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Characterization of 20 Pores per Inch (ppi) Open Cell Aluminum Foam of Alporas Rout Under Flexural and Hardness Test

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***Abstract*—** In this research the characterization of open cell aluminium foam with 20 pores per inch (ppi) of Alporas rout under mechanical loading is presented in order to provide a basic understanding with respect to pore size per unit length for the right selection in various engineering applications. For this purpose three point bending/flexural test and hardness test were performed on open cell aluminum foam to seek out their respective properties in each test. All samples and test procedure were performed as per ASTM standards. The captured results from the tests revealed that; the 20 pores per inch (ppi) exhibited 4.69 MPa bending strength at peak and 3.65 HRV1 hardness at 1Kg-force. Moreover the macro crack appeared at the central regime of the samples and ductile nature fractured was observed of three point bending test.

***Keywords*—** Open Cell Aluminum Foam, Characterization, Three Point Bending Test, Hardness Test, 20 Porse Per Inch (ppi).

I. Introduction

Metallic foams are composed of macro-cells which are characterized by solid-state strong material encompassed by 3D organization of voids. Metal foam is a new type of material having interesting and attractive mechanical and physical indications. Because of their cellular, strong and porous construction it has light weight, good strength and high energy engrossment capability owing to which its agreeable choice for the practical life application in different area [1].

Aluminum foam is a young class of metallic foam which have enclosed of inviting indications such as light weight, good strength, excellent energy engrossment and heat diffusion and transfer features. Due to these all core performance the aluminum foam is a best candidate for the space industry, automobile sectors, locomotive, packing and other different zones [2-7].

As per construction of cells and voids aluminum foam has broken into two major family open cell and closed cell aluminum foam. Open cell aluminum foam composed of only ligaments and edges that there are an open space exist between two adjacent cells, which is created by Alporas rout, spaceholder and foam casting method while closed cell aluminum foam comprised of solid-state that each cells and pores is closed off from adjacent cells which is created by melt foaming; powder metallurgy and gas injection process.

The utilizations and properties of aluminum foam relies on their fundamental qualities, for example cells and pores construction, size and dispersion as well as highly effected on manufacturing method [8]. The manufacturing process of aluminum foam is very complicated because every manufacturer creates different kind of foams due to the less research encourage.

The construction of cells and voids of aluminum foam are organized in such a way that they resist an extensive deformation under mechanical loading and engulf magnificent energy before rupture of cell and voids geometry [9]. A lot of investigations have focused on the behavior of aluminum foam to show that they have engulfed significant energy during compression and impact loading [10-16].

Aluminum foam exhibits three different zones (I-elastic, II-plateau and II-densification) of deformation during compression work in stress-strain graph. The first zone is elastic deformation in which cells of the foam deformed elastically and retain its original shape after removal of load. The second zone is called plateau territory which very important and responsible for engrossment of energy during compression load, in this territory the cells of foam shrink plastically and does not go back to past era. The plateau zone is originated by the creations and colonization of the cell-bands during deformation. In third zone the combination and compaction of cell-bands occurred which is called densification [17].

The more extensive application scope of aluminum foam, the working environment and deformation mechanism of cells is more complex when often subjected to mechanical loading during their service [18]. Therefore the fundamental understanding and behavior of Aluminum foam is required. In other side foaming process is very complex because every manufacturer creates different type of foam owing to insufficient research encouraged of researchers to find different type of properties of Aluminum foam in different condition.

This research is intent to contribute the above causes and focused on the characterization of open cell aluminum foam with 20 pores per inch (ppi) manufactured through Alporas rout under mechanical loading (three point bending/flexural and hardness test). Three point bending test and hardness test were conducted. After the experimental tests the result and discussions will be made on basis tables and samples images, The research result of this investigation can be used as guidance for the engineering design and application of the Aluminum foam in mechanical loading.

II. EXPERIMENTAL WORK

A. *Three Point Bending Test*

For this setup "American Society for Testing and Materials" ASTM- E290-14 and D7972-14 are followed for testing techniques and preparation of samples respectively. Three samples with same size were cut from the slab and kept the dimensions L=120mm B=30mm and T=15 mm by using Wire Electric Discharge Cutting Machine (WEDM). An electro-mechanical universal testing machine (Testometric, Model-M500-30AT) were used provided by "US-Pakistan Center for Advance Studies in Energy" UET Peshawar. In this machine sample are placed on two roller supports and apply load at the center of the sample as shown in "Fig. 1". The machine was set on 1mm/min mandrel loading rate at the 90° to sample. The experiment was accomplished at normal room temperature. The span of the beam/sample between the two supports was kept 65 mm as computed by given equation "(1)".

$$C = 2r + 3t \pm t/2 \quad (1)$$

The radius of the end of the mandrel and roller supports of the machine were used 10 mm. For each tested samples a force 'F' (N) of mandrel and deflection/defoemation 'δ' (mm) of the sample will be noted. The failure fashion and location of failure of each specimen will be observed.The peak value of deformation force (break force) at which failure occurred will also be identified.

B. *Hardness Test*

For this setup "American Society for Testing and Materials" ASTM- E18-20 and E110-14 are followed for testing techniques and preparation of samples respectively. For samples preparation, it is highly suggested that the thickness of sample must beyond the 10-times of 'indentation depth' and there is no visible effect of the indentation on the back side of the sample after experiment. A digital universal hardness testing machine (Tinius-olsen, Model-H-002-0001) were used provided by "US-Pakistan Center for Advance Studies in Energy" UET Peshawar. In this hardness machine the required sample is placed on the anvil properly. Then the machine was programmed to apply 1 kilogram-force (1 kgf) on the sample surface perpendicularly for the duration of 10 seconds, which refer as dwelling time as shown in "Fig. 2". Diamond pyramid shape having square base indenter was used for loading and depth of indentation. The machine calculates value of hardness on the base of 'indentation depth' on the surface of sample. Actually hardness machine used an equation "(2)" programmed in their integrated circuit (IC) as mentioned below. Each sample was tested four times and find out the average value of each sample. The space between the center of two nearest indentation were kept 3 times the dia (d) of indentation as shown in "Fig. 3".

$$HV = F/d^2 \times 1.854 \quad (2)$$

Figure 1. Three point bending test machine apply load with 1 mm/min on sample until fracture

Figure 2. Sample is placed on specimen holder and indenter apply load on sample of 1 kgf for 10 second

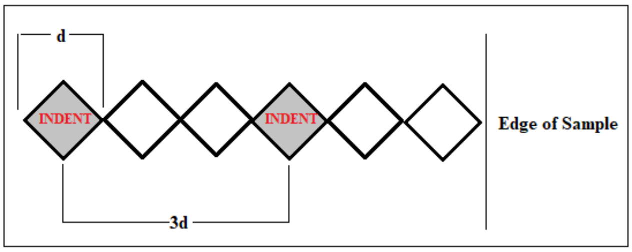

Figure 3. Schematic diagram of space between two nearest indentations

III. Experimental Results and Discussions

C. Three Point Bending Test

The details parameters, properties and their average value of each tested sample of flexural test were summarized in Table 1. The sample 20ppi-A exhibited the excellent behavior in which force (N) reached to highest value of 454.2 N with minimal displacement of 1.554 mm and shown maximum 6.561 MPa bending strength as compared to other two samples of the same pore sizes. It is important to note that, the variations in values of 20ppi-A, 20ppi-B and 20ppi-C may cause the orientations of the cell to the applied load is different in each sample. So the average valve of the bending strength is 6.686 MPa is noted at the average peak 324.4 N force.The bending policy of the all three sample of the 20 ppi occurred in three steps: (i)-step ‘elastic deformation region’ in this region the pores walls experienced deformation elastically and retain its original shape after removal of load, (ii)-step creation and appearance of micro cracks in pores/cell wall, in this stage force/load reached up to maximum value and cracks appears in all pores in jurisdiction of applied load (iii)-step is the failure stage, in this stage micro-cracks of each cells starts propagation and grow up and finally each crack of the each cells joints one another as a result of which a macro crack appears in outer surface of the sample center and sample becomes fail.

Table 1: Flexural properties of 20 ppi of aluminum foam

Samples	**Sample Dimensions (LxWxT)mm^3**	**Force at Peak (N)**	**Deformation at Peak (mm)**	**Deformation at Break (mm)**	**Bending Strength at Peak (MPa)**	**Bending Strength at Break (MPa)**
20-A	120x30x15	454.2	1.554	1.931	6.561	-834.586
20-B	120x30x15	342.7	1.351	5.915	4.95	-1.138
20-C	120x30x15	176.3	0.444	1.241	2.547	0.994
Average	-	**324.4**	**1.12**	**3.029**	**4.686**	-

D. Hardness Test

The Table 2 presented the hardness values of open cell aluminium foam with 20 ppi of Alporas rout in four trials and their average value is 3.65 HRV1. It can be noticed that the obtained hardness valves is actually the hardness of the solid state of the aluminium foam. The hardness could be further increased by decreasing number of pores per unit length. The main reason behind this is to reduce the number of pores per unit length will lead to increase the volume percentage of solid state and the hardness of the solid fraction/contents is significantly higher than the cell wall.

Table 2: Hardness values of 20 ppi of aluminum foam

Scale:HV1`			Dwell Time: 10 Sec			Load: 1Kgf
Sample I.D	**Test 1**	**Test 2**	**Test 3**	**Test 4**	**Average**	**S. Deviation**
20 PPI	2.74	3.25	5.1	3.5	3.6475	1.02

Conclusion

In this study, three point bending test and vickers hardness test have been performed on open cell aluminum foam with 20 pores per inch (ppi) prepared by Alporas rout. The following endings are condensed.

In bending test, failure occurred in three steps: (i) elastic deformation region (ii) creation and appearance of micro cracks (iii) failure stage; and macro cracks appeared at the center of the specimens on tension side. The average bending strength 4.69 MPa were obtained at the peak force. The bending strength could be increased if number of pores per unit length inceased. The average hardness value is 3.65 HRV1 were obtained and it could also be increased if number of pores per unit length decreased. Moreover, It is observed that the obtained hardness valve is actually the hardness of the solid state/phase of the aluminium foam.

Notations

c = Distance between two supports/span
d = Thickness of the sample for three point bending test
b = Width of the sample for three point bending test
r = radius of the end of the mandrel/plunger of three point bending test machine
HV = Vickers hardness
F = Apply load in kgf (Kilogram-Force)
d = Average of diagonals of d1 and d2 of the indentation (d1+ d2 /2)

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