METABK 56(3-4) 364-366 (2017)
UDC – UDK 621.762:621.7:539.21:621=111

THE INFLUENCE OF POROSITY ON MACHINABILITY OF SINTERED FE FOAM ELEMENTS

Received – Prispjelo: 2016-12-31
Accepted – Prihvaćeno: 2017-03-25
Original Scientific Paper – Izvorni znanstveni rad

The aim of the experiment was to study the machinability of porous metal foams formed by reduction of metal oxides during sintering. The analysis focused on the machining process of metal foams with respect to their porosity and mechanical properties. The factors investigated included the geometry of the specimens, the surface condition depending on the machining parameters (milling) and the porosity of the metal foam. The metallic porous structure was obtained as a result of sintering the mixture of iron based powders ASC 100.29 and DISTALOY SE (DIST SE) with porosity from 67,9 % (SE 1) to 77,8 % (SE 2) for ASC base powder and 75,7 % to 80.3 % for DISTALOY SE were used.

Key words: powder metallurgy, metal foam, porosity, sintered Fe foam, machining

INTRODUCTION

Metallic foams can be produced in a number of ways. Early attempts concentrated on the techniques similar to those used for polymer foaming, with a gas serving as the blowing agent. Alternative options included obtaining interconnected cellular structures through casting metal melts around polymer granules in the die. Many methods followed with variants on foaming processes [1-9].

Powder metallurgy (P/M) processes are employed in a variety of applications due to their ability to provide near-net-shape parts with microstructures not easily achievable otherwise [10]. In addition to the P/M techniques, such as slurry foaming and loose metal powder sintering, fibre metallurgy is used to obtain much higher porosities [11]. Another technique applied in metallic foam manufacture involves employing powder metallurgy with iron based powder mixtures and iron (III) oxide space holders added. This technique allows combining irregular cellular structures with open or closed pores [12-15]. The range of porosity depends largely on the type and size of particles of component materials and on the metal oxide to matrix metal ratio. Generating a porous structure requires the use of metal oxides that can be reduced easily in sintering atmospheres. Porous metal foam technology is suitable to produce components similar to those obtained by powder metallurgy [12].

Physical properties of metallic foams depend on their structure. It is essential to gain a better understanding of the relationship between the microstructure and foam properties. Substantial aspects of the structure of foam materials include porosity or relative density, pore and solid shape and bridges linking pores and solid regions [16]. Powder metallurgy has a great potential for the development of properties and shapes of manufactured components. However, the dimensional tolerances of produced parts do not allow their direct application and additional surface treatments of the metal foams are necessary to correct their geometry and surface structure[18]. The typical case is the deformation of foam geometries due to the non-uniform dispersion of the foaming agent or its settlement [16].

W. Depczyński, L. Nowakowski, P. Hepner, E.Miko, Kielce University of Technology, Poland

EXPERIMENTAL PROCEDURE

The specimens, SE 1, SE 2 and DIST SE foams, are produced in a shape of a deformed cylinder with maximum dimensions of 17 mm in diameter and 15 mm in height. The form and dimensional errors prevent the practical use of the semi-finished products in engineering applications. Figure 1 shows an example of DIST SE type sintered foam specimen.

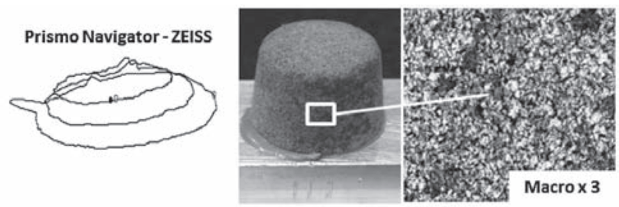

Figure 1 View of a DIST SE sintered foam specimen.

The form and dimensional accuracy of the four types of foams produced by sintering was determined with the use of the Zeiss Prismo Navigator (MPE_E = 0,9 + L/350 μm) coordinate measuring machine fitted with a VAST Gold S-ASS scanning probe. Electrical discharge machining (EDM) was performed with the use of ZAP BP-93L.The sintered foam cylindrical specimens

Ø15x10 mm were subjected to dry milling on the Hermle B300 machining centre with the Sandvik Coromant R216.32-10025-AK32AH10F cutter Ø10mm (Figure 2). Two operations were involved: face milling and peripheral milling of the specimens. The milling was done with the following parameters: cutting speed (V_c) = 470 m/min, feed rate v_f = 300 mm/min, cutting depth a_p = 0.5 (face milling) and 10 mm (peripheral milling), lateral feed a_e.

Following the EDM and mill finish, the sintered specimens were measured again with the aid of the ZEISS Prismo Navigator coordinate machine, and the diameters of the specimens, deviations of cylindricity and perpendicularity were determined, along with accuracy classes.

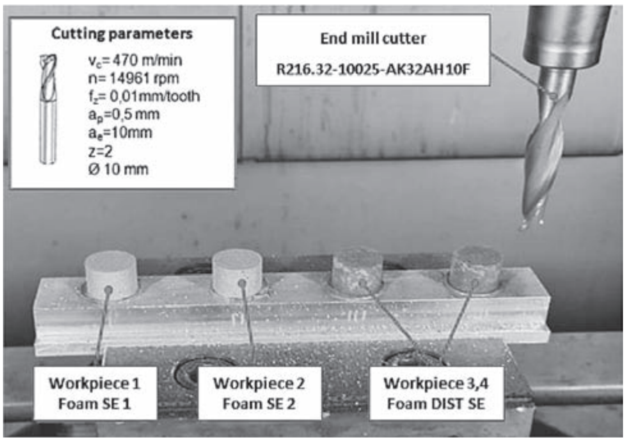

Figure 2 Milling the metal foam specimens on the HERMLE B300 machining centre

RESULTS AND DISSCUSSION

The measurements of the diameters and cylindricity deviations were performed on the near-cylindrical specimens. Additionally, perpendicularity deviation of the cylinder axis relative to the measuring face was determined. The following measurement strategies were used: a) measuring roundness profiles (three roundness profiles at the height of 18 mm, 3 000 points each), b) scanning the measuring face (a circle 10 mm in diameter, made up of 1 000 points).

Table 1 compiles the results for the diameters, cylindricity deviations and perpendicularity deviations of the cylinder axis relative to the measuring face of the foam specimens measured directly after the sintering process and electrical discharge machining (EDM).

This research aims at improving the dimensional and form accuracy of the foams produced by sintering and determining the effects of mechanical processing and electrical discharge machining (EDM) on this accuracy in sintered foams. The results indicate that the sintering process produces a semi-finished product with low dimensional and form accuracy, i.e.: the tolerance zone of the diameters measured: 0,7819 mm, an average cylindricity deviation: 0,488 mm, an average perpendicularity deviation of the axis of the cylinder relative to its measuring surface: 0,180 mm.

Table 1 **The results of diameters measurement values (after sintering and EDM).**

	Foams after sintering			Foams / EDM
Foam type	SE 1	SE 2	DIST SE	DIST SE
Mould/die diameter / mm	18 (max.)			-
Spec. diameter / mm	16,268	16,849	17,050	15,900
Cylindricity deviation / mm	0,460	0,321	0,683	0,265
Perpendicularity deviation / mm	0,182	0,102	0,255	0,613

The semi-finished product resulting from the sintering of metallic foams deviates strongly in terms of dimensions and shape, which makes it unsuitable for use in precision mechanical engineering applications.

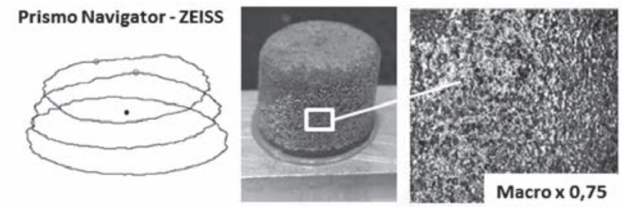

Figure 3 View of sintered SE 2 foam specimen after EDM

Table 2 shows the diameter measurement results and measured values of the deviations from the nominal diameter.

Table 2 **The results of diameters measurement values (deviations from the nominal diameter, 15 mm).**

Foam type	Meas. diam. / mm	Dev. in diam. / mm	Accuracy class IT
SE 1	14,976	0,024	IT8
SE 2	14,983	0,017	IT7
DIST SE	14,987	0,013	IT7
DIST SE /EDM	14,988	0,012	IT7

A post-EDM specimen is shown in Figure 3. As a result of EDM, the cylindricity deviation was 0,265 mm and the perpendicularity deviation was 0,613 mm. Additionally, the pores in the foam were closed with a metallic layer (Figure 3) caused by a series of electrical discharges. The results indicate that machining performed through the shoulder milling process produced sintered foam specimens in the accuracy class IT7 ÷ IT8. The smallest diameter deviation of 12 μm was reached for the DIST SE foams. The diameter deviation for the SE 1 foam was 24 μm, the value being twice that obtained for the DIST SE foams. The milling operation resulted in all diameter dimensions being below the nominal dimension, therefore corrections should be introduced while designing the machining process. An example of a specimen after machining is shown in Figure 4.

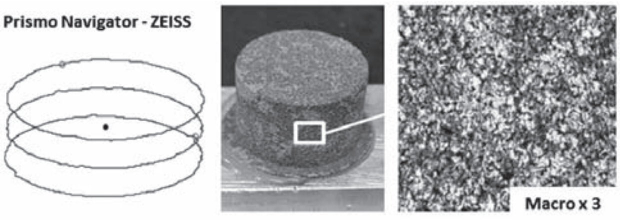

Figure 4 View of sintered SE 2 foam specimen after milling.

Table 3 **The results of diameters measurement values after machining process (deviations in cylindricity and perpendicularity).**

Foam type	Dev. in cylindricity, / mm, after		Dev. in perpendicularity, /mm, after	
	sint.	machin.	sint.	machin.
SE 1	0,460	0,074	0,182	0,004
SE 2	0,321	0,071	0,102	0,009
DIST SE	0,683	0,053	0,255	0,004
DIST SE /EDM	0,683	0,265	0,613	0,010

Table 3 shows the measurement results for cylindricity and perpendicularity deviations before and after machining.

The smallest cylindricity deviation measured after machining DIST SE foam specimens was 0,053 mm, with about 0,07 mm in other foam types. After EDM, the cylindricity deviation of 0,265 mm was obtained, this being about four times worse value than that recorded after machining. Analysis of perpendicularity deviations of the cylinder axis relative to the face showed the smallest value of 4 µm in SE 1 and DIST SE foams, with 9 and 10 µm in SE 2 and DIST SE foams respectively after EDM.

SUMMARY

This research evaluated the influence of face milling and EMD on the accuracy of form and dimension of sintered foam specimens. The findings indicate that sintering process produces semi-finished products of sintered foams of low form and dimensional accuracy with the tolerance zone of the diameters measured of 0,7819 mm, the average value of cylindricity deviation of 0,488 mm, the average value of perpendicularity deviation of the cylinder axis relative to the cylinder face of 0,180 mm. Also the EDM process left a metallic layer closing the pores in the DIST SE foam, also it reduced the cylindricity deviation from 0,683 mm to 0,265 mm, whereas the perpendicularity deviation increased to 0,613 mm. Machining through the shoulder milling produced the specimens of sintered foams with the accuracy in class IT7 ÷ IT8.

The porosity has nearly no effect on metal foam semi-product dimensional and form accuracy.

REFERENCES

[1] M.F. Ashby, A.G. Evans, N.A. Fleck, L.J. Gibson, J.W. Hutchinson , H.N.G.Wadley Metal Foams: A Design Guide; Buterworth-Heineman (2000)

[2] Parvanian A.M., Sadatfar M., Panjepour M. Kingston A., Sheppard A.P. The effects of manufacturing parameters on geometrical and mechanical properties of copper foams produced by space holder technique. Materials and Design 53 (2014), 681-690

[3] Parvanian A.M., Panjepour M., Mechanical behavior improvement of open pore copper foams synthesized trough space holder technique., Materials and Design, 49 (2013), 834-841

[4] Hangai Y., Zushida K., Fuji H., Ueji R., Kuwazuru O., Yosikawa N. Friction powder compaction process for fabrication open celled Cu foam by sintering – dissolution process route using NaCl space holder, Material Science & Engineering A 585 (2013), 468-474

[5] Bekoz N. Oktay E., Mechanical Properties of low alloy steel foams: Dependency on porosity and pore size. Materials Science and Engineering A 576 (2013), 82-89

[6] Murakami T., Ohara K., Narushima T. Ouchi C., Development of a New Method for Manufacturing Iron Foam Using Gases Generated by Reduction of Iron Oxide, Materials Transactions, 48 (2007) 11, 2937 - 2944

[7] Choi J. H., Jeong E-M., Park D., Yang S., Hahn Y-D., Yun J.-Y., The Effect of Fe and Fe_2O_3 Powder Mixing Ratios on the Pore Properties of Fe Foam Fabricated by a Slurry Coating Process., J. Kor. Powd. Met. Inst., 21 (2014), 4, 266-270

[8] Jin Ho Choia, Sangsun Yanga, Yang-Do Kimb, and Jung-Yeul Yun, The Effect of Binder Content for the Pore Properties of Fe Foam Fabricated by Slurry Coating Process, J. Kor. Powd. Met. Inst., 22 (2013), 2, 87-92

[9] Bednarova V., Lichy P. Lana I., Elbel T. , Casting routes porous metals with regular and irregular structure, Proceedings, International Conference Metal 2013 Brno (2013), 71-74

[10] P. Lowhaphandu , John J. Lewandowski, Fatigue and Fracture of Porous Steels and Cu – Infiltrated Porous Steel, Metallurgical and Materials Transactions A, 30 (1999) 2, 325–334

[11] Davies G.J., Zehn S. Review Metallic Foams: Their Production, Properties And Applications, Journal Of Materials Science 18 (1983), 1899 -1911

[12] Depczyński W., Sintering of copper layers with a controlled porous structure, Metal 2014: 23rd Int. Conference On Metallurgy And Materials (2014), 1219 - 1224

[13] B.H. Smith, S. Szyniszewski, J.F. Hajjar, B.W. Schafer, S.R. Arwade, Steel foam for struktures: A review of applications, manufacturing and material properties, Journal of Constr. Steel Research, 71 (2012), 1-10

[14] M.D. Demetriou, G. Duan, C. Veazey, K. De Blauwe, W. L. Johnson: Amorpphous Fe-based metal Foam. Scripta Materialia 57 (2007), 9-12

[15] A.H. Brothers, D.C. Dunand: Amorphous metal foams Scripta Materialia, 54 (2006), 513-520

[16] M. Saadatfar, F. Garcia-Moreno, S. Hutzler, A.P. Sheppard, M.A. Knackstedt, J. Banhart, D. Weaire, Imaging of metallic foams using X-ray micro – CT, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 344 (2009), 107-112

[17] Miko E., Micro-irregularities of metal surfaces, Strojniski Vestnik-Journal of Mechanical Engineering, 51 (2005), 10, 634-645

[18] Nowakowski L., Miko E., Skrzyniarz M., The analysis of the zone for initiating the cutting process of X37CrMoV51 steel, Proceedings, 22nd International Conference ENGINEERING MECHANICS (May 2016), Svratka, Czech Republic, pp. 426-429.

Note: The professional translator for the English language is Nina Kacperczyk, Kielce, Poland.