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PREPARATION OF ALUMINIUM FOAM EDGES FOR WELDING

ABSTRACT

This paper presents the results of cutting aluminum foams. The experiment includes the following mechanical methods of cutting: circular saw cutting, band-saw cutting, EDM cutting, water-jet cutting, and thermal cutting methods: laser cutting and air plasma cutting. The influence of the cutting method on the edge geometry was specified in the paper. EDM was defined as the most advantageous method of Al foam cutting, as providing the best aluminium foam edges surface quality for welding.

Key words: *aluminum foam, metal foam cutting, edge preparation for welding*

INTRODUCTION

Due to their unique properties, such as low density, energy absorption, vibration damping and good insulating properties, aluminium foams have become the object of numerous studies. Aluminium foams are manufactured using different methods, including powder metallurgy, vacuum evaporation, electrochemical deposition, casting methods, or using laser beam. The process of manufacturing foams with the use of laser was presented in the work of Y.P. Kathuria [1]. What follows from these studies is that the density of such products ranges from 0.88 to 1.04 g/cm^3, with porosity varying between 67% and 32% respectively. Beam interaction time was also a crucial parameter. In a different work Kathuria Y.P. et al. [2] focus on aluminium foaming using an Nd-YAG laser. The study shows how porous structure with a density of 0.40 g/cm^3 and porosity of 60% is made. Wherever laser was used for foam formation, foam expansion was observed. Malekjafarian M. et al. [3] describe some properties of foams, namely, foams with higher density have better mechanical properties.

It is believed that foams can be successfully cut using both thermal and mechanical methods. Investigation on different ways of cutting solid materials in accordance with the PN-EN ISO 9013:2008 [4] standard enables optimisation of processes in order to obtain high-quality edges, minimize costs and achieve appropriate efficiency. Technological parameters of laser, mechanical and water jet cutting determine the speed of the process and edge quality of cut aluminium foams. In order to fully determine the scope of research on cutting technologies, it is necessary to determine the properties of metal foams.

The structure of aluminium foams shown in Fig. 1 and its properties depend on density and the proportion of open and closed pores. The structure of foam consists of open and closed pores, and individual cells are connected with one another by nodes where struts meet, forming the wall of a cell. Relative density determines the size and the shape of the cells, anisotropy, as well as their distribution in the material. Hydrostatic weighing of a sample is the best way to measure density; defining geometric parameters involves macroscopic examination. In case of foams of higher density, the cells usually have a smaller diameter, they are distributed more evenly and it is more likely that smaller pores will be situated in the nodes of bigger cells. With the decrease of density, smaller pores are absorbed by the bigger ones, thus the foaming is non-uniform.

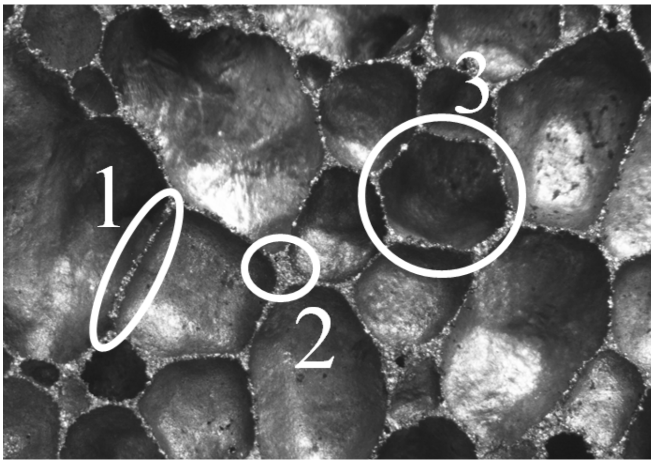


Fig. 1. The porous structure of aluminum foam; 1 space rotherwise the cell wall, 2 node, 3 different pore open cell after cutting

The cell structure of aluminium foams requires special techniques of welding and cutting:

- a rough cut can be done with virtually any method, though the quality of the cut will be low.
- high quality surfaces require the use of special techniques, such as chemical etching, water jet cutting, wire cutting or electrical discharge machining (EDM).

In English-language literature one can find different works discussing this problem; one of the broadest studies concerning cutting is that of Ashby and his research team [5], who recommend EDM, since it allows for retaining structural integrity. Yilbas B. S. [6] carried out laser cutting of triangular shapes in aluminium foam. The influence of the size of the triangle on the diffusion of the temperature field and thermal deformation was also studied. In a different work Yilbasa B.S. et al. [7] describe laser cutting of aluminium foams that allows avoiding structural damage that can be spotted in the process of mechanical cutting. Apart from describing aluminium foaming with a laser beam, Kathura [1] also described a method of cutting foam using a laser. In the conventional laser cutting of aluminium foam the distortion of pore walls is considerable and is effected by temperature. However, hybrid cutting, in which the laser beam is followed by a water jet, results in the reduction of thermal effects and improved pore structure. In his work, De Jaeger P. [8] wrote that depending on the cutting method, this operation may result in very different contact areas between foam and a joined material and lead to a high degree of deformation of the struts. Abolghasemi Fakhri M. [9] and his team describe porous titan foam used in orthopaedics and dentistry due to its light weight, high resistance and biocompatibility. In his work, Rajput V. et al. [10] presented the results of the research on aluminium composite foams reinforced with SiC. Knowing the properties of porous solid unreinforced material, he compared them with that of the Al-SiC composite foam. Further on, he described the influence of the amount of the SiC alloy addition on the size of pores, ageing of the composite and its properties. It was found that the composite ages faster than aluminium foams without additions, and that the peak ageing time remained invariant to SiC content.

METHODOLOGY OF THE CUT EDGE QUALITY STUDY

The material used in the study was porous foam of two-component alloy addition of aluminium and silicon also known as near-eutectic silumin AlSi9. The foam was made using a casting method in which gas is blown into metal in a liquid state. The foams used in the study are characterized by high porosity that makes up ~70-80% of their volume. The density of these foams with closed pores is 0.15–0.3 g/cm^3.

Cutting methods used in this study are characterized by other physical phenomena occurring in the cutting process. The section planes of aluminium foams that are 20mm thick reveal noticeable differences in case of particular processes. The initial cutting attempts were performed with the use of machines with work parameters shown in Tables 1-6. The tables feature optimum parameters that allowed for achieving the desired visual effect. The parameters were set according to the thickness of given material, foam type and cutting speed characteristic of a given method. Cutting speed and other parameters of the process were set experimentally and separately for every method. In order to conduct the study, cutting was done with the following machines and with the parameters presented in Table 1.

Table 1. *Parameters of the water jet cutting with or without abrasive blasting*

Machine	Manufacturer	Cutting speed	Water pressure	Abrasive
RT3020-1NK-1-10	Rychlý TOM	250mm/min	3500 bar	350 g/min
RT3020-1NK-1-10	Rychlý TOM	250mm/min	3500 bar	0 g/min

Table 2. *Parameters of the band saw mechanical cutting*

Machine	Manufacturer	Cutting speed	Blade dimensions	Total power	Feed per tooth
Economic 410	Bomar	70 m/min	2720 x 27 x 0,9 mm	1.1/1.5 kW	1200 mm/tooth

Table 3. *Parameters of the circular saw mechanical cutting*

Machine	Manufacturer	Cutting speed	Engine power	Blade diameter	RPM
Maecatome T300	Presi	10 mm/min	3.7 kW	250 mm	3000 Rpm

Table 4. *Parameters of the air plasma cutting*

Machine	Manufacturer	Cutting speed	Compressed air pressure	Rated output current	Compressed air flow	Total power
Air plasma 36	Ozas- Esab	60 mm/min	5 bar	35 A	130 l/min	11 kVA

***Table 5**. Parameters of the EDM cutting*

<table>
<tr><td colspan="2">Machine</td><td>Manufacturer</td><td>Working feed rate</td><td colspan="2">Working electrode dimensions</td><td>Dielectric fluid</td></tr>
<tr><td colspan="2">Futura II</td><td>AGIE</td><td>2 mm/min</td><td colspan="2">150 mm / 0.5 mm</td><td>Glifer, Ferol el</td></tr>
<tr><td>Cutting speed (cm/s)</td><td>Power (W)</td><td>Frequency (Hz)</td><td>Distance between the nozzle and the material (mm)</td><td>Nozzle diameter (mm)</td><td>Focal length (mm)</td><td>Nitrogen pressure (kPa)</td></tr>
<tr><td>10</td><td>1500</td><td>500</td><td>1.5</td><td>1.5</td><td>127</td><td>500</td></tr>
</table>

***Table 6**. Parameters of the laser cutting*

Cutting speed (cm/s)	Power (W)	Frequency (Hz)	Distance between the nozzle and the material (mm)	Nozzle diameter (mm)	Focal length (mm)	Nitrogen pressure (kPa)
10	1500	500	1.5	1.5	127	500

It is important to note that nitrogen is used in laser cutting, and air is used in plasma cutting. In case of mechanical cutting, the circular saw blade is thicker than the band saw blade. Water jet cutting is often done with the use of an abrasive in order to obtain better quality of the edge.

Due to the porous structure of aluminium foams, measuring points are situated at the nodes or struts. The number and distribution of the measuring points depends on the shape and size of the object examined; sometimes they also depend on the purpose for which the object is to be used. Planes obtained after cutting are classified in tolerance ranges according to intended maximal value of the PN-EN ISO 9013:2008 standard [4]. The measuring points were located in the places where maximal values were expected. There were six measure points and locations thereof. The following examinations were carried out:

- roughness tests *Rz5*: one measurement at the node every ~15mm in two lines on a confocal microscope,
- loss of the cell wall edges along the section plane,
- macroscopic examinations,
- scanning microscope examinations.

In the process of cutting section planes were obtained and thoroughly examined. The description of the microstructure of the foams under examination was done on the basis of the observation of section planes (cleaned with acetone in an ultrasonic cleaner) under the SEM JOEL JSM-6100 scanning microscope. The macroscopic examination was done using the Nikon AZ100 microscope with LED illumination system and the Nikon D80 camera with the Nikon 50 f/1.8 AF-S G 58 lens. The examination of orientation tolerance "u" was done using the Mitutoyo S1012B digimatic indicator; range: 0 - 12.7 mm ± 0,01 mm. The mean height of the profile Rz5 was measured on a confocal microscope. The number of structural losses was calculated using the Nikon Epiphot 200 optical microscope and NIS Elemenst 3.2. software.

RESULTS OF THE STUDY

The macroscopic examination reveals damaged structure and defects that are the result of using different cutting methods. The resultant surfaces were inspected using visual methods. In case of aluminium foams the difference between mechanical cutting and thermal cutting is evident. As a result of laser cutting (Fig. 8) and plasma cutting (Fig. 6) the cellular structure got completely destroyed. During plasma cutting a piercing gas was used, which increased the number of impurities (Fig. 6b). The best and least damaged structure was obtained with EDM (Fig. 7). Water jet cutting with an abrasive (Fig. 2) and without an abrasive (Fig. 3.), band saw cutting (Fig. 4) and circular saw cutting (Fig. 5) gave intermittent results.

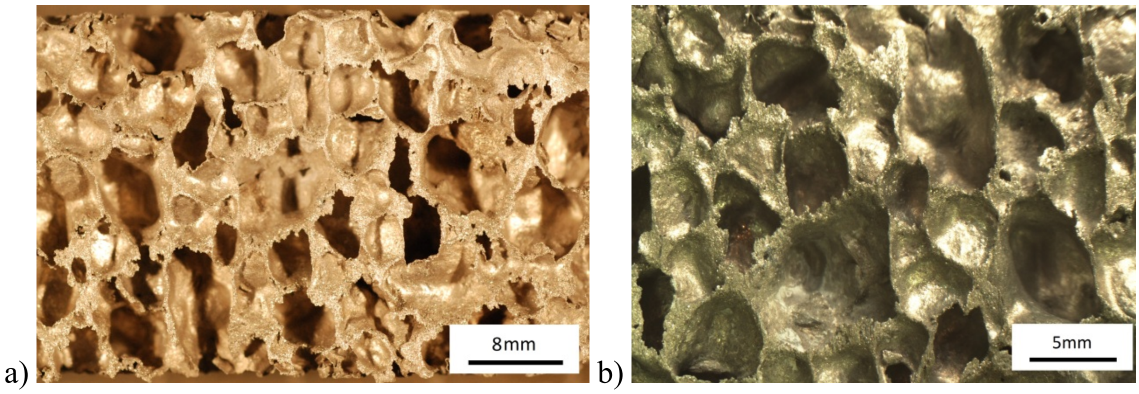


Fig. 2. a) and b) Macroscopic images of the surface after water jet cutting with an abrasive

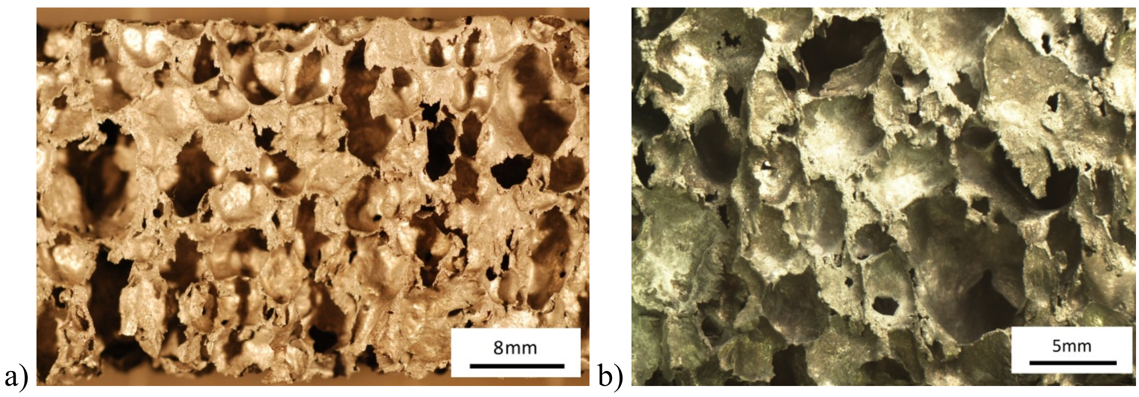


Fig. 3. a) and b) Macroscopic images of the surface after water jet cutting without an abrasive

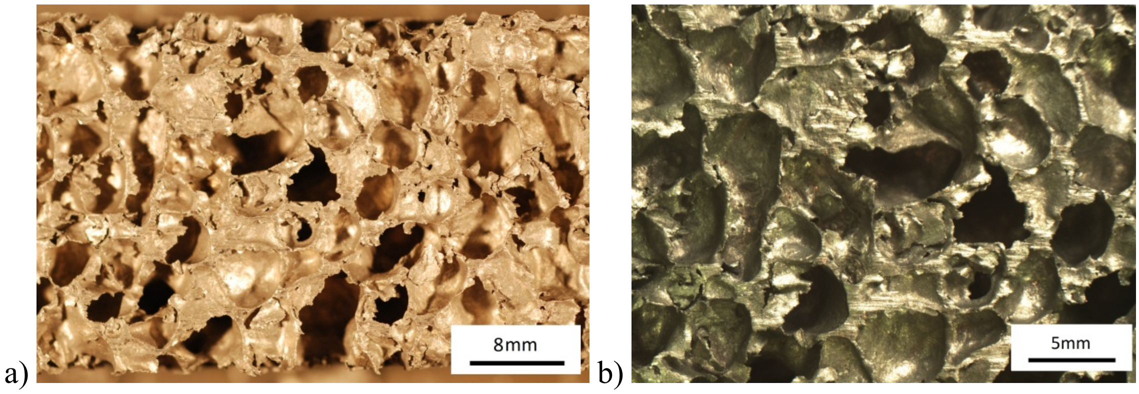


Fig. 4. a) and b) Macroscopic images of the surface after band saw mechanical cutting

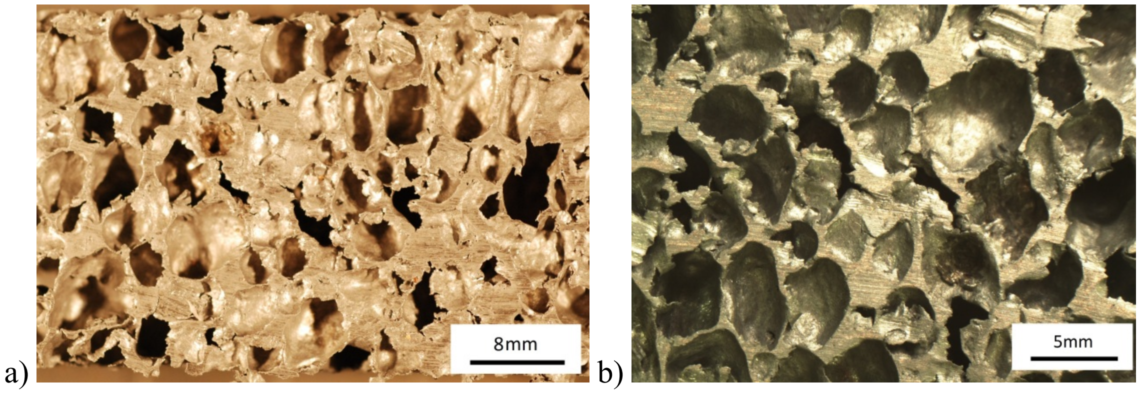


Fig. 5. a) and b) Macroscopic images of the surface after circular saw mechanical cutting

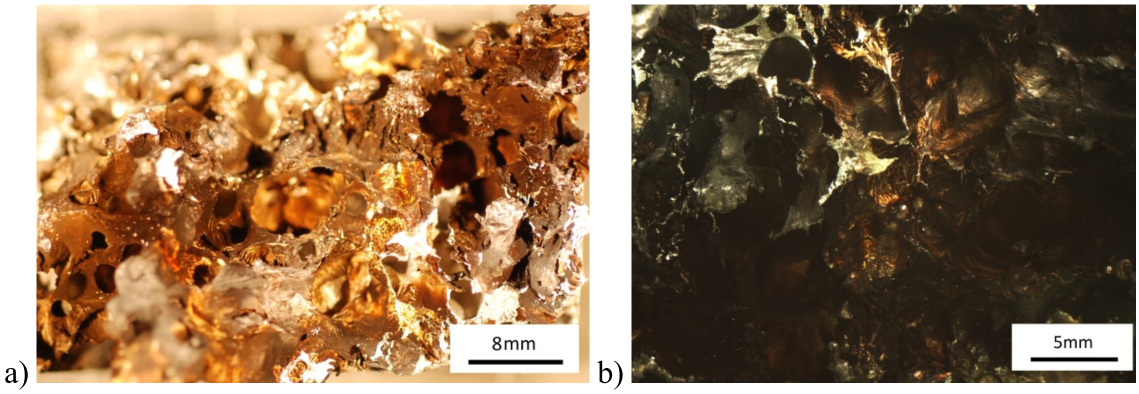


Fig. 6. a) and b) Macroscopic images of the surface after plasma cutting

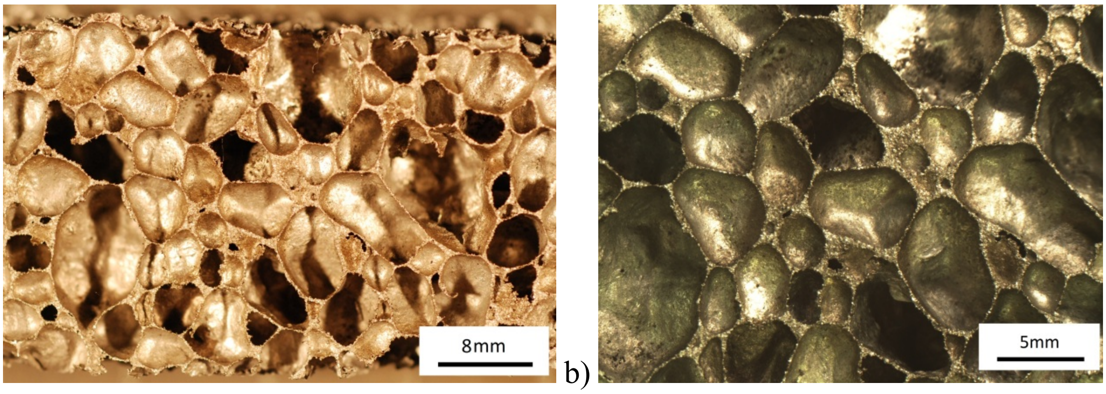


Fig. 7. a) and b) Macroscopic images of the surface after EDM cutting

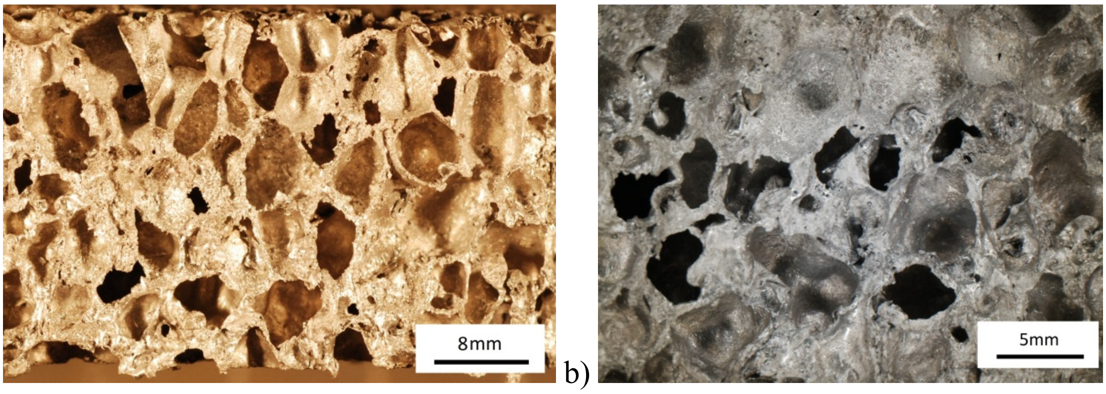


Fig. 8. a) and b) Macroscopic images of the section plane after laser cutting

At high magnification (20x and 25x – macroscopic), the microscopic examination reveals degradation and damages resulting from cutting the materials with different methods. The resultant surface of pores and nodes was investigated under the scanning microscope. In case of aluminium foams the difference between mechanical and thermal cutting is evident. With regard to water jet cutting with an abrasive, one can observe the effects of water gouging; still, the edges display a lesser degree of erosion than in case of water jet cutting without an abrasive (Fig. 10b.). The lines of the edges in Fig. 9a. are smoother than those after water jet cutting without an abrasive (Fig. 10a). Fig. 11.a shows the section plane with cracks that resulted from band saw cutting. Fig. 12a. shows that more material from the kerf is accumulated in open pores than in case of the samples cut with the band saw. Fig. 11b. shows the structure of the edge that cracked due to band saw cutting and a plastic fracture in the crack, while Fig. 12b. shows the section plane surface in the node. It is a typical texture in case of circular saw cutting that results from its blade being thicker than the one of the band saw; in addition, one can observe the effects of accumulating a higher amount of material in open pores. Fig. 13. shows clear edge lines after EDM. The appearance of the edges after thermal cutting is shown in Fig. 14. and 15. where interfusions and melting of the native material can be observed. Quality assessment of the edges of the aluminum foam cut by various methods is shown in Table 7.

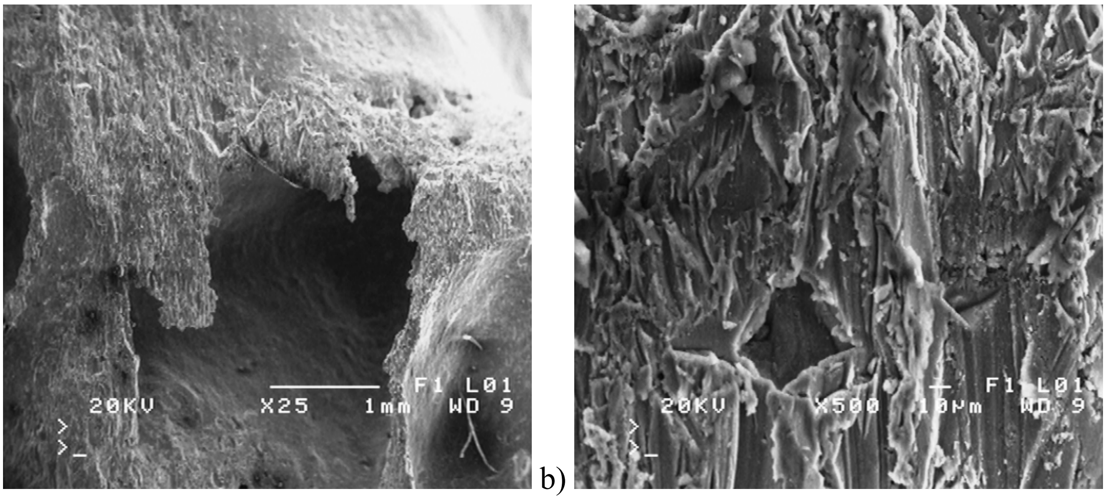
a) b)


Fig. 9. The cut surface image after waterjet cutting with abrasive; a) the effect of water gouging, b) abrasive effect of erosion

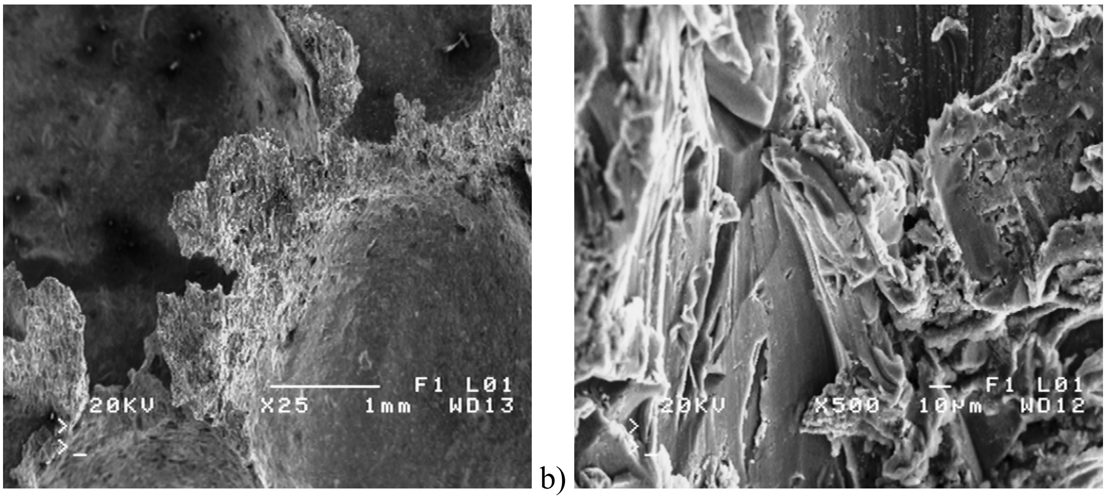
a) b)


Fig. 10. The cut surface image after cutting waterjet without the abrasive a) tattered structure with lower rate of plastic deformation than mechanical cutting, b) higher state of water erosion than in the case of an abrasive waterjet cutting, determining a larger roughness higher state of water erosion than in the case of an abrasive waterjet cutting, determining a larger roughness

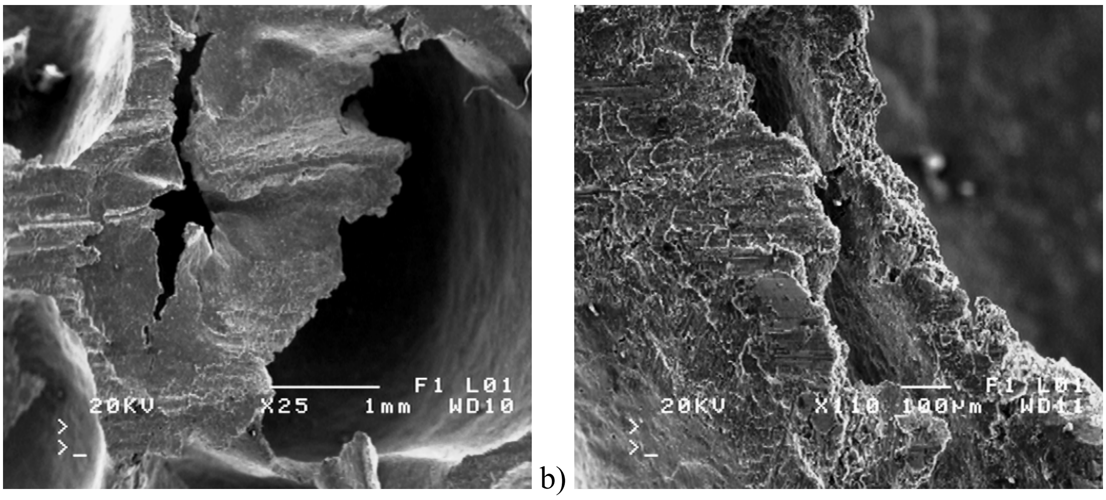
a) b)


Fig. 11. The cut surface image after band-saw, mechanical cutting; a) structure of broken edges after cutting, the visible effects of detachment of the cell walls at the contact with the saw, b) Structure of broken edges after cutting, plastic apparent breakthrough at the crack

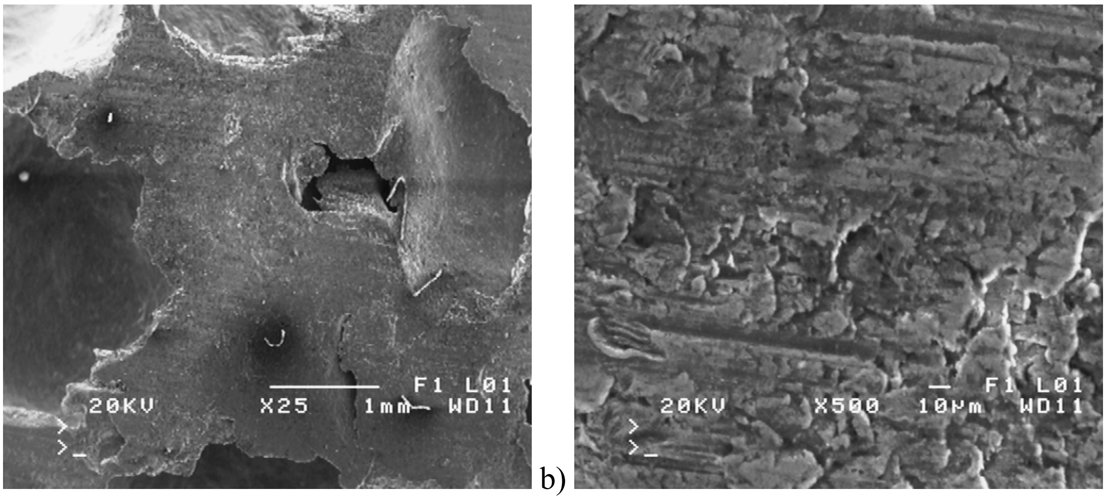
a) b)


Fig. 12. The cut surface image after circular saw mechanical cutting; a) a pore closed by the material picked up by the saw on the left- and right-hand side, and in between a pore closed by the material of the cutting process, b) cutting surface of a typical texture node after cutting circular saw, because of the greater thickness of the disk than tape cutting bandsaw visible effects of borrowing more material in place of the open pores

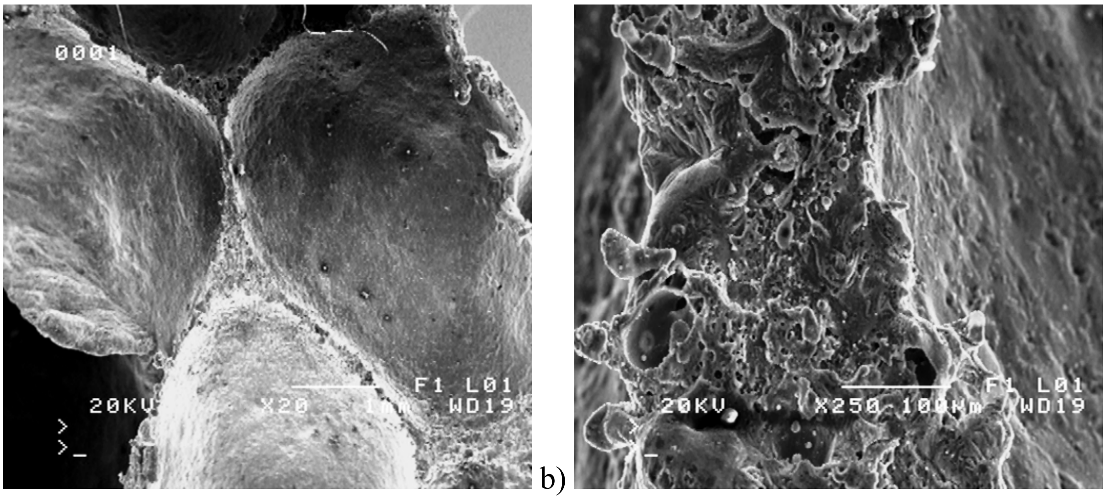
a) b)


Fig. 13. The cut surface image and after EDM cutting; a) view of the node in the cutting surface resulting from electrostatic discharge, b) the same at higher magnification

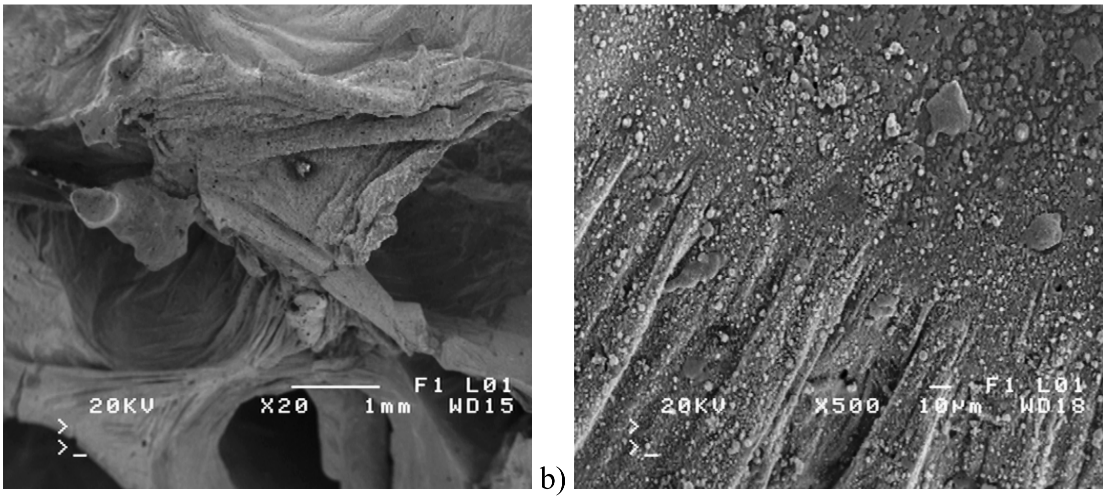
a) b)


Fig. 14. The cutting surface image after plasma cutting; a) the structure partially melted and then solidified, b) view of the debris as cleavage products

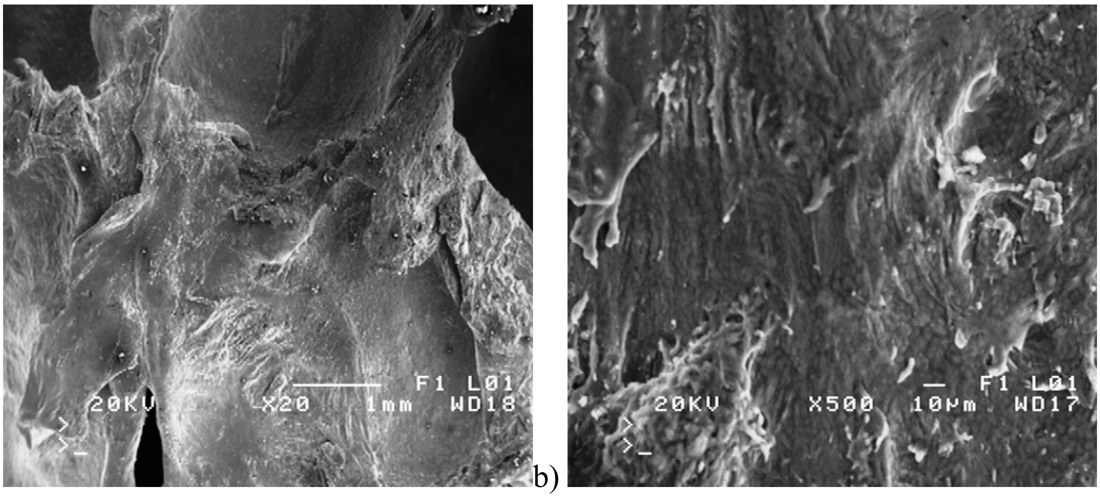
a)  b)

Fig. 15. View of the cutting surface image after laser cutting; a) melted structure effected laser heat and then solidified; b) plane cut with contamination, likely caused by contamination of the shielding gas – nitrogen

Table 7. *Quality assessment of the edges of the aluminum foam cut by various methods*

Sample	a mm	Δa mm	Orientation tolerance(u), mm						Max. u, mm	Defects in the structure after cutting, %
			1	2	3	4	5	6		
EDM	20	1	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0%
Laser	20	1	0.75	0.81	0.62	0.77	0.54	0.68	0.81	61%
Plazma	20	1	2.64	3.05	2.81	4.35	2.51	2.79	4.35	95%
Band saw	20	1	0.04	0.03	0.05	0.03	0.07	0.05	0.07	13%
Band saw	20	1	0.28	0.39	0.22	0.31	0.35	0.42	0.42	24%
Water	20	1	1.25	1.41	1.62	1.47	1.53	0.98	1.62	18%
Abrasive	20	1	0.25	0.31	0.24	0.29	0.36	0.19	0.39	5%

CONCLUSIONS

Methods of preparation of non-porous AlSi9 alloys are described in literature and are subject to regulations stipulated in different norms. What the sources lack, however, is data on the preparation of the edges of porous materials. The article presents the problems typical of cutting foams and other non-porous materials. The preparation of aluminium foam edges for welding is considerably different from the process of preparation of the edges for welding non-porous aluminium alloys. The problems derive from cellular structure of foams and low cell wall thickness that is no higher than 0.3 mm, while the fact that the materials contain voids makes it possible for the products of cutting to accumulate in the voids. The voids can significantly upset the process of cutting, especially in case of thermal cutting. The major difficulties in the preparation of edges are the lack of criteria or evaluation of their quality as well as limited possibilities of measuring geometric parameters. Each of the methods analysed influences the appearance of the section plane in a different way. With regard to thermal cutting methods, the best results can be obtained with highly concentrated laser beam. With regard to methods that do not cause partial melting of the material, the best results can be obtained with EDM and water jet with an abrasive respectively. There is a need to elaborate acceptance criteria for foam edges and develop reliable methods for surface evaluation. We are of the opinion that a confocal microscope is the right tool for the evaluation of the geometry, which will be the object of our further research.

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