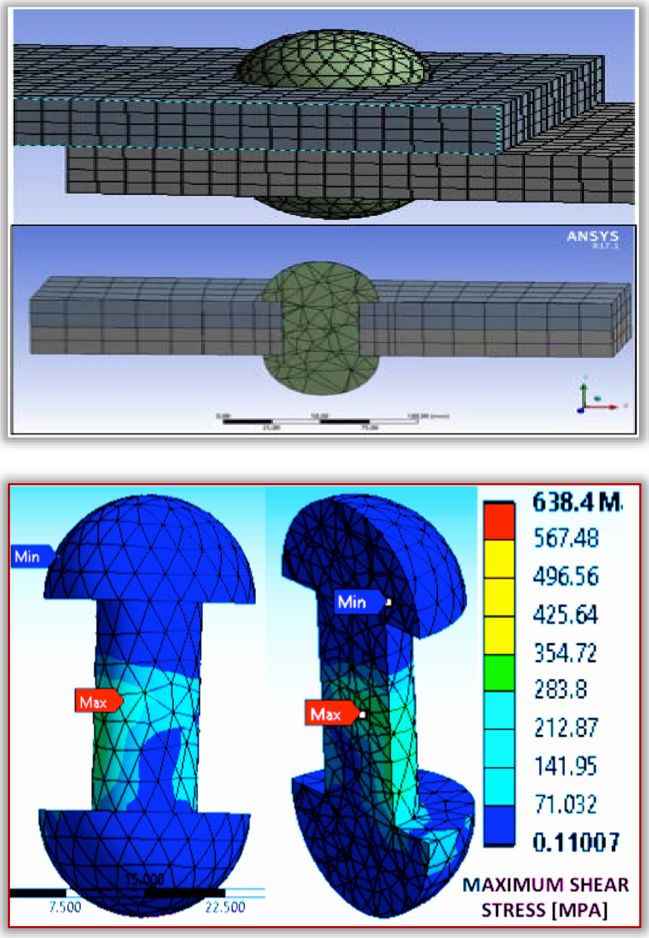

Figure 1. Single lab rivet model exposed to shear stresses

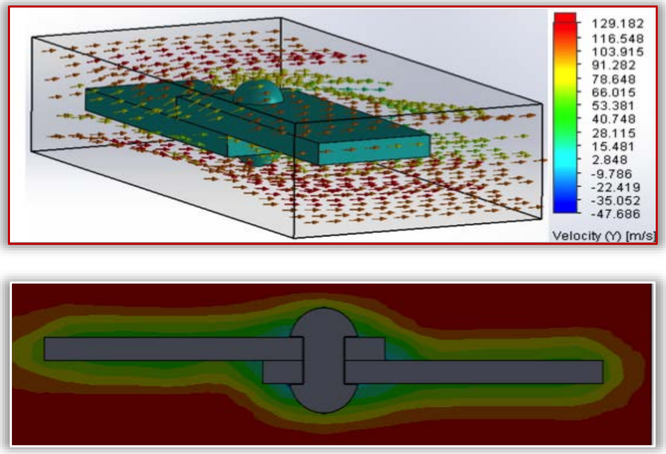

Figure 2. Rivets under airflow of velocity

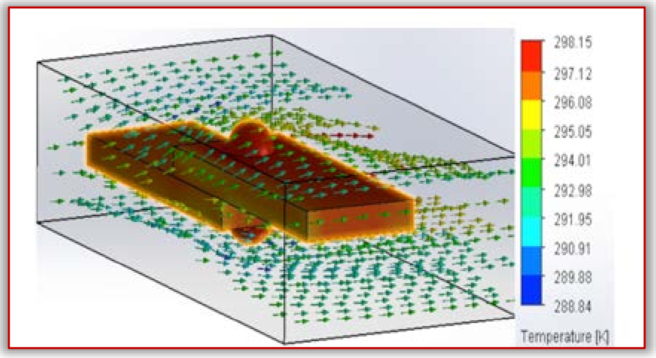

Figure 3. Rivets under airflow of pressure

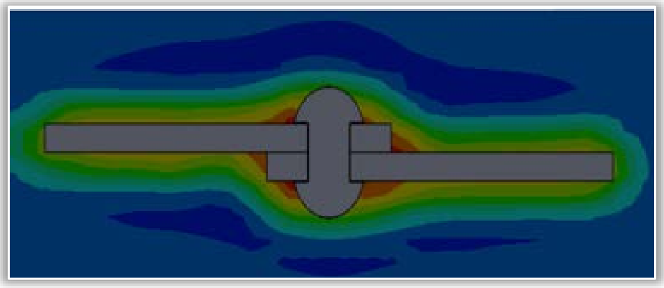

Figure 4. Rivet under temperature

The structural performance of the riveting process includes the durability of this riveted joint under a certain static load. Figure 5. 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 Figure 5. 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 Figure 6. The single rivet case model under deformation was analyzed as shown in Figure 6.

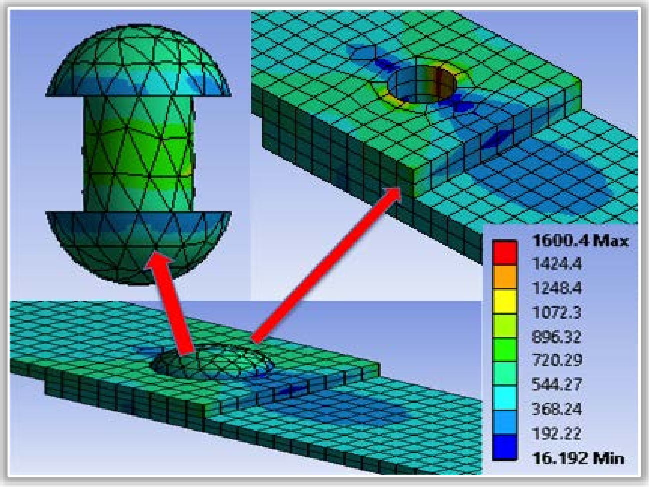

Figure 5. The stress distribution of rivets

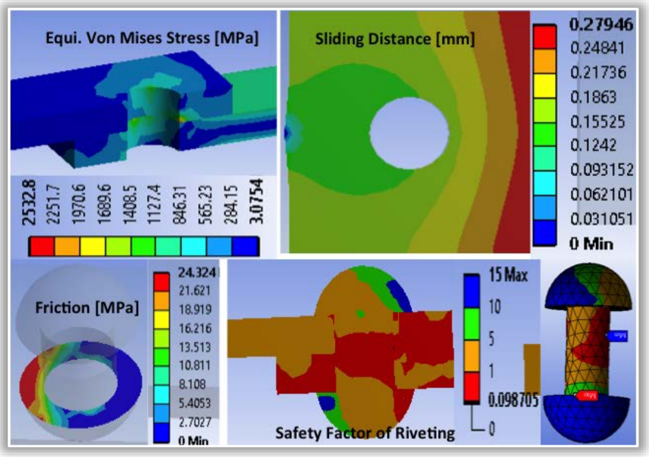

Figure 6. Friction, stress and rivet safety

Displacement caused by BSSF forces with maximum 950 N for sheared riveted joint was shown in Figure 6. The conditions of equilibrium boundary were adapted to BSSF model. The residual stresses occurred in rivet were computed thru FE ANSYS constitutive code. The von Mises equivalent strain ε_x (1) and octahedral shear stress τ_o (2) equations are developed to observe strain and stress level during squeezing forces applied. The solid element invariants are defined in equation as (1) and (2) follows:

$$\varepsilon v = \left[\frac{2}{9}\{(\varepsilon x-\varepsilon y)^2+(\varepsilon y-\varepsilon z)^2+(\varepsilon z-\varepsilon x)^2\} + \frac{1}{3}(\gamma^2 xy+\gamma^2 yz+\gamma^2 zx)\right]^{\frac{1}{2}} \quad (1)$$

$$\tau o = \frac{1}{3}\left[(\sigma x-\sigma y)^2+(\sigma y-\sigma z)^2+(\sigma z-\sigma x)^2 + 6\tau^2 yz+6\tau^2 zx+6\tau^2 xy\right]^{\frac{1}{2}} \quad (2)$$

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. Because 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 as shown Figure 7. Near the rivet head under bending force maximum value was 400 MPa with red circle 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 as exhibited in Figure 7.

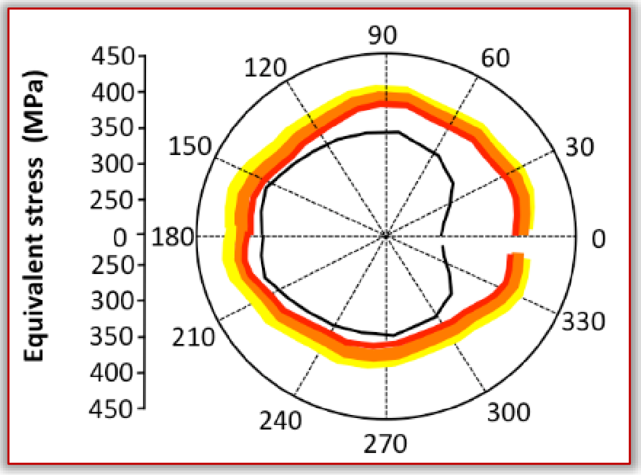

Figure 7. Near the rivet head under bending forces

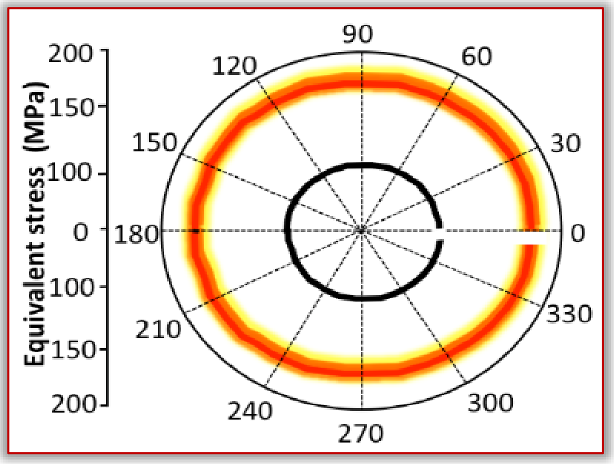

Figure 8. Near rivet head under sheering force

Depending on the bending forces of the rivet under airflow, different stress values were observed locally as given in figure 8. In the case of loading shearing forces with 174 MPa drawn by red circle, the distance is clearly visible due to the friction forces in the squeezing formation of the rivet head as shown in Figure 8. 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.

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's 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 wall of hole. The other part of the research generated data for airflow effect on the rivet during service. The analysis of the result related to airflow provided that residual tensile strength may cause breakage of the rivet.

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.

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