

Microstructure and Mechanical Characterization of H-Al-Si Alloy Fabricated by Ultrasonic Vibration Assisted Stirring and Squeeze Casting - T6 Ageing

Meghavath Peeru Naik^{1,2*} and Korabu Tulasi Balaram Padal¹

¹Department of Mechanical Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India

²Department of Mechanical Engineering, SRIT (Autonomous), Anantapur, Andhra Pradesh, India

*Correspondence to:

Meghavath Peeru Naik
Department of Mechanical Engineering,
Andhra University, Visakhapatnam,
Andhra Pradesh, India.

Department of Mechanical Engineering,
SRIT (Autonomous), Anantapur,
Andhra Pradesh, India.

E-mail: naik.peeru@mail.com

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Abstract

The present research article presents the novel fabrication route of Al-Si₂₂₋₂₄Cu_{3.8}Mg_{0.8} (H-AlSi₂₂₋₂₄), an alloy made of silicon and aluminum using ultrasonic vibration stirring and squeeze casting. Al-Si alloys were prepared by varying the wt.% of Si from 22, 23, and 24. The goal of the study is to investigate the effect of wt.% of Si and ageing (T6) on the microstructure and mechanical properties of the UVSS alloys. The results present that the increase in wt.% of Si under UVSS modifies the microstructure and refines the primary and eutectic Si in the alloy. Ultimate tensile strength and yield strength of alloys were raised with increase in wt.% of Si and ageing treatment.

Keywords

H-AlSi alloy, Stir casting, Squeeze casting, Hardness and tensile strength

Introduction

Hypereutectic (> 13 wt.%) aluminum-silicon (Al-Si) alloys is one of the interesting research areas in enhancing the properties of the alloys at elevated and ambient temperatures. Al-Si alloys possess superior properties such as low density, ease of castability, high wear and corrosion resistance, low outstanding mechanical qualities at high temperatures, good thermal conductivity, and low thermal expansion. Due to their low thermal expansion and strong wear resistance, hypereutectic Al-Si alloys are extremely effective in a variety of high-temperature applications, including those in autos [1-3] and aircraft. As a result of the brittleness and coarse size of the Si particles, hypereutectic Al-Si alloys have increased brittleness and inferior tensile strength at room temperature. By altering the size, weight percentage, and method of manufacturing of Si, Al-Si alloys can have different microstructures and mechanical properties. Researchers looked at how to improve mechanical qualities by altering the weight percentage of Si and inoculating modifiers [4-7] during conventional casting. The results showed that while strength was improved up to a point, it then started to degrade due to secondary phases and coarse Si particles. In order to refine the Si particles in the Al matrix and increase the alloy's strength, researchers also looked into novel approaches like *in-situ* synthesis [8], ultrasonic vibration [9, 10], powder metallurgy, squeeze casting [11-13], and rapid solidification techniques like spray deposition, planar flow casting, selective laser melting, and high pulse electron beam. They saw a superior improvement in the alloys tensile and yield strength. In addition, research is ongoing and advanced fabrication techniques are not appropriate for the creation of bulk scale alloys.

According to the literature, ultrasonic vibration assisted stir casting is a novel, practical, and affordable method for creating components of any shape and

size when compared to more sophisticated and conventional methods. Squeeze casting produces fine grains in the alloy and this motivates us to investigate the effect of wt.% of Si and the UVSS alloys on the mechanical asset of the alloys.

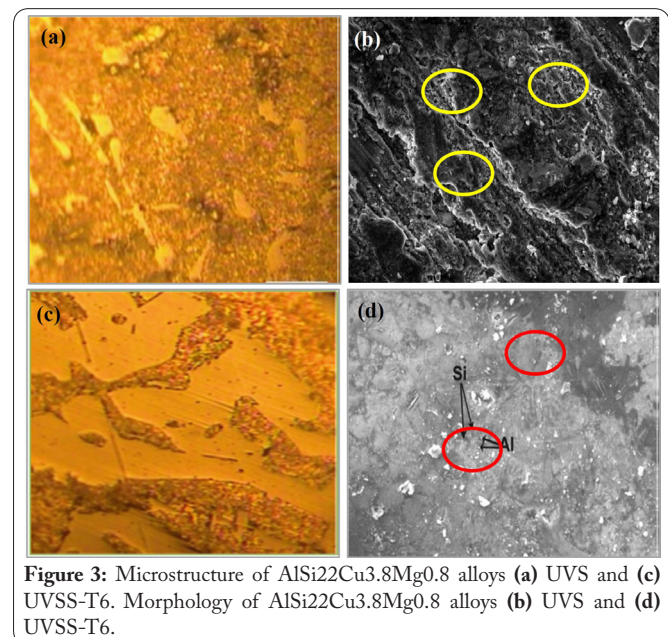
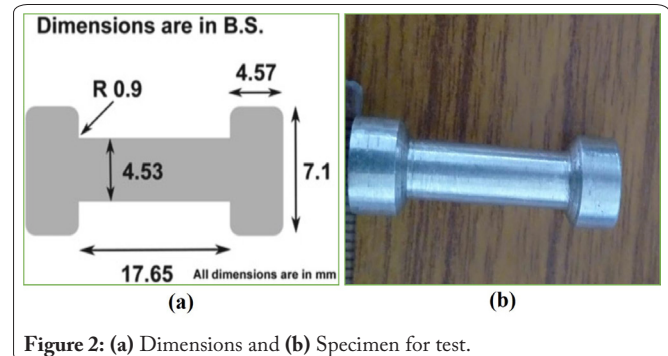
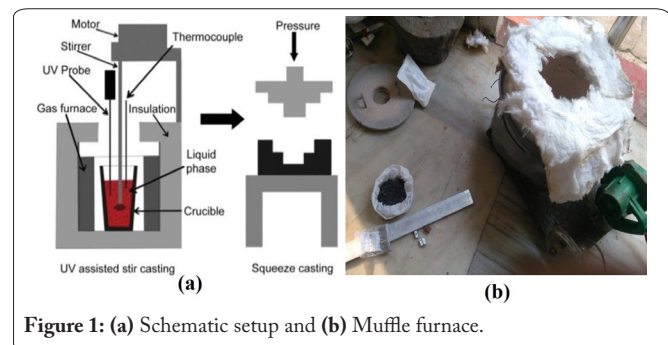
The present investigation was carried out to attain the following objectives. From the various researchers, the problem of the work has been identified the different casting techniques individually like stir casting, squeeze casting, rapid solidification technique, stir with ultrasonic vibration (UV), spray formed casting, etc., to characterize the chemical, mechanical behaviors, to identify the suitable application by casting the prepared composite, for the pre- and post-characterization of the surface, optical microscopy and scanning electron microscopy (SEM) microstructure examinations of the Al-Si24 alloy were used, and tensometers are used to gauge an alloy's tensile strength.

Materials and Method

T-6 conditions were used to create a hyper eutectic AlSi22-24Cu3.8-4Mg0.6-0.8 composite utilising a UV aided stir-squeeze manufacturing technique (UVSS-T6). On the other hand, the AlSi(22-24) composite, which had been stir cast with UV treatment, was primarily treated by a squeeze casting technique. The larger parts of the design (Figure 1) are a furnace with stir casting and squeeze casting setups, a titanium alloy horn and an ultrasonic vibration generator are included. The maximum power output for this UV test was 2.8 kW at a frequency of 20 kHz. A crucible is used to melt the aluminium and copper plates. As soon as the composite was melted, it was solidified down to 700 degrees Fahrenheit for stirring. For 15 min, the 300 rpm mechanically stirred composite was filled with preheated Si and Mg powders. For 20 min, the composite was heated to 1200 °C and grabbed. Ultrasonic shaking was then applied for roughly 5 min to the liquid composite to distribute the Si powder. A 200 °C heated die was used to transfer the melted composite after the UV-assisted stir casting process was finished. The AlSi composite billets were formed by pressing the composite at a pressure of 150 MPa. Hardening is carried out using the T-6 technique, and the AlSi(22-24) composite retains its properties throughout the process. This procedure begins by heating the billets in water (> 50 °C) for quick quenching; the billets are then put in water (not more than 165 °C) for an artificial-aging process, which comprises heating billets for four hours before cooling them at room temperature. 10 mm thick plates should be cut into, the AlSi composite billets are examined for their microstructure and physical essential qualities. The AlSi composite specimens polished using SiC sheets of 900 grit size, followed by 1 m paste of diamond. Benzene was used to clean the specimens after machining and polishing, in order to remove any residue. Figure 2a and 2b depict the size of the test object used for this testing. SEM and microstructural study were used to determine the composition and microstructures of the H-AlSi composites (Figure 3, figure 4, and figure 5). Physical properties of AlSi composites may be evaluated using the Brinell (250 kgf, ball diameter of 5 mm) and the tensometer (20 N) analytical techniques.

The mechanical and microstructural characteristics of

Al-Si(22-24) alloys have also been studied in order to know effects of UVS and UVSS casting process. EDX (Energy dispersive X-ray spectroscopy) testing onto samples that were cut into 40 x 40 x 10 mm pieces revealed the alloy structure of H-AlSi metal billets (40 x 40 x 100 mm). Additionally, the S-3700N SEM and the advanced metallurgical microscope (AMM) VFM-9100 Metzger Metavision were used to evaluate the Si-particle dispersion (SEM). The SEM and AMM samples were polished using Si-C sheets of sizes 800 and 1000 grit before being given a final polish (mirror finishing) with 1 m diamond paste. The samples then treated with acetone and benzene to end up any leftovers from cleaning and machining. All Al-Si samples were evaluated for hardness using Brinell hardness testing equipment. However, during the testing, a



ball with a diameter of 5 mm was applied with a stress of 250 kgf. A tensometer with a 20 N capacity was used to assess the tensile properties of H-AlSi alloys. Required load-displacement data were collected using tensometer software, despite fact that the tensile tensometer tests performed at a speed of 0.5 mm/min.

Results and Discussion

Microstructure

Microstructural studies were carried out using “optical and scanning electron microscope” to study the microstructure and morphology of the prepared alloys. The microstructure and morphology of the UVSS and UVSS-T6 alloys are shown in figure 3, figure 4, and figure 5. The findings show that the alloy contains primary Si and acicular eutectic silicon phases. According to figure 3, figure 4, and figure 5, the primary Si has a blocky morphology, whereas the eutectic Si displays a needle-shaped morphology. Additionally, it has been found that the fraction of primary and eutectic Si phases increases when Si weight percentage increases. The fine and homogenous distribution of eutectic Si in the UVSS alloys is depicted in the yellow-hued portions of figure 3a, 3b, 4a, 4b, 5a, and 5b. The homogeneous and fine distribution attributes to two mechanisms (i) primarily due to the pressure and heat applied during squeeze casting causes partial dissolution of the phases and re-precipitation and (ii) Ultrasonic vibration during casting. In contrast to the UVSS alloys, UVSS-T6 exhibits an increase in size and agglomeration of “eutectic Si in the alloys a shown in the red-coloured zones”. The agglomeration is due to the difference in coefficients of thermal expansions of Al and Si and also due to the heterogeneous nucleation sites.

Hardness

The rigidity of the prepared alloys was determined using ball with a diameter of 5 mm was applied with a stress of 250 kgf. The specimen is loaded at 6 different locations for each sample and the average value is considered for evaluation and comparison. The following equation 1 was used to determine the Brinell-hardness-number (BHN):

$$BHN = \frac{2P}{\pi D \left(D - \sqrt{D^2 - d^2} \right)}$$

Where, P = Applied load, D = Diameter of ball, and d = inner diameter.

The calculated hardness of the alloys is depicted in the figure 6 and it is observed that increase in wt.% of Si from 22 to 24 in UVSS alloys increases the hardness from 91.56 to 104.51 BHN attributes to the (i) “homogeneous distribution of fine eutectic Si” and (ii) the hard characteristic of silicon eutectic phase. It is also observed that UVSS-T6 alloys exhibits further improvement in hardness from 134.04 to 162.94 due to the fine precipitates in the matrix acts as hard substance for deformation.

Tensile strength

The mechanical properties such as yield strength and ultimate tensile strength of the UV assisted stir squeeze. At room

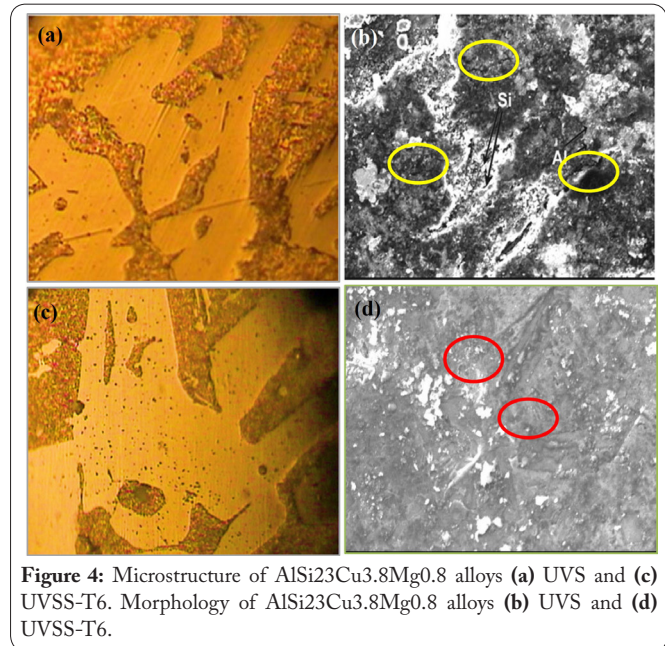


Figure 4: Microstructure of AlSi23Cu3.8Mg0.8 alloys (a) UVSS and (c) UVSS-T6. Morphology of AlSi23Cu3.8Mg0.8 alloys (b) UVSS and (d) UVSS-T6.

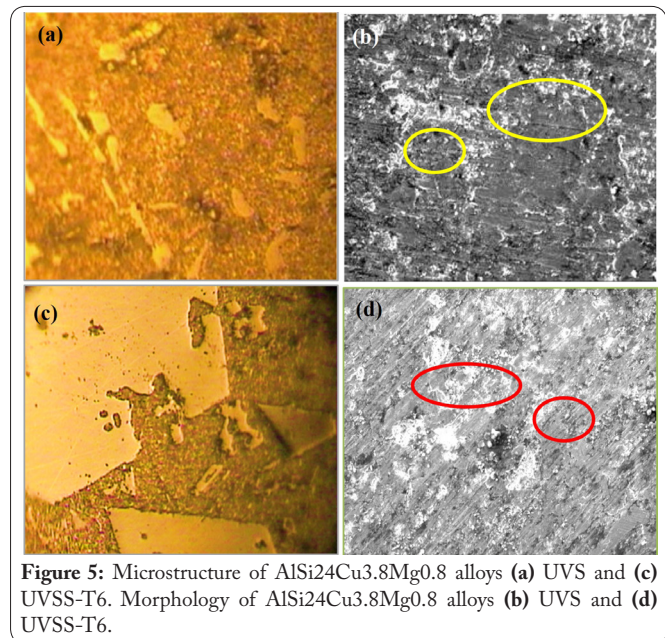


Figure 5: Microstructure of AlSi24Cu3.8Mg0.8 alloys (a) UVSS and (c) UVSS-T6. Morphology of AlSi24Cu3.8Mg0.8 alloys (b) UVSS and (d) UVSS-T6.

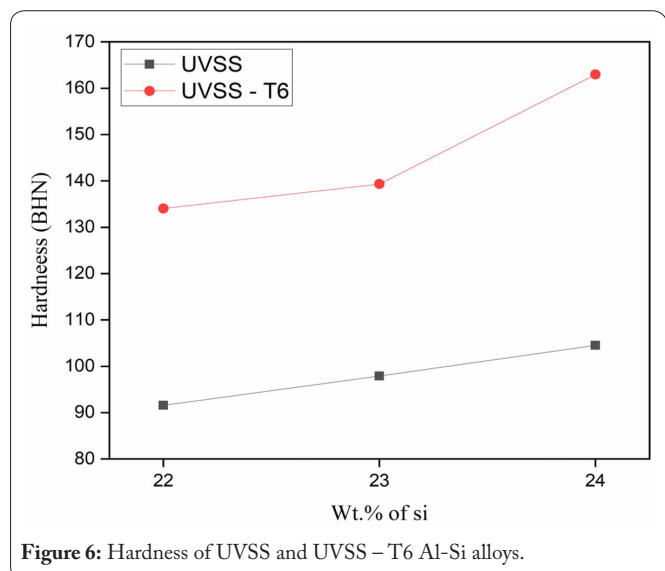


Figure 6: Hardness of UVSS and UVSS - T6 Al-Si alloys.

temperature, UVSS-T6 alloys were measured using servo-controlled universal testing equipment; the recorded results are shown in figure 7. The ultimate strength and yield strength of the alloys are seen to improve with an increase in the weight percentage of Si from 22 to 24 wt.% and aged (T6) alloys. The UTS, Y.S of the UVSS alloys are (169,142), (177,151) and (262, 234) MPa for 22, 23 and 24 wt.% of Si, respectively. The improvement in the strength attributes to the finely distributed acicular eutectic Si as an obstacle while deformation and requires more load, and also the refined grains of the alloys [14]. It is also noticed that the aged alloys i.e., UVSS-T6 exhibit higher ultimate tensile strength and yield strength as compared to the UVSS alloys. The ultimate tensile strength and yield strength of the alloys are (236,207), (281,242) and (387,369) MPa for 22, 23 and 24 wt.% of Si, respectively. The improved strength primarily attributes to the formation of fine precipitates and distribution of eutectic Si in the alloy acts as solid solution strengthening effect and obstructs the dislocation movement while deformation. Therefore, it is recommended that increase in wt.% of Si and the aged alloys can be used in the real time high strength applications.

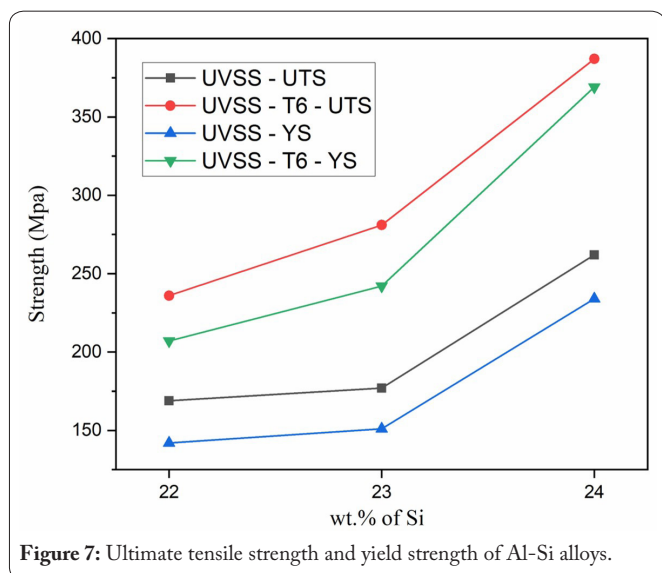


Figure 7: Ultimate tensile strength and yield strength of Al-Si alloys.

Conclusions

The following are the main findings from the inquiry after casting, experimentation, and result interpretation:

- A unique UVSS method was used to successfully create the hypereutectic Al-Si₂₄ alloy.
- Increase in wt.% of Si increases the fraction and homogeneous distribution of primary and eutectic Si.
- Increase in wt.% of Si increases the “hardness, yield strength” and ultimate tensile strength attributes to the solid solution strengthening effect.
- This demonstrates that UVSS-T6 casting process contributed to the improvement of mechanical characteristics in addition to the refining of microstructure.
- This work sheds new information on the interplay between H-AlSi alloys and self-properties enhancement of UVSS-T6 casting process, in industrial and automotive purposes.

Acknowledgements

None.

Conflict of Interest

The authors declare that there is no conflict of interest.

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