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SURFACE ROUGHNESS AT ALUMINIUM PARTS SAND BLASTING

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Abstract: *The aluminum and its alloys are materials which found a large extend in machine building. For various reasons, the workpieces made of aluminum and aluminum alloys are sometimes subjects of blasting operations. Under the action of the abrasive particles directed to the workpieces surfaces, phenomena of plastic deformation, and material removing could develop. As result, the surface roughness changes; the paper presents some considerations concerning such phenomena generated at the impact of the abrasive particles with the workpiece material. Experimental researches were also developed in order to better understand the influence exerted by certain operating factors on the parameters of surface roughness. On the basis of the experimental researches, empirical mathematical models were determined and discussed.*

Key words: *aluminum, sand blasting, phenomena, surface roughness, experimental research, empirical mathematical models.*

1. INTRODUCTION

Due to its convenient properties (high resistance to corrosion, good mechanical properties, low density etc.) and to a large presence in the earth crust, the aluminum is used in a high extend in various industrial fields. One must mention that not only the technical aluminum is used, but also the aluminum alloys are materials applied to solve various problems in machine building. Even the aluminum and some of its alloys have a high resistance to the oxidation phenomena, there are situation when the surfaces of aluminum parts must be cleaned or prepared for other operations and one of the techniques applied with this aim in view is the sand blasting.

The blasting could be considered as a technique of abrasive machining; this machining method is based on the effects generated at the contact of the abrasive particles transported by means of the compressed air jet with the workpiece surface. One can notice that there are machining methods which uses abrasive particles included in abrasive bodies and so-called free abrasive particles, respectively [3 and 9].

It is known that generally, the blasting is based on the mechanical effects generated at the impact of hard particles with the surface to be machined; usually, the particles are directed to the workpiece surface by means of a gas jet. As result of the impact effects, the various rests of rust, dirt, and old coatings are removed from the workpiece surface, but frequently the effect impacts could generate changes of the surface roughness; within this paper, some researches were developed to highlight the influence exerted by some blasting parameters on the roughness characteristics of the machined surface. In fact, the changes of the surface roughness under the action of the abrasive particles allowed the use of some machining techniques of abrasive jet engraving.

Ramakrishna Naidu et al. applied a shod blasting to improve the plain fatigue and fretting fatigue of test pieces made of Al-Mg-Si alloy AA6061 [8]; as active tools, they used spherical balls of aluminum oxide abrasives, having a size of 120 μm. They succeeded to increase the plain fatigue life by a factor 2.8 and fretting fatigue life by a factor 2.4, in the case of a maximum cyclic stress of 169 MPa.

Heaton noticed that plastic abrasives could be used in order to remove coatings from delicate surfaces in the case of aircraft skins [6]; he shown also that the cost of blasting used for stripping paint and powder coatings from sensitive aluminum substrates could be an argument in extending the application field of blasting; he remarked also some ecological advantages specific to the blasting, in comparison with other cleaning procedures.

Deardorff proposed an improving of the air blasting by using a special blast media in two stages [2]; he applied this improving for stripping a fighter. Deardorff considered that the blasting produces a very good clean

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and smooth metal surface, eliminates pitting, warping or excessive roughness, and the proposed blast media could be recycled up to 25 times.

Lee et al. applied blasting to an aluminum foil in order to obtain micro-nano hierarchical structure similar to those on the lotus leaf [7]; as blasting material, they used sodium bicarbonate, which can be considered as a low-cost material and which is soluble in water. The last aspect allows a simple removal of the blasted particles during an anodizing operation. The proposed solution was appreciated as a cost effective as compared to the conventional methods.

In the case of the abrasive jet machining of a nonmetallic material (acrylic polycarbonate polymers), Getu et al. noticed differences between the surfaces machined for various sizes of the nominal impact angle [5]; they proposed a normalized non-dimensional polynomial function to predict profiles of masked and unmasked micro-channels developed after abrasive jet machining at an oblique impact angle.

V. Fascio considered that if the energy of the abrasive particles is higher than that corresponding to the ultimate tensile strength, microcracks appear and processes of material removal develop during the abrasive jet machining [4]. She noticed that the distance between the nozzle and the workpiece surface could have values up to 90 mm and that various sizes of the inclination angle of the abrasive jet axis could be applied.

2. THEORETICAL CONSIDERATIONS

Generally speaking, the abrasive jet machining is applied to pieces made of fragile materials; in this case, it is expected that the material removal develops especially by micro cracking.

The aluminum and some of its alloys are characterized by a certain plasticity (it is considered a malleable and ductile metal; (yield strengths for pure aluminum R_m = 52–180 MPa, for aluminum alloys R_m = 200–600 MPa, relative elongation A = 5–62%, Brinell hardness HB = 110–470 MPa).

This means that there is a high probability that some of the abrasive particles will generate a certain *plastic deformation*, while other abrasive particles determine phenomena of *microcutting*; in fact, it is known that just the microcutting needs initially a plastic deformation of the workpiece material up to such stresses that a shearing phenomenon develops

If the abrasive particles present rounded surfaces and intersections of surfaces forming a blunt angle, it is expected that especially plastic deformation appear (Fig. 1,*a*). The superficial plastic deformation is accompanied by a hardening of this layer, if the workpiece material can be affected by such a phenomenon.

Micro shearing – microcracking phenomena develop especially when the plan abrasive surfaces are intersected by forming acute angles (Fig. 1,*b*); if the abrasive particles have a high kinetic energy, the pressure exerted by them on the workpiece surface exceed the compression resistance and microcracks appear.

Small quantities of the workpiece could be removed by the microcracks join or jut by braking of the asperities peaks under the action of the abrasive particles (Fig. 1,*c*).

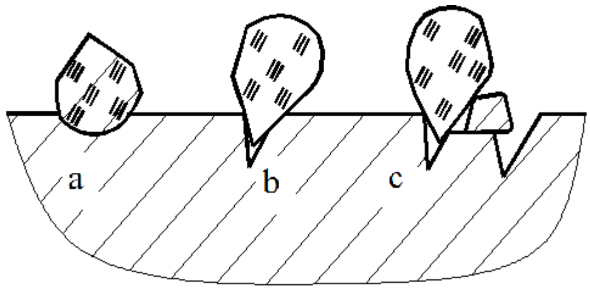


Fig. 1. Phenomena of plastic deformation, microcutting and micro cracking developed under the action of the abrasive particle.

If the direction of the abrasive jet is inclined in comparison with the workpiece surface and the abrasive particles have acute angles, a phenomenon of microcutting could develop (Fig. 1,c). When the aluminum alloys have a high enough hardness, certain phenomena of micro cracking could be observed. In all these cases, the stresses generated by the abrasive particle in the surface layer must exceed the strength of compression of the workpiece material; if this condition is not accomplished, only elastic deformation phenomena could develop.

Due to the plasticity of the aluminum, sometimes the abrasive particles could remain in the surface layer of the workpiece and, of course, this fact could not be convenient for the aluminum part use.

When the surface layer of the workpiece is affected by phenomena of plastic deformation, microcutting and micro cracking, it is expected that the surface roughness parameters be changed.

The sizes of the surface roughness parameters could depend on many input machining factors: the shape and the mechanical properties of the abrasive particles material, the mechanical properties of the workpiece material, the direction of the abrasive jet axis to the flat surface of the workpiece, the distance between the nozzle by which the abrasive particle leave the blasting gun and the workpiece flat surface, the pressure and the speed of the compressed air transporting the abrasive particles etc.

It is expected that the sizes of the usual surface roughness parameters increase at the increase of the abrasive dimensions and of the kinetic energy of the abrasive particles; the sizes of the surface roughness parameter could decrease for higher distance between the nozzle and the workpiece flat surface.

3. EXPERIMENTAL RESEARCH

In order to experimentally study the roughness of the surfaces affected by a sand blasting process, a blasting gun type 650R (Prodif Air comprimé – France) was used.

The compressed air was obtained by means of a compressor (p = 0.6 MPa); the circulation of the compressed air in the blasting gun determines the absorption of the abrasive particles from a recipient (Figs. 2 and 3); one can suppose that the distribution of the abrasive particles impacts with the workpiece surface could corresponds to the Gauss's law (Fig. 3).

The experiments were designed to highlight the influence exerted by some working parameters on the roughness characteristics of the blasted surface.

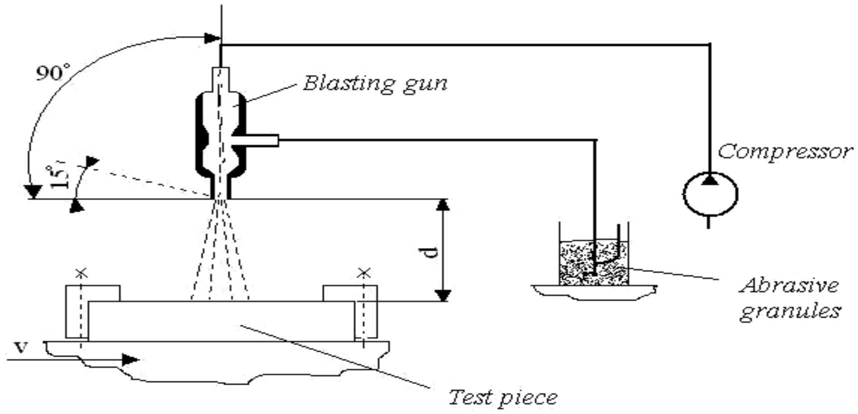


Fig. 2. Scheme of sand blasting process [10].

With this aim in view, a complete factorial experiment with three variables (average dimensions *g* of the abrasive particles, distance *h* from the nozzle to the test piece surface, angle *α* between the direction of the abrasive jet and the test piece flat surface) at two levels was designed.

A surface roughness meter type Mitutoyo was used in order to evaluate the roughness of the surface affected by the blasting process. The sizes of the following surface roughness parameters were measured: arithmetic mean deviation of the profile *Ra*, maximum height of the profile *Ry* (determined as sum of height *Yp* of the highest peak from the mean line and depth *Yv* of the deepest valley from the mean line), ten-point height of irregularities *Rz*, root-mean-square deviation of the profile *Rq*.

The experimental conditions and results are presented in Table 1.

Three measurements were made for each experiment; the average value of the above mentioned surface roughness parameters were also included in Table 1.

The duration of the blasting process applied on the surface of each test piece was of about 30 s; taking into consideration a surface of $20 \times 40 = 800$ mm^2, a specific duration t_s of the blasting process could be determined as a ratio between the blasting process duration t_b and the size of the area A_b of the surface affected by the blasting process:

$$t_s = \frac{t_b}{A_b}. \tag{1}$$

In the case of developed experimental researches, the specific duration was $t_s = 30 / 800 = 0.0275$ s/mm^2.

The experimental results were mathematically processed by means of specialized software, based on the method of least squares [1].

The software can show which is the most adequate empirical relation among five such relations (polynomial of first degree, polynomial of n degree, power, exponential and hyperbolic function); as criterion in establishing the most adequate function, the Gauss's sum criterion was used. In principle, the Gauss's sum takes into consideration the sum of the squares of the differences between the measured values and the values corresponding to the selected function for the same experimental points.

In this way, the most convenient empirical model written afterwards was determined; for each model, the Gauss's sum was also mentioned.

$$Ra = 3.095 g^{0.531} h^{-0.068} \alpha^{0.0922}, \tag{2}$$

Gauss's sum being $S_{G1} = 0.2973505$,

$$Ry = 13.242 \cdot 1.908^{g} 1.005^{h} 1.002^{\alpha}, \tag{3}$$

for which the Gauss's sum is S_{G2}=42.28105,

$$Rz = 12.43 \cdot 1.791^{g} 1.003^{h} 1.001^{\alpha}, \tag{4}$$

when the Gauss's sum is S_{G3}=11.6205, and

$$Rq = 3.882 g^{0.525} h^{0.0681} \alpha^{0.0884}, \tag{5}$$

for which the Gauss's sum is $S_{G4} = 0.5275374$.

At the same time, it is well known that within the study of machining processes, frequently the power type functions are used to highlight the influence exerted by various factors on the size of a parameter of interest, when the investigated parameter has a monotonous variation (without maximum or minimum points).

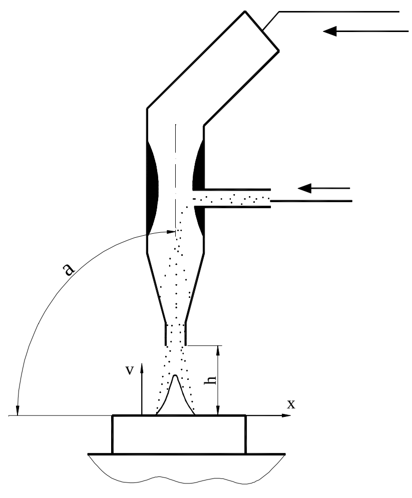


Fig. 3. Abrasive particles impact with the flat surface of the test piece.

Table 1

Experimental conditions and results

Average dimension of the abrasive particles g_{min} = 0.35 mm, g_{max} = 1.6 mm							
Distance between the nozzle and the workpiece flat surface h_{min} = 10 mm, h_{max} = 40 mm							
Angle between the abrasive jet direction and the workpiece flat surface α_{min}= 15^0, α_{max} = 90^0							
Experiment no.	**Average dimension of the particles, *g*, mm**	**Distance between the nozzle and the test piece, *h*, mm**	**Angle between the jet axis direction and the test piece surface, *α*, grade**	**Surface roughness parameter**			
				***Ra*, μm**	***Ry*, μm**	***Rz*, μm**	***Rq*, μm**
1	2	3	4	8	9	10	11
1	0.35	10	15	2.94	23.98	19.09	3.68
				2.73	21.13	17.45	3.46
				3.08	19.61	18.90	3.94
Average value				2.92	21.57	18.48	3.69
2	0.35	10	90	3.07	18.46	16.99	3.71
				2.76	18.74	16.14	3.43
				2.72	18.09	17.05	3.42
Average value				2.85	18.43	16.73	3.52
3	0,35	40	15	2.86	18.92	17.00	3.56
				2.31	16.21	13.72	2.85
				2.70	19.19	16.22	3.34
Average value				2.62	18.11	15.65	3.25
4	0,35	40	90	3.73	27.95	23.30	4.74
				3.97	36.22	23.77	5.00
				3.71	23.07	20.55	4.63
Average value				3.80	29.08	22.54	4.79
5	1,6	10	15	7.13	43.37	39.12	9.02
				5.86	41.64	34.28	7.29
				6.53	53.33	35.07	8.10
Average value				6.51	46.11	36.16	8.14
6	1,6	10	90	6.17	31.25	28.42	7.31
				6.79	49.52	38.42	8.52
				6.23	45.52	33.18	7.65
Average value				6.40	42.10	33.34	7.83
7	1,6	40	15	5.86	46.54	36.36	7.52
				6.14	36.49	36.85	7.34
				6.07	40.27	33.51	7.51
Average value				6.02	41.10	35.57	7.46
8	1,6	40	90	8.49	71.21	49.05	10.62
				8.85	67.70	47.20	10.85
				7.80	60.56	44.41	9.74
Average value				8.38	66.46	46.89	10.40

$$Ry = 18.721 g^{0.531} h^{0.112} \alpha^{-0.0984}, \quad (6)$$

the Gauss's sum being in this case S_{G5}=4228109, and

$$Rz = 18.635 g^{0.479} h^{0.0823} \alpha^{0.0642}, \quad (7)$$

when the Gauss's sum is S_{G6} = 11.62069.

The analysis of the empirical models represented by the relations (2), (5), (6) and (7) shows that for all the surface roughness parameters, the distance *h* between the nozzle and the flat surface of the test pieces and, respectively, the angle between the direction of the abrasive jet and the same flat surfaces of the test pieces practically does not influence the sizes of the surface roughness parameters, because the exponents attached to these factors in the empirical models are very slow.

One may also notice that the influence exerted by the average dimension *g* of the abrasive particles is of the same size order, because the sizes of the exponents attached to the factor *g* are close enough (0.479–0.531).

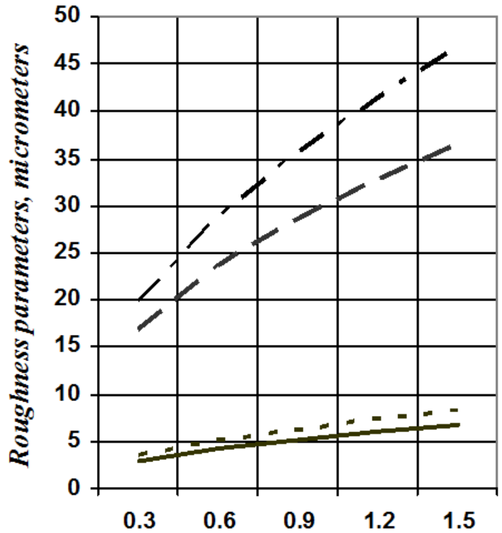


Fig. 4. Influence exerted by the average dimension of the abrasive particle on the sizes of the considered surface roughness parameters.

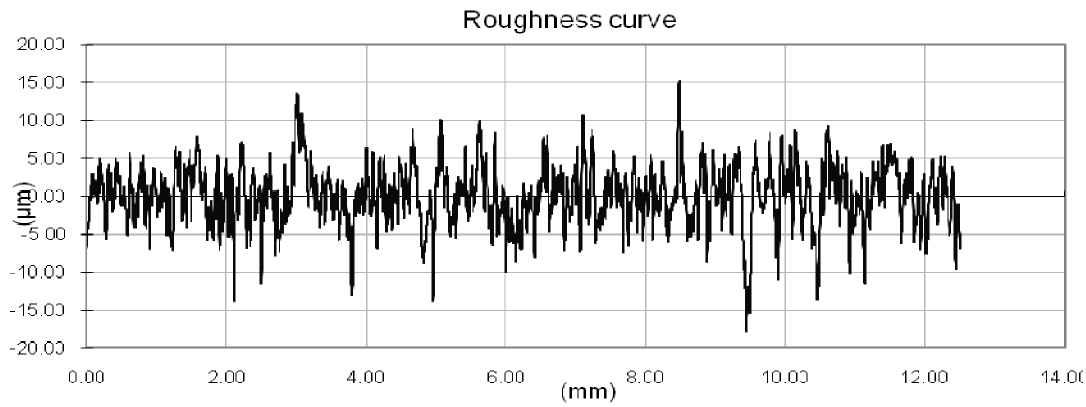
As the experimental results included in Table 1 show, the maximum sizes of the considered surface roughness parameters correspond to the situations when the average dimension of the abrasive particles is g = 1.6 mm, the distance between the nozzle and the flat surface or the test piece is h = 40 mm and the abrasive jet has a direction perpendicular to the test piece surface ($\alpha = 90^0$).

The diagram from Fig. 4 was designed in order to highlight the variation of the surface roughness parameters when the size of the abrasive particle average dimensions changes. A more intense variation of the surface roughness parameters *Ra* and *Rz* can be noticed and this fact could be explained by the modalities used in order to define these roughness parameters.

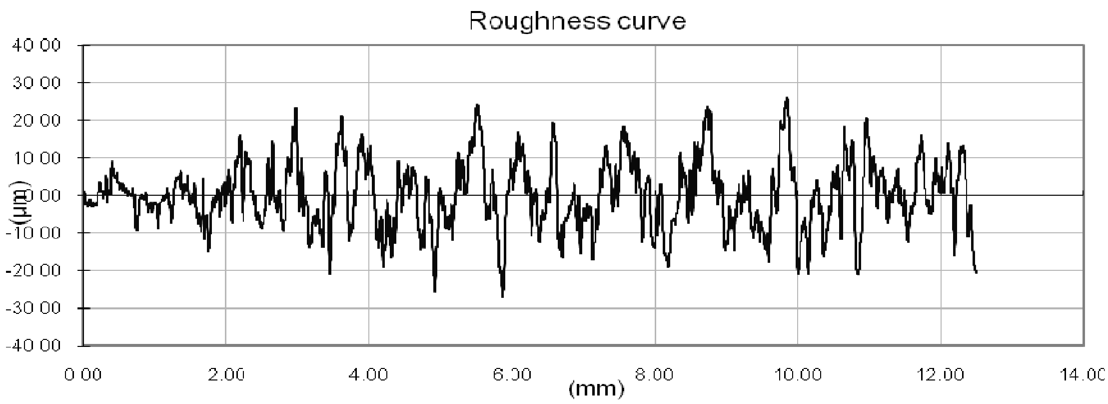
Two surfaces profiles corresponding to the situations when the minimum and the maximum sizes of the roughness parameter *Ra* were used are presented in Fig. 5; as expected, the distance between the asperities peaks is considerably lower in the case when small abrasive particles are used, due to the higher density of impacts.

4. CONCLUSIONS

There are practical situations when parts made of aluminum or aluminum alloys must be blast sanded; the specialty literature highlighted the preoccupation of the researchers to better understand the phenomena specific to the aluminum parts sand blasting and to the possibilities to optimize this process. The theoretical analysis of the sand blasting of aluminum parts shows that phenomena of plastic deformation and microcutting could preferential develop during the process. Some experimental researches were designed and developed to study the influence exerted by the sizes of some operating parameters (average dimension of the abrasive particles, dis-



a



b

Fig. 5. Profilograms corresponding to the test pieces having the minimum and maximum size of the surface roughness parameter *Ra*: *a* – g = 0.35 mm, h = 40 mm, $\alpha = 15^0$ Ra = 2.62 μm; *b* – g = 1.6 mm, h = 40 mm, $\alpha = 90^0$, Ra = 8.38 μm).

tance between the nozzle and the flat surface of the test piece, the angle between the direction of the abrasive jet and the flat surface of the test piece) on the sizes of certain surface roughness parameters. The experimental results were mathematically processed and empirical models type power functions were determined.

The empirical models show that for the considered experimental conditions, the distance between the nozzle and the flat surface of the test piece and, respectively, the angle between the direction of the abrasive jet and the flat surface of the test piece practically does not influence the sizes of the surface roughness parameters. At the same time, one may notice that the influence exerted by the average dimension of the abrasive particles on the surface roughness parameters has the same character, the sizes of the exponents attached to the average dimension of the abrasive particles in the power type functions being close enough.

In the future, there is the intention to design and to build specialized equipment, able to facilitate the study of the influence exerted by various factors on the properties of the surface layer affected by the abrasive jet machining.

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