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Experimental Investigation on Flap Peening Process of Aluminum Alloys Sheets at Various Flapping Rotational Speed

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Abstract

In this paper, flap peening treated of 2024 T3 aluminum alloy sheets with 2.5 mm thickness were investigated and presented. The specimens used for the studies were taken from an Airbus A330-200 aircraft fuselage scrap plate near the waste vent hole area. There are 5 specimens were investigated with different surface treatments. The sheets were blended out to simulate the damaged areas and sharp edge removal. Furthermore, the flap peening was applied to improve the characteristics of the damaged material surface at various rotational speeds (1500, 2500, and 3500 rpm). For investigation, the tensile strength, roughness, and hardness of the specimens were measured to study the effects of the repair process. Afterward, the specimen's macrostructure was investigated for observing the effect of corrosion removal and shot peening on the metal surface to the inner side microstructure and the occurrence of crack propagation. The measurements show there was a significant improvement in strength and hardness after flap peening was applied. Although flap peening application at 3500 rpm resulting better material properties, the difference is not significant compared to the 2500 rpm rotational speed. The result of microstructure and crack propagation observation using optical microscopy proved that shot peening on the outer surface of the material with rotations of 1500 rpm, 2500 rpm, and 3500 rpm compared to the original specimen does not have an impact on the internal microstructure of the material, and no crack propagation occurred. However, excessive flap peening intensity may potentially affect lower fatigue life, as reported by the previous research. Further study is needed to know how far the effect of the treatment on the fatigue life of the material and the optimum parameter for the flap peening process.

Index Terms: Flap peening process, aluminum alloy, hardness, tensile strength, microstructure

Introduction

Aluminum alloy delivers a valuable mixture of material properties, depending on which elements were added. It is used in a massive variety of products including aircraft fuselages and automotive parts or body structures [1]. Aluminum alloys have been the primary material of choice for structural components of aircraft from about 1930 until today [2], typically comprising 80 percent of the airframe weight [3]. It's tough, lightweight, flexible, rust-resistant, ecofriendly, and recoverable [4]-[6]. Despite these advantages, corrosion and stress corrosion cracks still can be found in the aircraft structure [7], [8]. Once the fuselage surface is restored from slight damage, re-peening the surface is required. In this case, rotary flap peening was often used to restore the compressive residual stress layer, because it is quick, clean, and cost-effective. However, the incorrect parameter used in the flap peening process may potentially affect the lower fatigue life of the material [9].

For more than 50 years, the aircraft industry has used rotary flap peening. It was initially created by 3M^{TM} for helicopters in the early 1960s, and it is renowned as an effective technique for re-peening small sections after blending to eliminate a scratch or surface damage [10], [11]. It employs 1 mm tungsten carbide balls bonded to a flexible polymeric flap striking the material and creating residual compressive stress on the surface [8].

Peening is frequently used to improve component fatigue performance and reduce inspection needs. Rotary flap peening is frequently used to re-introduce the necessary compressive residual stresses in the component if it receives a scratch or a minor surface flaw. To produce the consistent rotational speed, Shockform Inc. introduced FlapSpeed™ controller that ensures the requested rotational speed is always maintained, thus providing an optimal and repeatable peening intensity. It was reported that the use of the controller resulting better surface finish, and equivalent or better compressive residual stress profiles [9].

Figure 1. *FlapSpeed Pro kit*
Source: *Electronics Inc.*

Several studies have been conducted to research the effect of the flap peening process on the material properties. Recently, Shaban et al. [12] compared different flap peening rotational speeds (1000-8000 rpm) effects on several aluminum materials. It was reported that surface roughness and hardness were increased by higher flap peening rotation. A similar experiment was conducted to study the effect of flap peening rotational speed (2000-12000 rpm) and standoff distance (8-14 mm) on aluminum alloy (7075-T6) material properties [8]. The hardness and morphology of the treated specimen were compared. It shows that the highest rpm at 14 mm distance treatment gives the optimum surface properties.

In the present work, 2024 T3 aluminum alloy sheets, with copper as the primary alloying element, were treated using flap peening at various rotational speeds. The samples were then compared to study the effects on material properties, including hardness, strength, and morphology.

Experimental Method

The specimens selected for the present study are aluminum alloy type (2024-T3) taken from an Airbus A330-200 aircraft fuselage scrap, and the material properties was shown in table 1. The specimens were 2.5 mm thick and cut to 120 × 50 mm in size. After the paint was removed from the surface, a sanding process was applied before the peening process was conducted to blend out any scratches from the damaged sheets, resulting in the thickness being reduced to 2.2 mm.

Tabel 1. *Mechanical properties of the specimen [13]*

Properties	Aluminum 2024-T3
Shape	Plate 2.5 mm thick
Tensile Yield Strength (MPa)	345
Ultimate Tensile Strength (MPa)	483
Elongation (%)	18
Hardness, HRB	75

FlapSpeed peening tool set equipped with Shockfrom speed controller was used to apply the further surface treatment. As per Structure Repair Manual (SRM) 51-29-11 for the aircraft, the recommended flapping speed is 2500 rpm for the specified plate type with intensity 0.01 mm. Furthermore, various flapping speed was applied to the different specimen, i.e., 1500, 2500, and 3500 rpm, to study the effect on the material properties. The peening time was set as 6 minutes, obtained by multiplying the area of the required part in square inches with saturation time and divided by 2.25 square inches of Almen test strip. The saturation time is 5.74 and was acquired from curve solver software provided by Sockform with converting the specified peening intensity. The orientation of the flapping was directed in 3 different ways (horizontal, vertical, and 45 degrees; switched every 2 minutes).

Five specimens were prepared with different peening treatments and were named specimens 1, 2, 3, 4, and 5. Specimen No. 1 was tested in the original condition without any additional treatment while specimen No. 2 was blended-out only without peening treatment. Other specimens were blended-out and peened with different rotational speeds as shown in Table 2.

Tabel 2. *Specimen's treatment*

Sample No.	Thickness (mm)	Flap Speed (Rpm)
1	2.5	No treatment
2	2.2	No treatment
3	2.2	1500
4	2.2	2500
5	2.2	3500

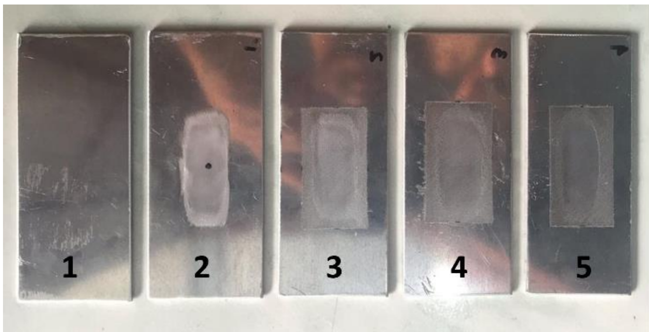

Figure 2. *The area of surface testing.*

Rockwell (B) hardness test was performed to the treated specimens using Mitutoyo HR-430MR Rockwell Hardness Tester. The following surface test using Mitutoyo Surface tester SJ-210 was conducted to measure the surface roughness. Several measurements were performed on each specimen and the average surface roughness (µm) is presented. Figure 2 shows the area of the measurement on the specimen surface. The tensile strength measurement was conducted using the Universal Testing Machine (UTM) at GMF Aeroasia facility. The tensile specimens were mounted on UTM, and only those that fractured within the gauge length had their tensile strength and elongation during testing calculated.

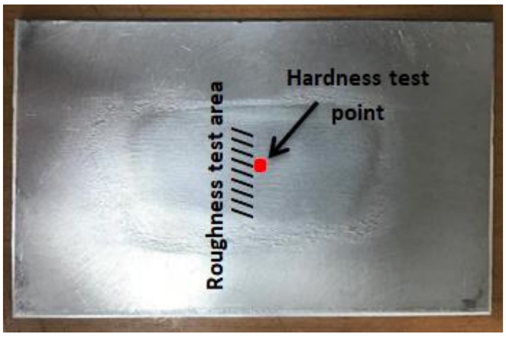

Figure 3. *The area of surface testing.*

The microstructure of the specimen cross section was observed using Meiji Techno Metallurgical Microscope MT7100 with 200 times magnification. The same optical microscope was used before to investigate the coconut fiber composite microstructure in the previous experiment, the report was presented in the reference [14]. For this purpose, the specimen was sanded gradually from 100 to 1500 grit sanding paper as shown in figure 3.

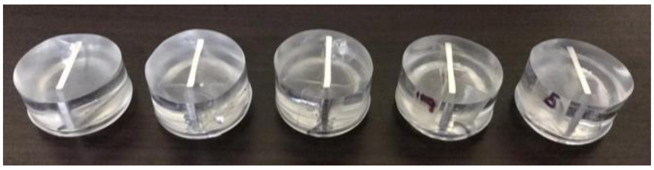

Figure 4. *Specimen preparation for microstructure observation.*

Results and Discussion

The tensile test, hardness test, roughness measurement, and optical microscopy observation are discussed here.

Figure 5 shows the comparison of hardness (HRB) and average roughness of the specimens at different flap peening rotational speeds. The material initial hardness was presented by specimen No. 1 (73 HRB). The blend-out process does slightly affect the hardness, and a significant effect appeared after applying flap peening. The hardness of the material increases gradually from 87 to 92 and 97 by increasing rotational speed from 1500 to 2500 and 3500 respectively. Based on the result, increasing the rotational speed result in a higher hardness number. However, it may potentially affect a lower fatigue life [9]. Further study essentially needs to be conducted to know how far the effect of the treatment on the fatigue life of the material and the optimum parameter for the flap peening process.

The average roughness measurement results show typical trending line to hardness number results. The flap peening process with higher rpm increased the surface roughness. The previous research shows that smoother surface results in better fatigue life [9].

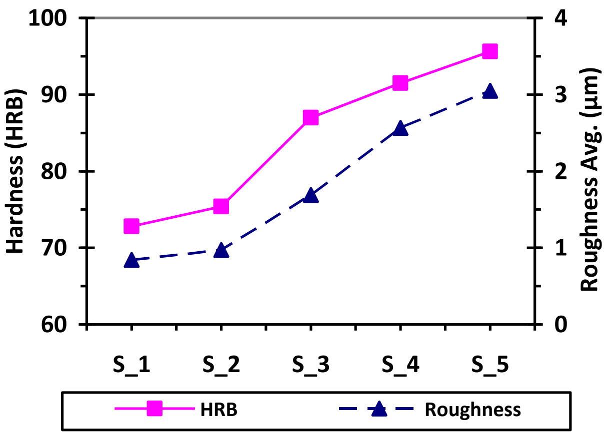

Figure 5. *The hardness and roughness testing results of the specimens.*

Figure 6 shows the comparison of ultimate tensile strength and elongation of the specimens at various flap peening speeds. The results show the strength and elongation of the material increased as the result of higher flap peening intensity. The previous experiment conducted by Tolephih et al. reports that as the shoot peening time on AA 2024-T3 increased, the elongation of the material also increased. However, as the time is longer than 9 minutes, the elongation tends to decrease [15]. Based on this report, the trend line of the elongation will reach the maximum at a certain point and will be decreased gradually because of the decreased material strength.

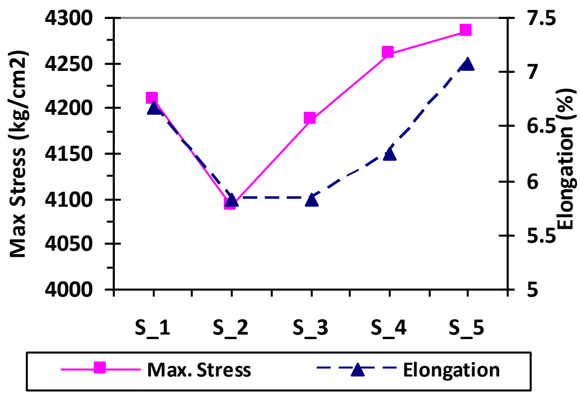

Figure 6. *Ultimate tensile strength and elongation results of the specimens*

Figure 7 shows the results of observations using optical microscope on the specimens of original, blended out and peened for various rotation speeds. Observations were conducted from the side of the peened plate, not from the surface. The purpose of this observation is to observe whether there are changes in the microstructure or the appearance of cracks propagation in the inside of the peened surface.

Sample No. 1 is the inner microstructure of the original condition specimen without any treatment, while specimen No. 2 was blended-out only, without peening treatment. From these two specimen samples. These specimens had no obvious change, seems to be almost same. This means that the inner microstructure of the material is not affected by the blended-out process.

Samples no. 3, no. 4 and no. 5 are shot peened specimens at 1500 rpm, 2500 rpm and 3500 rpm rotational speed. From these three images, the microstructure of these specimens had no obvious change, there aren’t any cracks propagation in the inner side on shot peened surface specimen, likewise when compared to the original specimens. This proves that shot peening on the outer surface of the material with rotations of 1500 rpm, 2500 rpm and 3500 rpm does not have an impact on the internal microstructure of the material, and no crack propagation occurred, likewise when compared to the original specimen.

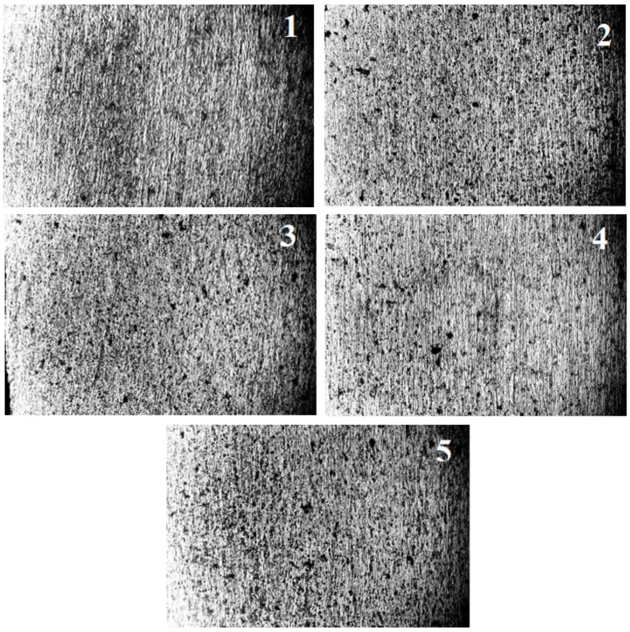

Figure 7. *Microstructure of the specimens at 200 times magnification.*

Conclusion

The investigation of aluminum alloy 2024 T3 has been conducted to study the effect of the flap peening process on the hardness, surface roughness, tensile strength, and microstructure of the material. The flap peening was applied to the specimens at various rotational speeds, i.e., 1500, 2500, and 3500 rpm.

Results showed that increasing the rotational speed result in a higher hardness number, surface average roughness, ultimate tensile strength, and elongation of the material. The observation of the microstructure and crack propagation using optical microscopy proved that shot peening on the outer surface of the material with rotations of 1500 rpm, 2500 rpm, and 3500 rpm compared to the original specimen does not have an impact on the internal microstructure of the material, and no crack propagation occurred.

However, excessive flap peening intensity may potentially affect lower fatigue life. Further study regarding the effect of the flap peening process parameter on the fatigue life is necessary.

Acknowledgments

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