DEPENDENCE OF MANUFACTURING PRECISION OF WEDM CUTTING TECHNOLOGY ON POROSITY OF ALUMINUM FOAM

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Abstract

The contribution is focused on assessing the influence of ALPORAS aluminum foam porosity on dimensional precision of machined workpiece using electro-erosion wire cutting technology. The surface structure of material is formed by continuous nets of membrane material, pore volumes and cavities filled with gases residues after foaming. Due to the material structure cutting process is not continuous throughout whole material and electric discharge have to be initiated at the border of each pore in cutting line. This has an influence on the stability and accuracy. Deviations from the nominal dimension were measured, and for graphic representation the type A of standard uncertainty were calculated. From measured data the "barrel effect" can be determined. Barrel effect can cause the edge of a wire cut part to have a "bow" or "belly" shape.

Keywords: WEDM, aluminum foam, barrel effect, pore size

1. INTRODUCTION

Wire electrical discharge machining (WEDM) belongs to the group of unconventional machining processes. WEDM is characterized by a minimum width of cut. WEDM is a technology that is used in particular for producing high precision and difficult machinable materials (electrically conductive ceramic materials, cemented carbides, hardened steel, titanium alloys, etc.), the production of cutting, and stamping tools [1].

The capability of WEDM technology to machine and, doing so, not to affect the surrounding environment in places, where material is clamped, has its disadvantage consisting in cutting speed which is lower in comparison with conventional machining methods. It is caused by a tool of a wire electrode with circular section with diameter of 0.1 up to 0.3 mm which is melted through porous structure by means of spark gap (size of 0.15 mm up to 0.5 mm) that separates the particular parts of material each from other [3].

Technology WEDM is used for machining also aluminum alloy material that can be effectively machined by conventional methods. Application of this technology is especially for expensive alloys with the requirement for a maximum saving of material or a high precision production achieved with WEDM [2]. In the case of aluminum foam it is assumed that it is not necessary to machine since it fills the profile during foaming, but if we want to determine the properties of such material we need to produce samples with high accuracy, which can't be achieved by conventional machining methods.

2. POROUS MATERIAL OF ALPORAS ALUMINUM FOAM

ALPORAS is an aluminum foam material formed by its porous structure based on powder metallurgy. [8] Pores are separated from each other by particular membranes whose distance from each other can be determined as a size of bubbles formed by gases. The bubbles of pores came into being in the course of heat treatment of compacted aluminum powder and its additions due to a decomposition of TiH_2 to $Ti+H_2$ [4, 5], see **Figure 1**. Owing to this structure it is necessary to choose the way of processing of aluminum foam by machining methods very carefully to avoid a structure damage resulting from processing [6]. The membranes have not a regular form in the total cross-section of material and the whole structure is very specific. Therefore it is necessary to process this material with care [7, 8, 9].

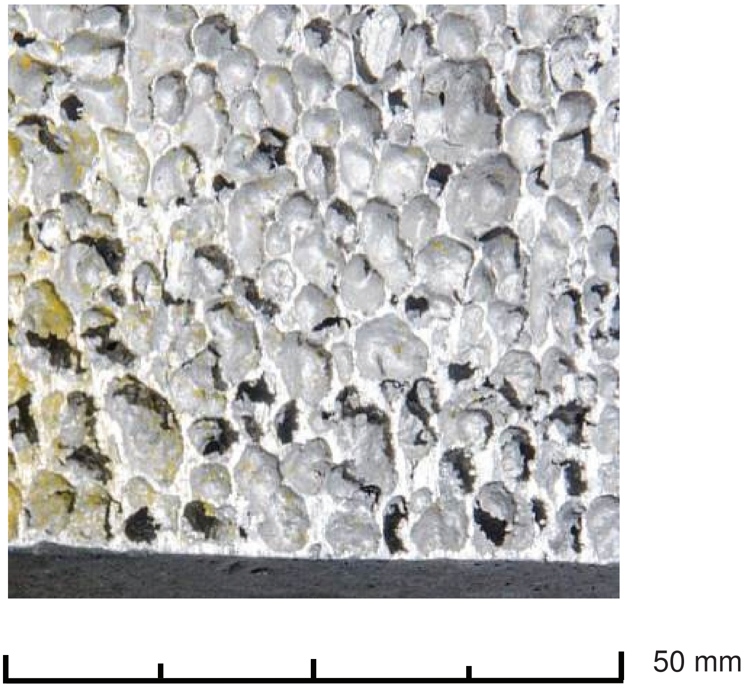

Figure 1 Aluminum foam

2.1. Utilization of aluminum foam

The use of aluminum foam itself is based on its properties, especially on low specific weight, excellent capability of energy absorption, incombustibility, low thermal conductivity and excellent sound insulation. The material can be applied in a wide range of using for lightening of structural members of means of transport (aircrafts, cars, trains, ships) as a fire division wall or a sound insulation [11].

Porosity structure of studied ALPORAS aluminum foam material differs in dependence on various positions of foaming. Porosity in the field from which the direction of foaming starts has a denser character with smaller pores than in the more remote fields where the pores are bigger and the number of them is smaller. It can be seen in the **Figure 2** in x-ray micro computed tomography. Basis and direction of foaming are shown on the left. The number of pores is irregular and achieves approx. 63% up to 69% material cross-section [8].

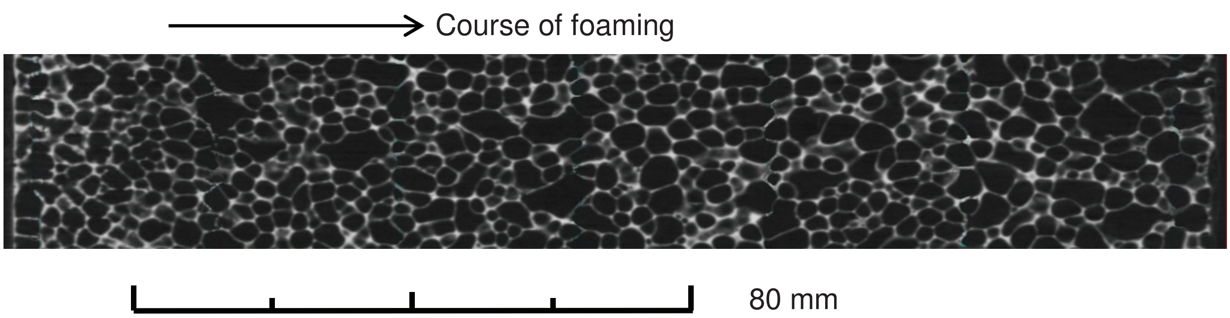

Figure 2 Cross-section of Al foam

2.2. Application of WEDM technology for cutting of ALPORAS aluminum foam

Using of technology of electro-erosion wire cutting for separation of aluminum foam parts is based on physical principle of electro-thermic erosion of this technology and material properties of aluminum foam. The combination of technology can be applied using a mechanically non-destructive principle of electro-erosion, in the course of which material is stressed only by clamping forces throughout the volume of material as great as possible and brittle structure of porous aluminum formed by thin membranes [10].

The wire electrode must be tensioned by a constant tractive force, otherwise there exists a danger of short-circuit or breaking. Under the influence of interrupted cut the wire is worn-out irregularly, intension of voltage and current have irregular character. Owing to this fact this constant tensile stress cannot be guaranteed and therefore it is impossible to carry out machining in such an effective way as with cutting in compact material of the same cross-section. Electrical discharges take place only in places which are situated near particular membranes. The device makes its best to form a stable arc in the places with pore holes and owing to this fact a destabilization of spark GAP occurs. In spite of this fact a high accuracy of machining can be achieved.

3. DETERMINATION OF ACCURACY OF CUTTING ALUMINUM FOAM AND INTENSION OF BARREL EFFECT

3.1. Accuracy of aluminum foam

In order to determinate accuracy of cutting of aluminum foam material the rollers with nominal size of Ø 22 mm and height of 100 mm, see **Figure 3**, were used. Altogether 4 rollers have been cut determined for mechanical tests [12].

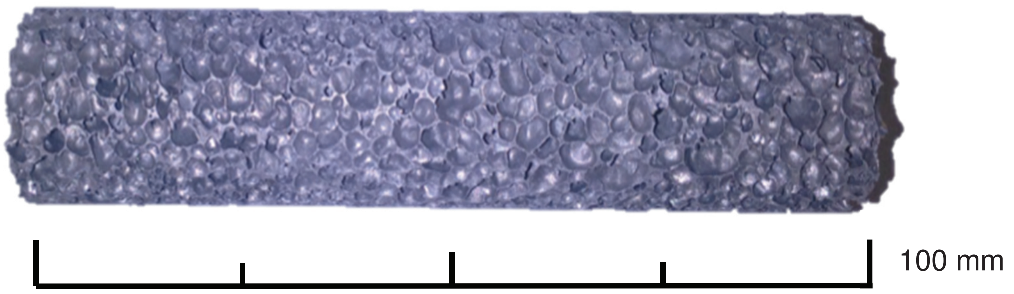

Figure 3 Aluminum foam roller

The first two rollers were cut in the distance of 17 mm from the basis of foaming and the two others in the distance of 148 mm from the basis of foaming which were always measured ten times in the range of 20 mm. The maximum measured size of roller diameters amounted to Ø 22.02 mm and the minimum measured size of rollers amounted to Ø 21.99 mm. It can be stated that the prescribed dimensions of roller size have been kept to for needs of mechanical tests $\varnothing\, 22\,^{+0.1}_{-0.05}$ mm. The dimensions were measured by means of a disc-type micrometer because the power affecting some thin membrane lines which would be damaged if another analogical method of measuring is used, is very small. Using coordinate measuring machines could cause deformation of pore borders owing to clamping and together with optical methods also inaccuracy of measurements caused by asymmetry of membrane distribution in measured planes.

3.2. Expression of uncertainty of measurement

To characterize the interval of values concerning the results of measurement of determined deviations from nominal size a standard uncertainty of type A has been calculated which characterizes the interval of values concerning particular results of measured values. The resulting values were then put down together with measured values into the **Figure 4**.

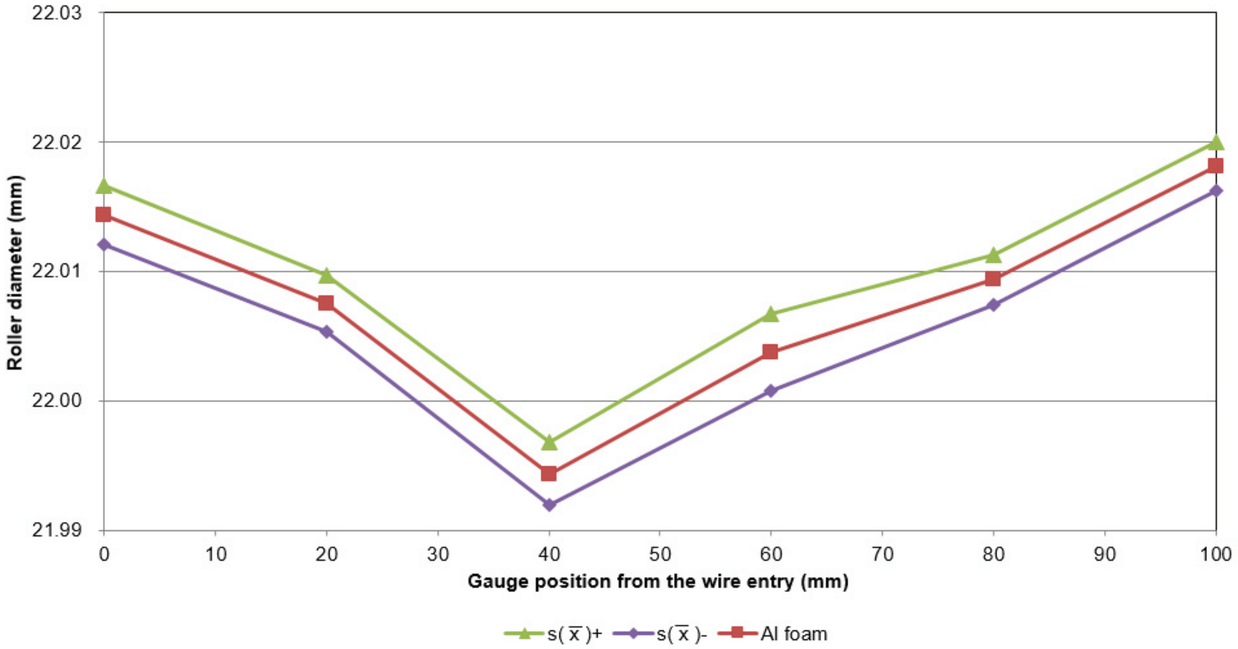

Figure 4 Sizes of diameters of aluminum foam rollers

Arithmetic mean of roller sizes which have been manufactured amounts to Ø 22.008 mm. This value differs only a little from the nominal size and is in tolerance which the WEDM technology disposes of (0.005 mm up to 0.15 mm). The manufactured rollers are mostly produced with positive tolerance because it is required for subsequent compression tests. If required, the tolerance zone could be displaced by a suitable adjustment of machine correction to concrete range close to the nominal size. The values of standard deviations have a very small dispersion around the values of measured diameters of rollers, namely only in order of units of thousandths of millimetres, although a cut with irregular character is concerned. Just this irregular character of a cut results in cutting of a smaller quantity of material in the given field owing to density and size of pores of the bubble shape. Thus, the electrode is not worn-out excessively, although the height of a cut amounts to 100 mm. Nor the quantity of metal steams and particles that have arisen in the course of electro-erosion is not big and therefore there is a small risk of enlargement of spark gap under the influence of side discharges through these particles.

3.3. Barrel effect

This phenomenon is defined only with material with solid section and its size and form have regular course, where the barrel effect is more evident with high cuts in 1/3 from the lower edge of the workpiece owing to a worn-out wire electrode for smaller cut and higher concentration of residues of melted material [13]. As shown in the **Figure 4**, the highest rates of barrel effect with aluminum foam are achieved just in the first half after wire entry into material (in comparison with the influence of foam porosity on uncertainty of measurement which has not been affected too much owing to delimitation of spark gap by discharges in cut between membranes and the barrel effect cannot be affected by change of technological parameters considerably). The resulting form of rollers is influenced by a limited number of discharges which would delimitate a form trajectory in the given height of material of half-finished product.

A further factor of wireline in porous material is a movement of dielectric. In compact material the place for direction of flow of working liquid is strictly delimited by a spark gap around the wire electrode. Thus, the most of dielectric is led in direction of trajectory of the wire electrode. In comparison with it flow of dielectric with porous metal is affected by pore gaps, liquid has no sufficient leading, liquid stream is weakened and owing to penetration into the interspace a local whirling of dielectric occurs resulting in destabilization of wire electrode which forms then other form of barrel effect than with compact material.

4. CONCLUSIONS AND DISCUSSION

Machining of non-homogenous structure of any material has to be performed with special care owing to different behaviour in the course of machining by technological processes. Porosity of ALPORAS aluminum foam forms an interrupted cut for the WEDM tool electrode and it increases claims for wire tension, dielectric supply and setting-up of technology of the cut itself. Porosity has a positive character of standard deviation from nominal size, stability of discharges, gas offtake with metal steams and particles, which can use interspace in particular pores. The measured values acknowledge a high dimensional accuracy of the WEDM technology. As a result, workpieces with high dimensional accuracy and quality surface treatment without damaging neighbourhood of cut due to technology can be achieved.

Barrel effect with aluminum foam has an opposite character than with compact material. In this particular case the minimum of the inner cut part is at the gauge distance 40 mm. The main cause consists in origin of this effect (with compact material occurs owing to worn-out of the wire electrode and wire tension a smaller diameter). With cuts in ALPORAS material the wire wear is minimum, nevertheless irregularity of material cross-section results in unstable flow of dielectric which forms owing to its pressure whirling in pores which affect stability of wire tension and form deviations from cut direction. Setting-up of smaller flow of dielectric caused a shortage of dielectric in the whole cross-section of a part and resulted in cut short-circuit.

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