Material Structure Influence on Surface Roughness in Nanofinishing Electrochemical Process.

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Abstract

The paper presents results of the research aiming to check if and how material structure affects surface roughness in electrochemical process nanofinishing. Piece of aluminium alloy AA 1200 after severe plastic deformation have been prepared in automatic roll bonding manner. Various level of deformation has been implemented, what resulted in various level of material granularity. Severe plastic deformation gives possibility to obtain nanometric grain sizes. Electrochemical polishing was carried in 15% $NaNO_3$ electrolyte under various voltage conditions. The experimental results proved that electrochemical machining is satisfying method for such a especially prepared material smoothing. The surface roughness significantly depends on the reactions appearing on phase boundary, which is between the electrolyte and machined material. It was shown, that material structure strongly affects results of material smoothing with use of electrochemical machining. Small grain size makes material much isotropic, thus electrochemical dissolution is more effective and make it possible to reach surface roughness parameters values in nanometric scale.

Keywords:
ECM, nanofinishing, roughness

1 INTRODUCTION

Electrochemical machining (ECM) is an important technology in machining difficult-to-cut materials and to shape sculptured surfaces without tool wear and without inducing residual stress. Such advantages are the reason that ECM is a very good alternative for finishing machining of sculptured surfaces initially machined by other methods [1], [2].

2 ACCUMULATIVE ROLL BONDING – ARB

The ARB [2] method consists in rolling with 50% reduction of two metal sheets stacked in a pack. The obtained sheet is cut into halves and after preparing the adhering surfaces and folding in a pack, they are subjected to successive rolling cycles. The concept of the ARB process is shown in Fig. 1.

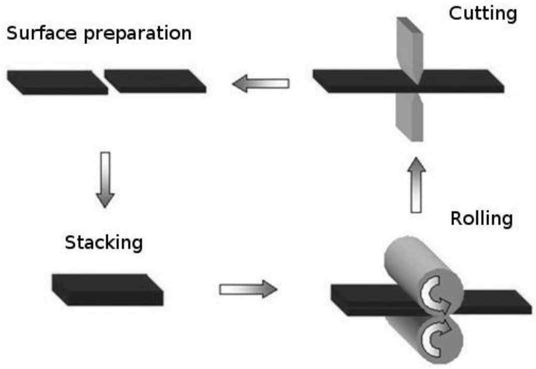

Fig.1. Scheme of the Accumulative Roll Bonding process

Assuming g_0 as the initial thickness of the sheet, then after successive cycles of ARB process the approximated thickness of the layer is:

$$g_n = \frac{g_0}{2^n} \quad (1)$$

while the total reduction after n-cycles is:

$$z_n = 1 - \frac{g_n}{g_0} = 1 - \frac{1}{2^n} \quad (2)$$

At the assumption that the material is deformed in a plane state of strain and in accordance with Huber–von Mises–Hencky plasticity condition the equivalent deformation is calculated according to the dependence:

$$\varepsilon_n = \left[\frac{2}{\sqrt{3}} \ln(\frac{1}{2}) \right] * n = 0.8 * n \quad (3)$$

The ARB method become more and more interesting in industrial applications for preparing nanocrystlline structures.

3 ELECTROCHEMICAL MACHINING

In many cases the quality of the detail can be significantly improve by increasing its surface quality. In case of electrochemical machining the surface quality can be increased by using pulse interelectrode voltage. In order to reach micro and nano-values (Ra << 100 nm) surface roughness parameters like time pulse and time interval should be optimal. Results of experimental tests proved that material structure, especially fine grain size, strongly improves surface roughness after ECM smoothing. For measurements equipment designed and built in the Institute of Advanced Manufacturing Technology has been applied. The test stand scheme is presented below (Fig. 2).

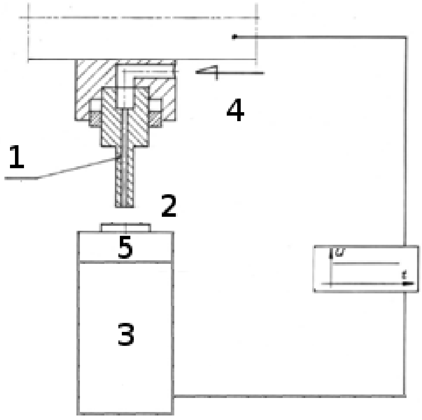

Fig. 2. Scheme of ECM sinking test stand : 1-working tool, 2-workpiece electrode, 3-machine body, 4-electrolyte inlet, 5-electrode clamp

4 RESULTS

In order to prove the assumption, that ultrafine crystalline structure strongly affect the quality of the machined surface in ECM smoothing, following test has been applied. The aimed to compare the surface roughness of typical aluminium alloy with no severe plastic deformation, and aluminium alloy after special plastic treatment ARB, that introduces high grain granularity.

The first material aluminium alloy PA 6 was machined by means of ECM sinking with following initial conditions and assumptions:

Examined factors:

- interelectrode voltage U=14-20V
- machining time t=1-9s
- sinking speed v_f=0,1-1,2mm/min

Resultant quantities:

- roughnes Ra,
- removed allowance thickness a,

Constant factors:

- elektrolyte $NaNo_3$, concentration Ce=10%
- pause time tp=1ms
- pulse time ti=3ms
- temperature 298K
- cylindrical electrode of diameter d= 6mm
- thickness of initial interelectrode gap S_0=0,15 mm.

During the process of ECM smoothing, the surface roughness factor Ra was significattly decreased by applying machining by sinking with vf=1,2mm/min. It resulted in higher allowance thickness a=1,25mm, and Ra= 0,195µm. The tendencies are presented on the figures below. The figures were prepared upon data from measurement and values estimated by use of experiment planning method[4], [5].

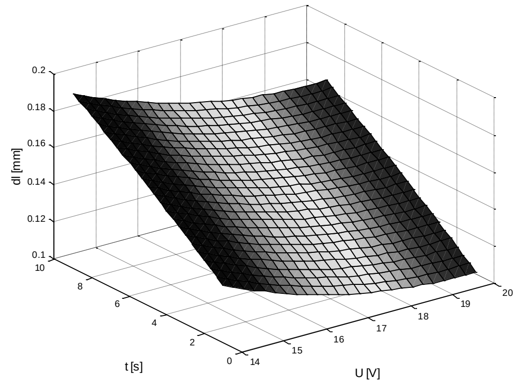

Fig 3. Dependence a(U,t) for ECM sinking of PA6 (dl=da)

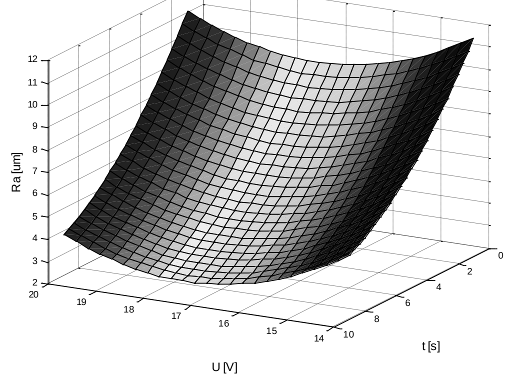

Fig. 4. Dependence Ra(U, t) for ECM sinking of PA6.

The samples for second tests were made of aluminum alloy consisting of Al – Fe 0,6% – Si 0,3% after recristallization at 450°C (723K) and the grain size ca. 20÷30m. One of them was left as it is, the others three were subjected to ARB process (n= 1, 5, 9). The plastic treatment consisted in rolling and stacking of material in order to obtain ultra fine crystalline structure and change mechanical properties.

Three samples were prepared in The Institute of Metallurgy and Material Science in Krakow. Various tension resulting from amount of rolling cycles was implemented. Detailed information about deformation level is presented below. The samples where then electrochemically smoothed. The roughness Ra and Rz was measured and the results are presented in the Table 1.

The samples were machined on ECM sinking test stand with use of following conditions and assumptions :

Examined factors:

- level of material deformation (determined from amount of rollings),

Resultant quantities:

- terminal interelectrode gap Sk [mm],
- surface roughness Ra [µm]

Fixed factors:

- size of the material grains without rolling
- primary ineterelectrode gap S_0 = 0,15mm
- electrolyte: 15% $NaNO_3$
- electrode shift l =0,6mm
- area of electrode A=0,715 cm^2
- pulse time t_i = 3ms
- pause time t_p = 1ms
- electrode travel speed v_p=1,2 [mm/s]
- electrolyte pressure pe = 1,6 [bar]
- electrolyte flowrate Qe = 2,5 [l/min]
- machined material: aluminium alloy Al – Fe 0,6% – Si 0,3%

The picture below presents the photography of the sample surface after ECM smoothing. The surface is shiny and smooth.

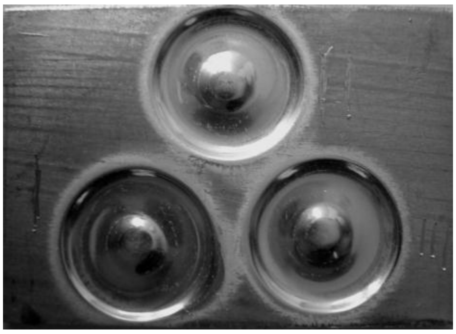

Fig. 5. Picture of the sample surface after electro-chemical finishing. Electrode face area A=0,715 cm^2

	S_k [mm]	Ra [um]	Rz [µm]
Aluminium Not rolled	na	0,029	0,212
1x, ε_n=0,8	0,376	0,018	0,127
5x, ε_n=4	0,284	0,080	0,437
9x, ε_n=7,2	0,282	0,093	0,375

Table. 1. Results of electrochemical nanofinishing of PA6 aluminum Alloy after ARB process. Multiplicity of rollings 1x, 5x, 9x.

Samples were examined with use of scanning electron microscopy. Because of expected fine grain sizes, the machined surfaces were observed in small and high magnifications. It was stated, that observation of grain boundaries is not possible without surface etching, therefore their size was not estimated. Then the sample 9x rolled (brittle) was broken and the structure photographs were prepared.

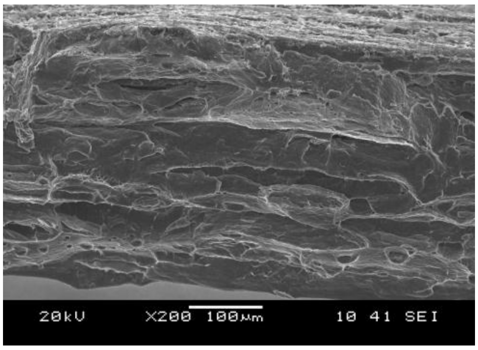

Fig. 6. The microphotography of the sample fracture. Magnification 200x

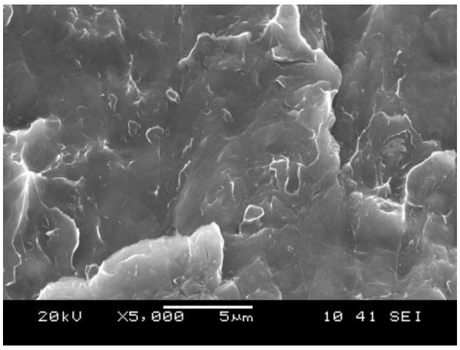

Fig. 7. The microphotography of the sample fracture. Magnification
5000x.

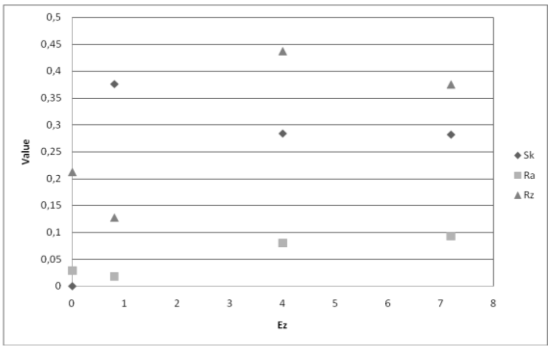

Fig. 8. Dependence of Sk, Ra and Rz from Ez.

5 SUMMARY

The research revealed, that material structure affects the surface roughness after ECM smoothing process. The PA6 alloy sample, with no plastic treatment, measured surface roughness after ECM smoothing by sinking was Ra=0,195µm. While the sample that was only one time rolled after ECM smoothing by sinking had the Ra=0,018µm and Rz=0,127µm. This is very promising result considering the fact, that highly dispersed materials with fine grain sizes are desired because of their isotropic physical and mechanical properties. Therefore ECM smoothing of such a materials gives possibility to obtain highly reflective surfaces. The experimental results proved that electrochemical machining is satisfying method for such a especially prepared material smoothing. The surface roughness significantly depends on the reactions appearing on phase boundary, which is between the electrolyte and machined material. It was shown, that material structure strongly affects results of material smoothing with use of electrochemical machining. Small grain size makes material much isotropic. Electrochemical dissolution in grain boundaries is intensive, thus electrochemical dissolution is more effective and make it possible to reach surface roughness parameters values in nanometric scale.

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