UDK 621.762:621.9:532.6:661.862
Original scientific article/Izvirni znanstveni članek

ISSN 1580-2949
MTAEC9, 51(1)19(2017)

EFFECT OF CUTTING PARAMETERS ON THE DRILLING OF $AlSi_7$ METALLIC FOAMS

VPLIV PARAMETROV REZANJA PRI VRTANJU KOVINSKIH PEN IZ $AlSi_7$

Gultekin Uzun[1], Ugur Gokmen[2], Hanifi Cinici[1], Mehmet Turker[1]

[1]Gazi University, Faculty of Technology, 06500 Ankara, Turkey
[2]Gazi University, Vocational School of Technical Sciences, 06500 Ankara, Turkey
uzun.gultekin@gazi.edu.tr

Prejem rokopisa – received: 2015-05-27; sprejem za objavo – accepted for publication: 2015-12-17

doi:10.17222/mit.2015.106

In this study, the behaviors of Al matrix metallic foams, produced by the powder-metallurgy method, against the hole-drilling operation were examined. The stirred Al, 7 % Si and 1 % TiH_2 powders were pressed in a mould under uniaxial pressure (600 MPa) and then deformed, and in this way foamable block samples were obtained. The block samples were subjected to a foaming process at 710 °C. The obtained samples were drilled at different cutting speeds (10, 30, 50, 70) mm/min and feed rates (0.15, 0.225, 0.30) mm/r with drill tips of different diameters (4, 5 and 6) mm. It was observed that the foam affected the chip breakings and chip adhesions increased in proportion to the cutting speed. In the deviation from circularity, the feed rate turned out to be a more effective parameter than the cutting speed.

Keywords: foams, cutting, machining, tooling

V študiji je bilo preiskovano obnašanje kovinskih pen na osnovi Al, izdelanih po metodi metalurgije prahov, pri vrtanju luknje. Mešanica Al, 7 % Si in 1 % TiH_2 prahov je bila stisnjena v orodju z enoosnim tlakom (600 MPa) in potem deformirana, da so bili dobljeni vzorci sposobni za penjenje. Vzorci so bili izpostavljeni procesu penjenja pri temperaturi 710 °C. Dobljeni vzorci so bili vrtani pri različnih hitrostih rezanja (10, 30, 50, 70) mm/min in hitrostih podajanja (0,15, 0,225, 0,30) mm/r, s svedri z različnimi premeri (4, 5, 6) mm. Ugotovljeno je, da pena vpliva na lomljenje ostružkov, oprijemanje ostružkov pa se povečuje proporcionalno s hitrostjo rezanja. Pokazalo se je, da na odstopanja od kroga bolj vpliva hitrost podajanja kot pa hitrost rezanja.

Ključne besede: pene, rezanje, strojna obdelava, orodja

1 INTRODUCTION

Foams of cellular structure and materials having high porosity are materials on which intensive studies are made due to their combination of mechanical and physical properties.[1] Maintaining the high-temperature strength and structure of metallic foams with respect to porous polymer materials is one of their important characteristics.[2] Al has a great importance among the metallic foams.[3] Nowadays, these materials are used in engineering applications and attract a lot of attention.[4] Al foams are known with their thermal strength, acoustic insulation, and sound- and energy-absorbency properties.[5] They can be used as a filling material in profiles for energy absorption.[6] Among their areas of usage, automotive and space industry lead, especially where a lower density is needed.[7] The machines that are being used in industrial applications are subjected to vibration and dynamic loads during running. These vibration and dynamic loads cause high noise and wear in the moulds. For the purpose of minimizing these problems aluminum foams are preferred in the machine manufacturing because of their low- and high-energy damping abilities.[8] In the industrial applications, metallic foams can be joined with bolts and rivets because of their porous structures. During the drilling of foams, cutting and feed speeds cause the breakdown or plastic deformation of porosities. Besides the chip formation that occurred the during drilling operation, it also affects the cutting speed and cutting temperature. For this reason the surface quality and gauge accuracy of the hole change.[9-13]

In this study, Al matrix metallic foams were produced by the powder-metallurgy (PM) method. For the purpose of examining the effect of the foaming time period on the porosity morphology, foaming was carried out for different periods (8, 10, 12, 14 and 16) min. After determining a suitable foaming period, depending on the porosity structure, foam samples of 25×40×120 mm were produced. Al foams of high porosity were subjected to drilling at different cutting speeds (10, 30, 50, 70) m/min and feed rates (0.15, 0.225, 0.30) mm/r with drill tips of different diameters (4, 5, and 6 mm). During the drilling operation, effects of the cutting parameters on the cutting force were examined by measuring the cutting forces. After the drilling operation, measurements of the deviation from circularity were made and the samples were compared, depending on the process parameters.

2 MATERIALS AND METHOD

2.1 Material

In the experimental studies, Al powders and Si powders with 99.9 % purity were used as the matrix material and 98 % pure TiH_2 powders as the foaming agent. The physical properties of the used powders are given in **Table 1**.

Table 1: Physical properties and production methods of the powders used in the tests
Tabela 1: Fizikalne lastnosti in metode izdelave prahov, uporabljenih pri preizkusih

Materials	Physical properties			
	Production method	Melting temperature (°C)	Density (g/cm^3)	Powder size (μm)
Aluminum	Gas atomization	660	2.7	<160
Si	Gas atomization	1410	2.34	<10
TiH_2	–	<400	3.91	<45

2.2 Method

2.2.1 Aluminum foam production

7 % Si and 1 % TiH_2 (both by weight) were added to 99.9 % pure Al powder and stirred for 1 h. The powder mixture was pressed one-way in a mould under 600 MPa pressure and block samples were obtained. The obtained samples were subjected to preheating at 550 °C for 1 h. Then, the samples were 50 % deformed and cut for foam production in (10 × 40 × 120) mm sizes (**Figure 1**). Foamable block samples were subjected to the foaming process at 710 °C and Al foams of (25 × 40 × 120) mm were obtained.

2.2.2 Drilling operation

Drilling tests were made at the Johnford VMC 550 CNC vertical machining center. As the cutting tool, uncoated HSS (DIN 338) drills (manufactured by the WERKO cutting tool company) having (4, 5, and 6) mm diameter were employed. The technical characteristics and cutting parameters of the HSS drills used in the tests are given in **Table 2**.

Table 2: Cutting-tool characteristics and cutting parameters
Tabela 2: Značilnosti rezilnega orodja in parametri rezanja

Cutting tool materials	HSS
Standard	DIN 338
Cutter geometry	Ø4, Ø5, Ø6, mm 118°
Cutting speed	10, 30, 50, 70 m/min
Feed rate	0.15, 0.225, 0.30 mm/r
Cutter type	Cylindrical shank drill

Drilling tests were made under dry cutting conditions and 15 mm deep longitudinal holes were drilled. Taking into consideration the heat distribution around the drilled hole, the distance between the hole axes was specified to be 8 mm.

In the drilling operation, among the three force constituents, since the radial and cutting forces are relatively small, the third force constituent which is axial force (feed force, F_z) and torque (M_z) values are taken into consideration. In this study, three cutting-force constituents were measured, but only the axial force (F_z) was evaluated. Because of the porous structure of the material, variations occurred in the axial force. For this reason the maximum-cutting force values were taken as a reference for the axial force. Cutting-force measurements were made with a Kistler 9257A type dynamometer attached to the vertical machining center worktop. An attachment mould was designed and manufactured for better attachment of the samples to the dynamometer. In **Figure 2** the test set-up is given. For the purpose of eliminating the twisting effect on the drill, the dislocation distance of drill tip from the tool holder was kept to a minimum. This value remained constant in all of the tests to determine the comparison accuracy in the obtained data.

Deviation from circularity is defined as the difference between the biggest and smallest radius measured from a certain center point (**Figure 3a**). However, there are several ways of determining a hole center. There are widely used methods such as the minimum radial deviation (MRD), in which the point of the smallest radial deviation is assumed to be the center and the least-squares circle (LSC). In the measurements of deviation from circularity of the holes using CMM, the

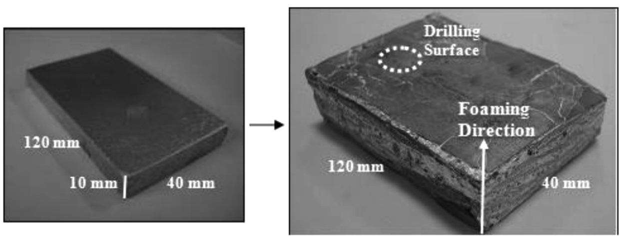

Figure 1: Sample picture before and after foaming process
Slika 1: Posnetek vzorca pred in po postopku penjenja

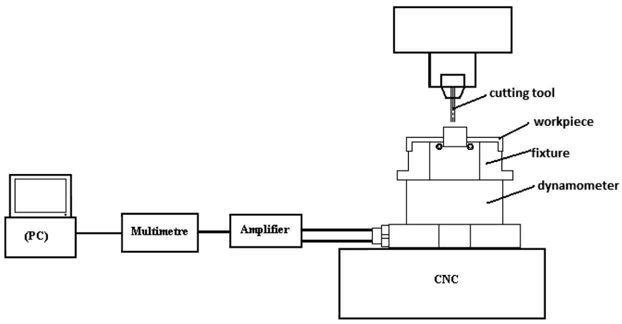

Figure 2: Test set-up
Slika 2: Eksperimentalni sestav

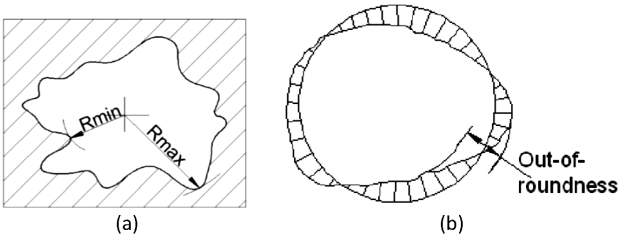

Figure 3: Circularity measurements: a) *DFC*-deviation from circularity, b) LSC-least squares circle[12]
Slika 3: Merjenja krožnosti: a) DFC-odstopanja od krožnosti, b) LSC-krog najmanjših kvadratov[12]

LSC method was employed for the determination of the center point. The LSC method center point expresses the center of the circle, having the sum of least squares of the radial coordinates (**Figure 3b**).

The measurements of DFC of the drilled holes were carried out with a Mitutoyo CMM (Coordinate Measuring Machine). The deviation from circularity and from the hole diameter were determined by taking coordinates from at least three separate points in each hole by using a Ø4 mm prop.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Pore morphology and density

In the foam production by pore morphology (PM) method the parameters must be selected properly and the process must be controlled.[14] Banhart, in his study, examined the linear expansion of Al/TiH_2 mixture that was subjected to the foaming process at 750 °C and stated that linear expansion varied with respect to the time and in the case of exceeding the maximum expansion duration, the adhesion of pores and then breakdowns started.[15] In the case of suitable foaming duration it is possible to produce a homogeneous structured foam with high porosity. The pore morphologies of Al foams obtained in the experimental studies are given in **Figure 4**. In the produced foams, the highest density value (1.01 g/cm^3) was obtained in the foaming processes lasting for 8 min, whereas the lowest value (0.58 g/cm^3) was obtained in the foaming processes for 16 min. When the pore morphology (**Figure 4a**) obtained in the foaming process for 8 min is examined, it is clearly seen that certain areas remained without foaming. This is attributed to the insufficient foaming duration. The porosity structure of the 16 min foaming process is shown in **Figure 4c**. With the increasing of the foaming duration thinning on the pore walls and partially adhesions of pores were observed. It is thought that adhesion of the pores is leading to pore coarsening and causing a decrease in density. It can be said that parallel to the pore structure and the obtained density (10 min – 0.88 g/cm^3) the ideal foaming duration is 10 and 12 min (**Figure 4b**). When time saving is considered, it is thought that 10 min foaming duration will be sufficient.

Mechanical characteristics of metallic foams may vary depending on the shape size and surface area of the pores in the structure. Mechanical characteristics of the foam structure are mostly affected by the density and metal matrix specification.[16] The mechanical performance of Al matrix foams is evaluated depending on the microstructural properties and the pore geometry. Pore wall thickness and side geometry involve microstructural variables. Geometrical characteristics involve pore shape, pore size and the distribution and defects in the pore structure.[17] During 10 min of foaming duration in which the homogeneous distribution of pore structures were observed, drilling (with different diameters) was applied to the obtained foams (**Figure 5**). When the sec-

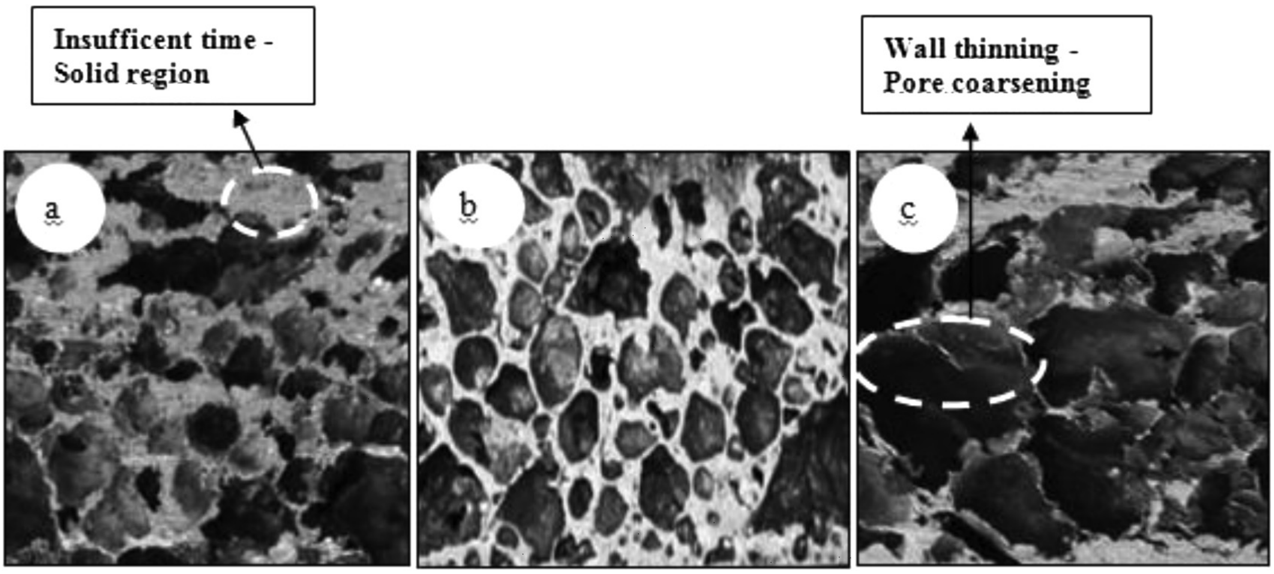

Figure 4: Effect of foaming duration on pore morphology: a) 8 min, b) 10 min, c) 16 min
Slika 4: Vpliv trajanja penjenja na morfologijo por: a) 8 min, b) 10 min, c) 16 min

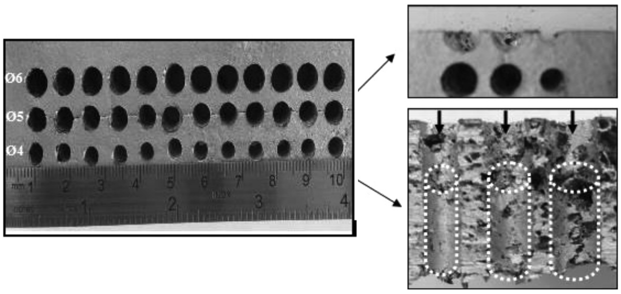

Figure 5: Pictures of drilling surface and holes section of Al foam sample

Slika 5: Posnetek vrtane površine in presek lukenj na vzorcu Al pene

tional pictures of drilled surfaces given in **Figure 5** were examined, closure and regional concentrations were located on the pores, depending on the effect of the drilling force. H. Bart-Smith et al.[18], in a study on the energy-damping capacity of Al foams, mentioned the distribution of regional deformation bands and accumulation depending on the compression deformation. In their study, during drilling, it is thought that the pores around the drill tip joined partially (depending on the applied pressure) and regional concentrations were created.

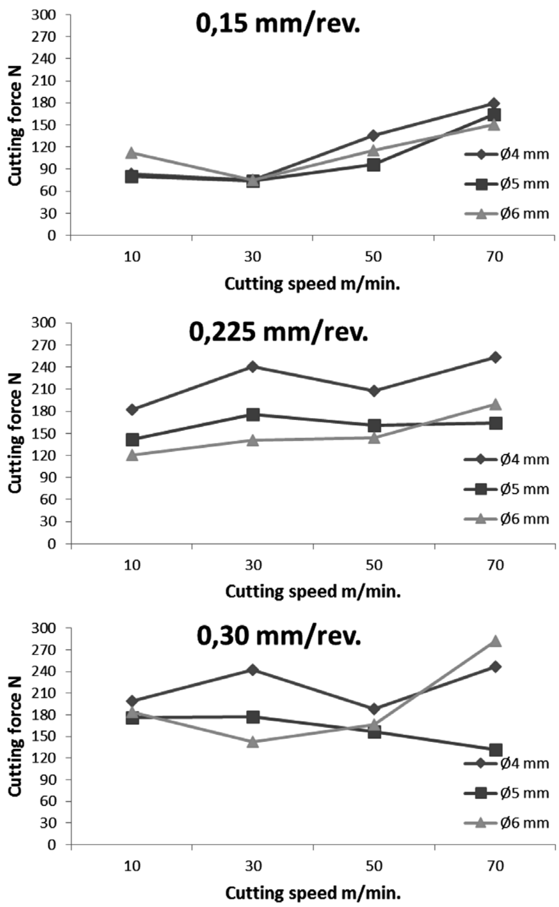

Figure 6: Variation in feed force depending on the cutting speeds, feed amount and drill diameter

Slika 6: Spreminjanje sile podajanja v odvisnosti od hitrosti rezanja, podajanja in premera svedra

3.2 Evaluation of cutting forces

The variation of feed force (F_z) values with respect to the cutting force, feed and tool type of the holes obtained after the drilling operations is given in **Figure 6**. From this figure it is clear that for all three cutting types, the obtained feed force values increased with the increasing cutting speed and feed. The increased feed values caused the chip volume removed per unit time to increase and consequently growing of cutting forces.[19,20] With the increasing feed amount, the feed force increased in the interval of 200–500 %. From the graphs it was observed that feed force was 80–164 N at the 0.15 mm/r feed amount, 120–254 N at 0.225 mm/r and 132–282 N at 0.30 mm/r. The feed force increased for all feed rates with the increasing cutting speed. This was attributed to the higher adhesion tendency of the Al material on the cutting tool. The adhesion criteria on the cutting tool are clearly seen in **Figure 7**.

In **Figure 7** it is clearly seen that the chip adhesions increase with increasing cutting speed. During machining of aluminum and some aluminum alloys, the chip is continuous, quite thick, strong and is not broken easily. An increase was observed in the cutting forces with the increasing difficulty of the hard chip discharge. Difficulties in the chip discharge depending on drilling length, which is the most important problem in drilling operations, cause the chips to squeeze in the hole, to increase the cutting forces and even to break the tool.[21–23] It was seen that due to the porous structure in the foam material, chip breakings failed with the increasing cutting speed and more material adhered on the cutting tool. Chips were broken at lower cutting speeds and fewer adhesions were observed. With the increasing feed amount, formation of more chip caused higher feed

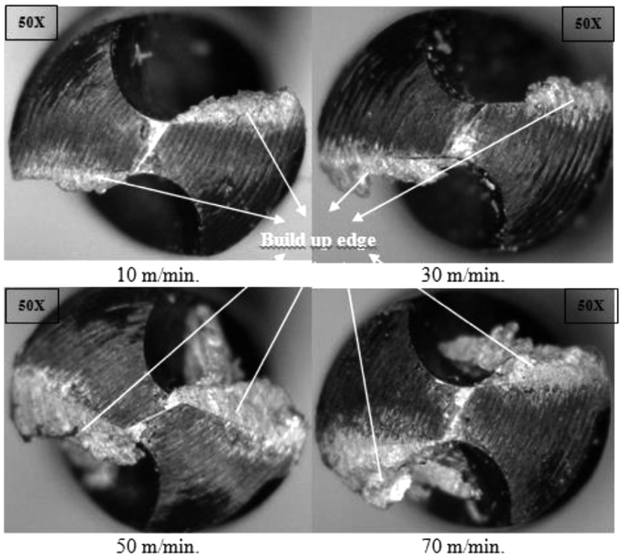

Figure 7: Built-up edge on the cutting tool with the increasing cutting speed

Slika 7: Nastajanje roba na rezilnem orodju pri naraščanju hitrosti rezanja force, whereas at lower feed rates less feed force was created. In all feed rates and cutting speeds the highest cutting force was obtained with Ø4 mm drills. This can be explained with the cutting tool of small diameter causing extensive squeezing of the chips. The lowest feed forces were obtained with Ø6 mm drill.

3.3 Evaluation of hole diameters

In the literature it is stated that the diameter in the hole inlet and deviation from circularity (*DFC*) values are higher with respect to the hole outlet because of the dynamic instability of cutting tool in the first entry to the hole. It is said that there are decreases in these values along the hole inlet and outlet and this is due to guidance of the hole to the drill till the hole outlet.[12] For the purpose of providing a comparison accuracy, deviation values in the hole diameter were obtained by the measurements made at the hole inlet. Variations in the diameter values of the holes drilled under different cutting conditions and cutting parameters are given in **Figure 8**.

From the **Figure 8** it was observed that at 0.15 and 0.225 mm/r feed rate, the hole diameter values decreased with the increase of cutting speed, whereas at 0.30 mm/r feed rate, hole diameter values increased. At 0.15 and 0.225 mm/r feed rate, increasing of cutting speed caused decreases of 11 % in hole diameters for all drills. The increasing tendency in the hole diameters depending on cutting speed at the highest feed rate (0.30 mm/r) was measured to be 16 % in the Ø4 mm drill, 23 % in the Ø5 mm drill and 7 % in the Ø6 mm drill. It is thought that the increasing cutting and feed speeds caused the hole diameters to get bigger by increasing the vibrations.[24] It was decided that fewer deviations in the hole diameters are due to less vibration at lower feed rate and slower penetration into the pieces. During the cutting operation, bending and shape variations occur in the material at the feed direction due to its porous structure. This can be more clearly seen at higher feed rates. For this reason, higher deviations from the diameter were determined at higher feed rates. It can be said that the feed rate is more effective than the cutting speed for the increase in the hole diameters.

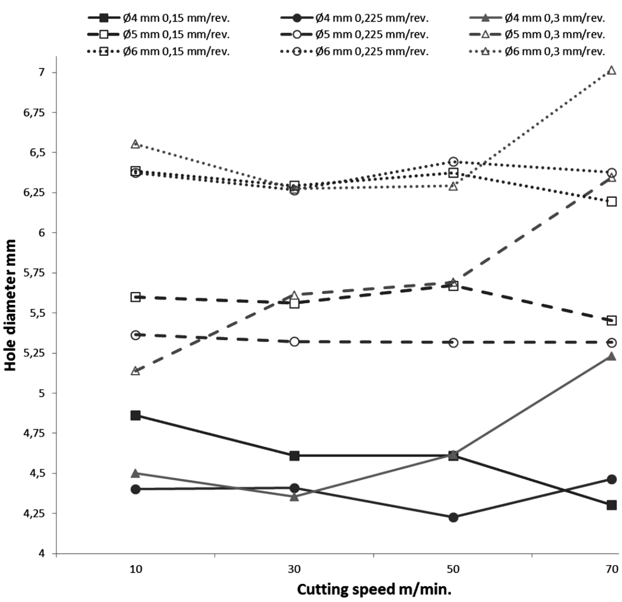

Figure 8: Variations in the hole diameters depending on the cutting parameters and cutting conditions

Slika 8: Spreminjanje premera luknje v odvisnosti od parametrov rezanja in pogojev pri rezanju

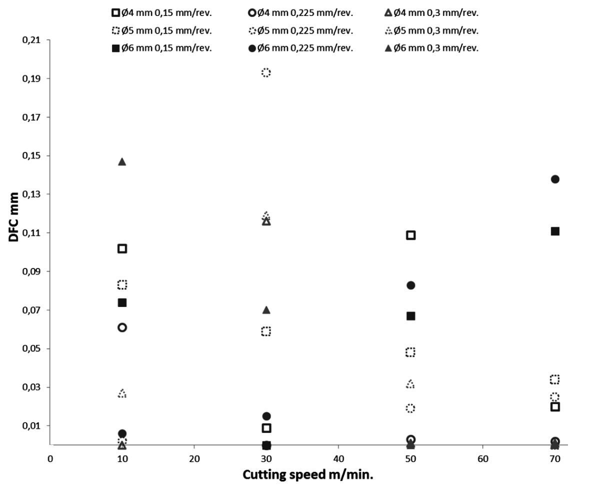

Figure 9: Variations of DFC depending on cutting parameters and cutting conditions

Slika 9: Spreminjanje DFC od parametrov rezanja in pogojev pri rezanju

When the *DFC* graph (**Figure 9**) was examined, a maximum *DFC* value of 0.2 mm was recorded. Decreases were observed in the *DFC* values with the increases in cutting speed. Especially at 70 m/min cutting speed and 0.3 mm/r feed rate, the lowest *DFC* values were obtained. The effect of feed rate on the *DFC* value at 50 m/min cutting speed is seen more clearly. Decreases were observed in the *DFC* values with the increase in the feed rate. This can be explained with the more rapid penetration and less distortion on the surface. At lower feed rates, overcontact of drill to the hole walls caused the *DFC* value to increase. As far as the *DFC* is concerned, the feed rate was more effective than the cutting speed.

4 CONCLUSION

In this study, the effect of different foaming durations on the pore structure of Al foam material was examined and the foaming duration for homogenous pore distribution was determined. The obtained samples were drilled with drills of different diameters at different feed rates and cutting speeds. The behaviors of the Al foam structure were evaluated during the drilling operation, depending on the drilling parameters. The obtained data as a result of the experimental study is given below.

Feed forces increased with the increase in cutting speed. This can be explained by the increasingly harder chip discharge.

Feed force exhibited increases in the interval 200–500 % with the increase in feed amount.

Foamed structure affected the chip breakings causing an increase in chip adhesions proportionally with the cutting speed.

The highest feed forces were measured with Ø4 mm drills, whereas the lowest ones were determined with Ø6 mm drills.

The lowest *DFC* values were obtained with Ø6 mm drills by using the tool on which the lowest feed forces occurred.

Feed rate turned out to be a more effective parameter than the cutting speed for *DFC*.

In all of the cutting tools, DFC was less at the higher cutting speed and higher feed feed rate combinations.

5 REFERENCES

[1] J. Banhart, Manufacture, characterization and application of cellular metals and metal foams, Progress in Materials Science, 46 (**2001**), 559–632, PII: S0079-6425(00)00002-5

[2] P. S. Liu, K. M. Liang, Functional materials of porous metals made by P/M, electroplating and some other techniques, Journal of Materials Science, 36 (**2001**) 21, 5059–5072, doi:10.1023/A:1012483920628

[3] P. R. Onck, R. Merkerk, J. T. M. De Hosson, I. Schmidt, Fracture of metal foams: In-situ testing and numerical modeling, Advanced Engineering Materials, 6 (**2004**) 6, 429–431, doi:10.1002/adem.200405156

[4] A. Kim, M. A. Hasan, S. H. Nahm, S. S. Cho, Evaluation of compressive mechanical properties of Al-foams using electrical conductivity, Composite Structures, 71 (**2005**) 2, 191–198, doi:10.1016/j.compstruct.2004.10.016

[5] Y. Y. Zhao, D. X. Sun, A novel sintering-dissolution process for manufacturing Al foams, Scripta Mater., 44 (**2001**), 105–110

[6] L. E. G. Cambronero, J. M. Ruiz-Roman, F. A. Corpas, J. M. Ruiz Prieto, Manufacturing of Al-Mg-Si alloy foam using calcium carbonate as foaming agent, Journal of Materials Processing Technology, 209 (**2009**), 1803–1809, doi:10.1016/j.jmatprotec.2008.04.032

[7] J. Banhart, J. Baumeister, Deformation characteristics of metal foams, Journal of Materials Science, 33 (**1998**), 1431–1440, doi:10.1023/A:1004383222228

[8] R. Neugebauer C. Lies, J. Hohlfeld, T. Hipke, Adhesion in sandwiches with aluminum foam core, Production Engineering, 1 (**2007**) 3, 271–278, doi:10.1007/s11740-007-0046-4

[9] S. Kalidas, R. E. DeVor, S. G. Kapoor, Experimental investigation of the effect of drill coatings on hole quality under dry and wet drilling conditions, Surface and Coatings Technology, 148 (**2001**) 2–3, 117–128, doi:10.1016/S0257-8972(01)01349-4

[10] R. P. Zeilmann, W. L. Weingaertner, Analysis of temperature during drilling of Tİ6Al4V with minimal quantity of lubricant, Journal of Materials Processing Technology, 179 (**2006**) 1–3, 18–23, doi:10.1016/j.jmatprotec.2006.03.077

[11] S. Yağmur, A. Acır, U. Şeker, M. Günay, An Experimental Investigation of Effect of Cutting Parameters on Cuttıng Zone Temperature in Drilling, Journal of the Faculty of Engineering and Architecture of Gazi University, 28 (**2013**) 1, 1–6

[12] T. H. Mohammed, Hole quality in deep hole drilling, Materials and Manufacturıng Processes, 16 (**2001**) 2, 147–164, doi:10.1081/AMP-100104297

[13] S. Mohan, H. S. Shan, Analysis of Roundness Error and Surface Roughness in the Electro Jet Drilling Process, Materials and Manufacturing Processes, 21 (**2006**) 1, 1–9, doi:10.1081/AMP-200060398

[14] U. Gökmen, M. Türker, Effect of Al2O3 Addition on the Foamability Behaviour of Aluminum And Alumix 231 Based Metallic Foam, Journal of the Faculty of Engineering and Architecture of Gazi University, 27 (**2012**) 3, 651–658

[15] J. Banhart, Manufacture, characterization and application of cellular metals and metal foams, Progress in Materials Science, 46 (**2001**), 559–632, PII: S0079-6425(00)00002-5

[16] A. Uzun, U. Gökmen, H. Cinici, H. Koruk, M. Türker, Investigation of modal properties of $AlSi_7$ foam produced by powder metallurgy technique, Material Testing, 55 (**2013**) 7–8, 598-601, doi:10.3139/120.110475

[17] A. H. Benouali, L. Froyen, J. F. Delerue, M. Wevers, Mechanical analysis and microstructural characterisation of metal foams, Materials Science and Technology, 18 (**2002**) 5, 489–494, doi:10.1179/026708302225002056

[18] H. Bart-Smith, A. F. Bastawros, D. R. Mumm, A. G. Evans, D. J. Sypeck, H. N. G. Wadley, Compressive deformation and yielding mechanisms in cellular Al alloys determined using X-Ray tomography and surface strain mapping, Acta Materialia, 46 (**1998**) 10, 3583–3592, doi:10.1016/S1359-6454(98)00025-1

[19] Sandvik Coromant, Modern Metal Cutting, Sandvikens Tryckeri, Sweden, 1994, 2–61

[20] G. Uzun, I. Korkut, The effect of cryogenic treatment on tapping, The International Journal of Advanced Manufacturing Technology, 67 (**2013**) 1–4, 857-864, doi:10.1007/s00170-012-4529-x

[21] K. W. Kim, T. K. Ahn, Force prediction and stres analysis of a twist drill from tool geometry and cutting conditions, International Journal of Precision Engineering and Manufacturing, 6 (**2005**) 1, 65–72, http://www.dbpia.co.kr/Article/686491

[22] M. Pirtini, I. Lazoglu, Forces and hole quality in drilling, International Journal of Machine Tools & Manufacture, 45 (**2005**) 11, 1271–1281, doi:10.1016/j.ijmachtools.2005.01.004

[23] L. J. Wang, X. Wang, H. F. Zhao, Effect of the cutting ratio on cutting forces and the drill life in vibration drilling, The International Journal of Advanced Manufacturing Technology, 24 (**2004**) 11–12, 865–872, doi:10.1007/s00170-003-1803-y

[24] M. Kurt, Y. Kaynak, E. Bagci, Evaluation of drilled hole quality in Al 2024 alloy, The International Journal of Advanced Manufacturing Technology, 37 (**2008**) 11–12, 1051–1060, doi:10.1007/s00170-007-1049-1