Effect of rivet material and punch pressure on equivalent plastic strain of riveted joints in Al-alloy 2024 plates

R. Masoudi Nejad, M. Tohidi, G. Wheatley, A. Jalayerian Darbandi, H. Ghasemi

***Abstract*—**The purpose of this paper is to evaluate the equivalent plastic strain (PEEQ) for riveted joints of Al-alloy 2024 plates. For this purpose, according to field observations, the parameters affecting the equivalent plastic strain are obtained. The relevant geometrical parameters such as rivets length, holes diameter, and dimensional tolerances as well as the rivet pattern and the rivet joints material are considered. In this study, modeling is performed using the finite element method. For this purpose, a three-dimensional elastoplastic model is used for simulation. The information obtained from the finite element method in this study made it possible to place the rivets in this type of joint for use in high-safety structures such as the aerospace industry. This method increases the confidence of the design of riveted joints and also reduces the cost and number of experimental tests related to determining the maximum equivalent plastic strain in this joint. Also, using this method reduces the costs of failure and fracture of sensitive components. The results showed that the geometric parameters and the rivet material have a significant effect on the equivalent plastic strain in riveted joints of Al-alloy 2024 plates.

***Keywords*—** Equivalent plastic strain, Friction coefficient, Finite element methods, Riveted joint, Al-alloy 2024 plate.

I. Introduction

INCREASING human needs and the striving to meet them has led to the creation of new and complex challenges in all scientific and technical fields, which are not excluded from the field of mechanical and structural engineering. In most cases, the necessity to design and analyze components with complex geometries and properties under irregular loads means that the use of existing classical methods with complex governing equations and varied boundary and initial conditions are impossible to use to solve these equations analytically. As a result, numerical methods should be utilized to deal with the conundrum. In the field of fatigue studies of other joints, fracture, fatigue and crack growth in welded joints [1], solder joints [2], adhesives [3] and also screws [4] are topics that could be investigated. Taylor et al. [5] used crack growth to examine fatigue in welded joints. The methods presented in this study are modeled up to a 20% error in fatigue life. Fatigue tests are employed to determine the mechanical and metallurgical properties of welded joints for aluminum alloys. Guo et al. [6] demonstrated that metallurgical defects of 0.3 mm can decrease the fatigue life of the welded joint. Zhang et al. [7] also studied the welded joints of nickel alloys. The crack growth due to creep and fatigue of welded joints of Nickel alloy FGH95 is studied experimentally. The effect of the preload on the fatigue of screw joints is assessed by experiment and FEM. Experiments indicated that the preload has an impact on the screw strength [4]. Research on the thermal properties of fatigue in solder joints illustrated that with increasing fatigue cycles, fatigue damage in solder joints becomes serious [2]. The use of hybrid joints also gives new mechanical and metallurgical properties to the structure. For instance, a study on the strength and fatigue life of weld-screw joints showed that the use of hybrid joints improves the stress distribution and, as a result, fatigue life is increased in comparison with non-hybrid joints [8]. However, such hybrid joints are more commonly used in composite materials. Among the numerous numerical methods available to solve problems, three of them can be named as the most well-known methods. These are the element free method (EFM), the boundary element method (BEM) and the finite element method (FEM), respectively. Abundant research is performed in the field of evaluating the parameters affecting fatigue crack growth [9-13]. Shiotani et al. [14] developed a new method for strain distribution at a sample surface. In this technique, in order to determine the strain distribution, they used three spherical waves in

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holography. The area under study will be enlarged using these spherical waves and could be utilized for small samples. Li et al. [15] in a new method measured the temperature contour near a radiator using holography. The temperature deviation obtained in this method in comparison with the use of thermocouples will be relatively lower. This shows that holography is a rational and effective way to find temperature contours in boundary regions, which interact with a fluid. Hung et al. [16] are able to calculate in-plane strains using the dual-beam phase shift technique, which is similar to the application of a large number of strain gauges.

Many types of research are performed in the field of evaluating fatigue behavior. Most numerical methods are verified by experimental and analytical methods. To have a more accurate determination of the fatigue strength of a riveted joint, having knowledge about the stress distribution around the rivet and joint hole is essential and this stress distribution could be obtained using FEM. However, these analytical models are applicable for simple geometries such as a simple and symmetrical rivet, and their verification must be examined by experiment. Most studies on the plastic strain of riveted joints in aluminum sheets employed plastic strain relations to investigate the plastic strain of riveted components. Since many parameters affect the mechanical properties of the joint, in this paper, first by considering the effective parameters and performing them using a three-dimensional elastoplastic finite element model, the stress distribution and equivalent plastic strain are specified and as a result an optimal joint is acquired by finite element method.

II. MATERIALS AND METHODS

The riveting process used to connect two pieces (usually plates) is widely used in various industries such as aerospace, marine and construction industries. This joint is based on integrity and refers to the mechanical force and a riveted joint. The riveted joint consists of two parts called the rivet shank and the rivet head. The riveted joint is one of the most important ways to permanently connect thin metal plates to each other. The Al-alloy 2024 is preferred for its low fuselage due to its high fracture toughness and acceptable tensile strength. Due to the characteristics and extent of the presence of Al-alloy 2024 in the aerospace industry, in this study, the parameters affecting the equivalent plastic strain on this alloy have been investigated. Plates and rivets are prepared from 2024 aluminum alloy since the research on the plastic strain of riveted joints includes studies that use this material. The chemical composition of Al2024 which is the sample utilized in the present study is given in Table 1. Also, the mechanical properties of the materials used in this study are presented in Table 2. To create the samples, aluminum plates with dimensions of 75*140 mm and a thickness of 1.7 mm are modeled. The rivet shank length is 6 mm. Also, other effective parameters on riveted joints are given in Table 3.

Table 1. Chemical analysis of 2024 Aluminum (in wt %) [13].

Aluminum	**Al**	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Si**	**Ti**	**Zn**
2024 Aluminum	94-90.7	0.1	4.9-3.8	0.5	1.2-1.8	0.9-0.3	0.05	0.15	0.25

Table 2. Mechanical properties of materials used in experiments [13].

Related model	**material**	**Young modulus [MPa]**	**Poisson ratio**	**Yield strength [MPa]**	**Ultimate tensile strength [MPa]**
rivet	Al2024-T4	69824.3	0.33	244.38	402.63
rivet	Steel Mo40	201916.5	0.285	289.51	672.83
sheet	Al2024-T3	71572.0	0.33	378.02	571.92

Table 3. The effective parameter on equivalent plastic strain of riveted joints.

parameters	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Rivet material	steel Mo40 (St)	Al2024-T4 (Al)	-	-
Rivet shank diameter (mm)	2.8	3.8	4.8	5.8
Punch pressure (MPa)	1.2Sy	1.4Sy	1.6Sy	1.8Sy

III. FINITE ELEMENT METHOD

The simulation of riveting is carried out in two steps in order to improve significantly the calculation cost. First, the rivets are inserted into the holes and then punched. Second, the friction force between the punch and the rivet is removed and only the normal force between the punch and the rivet remains. The punch is kept under constant pressure until the model is ready to be applied with tensile force. For stress concentration regions, the local seed size is 0.6 mm and for the global seed, the size is 5 mm. Moreover, the higher the friction coefficient is, the shorter the component life will be [17]. Therefore, friction coefficient values are selected for the lubricated state. General-contact is defined for the whole assembly and self-contact is defined for rivets. The symmetry boundary condition is applied for the whole assembly since it is halved from the middle due to its symmetry. Beneath all the rivet heads is completely fixed. Furthermore, all degrees of freedom of the punch point mass are fixed, except in the punching direction. Regarding the yield strength of the rivet and its punch pressure coefficient, the amount of pressure, which should be applied on the punch, was calculated. In this study three materials which are defined for assigning to aluminum rivets, steel rivets and sheets are Al2024-T4, steel Mo40 and Al2024-T3, respectively. After the punching simulation step, the following steps should be performed to simulate the tensile process. 23 kN is applied to one side of the sheets and the other side is totally fixed. All the degrees of freedom of the punch are fixed and at this step the “surface to surface” contact is used for all surfaces, instead of general contact. Moreover, beneath the punch, friction is removed. Figure 1 shows the finite element modeling of the studied sample.

IV. RESULTS AND DISCUSSION

After the desired simulation with considering Table 3, the maximum equivalent plastic strain to each condition is calculated. The simulation results for the 8 conditions related to the equivalent plastic strain contours are shown in Figures 2-5. Now, considering that the purpose of calculating the maximum equivalent plastic strain on the plates, the results of the maximum equivalent plastic strain for 8 simulations in Al-alloy 2024 plates are presented in Table 4. It should be noted that the integral point parameters including strain and stress are read from the integral points; otherwise, by reading from nodes, they will be read more than their real value.

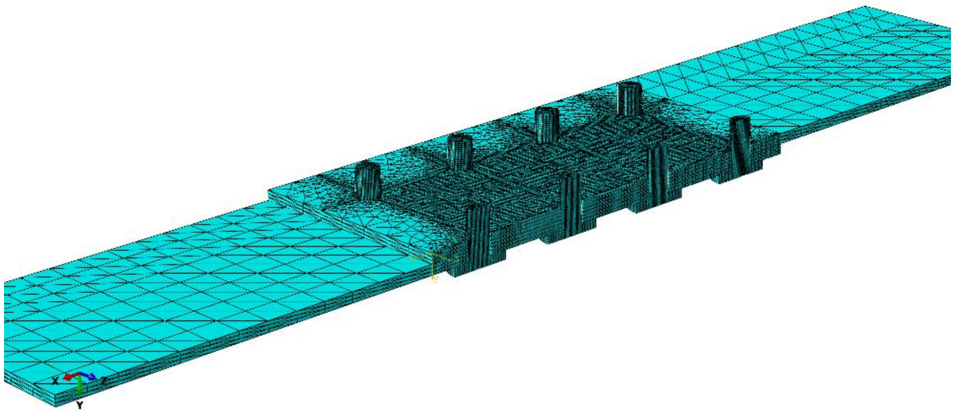
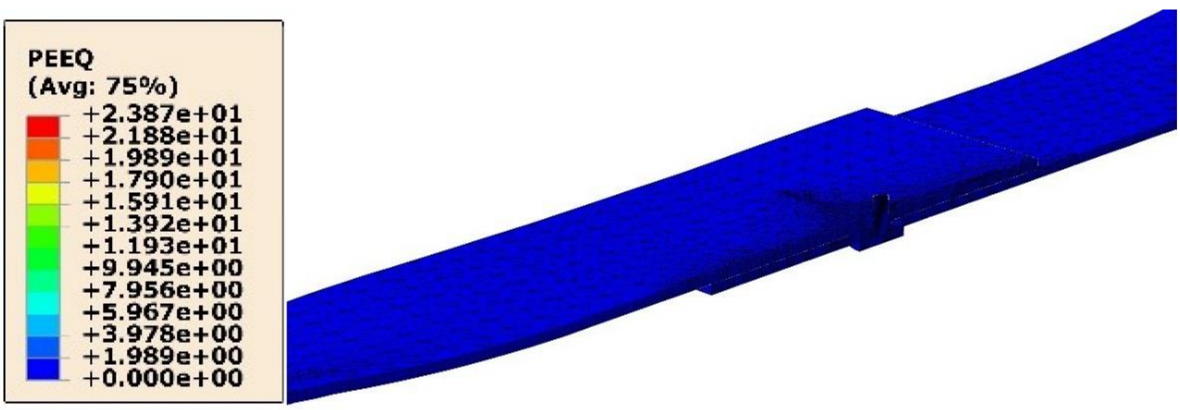


Fig. 1. Finite element model of the studied sample.



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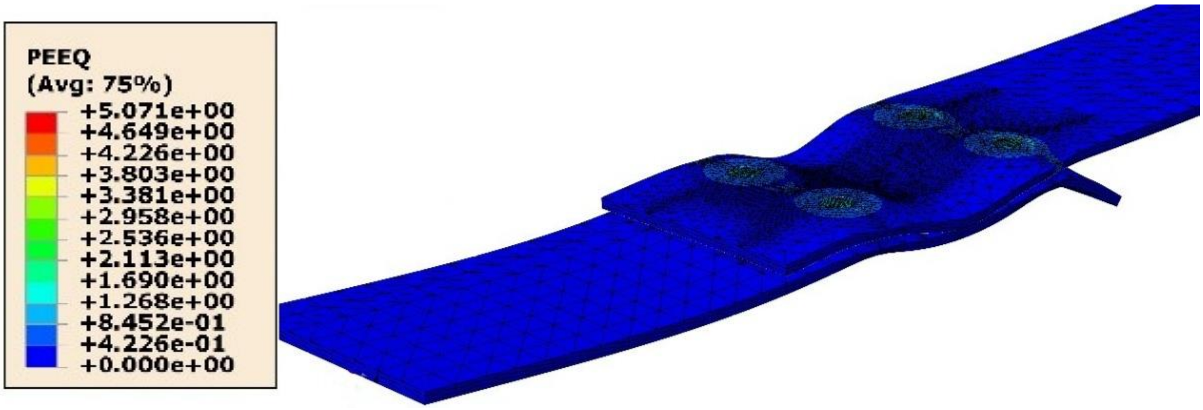
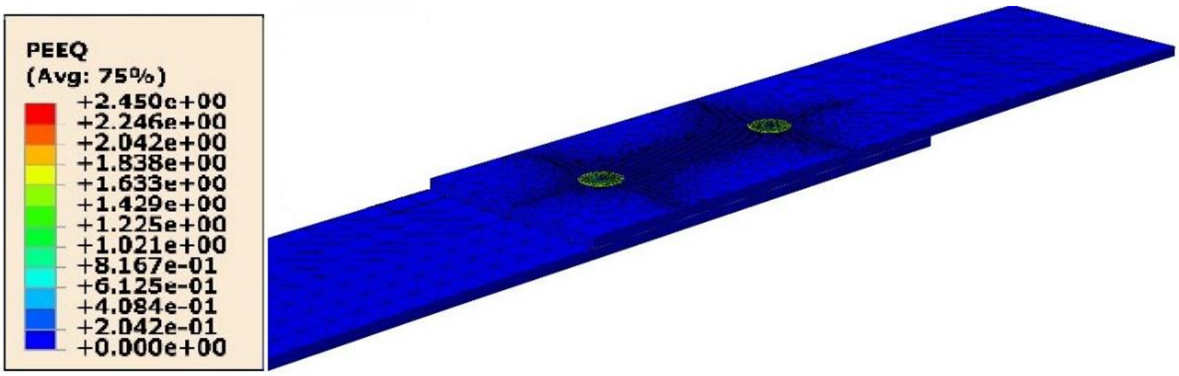


(b)

Fig. 2. PEEQ contour for a rivet shank diameter of 2.8 mm and punch pressure of 1.2*Sy: (a) Al2024-T4, (b) Steel Mo40.



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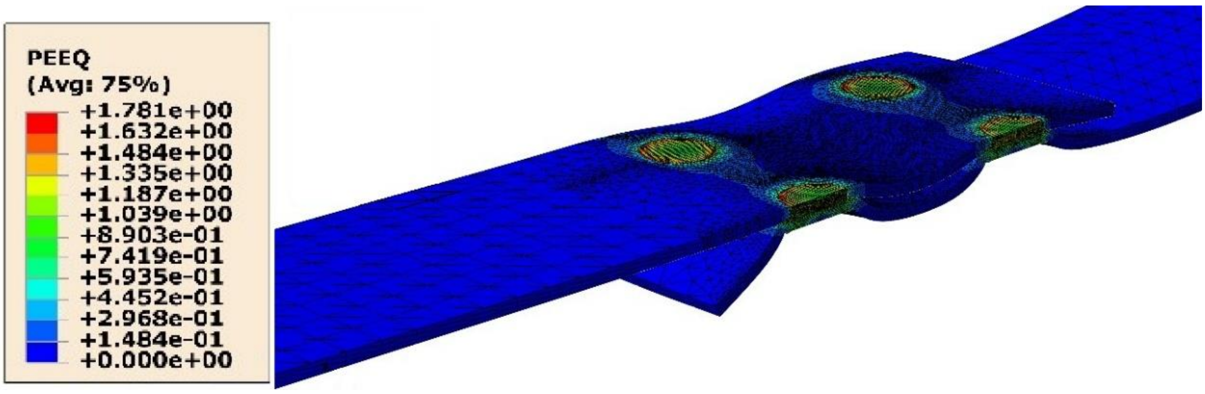

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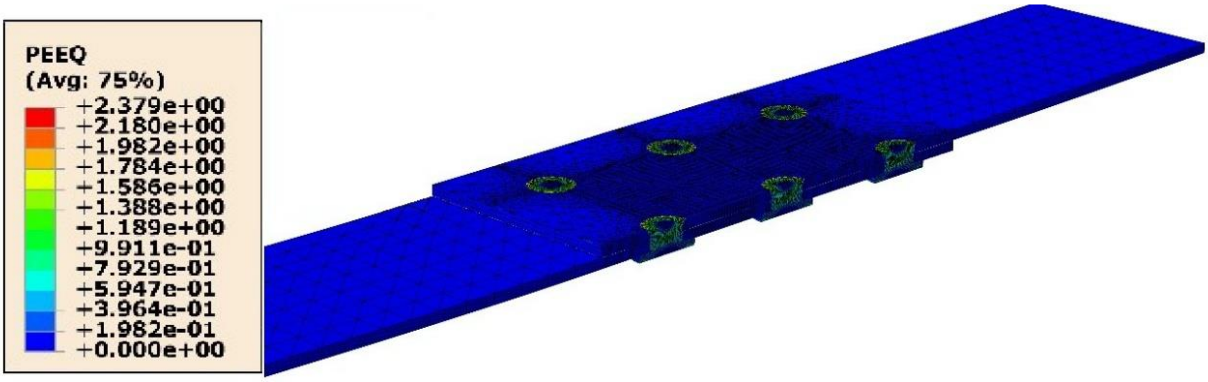
Fig. 3. PEEQ contour for a rivet shank diameter of 3.8 mm and punch pressure of 1.4*Sy: (a) Al2024-T4, (b) Steel Mo40.



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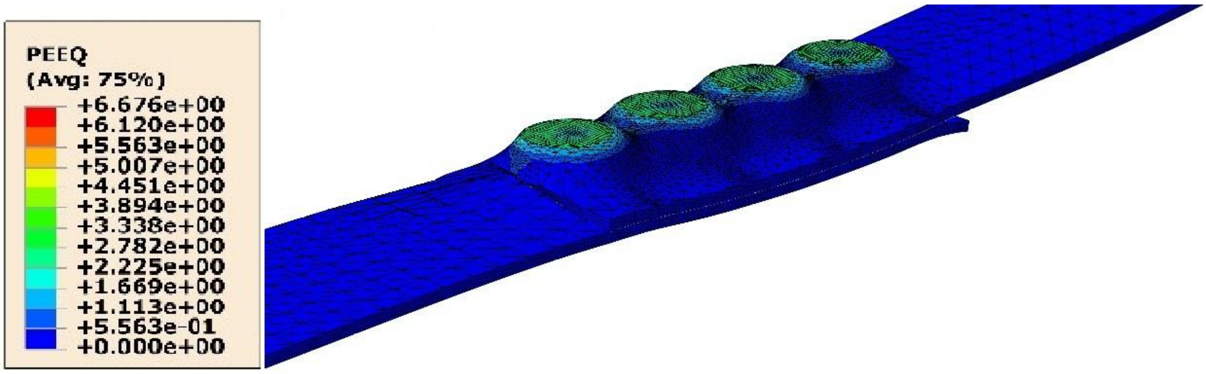
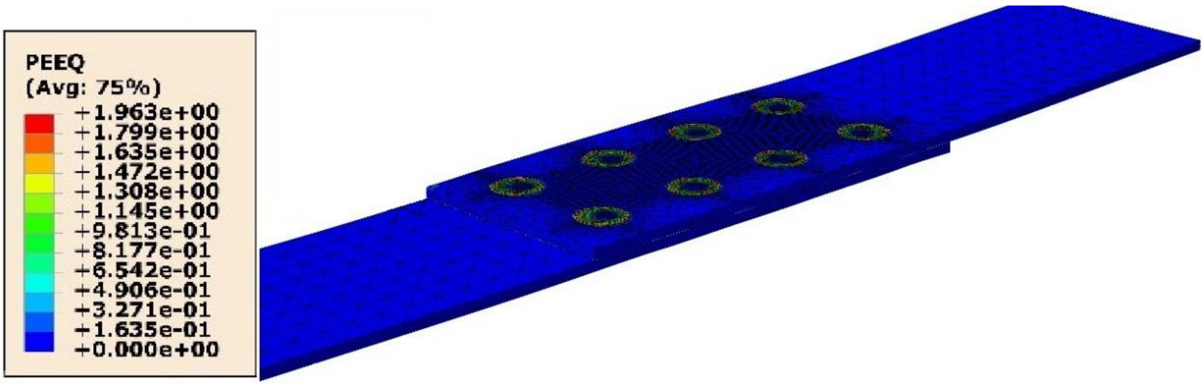


(b)

Fig. 4. PEEQ contour for a rivet shank diameter of 4.8 mm and punch pressure of 1.6*Sy: (a) Al2024-T4, (b) Steel Mo40.



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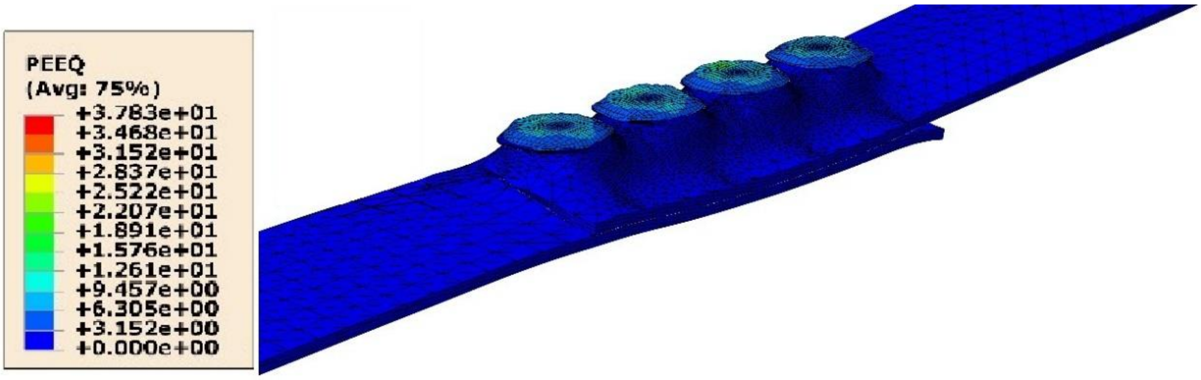

(b)

Fig. 5. PEEQ contour for a rivet shank diameter of 5.8 mm and punch pressure of 1.8*Sy: (a) Al2024-T4, (b) Steel Mo40.

Table 4. Maximum PEEQ results.

Rivet material	Rivet shank diameter (mm)	Punch pressure (MPa)	Max PEEQ
Al2024-T4	2.8	1.2*Sy	23.87
Steel Mo40	2.8	1.2*Sy	3.268
Al2024-T4	3.8	1.4*Sy	1.295
Steel Mo40	3.8	1.4*Sy	1.601
Al2024-T4	4.8	1.6*Sy	0.888
Steel Mo40	4.8	1.6*Sy	4.364
Al2024-T4	5.8	1.8*Sy	0.639
Steel Mo40	5.8	1.8*Sy	7.694

As can be seen for the rivet shank diameter of 5.8 mm, the punch pressure of 1.8Sy and the material Al2024-T4, the equivalent plastic strain value is less than all other conditions and can be considered as the best condition for effective parameters.

V. CONCLUSIONS

Many parameters affect the performance of the joints over time and different loads. Parameters such as the material of joints, the geometry and the dimensional tolerance of joints and the residual stress can be mentioned. Given the breadth of these factors, the study is essential to achieve a proper joint in terms of fatigue lifetime and safety. In this study, finite element methods have been used and finally the best riveted joint has been found. The parameters studied were the material of the riveted joints, the rivet shank length, the rivet shank diameter, the punch pressure, the number of lateral holes and the number of longitudinal holes. Finite element simulations are performed to find the maximum equivalent plastic strain for the 8 conditions studied. The minimum equivalent plastic strain was the maximum in the case where the rivet shank diameter was 5.8 mm, the pressure was 1.8Sy and the rivet material was Al2024-T4. As a result, the levels determined in this case were recognized as the best for this riveted joint. It is also suggested that research on other parameters and the use of optimization methods be done in future research.

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