Influence of Centrifugal Shot Peening Parameters on the Impact Force and Surface Roughness of EN-AW 2024 Aluminum Alloy Elements

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ABSTRACT

This article presents the results of experimental studies on the influence of centrifugal shot peening parameters on the impact force F_u occurring during the machining of the EN – AW 2024 aluminum alloy. The surface roughness parameters Ra, Rt, Rpk, Rvk and surface topography were also analyzed. Centrifugal shot peening was carried out on the FV-580a vertical machining center using a centrifugal shot peening head. Variable parameters of the centrifugal shot peening were: tangential speed v_g and infeed g. On the basis of the results obtained, it was found that the increase the tangential speed v_g and the infeed g causes an increase of the impact force. After centrifugal shot peening, numerous micro-cavities were formed on the surface of the EN-AW 2024 aluminum alloy samples, which may can accumulate lubricants in their space. During centrifugal shot peening, low values impact force F_u were obtained, which confirms the legitimacy of using this method as a finishing machining of elements with low stiffness.

Keywords: surface roughness, impact force, Centrifugal shot peening, EN-AW 2024 aluminum alloy

INTRODUCTION

One of the methods of finishing machining elements is burnishing and shot peening. It consists in using the phenomenon the local plastic deformation surface layer caused by the impact of a hard tool on the surface. This technology is successfully used in the technological process of producing such machine elements as: dies, moulds, shafts, compressor turbine blades, spring leaves, rear suspension control arms [1].

Burnishing allows obtaining a low surface roughness [7, 17] and modification of the surface roughness profile, which translates into an increase in the material ratio [5].

During shot peening the forces acting on the workpiece are much smaller compared to burnishing. This allows for machining of elements with low stiffness, e.g. thin-walled elements. The effect of shot peening, which includes centrifugal shot peening, is "knocking out" on the

machined surface the cavities, which may constitute potentially "pockets" for accumulation of a lubricating medium in their space, which reduces the abrasive wear [4]. The shape of the micro asperities, which is more streamlined, contribute to the increased adsorption and chemical activity of the shot peened surface [12]. As a result of shot peening, the density increase and the concentration of crystal structure defects changes, which is confirmed by the studies that were carried out by annihilation techniques. The effect of these changes is an increase in the microhardness [2] and creation of compressive residual stresses in the surface layer [19, 22, 14]. Another advantage of shot peening is the possibility of increasing the fatigue strength and life of the elements subjected to variable loads [13, 18]. The beneficial effect of shot peening, apart from improving the properties of the surface layer is also deburring and rounding of the workpiece edges [9]. Shot peening is also successfully used for machining Ti-6Al-4V

implants produced by DMLS (direct metal laser sintering) additive technology [23, 24].

Centrifugal shot peening consists in hitting the machined surface with balls mounted radially in the holes of the rotating head. Centrifugal shot peened elements, protected from falling out, move radially during machining [21]. Centrifugal shot peening can be integrated with grinding [10].

Centrifugal shot peening is very often performed on numerically-controlled machining centers [15, 21]. The occurrence of an impact motion during shot peening, and thus a component of the force perpendicular to the surface, may cause the loads on the machine tool spindle and contribute to the destruction of the tool. The knowledge of the force occurring during shot peening is important, especially when designing a technological process. There are no publications in the literature on the measurement of force during centrifugal shot peening. There are only studies on the measurement of forces during ball burnishing and sliding burnishing [3, 6, 16].

The aim of this study was to assess the influence of technological parameters of centrifugal shot peening on the value of the impact force and surface roughness of the elements made of the EN-AW 2024 aluminum alloy.

RESEARCH METHODOLOGY

The research used the specimens made of the EN-AW 2024 aluminum alloy with the dimensions of 4×15×100 mm. The EN-AW 2024 aluminum alloy is most commonly used in the manufacturing of airframes, wings sheathing, aircraft and car rims. It is also widely used for the structural components that require high strength at temperatures up to 150°C, such as aircraft engine pistons and Diesel engine [11]. The specimens used in the experiment were pre-milled using R245–050022-DC50 milling head with a diameter of $d = 50$ mm, equipped with R245–12F3 inserts. The following technological

parameters process were used: cutting speed $v_c = 125$ m/min, feed speed $v_f = 200$ mm/min, number of tooth z = 4. Figure 1 shows the research plan, which includes a set of variable, constant and output factors.

The centrifugal shot peening research was performed on an FV-580a vertical machining center. A special head with diameter $d_g = 70$ mm, which in the housing has symmetrically arranged shot balls with a diameter $d_k = 6.3$ mm in the number $z_k = 12$, was used as a tool. The kinematics of centrifugal shot peening on a vertical machining center is described in detail in [15]. The machining parameters (tangential speed – v_g, feed rate – v_f, infeed – g, cross-feed – f_p), selected on the preliminary research, were presented in Table 1. The experiment for the given conditions was repeated seven times.

One of the variable parameters of centrifugal shot peening was the infeed – g, which is defined as the difference between the maximum head radius R_{max} and the distance between the head axis and the machined surface R (Fig. 2).

The impact force F_u, which is component perpendicular to the centrifugal shot penned surface, was measured with tensometric dynamometer. The force gauge consisted of a NA1 tensometric beam with a measuring range to 400 N and accuracy of 0.01 N, and also and a 24-bit A/C HX 11 converter. The transducer in cooperation with the Arduino Nano mini controller allows saving the results in real time in the Microsoft Excel

Table 1. Centrifugal shot peening conditions used in the tests

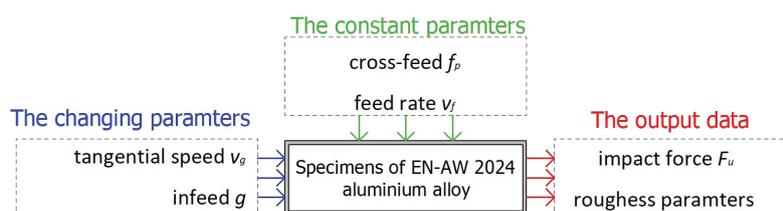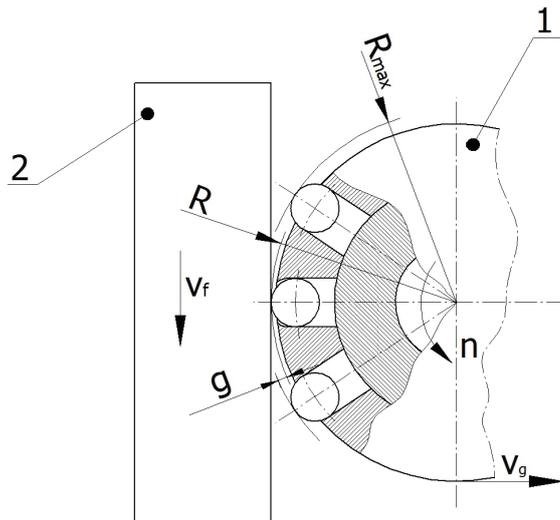| v_g, m/min	g, mm	v_f, mm/min	f_p, mm
132			
264	0.45		
396			
528		2304	0.08
	0.35		
396	0.4		
	0.5		

Figure 1. Research plan

Figure 2. Scheme of the centrifugal shot peening and graphical interpretation of the infeed *g*: 1 – centrifugal shot peening head, 2 – sample (where: R_{max} – maximum head radius, *R* – distance between the head axis and the machined surface, v_g – tangential speed, v_f – feed rate, *n* – speed of rotation *g* – infeed

program [8]. The impact force F_u is defined as the value at the moment, when the shot penned head contacts the workpiece surface.

The T8000RC 120–140 device from Hommel-Etamic was used for 2D surface roughness and 3D topography measurements. The scanned area was 4.8×4.8 mm. Hommel Map Basic version 6.2 was used to determine 3D surface roughness parameters.

RESULTS

Figure 3 shows an example of the force as a function of the sampling time. There are three characteristic stages of the tool work: the entry zone, the stable work zone and the exit zone. At the moment of the impact of ball on the surface of the workpiece, the force increases rapidly and this is the impact force F_u, next it decreases and stabilizes at a certain level (it is most likely the value of the friction force between the system components). The lack of contact between the ball and the workpiece in the exit zone causes that the force value decreases to zero.

The impact force F_u increases along with the rotational speed *n*, and thus tangential speed of the head v_g (Fig. 4). It is related to the increase of the collision energy, which occurs with the increase of speed v_g. The higher the collision energy translates into larger the degree of deformation machined surface, which creates greater resistance. The 400% increase the v_g speed cause the F_u impact force to increase by about 950%. The
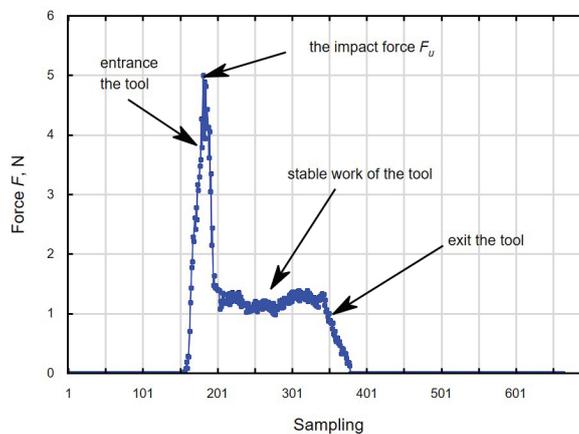

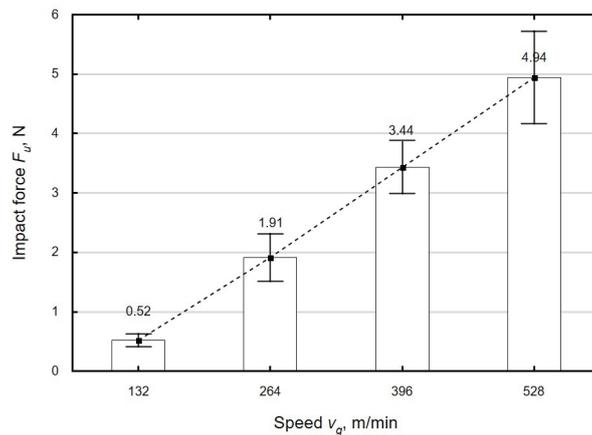**Figure 3**. The course of the force during centrifugal shot peening ($v_g = 528$ m/min, $g = 0.45$ mm)

Figure 4. The influence the tangential speed v_g ($g = 0.45$ mm, $v_f = 2304$ mm/min, $f_p = 0.08$ mm) on the impact force F_u

highest standard deviation occurs for the maximum value of the speed v_g, which may suggest that the character of the work is less stable for this speed.

The figure 5 presents the influence of infeed g on the tested variable. While analyzing the obtained results, it should be noted that an increase of infeed g in the range from 0.35 to 0.45 mm caused an increase of the impact force F_u. A further increase of infeed led to slight changes the F_u value. It can be assumed that the change of the infeed in the upper value will have lesser influence on the durability of the head than the tangential speed v_g.

The face milling was the pre-machining before centrifugal shot peening. An exemplary topography and surface profile were presented in Figure 6. On the milled surface there is unidirectional pattern of micro asperities, which have similar height with characteristic trace of the work

the edge. The surface shows "peaks" and "valleys", which are the result of mapping the work of the tool nose. The resulting surface should be classified as unidirectional anisotropic.

The roughness parameter Ra is most often used to assess the surface quality, but it is difficult to evaluate the stereometric properties of the surface on the basis of its value. The value the total height of the profile Rt allows for the prediction of the occurrence the peaks and valleys in the machined surface.

The figure 7 shows the influence of the tangential speed v_g on the surface roughness parameters Ra (Fig. 7a) and Rt (Fig. 7b) after centrifugal shot peening. The increase of speed v_g causes the enhanced kinetic energy, which influences the size of the elastic-plastic deformations of the surface irregularities. The occurring deformations determine the surface roughness, which translates into an increase in the analyzed variables.
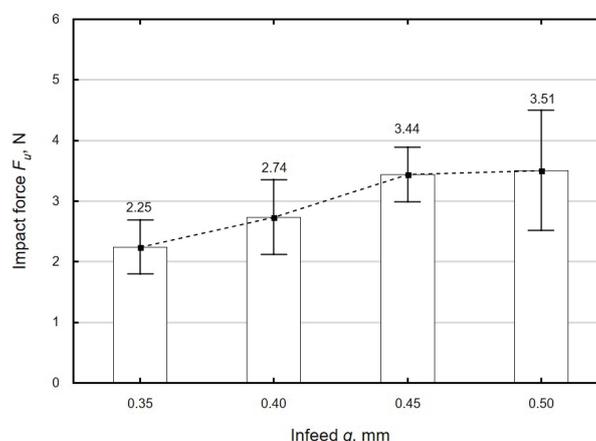

Figure 5. The influence infeed g ($v_g = 396$ m/min, $v_f = 2304$ mm/min, $f_p = 0.08$ mm) on the impact force F_u
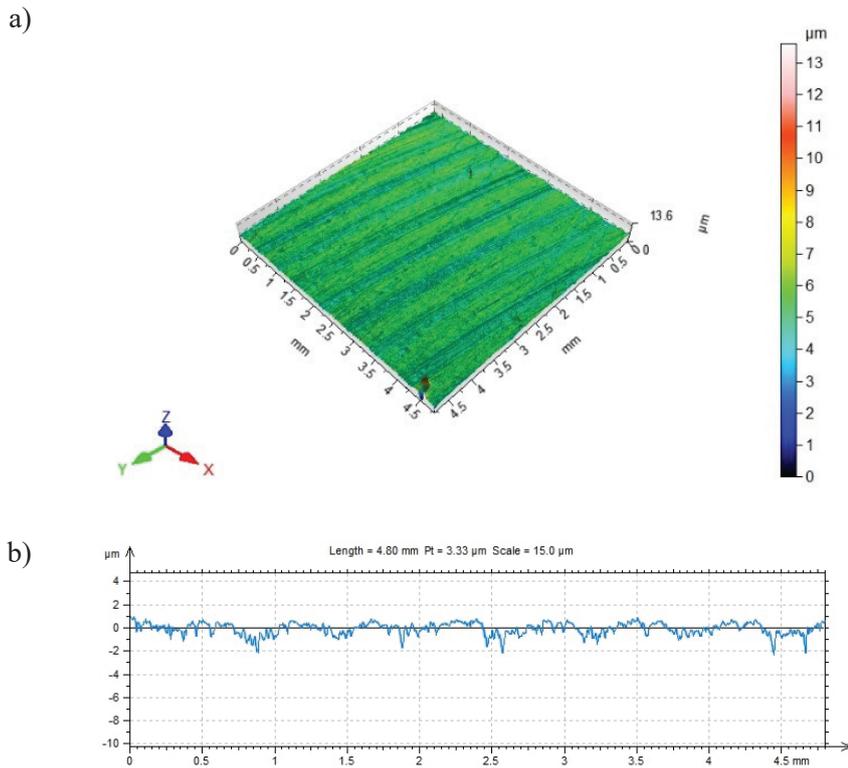
a)

b)

Figure 6. The surface topography (a) and surface profile (b) of the
EN-AW 2024 aluminum alloy samples after milling

The largest changes in the roughness parameter *Ra* and *Rt* are visible for the speed range $v_g = $ 264÷396 m/min. The *Ra* values are from 23% to 82% higher than after milling. In the case of the *Rt* parameter, the maximum increase of this parameter was achieved by about 9% compared to the value after milling.

During centrifugal shot peening for speed v_g in the range from 132 m/min to 396 m/min on the machined surface traces, which the reduced height of the peaks (*Rpk*) increase, while the

reduced depth of the valleys (*Rvk*) decrease, as a function of the analyzed variable (Fig. 8). The changes that occur are most likely related to the properties of the tested material and the character of "contact" of the tool with the centrifugal shot peened surface. The EN-AW 2024 aluminum alloy is a material susceptible to the elastic-plastic deformation. The high friction occurs between the peened surface and the shot balls, which is caused by a wide angle between the normal velocity vector and the peened surface [15]. The
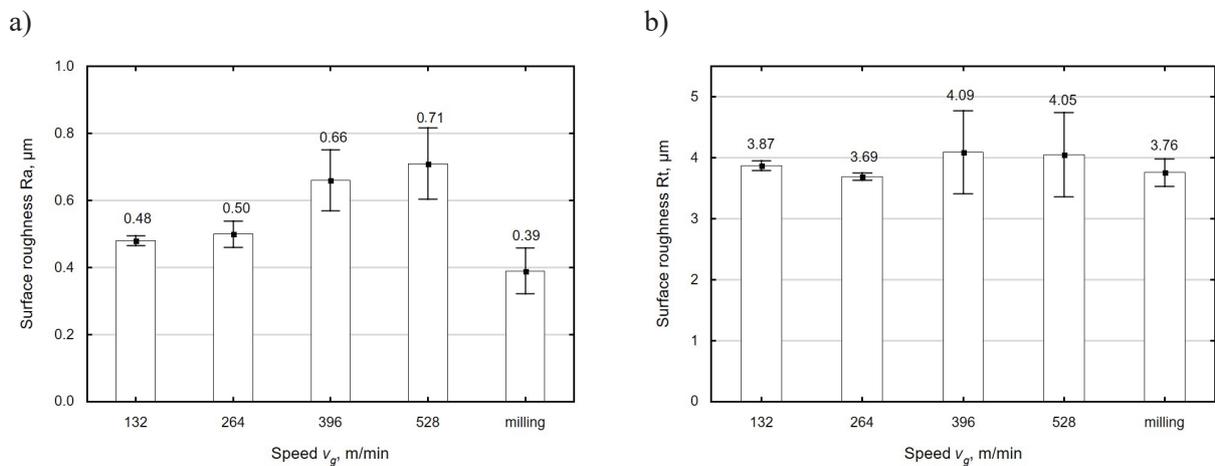
a)

b)

Figure 7. The influence the tangential speed v_g on the roughness parameters *Ra* (a) and *Rt* (b)
(g = 0.45 mm, v_f = 2304 mm/min, f_p = 0.08 mm)

Figure 8. The influence the tangential speed v_g on the roughness parameters *Rpk* and *Rvk*
$(g = 0.45$ mm, $v_f = 2304$ mm/min, $f_p = 0.08$ mm)
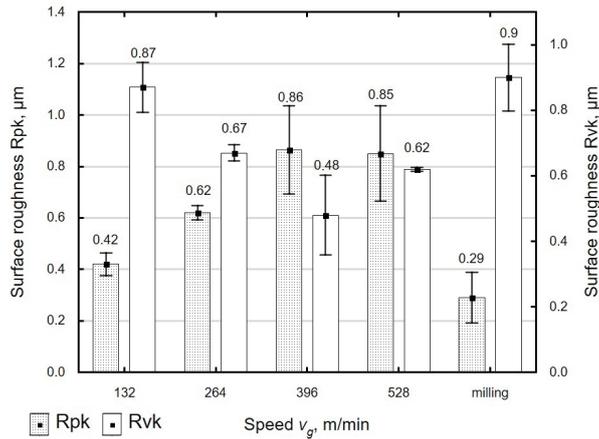
intense impact of shot balls and the material susceptibility to deformation favor the formation of micro-cavities, which have intensely deformed sharp peaks of high height and deformed valleys. In the range of $v_g = 396 \div 528$ m/min, there were no significant changes in the *Rvk* parameter, while the *Rpk* parameter increased.

The change of the infeed in the range of $g = 0.35 \div 0.4$ mm causes a decrease in the values of the analyzed roughness parameters *Ra* and *Rt* (Fig. 9). However, a further increase of infeed caused a slight increase in the *Ra* and *Rt* parameter. A similar character of changes was observed for the reduced height of the peaks *Rpk* and the reduced depth of the valleys *Rvk* (Fig. 10). An increase the infeed causes that the shot balls hit the machined surface from a shorter distance, but with higher force F_u (Fig. 5). This causes an intensive deformation of the centrifugal shot peened

surface. The smaller changes of the analyzed variables were observed for large infeed values. This is due the greater hardening of the material, which makes it more resistant to plastic deformation. The smallest value of the analyzed parameters were obtained for the infeed $g = 0.4$ mm.

The use of centrifugal shot peening for samples made of the EN-AW 2024 aluminum alloy resulted in an increase in the analyzed roughness parameters *Ra*, *Rt*, *Rpk* in relation to the surface after milling. A beneficial effect obtained by centrifugal shot peening, despite the decrease the value of the *Rvk* parameter, is the change the shape of the micro-cavities. The resulting machining traces (Fig. 11a and 11b) have a spherical shape, which suggests that they can become potential "pockets" capable of accumulating lubricants. The increase the retention capacity of the centrifugally shot peened surface may contribute to the reduction of abrasive wear [20].
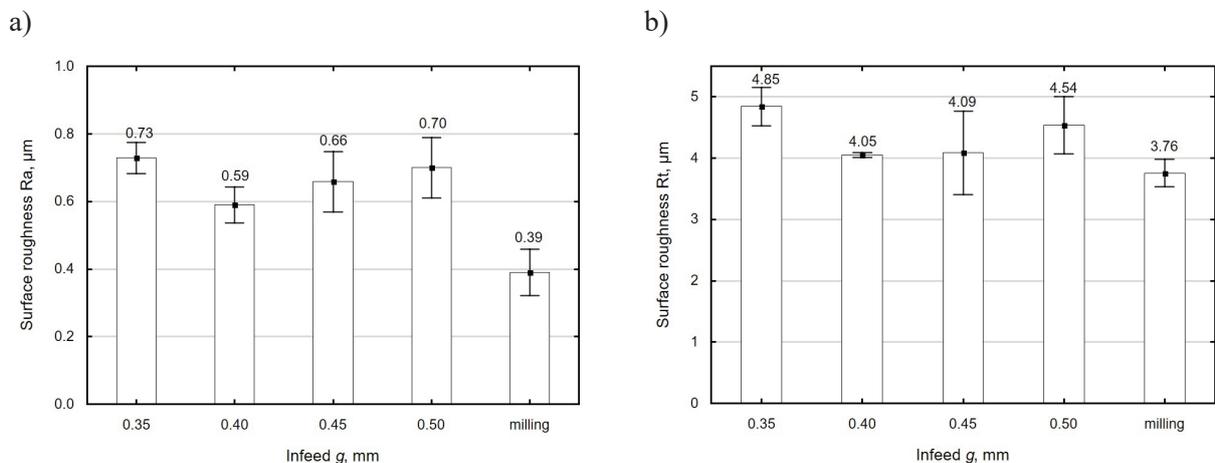
a)

b)

Figure 9. The influence infeed *g* on the roughness parameters *Ra* (a) and *Rt* (b)
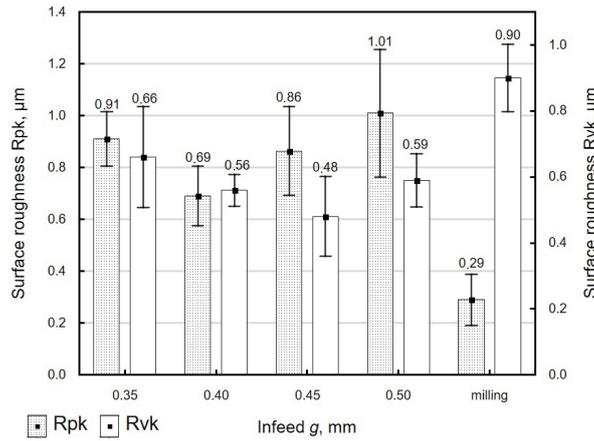$(v_g = 396$ *m/min*, $v_f = 2304$ mm/min, $f_p = 0.08$ mm)

Figure 10. The influence infeed *g* on the roughness parameters *Rpk* and *Rvk*
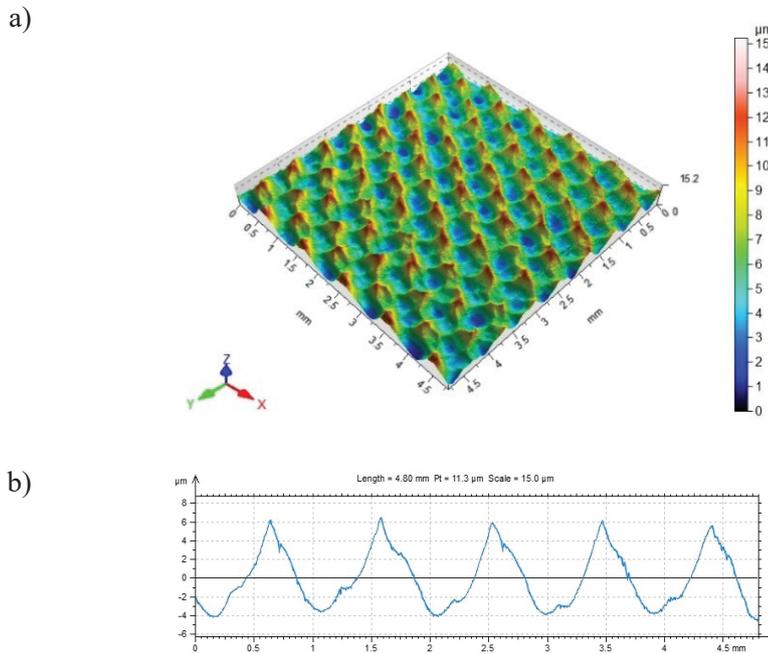(v_g = *396 m/min*, v_f = 2304 mm/min, f_p = 0.08 mm)

a)

b)

Figure 11. The surface topography (a) and surface profile (b) of EN-AW 2024 aluminum alloy samples
after centrifugal shot peening (v_g = 528 m/min, *g* = 0.45 mm, v_f= 2304 mm/min, f_p = 0.08 mm)

CONCLUSIONS

On the basis of the conducted research of centrifugal shot peening of the elements made of the EN-AW 2024 aluminum alloy, the following conclusions can be drawn:

1. The impact force F_u, occurring during centrifugal shot peening, does not reach high values in the range of the analyzed technological parameters.

2. An increase the tangential speed v_g and the infeed *g* causes an increase in the value of the analyzed force F_u. The changes are more visible for the tangential speed of the head v_g in the analyzed range than for the infeed *g*.

3. The surface roughness of the elements from the EN-AW 2024 aluminum alloy slightly increase after centrifugal shot peening.

4. After centrifugal shot peening, only the *Rvk* parameter is reduced in relation to the value following milling. As a result of centrifugal shot peening, the shape of the surface profile valley also changed.

5. During centrifugal shot peening, low values of impact force F_u occur, which confirms the possibility of using this method of as a finishing machining of elements with low stiffness.

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