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RESEARCHES REGARDING THE PROCESSING OF COMPOSITE MATERIALS BY MEANS OF A HYDROABRASIVE JET

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ABSTRACT

The paper comprises the results of experimental researches regarding the processing of titanium-based composite materials by means of hydroabrasive jets. The samples, executed of titanium reinforced with TiB particles, were subjected to cutting and drilling operations. The hydroabrasive jet consists of an homogenous mixture of water and quartz and amaldine (ferrous-aluminous granate) particles with diameters of 0.08 to 0.15 mm. The technological installation used for this has following parameters: maximal working pressure - 250 MPa; maximal water flow - 2 l /min; amplifying factor - 32:1; nozzle diameter: 0.2 mm. It has been noticed that by increasing the pressure, the jet's efficiency increases as well, while the increasing of the feed rate has an reversely proportional influence on the efficiency and processing depths.

Keywords: processing, hydroabrasive jet, composite materials

1. THEORETICAL CONSIDERATIONS

One of the theoretical approaches of the processing of materials by means of high-pressure abrasive jets considers that both the processed material and the abrasive particles are homogeneous and have an elastic behaviour. In this case, Hooke's law can be applied and the values of stresses that appear can be calculated with Hertz' formulas.

- The maximal compression stress is determined as:

$$\sigma_{max} = \frac{3F}{(2\pi a)^2} \tag{1}$$

where *a* is the radius of the contact circle and *F* is the compression force.

- The reduced elasticity modulus is determined with the formula:

$$E^* = \frac{2E_1E_2}{(1-\nu_1^2)E_2 + (1-\nu_2^2)E_1} \tag{2}$$

where: E_1, E_2 are the elasticity modules of the two materials
ν_1, ν_2 are the transversal contraction coefficients of the two materials

- The compression force F produces a displacement *w* of the distances of gravity centres of the two bodies:

$$w = \sqrt[3]{\frac{9F^2}{4R_1E^{*2}}} \tag{3}$$

In these bodies, a compression stress appears at the edge of the contact radius, reaching the maximal value for the tensile strength (decisive for fragile materials):

$$\sigma_{max,t} = \frac{1}{3}(1-2\nu_i)\sigma_{max} \qquad i = 1,2 \tag{4}$$

Ductile materials fail only when the maximal value of the tangential stress is reached, it being located at the depth a/2 in both bodies. For steels, $\tau_{max} = 0.3\sigma_{max}$

Knowing the values of all intervening parameters, we can calculate the force that affects the material. Generally, it is considered that the processing with high-pressure jets goes through 2 stages:

- stage I, penetration of the material's outer layer and creation of optimal conditions for its in-depth penetration (initialisation of the processing)
- stage II, development of the processing down to the desired depth

Characteristic for the first stage is an induction of fissures in the material due to the shock waves generated by the jet's impact with its surface and the pressure created varies function of the impact frequency of elementary fluid particles.

Considering the impact of a single elementary fluid particle, the braking at contact with the material generates a high-pressure spherical shock wave, and in the liquid there occurs, at the part surface, a pressure chamber (Mach chamber) that limits the shock wave. A shearing force appears in the impacted material, followed by the appearance of fissures sideways from the impact point.

In the second stage, the energy needed for continuing the process is smaller and the processing mechanisms are cavitational erosion and fatigue-induced material dislocations.

The cutting with hydroabrasive jet is a "clean" method, without shocks, vibrations or heat emission, which doesn't create structural changes or stresses in the cutting area and doesn't produce chips or slag.

2. EXPERIMENTAL RESEARCHES

2.1. Materials

As part of the experiments, there were processed test samples made of composite titanium-based alloys strengthened with TiB particles obtained by metallic alloying and hot pressing.

Table 1 shows the main mechanical properties of the studied materials, function of their composition:

Table 1 Mechanical properties of the studied materials

Matrix composition	volumic % of TiB particles	E [GPa]	$R_{p0,2}$ [MPa]	R_m [MPa]	A5 [%]
Ti6Al4V	10	136.6	540	1000	0.25
Ti6Al4V	20	154	1170	-	3.1

The hydroabrasive jet used for cutting consists in a homogeneous mixture of water and two types of abrasive particles: quartz and almandine (ferro-aluminous granate – $3FeO{\cdot}Al_2O_3{\cdot}3SiO_3$), with following characteristics:

Quartz: - particle size: 100-150 Mesh (0.08-0.1 mm);
- Mohs hardness: 7
- specific weight: 2200-2600 kg/m^3.

Almandine: - particle size: 80-120 Mesh (0.1-0.16 mm);
- Mohs hardness: 7...7.5
- specific weight: 3900-4200 kg/m^3.

The water used for the experiments was filtered and distilled in order to remove impurities and chemical compounds that would precipitate on the circuit elements.

2.2 The experimental installation

The installation used for the processing with hydroabrasive jet is composed of:

- high-pressure generating station;
- electric control panel;
- workstation;
- system for the feeding with abrasive particles.

The installation's main parameters are:

- maximal work pressure:	250 MPa;
- maximal water flow:	2 l/min;
- amplification ratio:	32:1;
- nozzle diameter:	0.2 mm;
- distance between mixing tube and part:	3...4 mm;
- flow of abrasive particles:	4.5...6.5 g/s.

The workhead (figure 1) is the processing "tool", transforming the static, pressure energy into the jet's dynamic energy.

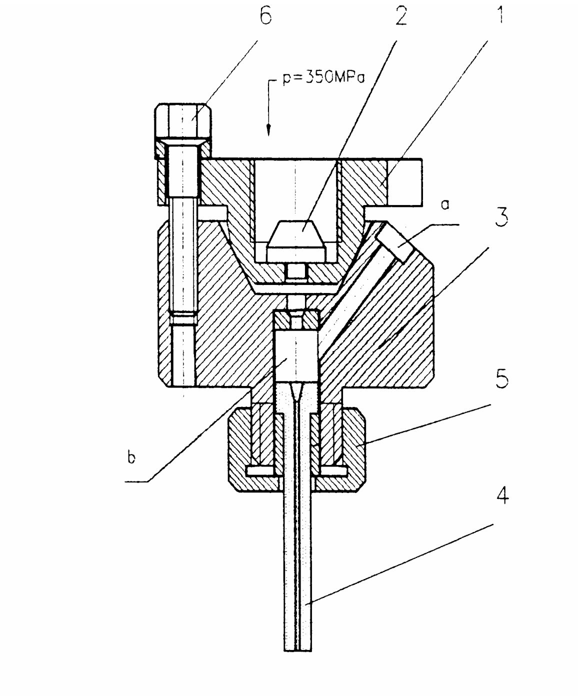

Figure 1 The workhead [1]:
1 – upper body; 2 – nozzle;
3- lower body; 4 – mixing tube;
5 – lid; 6 – screw;
a - abrasive feeding; b - mixing chamber

2.3 Cutting with hydroabrasive jet

Cutting experiments were carried out for each of the two composite materials, with each of the two types of abrasive particles, the results being presented in table 2.

Table 2. Characteristics of the cutting with hydroabrasive jet

Composite material	Abrasive material	Material thickness (mm)	Cutting speed (mm/min)	Cutting width (mm)	Appearance of the edges
Ti6Al4V+10%TiB	quartz	3	45	2	plain
Ti6Al4V+10%TiB	quartz	5	37	2.2	plain
Ti6Al4V+10%TiB	almandine	3	40	2	clean, slightly rounded
Ti6Al4V+10%TiB	almandine	5	35	2.3	clean, rounded
Ti6Al4V+20%TiB	quartz	3	42	2.2	plain
Ti6Al4V+20%TiB	quartz	5	33	2.4	without breakings
Ti6Al4V+20%TiB	almandine	3	38	2.4	slightly broken
Ti6Al4V+20%TiB	almandine	5	33	2.6	slightly broken

After analysing the achieved results, we can say that:

- the cut's width at the jet's entrance depends on the material's characteristics and decreases with the increase of the cutting speed;
- the cut's width at the jet's exit depends on the material and increases with the pressure;
- the cut flank's angle depends on the material, decreases with the increase of the pressure and is larger in harder materials.

2.3 Drilling with hydroabrasive jet

When drilling, neither the hydroabrasive jet, nor the part have relative movements; the jet enters the part in axial direction.

The hole displays a tilting of the walls, the conicity *K* being calculated function of the work pressure, distance between part and nozzle and part thickness.

The results of drilling with hydroabrasive jet of titanium-based composite materials are shown in table 3.

Analysing the achieved results it can be noticed that the material with the highest ductility has the lowest conicities and if the specific volume of eroded material is calculated, it decreases with the increasing yield strength of the material.

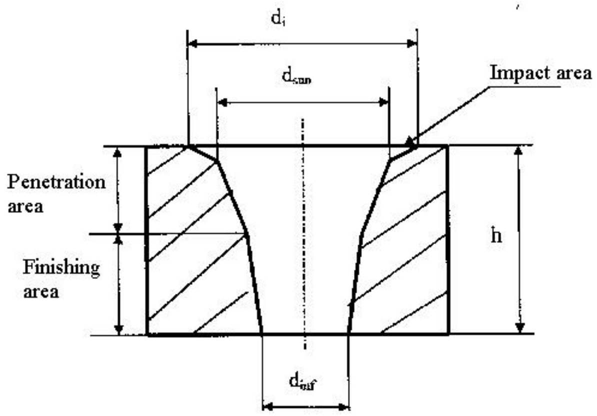

Figure 2 Geometrical parameters of a hole drilled with hydroabrasive jet [1]
di = equivalent diameter of the impact area;
h – hole depth; d_{sup} = diameter in the upper hole side; d_{inf} = diameter in the lower hole side.

Table 3. Parameters at the drilling with hydroabrasive jet

Composite material	Abrasive material	Material thickness (mm)	Distance from the part (mm)	Geometrical parameters		
				K [°]	d_{sup} [mm]	d_{inf} [mm]
Ti6Al4V+10%TiB	quartz	5	3.5	4.27	2.15	1.87
Ti6Al4V+10%TiB	almandine	5	3.5	3.15	2.07	1.52
Ti6Al4V+20%TiB	quartz	5	3.5	4.58	2.54	1.98
Ti6Al4V+20%TiB	almandine	5	3.5	4.12	2.72	2.12

3. CONCLUSIONS

The efficiency of cutting with hydroabrasive jet is characterised by the process parameters, by the processing type and by the equipment used.

The process parameters influencing the processing are:

- the pressure, as by its increasing the efficiency increases due to the intensifying of the mixing of abrasive particles with water and the acceleration of the particles on the processed surface;
- cutting speed – its increase reduces the cutting depth;
- impact angle – its optimal value is 90°.
- size of the abrasive particles – the optimal size is 0.1...0.3 mm; the increase of hardness increases the processing's efficiency.

The processing type (cutting or drilling) shows some specific aspects:

- the cut is wedge-shaped, wider at the jet entrance;
- the cut dimensions are smaller for ductile materials;
- the cut width at the upper side increases with the abrasive particle flow and decreases with the cutting speed size;
- the cut width at the lower side increases with the pressure increase and with the abrasive particle flow;
- the hole displays a wall tilt and an edge rounding at the entrance;
- the hole conicity is larger for fragile materials.

The processing equipment must fulfill certain constructive-functional conditions, such as:

- it must provide a coherent hydroabrasive jet, i.e. the jet should be coaxial with the mixing tube;
- the tube's length/diameter ratio should be l_t/d_t = 30...50.
- the optimal particle dimensions should be 0.1...0.5 mm.

4. REFERENCES

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