DOI: https://doi.org/10.24425/amm.2022.139675

NABEEL ABU SHABAN[1], NABEEL ALSHABATAT[2], SAFWAN AL-QAWABAH[1*]

EFFECT OF FLAP PEENING SPEED ON THE SURFACE QUALITY AND MICRO HARDNESS OF AIRCRAFT ALUMINUM ALLOYS

Flap peening (FP) is a cold working technique used to apply a compressive force using small shots, this will lead to enhance the surface properties that it can sustain for long life during working conditions. In this study, several aircraft aluminum alloys materials namely; 2219 T6, 2024 T6, 7075T6, and 6061 T6 were flap peened under different rotational speeds. The effect of rotational speed on the average surface roughness (Ra) and average surface micro hardness have been investigated. As seen by the Scanning Electron Microscope SEM phots that the hardness of peened layer is increased. It was found that as the flap peening speeds increase the percent change in surface roughness (Ra) increases, and the percent change in surface micro hardness decreases. The maximum increase in Ra occurs in 2219 T80 and the minimum in 6061 T6 alloys, and for hardness, it is reported that the maximum occurs in 6061 T6 and the minimum in 2019 T80 alloy.

Keywords: Surface roughness; Surface quality; Material processing; Flap speed; Surface hardness

1. Introduction

The high specific strength of aluminum alloys has extended its potential applications to the aerospace field. Mechanical surface enhancement technologies have been used for improving the fatigue strength of aluminum alloys because it is well known that most failures of material occur at its surface. The selection of these Al-alloys; 2219 T6, 2024 T6, 7075T6, and 6061 due to their wide usage in the aircraft industry, i.e. Boing airplanes. most airplanes parts especially that subjected to cyclic loading after should be flap or shot peened to enhance its life time, also it will be preventing treated parts from crack initiation and crack propagation, on the other hands this process used to repair the failure of some parts.

Among such technologies, Shot peening, which is one of the surface modification processes, is widely used in the industry. It induces severe plastic deformation directly onto the surface region of materials. It has been reported that severe plastic deformation on the surface region leads to surface un crystallization and which causes improvements in mechanical, corrosion, wear properties, and fatigue strength, [1-6]. The atoms on the surface of a piece of manufactured metal will be (mostly) under tensile stresses which leftover from grinding, welding, heat treatments, and other stressful production processes. Cracks promulgate easily in areas of tensile stress because the tensile stresses are already working to pull the atoms of the metal apart. By shot peening the material you introduce a layer of compressive stress by compacting the material. As the shot peening is performed, the atoms on the surface of the metal become crowded and try to restore the metal's original shape by pushing outward. The atoms deeper into the metal are pulled toward the surface by their bonds with the atoms in the compressive layer. These deeper atoms resist the outward pull creating internal tensile stress that keeps the part in equilibrium with the compressive stress on the surface, [7-9]. A flap peening process is a form of shot peening and it is very useful for reworking small spaces. The flap is also called freestanding peening because the shot is attached to the flap allowing for use on the assembled structures since the shot does not fly in all directions. On the other hand, Sheen peening is used to shape parts like side panels, and although the intensity is limited by the flap it is still high enough to enable straightening under certain conditions. Improved fatigue for lead polishing has been well documented but not the case for volatile staining. Recently, an OEM questioned the flap straightening process to conclude that this process would reduce the shelf life of the part. The method was surprisingly effective, so it was incorporated

1 AL-ZAYTOONAH UNIVERSITY OF JORDAN, MECHANICAL ENGINEERING DEPARTMENT, AMMAN, JORDAN
2 TAFILA TECHNICAL UNIVERSITY, MECHANICAL ENGINEERING DEPARTMENTTAFILA 66110, JORDAN

* Corresponding author: safwan1q@gmail.com

into our straightening and straightening process specifications. It was decided that although the inhibition process is known to increase the life of fatigue, we must test it on straight samples to demonstrate that the method is a viable and cost-effective method without affecting the parts. Peening is a cold old process for metals. When the medieval blacksmiths crafted swords and shields, they punched the metal and moved the remaining pressure to the surface. This reinforced the surface pressure of the material pressure, which improved the resistance to fatigue fracture and stress wear. The upper plate has generally replaced the blacksmith hammer in the modern industry. But the benefits of the process are the same. Most peening methods of fire cast steel fire on the work surface. An air blast, similar to a sandblast, or a centrifugal wheel is used to drive fairly high speed. For small and/or hard-to-reach surfaces, the captive shot method is more convenient and effective. The shot is incorporated into a rotating brush or flap. A spinning brush or flip-flop is held close to the surface so that the captive fire hits the metallic surface with each revolution, [10]. Flap peening is a cold working process that imparts a small indentation on the surface of a part by impacting small spheres called shot onto the material surface. This process creates the same effect that a peening hammer does by causing the outer surface to yield in tension. The material directly beneath it is subjected to high compressive forces from the deformation and tries to restore the outer surface to its original shape. By overlapping the surface indentations, a uniform compressive layer is achieved at the surface of the material. The compressive layer squeezes the grain boundaries of the surface material together and significantly delays the initiation of fatigue cracking. As a result, the fatigue life of the part can be greatly increased, [10]. Surface integrity contains several indexes, such as surface roughness, surface topography, surface residual stress, surface microhardness, and microstructure, [11]. Friction was considered as an influencing parameter on the results of peening. Meguid et al., [12] determined that the presence of friction, in the form of the friction coefficient μ, between shots and the surface leads to a decrease in surface plastic deformation and surface residual stresses. Similar conclusions on the effect of friction revealed that friction does not have a significant effect on the variation of residual stresses and plastic strains for $0.1 \le \mu \le 0.5$, one of the primary methods for obtaining materials with better mechanical properties is the surface treatment technology. Among these processes is laser surface alloying, which can lead to obtaining good wear resistance on aluminum substrate, [13-15].

In this study, the effects of flap peening speed on the average surface microhardness and average surface roughness (Ra) of aircraft aluminum alloys namely; 2219 T6, 2024 T6, 7075T6, and 6061 T6 will be investigated.

2. Experimental part

2.1. Materials

The materials used in this study are 2219 T80, 6061 T6, 7075 T6, and 2024 T3 aluminum alloys which were supplied as rolled plates with 6 mm thickness. The chemical compositions of these alloys are summarized in TABLE 1.

2.2. Flap peening process

Flap peening uses a flexible flap equipped with tungsten carbide balls embedded in a Kevlar matrix. The flap is installed on a shaft and rotated using a pneumatic or electric grinding wheel. The flap is then applied to the part to be peened or shaped and the end balls strike the part to treat it. The process is controlled by the rotational speed of the shaft and the size of the flap. The flap peening machine, Almen strip, schematic diagram of the flap peening process, and a sample flap peened workpiece are shown in Fig. 1.

2.3. Experimental procedures

2.3.1. Methods of flap peening

2.3.1.1. Strain peening

When the pressure above the compressive pressure exceeds the external pressure causes more pressure over the entire compressive layer. This pressure is being created. When the damping media is on the surface, the surface layer is tenser due to the preload. Yield creates additional pressure.

2.3.1.2. Intensity

To change media size and snapshot speed using larger media or increasing snapshot flow velocity increases the intensity of snapshot stabilization. This process is done before the polishing process. The detection time for the material is determined from the saturation point of the saturation curve, [16].

TABLE 1

Chemical compositions of aluminum alloys (wt. %)

Al Alloy \ Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	V	Zr	Al
2219 T80	0.06	0.14	6.7	0.31	0.01	0.00	0.03	0.04	0.07	0.13	Bal.
6061 T6	0.74	0.6	0.35	0.07	1.0	0.18	0.18	0.03	0.01	0.00	Bal.
7075 T6	0.74	0.6	0.35	0.07	1.0	0.18	0.18	0.03	0.01	0.00	Bal.
2024 T3	0.50	0.5	4.9	0.9	1.8	0.1	0.05	0.2	0.15	0.05	Bal.

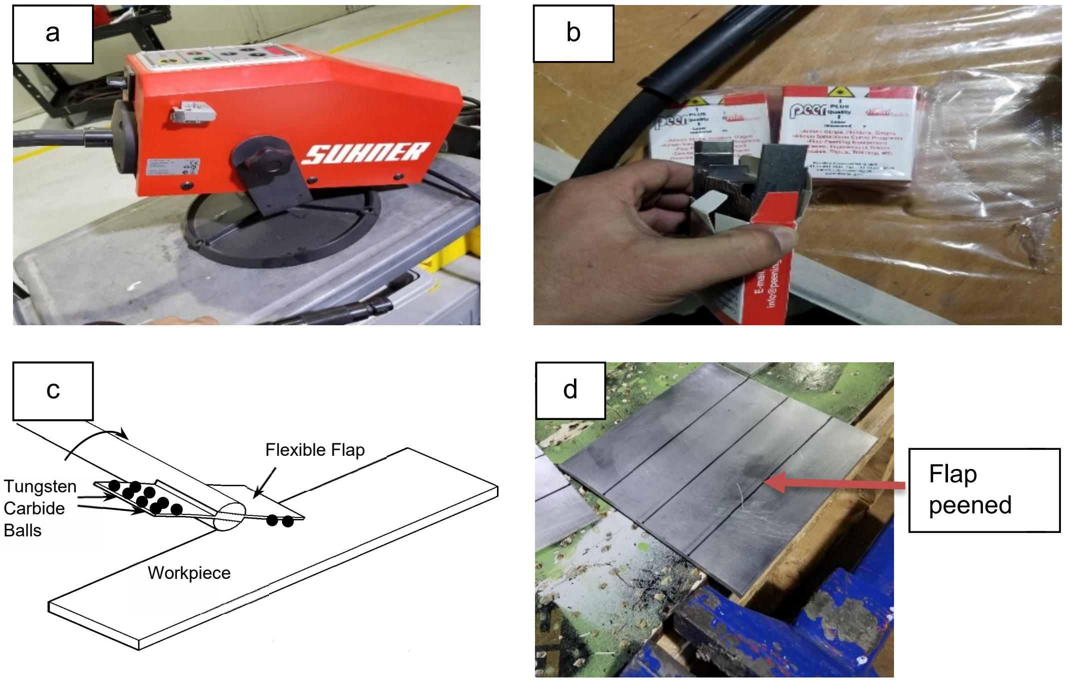

Fig. 1. a) SUHAER flap peening machine, (b) Almen Strips, (c) Schematic of flap peening strip, and (d) a sample of the tested material

2.3.1.3. Coverage

Coverage is the measure of the original surface area that has been obliterated by shot dimples. Coverage is crucial to high-quality shot peening and should never be less than 100%. A surface that does not have 100% coverage is likely to develop fatigue cracks in the un-peened surface areas. Miao et al. [16] showed from FE simulation that the influence of stretching on the arc height is negligible. Moreover, the arc height along the length depends mainly on the dimensions of the strip and Young's modulus of elasticity. Also, the thinner strip and softer material will experience higher deformation under the same induced bending moment.

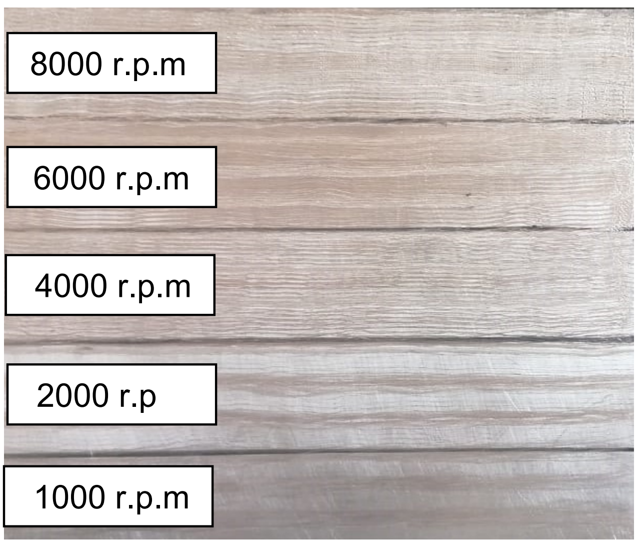

Fig. 2. Aluminum workpiece after flap peeing process at different speeds, 10×

2.3.1.4. Flap peening test

This procedure is usually used when it is necessary to pre-stress the surface of a component or part of the structure. Every workpiece is divided into five regions, where each region is flap peened at rotational speeds; 1000, 2000, 4000, 6000, and 8000 rpm as shown in Fig. 2. The feed rate of the flap peen mandrel is fixed at 300 mm/min, where the standoff distance is also fixed at 15 mm. a SUHAER flap peeing machine was used in this investigation that is shown in Fig. 1a.

Peening flaps must be discarded after 30 minutes of use, or, after, the loss of 20% of the tungsten carbide balls if this occurs sooner. The main specifications of the flap and balls are shown in TABLE 2.

TABLE 2

Main specifications of flap and balls (shots)

Ball material	Ball hardness (HV)	Ball diameter (mm)	Intensity (mm N)	Standoff Distance (mm)	Arc height (mm)
Tungsten carbide balls	1330	0.125-0.425	0.3	15	0.15

2.3.2. Surface Roughness test

Average surface roughness (Ra) was measured after each flap peening process, using SURF-CORDER roughness tester based on a cut off distance = 0.8 mm based on ISO 13565 (Rk). A sample of surface texture for Ra measurement is shown in Appendix A. The measurements were taken at three different locations, then the average of (Ra) was obtained.

2.3.3. Microhardness tests

Vickers microhardness measurements were conducted more than 10 times for each hardness value using micro Vickers hardness tester (HWDM-3) with a load of 100 gmf and dwell time of 10 s.

2.3.4. Macrostructure examination

A microscope type (NIKON 108) was used in the macrostructure test, that a photomicroscans at 10× and 20× were performed for different aluminum alloys.

3. Results

3.1. The effect of flap peening speed on the microhardness of Al alloys

The average microhardness of 2219 T80, 2024 T3, 7075 T6, and 6061 T6 aluminum alloys (as received) are summarized in the histogram of Fig. 3. The 6061 T6 alloy has the maximum microhardness and the 7075 T6 alloy has the minimum microhardness.

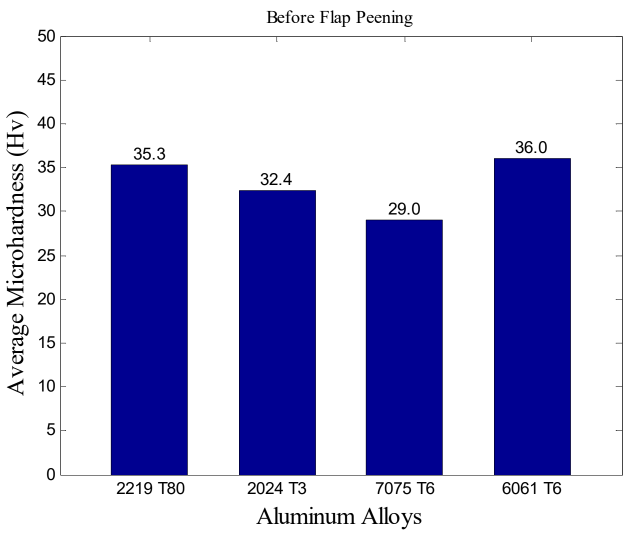

Fig. 3. Average micro-hardness of Al alloys before flap peening process

The microhardness results after flap peening are shown in Fig. 4. The microhardness of all the aluminum workpieces increases as the flap peening speed increase. For all rotational speeds under consideration, the microhardness increases by the flap peening process. Also, there is an indirect relation between the microhardness and the rotational speeds under consideration. At 1000 rpm rotational speed, the maximum percentage increase in microhardness occurs in 6061 T6 (i.e., 140%) and the minimum percentage increase in microhardness occurs in 2219 T80 (i.e., 65%). Also, it can be seen that the minimum microhardness values occur at high velocities and they are being still greater than those values before the flap peening process for all aluminum alloys.

The trend of the results agrees with those available in other studies of the shot peening process conducted on 2024 T3 alloy [17]. The increase in microhardness results from the dislocations on the surface by energy form shots and from the small precipitations that remained undissolved and kept its original shape despite severe plastic deformation could be considered to be a secondary factor for the surface hardening [17]. The microstructural effect of shot peening in aluminum alloys is ambiguous. On one side, work hardening is responsible for enhanced resistance to crack initiation, on the other side, it causes lower crack growth resistance due to material embrittlement, [18]. Regarding the effect of sever plastic deformation Wu. et al. [19] reported that there is an induced subdivision of grain and aluminum alloy 7075 was nano crystallized by subgrain rotation to accommodate the strain, where other researchers reported that severe plastic deformation grains of aluminum alloy 2024 were refined into nano-sized grains by the sequence of dense dislocation and twining, submicron grain, and breakdown of subgrains when severe plastic deformation was applied to the surface of aluminum alloy 2024, [20]. As a result of the flap, the peening process will enhance the fatigue life of mechanical parts, where the shot peening process can identify the fatigue source location in the subsurface and improve the fatigue life about 23 times than the milling process, [21]. The indirect relation between the flap peening velocity and the microhardness values due to the micro-cracks which are formed at high velocities. These micro-cracks make the indenter of the testing machine to go easily in the surface layer, however, the trace of indenter is increased so the hardness value of hardness will decrease, moreover, the increase in hardness depend on the ductility limit of material which to be peened. aser power. The average micro-hardness value after surface laser process was increased from 30 HV to 189 HV for Al-CuMgMn alloy, [22], moreover, a related study reported that the effect of the flap peening process parameters on the corrosion and oxidation resistance of the (7075-T6) aluminum alloy show a significant modification on the surface morphology, [7].

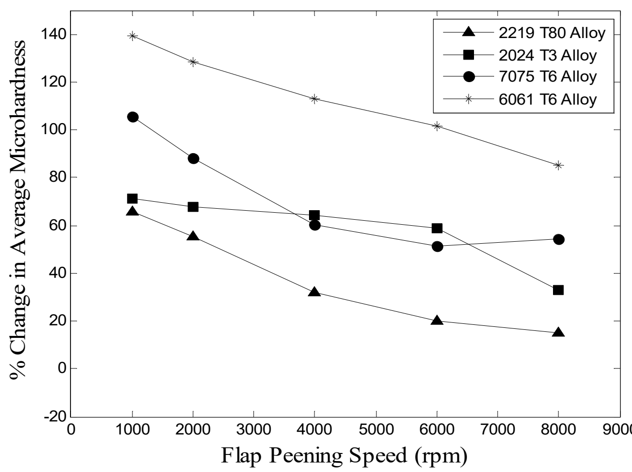

Fig. 4. The % change in average microhardness (HV) after flap peening for aluminum alloys

3.2. The effect of flap peeningspeed on the average surface roughness of Al alloys

The average surface roughness (Ra) values of the aluminum alloys workpieces, before flap peening processes, are summarized in the histogram of Fig. 5.

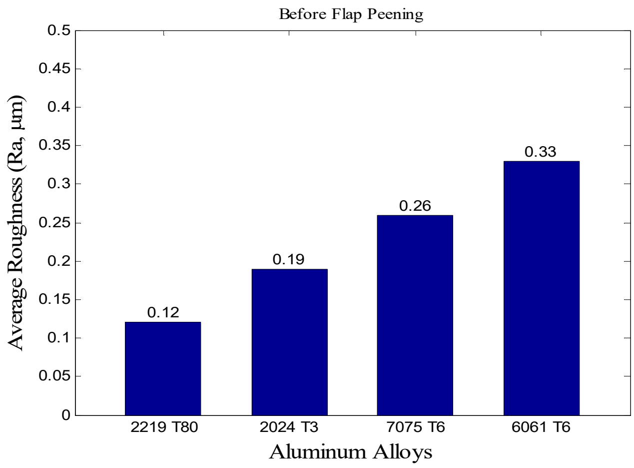

Fig. 5. Average surface roughness (Ra) of Al alloys before flap peening

The percentage change in roughness (Ra) versus the rotational speed of flap peening is shown in Fig. 6. It is obvious that as the flap peening velocity increases the roughness increases. This is expected and agrees with other studies investigated surface plastic processes such as shot peening and roller burnishing, [19], Furthermore, Fig. 6 shows that the maximum percentage increase in the roughness occurs in the 2219 T80 alloy, and the minimum percentage decrease in the roughness occurs in the 6061 T6 alloys. By comparing the effects of the rotational speed of the flap pening process on the microhardness and roughness of the aluminum alloys, it can be note that 6061 T6 alloy has the maximum percentage increase in microhardness and the minimum percentage increase in roughness among all the aluminum alloys under consideration. Also, it can be note that 2219 T80 alloy has the minimum percentage increase in microhardness and the maximum percentage increase in roughness among all the aluminum alloys under consideration. In general, the increase in microhardness accompanies with an increase in roughness, this can be attributed also to the existence of elements Mg, Si, Cr, and Zn that available in the 6061 T6 alloy, where the effect of shot peening on the average surface roughness was studied by [18] show that the effect of the shot peening process on samples is very strong and causes a significant increase in surface roughness; different milling parameters caused the huge difference of surface roughness Ra from 0.184 to 1.4 µm. [23] reported that sometime the increase in surface roughness values is an advantage that the shot impacts create a higher surface roughness, which may contribute to better adhesion of surface coatings that are usually applied to reduce oxidation.

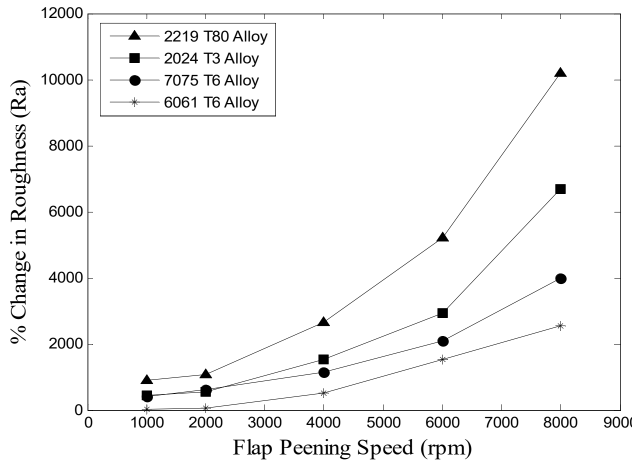

Fig. 6. The % change in the surface roughness (Ra) of Al alloys after flap peening

3.3. The effect of flap peening velocity on the surface topography of Al alloys

Fig. 7 shows the surface of aluminum alloy workpieces both at high and low flap peening speeds. The grooves have more depth at high speeds more than those at low speeds. This

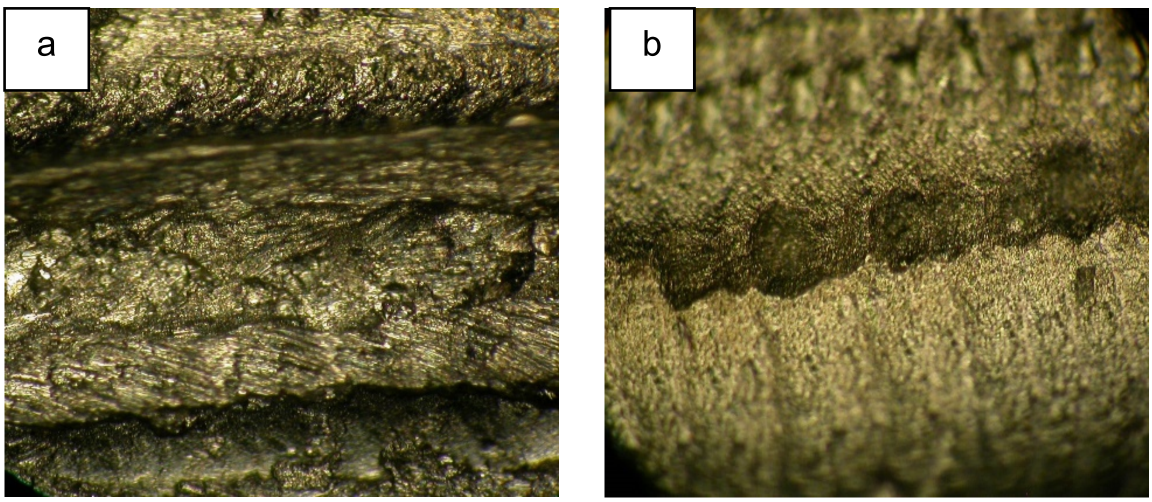

Fig. 7. Photomacrograph of the peened surface at 20×, a) flap peened surface at low speed, b) flap peened surface at high speed

can explain the increase in the average surface roughness, Ra, at high speeds. Also, the deepest grooves make the micro indenter easily to go through the surface layer, which leads to a reduction in the microhardness values. [24] reported that the microhardness, residual stresses, and surface roughness of 7075 alloy under different heat treatment conditions was enhanced, and they recommend to have heat treatment after surface plastic deformation.

3.4. Analysis of depth of flap peened layer

Fig. 8 shows the maximum depth of flap peened layer for 2219 T80 that achieved (at speed of 1000 rpm), the depth is 115 µm, it obvious that it has a homogenous and constant depth, the type of residual stresses in this layer changed from tensile to compressive one. however, it has a high hardness value, However, it will sustain for high load especially under cyclic load. It is very important to avoid reach over peening, that will lead to the incitation of cracks, also it obvious that the grains in the peened layer were refined due to severe plastic deformation, this can explain the high increase in microhardness values after the peening process, this is consistent with previous study Breuner et.al. that reported shot peening leads to high compressive residual stresses and increased surface hardness of the specimens due to work hardening. Stress-free annealing at 750 _C for 8 h reduces both effects; however, they are still significant [25].

The results revealed significant growth of dendritic arms during the solidification process, which is accompanied by disintegration and fragment production [26].

SEM scans in Fig. 9 show the general surface (as received) of 2219 T80 alloy, it obvious that it free of intermetallic compounds.

On the other hands it is clear that in the SEM scans in Fig. 10 after sever plastic deformation that caused by flap peening there are an intermetallic compound in white color, this can explain the increases in the hardness values, it is also obvious from Fig. 10 that the distribution of these intermetallic compounds is homogenous, where their shapes are eqi-axed.

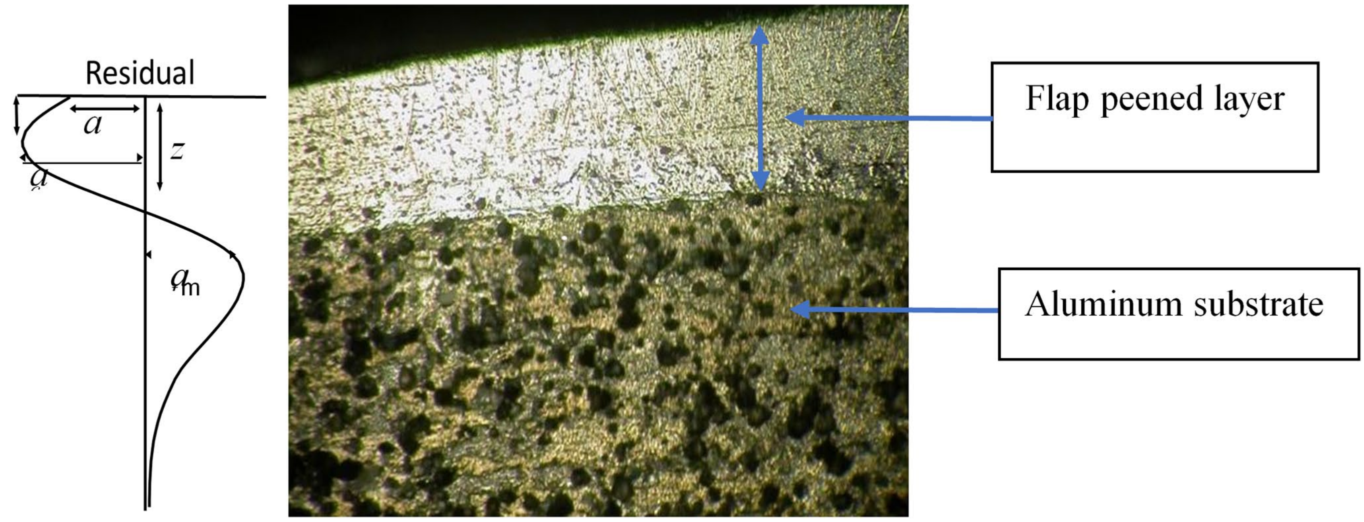

Fig. 8. Photomicroscan shows the flap peened layer of 115 µm depth for 2219 T80 aluminum alloy

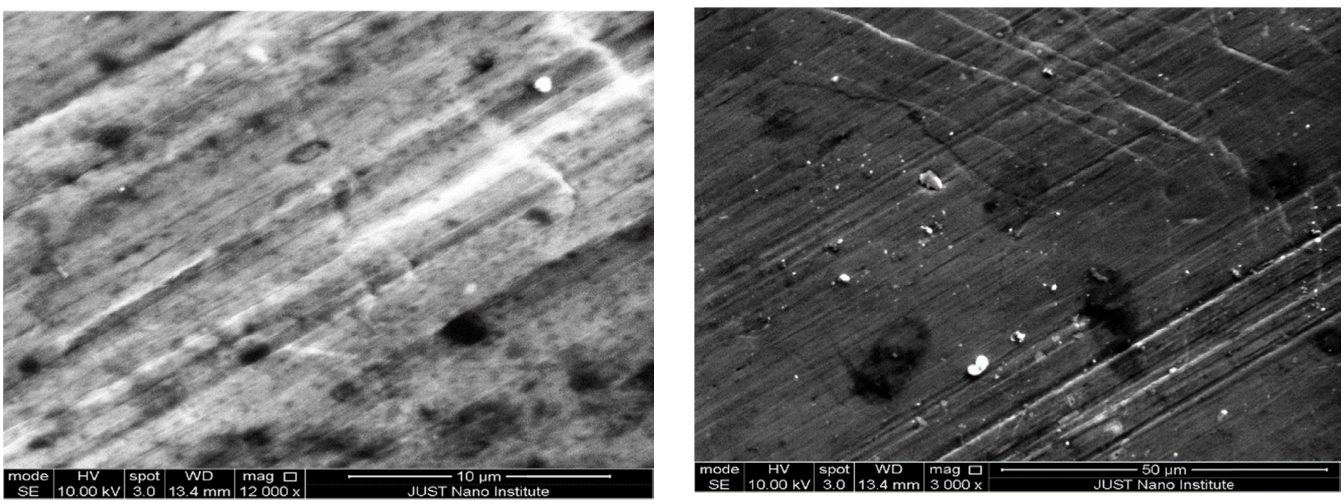

Fig. 9. SEM of 2219 T80 alloy before flap preening process at 12000× and 3000×

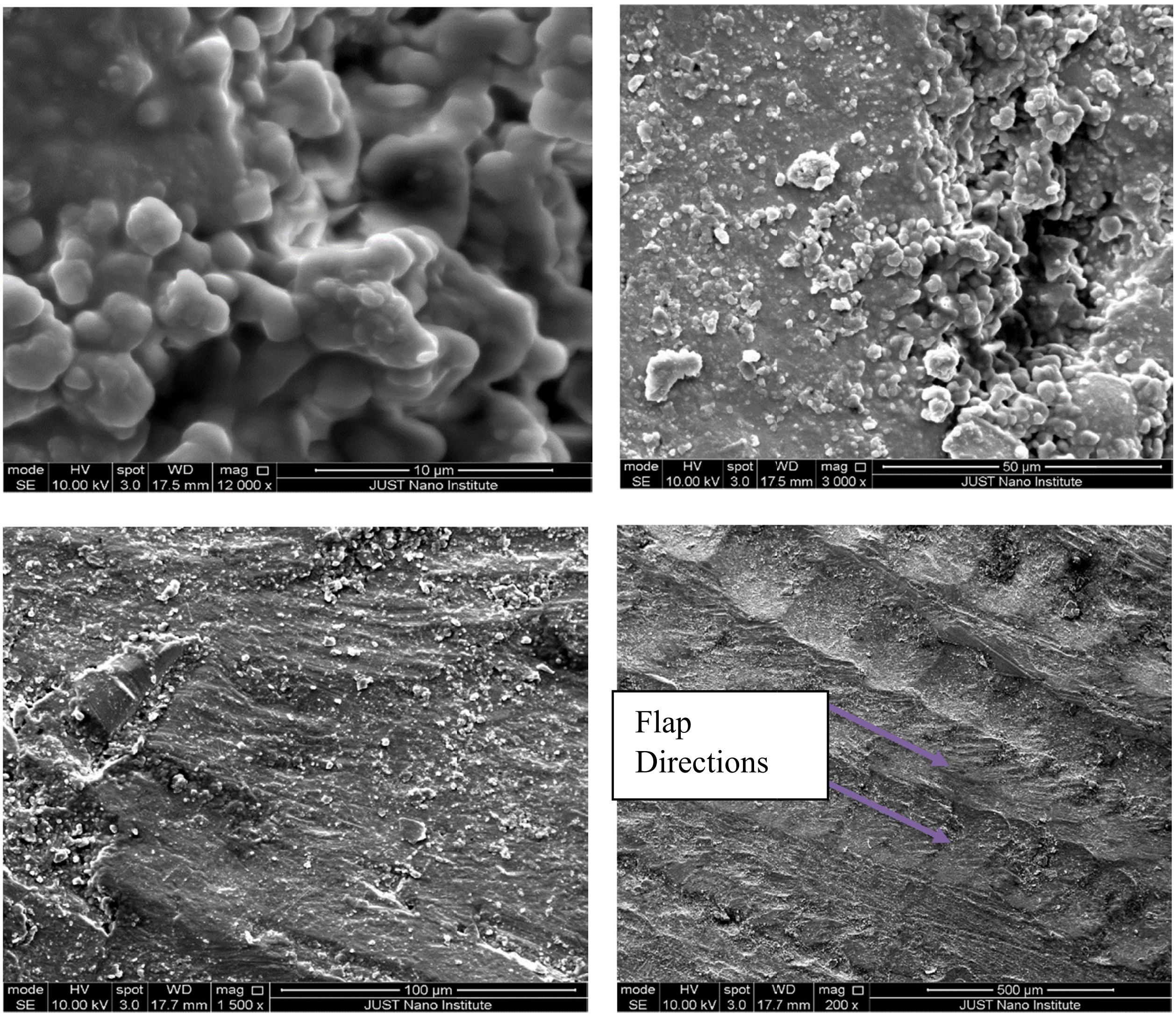

Fig. 10. SEM of flap peened layer of 2219 T80 alloy at 12000×, 3000×, 1500× and 300×

4. Conclusions

The following can be concluded:

- The flap peening process should be used for the aircraft industry.
- The best flap peened layer depth is 115 µm that achieved at 1000 r.p.m. for 2219 T80.
- There is a direct relationship between the flap speed and the surface roughness Ra.
- It is recommended to work at 1000 rpm flap peening speed, so the following surface roughness and the percentage increase in microhardness can be achieved:
  - For 2219 T6, Ra = 1.17 µm and % increase in hardness is 65%.
  - For 2024 T6, Ra = 0.99 µm and % increase in hardness by 70%.
  - For 7075 T6, Ra = 1.27 µm and % increase in hardness by 107%.
  - For 6061 T6, Ra = 0.38 µm and % increase in hardness by 140%.
  - After peening process heavy plastic deformation produce homogenous intermetallic compound that resulted in the enhancement in the hardness values.
  - Shot impacts create a higher surface roughness, which may contribute to better adhesion of surface coatings that are usually applied to reduce oxidation.

Aknowlegment

Authors would express their thanks to students; Haitham Abu Alsamen, Mohammad Al Zaghaybeh, and Abedlrahman Abedlrahman for their help in this study, also express their thanks to Al-Zaytoonah University of Jordan for its research fund No. (11/11/2020-2021).

REFERENCES

[1] D. Hammond, S. Meguid, Eng. Fract. Mech. **37**, 373-387 (1990). DOI: https://doi.org/10.1016/0013-7944(90)90048-L

[2] S. Zagar, J. Grum, J. Mech. Eng. **57**, 379-384 (2011). DOI: https://doi.org/10.5545/sv-jme.2010.092

[3] L. Wen, Y. Wang, Y. ZhouL, L. Guo, Mater. Chem. Phys. **126**, 301-309 (2011). DOI: https://doi.org/10.1016/j.matchemphys.2010.11.022

[4] C.A. Rodopoulos, S. Curtis, E. Rios, J. SolisRomero, Int. J. Fatigue **26**, 849-856 (2004). DOI: https://doi.org/10.1016/j.ijfatigue.2004.01.003

[5] A. Ali, X. An, C.A. Rodopoulos, M. W. Brown, P. O'Hara, A. Levers, S. Gardiner, Int. J. Fatigue **29**, 1531-1545 (2007). DOI: https://doi.org/10.1016/j.ijfatigue.2006.10.032

[6] H. Suzuki, H. Makino, K. Mizuno, T. Tomita, Influence of shot peening on fatigue strength of aluminum-alloy parts. Proceedings of the 10th ICSP, American Shot Peening Society: Tokoyo, (2008).

[7] K. Abushgair, Jordan J. Mech. Ind. Eng. **11** (3), 173-180 (2017).

[8] S. Forgues, B. Labelle, M. King, N. Manor, Controlled Rotary Flap Peening for Repair Applications, Proceedings of the 11th ICSP, American Shot Peening Society: Indiana, (2011).

[9] A. Dmowska, B. Nowicki, A. Podolk-Lejtas, Advanced in Tribology **2012**, 1-12 (2012). DOI: https://doi.org/10.1155/2012/723919

[10] M. Van Sickle, M. Ramulu, Assessment of Field Surface Treatments for Prolonging the Life of Steel Welded Joints Subjected to Fatigue Loading, Proceedings of the 12th ICSP. American Shot Peening Society: Goslar, Germany, (2014).

[11] I.S. Jawahir, E. Brinksmeier R. M'Saoubi, D.K. Aspinwall, J.C. Outeiro, D. Meyer, Umbrello, A.D. Jayal, CIRP Annals. Manuf. Technol. **60** (2) 603-626 (2011). DOI: https://doi.org/10.1016/j.cirp.2011.05.002

[12] S.A. Meguid, G. Shagal, J.C. Stranart, J. Mater. Process. Technol. **92-93**, 401-404 (1999). DOI: https://doi.org/10.1016/S0924-0136(99)00153-3

[13] M. Sroka, E. Onda, W. Pakieła, J. Mater. **13**, 311-320 (2020). DOI: https://doi.org/org/10.3390/met11050712

[14] K. Sahoo, J. Sahu, M. Masanta, Lasers Based Manufacturing; Joshi, N., Dixit, S., Eds.; Springer: New Delhi, India, (2015).

[15] T. Chwalczuk, D. Przestack, P. Szablewski, A. Felusiak, A. Microstructure characterisation of Inconel 718 after laser assisted turning, MATEC Web Conf. **188**, 1-5 (2018).

[16] K. Mori, K. Osakada, N. Matruoka, J. Mater. Process. Technol. **45**, 607-612 (1994). DOI: https://doi.org/10.1016/0924-0136(94)90406-5

[17] K. Han, D. Peric, A. Crook, D.A. Owen, Engineering Computation, **17**, 593-619 (2000). DOI: https://doi.org/10.1108/02644400010339798

[18] Mesay Alemu Tolcha, Moera Gutu Jiru 2 and Hirpa Gelgele Lemu, Metals **11**, 1-15 (2021). DOI: https://doi.org/10.3390/met1105071

[19] H. L. Zion, W. S. Johnson, Parametric two-dimensional finite element investigation: Shot peening of high strength steel, AIAA J. **44**, 1973-1982 (2006). DOI: https://doi.org/10.2514/1.19411

[20] H.Y. Miao, S. Larose, C. Perron, M. Lévesque, On the potential applications of a 3d random finite element model for the simulation of shot peening, Adv. Eng. Softw. **40**, 1023-1038 (2009). DOI: https://doi.org/10.1016/j.advengsoft.2009.03.013

[21] K. Cho, K. Song, S. Oh, Y. Lee, K. Lim, W. Lee, Surface hardening of aluminum alloy by shot peening treatment with Zn based ball, Mater. Sci. and Eng. A, **543**, 44-49 (2012). DOI: https://doi.org/10.1016/j.msea.2012.02.043

[22] L. Wagner, G. Lütjering, Influence of shot peening parameters on the surface layer properties and the fatigue life of Ti-6Al-4V, Proceedings of the 2nd ICSP, American Shot Peening Society: Chicago, (1984).

[23] Y. Madhavi, L. R. Krishna, N. Narasaiah, Influence of micro arc oxidation coating thickness and prior shot peening on the fatigue behavior of 6061-T6 Al alloy, Int. J. Fatigue. **126**, 297-305 (2019). DOI: https://doi.org/10.1016/j.ijfatigue.2019.05.013

[24] S. Žagar, B. Markoli, I. Naglim, R. Šturm, The Influence of Age Hardening and Shot Peening on the Surface Properties of 7075 Aluminium Alloy, Materials **14** (9), 2-11 (2021). DOI: https://doi.org/10.3390/ma14092220

[25] C. Breuner, S. Guth, E. Gall, R. Swad´zba, J. Gibmeier, M. Heilmaier, Influence of shot peening on the isothermal fatigue behavior of the gamma titanium aluminide Ti-48Al-2Cr-2Nb at 750 _C, Metals **11** (7), 2-12 (2021). DOI: https://doi.org/10.3390/met11071083

[26] Raed Abendeh, Rana Alhorani, Hesham S. Ahmad, and Mousa Bani Baker, Jordan J. Civ. Eng. **15** (4), (2021).