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THE AXIAL FORCE IN ALUMINIUM FOAM DRILLING

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Preliminary notes

Metals in foam shape, the so called metallic foams or metal foams, consist of a base metal material with a certain amount of gas bubbles dispersed throughout the body of the material. These bubbles are actually foam cavities or cells. Metal foams are low-density materials with high strength and rigidity, as well as with good damping capacity. Therefore, their application in the lightweight structure concepts is the object of intensive research. It is possible to join such elements by welding or by screw fastening, and this paper presents the results of researches into the drilling process of closed cell aluminium foam samples. They are produced by the production method of indirect foaming by means of an AlSi12 precursor. The axial force in aluminium foam drilling is established in dependence on relevant drilling process parameters.

Keywords*: aluminium foam, axial force, drilling*

Aksijalna sila kod bušenja aluminijske pjene

Prethodno priopćenje

Metali u obliku pjena, takozvane metalne pjene se sastoje od osnovnog metalnog materijala unutar kojeg su u određenoj mjeri raspršeni mjehurići plina. Mjehurići plina tvore šupljine, ćelije odnosno pore. U odnosu na svoju malu gustoću, metalne pjene imaju veliku čvrstoću, krutost i izvrsna svojstva prigušenja, zbog toga se njihova primjena u lakim konstrukcijama danas intenzivno istražuje. U tim konstrukcijama, metalne pjene je moguće međusobno zavarivati ili spajati vijčanim spojevima. U radu je istraživan postupak bušenja aluminijske pjene dobivene aktivacijom iz prekursora AlSi12. Mijenjajući režim obrade, ustanovljena je ovisnost aksijalne sile bušenja o utjecajnim parametrima procesa bušenja.

Ključne riječi: *aluminijska pjena, aksijalna sila, bušenje*

1 Introduction
Uvod

The term "metal foam" or "metallic foam" represents a relatively new class and form of a non-homogenous material which consists of a base metal material with a smaller or larger amount of gas bubbles dispersed throughout the metal body. These bubbles are actually cavities or cells in the base metal [1, 2, 3, 4].

Although the first metal foams were created in the middle of the twentieth century, their properties and the potential of industrial applications have been the object of intensive research only for the last ten years. They are still not widely used in industry, primarily due to the problem of creating metal foams with constant quality and homogeneity and also due to the insufficient knowledge about the foaming process. Another problem, according to [5, 6], is due to high costs ranging from 15 to 25 EUR/kg and insufficient knowledge about reliable physical properties of metal foams.

A base metal for metal foams can be any metal that exists in the form of powder. Today, the most commonly used metals for metal foams are aluminium, zinc and nickel, and their alloys. The properties of metal foams generally depend on the type of the base metal and the conditions of the processing method. Closed cell metal foams are materials with high strength and rigidity, as well as with good damping capacity and low thermal conductivity. Since round gas bubbles in closed cell aluminium foams are separated from each other by thin aluminium metal film, these foams are low-density materials, which can float on the water surface, Figure 1.

Figure 1. Closed cell aluminium foam floats on the water surface
Slika 1. Uzorak aluminijske pjene pliva na vodi

Due to their good mechanical and physical properties, one of recent solutions is integrating the aluminium foam with conventional aluminium and steel sheets or tubes. The obtained products are called aluminium foam sandwich structures and tube profiles filled with aluminium foam. Such products could become standard lightweight structural elements in automobile and truck industry [7, 8, 9], could be used in architecture for self-supporting wall panels with good sound absorption and fire resistance [10], and for fast-moving elements in the building of high dynamic machine tools [11, 12]. Such elements can be joined by welding or by screw fastening.

This paper presents the results of researches into the drilling process of closed cell aluminium foam samples, which are produced by the production method of indirect foaming by means of an AlSi12 precursor. The axial force in aluminium foam drilling is established in dependence on relevant drilling process parameters, such as the cutting speed and the drill point angle.

2
The manufacture of closed cell aluminium foam
Izrada aluminijske pjene zatvorenih pora

The term "closed cell metal foams" means that round gas bubbles are captured in the structure of the base metal and separated from each other by metal film. Although there are various production methods available for the manufacture of closed cell metal foams, they all have one feature in common: to disperse gas bubbles within the structure of the base metal. There are manufacturing procedures with direct foaming by bubbling a gas through molten alloys and a procedure with indirect foaming by precursors [6, 13, 14]. The previously mentioned method for the manufacture of closed cell metal foam samples has been applied at the Foundry Chair of the Faculty of Mechanical Engineering and Naval Architecture in Zagreb. Samples were produced by using the production method of indirect foaming by means of precursors. The AlSi12 precursor, used for the manufacture of closed cell aluminium foam, Figure 2, was provided by the Austrian firm Alulight International GmbH [15, 16].

Figure 2. Precursor AlSi12
Slika 2. Prekursor AlSi12

The equipment used for the manufacture of closed cell aluminium foam samples consists of a LINDBERG electric furnace, type CR-5, a HEWLETT-PACKARD measuring instrument, type 3852A, two Ni-CrNi thermocouples, a computer for the storage and processing of data and of safety equipment.

The activation of the AlSi12 precursor was carried out by putting the precursor into a mould, which was heated on temperature 620 ^{o}C in the electric furnace. The mould was a square steel tube with dimensions of 25x25x100 mm and with the bottom end closed. The first interval of the fast heating of the precursor in the steel tube lasted approximately 150 seconds, while the isothermal activation process at 580 ^{o}C lasted only 50 seconds. In the process of heating, the titan-hydride decomposes and the released hydrogen dissolves in aluminium, forming bubbles that create the cell structure, i.e. the closed-cell aluminium foam.

With this production method of indirect foaming by means of precursors or by precursor activation, homogeneous closed cell aluminium foam samples with the mean cell size of 0,5-1,5 mm were obtained [12]. A cross section of an aluminium foam sample which was used for research of the axial force in drilling is presented in Figure 3.

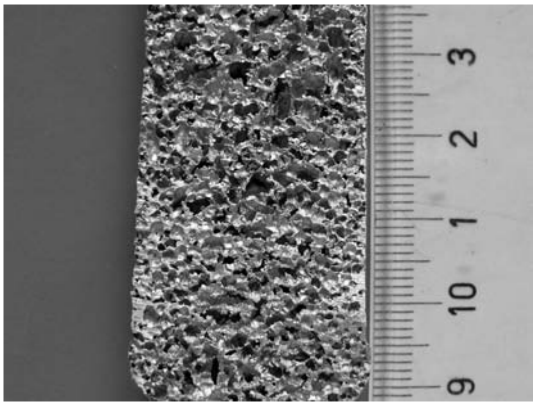

Figure 3. Aluminium foam sample for axial drilling force research
Slika 3. Aluminijska pjena zatvorenih pora za istraživanje aksijalne sile bušenja

3
Planning of the experiment
Planiranje eksperimenta

The experiment of drilling was performed at the Chair of Machine Tools, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. A three-component Kistler dynamometer, Type 9257B, was used to measure the axial drilling force. Although the dynamometer has a possibility to simultaneously measure the three components of the cutting force (F_x, F_y, F_z), in our test the axial drilling force will correspond to the component F_z which acts in vertical direction.

The dynamometer was tightened with screws onto the table of the ALG-100 tool-and-die milling machine – Prvomajska Zagreb. The clamp for clamping the aluminium foam workpieces was fastened with screws on the dynamometer, Figure 4. For easier monitoring of axial drilling force, a plastic pad was used under the workpiece.

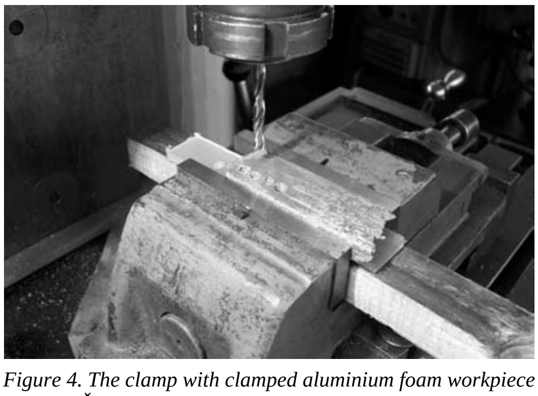

Figure 4. The clamp with clamped aluminium foam workpiece
Slika 4. Škripac sa stegnutim obratkom od aluminijske pjene

Figure 5 presents the digital signal form of axial drilling force measurement, from which it is possible to determine the mean value of the axial drilling force. The figure clearly shows four different measuring areas for one drilling pass. These areas are:

- I - Measuring area before drill and aluminium foam workpiece contact,
- II - Measuring area of aluminium foam crust drilling,
- III - Measuring area of aluminium foam heart drilling,
- IV - Measuring area of plastic pad drilling.

Figure 5 shows the moment of contact between the drill and the workpiece, the measuring area of aluminium foam crust drilling (Measuring area II) and the measuring area of aluminium foam heart drilling (Measuring area III). One can also see the moment when the drill exits the aluminium foam workpiece, i.e. the intensive increase of axial drilling force when the drill comes into contact with the plastic pad (Measuring area IV).

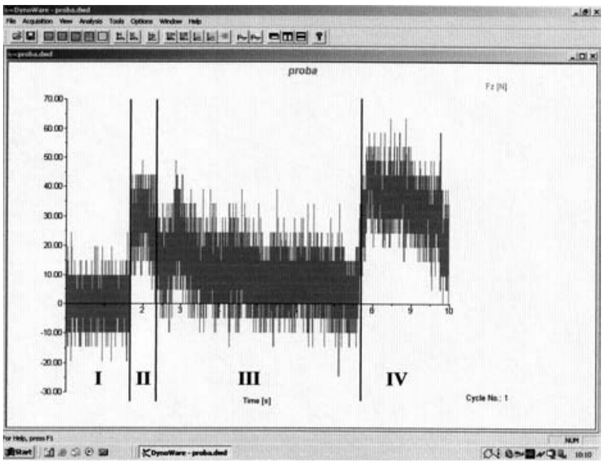

Figure 5. Reading of axial drilling force measurement
Slika 5. Očitanje mjerenja aksijalne sile bušenja

In this experimental investigation, the following parameters are chosen as the ones affecting the drilling process and the axial drilling force of aluminium foam the most:

- v_c (m/min) – cutting speed,
- 2φ (°) – drill point angle.

Beside these parameters, there are also disturbance parameters, which are considered as a constant, and it is assumed that they have no influence on the drilling process. These are, for example, machine tool stiffness, workpiece material, angle of drill spiral, etc. In the axial drilling force measurement mentioned before, Figure 5, it is established that the axial force in drilling the aluminium foam crust and the aluminium foam heart has different values. Consequently, the mean value of measured results will be given separately.

4 Results of investigation

Rezultati istraživanja

In order to establish the dependence of the axial force F_a on the cutting speed v_c in the aluminium foam drilling, standard highspeed steel drills of 4,5 mm in diameter and the drill point angle values of 2φ=80° and 2φ=120° were used. The selected values of the drill point angle have been realised by grinding the drill on a UOZA-3 grinding machine. The chosen cutting speed values, with a constant feedrate per the tooth value of $f_{zsr} \approx$ 0,06 mm, are presented in Table 1. The last two right columns of Table 1 represent the mean values of measured axial forces in drilling the aluminium foam crust and the aluminium foam heart, for given cutting conditions.

Table 1. The mean values of measured axial forces in drilling aluminium foam crust and aluminium foam heart, for corrospondent drilling conditions.
Tablica 1. Srednje vrijednosti aksijalne sile bušenja površinske kore i jezgre aluminijske pjene za odgovarajuće parametre bušenja.

v_c m/min	n min^{-1}	f_{zsr} mm	v_f mm/min	2φ	F_a -crust N	F_a -heart N
6,53	462	0,06	56	80°	21,5	10,26
10,43	738	0,06	84	80°	20,7	10,21
16,12	1140	0,06	130	80°	21,45	10,39
6,53	462	0,06	56	120°	19,6	9,64
10,43	738	0,06	84	120°	23,1	9,71
16,12	1140	0,06	130	120°	20,15	8,54

In order to enable a better and easier analysis, the results of measured axial drilling forces from Table 1 are presented in a diagram form in Figures 6 and 7. Points in diagrams are average values of all the data obtained during measuring period II. A diagram which presents the dependence of the axial force in drilling the aluminium foam crust on different values of the cutting speed and two different drill point angle values of 2φ=80° and 2φ=120° is given in Figure 6.

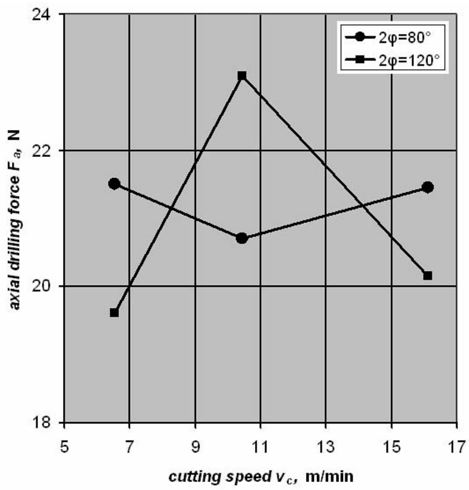

Figure 6. Dependence between axial force in drilling aluminium foam crust on cutting speed and drill tip angle
Slika 6. Ovisnost aksijalne sile bušenja površinske kore aluminijske pjene o brzini rezanja i kutu vrha svrdla

From this diagram, Figure 6, it is obvious that the increase in the cutting speed value has no important influence on the axial force in drilling the aluminium foam crust. In drilling with a 2*φ*=80° drill, the axial drilling force slightly decreases and then slightly increases with the increase in the cutting speed value. The opposite is true when drilling with a 2*φ*=120° drill, i.e. the axial drilling force first increases and then decreases. In both cases the value of axial force in drilling the aluminium foam crust is changing slightly between 19,6 N and 23,1 N.

The diagram in Figure 7 presents the dependence of axial force in drilling the aluminium foam heart on different values of cutting speed and on two different drill point angles with a constant feedrate per tooth of the drill.

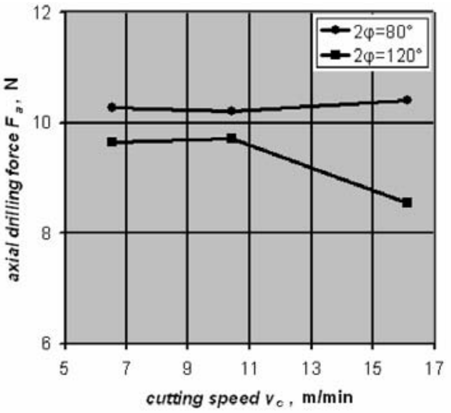

Figure 7. Dependence between axial force in drilling aluminium foam heart on cutting speed and drill tip angle
Slika 7. Ovisnost aksijalne sile bušenja jezgre aluminijske pjene o brzini rezanja i kutu vrha svrdla

The obtained results show that axial forces in drilling the aluminium foam heart with a 2*φ*=120° drill have slightly smaller values than in drilling with a 2*φ*=80° drill. However, the differences are negligible, because the highest difference of only 1,85 N is obtained with the highest cutting speed value. Since the measured axial drilling forces, Figure 7, have very similar values, it can be concluded that the cutting speed has no important influence on the axial force in drilling the aluminium foam heart, neither in drilling with a 2*φ*=80° nor with a 2*φ*=120° drill.

5 Conclusion
Zaključak

The paper presents results of experimental investigation on axial forces in drilling the aluminium foam with mean closed cell size of 0,5-1,5 mm, manufactured with indirect foaming by AlSi12 precursors. It is established that the axial force in drilling the aluminium. foam crust and aluminium foam heart have different values.

From Figure 6 it can be seen that the mean value of the axial force in drilling the aluminium foam crust is approximately 21 N, while the axial force in drilling the aluminium heart is almost constant (Figure7), and its mean value is approximately 10 N. It can be concluded that the value of axial force in drilling the aluminium foam crust is approximately twice greater than the value of the axial force in drilling the aluminium heart. The result is normal because the aluminium foam crust is not porous and it is expected that it will give higher reaction to the drill penetration in the drilling process.

The final conclusion drawn from the measured results presented in Figures 6 and 7 is that neither the cutting speed nor the drill point angle, within experimental boundaries, have any significant influence on the axial drilling force, either in drilling the aluminium foam crust or in drilling the aluminium foam heart.

6 Literature
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