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The Effect of Geometrical Ratio and Nanoparticle Reinforcement on the Properties of Al-Based Nanocomposite Hollow Sphere Structures

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Abstract**—**In the present study, the properties of Al-Al_2O_3 nanocomposite hollow sphere structures were investigated. For this reason, the Al-based nanocomposite hollow spheres with different amounts of nano-alumina reinforcement (0-10wt %) and different ratio of thickness to diameter (t/D: 0.06-0.3) were prepared via a powder metallurgy method. Then, the effect of mentioned parameters was studied on physical and quasi static mechanical properties of their related prepared structures (open/closed cell) such as density, hardness, strength, and energy absorption. It was found that, as the t/D ratio increases the relative density, compressive strength and energy absorption increase. The highest values of strength and energy absorption were obtained from the specimen with 5 wt. % of nanoparticle reinforcement, t/D of 0.3 (t=1 mm, D=400μm) as 22.88 MPa and 13.24 MJ/m^3, respectively. The moderate specific strength of prepared composites in the present study showed the good consistency with the properties of others low carbon steel composite with similar structure.

Keywords**—**Hollow sphere structure foam, nanocomposite, t/D (thickness, diameter), powder metallurgy.

I. Introduction

LIGHTNESS, high specific strength [1], and energy absorption [2] introduce the metal foams as the potential materials for several strategic applications [3]. Hollow sphere structures are a new class of metal foams which have some certain specifications such as properties, controllability and tailoring [4]. In order to enhance the final properties of metal foams making composite materials is a solution [5]. The addition of reinforcement to cell wall or matrix materials in hollow sphere structures can deliver the composite metal foams with different properties [6]. Also, the thickness to diameter ratio (t/D) of spheres is an important factor which affects the specific mechanical properties [7].

In the present work, the properties of Al-Al_2O_3 nanocomposite hollow sphere structures were characterized and the effect of t/D ratio and nanoparticle reinforcement on final properties was investigated. Finally, the results compared with others research.

II. Experimental

The Al-Al_2O_3 nanocomposite hollow sphere structures were prepared using powder metallurgy technique. For this reason, individual hollow spheres were produced by fluidized bed coating with different content of Al_2O_3 (0, 2.5 and 5 wt. %) in t/D ratios of 0.06, 0.11, 0.18 and 0.30. Then, the open/closed cell structures were prepared using the PM route. The sample preparation procedure is given elsewhere [8], [9]. Table I is given the prepared foam samples specifications. The density and quasi static compressive strength and energy absorption of specimens were characterized. The effect of t/D and nanoparticle addition on the mentioned properties was investigated.

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TABLE I
Foam Samples Specifications and Density

Sample Code	t/D ratio	Structure bulk density (g/cm^3)	Structure relative density (%)	Matrix Porosity (%)	Sphere Wall Thickness (%)
HSS-R0-D3.5-t200	0.06	0.74	27.21	16.00	13.00
HSS-R2.5-D3.5-t200	0.06	0.73	26.64	17.00	12.00
HSS-R5-D3.5-t200	0.06	0.76	27.54	17.00	15.00
HSS-R0-D3.5-t400	0.11	0.93	34.19	15.00	11.00
HSS-R2.5-D3.5-t400	0.11	0.93	33.94	16.00	12.00
HSS-R5-D3.5-t400	0.11	0.94	34.06	16.00	12.00
HSS-R0-D1-t200	0.18	1.12	41.18	15.00	12.00
HSS-R5-D1-t200	0.18	1.13	40.94	17.00	13.00
HSS-R0-D1-t400	0.30	1.43	52.57	15.00	12.00
HSS-R5-D1-t400	0.30	1.41	51.09	17.00	11.00

Sample designation: HSS-R5-D3.5-t400. HSS: Al based Hollow Sphere, Structure, R5: Reinforcement content (5wt. %), D3.5: Sphere diameter (3.5 mm), t400: mean sphere wall thickness (400 μm)

III. Results and Discussion

A. The Effect of t/D Ratio on Density

Table I gives the bulk and relative density of foam specimens. Fig. 1 shows the closed cell foam structure density versus t/D. As it is seen, an increase in t/D leads to increase the sphere density and as a result final foam structures.

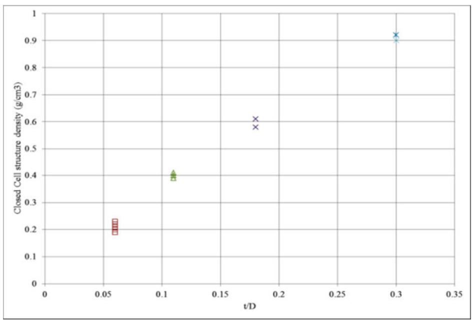

Fig. 1 The density of closed cell structures versus t/D ratio

B. The Effect of t/D Ratio and Reinforcement on Hardness

Fig. 2 has shown the effect of nano-alumina reinforcement content on microstructure of spheres' wall and matrix for several samples. The hardness in both cases increased as the nanoparticle reinforcement increased. Also, the hardness value levels of sphere wall are higher than nanocomposite matrix. As the porosity level in sphere walls are less than matrix one, increasing alumina content lead to an increase in composite hardness because of inherent higher hardness of alumina particles. This issue simply is evaluated by mixtures law:

$$H_c=H_m f_m+H_r fr \quad (1)$$

which H_r, H_m and H_c are hardness of reinforcement, matrix and composite and f_r and f_m are volume fraction of reinforcement and matrix, respectively [10].

The presence of nanoparticles lead to higher values of hardness due to the nanoparticles' higher surface area and lower level of defects in fine particles in comparing with coarse one. Also, as the particle size decreases, there exist more obstacles for grain growth; so the higher hardness is predictable.

Investigating the effect of t/D on hardness values showed no significant difference between micro-hardness values for samples with similar t/D ratios. This suggests that for hardness evaluation, the factors such as porosity and reinforcement content are more effective than size effect.

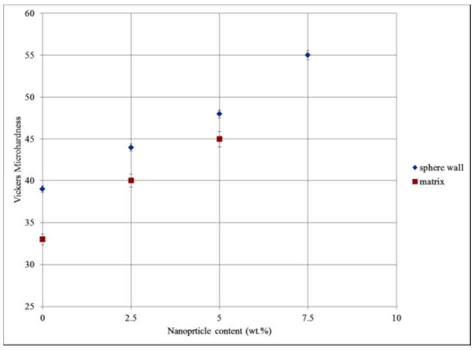

Fig. 2 The effect of nanoparticle reinforcement on sphere walls and matrix microhardness

C. Compressive Strength and Energy Absorption

Fig. 3 has shown the stress-strain curves for some composite *foam*. As seen, all curves indicate the behavior feature of metal foams included three distinct regimes: linear elastic region up to5% strain, a plateau region in relatively constant stress with high strain values and a densification region up to 50-60% strain similar to bulk materials. The oscillations in the plateau region in the curves are related to buckling of sphere walls [11].

D. The Effect of Density and Reinforcement on Strength and Energy Absorption

Figs. 4 and 5 have shown the effect of closed cell structure density on the compressive strength and energy absorption of samples with 5 wt.% of nanoparticles addition and without nanoparticles. As seen increasing relative density lead to increase in compressive strength and energy absorption. Also, in a given relative density, the addition of nanoparticle reinforcement leads to increasing compressive strength and energy absorption. As the relative density increases the porosity level in structure decreases and as a result the load bearing surface increases. Therefore, strength and energy absorption (area under curve) increase.

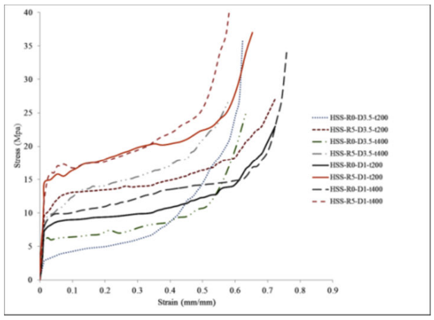

Fig. 3 Compression Stress-Strain curves of some samples

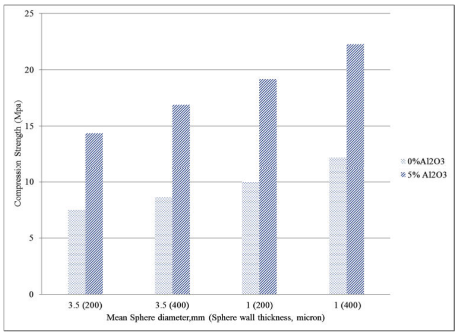

Fig. 4 The effect of relative density on compression strength

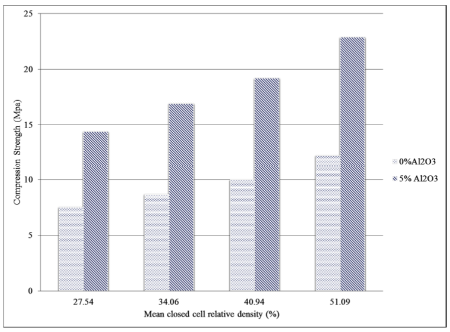

Fig. 5 The effect of relative density on energy absorption

E. The Effect of Sphere Size, t/D and Reinforcement on Strength and Energy Absorption

Fig. 6 shows the influence of size effect, sphere wall thickness and nanoparticle additive on the compressive strength of composite foams. As it is seen, in a given wall thickness as the sphere size decreases from 3.5 to 1.0 mm, the compressive strength of final structure increases. Also, the compressive strength in a given sphere size is higher in case of thicker sphere walls. Furthermore, nanoparticle reinforcement leads to increase in compressive strength than the structures without additives.

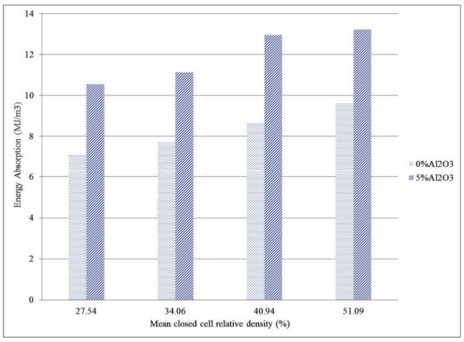

Fig. 6 The influence of size effect on composite foams compression strength

The large size of hollow spheres has harmful effects on mechanical properties. Smaller hollow spheres have better mechanical properties because the higher the curvature of the wall gives higher values of compressive strength and mechanical stability. This issue is in consistent with [12] and [3] researches about hollow spheres.

Fig. 7 illustrates the effect of t/D on compressive strength of several structures with and without reinforcements. As seen, the strength increases as the t/D increases. The thickness to diameter ratio significantly affects the stress distribution pattern. As the t/D ratio increases, the maximum bending stress situation in lateral sphere wall transferred from wall-anvil contacts to sphere center line which lead to changes in wall fracture modes. When t/D ratio decreases, the maximum stress in wall transferred from sphere center line to wall anvil contacts and leads to decrease in compressive strength [13].

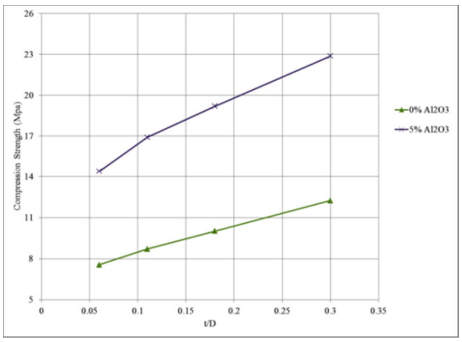

Fig. 7 The effect of t/D on compression strength

Fig. 8 has shown the t/D effects on specific strength of composite foam structures for both sets of samples, as the t/D increases the specific strength decreases because the density is increased as t/D increase.

The foam energy absorption increases as t/D increases as well. According to aforementioned subjects about the relation between t/D and density higher t/D values has the higher capacity of load bearing and as a result lead to increasing energy absorption from area under stress- strain curve.

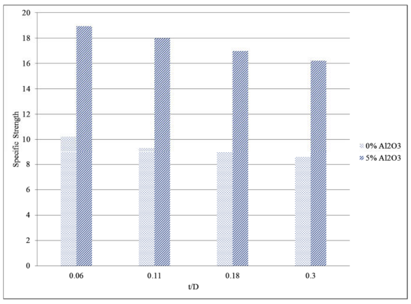

Fig. 8 The effect of t/D on specific compression strength

The composite foam with 200 µm wall thickness, 5 wt.% of nanoparticles, had the compressive strength value by 40% more than low carbon steel composite foam in similar sphere size [14]. The studied composite foam revealed the good energy absorption which in higher values are 6-10 times more than Al foams and Georgia Tech steel hollow spheres [15] and equal to Franhufer stainless steel hollow sphere structures [16].

IV. Conclusions

The effect of t/D ratio and nanoparticle reinforcement was investigated on the properties of hollow sphere structures based on Al-Al_2O_3 nanocomposites. The results showed:

- For hardness evaluation, the factors such as porosity and reinforcement content are more effective than size effect.
- In a given wall thickness as the sphere size decreases from 3.5 to 1.0 mm, the compressive strength of final structure increases. Likewise, the compressive strength in a given domain size is higher in case of thicker sphere walls.
- The composite foam with 200 µm wall thickness, 5 wt. % of nanoparticles, had the compressive strength value by 40% more than low carbon steel composite foam in similar sphere size.

References

[1] J. A. Santa Maria, B. F. Schultz, J. B. Ferguson, P. K. Rohatgi, "Al–Al_2O_3 syntactic foams – Part I: Effect of matrix strength and hollow sphere size on the quasi-static properties of Al-A206/Al_2O_3 syntactic foams" *Mat. Sci. Eng.* A, no. 582, pp. 415–422, 2013.

[2] I. Norbert Orbulov, "Compressive properties of aluminium matrix syntactic foams", *Mat. Sci. Eng.* A, no. 555, pp. 52– 56, 2012.

[3] G. Castro, S. R. Nutt, X. Wenchen, "Compression and low-velocity impact behavior of aluminum syntactic foam", *Mat. Sci. Eng.* A, no. 578, pp. 222-229, 2013.

[4] Y. Liu, H.-Xiang Wu, X. Zhang, B. Wang, "The influence of lattice structure on the dynamic performance of metal hollow sphere agglomerates", *Mech. Res. Com*., no. 38, pp. 569-573, 2011.

[5] M. Amirjan, H. Khorsand, M Khorasani," Fluidized bed coating efficiency and morphology of coatings for producing Al-based nanocomposite hollow spheres", *Int. J. Min., Met. Mat*., Vol 21, no. 11, pp.1146, Nov. 2014.

[6] L. P. Lefebvre, J. Banhart, D. Dunand, "Porous Metals and Metallic Foams: Current Status and Recent Developments", *Adv. Eng. Mat*., pp. 775-787, 2008.

[7] S. Roy, A. Wanner, T. Beck, T. Studnitzky, G. Stephani," Mechanical properties of cellular solids produced from hollow stainless steel spheres", *J. Mat. Sci*., no. 46, pp. 5519-5526, 2011.

[8] M. Amirjan, H. Khorsand, "On the Microstructure and Properties of Al-Al_2O_3 Nanocomposites Hollow Sphere Structures" *Proc. of 5th Int. Cong. Nanosci. Nanotech. (ICNN2014)*, 22-24 Oct. 2014, Tehran, Iran

[9] M. Amirjan, H. Khorsand," The Effect of Al_2O_3 Nanoparticle Addition on the Coating Behavior of Al-based Suspensions in Producing Nanocomposite Hollow Spheres", *Proc. of 5th Int. Cong. Nanosci. Nanotech. (ICNN2014)*, 22-24 Oct. 2014, Tehran, Iran

[10] M. Rahimian, N. Parvin, N. Ehsani, "Investigation of particle size and amount of alumina on microstructure and mechanical properties of Al matrix composite made by powder metallurgy", *Mat. Sci. Eng. A*, no. 527, pp. 1031-1038, 2010.

[11] A. Fallet, P. Lhuissier, L. Salvo, Y. Brechet, "Mechanical Behavior of Metallic Hollow Spheres Foams", *Adv. Eng. Mat*., no. 10, pp. 858-862, 2008.

[12] A. Rabiei, L. J. Vendra, "A comparison of composite metal foam's properties and other comparable metal foams", *Mat. Let*, no. 63, pp. 533-536, 2009.

[13] P. Li, N. Petrinic, C. R. Siviour, "Finite element modelling of the mechanism of deformation and failure in metallic thin-walled hollow spheres under dynamic compression", *Mech. Mat*., no. 54, pp. 43-54, 2012.

[14] P. Neville, A. Rabiei, "Composite metal foams processed through powder metallurgy", *Mat. Des*. No. 29, 2008.

[15] T. J. Lim, B. Smith, D. L. McDowell, "Behavior of a random hollow sphere metal foam", *Acta Mat*., no. 50, pp.2867-2879, 2002.

[16] G. Stephani, D. Kupp, T. D. Claar, U. Waag, "Fabrication of Ti-Based Components with Controlled Porosity", *Int. Conf. on Powd. Met. Partic. Mat.*, Fraunhofer Institute for Manufacturing and Advanced Materials. pp. 50-58, 2001.