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An Investigation for Surface Integrity of Al_2O_3/A356 Composites Using Roller Burnishing Process on a Milling Machine

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Abstract. Roller burnishing process was applied to Al_2O_3/A356 composite specimens,. The process was carried out on vertical milling machine. Effects of the burnishing process with varying process parameters on the characteristics of the machined surface and sub-surfaces were investigated. Residual stress distribution at different depths beneath the burnished surfaces, microhardness distribution, surface roughness were used as criteria to obtain the optimum burnishing conditions that give burnished surfaces with high integrity for the Al_2O_3/A356 composite.
Results showed an improvement in surface characteristics of Al_2O_3/A356 composites using burnishing process. The better surface roughness was obtained with double passes burnishing, depth of penetration of 0.12 mm, and burnishing speed of 72 mm/min. Increase of number of burnishing passes increases the value of residual compressive stress and the microhardness at the burnished surface and subsurface. The microhardness slightly decreased with the increase of burnishing speed.

Introduction

Introducing of new lightweight materials which have greater strength has led to the development of a new generation of composite materials. Aluminum (Al) alloys are the most widely used in the high strength to weight ratio. Previous researchers [1,2] concluded that, the yield strength, ultimate tensile strength and the elastic modulus of Al alloys are improved with the addition of nano particles although some reduction in ductility is observed. Machining processes as well as such as turning, boring, shaping, reaming and milling are alone sometimes not sufficient to produce good surface finish. Grinding usually follows them. However, grinding without heat treatment does not improve the surface hardness [3]. Sadat [4] reported that, machining metal matrix composites using traditional methods can lead to the damage of surface and subsurface. This was attributed to that, During machining operation the aluminum matrix are partially or totally removed from the surface leaving behind cavities of various shapes and depth. Some of these particles are passed underneath the tool flank and dragged by the tool flank along the surface that lead to grooves of various width and length.

Since Al alloys usually show ductile fracture, which occurs at low rate after plastic deformation, burnishing is suitable to improve the surface characteristics for such alloys where grinding is difficult due to Smearing of aluminum matrix on the ground surfaces.

Recently, considerable attention has been directed to the burnishing process, it is a simple and effective for improvement in surface characteristics. It can be carried out using existing machines, e.g. milling machines. Burnished surface has a greater resistance to wear and better fatigue life [3]. The burnishing process can be achieved by applying a polished and hardened ball (or roller) onto a metallic surface under pressure. This will cause the peaks of the metallic surface to spread out permanently, when the applied burnishing pressure exceeds the yield strength of the material, the metal fill the valleys [5]. A roller burnishing process is shown in Fig. 1.

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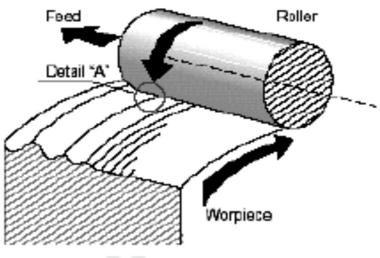


Fig. 1. Roller burnishing process [3]

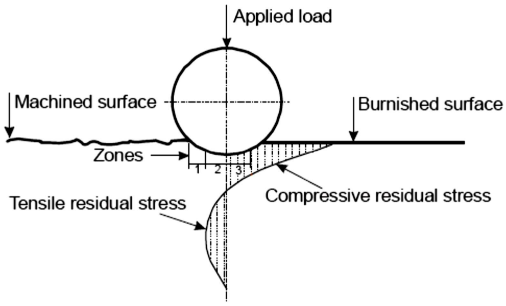


Fig. 2. Schematic representation of the residual stress distribution in the burnishing process [5]

After burnishing, the surface of the metallic material will be smoothed out and because of the plastic deformation the surface becomes work hardened, the material being left with a residual stress distribution (Fig. 2) that is comprehensive in the surface [5]. The generated compressive residual stress within the machined surface will extend the fatigue life.

Thamizhmanii et al [6] discussed the effect of burnishing parameters on surface finish and surface hardness. Khabeery et al [7] reported that residual stresses are the vital aspect in assessing integrity of the machined components and it can be changed from tensile to compressive by the burnishing process. Pałka e al. [8] used the burnishing to increase the strength and the rigidity of the plates of heat exchangers to get better erosion and wear resistance via higher surface hardness.

Most of the work on burnishing, however, was concerned with the effect of the burnishing process on the surface roughness and surface hardness. It was suggested by many investigators [7] that an increasing compressive residual stress can be achieved by burnishing but a little work has been done in this direction. Al composite also got a little attention as a material can be finished by burnishing.

The purpose of the current research was to investigate the roller burnishing of Al_2O_3/A356 composites using simple constructed roller burnishing tool. A set of experiments had been performed to investigate the effectiveness of this tool on surface enhancement with varying process parameters such as, burnishing speed, number of passes, and burnishing depth to understand their role on surface characteristics. The effect of burnishing process using roller burnishing tool on sub-surface characteristics was studied. For this purpose the variation of residual stresses and/or microhardness in burnished surfaces and sub-surfaces were measured.

Experimental Work

Test material. Al_2O_3/A356 composite specimens were used for the present work. This material was selected because it is widely used for high temperature structures such those in the automotive field. Specimens were prepared from an A356 alloy reinforced with 20% volume fraction of Al_2O_3 via the compocasting method using mechanical mixing of the matrix particles i.e. the A356 alloy which was previously bought into the semisolid state and addition of particles of the strengtheners [9]. Addition of Al_2O_3 powder particles of an average size of 10µm was done.

Table 1: A356 Alloy Chemical Composition (in Weight%)

Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb+Sn	Ti	Sr	Others	Al
6.5	0.15	0.03	0.03	0.40	0.03	0.05	0.03	0.20	0.01	0.10	Bal.

The mechanical properties of Al_2O_3/A356 composite were measured as UTS 230MPa, % elongation of 10%, and surface hardness was in the range from 162 to180 HV.

Tooling and Test equipment. The Single roller burnishing tool consists of roller mounted between two bearings as shown in fig. 3. The roller made out of Carbon chromium steel with diameter of 25 mm and has a hardness of 69 HRC. The roller material is commercially available and usually used in roller bearing. This tool was mounted on standard milling machine machines fig. 4, thereby eliminating the need for any additional investment in machines. A Universal milling machine model (JET JVM-4VS) with an automatic feed was used. The available depth of cut and table speed were used to complete the experiment.

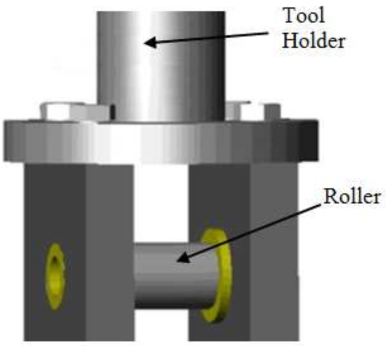


Fig. 3. Roller burnishing tool

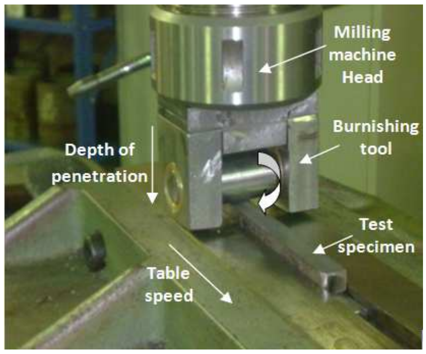


Fig. 4. Mounting of roller burnishing tool on the universal milling machine

Measurements. The surface roughness was measured using Mirotoyo talysurf model 402 series 178. The selected meter cut-off for each measurement was 0.8 mm. Five measurements for each specimen were taken and the surface roughness values were averaged.

A HWDM-3 Micro-hardness tester with Vickers pyramid indenter was used for hardness measurements across the depth below and perpendicular to the burnished surface. The measurements were taken across the depth at an incremental of 50 microns starting from the edge of the surface and going deeper. The microhardness is taken as an average of three readings taken at three different points for each depth.

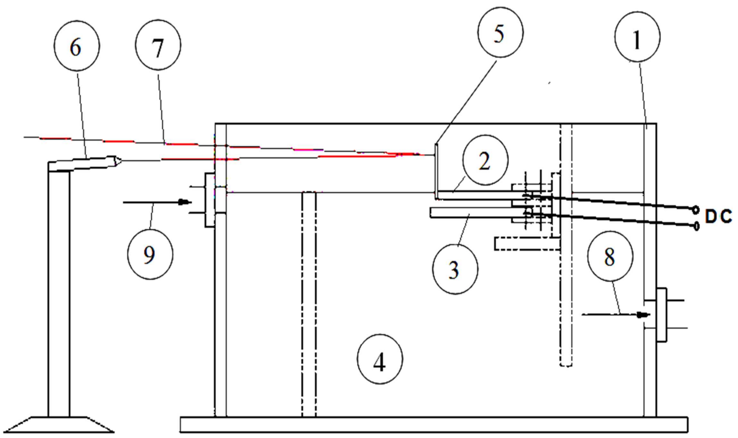
To measure the residual stress at layers which are at different depths beneath the burnished surface, the deflection etching technique was used. This technique is based on the fact that, if a thin layer of the machined or burnished surface is removed by chemical etching this will lead to a remove partially the stresses which consequently will change the radius of curvature of the specimen bar. Theory of elasticity was used to determine the stress distribution from the knowledge of the changes in curvature and thickness of the bar due to successive removal of thin layers.

A schematic diagram of the electrolytic etching apparatus which was used for residual stress measurements is given in fig. 5. The residual stress on the surface of some test samples prior burnishing was measured using the deflection etching technique. The measured value range was -40 to -100 MPa.

Test parameters. The burnishing parameters are listed in the Table 2.

Table 2: Burnishing Parameters

Speed [v] mm/min.	24, 55, 72, 97, and 122
Depth [t] mm	0.04, 0.08,0 .12, 0.14, and 0.22
No. of passes [n]	1, 2, and 3
conditions	Dry



(1)Tank, (2) test specimen, (3) etching tool, (4) electrolyte, (5) mirror, (6) laser pointer, (7) reflecting laser light, (8) electrolyte exit, (9) electrolyte inlet

Fig. 5. Residual stress measurements apparatus

Sadat [4] reported that the application of a lubricant does not affect significantly the surface integrity of the machined metal matrix composites. Therefore, it is convenient to conduct the burnishing processes in the dry conditions. . To obtain a uniform depth of penetration during burnishing, the work piece was held in a universal vice and parallelism is maintained all over the burnished length.

Results and discussion

Effect of burnishing parameters on surface roughness. The initially machined surfaces produced by face milling had an average surface roughness R_a of 3.15μm. Test results show that R_a values of burnished surfaces of Al_2O_3/A356 composite were significantly decreased after the burnishing process.

Effect of burnishing depth on surface roughness is illustrated in Fig. 6 for different number of passes at a speed of 55 mm/min. The figure shows that a burnishing depth ranging between 0.08 and 0.12mm gives the lowest surface roughness at 2 passes. Therefore it is more convenient to use the value of burnishing depth of 0.12 with 2 passes for the subsequent experiments.

For a single pass, surface roughness R_a decreased with the increase of burnishing depth up to a depth ranging from 0.08 to 0.12mm. Further increase in the depth caused an increase for the surface roughness. For both 2 and 3 passes, the same trend was observed. But 2 passes roller burnishing gave a lower R_a compared to 1 and 3 passes. This can be attributed to the increase of burnishing force which resulting from the increase of burnishing depth. This causes the region of plastic deformation to widen due to the increase of size of buldge in front of the burnishing tool which increases R_a. The increase of number of passes causes the plastic deformation to be repeated which improved R_a at low depth and deteriorates it for high depth values. Excessive roller burnishing depth and number of passes can produce flaking of the burnished surface, and it may cause formation of lapping which can lead to a deterioration of surface roughness. R_a as it is clear from the figure is decreased by increasing burnishing depth or number of passes to a certain limit and after that it increases again.

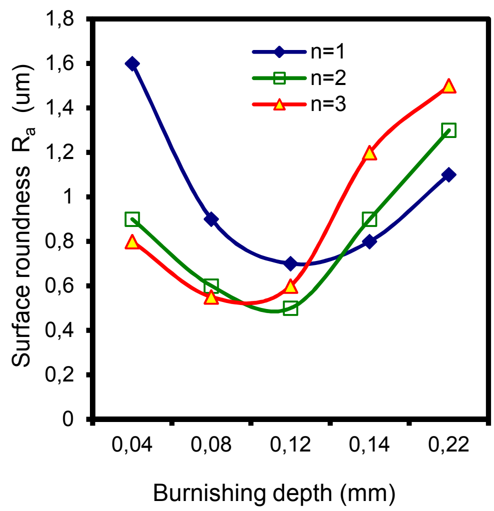


Fig. 6. Effect of burnishing depth on surface Roughness at different number of passes

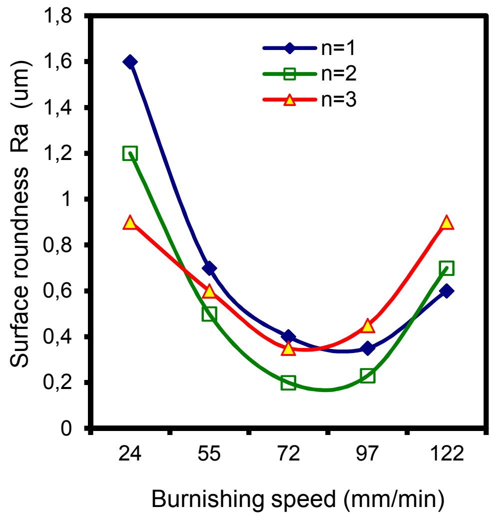


Fig. 7. Effect of burnishing speed on surface roughness at different number of passes

It can be also observed that the range of burnishing depth which gives the lowest R_a is lower than that range which was obtained with other aluminum alloys as in reference [5, 7]. This is due to the fact that, the micron-sized particles added to Aluminum alloy to improve its mechanical properties reduced the ductility [10, 11].

The influence of burnishing speed on R_a is illustrated in fig. 7 at a constant burnishing depth of 0.12mm and different number of passes. Fig. 7 shows that R_a initially decreased to a certain level with increasing speed, and after that R_a increased with further increase of the speed beyond a speed of 97 mm/min.

R_a was high at low burnishing speeds because the roller material and the work piece material became in contact for long time and adhered and caused damage of surface. Increasing of the speed from 24 up to 97 mm/min. causes less time contact and chance for adherence became less and hence less damage on the surface is expected.

Beyond the speeds 97 mm/min., the surface started to deteriorate, as the surface of the metal was over work hardened due to plastic deformation caused by the increase of speed. Deterioration of R_a at high speeds may be also due to the occurrences of chatter. The same trend was observed for all number of passes, but the best surface roughness was obtained with two passes roller burnishing.

Effect of burnishing parameters on microhardness. The microhardness distribution over a section of the test work piece after burnishing with different number of tool passes at a speed of 72 mm/min, and burnishing depth of 0.12mm is shown in fig. 8. It can be seen from the figure that, an increase in microhardness up to 285 HV was achieved in these experiments. This value is higher than that recorded for the metal prior to burnishing. The increase of hardness is attributed to work hardening associated with plastic deformation, and to induced compressive residual stresses in the burnished surfaces.

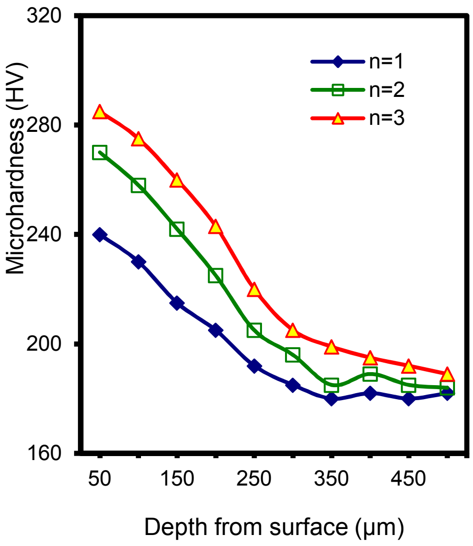


Fig. 8. Microhardness distribution across the subsurface layer

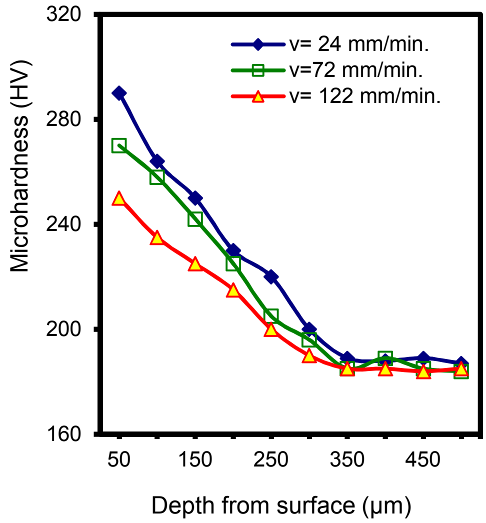


Fig. 9. Effect of burnishing speed on microhardness of subsurface layer

A gradual decrease in hardness was observed through the depth beneath burnishing surface. The increase in burnishing passes also increases the depth of the hardened layer and the hardness at any depth increases with the increase of number burnishing passes. This is due to the increase in pressure subjected by the burnishing tool, which leads to an increase in the action of the repeated plastic deformation and the hardness.

Effect of burnishing speed on microhardness of subsurface layer at 0.12mm burnishing depth , and using two burnishing passes is shown in fig. 9. Microhardness decreased with the increase of burnishing speed. This result could be explained by an increase in recovery of the work-hardened materials due to an increase in surface temperature during deformation [12]. The effect of burnishing speed on microhardness is noticeable at the subsurface layers which fall below the burnishing surface. At subsurface layers below 350 μm, the effect of burnishing speed on microhardness is not significant.

Effect of burnishing parameters on residual stress. Fig. 10 shows the residual stress distribution along the subsurface layers beneath the burnished surface at a burnishing a speed of 72 mm/min, burnishing depth 0.12mm, and different number of passes.

It can be seen that the compressive residual stress beneath the surface is higher than on the burnished surface. Peak values of 500 to 700 MPa of compressive residual stress were observed at a depth of 0.03 mm from the burnished surface. The compressive residual stress decreases with depth after the peak point. Then the compressive residual stress starts to changes to tensile residual stress below a depth of 0.3 mm from the machined surface with single pass burnishing, and 0.5 mm for double and triple passes.

The increase of number of burnishing passes increases the value of residual compressive stress at the burnished surface and subsurface. This is due to the increase in pressure subjected by the burnishing tool, which leads, as mentioned earlier, to an increase in the action of the repeated plastic deformation and the internal compressive residual stresses.

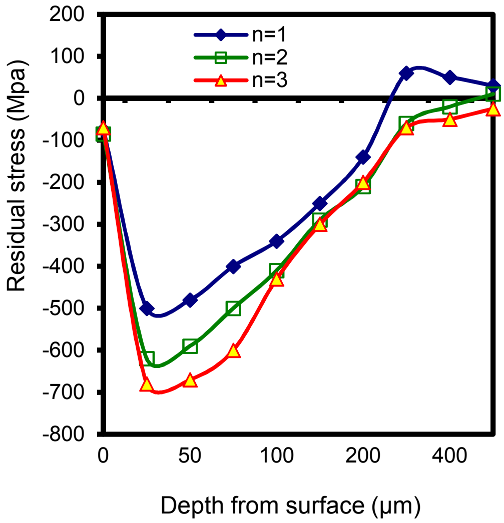


Fig. 10 Residual stress distribution along the subsurface layers for different number of passes

From Figs. 8 to 10, it could be observed that the depth of cold work layer, which is the distance from surface to the point where the measured hardness is equal to base metal, for Al_2O_3/A356 composites is lower than that attained by burnishing process with other aluminum alloys [7].

Conclusions

This paper presents an experimental investigation to assess the effects of the roller burnishing process and related parameters on the surface characteristics of Al_2O_3/A356 composites. The roller burnishing process was useful in improving the burnished surface characteristics of Al_2O_3/A356 composites with proper burnishing parameters.
The following conclusions can be drawn from the investigation:

1. The better surface roughness was obtained with double passes burnishing, depth of penetration of 0.12 mm, and burnishing speed of 72 mm/min.
2. Increase of number of burnishing passes increases the value of residual compressive stress and the microhardness at the burnished surface and subsurface.
3. The microhardness slightly decreased with the increase of burnishing speed. The effect of burnishing speed on microhardness is noticeable at the subsurface layers which fall below the burnishing surface. At subsurface layers below 350 μm, the effect of burnishing speed on microhardness is not significant.
4. In burnishing of Al_2O_3/A356 composites there is some limitation to increase the burnishing depth and number of passes. The depth of cold work layer also is lower than that attained with other aluminum alloys. This is due to the fact that, the micron-sized particles which added to Aluminum alloy to improve its mechanical properties reduces the ductility.

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