

JET SHAPE AT ABRASIVE JET MACHINING

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ABSTRACT: The abrasive jet machining could be considered as a machining method based on the effects generated at the contact of the abrasive particles transported by a jet of compressed air with the workpiece material. One of the factors able to affect the shape of the abrasive jet is the distance between the nozzle and the workpiece surface. Due to the decrease of the pressure from the jet initial axis to the external zone, the abrasive jet has a conical shape. In the paper, there are some considerations and experimental results referring to the study of the width of the line generated by the abrasive jet on a carbon steel test piece, for various distances between the nozzle and the test piece surface. An empirical model offering an image about the change of the abrasive jet shape with the standoff distance was established.

KEYWORDS: Abrasive jet machining, Stand-off distance, Experimental research, Empirical mathematical model

1. INTRODUCTION

The abrasive jet machining method is based on the effects exerted on the workpiece surface by the abrasive particles placed in a high velocity gas stream [1, 3-11]. There are various machining techniques which use the above mentioned effects; if the intensity of the process is analyzed, one can identify *superficial machining methods* (able to affect only the surface layer of the workpiece) and *machining methods able to determine a significant material removal from the workpiece* (abrasive jet cutting, drilling, milling etc.).

In the group of superficial abrasive jet machining methods, some machining methods such as engraving, scratch finishing can be included.

Engraving could be considered as a machining method by which a text or a design is transferred on the surface of a metallic or non-metallic workpiece material.

Rani and Seshan highlighted the utility of the design of experiments in the study of the abrasive jet machining [10]; they considered that if equations are experimentally determined by statistical design of experiments, the prediction of the material removal rate is possible. Their study showed some interactions between the variables considered (nozzle tip distance, system pressure and powder flow rate).

Balasubramaniam et al. noticed that there were not detailed investigations concerning the shape of the abrasive jet machined surface [1]; they established a semi-empirical mathematical relation able to characterize the generated surface. One of their conclusions was that the entry side diameter increases with the increase of the main input parameters.

Ghobeity et al. studied the spatial distribution of particles in the jet in the case of an abrasive jet micromachining [5]. They established that the probability of an abrasive particle arriving at the surface at a given radial distance from the center of the surface of the impact corresponds to a Weibull distribution. A semi-empirical model for unmasked channels was proposed on the basis of the erosive power distribution of the jet.

Ghobeity et al. noticed that there is a uncontrolled variation in the abrasive mass flux due to phenomena of particle packing and local cavity formation in the recipient where the abrasive particles are deposited [4]. They used a mixing device to improve the process repeatability in the abrasive jet micro-machining; they appreciated that to ensure the best repeatability, a powder reservoir-mixing device and the control of the powder level in the reservoir are necessary.

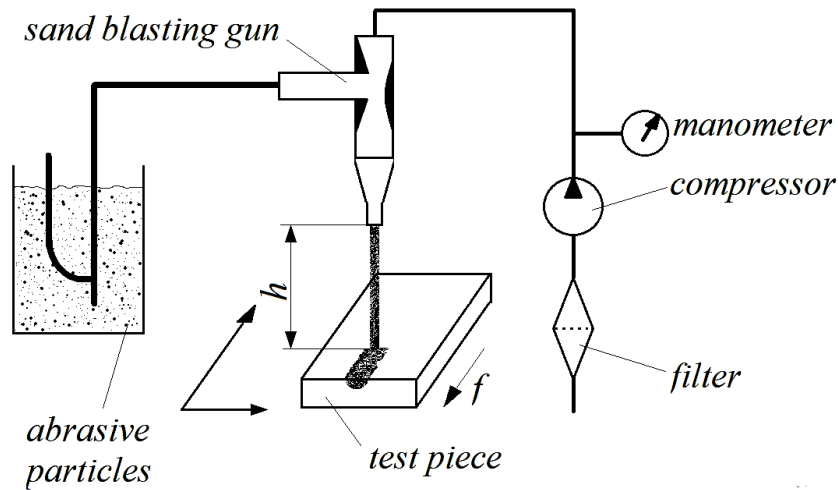


Fig. 1- Schematic representation of the equipment for surface abrasive jet machining

Li et al. developed a theoretical analysis for particle velocities within a microabrasive air jet and proposed some models by taking into consideration the nozzle length, particle mean diameter, particle density, air density and air flow velocity [8]. The distribution of the particle velocities along the jet centerline downstream from the nozzle was established considering surrounding air entrainment and air-particle interaction.

They verified the validity of the theoretical results by developing some experimental

research.

A novel technique able to improve the obtaining planar areas and transitional slopes in glass could be based on the target oscillation in a direction perpendicular on the scan direction; Ghobeity et al. studied such a technique in order to ensure negligible surface profile waviness of the surface affected by the abrasive jet machining process [6].

An investigation concerning the characteristics of the abrasive gas jet was

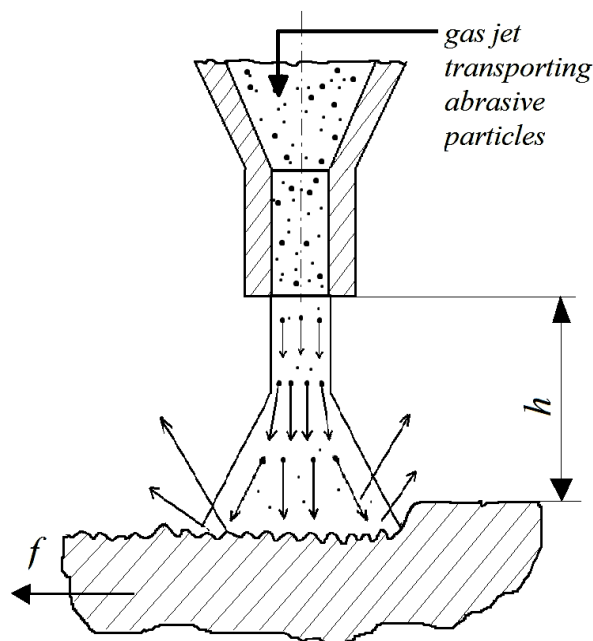


Fig. 2 - Impact of the abrasive particles with the workpiece surface

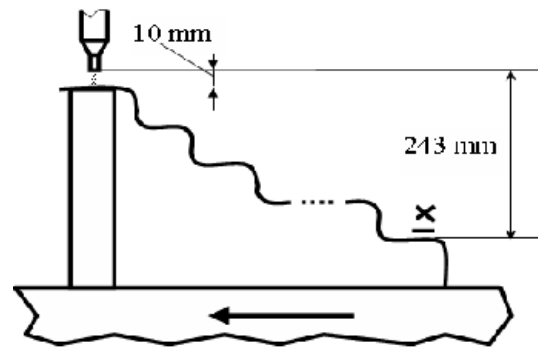


Fig. 3 - Abrasive jet machining of the stepped surface of the test piece

developed by Isupov and Lukin [7]. He appreciated that the surfaces affected by the action of the abrasive jet is characterized by an increased lubricant capacity, due to the presence of the lubricant micropockets and lubricant microchannels.

Pawlowski developed an ample study (a doctoral research) of the possibilities to use the powder blasting as a technique to machine brittle materials using a mask resistant to the erosion process action; he proposed new materials for masks (Polydimethylsiloxane - PDMS and a photosensitive epoxy like SU8 [9]. The experimental research proved the good operating properties of the proposed materials.

2. THEORETICAL CONSIDERATIONS

The abrasive jet is obtained by means of a jet of compressed air which arrives to a machining tool (for example, a sand blasting gun), where a diminished section of the tube for circulation of the compressed air determines a depression able to absorb the abrasive particles found in an adequate recipient (fig. 1).

The compressed air containing abrasive particles is directed to the workpiece surface by means of a nozzle. Initially, for a very short distance, it is possible that the abrasive jet has a cylindrical shape, but afterwards, due to the decrease of the pressure from the jet axis and to the resistance generated by

the atmospheric gas, the jet gets an approximately conical shape.

At the contact with the workpiece material, the abrasive particles generate phenomena of plastic deformation, microcracking and microcutting; within such effects, the abrasive particles transmit a part of their kinetic energy to the workpiece material. After their impact with the workpiece material, the abrasive particles are removed from the work zone by the air circulation.

The diameter of the initial cylindrical zone of the abrasive jet is essentially determined by the diameter of the orifice existing in the nozzle. In accordance with the principles of the fluids circulation, the speed of the gas is higher in the jet axis and this means that the abrasive particles placed here have a higher kinetic energy; as a consequence, it is expected that this particles exert a more intense effect on the workpiece surface.

For an accurate engraving, it is necessary to know the width of the line traced as a result of the relative motions developed between the nozzle and the workpiece; this means that the engraving process could be made by using the cylindrical shape of the abrasive jet. The area of the zone of contact between the abrasive jet and the workpiece surface is a factor determinant for the machining accuracy and for the adequate establishing of the eventually superposition off the zones affected by the action of the abrasive jet.

Therefore, it is important to have information about the shape and the dimensions of the abrasive jet.

3. EXPERIMENTAL RESEARCH

As above mentioned, due to the decrease of the pressure in the abrasive jet, from the jet axis to the exterior, the jet gets a divergent shape; this means that the diametric dimension of the jet increases and an increase of the surface affected by the engraving process could be also remarked.

An experimental research was designed and developed to verify these aspects and to obtain some information concerning the influence exerted by the distance between the nozzle and the workpiece surface on the width of the zone affected by the engraving process.

Simple equipment for sandblasting was used; a compressor generates the compressed air directed to the sandblasting gun. River sand was used as material for abrasive particles; these particles were absorbed (by the depression appeared in the blasting gun) from a recipient containing the granular abrasive material. The average dimension of the abrasive particles was of about 1.6 mm.

A test piece made of carbon steel was bent to obtain some stepped surfaces so that the width of the surface affected by the abrasive engraving is highlighted, for various distances between the nozzle and the workpiece surface (fig. 3).

For the first surface (the closest to the nozzle), the distance between the nozzle and the test piece was of 10 mm; the profile of the

plate was inscribed on a paper, in order to easily and more precisely determine the distances between the nozzle and the surfaces perpendicular on the direction of the abrasive jet (these surfaces were found at various distances from the nozzle used to generate the abrasive jet).

The initial examining of the engraving process showed a central zone with aspect totally changed by the engraving process and, respectively, two lateral zones, where the number of impacts with the abrasive particles was lower and, therefore, the machined surface is not continuous. However, the width of this band obtained as a consequence of a straight trajectory of the relative motion between the nozzle and the test piece. One can appreciate that the accuracy measure in the case of the two bands was of about $\pm 0,5$ mm, but the width was not rigorously constant..

The results obtained by measuring the widths of the above mentioned bands were inscribed in the table 1.

The mathematical processing of these results was made by using software based on the method of the least squares; thus, two empirical relations able to highlight the influence exerted by the distance between the nozzle and the test piece on the width of the band obtained on the test piece (as a result of the abrasive jet action) were determined.

The most adequate empirical relation for the width of the band with uniform aspect (for

Table 1. Influence exerted by the distance h on the widths b_1 and b_2 of the bands obtained as a consequence of the impact of the abrasive particles with the material of the test piece

Width b , mm	Distance h , mm						
	10	45	87	130	170	206	243
Width b_1 of the surface presenting a uniform aspect, mm	8,5	18,5	22	33	37	46	49
Total width b_2 of the surface affected by the abrasiv machining process, mm	12	27	36	47	54	63	67

which the Gauss' criterion has the value $s_G=2.5504$) correspond to a polynomial of second degree:

$$b_1 = 7,253 + 0.2059h - 1.292 \cdot 10^{-4} h^2. \quad (1)$$

One appreciated that supplementary information could be offered by a power type function, which was established by means of the same software:

$$b_1 = 2.288h^{0.5471}. \quad (2)$$

In this case, the value of the Gauss' criterion was $s_G=6.0126$.

In the case of the total width of the band, the most adequate empirical model was just a power type function:

$$b_2 = 3,423h^{0.2393}, \quad (3)$$

in this case the Gauss' criterion being $s_G=1.596$.

The analyze of the empirical model constituted by the relation (1) highlights a dependence of the width b_1 on the distance h between the nozzle and the test piece surface close to the linear one, because the value of the coefficient attached to this variable at the second power is very low ($1.292 \cdot 10^{-4}$).

Another remark refers to the values relatively close (0.5471 and, respectively 0.5393) of the exponents attached to the variable h in the case of the empirical relations corresponding to the widths b_1 and b_2 of the bands; this fact highlights a similar evolution of the two widths with, b_1 and b_2 , with the distance h between the nozzle and the test piece.

Graphical representations of the variation of the two widths b_1 and b_2 with the distance h between the nozzle and the test piece surface are presented in figure 4.

If the experimental results are considered, the divergence angle α could be determined by means of the relation:

$$\alpha = \arctg \frac{B - b}{2d}, \quad (4)$$

where B and b are the widths of the band generated on the test piece by the machining process and d is the distance between the zones where the band width was measured.

By means of the relation (4), one may calculate two sizes for the divergence angle" $\alpha_1=4.96^\circ$, if the zone of the test piece is completely changed by the action of the abrasive jet and $\alpha_2=6.73^\circ$, if the width of the entire zone affected by the abrasive process is considered.

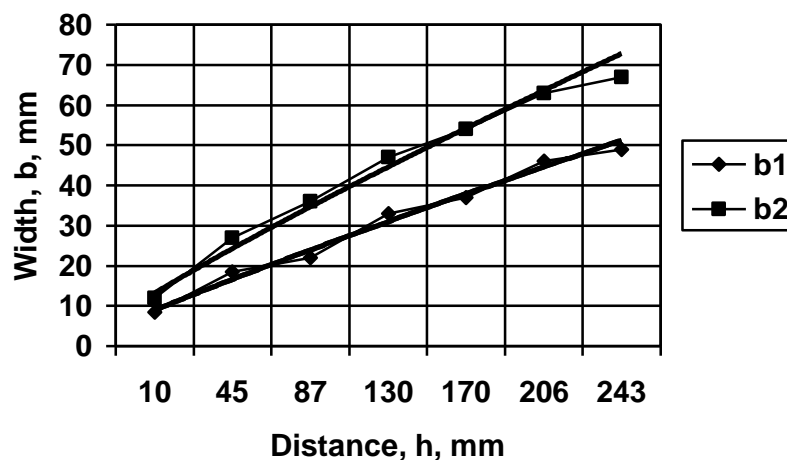


Fig. 4. Influence exerted by the distance h between the nozzle and the workpiece on the width of the surface affected by the abrasive machining process: b_1 – the with of the surface which presents a uniform aspect; b_2 – the total width of the surface affected by the abrasive machining process: the lines correspond to the power type empirical functions

CONCLUSIONS

In the case of the abrasive jet engraving, it is important to know the diametric dimension of the abrasive jet, because this dimension exerts a fundamental influence on the width of the line inscribed on the workpiece. Essentially, the diametric dimension of the abrasive jet is determined by the diameter of the nozzle used to generate the abrasive jet. If initially the abrasive jet has a cylindrical shape, afterwards, due to the decrease of the pressure from the jet axis to the exterior, the abrasive jet gets a conical shape. This means that the diameter of the abrasive jet increase with the distance between the nozzle and the workpiece surface. Some experimental researches were proposed and developed to show how the distance between the nozzle and the workpiece surface exerts influence on the width of the machined surface. With this aim in view, simple sandblasting equipment was used to machine a workpiece made of a plate bent so that to present stepped surfaces. Two types of surfaces were obtained as a consequence of the interaction of the abrasive jet with the workpiece material; thus, there is a surface with a uniform aspect and a surface which was not totally affected by the action of the abrasive particles. By measuring the width of the two zones and by mathematical processing of the experimental results by means of specialized software, empirical models were established. The analysis of these models highlighted a similar variation of the two widths with the distance between the nozzle and the test piece surface. In the future, the research could take into consideration the influence exerted by other factors (diameter of the orifice from the nozzle, the pressure of the compressed air used to generate the abrasive jet) on the width of the band obtained as a result of interaction between the abrasive jet and the workpiece material.

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