

The influence of milling-burnishing successive and simultaneous processes on the surface roughness

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Abstract. The present techniques do not offer the possibility for milling and burnishing at the same time. The novelty of this study is the development of a new tool and tool holder that allows this processes to take place simultaneous. Magnesium alloys have a wide range of usages in industry; in the past years they seem to be a promising solution to classic implants. Improvements in fatigue and tensile strength need to be made. Heat treatments are difficult to implement, so the solution is a mechanical treatment. The burnishing process offers very good results, but it has difficulties in simultaneous machining with the milling process. Thereby a hydraulic roller burnishing tool and a special tool holder was manufactured to solve this issue. The combined process was carried out on a CNC milling machine. This study seeks to highlight the influence of the milling-burnishing process parameter on the surface roughness in the case of magnesium alloy AZ31B-F. Parameters like speed and feed of cut, burnishing pressure and depth where taken into consideration. It was noted that with the increase of the feed, speed, pressure and depth of burnishing the general percentage improvement of the surface roughness was higher.

1. Introduction

In recent years research in the field of biodegradable implants shows great interest and results [1]. Intense investigations have been made for magnesium alloys as they meet requirements like: biocompatibility, non-toxic degradation in living tissue, physical and mechanical properties similar to the human bone (table 1) [2]. However, magnesium based alloy have a high degradation rate in the human body. Metabolic activities require an amount of 300÷400 [mg/day] of magnesium [3]. This is because it's a co-factor for removal of DNA (Deoxyribonucleic acid) damage and DNA replications [4].

The degradation rate must be corelated to the bone fracture healing time. It has to provide sufficient mechanical support as the implant degradates. Improving the degradation rate requiers a chemical or mechanical surface treatment. Silicon of fluorides coatings can improve this rate [5]. Grain refinement is another way to obtaine superior results and it can be obtained by using SPD (severe plastic deformation). SPB (severe plasticity burnishing) and LPB (low plasticity burnishing) can be used as plastic deformation processes [6]. The burnishing process requiers a preformed machined part. This process can be usually executed in the same time with the turning process or after a milling operation.

One important aspect is the relationship between the surface roughness and the degradation rate. Research shows that a smooth surface leads to a higher degradation rate [2, 7].

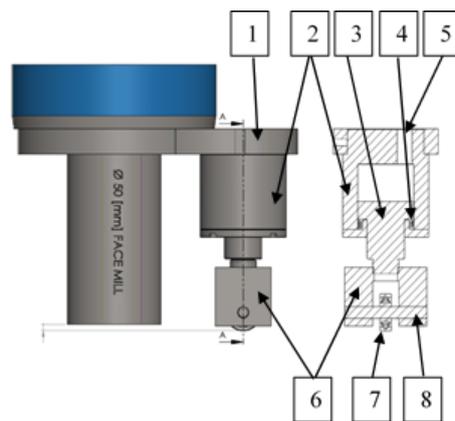


Table 1. Physical and mechanical properties of various implant materials in comparison to the human bone [2]

Properties	Human bone	Mg alloy	Ti alloy	Poly lactide
Density [g/cm ³]	1.8-2.1	1.74-2.0	4.4-4.5	1.25-1.29
Compressive yield strength [MPa]	3-20	41-45	110-117	45.5-61.4
Elastic modulus [GPa]	130-180	65-100	758-1117	3.75

2. Material and experimental setup

Current burnishing tools do not offer the possibility of simultaneous machining with the milling process. This fact leads to the necessity of developing and machining a new tool and tool holder (figure 1). This allows the successive and simultaneous milling-burnishing process to be implemented. The tool is composed from a tool holder (1), piston housing (2), piston (3), seal (4), hydraulic oil inlet (5), roller support (6), deforming roller (7), roller shaft (8). The distance from the face mill to the roller represents the burnishing depth and can be adjusted.

**Figure 1.** Schematic representation of the high pressure roller burnishing tool

2.1. Material

The material chosen for this study is AZ31B-F magnesium alloy, with the chemical composition given in table 2. Samples measuring a thickness of 20 [mm], a width of 72 [mm] and length of 102 [mm] were obtained by water jet cutting.

Table 2. Chemical composition of AZ31B-F magnesium alloy [%]

Al	Ca	Cu	Fe	Mg	Mn	Ni	Si	Zn
2.5÷3.5	<0.04	<0.05	<0.005	97	>0.2	>0.005	<0.1	0.6÷1.4

2.2. Experimental plan

The input parameters given in table 3 were used in the milling-burnishing process. The values were chosen by taking into consideration aspects like: maximum pressure and depth burnishing that the CNC equipment can handle, the parameters are linked by the same ratio, for a smooth ANOVA

analysis, the maximum milling cutting speed meets the HSM (high speed machining) requirements. For the machining direction experiments were made for both simultaneous and successive process. The reverse machining direction experiments were made only for the successive process. The combination of the input factors results in a number of 54 samples for each of the processes, giving a total number of 162 samples.

The surface roughness was analysed with respect to the combinations stated above. It was measured using the Namicon Roughness Tester TR-200 as the absolute roughness (R_a).

Table 3. Milling-burnishing input parameters

Input parameter	Min. value	Avg. value	Max. value
Cutting speed [m/min]	100	350	600
Feed per tooth [mm/tooth]	0.06	0.08	0.1
Milling depth of cut [mm]		0.6	
Burnishing pressure [bar]	30	60	90
Burnishing depth [mm]	0.5	-	0.75

2.3. Milling-burnishing experimental setup

The milling-burnishing experimental setup is highlighted in figure 2. The study was performed on a 3 axes Knuth RapiMill 700 milling machine. The cutting tool is a Sandvick Coroman 490 with a diameter of 50 [mm] and CCMT inserts having a tip radius of 0.8[mm]. A low pressure pump provides the hydraulic oil for the high pressure Ecoroll HGP 3.0 pump. The pressure is indicated by a dial gauge. The magnesium samples were fixed in a vise. The experiment was conducted in both successive and simultaneous conditions.

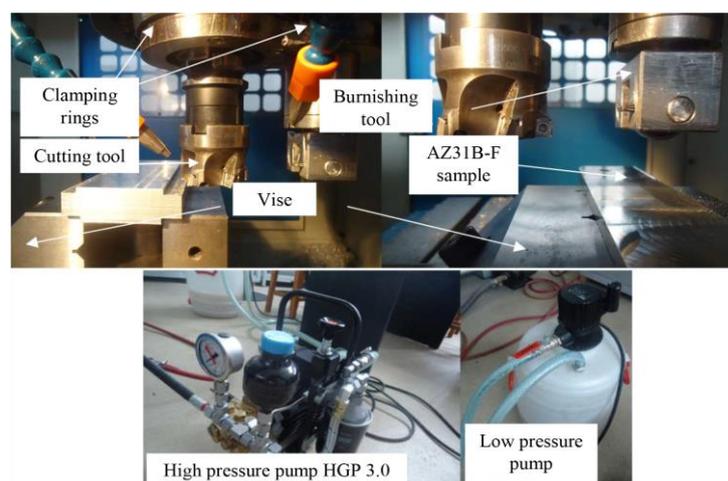


Figure 2. Experimental setup of the milling-burnishing process

3. Results

The roughness measurements were taken on the milled surface and on the burnished one. The result where interpreted as percentage improvement (Equation 1), where R_{a_m} represents the surface roughness measured after the milling operation and R_{a_b} is the surface roughness of for the burnished surface. The results for the milling surface roughness range from 0.18 to 0.67 [μm] and those for the

burnished surface roughness are from 0.12 to 0.35 [μm]. The comparison was made between the simultaneous and successive surfaces.

$$\text{Percentage improvement} = \frac{Ra_m - Ra_b}{Ra_m} * 100 \quad (1)$$

3.1. Cutting speed

The average percentage improvement in surface roughness with respect to the cutting speed is given in figure 3. It can be noted that the simultaneous process in the machining direction offers better results when cutting with a speed of 100 [m/min]. The highest improvement is of 62.82 [%], from 0.35 to 0.13 [μm] and was obtained for a cutting speed of 100 [m/min]. The smallest improvement was recorded for a speed of 600 [m/min] from 0.25 to 0.22 [μm], meaning 12.0 [%]. As the speed increases smaller percentage improvements are obtained. In the case of the successive operations better results were obtained when milling-burnishing with a speed of 350 [m/min], for both machining directions.

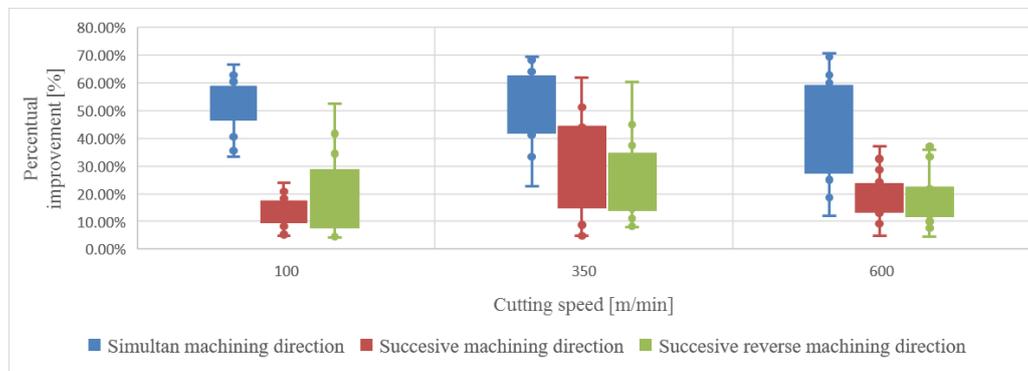


Figure 3. The influence of the cutting speed on the surface roughness

3.2. Cutting feed

In figure 4 it is presented the influence of the feed on the roughness average percentage improvement. It can be observed that with the increase of the feed slightly better result are obtained for the simultaneous process. The results for a feed of 0.1 [mm/tooth] are scattered on a larger value range. The most significant improvement is from 0.46 to 0.14 [μm], meaning 69.75 [%]. Successive machining is efficient when low feeds are used. In the case of the successive process the increase of the feed offers improvements for milling-burnishing with reverse machining direction.

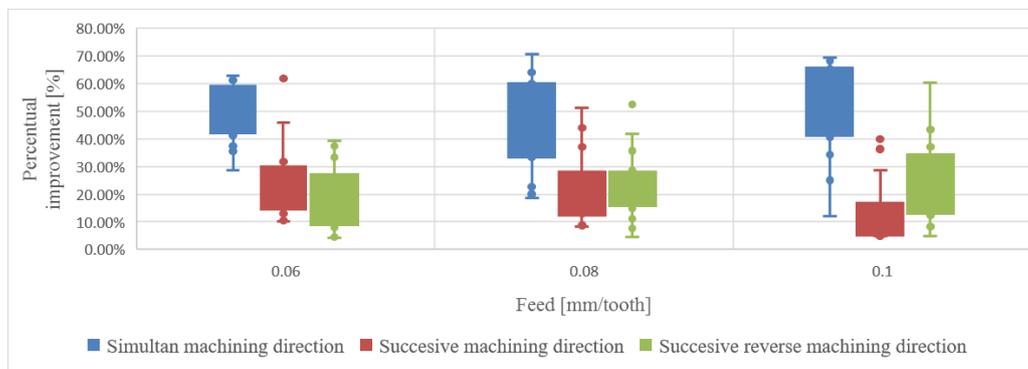


Figure 4. The influence of the feed on the surface roughness

3.3. Burnishing pressure

The increase of the burnishing pressure to 60 [bar] leads to slightly smaller average percentage improvements (figure 5). This also outlines the fact that the process is more stable by means of the certainty of the obtained results. Machining with a pressure of 90 [bar] results in a higher interval value. The percentage varies from 12.00 [%] to 70.73 [%]. It is noted that successive milling-burnishing results in the opposite of the simultaneous process. As the pressure increases the percentage improvement is higher, but the interval in which the results are scattered is smaller. Changing the machining direction does not lead to a significant change in the surface roughness percentage improvement.

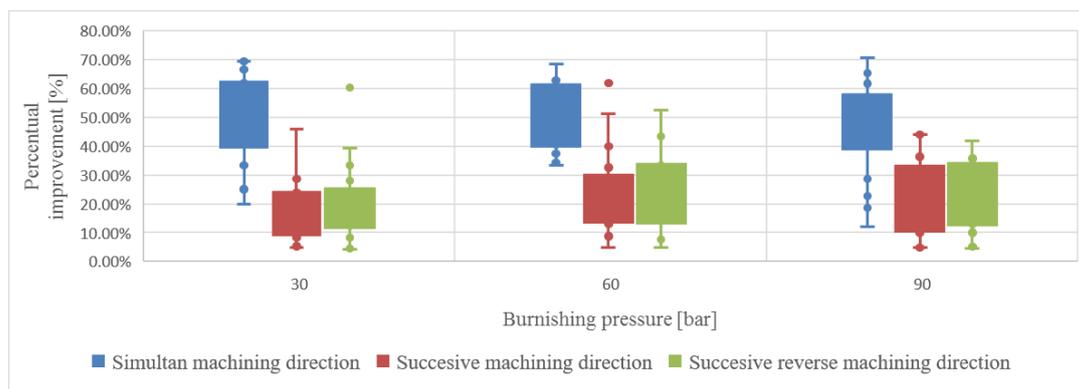


Figure 5. The influence of the burnishing pressure on the surface roughness

3.4. Burnishing depth

From figure 6 it can be noted that ranging the burnishing depth from 0.5 to 0.75 [mm] results in obtaining higher average roughness percentage improvement. The most significant result is the decrease in the surface roughness from 0.41 to 0.12 [μm]. Also the results are scattered on a smaller range from 33.33 to 70.73 [%], compared to those obtained for machining with 0.5 [mm] depth: from 12.00 to 61.90 [%]. The stability of the process can be observed when successive milling-burnishing in the machining direction is combined with the 0.75 [mm] depth. This also offers the smallest roughness percentage improvements.

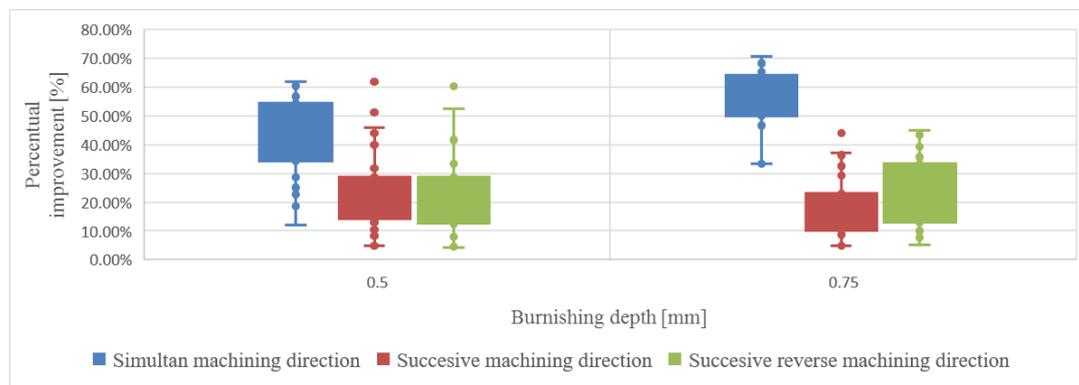


Figure 6. The influence of the burnishing depth on the surface roughness

4. Conclusions

This experimental study shows that improvement in the surface roughness in the case of magnesium alloy AZ31B-F can be obtained by using the simultaneous or successive milling-burnishing process. The process was performed by changing the cutting feed and speed, burnishing pressure and depth and type of process.

The simultaneous milling-burnishing process performed using smaller cutting speed leads to higher roughness percentage improvement and process stability. The successive process offers optimal results when using average speeds.

Higher feed results in higher roughness percentage improvement, but the process is not that stable as using lower feeds. Also higher feeds offer poor results for successive milling-burnishing in the machining direction.

A higher burnishing pressure offers higher roughness percentage improvement. The exact opposite happens when successive milling-burnishing process machining is used.

Higher burnishing depth gives better results for the simultaneous process, while using small depths offers smaller roughness percentage improvement.

From the analysis of the results it is obvious that the highest percentage improvements were obtained when the simultaneous milling-burnishing process was used. Although the successive process offers lower improvements than the simultaneous one, the results showed that using the burnishing process improves the milling surface roughness.

It can be concluded from this study that in the case of milling-burnishing magnesium alloy AZ31B-F the surface roughness can be improved by means of machining with the indicated input parameters (cutting speed and feed, burnishing pressure and depth) and type of process (simultaneous and successive).

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