Proceedings of the International Conference on Applied Mechanical Engineering Research (IC-AMER2019)
NIT Warangal, India – May 02-05, 2019
Paper No. XXX (The number assigned when the papaer is accepted)

Effect of Exfoliated Vermiculite as thickening and foaming agent on the Physical Properties of Aluminium Foam

V.V.K.Lakshmi[a,*], K.Arun Vikram[a], K Suresh[a], B Surendra Babu[a]
[a]*Department of Industrial Engineering, GITAM Institute of Technology, Visakhapatnam-530045, Andhra Pradesh, India*

*Corresponding author Email: lakshmi.vennela@gitam.edu

In this paper Exfoliated Vermiculite (EV), a siliceous non metallic particle is used as both thickening and foaming agent to fabricate low density metal foam via the oxidation reduction method. Aluminum Alloy 5083 is used as base metal. EV particles 0.1mm size that were dehydrated by pre heating were added as thickening agents and EV particles 1mm size containing 5% moisture are used as foaming agent to produce bubbles. The density of the foam produced is reduced by about 50% when compared to pure Al5083. The macrostructure reveal that 1.5% EV particle addition resulted in uniform foam. Average pore size varied from 0.1mm to 2 mm with varying EV %. With increase in thickening agent percent the pore size decreased and after 1.5% the pores size increased. The density of foam increased with increase in percentage of thickening agent. From the Compressive stress strain curves at strain rate of 1mm/min the plateau stress increased with the density. The energy absorption for the foam is found to be 4MJ/m^3 for 1.5% EV particles. The energy absorption efficiency is 65%.

***Keywords*:** Metal Foam,Composite; Vermiculite; Aluminium

1. Introduction

Aluminium closed cell foams due to light weight find applications in automobile, shipping, aviation, packaging, military equipment where load bearing and heat insulation is of prime concern. Metal foams possess low strength to weight ratio stiffness, low densities, and good impact energy absorption in comparison to solid metals. By proper engineering of size, shape of the pores desired mechanical properties can be achieved[1,2]. Closed cell metal foams are formed by gas foaming techniques whereas open cell foams are formed by infiltration technique. The methods generally adopted for fabrication of metal foams are powder metallurgy technique, stir cast method and infiltration technique. It is important to maintain the viscosity of the melt molten metal to prevent escaping of the gas bubbles. Therefore thickening agents like calcium, copper, siliceous materials like perlite etc which increase viscosity are added to melt as gas formed cannot escape from thick for aluminium and its alloys[3,4]. The gas bubble formation in the melt is done by adding foaming agents such as hydrides, polymeric agents, carbonates, sulphates or organic compounds as they release gases at the temperature by either vaporization or decomposition. The commonly used foaming agents are TiH_2, $CaCo_3$[5-10]. The mechanical properties of foam metals greatly depend on the uniformity of the pores, pore size which in turn depend on foaming agent size, quantity, time of exposure, temperature of the melt[16-18].

Till date, to the best of knowledge of the author(s), Exfoliated Vermiculite (EV) is not used as a thickening or foaming agent. And in addition literature reports, only one kind of material usage as either thickening agent or foaming agent. Hence, this work shows a novelty of usage of EV as both thickening and foaming agents simultaneously with base material as aluminium alloy (Al-5083).

The magnesium in Al-5083 readily reacts with steam and aids in the bubble formation for foaming. Water carrying agent, vermiculite is used as foaming agent and foaming was done via the oxidation reduction method. The exfoliated vermiculite EV, particles have layered like structure and belongs to mica group. Vermiculite belongs to silicate group of minerals with oxides of alumina, magnesium, silicon. It costs less, light in weight, offers better resistance to fire at elevated temperatures, non toxic and has wide applications in packaging, insulation application[11]. EV also acts as a mild lubricant due to plate like structure.

2. Materials and methods

Exfoliated vermiculite which has accordion like structure with an average size of 0.1 mm to 1 mm and density of 0.36 g/cc is considered for study. The composition by weight of EV particles is Sio_2:40.52%, Al_2O_3:16.74%, Fe_2O_3:4.32%, TiO_2:0.63%, Cao: 0.47%, MgO:3.68%, Loss 11.05% and Moisture: 7.89%. EV particles used for foaming are approximately an average size 0.1 mm and contain moisture. The composition by weight of the base material Al-5083 is 0.4%Si, 4%Mg, 0.4%Fe, 0.15%Ti, 0.4%Mn, Cu0.1% and remainder Al. Al5083 alloy having density of 2.66 g/cc has good cast ability and high reactivity of magnesium content which readily reacts with oxygen to form bubbles[12,13] and apart from it, presence of Mg improves the wet ability.

Stir casting technique is used for fabrication of foam formation. The Al5083 is melted above solidus temperature to 680^{o}C where liquid and solid phases co-exist. Dehydrated EV particles with 0.1 mm are added with weight% of 1.5% as thickening agent to the Al5083 melt. The slurry which is in plastic range is made to have uniform dispersion of the particles by means of stirring at speed of 1200 rpm for 2 minutes. Later, the temperature is raised to 1000^{0}C above liquidus phase and EV particles of average size 1 mm with weight% of 0.5%, 1.0%, 1.5% and 2%, containing moisture are added and stirred at 1200 rpm to aid steam generation and bubble formation. The mixture is held at the temperature for one minute in the graphite mould of the furnace for movement of bubbles. Then, the mixture with mould is immersed in water and cooled. Thus the obtained mixture is cut into piece for testing and analysis like thermal gravimetric analysis, Microstructures, Density, volume fraction, viscosity and bubble velocity evaluation of metal foams and Quasi Static Compression tests.

3. Results and Discussion

3. 1. Thermo Gravimetric Analysis

The thermal gravimetric analysis (TGA) of EV of average size 1mm-2mm is shown in Fig.1. TGA plot shows the loss weight of particles with increase in temperature from 50^{0}C to 300^{0}C and also found around 10 % mass loss during heating from 0 to 1000^{0}C. Initial mass loss occurred at 50^{0}C due to hydration of water molecules present on the surface, while mass loss of 2.5% observed between 50^{0}C to 300^{0}C which is due to hydration of free molecules hydroxyl molecules present in the inter lamella spaces. Loss of mass between 300^{0}C to 800^{0}C is due to loss of water molecules and chemical reactions between cations[14].

3. 2. Microstructure

The microstructure structure of EV particles consists of pores in between the plate like lamellar structures. The clay mineral, has silica tetrahedral layer represented by $(Si_2O_5)_2$. The energy-dispersive X-ray spectrometer (EDS) provides a semi quantative analysis of minerals present in the vermiculite particles.

EV particles with 0.5% as thickener exhibited a large pore size due to less viscosity. The bubbles rose rapidly, collapsed and formed irregular distribution of voids, while with 1.5% weight of EV particles showed average pore size of 0.5mm uniformly distributed.

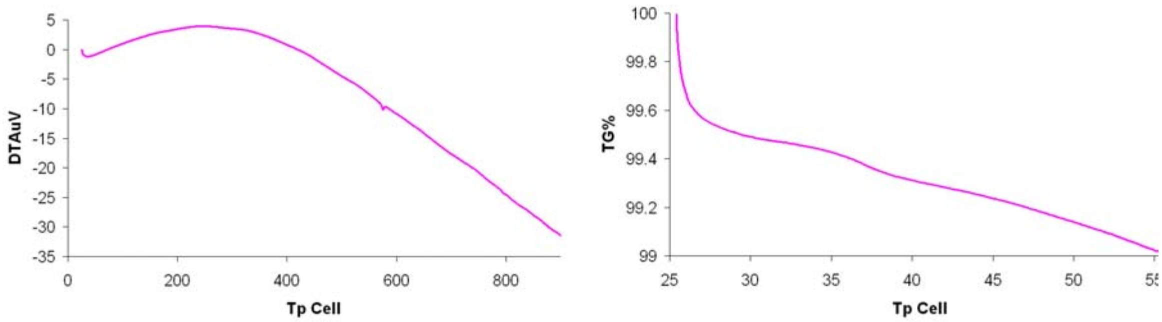
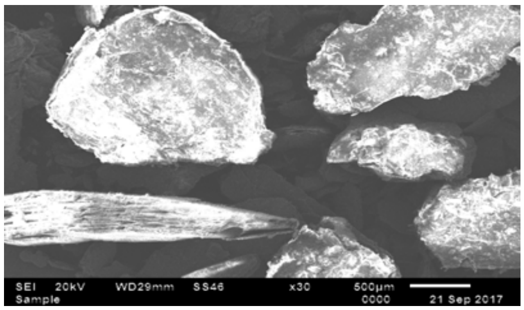


Figure 1. TGA of Vermiculite particles



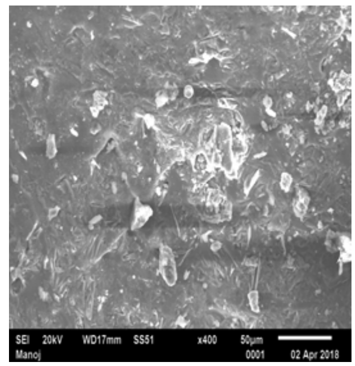


Figure 2: SEM of EV particles

Figure 3: SEM showing oxides

The SEM shown in Fig. 3 shows a larger amount of oxygen (steam) at interface of EV particle and metal, which is due to addition of moisture containing EV particles. The alloy contains 4% magnesium which readily reacts with steam at high temperatures and so it reacts with the steam to form MgO, there by releasing H_2 gas. The release of H_2 is oxidation reduction process which forms bubbles. These oxides and films formed, damp the surface waves in liquid metal preventing the rapture of the film[1,2]. The foam is stabilized due to melt viscosity maintained by addition of thickener. The liquid layer is thick for 1.5%EV addition, hence particles are drawn towards the oxide film and also the oxide layer restrains the EV particles to progress further down.

.

3.3. Density, volume fraction, viscosity and bubble velocity evaluation of metal foams

The density of the foam was measured based on weight and volume of pieces. Density of the EV flakes is 0.64-1.12 g/cc. The density and porosity variation with respect to EV% are shown in figure 4a and 4b. The average porosity ranges from 60 to 80%[15]. The pore size is mainly dependent on the bubble formation and moving velocity in melt. The bubble velocity can be determined by the Stokes equation (i.e. Eq:1) for gas liquid two phase flow[16]. Assume pore size equal to the bubble size of the formed gas.

$$V = 1/18gd^2(\rho_1 - \rho_g)1/\mu \qquad (1)$$

Where "g" acceleration due to gravity, "d" diameter of pore, "ρ_1" density of Al, ρ_2 density of gas, "μ" dynamic viscosity of melt.

Greater the pore (bubble) size, greater the velocity with which it rises in the melt. The literature mentions 1.5% EV particles rather than 0.5% exhibit less velocities with all bubble diameters[16]. Hence in this paper, EV particles with 1.5% and velocities of bubble as 0.393 m/s for of Φ1.5 mm and 0.043 m/s for Φ 0.5mm bubble size are considered[16]. It is evident from figure 4a and 4b, that as the density increased the porosity decreased which happened due to increase in thickening agent.

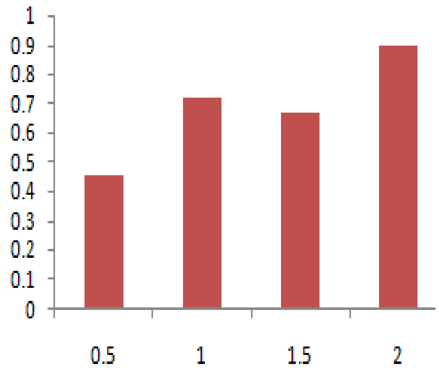


Figure 4a: Density Vs %EV

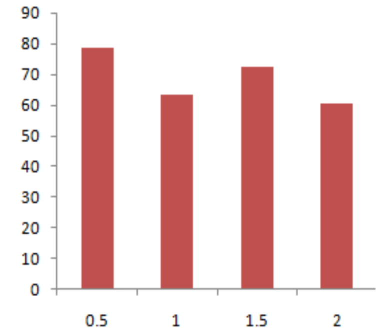


Figure 4b: Porosity Vs %EV

3.4. Quasi Static Compression tests

The compression properties of the foam are evaluated experimentally at low strain rate using a uni-axial computer controlled INSTRON testing machine. The test samples for compression test are as per ASTM E9 specifications with dimensions of 30mm*20mm*20mm. The crosshead speed is taken as 0.01 mm/s and the quasi static compressive stress tests results of foam at rate of 1mm/min are shown in figure 5. It is observed that as density increases the compressive stress increased.

Plateau stress is a prime parameter that influences the cushion effect and is observed in the range of 5% and 40% of the strain. An earlier drop in stress for sample 1.5% EV particles can be attributed to two causes. It can be either due to strain hardening or collapse of pores. If the drop is due to first cause then the stress curve should exhibit a steady rise due to dislocations. But in the graph the stress is almost constant after the initial drop hence the drop is due to early collapse of few pores[18] .The plateau stress increased with density. As the EV particles increases from 0.5 to 2% the compressive yield strength increased. For metal foams with significant plateau region the area under the plateau portion of graph gives is the energy absorption capability of the foam[17].

The foam energy absorbing capacity is 1.3 to 12 MJ/m3 and is shown in figure 6. As the %EV particles increased the viscosity of melt increased which prevented the foaming process and the bubble movement into the melt. Addition of 0.5% thickening agent could not increase the melt viscosity substantially and hence the pores moved rapidly and pore coalesced to form an elliptical large pores there by reducing the cell wall thickness.

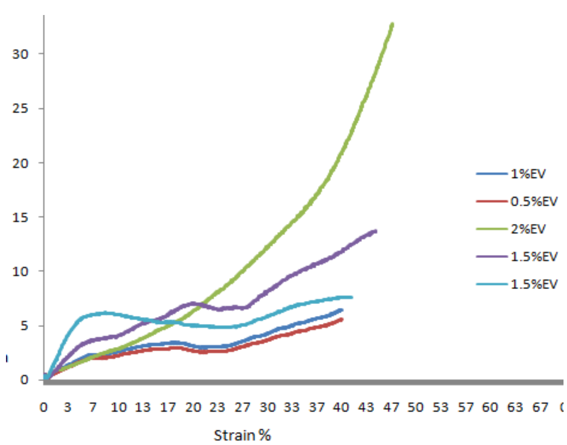


Figure 5: Compressive stress vs strain

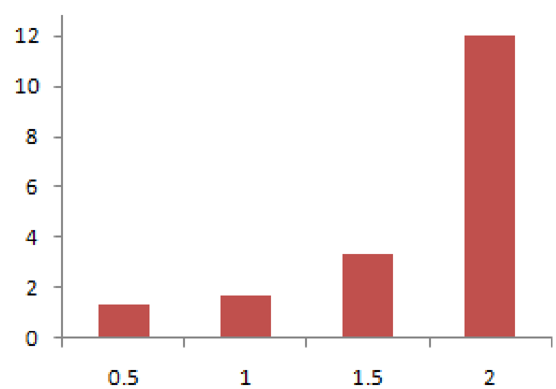


Figure 6: Energy absorbed by foam vs EV %

4. Conclusions

In this research exfoliated vermiculite is successfully used as foaming and thickening agent to fabricate foam via oxidation reduction technique.

- EV particles with 1.5% is suggested as superior foam properties such as pore size, shape uniformity was ob- served. 0.5% EV particle as thickeners resulted a very low density 0.58mm/cc and 70% porous foam. But the pore size was 2mm and energy absorbing capacity was low. Hence 1.5% EV particle addition resulted in good foam properties.
- It is observed that in the process the time of holding the mixture in the furnace post addition of foaming agent if too long the bubbles settle and if less the pores are not dispersed uniformly.
- It is observed that addition of EV particles as thickening agents, the pore size increased from 0.01mm to 2mm.
- The constant stress region from strain 5% to 30% is observed in all samples except the sample with 2% EV particle foam with density of 1.2g/cc and porosity 50% which behaved like a metal rather than foam.

References

[1]Banhart J, *Prog Mater Sci*. 46, 559–632(2001).
[2]Banhart J, Baumeister J, *J Mater Sci*. 33, 1431–40(1998).
[3] Z.-L. Song, L.-Q. Ma, Z.-J. Wu, D.-P, *J. Mater. Sci.* 35, (2000).
[4] A. Heidarzadeh, M. Emamy, A. Rahimzadeh, R. Soufi, D.S.B. Heidary, S. Nasibi, et al., *J. Mater. Eng. Perform*. 23, 469–476(2014).
[5] M. Aboraia, R. Sharkawi, M.A. Doheim, *J. Eng. Sci. Assiut Univ*. 39 ,441–451(2011).
[6]F. Von Zeppelin, M. Hirscher, H. Stanzick, J. Banhart F. Von Zeppelin, M. Hirscher, et al., *Compos. Sci. Technol*. 63 (2003).
[7] L.E.G. Cambronero, J.M. Ruiz-Roman, F.A. Corpas, J.M.R. Prieto, *J. Mater. Process. Technol.* 209, 1803–1809 (2009).
[8]] M.G. Nava, A. Cruz-Ramírez, M.Á.S. Rosales, V.H. Gutiérrez-Pérez, A. Sánchez-Martínez,, *J. Alloys Compd. 698,* 1009–1017 *(2017).*
[9] H.C. Madhu, S. V Kailas, *Mater. Charact*. (2018).
[10] M. Haesche, D. Lehmhus, *J. Mater. Sci. Technol*. 26, 845–850 (2010).
[11] S.A.Suvorov, V.V.Skurikhin, *Refract.Ind.Ceram*. 44, 186–193 (2013).
[12] M.Taherishargh, I.V.Belova, G.E.Murch,T.Fiedler, *Materials Science & Engineering A.* 604, 127–134(2014).
[13] Mondal DP, Das S, Ramakrishnan N, Uday Bhasker K, *Composites Part A: Applied Science and Manufacturing*. 40, 279-288(2016).
[14] Marcos C, Arango YC, Rodriguez I., *Appl. clay sci..,* 42, 368-378(2009).
[15] V.V.K.Lakshmi, K.V.Subbaiah, B.S Babu, *Materials Today:Proceedings.* 5, 19424–19430 (2018).
[16] G Avinash et al*, IOP Conf. Ser.: Mater. Sci. Eng.* 338 (2010).
[17]P.K. Rohatgi, D. Weiss, N. Gupta, JOM. 58,71–76(2006).
[18]D.K Rajak,L.A.Kumaraswamidhas,S.das, *Mater.Sci.Technol*. 32,1338-1345(2016).