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Comparison finite element analysis on duralium strength against multistage artificial aging process

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ABSTRACT

Purpose: To analyze and estimate the strength of duralium rivets which had been treated by using multistage artificial aging compared with duralium that had not been treated. This processwas necessary to be conducted in riveting process effectively. Duralium has been widely used in aerospace industry, one of duralium usage in aerospace industry is aircraft fittings such as rivet. Riveting is one of method that used for joining airframe structural components. During riveting process, the load transfer causing stress that led to the fatigue. Riveting process also causes deformation on the rivet and sheet metal. Deformation that occurs on the rivet will affect the performance of rivet structure. Thus, duralium rivet was analyzed its total deformation, shear stress, and its equivalent stress Von Misses.

Design/methodology/approach: that used in this study was finite element analysis. Geometry of rivet that used in this study was drawn by using Autodesk Inventor Professional 2018. While total deformation, shear stress and equivalent stress Von Mises on duralium rivets were found out by using ANSYS Workbench 18.1.

Findings: Comparison result was obtained between duralium rivet with and without treatment of multistage artificial aging. The result shown that total deformation, shear stress and equivalent stress Von Mises which obtained by duralium rivet with multistage artificial aging had the lower value than duralium rivet without multistage artificial aging. Duralium rivet with multistage artificial aging could be used as aircraft fitting which had the higher strength.

Research limitations/implications: Direct experiment on duralium rivet had not been done yet, this study only did simulation based on data that obtained form previous research that had been conducted by the researcher.

Practical implications: Duralium rivet with multistage artificial aging had lower value on total deformation, shear stress, and equivalent stress Von Misses, thus duralium rivet with multistage aritificial aging had a higher strength.

Originality/value: Application of duralium as a rivet with treatment of multistage artificial aging.

Keywords: Mechanical properties, Duralium, Multistage artificial aging, Finite element analysis, Riveting

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Duralium is one kind of aluminum alloy that composed of Al-Cu-Mg with percentage of 3%-4.5% Cu, 0%-1% Mg, 0%-0.7% Mn, 0.4%-1% Fe, 0.3%-0.6% Si and the percentage of Al is adjustable [1,2]. Duralium has several properties that is excellent such as light, ductile, and resistant of corrosion, thus this alloy is widely used in automotive and aerospace industry [3,4]. Aerospace industry uses aluminum alloy up to 90% [5]. According to the use of aluminum alloy which increase up to 9.9% per year in tons [6], mechanical properties of this alloy should be improve [7,8]. One of method that can be conducted to improve mechanical properties of aluminum alloy is artificial aging [9-11]. Aging treatment in this study used multistage artificial aging, previously study shown that this treatment was able to improve mechanical properties of duralium [8, 12].

Duralium is widely used for aircraft fittings, gear and shafts, bolts and nuts, couplings, fuse parts, hydraulic valve bodies, missile parts, fastening devices and orthopedic equipment [13]. One kind of aircraft fittings is rivet that often find in the aircraft structures [14]. Riveting joint is one of method that applied in joining airframe structural component permanently and this method will be used in the future [15,16]. There are several advantages in applying riveting joint such as uncomplicated joining process, dependable joining intensity, high working effectiveness, and so on, thus it is used widely in the aircraft industry [16]. Besides that, according to testing that conducted by Anthony Fokker and Hugo Junkers in 1917, they made The J4 which its fuselage, tube frame, and corrugated metal sheets constructed with duralium. Then they welded together the duralium parts that caused material deteriorated [17]. Thus, riveting joint is the most effective method to fasten aircraft structures. However, during riveting process, the load transfer causing stress that led to the fatigue. Riveting process also causes local deformation on the rivet and sheet metal. Deformation on the rivet that occurs due to the load transfer will affect the performance of rivet structure, that makes the panel out of tolerance [18]. This study aimed to analyze and estimate deformation of rivet duralium and sheet metal effectively. Comparison result was found out between duralium rivet with and without multistage artificial aging.

2. Simulation riveting process

There were two main types of riveting joint, that were lap joint and butt joint. The following figure was one of type of riveting joint which was used in this study.

Figure 1 shown double-riveted lap joint, that included two sheets metal and several countersunk head. The Table 1 explains determination of symbols in Figure 1.

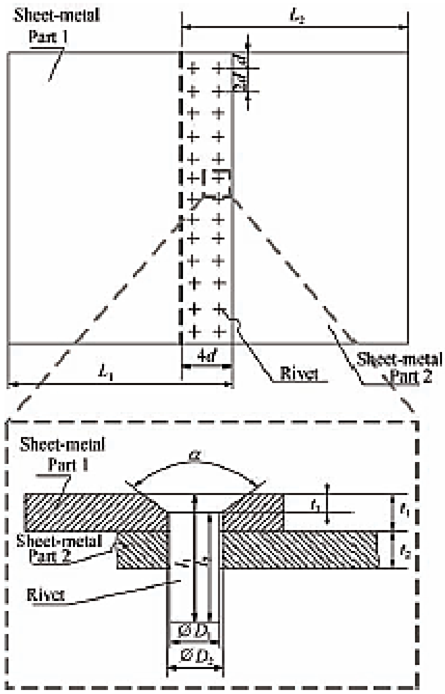


Fig. 1. Lap joint [16]

Geometry of rivet that used in this study was drawn by using Autodesk Inventor Professional 2018, while the analyzes and simulation of riveting process was performed by using Workbench ANSYS 18.1. Table 2 shown the parameter value of rivet geometry which made of aluminum alloy 2024-O (duralium without multistage artificial aging) and aluminum alloy 2024-T6 (duralium with multistage artificial aging). Figure 2 shown the riveting process, while Figure 3 shown the force that work during riveting process.

Table 1.
Determination of symbol in Figure 1

Symbol	Determination
l_1	Length of rivet
l_2	Length of rivet except countersunk head
a	Angle of countersunk head of rivet
D_1	Diameter of rivet
D_2	Diameter of riveting hole on the sheet-metal parts
t_1, t_2	Thickness of two sheet-metal parts
t_3	Height of cone shaped hole on the sheet-metal part 1
$2d$	Distance between two rivets
L_1, L_2	Length of two sheet-metal parts

Table 2.
Parameter value of rivet [16]

Parameter	Value
Length of rivet l_1, mm	9
Length of rivet except countersunk head l_2, mm	8
Angle of countersunk head of rivet a, °	120
Diameter of rivet D_1, mm	4
Diameter of riveting hole on sheet-metal parts D_2, mm	4.1
Thickness of two sheet-metal parts t_1, t_2, mm	2.5
Height of cone-shaped hole on sheet-metal Part 1 t_3, mm	1

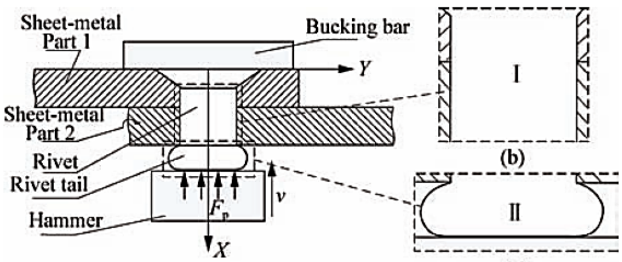


Fig. 2. Riveting process [16]

3. Result and analysis

3.1. Total deformation

Total deformation of rivet for duralium with and without multistage artificial aging were shown in Figure 4. Figure 4 shown the part of rivet and sheet-metal which had deformation due to riveting process. The greatest deformation

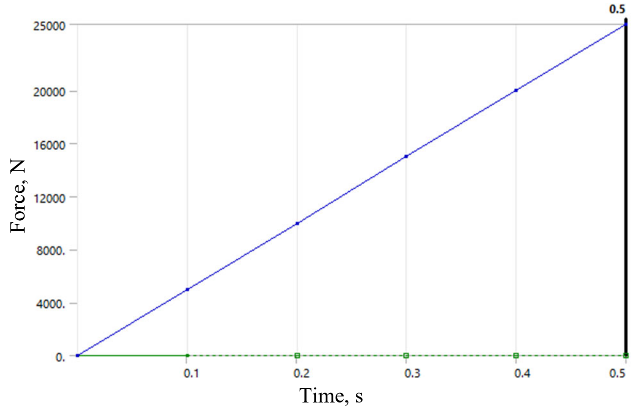


Fig. 3. Force during riveting process

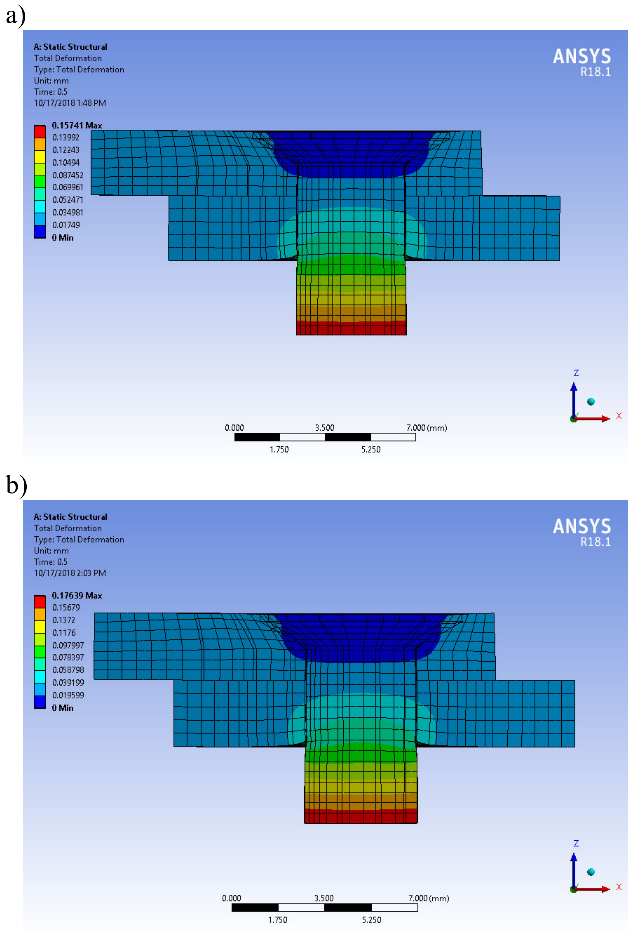


Fig. 4. Total deformation of duralium rivet: a) 2024-O, b) 2024-T6

was obtained at the rivet tail at the end time of 0.5 s with load transfer of 25 kN. Figure 4a shown the deformed area of duralium rivets that were not treated multistage artificial aging (2024-O). The red area shown the maximum deformation area, while the dark blue area shown the minimal deformation area. The maximum deformation that occurred in the red area was 0.17639 mm. Deformed area of duralium rivets that were treated multistage artificial aging (2024-T6) shown in Figure 4b. The red area shown the maximum deformation area, while the dark blue area shown the minimal deformation area. The color column on the left side shown the amount of deformation that occurred in the rivet. The maximum deformation that occurred in the red area was 0.15741 mm after getting a force for 0.5 second with an increase in force of 5 N per 0.1 second.

The value of total deformation was presented in Figure 5. According to Figure 5, total deformation of duralium with multistage artificial aging (2024-T6) had the lower value than total deformation of duralium without multistage artificial aging (2024-O). The maximum total deformation of rivet 2024-T6 at 0.5 s was 0.15741 mm, while maximum total deformation of rivet 2024-O was 0.17639 mm. The lower deformation value of rivet was recommendable [19]. This meant rivet 2024-T6 had the better performance than rivet 2024-O. The lower deformation value indicated the that material had the higher ductility [12]. This meant the ductile rivet had the higher fatigue life of riveted joint [15].

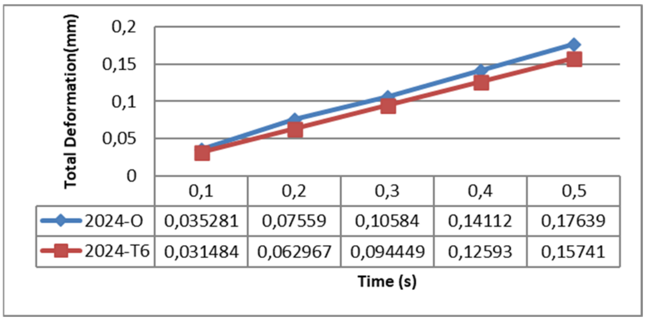
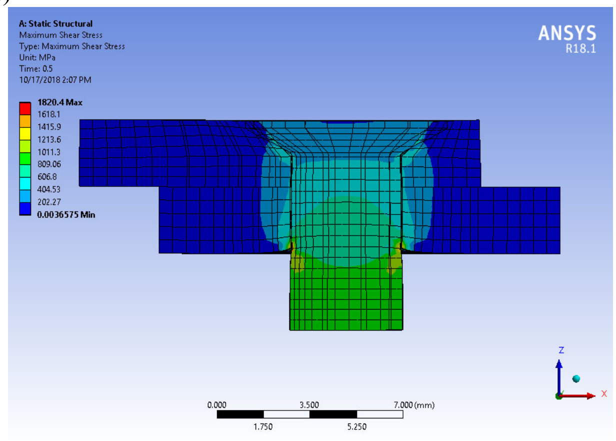


Fig. 5. Comparison of total deformation on rivet 2024-O and 2024-T6

3.2. Shear stress

Analyzing shear stress was one of method that used to understand the material failure [20]. Figure 6 presented the shear stress which had been experienced by rivet. The maximum shear stress was found at the butt of rivet joint (at the middle rivet). The result of study shown that rivet 2024-O had the higher value than rivet 2024-T6. While in this case, the lower value was recommendable. The maximum shear stress value of rivet 2024-O at 0.5 s with load transfer of 25 kN was 1820.4 MPa, while the maximum shear stress value of rivet 2024-T6 was 1754.7 MPa. Figure 7 shown the comparison shear stress on rivet 2024-O and rivet 2024-T6. Rivet 2024-T6 had slightly lower shear stress than rivet 2024-O.

a)



b)

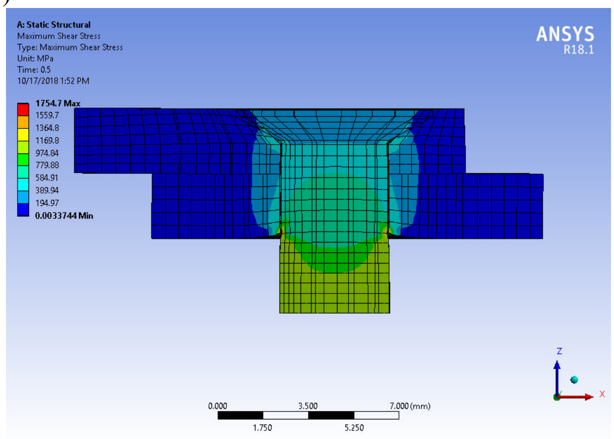


Fig. 6. Maximum shear stress of rivet: a) 2024-O, b) 2024-T6

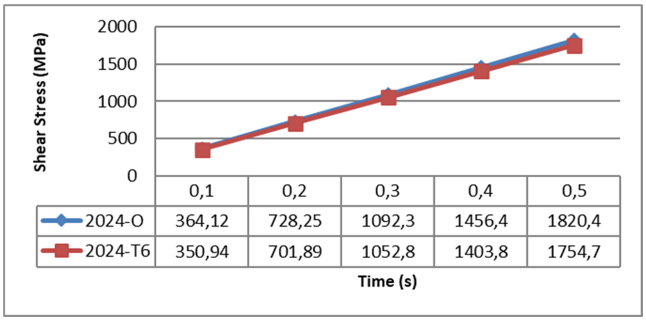


Fig. 7. Comparison of shear stress on rivet 2024-O and 2024-T6

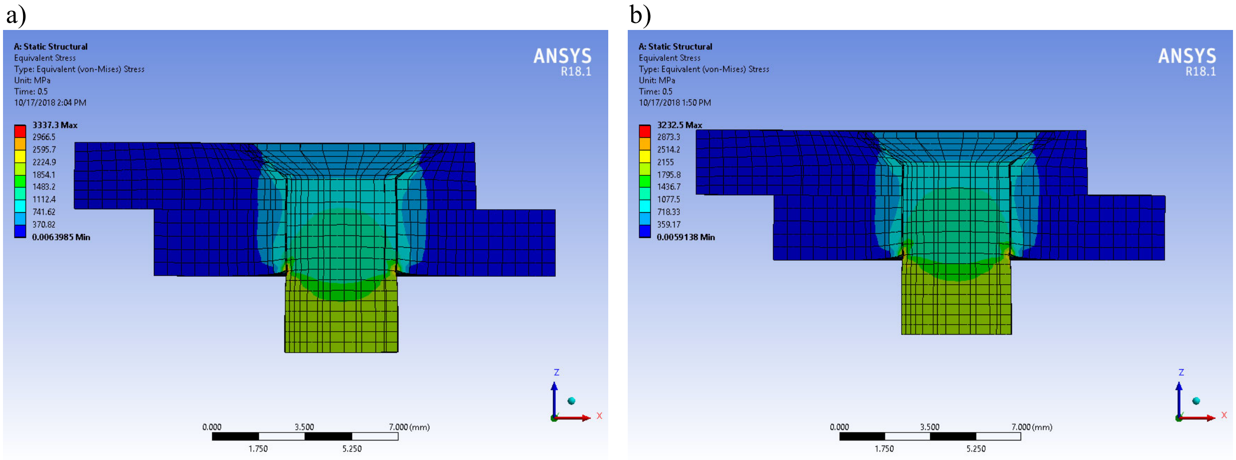
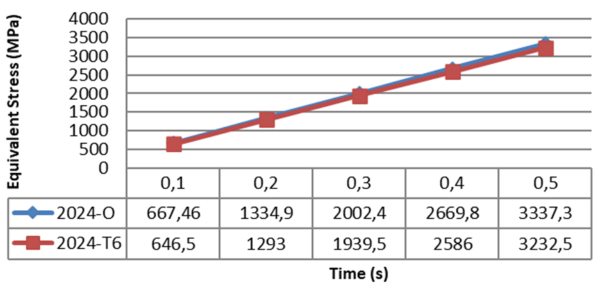


Fig. 8. Maximum equivalent stress of duralium rivet: a) 2024-O, b) 2024-T6

3.3. Equivalent stress (Von-Mises)

Figure 8 shown the equivalent stress that occurred at rivet. In this case, the best result was the rivet which had the lowest stress. The equivalent stress influenced the rivet and sheet metal in the area of rivet. Figure 9 shown that the value of equivalent stress of rivet 2024-O was higher than rivet 2024-T6. This meant that rivet 2024-T6 had the better performance than rivet 2024-O.



	0,1	0,2	0,3	0,4	0,5
2024-O	667,46	1334,9	2002,4	2669,8	3337,3
2024-T6	646,5	1293	1939,5	2586	3232,5

Fig. 9. Comparison of equivalent stress on rivet 2024-O and 2024-T6

4. Conclusions

Based on the result, it could be concluded that rivet duralium with multistage artificial aging (2024-T6) had the better performance compared with rivet duralium without multistage artificial aging (2024-O). This was proved that rivet 2024-T6 had the slightly lower value of total deformation than rivet 2024-O which was 10.76%. The shear stress value of rivet 2024-T6 was lower than rivet 2024-O which is 3.6%. The equivalent stress (Von-Mises) value of rivet was also lower than rivet 2024-O which was 3.14%. This meant that material with multistage artificial aging value had the higher ductility, thus the fatigue of material could be decreased.

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