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The effect of thermal processing parameters on the mechanical properties of aluminium alloy foam

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ABSTRACT

Purpose: The purpose of this study was to investigate the influence of three thermal processing parameter called stress relieving on mechanical properties of the aluminium alloy foam.

Design/methodology/approach: The samples were undergone by stress relieving method using vacuum furnace. Hardness measurement was carried out using microhardness Vickers at 150 mN load and 15 s loading time. Compressive strength, plateau stress and energy absorption were calculated using a universal testing machine.

Findings: It was found that the highest value of hardness of 192.78 Hv was obtained when the stress relieving process is set with the following parameters: heating (500°C); holding time (120 min) and stabilization temperature (450°C). Since higher heating temperature and longer holding time produce sample with larger grain size and has an adverse effect on the hardness value It was revealed that the mechanical properties of aluminium alloy foam were enhanced when the heating temperature was decreased, holding temperature was diminished and the stabilization temperature was increased. Overall, the presented results showed that the thermal processing parameters such as heating temperature, holding time and stabilization temperature have a significant influence on improving the mechanical properties of aluminium alloy foam.

Research limitations/implications: The properties of closed-cell aluminium alloy foam are highly sensitive and depend on the post heat treatment process. The processing parameters should be controlled in order to manipulate the properties of closed-cell aluminium alloy foam.

Originality/value: To investigate the influences of these processing parameters on the physical and mechanical properties of the closed-cell aluminium alloy foam.

Keywords: Thermal processing parameters, Heat treatment, Aluminium alloy foam, Mechanical properties

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PROPERTIES

1. Introduction

Aluminium foam is a structural material that comprises hollow or porous particles trapped in a metal matrix [1]. According to the structure, aluminium foam divided into two groups namely open and closed cell new [2]. The application of aluminium foam is developing rapidly in few last decades, it due to a unique combination of properties such as light weight, high energy absorption capability and high specific stiffness [3,4]. Recently, the aluminium foam is utilized in the field of automotive, railway, aerospace, and chemical application where lightweight materials and improvement in comfort and safety are required [5].

Their structures have a strength to withstand an enormous plastic deformation when stress is applied. Therefore, modifying the mechanical properties of aluminium foam is needed. Several heat treatment process to altering the mechanical properties of foam have done by previous study. Jeenager et al. [6] study about the effect of aging treatment in the aluminium foam and resulting in energy absorption is improved during aging treatment. In the Lehmus and Banhart [7] study, the heat treatment showed that the hardness and compressive strength of closed-cell aluminium foam was higher than untreated. The absorption energy per unit of the aging treatment was 34%-64% higher than the as-received foam [8]. In result done by Campana and Pilone [9], the elastic limit, plateau stress and energy absorption is increased during aging treatment on both 7075 and 6061 closed-cell aluminium alloy foam.

However, the properties of closed-cell aluminium alloy foam are highly sensitive and depend on the post heat treatment process. To overcome this issue, processing parameters such as heating temperature, holding time and stabilization temperature should be controlled in order to manipulate the properties of closed-cell aluminium alloy foam. Therefore, it was vital to evaluate the influences of these processing parameters on the physical and mechanical properties of the closed-cell aluminium alloy foam.

2. Methodology

2.1. Materials

The commercial closed cell aluminium alloy with the trade name ALPORAS (shinko wire co.) used in this experiment. Aluminium foam was produced by foaming the melt with blowing agent. The process was started with the addition of 1.5wt.% Ca into the molten aluminium in order to increase its viscosity. Titanium hydride (TiH_2) of 1.6wt.% was also added to the molten aluminium as the blowing agent [10].

2.2. Experimental procedure

Stress relieving method was applied in this experiment. The experiment was carried out using vacuum furnace with 150 mTor and heating rate of 10°C/min. The heating temperature, holding time and stabilization temperature was set up based on the design matrix. The design matrix of the influence of heating temperature, holding time, and stabilization temperature was tabullated in Table 1, Table 2 and Table 3, respectively. Afterward, the specimen was held for 30 minutes followed by heating it until stress relieving temperature was achieved. Subsequently, the specimen was held at this temperature according to the design matrix and finally was subjected to furnace cooling. The schematic diagram of stress relieving method is illustrated in Figure 1.

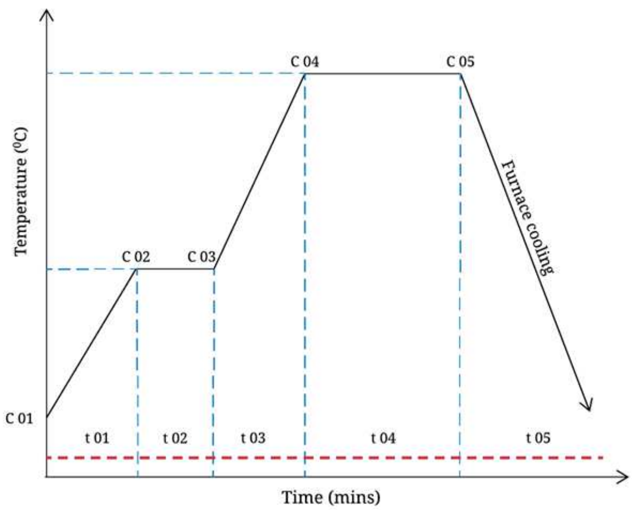

Fig. 1. Temperature profile for stress relieving method

2.3. Hardness properties

The specimen was cut using an abrasive cutting machine with dimensions of 10 mm x 10 mm x 5 mm. The closed-cell aluminium foam was mounted with epoxy resin by using the hot compaction press machine then grinded by using the disk platen grinding machine. After the grinding process, it was followed by polishing the mounted specimen. A 6-micron diamond abrasives solution was used for the polishing process. Microhardness tester LM24AT was used to determine the hardness properties according to ASTM E 92 with load and loading time were 150 mN and 15 s, respectively.

Table 1.
The influence of heating temperature on the mechanical properties of aluminium foam

Run	Heating Temperature, °C	Holding Time, min	Stabilization Temperature, °C	Hardness, HV	Compressive strength, N/mm^2	Plateau Stress, N/mm^2	Energy absorption, N/mm^2
1	460	60	450	222.00	3.43	2.85	128.63
2	480	60	450	203.90	3.15	2.59	120.91
3	500	60	450	188.20	2.90	2.37	114.34
4	520	60	450	174.89	2.69	2.18	108.91
5	540	60	450	163.98	2.51	2.04	104.64
6	560	60	450	155.47	2.37	1.93	101.52
7	580	60	450	149.35	2.26	1.87	99.55
8	600	60	450	145.63	2.19	1.84	98.72
9	620	60	450	144.31	2.15	1.85	99.05
10	640	60	450	145.39	2.14	1.91	100.53

Table 2.
The influence of holding time on the mechanical properties aluminium foam

Run	Heating Temperature, °C	Holding Time, min	Stabilization Temperature, °C	Hardness, HV	Compressive strength, N/mm^2	Plateau Stress, N/mm^2	Energy absorption, N/mm^2
1	500	20	450	227.41	3.52	2.78	130.99
2	500	40	450	206.39	3.19	2.55	122.10
3	500	60	450	188.20	2.90	2.37	114.34
4	500	80	450	172.82	2.65	2.22	107.71
5	500	100	450	160.26	2.43	2.12	102.23
6	500	120	450	150.53	2.24	2.05	97.89
7	500	160	450	143.61	2.09	2.03	94.68
8	500	180	450	139.51	1.98	2.04	92.61
9	500	200	450	138.22	1.90	2.10	91.69
10	500	220	450	139.76	1.85	2.19	91.90

Table 3.
The influence of stabilization temperature on the mechanical properties of aluminium foam

Run	Heating Temperature, °C	Holding Time, min	Stabilization Temperature, °C	Hardness, HV	Compressive strength, N/mm^2	Plateau Stress, N/mm^2	Energy absorption, N/mm^2
1	500	60	345	155.88	0.98	2.15	63.20
2	500	60	360	154.38	1.40	2.05	74.71
3	500	60	375	154.91	1.77	1.99	84.83
4	500	60	390	157.49	2.10	1.98	93.54
5	500	60	405	162.11	2.37	2.01	100.84
6	500	60	420	168.76	2.60	2.09	106.75
7	500	60	435	177.46	2.78	2.20	111.24
8	500	60	450	188.20	2.90	2.37	114.34
9	500	60	465	200.97	2.98	2.58	116.02
10	500	60	480	215.79	3.02	2.83	116.31

In this test, the force was applied smoothly. Subsequent, the force was removed and both diagonals were calculated in which the average was used to calculate the HV according to equation (1) [11].

$$HV = \frac{2000P\,sin\left(\frac{\alpha}{2}\right)}{d^2} = \frac{1.854\,P}{d^2} \quad (1)$$

where P is denoted as the applied load in gf, d is the mean diagonal in μm and α is the face angel of 136°.

2.4. Compression testing

According to ASTM: D 1621-00 standard test method, universal testing machine with max load 5 KN was used to calculate the compression properties of aluminium alloy foam, it present in Figure 2. The test was carried out by using a crosshead speed of 1 mm s^{-1}. The first peak stress on the stress-strain graph was calculated as compressive strength (σ_y) [12]. Whereas, the plateau stress (σ_{pl}) was calculated by quantifying the average stress value between 5% and 30% compressive strain [13]. Later on, area under the stress-strain curve up to densification was defined as energy absorption (W) and was calculated using equation (2) [14].

$$W = \int_0^{\varepsilon_d} \sigma(\varepsilon)d\varepsilon \quad (2)$$

where ε_d is the densification strain that was examined by intersection of plateau stress and the densification loading [15].

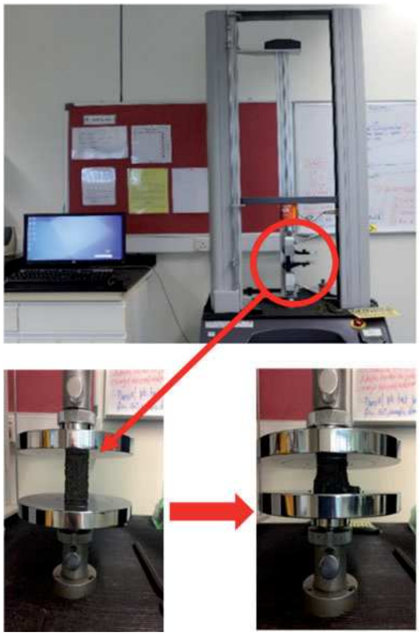

Fig. 2. Mechanism of compressive testing

3. Results and discussion

The effect of three factors: heating temperature, holding time and stabilization temperature were studied. It was found that all chosen factors have a significant influence on the mechanical and physical properties of closed-cell aluminium alloy foam in which the details are explained in the next section.

3.1. The effect of heating temperature

The heating temperature showed a significant influence on the mechanical properties of closed-cell aluminium alloy foam and can be seen graphically in the Figure 3. In view of the result obtained, the decreased in mechanical properties for aluminium alloy foam can be attributed to the enhancement of heating temperature due to recovery, recrystallization and grain growth process [16].

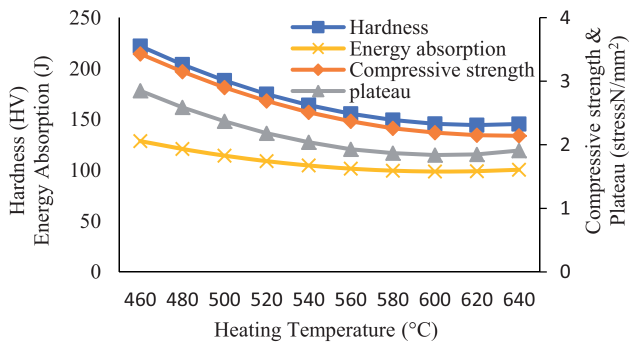

Fig. 3. The effect of heating temperature on the mechanical properties of aluminium alloy foam

During stress relieving process, the closed-cell aluminium alloy foam went through the recovery process to enhance the mechanical properties, resulting in the increased of an atomic diffusion at the higher temperature. If the heating temperature was enhanced during the stress relieving process, the grain boundary will develop into a new grain, followed by the establishment of the nuclei and then develop to become larger nuclei [17]. This process is known as grain growth. Therefore, lower temperature of stress relieving process was required to improve the microstructure of the material. The results obtained also comparable with the previous work carried out by Jones and Humphreys [17], whereby the precipitation growth becomes larger when the heating temperature was enhanced. As ascertained by Callister and Rethwisch [16], the mechanical properties of the metal become softer and weaker when the heating temperature during the treatment was raised.

3.2. The effect of holding time

The effect of holding time on the mechanical properties of closed-cell aluminium alloy foam can be seen in Figure 4. To examine the effect of holding temperature parameter on the mechanical properties of closed-cell aluminium alloy, the other parameters such as heating time and stabilization temperature were set at a constant value. Generally, the mechanical properties of closed-cell aluminium alloy are increasing with the reduction of the holding temperature. This was due to the recovery and recrystallization process which depended on time and temperature during the heat treatment process. Puspitasari et al. [18] explain that the poor microstructure was formed when both holding time and temperature were enhanced and the grain becomes larger. This is in agreement with the work reported by Olorunniwo et al. [19], in which the increase in holding time would generate a reduction in the number of grains.

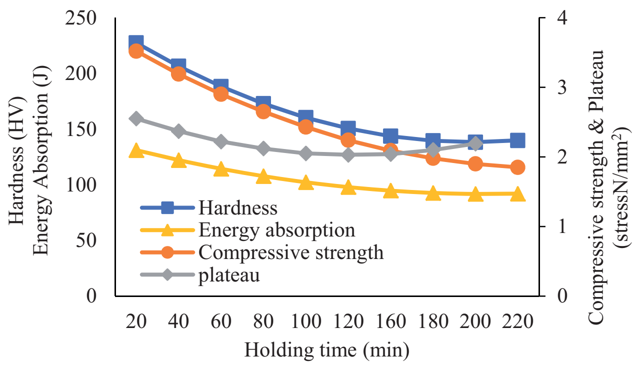

Fig. 4. The effect of holding time on the mechanical properties of aluminium alloy foam

3.3. The effect of stabilization temperature on the mechanical properties

The influence of stabilization temperature on the mechanical properties of closed-cell aluminium alloy shows in Figure 5 and the significant influence presented in Table 3. The mechanical properties result comprised hardness properties, compressive strength, plateau stress and energy absorption. In order to study the influence of mechanical properties with stabilization temperature, the closed-cell aluminium alloy foam undergone the stress relieving process at a constant heating temperature and holding time. During the increasing of stabilization temperature, it can be observed that the hardness, compressive strength, plateau stress and energy absorption were raised 7%, 43%, 10%, and 18%, respectively. This finding was due to the vibrational atomic motion in the recovery process. At any instant of time, not all atoms vibrate at the same frequency and amplitude. This will affect the microstructure of the material as ascertained by Callister and Rethwisch [16]. Therefore, the stabilization temperature was applied to stabilize the microstructure from the subsequent softening process at higher temperatures.

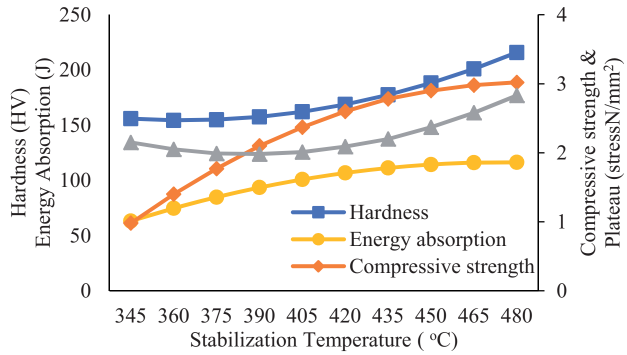

Fig. 5. The effect of stabilization temperature on the mechanical properties of aluminium alloy foam

4. Conclusions

Three stress relieving parameters such as heating temperature, holding time and stabilization temperature have an influential effect on the physical and mechanical properties of closed-cell aluminium alloy foam. For the effect of heating temperature on the mechanical properties of closed-cell aluminium alloy foam, the mechanical properties namely hardness, compressive strength, plateau stress and energy absorption were increased when the heating temperature was decreased. For the effect of holding time on mechanical properties, it was found that the mechanical properties diminished with the rising of the holding time. Afterward, the mechanical properties of closed-cell aluminium alloy foam were enhanced with the increase in the stabilization temperature.

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