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Effect of Age Hardening and Quenching Media on Aluminium Foams

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Abstract
The appearance of a new class of engineering materials, known as metal foams, has recently drawn in the past few years a great deal of attention not only of researchers but of the industry as well. This is of course due to their outstanding combination of mechanical and physical properties. Aluminium foams were synthesized by liquid metal foaming technique using TiH_2 as a foaming agent and Ca metal as thickening agent. The base metal chosen for foaming was Al 2014 aluminium alloy owing to its better strength and ability to be heat treated. Age hardening of the alloy foam has been conducted at a temperature of 177ºC with changing aging time values in order to determine the most optimum aging time and temperature values. The effect of age hardening on Al 2014 alloy foam is studied in the present work. The enhancement in plateau stress in age hardened foam specimens is compared with existing results and found that the results are comparable with the literature.

Keywords: Aluminium Foams, Aging, Age hardening, plateau stress

1. Introduction

Metal foams are an interesting class of light weight materials having unique combination of properties such as mechanical, thermal, electrical, and acoustic[1-3]. Metal foams are the metals intentionally fabricated with high degree of porosity. Metal foam is a three-dimensional array of cellular metal. They consist of air dispersed in a solid metal matrix, similar to the polymer foams. Metal foams feature an interconnected network of solid struts or plates that form the edges and walls or faces of the cells. These structures exhibit low weight and high strength. The multifunctional performance of metal foams makes them attractive for numerous uses, including lightweight structures, energy absorption devices, thermal insulation, acoustic insulation and vibration damping devices, convective heat flow, thermoelectric generator for automobile heat recovery, heat exchangers, etc. [4-6].

2. Experimental Set-up

Preparation of specimen

A special muffle furnace, with door at the top for adding TiH_2 and Ca metal and was designed for the melting of 1 kg of aluminium alloy. This furnace is equipped with easily removable motorized stirring attachment for stirring of molten metal and has a provision for digital temperature controller for measuring temperature up to 1000ºC. For the stirring of the melt after addition of calcium and $TiH_{2,}$ a graphite stirrer was used. Foam samples were made in this furnace by melting Al 2014 alloy and then adding Ca metal for viscosity enhancement and TiH_2 as foaming agent.

Heat treatment of Al 2014 alloy foam

A High Temperature Programmable furnace was used for precipitation hardening of AA2014 aluminium alloy foam. The maximum temperature of the furnace is 1450ºC and the load capacity is 5kW. The size of the muffle of the programmable furnace is 123 mm × 150 mm × 300 mm. An age hardening curve for bulk Al 2014 alloy was chosen depicting aging temperature of 177ºC and time of 10 hours [7].

Quasi-static compression test

The quasi-static compression tests of closed-cell aluminium foams were carried out on the universal testing machine Instron. This is an electromechanical test instrument and can test a wide range of materials in tension or compression. Foam samples of dimensions 20 mm X 20 mm X 25 mm were cut from the raw foam sample moulded in the crucible. The samples were of different relative densities mainly 0.12, 0.15 and 0.20. Then the heat treatment of foam samples was carried out followed by the quasi static compression test.

3. Experimental results

Effect of relative density

As foamed samples of aluminium foams of varying densities of 0.12, 0.15 and 0.20 were tested in quasi static compression tests and compressive behavior of them is shown in Fig. 1.

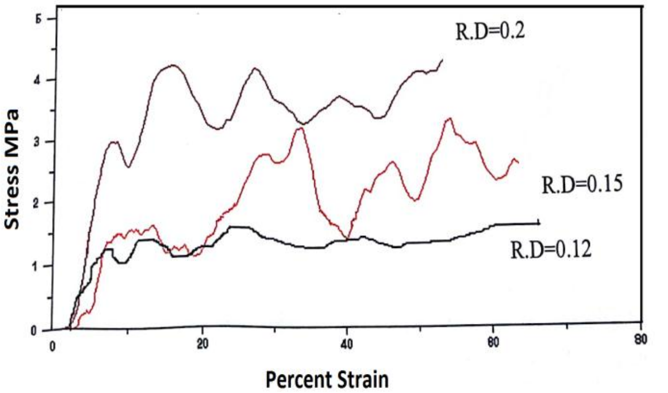

Fig.1. Compressive behavior of as foamed foam samples with different relative densities.

The compressive behaviors of different foams show a significant increase in plateau stress with increase in relative density. The 0.2 R.D. foam sample shows the highest value of plateau stress as expected. When compared with literature same behavior i.e. the compressive strength or plateau stress increases with increase in the density of the foam has been reported [8-10].

Effect of precipitation hardening on foam:

The stress-strain curves of heat treated and as foamed foam specimens of 0.2 relative density in quasi-static loading obtained are shown in Fig 2

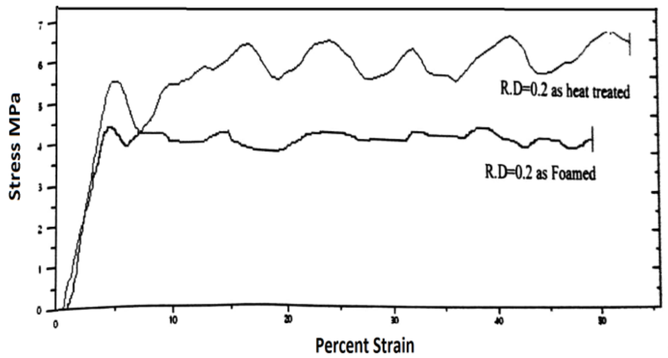

Fig.2. Compressive behavior of foam samples with 0.20 R.D. heat treated and as foamed.

The above graph shows compressive behavior of as foamed and heat treated foam samples with R.D=0.2. The compressive behaviour of heat treated foam with relative density 0.2 during quasi-static loading shows that the plateau stress decreases after attaining a maximum compressive stress. This decrease in stress shows a brittle failure. The result obtained in this work is compared with the results in literature. In quasi-static compression, the increase in plateau strength or compressive strength of present foam with relative density 0.2 is about 28%, whereas Banhart and Baumister (1998) reported an enhancement of compressive strength for AA2014 foam with relative density 0.22 produced by powder foaming Fraunhofer process as about 30% [11]. Feng et al. (2003) reported an enhancement in compressive strength for open-cell foam with relative density 0.13 as about 26% [12]. So, the obtained result is of the same order of magnitude as those published in literature.

Effect of quenching medium after solutionising:

This part of the work was motivated by discrepancy between the enhancement of strength observed in water-quenched samples of Khan (2010) [13] and Banhart et al air quenched samples. Whereas Banhart et al.(1998) [11]and Feng et al. (2003)[12] air quenched samples showed an increase in the range of 26-30 %, Khan's [13]water quenched samples showed an increase only of 18%. The alloys of two works were also different. The reason of the difference in the result is either due to alloying or difference in quenching medium. For analyzing the effect of quenching, different quenching medium on the same alloy were used. The results on air and water quenched samples are shown in Fig.3.

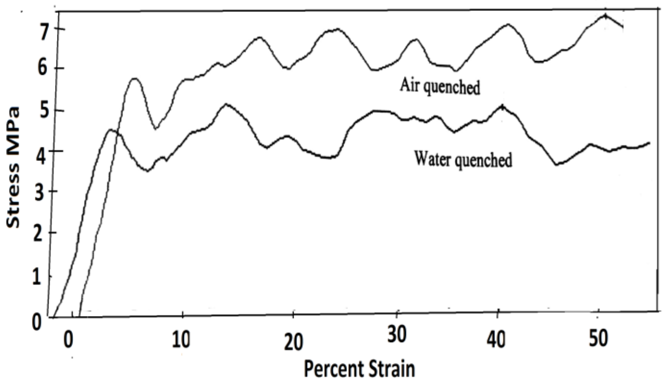

Fig.3. Compressive behavior of foam samples with R.D=0.2, solutionized at 505ºC for 1 hour followed by air or water-quenching.

The water-qu R.D=0.2 as Foamed /ery insignificant increase in str ned specimen, but there is a significant increase (28%) in air quenched specimens to as foamed specimens. So in this study both air-quenching and water quenching has been done for the same alloy and results shows that air-quenching is more effective than water quenching. Reasons for this are explained in literature [14-15], as follows:

- In water quenching process water may have induced high thermal stresses which in turn would have created cracks.
- Also, as the outer surface of a metal foam as well as the inner cell walls are not free of cracks from the beginning, water can enter the foam after quenching. Intruding and evaporating water could have unpredictable effects both on foam structure and on quenching rates.

So, the strength of air quenched foam specimens are found more than water quenched foam specimens.

Optimal aging time for foam and bulk material

The peak aging time for bulk alloy for a temperature of 505ºC is 10 hours [7]. To find out the peak aging time of aluminium foam, three different aging times of 5 hours (less than bulk alloy), 10 hours (same as bulk alloy) and 20 hours (more than bulk alloy) were selected.Our goal is to verify whether the foamed alloy also has the same or different peak aging time. We thus selected 5 hour (less than the bulk), 10 hour (same as the bulk) and 20 hour (more than the bulk) as three different aging temperatures of our foam. The results of compressive test on these samples aged at these three different specimens are shown in Fig.4-7.

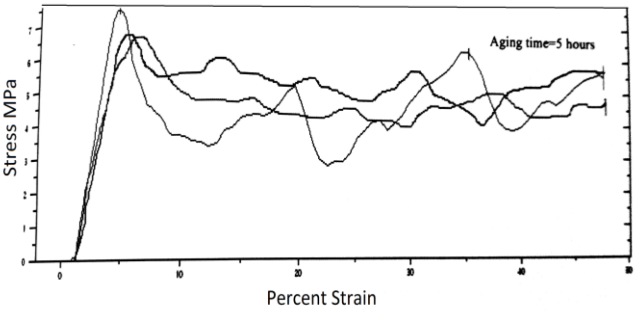

Fig.4. Compressive behavior of foam samples with 0.15 R.D. and aging time 5 hours.

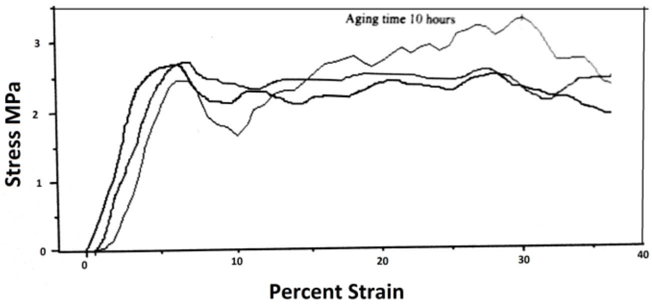

Fig.5. Compressive behavior of foam samples with 0.15 R.D and aging time 10 hours.

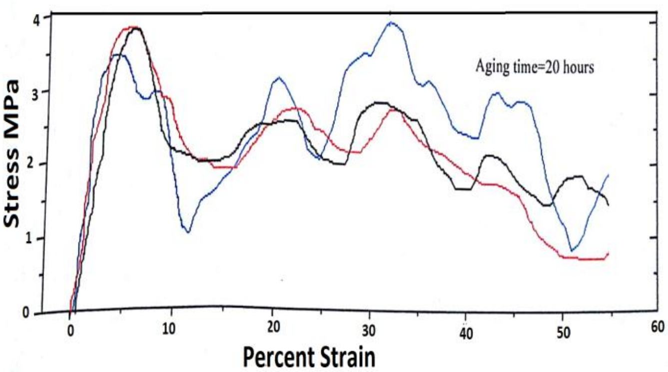

Fig.6. Compressive behavior of foam samples with 0.15 R.D and aging time 20 hours.

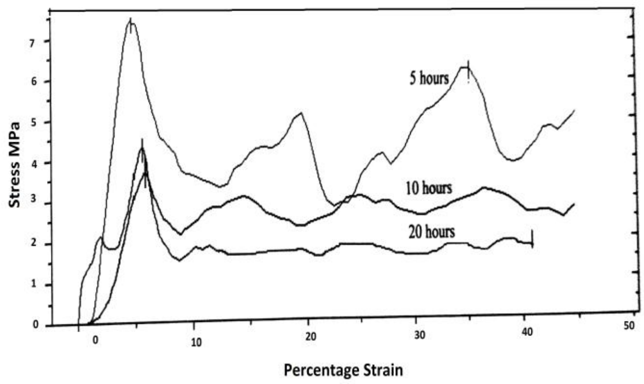

Fig.7. Compressive behavior of foam samples with R.D.=0.15 heat treated air quenched 5 hours, 10 hours and 20 hours.

The strength of the foam specimens aged for 5 hour is found out greater than those of specimens aged at 10 and 20 hours. This is a clear indication that peak aging time for foams is less than that of bulk alloy. The reasons for peak aging time for foam is less than that of bulk could be due to enhanced precipitation kinetics leading to heterogeneous nucleation of precipitates on the free surface of the foam. Since foam has much larger free surface than the bulk and this may explain the faster nucleation kinetics in foam.

4. Conclusion

i) Compressive behavior of as foamed and heat treated foamed specimens show increase in plateau strength as the relative density increases.
ii) The heat treated foam specimens with relative density 0.20, solutionized at 505^{0}C for one hour quenched in water and air and show an increase of 28% in plateau strength with air quenching. Results also show that the air quenched is more effective than water quenching.
iii) Aging time of heat treatment of foamed specimens were carried out and results showed that peak aging time of foamed material is less than that of bulk aluminium alloy, i.e. 5 hours in comparison to 10 hours for bulk aluminium alloy.

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