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Comparative Analysis of the Effect of Machining with Wire and Ceramic Brushes on Selected Properties of the Surface Layer of EN AW-7075 Aluminium Alloy

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ABSTRACT

In the cutting process, when the cutting edge leaves the material, burrs are often formed on the edges of the workpiece. Due to inconveniences associated with burrs, such as problems with properly fixing the workpiece on the machine for further processing or problems with parts working in assemblies, deburring operations must be performed. In addition to that, burrs may pose danger for workers at the production stage and for customers at the stage of using the finished product. One of the popular deburring methods is brushing. Apart from deburring, brushing can be used to change surface layer properties. The aim of this study is a comparative analysis of the effect of machining with wire and ceramic brushes on microhardness and the surface quality of EN AW-7075 aluminium alloy. Results show that, for all defined brushing conditions, lower surface roughness parameters are obtained when using ceramic brushes rather than wire brushes. In contrast, the use of wire brushes leads to increased microhardness of the surface layer.

Keywords: surface roughness, microhardness, wire brushing, ceramic brush.

INTRODUCTION

Final operations on production lines where products are manufactured by machining are usually performed at the locksmith's workstation. These operations involve checking, rounding and deburring the edges of the workpiece. The choice of the edge processing method depends on the workpiece size [1]. Automated processing such as vibratory finishing is used for small parts [2]. Other methods are rotary-abrasive, abrasive blasting and abrasive flow machining [3]. Abrasive water jet machining can be used for deburring, particularly in hard-to-reach workpiece areas [4, 5]. To automate most production processes, deburring methods without human intervention are being investigated, especially for large-size parts produced on CNC machines. Given that the workpiece is fixed on the CNC machine table, the deburring process can be conducted using dedicated tools such as brushes. The main area of industrial application of the brushing treatment is deburring. However, brushing can also play other functions, e.g. it can be used for surface cleaning [6], removing corrosion and old varnish coats, hole finishing [7], surface layer modification and strength improvement [7, 8]. Examples of the above-mentioned applications and effects of brushing are shown in Figure 1.

The studies [9–12] showed that the brushing treatment induces changes in surface layer properties, in terms of both surface roughness and microhardness. It is estimated that up to 80% of damage to machine components occurs at the surface or in the surface layer directly below the surface. One of the popular ways to improve strength and fatigue life is to introduce residual stresses into the surface layer of an object. The study [9] showed that beneficial compressive stresses in the surface layer were induced after brushing with a cylindrical wire brush. Brush fibres hitting the

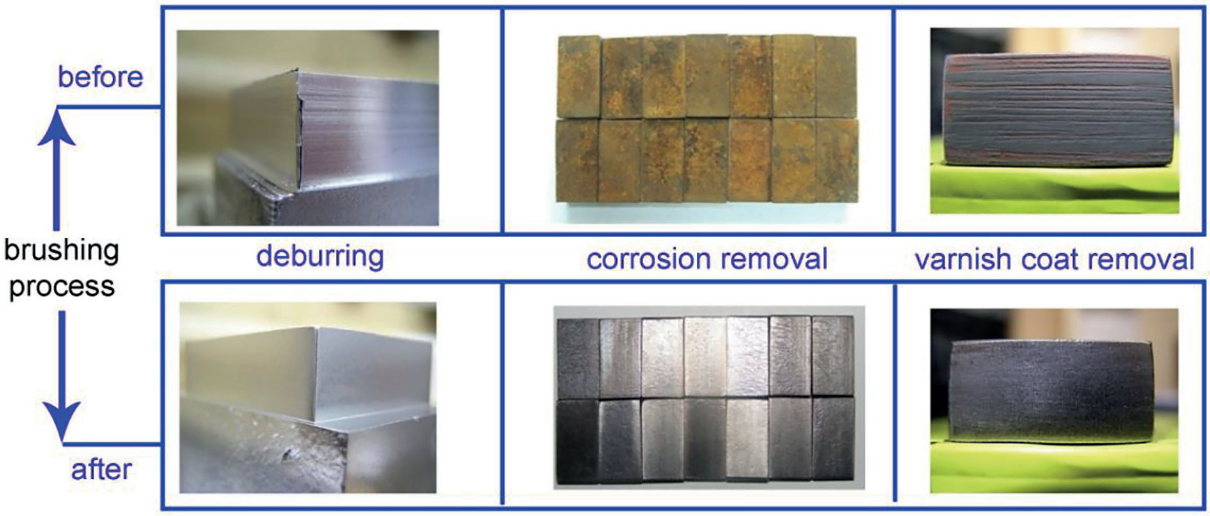


Fig. 1. Examples of applications of brushing

surface can produce a similar effect in the surface layer as shot peening or shot blasting [13].

Compressive residual stresses have a significant impact on improving fatigue strength [14–16]. The study [17] investigated the effect of brushing process on the surface roughness, residual stresses, surface layer work-hardening, and fatigue strength of AA 5083 aluminium alloy. It was established that the wire-brush hammering of notched samples led to increased fatigue life.

In addition to surface cleaning and corrosion product removal, the brushing treatment can increase corrosion resistance. This is possible due to the grain refinement that occurs after brushing. Influence of brushing on corrosion resistance of AZ31B magnesium alloy was analysed in [18]. It was shown that the corrosion resistance of the brushed magnesium alloy sheet was about four times higher than for the non-brushed workpiece. Corrosion resistance is correlated with the formation of structural defects. The study [19] proposed a novel method of detecting defect using recurrence plots and recurrence quantifications. In addition, continuous surface nanocrystallization (SNC) of rebars was obtained through the brushing process, which significantly improved corrosion resistance [20]. The process of nanocrystallization was also investigated in [21]. It was shown that the surface nanocrystallization of mild steel could be obtained by wire brushing and that an ultrafine-grained surface layer with an average grain size of 77 nm could be produced through this treatment.

Ceramic fibre brushes are relatively new tools. The problem of surface uniformity after ceramic brush machining aimed at automatic lapping of a large work surface was studied in [22]. Variable revolution speed, feed rate, preload and protrusion were used in the study. The numerical model took into account different values of fibre projection length from the sleeve. It was found that elastic deformation of the brush tip had a significant effect on the surface profile.

The study [23] investigated the influence of ceramic brush machining on the edge state and surface quality of aluminium alloy after AWJ cutting. It was shown that in the water jet cutting process burrs were formed primarily at the exit side of the jet. A desired deburring effect was obtained for all tested fibre types yet the edge state (chamfering or rounding) depended on the fibre rigidity.

The objective of this study is a comparative analysis of the effect of treatment with wire and ceramic brushes on microhardness and the surface quality of EN AW-7075 aluminium alloy. These tools are dedicated to finishing both edges (deburring, rounding) and surfaces.

TEST METHODOLOGY

Overall methodology of the study is schematically shown in Figure 2. The experiments were performed using two types of tools for surface finishing: an XEBEC ceramic brush and an end wire brush. Surface topography and roughness were measured with the T8000RC120-400 profilographometer. Visual assessment of the surface after brushing was performed using the Keyence VHX 5000 digital microscope. Surface microhardness was analysed with the Leco LM700 tester. The load on the indenter was 50 g for a period of 15 seconds.

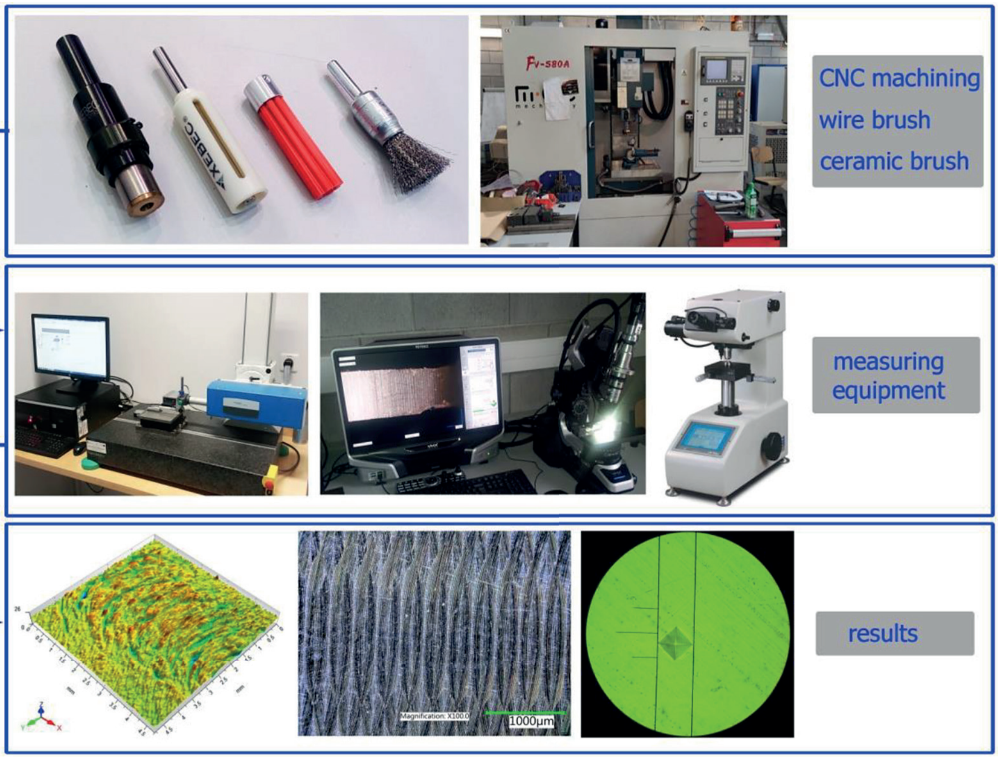


Fig. 2. Scheme of the experimental set-up

EN AW-7075 aluminum alloy specimens with dimensions of 10x15x60 were used for testing. Table 1 shows the physical properties and chemical composition of this alloy.

Before brushing, all specimens were milled using an Iscar carbide end mill with a diameter of D = 20 mm. This cutter is characterized by geometry dedicated to machining of light alloys. Fixed milling parameters (a_p = 0.5 mm, v_c = 500 m/min, f_z = 0.1 mm/tooth) were set to ensure that surface finish would have constant roughness. The mean value of the surface roughness parameter Ra was 1um. Effects produced with the brushing treatment were compared to the roughness obtained by milling.

To compare machining effects produced with the two types of brushes, tools with the same diameter, D = 15 mm, were used. In addition, the experiments were conducted using three different feed rates. Details of the experimental parameters are given in Table 2.

Table 1. Chemical composition and physical properties of EN AW-7075

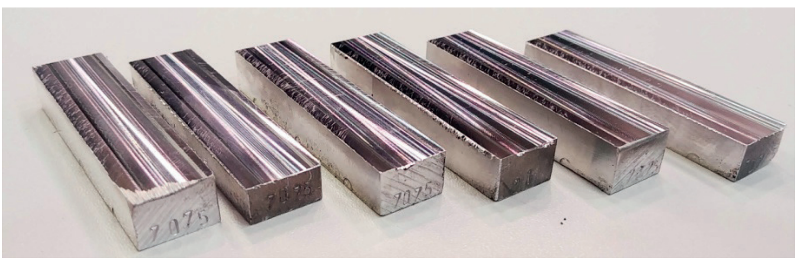
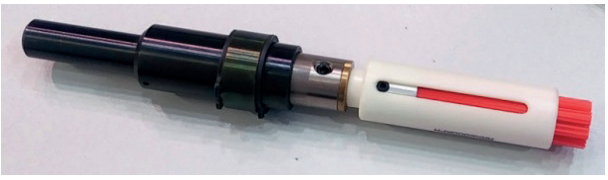
Chemical composition, Wt.%								
Cu	Zn	Mg	Mn	Cr	Si	Fe	Ti	Al
1.59	5.78	2.56	0.01	0.18	0.07	0.13	0.05	Rest
Physical properties								
Rm MPa			$Rp_{0.2}$ MPa			HB		
599			488			172		
View of example samples								
								

Table 2. Tools data and brushing conditions

Tools data					
Ceramic brush		Wire brush			
					
Tool diameter: 15 mm Fibre type: ceramic A11 (red) Fibre projection length from sleeve: 12 mm		Tool diameter: 15 mm Fibre type: steel (0.2mm) Fibre length: 25 mm			
Cutting parameters					
Medium	Brush speed [m/min]	Feed rate [mm/min]			Offset [mm]
Dry machining	160	140	370	1000	2

Medium-flexibility ceramic fibres (A11: Red) recommended for many different materials were used in the experiments.

RESULTS

Surface roughness

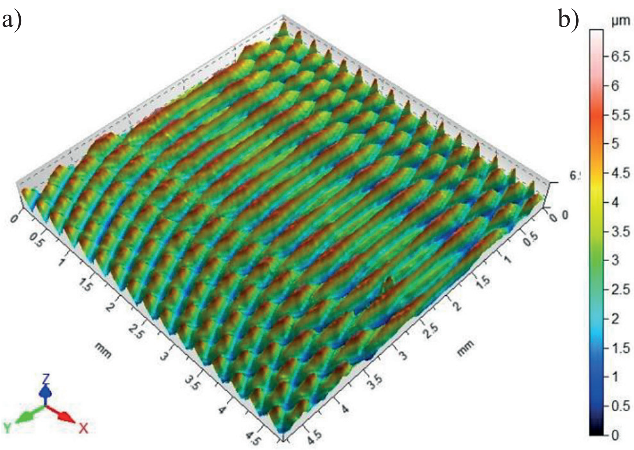
An example of the surface topography after the milling process is shown in Figure 3. The characteristic marks on the surface are the result of the shape of the blade mapping onto the surface layer, and the distance between the individual marks equals the feed per tooth f_z.

Table 3 contains sample images showing the surface topography after treatment with ceramic and wire brushes. At low feed rates, the brushes have longer contact with the workpiece, which leads to the removal of machining marks produced during milling. The ceramic brush treatment resulted in the removal of sharp peaks of micro-inequalities and reduced roughness compared to the surface after milling in the entire range of applied feed rates. In contrast, the wire brush treatment led to increased roughness in relation to the initial treatment.

The effectiveness of removing the sharp peaks of micro-inequalities is shown in the surface topography images in Table 4. It can be observed that the wire brush removed and deformed the material more intensively than the ceramic brush.

However, for the whole range of applied feed rates, the wire brush treatment led to higher values of the roughness parameter Ra compared to milling (Fig. 4). If the wire brush contact with the workpiece is longer (lower feed rate), greater deformation (increased roughness) of the surface layer can be observed.

a)



b)

ISO 25178		
Height Parameters		
Sq	1.21	µm
Ssk	0.480	
Sku	2.49	
Sp	3.95	µm
Sv	3.01	µm
Sz	6.96	µm
Sa	0.991	µm
Functional Parameters		
Smr	0.513	%
Smc	1.86	µm
Sxp	1.72	µm

Fig. 3. Surface roughness after milling: (a) topography; (b) parameters

Table 3. Surface topography after brushing

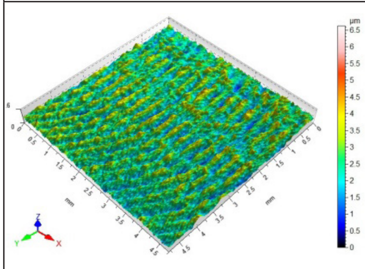
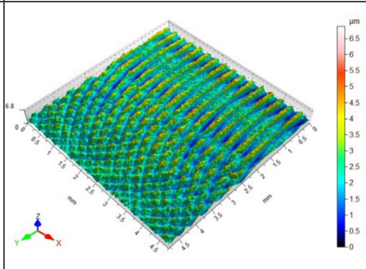
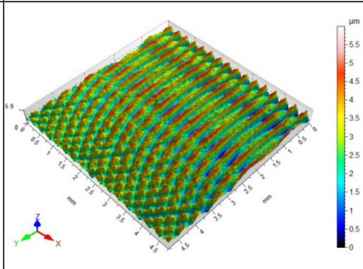
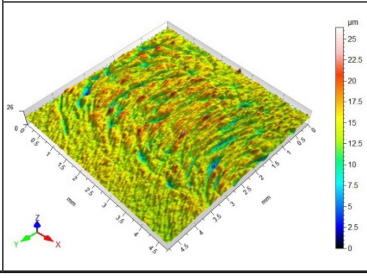
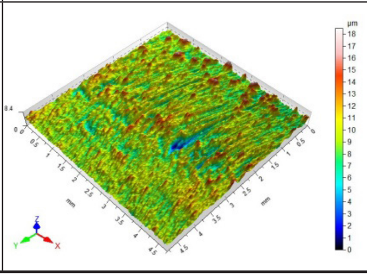
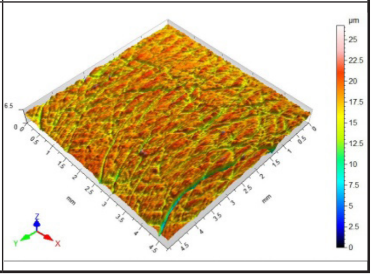
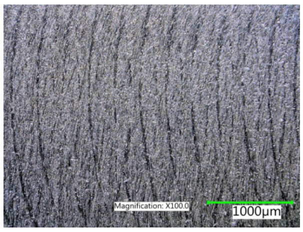
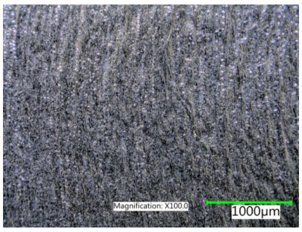
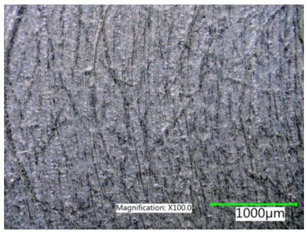
Type of brush	Feed rate		
	v_f = 140 mm/min	v_f = 370 mm/min	v_f = 1000 mm/min
Ceramic brush	Sa = 0.504 µm	Sa = 0.615 µm	Sa = 0.774 µm
			
Wire brush	Sa = 1.54 µm	Sa = 1.30 µm	Sa = 1.30 µm
			

Table 4. Real view of surfaces after brushing process

Type of brush	Feed rate		
	v_f = 140 mm/min	v_f = 370 mm/min	v_f = 1000 mm/min
Ceramic brush			
Wire brush			

Ceramic brushes ensure better finishing properties. Compared to milling, the ceramic brush treatment leads to improved surface roughness in all analysed cases. The lowest roughness value (Ra = 0.49 um) was obtained for the feed rate vf = 140 mm/min.

Surface microhardness

Brush fibres hitting the surface can induce a similar strain hardening effect as shot peening or shot blasting. Figure 5 shows the influence of feed rate and brush type on surface microhardness. The ceramic brush treatment has an insignificant effect on microhardness (its value is within standard deviation). This indicates that ceramic fibres have a predominantly abrasive effect on the workpiece surface. However, after machining with the wire brush, the microhardness increases significantly compared to its value before brushing (average microhardness HV0.05 after milling is 175). The maximum average microhardness HV0.05 after wire brushing is 201 for a feed rate of 140 mm/min. This indicates a shot peeing effect caused by the brush filaments hitting the workpiece surface.

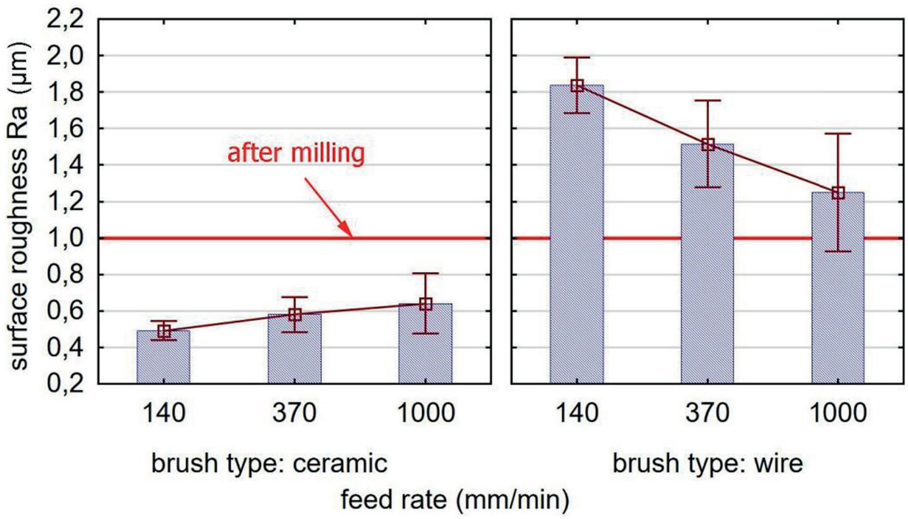


Fig. 4. Effect of feed rate and brush type on surface roughness

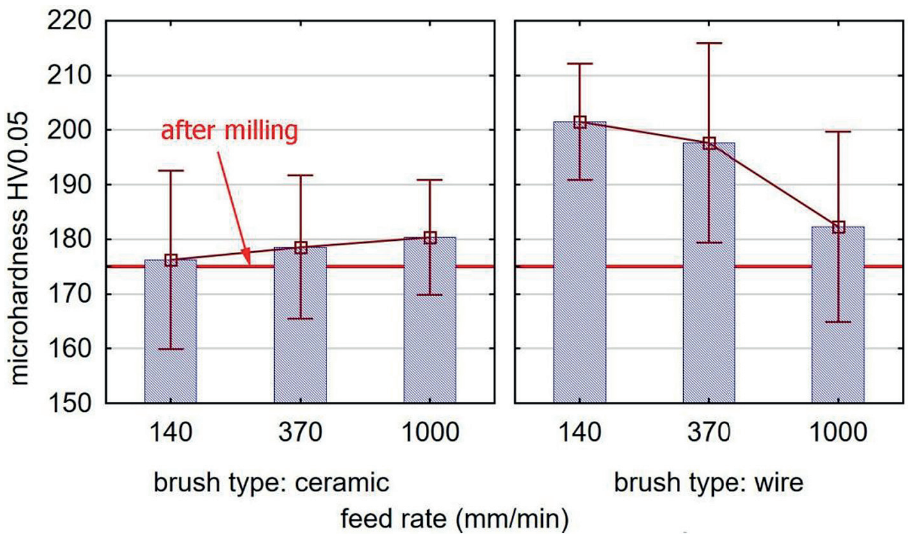


Fig. 5. Effect of feed rate and brush type on surface microhardness

CONCLUSIONS

The experimental results of the study investigating the impact of treatment with wire and ceramic brushes on the microhardness and surface quality of EN AW-7075 aluminium alloy lead to the following conclusions:

- brushing can be used for surface finishing to impart specific stereometric as well as physical properties;
- the Sa parameter is lower for a longer contact time of the ceramic brush with the surface (the lowest value of Sa = 0.504 µm was obtained in brushing with a feed rate of 140 mm/min);
- wire brushing leads to almost complete removal of milling marks;
- the wire brush treatment leads to an increase in the roughness parameter Sa;
- for the whole range of applied feed rates, lower values of the Sa and Ra roughness parameters could be observed after ceramic brush machining, when compared to roughness after milling;
- wire brushing leads to surface degradation and increased roughness parameters;
- microhardness increases significantly after wire brushing compared to milling (the maximum average value HV0.05 after wire brushing was 201 for a feed rate of 140 mm/min), which indicates a shot peeing effect caused by the brush filaments hitting the workpiece surface.

It should be noted that the wire brush treatment does not always lead to increased surface roughness and that its effects strongly depend on initial roughness. For higher roughness values after milling, improved surface roughness can be observed after wire brushing.

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