Analysis of tensile strength, microstructure, and fractograph of Al-Si with snail shell powder as reinforce agent

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Abstract. This research aimed to increase the mechanical property of Al-Si alloy by adding snail shell powder reinforcement using the stir casting method. This research used 1 minute, 2 minutes, and 3 minutes variations of stirring time. The snail shell powder percentage in this research was 0.05 wt% from the total 1.5 kg Al-Si alloy. The stir casting method was performed by melting the Al-Si in the furnace then was stirred at 500 rpm speed in 850°C temperature before sprinkled with snail shell powder. After the stir casting process, the Al-Si alloy was poured into permanent cylindric mould according to the tensile test specimen. The specimens then tested with the mechanical test to find the tensile strength and microstructure. The results showed increases of the mechanical property with the best result was found in the specimen with a stirring time of 3 minutes with the value of 21.04 kg/mm².

Keywords: stir casting, snail shell powder, aluminum alloy, tensile strength

1. Introduction
Aluminium alloy is usually known as a lightweight alloy and can be combined with various elements to increase the pure aluminium’s strength. Several elements that can be mixed into pure aluminium are magnesium, silicon, zinc, copper, nickel, and titanium (1). Additional element helps increase the tensile strength and hardness and decrease the melting point of pure aluminium. Silicone addition gives excellent results on aluminium’s tensile strength and hardness (2). Silicone not only increases the aluminium’s tensile strength but also improves aluminium’s casting characteristic with improvement in mechanical property and corrosion resistance. Additional
silicone also increases Al-Si alloy’s hardness. The result has an excellent surface with no heat ductility, very good for alloy castings, is lightweight, has a small expansion coefficient, and is a good conductor for electricity and heat (3–5).

In several parts of Indonesia, snail (*Achatin fulica*) is already used as the main ingredients of food supplement or local culinary such as satay or snacks. The majority of snail shell waste is discarded. Therefore, this research explored the utilisation of snail shell, not only to process the waste but also improve its value that could open new industry for the locals (6). The main element of the snail shell is calcium carbonate (CaCO$_3$) contains one of the two crystal shape: calcite and aragonite. The rests are an organic matrix of protein that is known as conchiolin for 5% that consists of three layers: hypostracum, ostracum, and periostracum (7). Snail shell waste is usually discarded because it has low value and often thought as pollution so that it rarely utilised as valued products. However, the snail shell particle has a high hardness; thus, it can be an excellent alloy to strengthen the aluminium (6).

Snail shell has 97–98% calcium carbonate (CaCO$_3$) (8). According (9) the XRD test showed 98–99% element of snail shell as CaCO$_3$. The SEM-EDS showed 98% of CaCO$_3$ in snail shell (10). Based on observation, the requirement of calcium carbonate continuously increases along with the industrial era since 1983, such as alloy material utilisation (11). The usage of alloy with other materials improve the strength, durability, toughness, and performance and causes researchers to experiment by combining several materials to generate new alloy notably that used aluminium silicon (Al-Si) (9).

Stir casting is a casting method by stirring the liquid metal using automatically stirring rod driven by a motor. Stir casting is used as a medium to mix liquid metal with strengthening material such as reinforcement powder. The first step in stir casting is melting the pure or alloy metal until it becomes liquid then stir regularly using a stirring rod until it forms a whirlpool. The rotation speed is around ±100–500 rpm for a couple of minutes (12,13). Then adds the reinforcement powder little by little into a ladle that functions as a container for the liquid. The advantages of stir casting can mix and distribute dry reinforcement due to the mechanic stirring force that causes the reinforcement material to be trapped inside the liquid metal (13).

Mechanical property improvement can be performed by controlling the additional material, alloy element, compaction level, heat treatment, etc. To improve the Al-Si mechanical property, the researcher controls the reinforcement material, casting process, temperature, etc. Reinforcement process not only occurred in technical subjects but also mechanical reaction between Al-Si and reinforcement. The chemical reaction occurred due to the distribution reinforcement in the Al-Si liquid (14). Mechanical property can be determined by controlling the alloy microstructure. Heat treatment defines the mechanical property and casting microstructure. Generally, heat treatment is conducted to obtain ductility combination and optimal strength from the snail shell Al-Si alloy (15). In this research, the matrix of Al-Si that was obtained from the used piston is strengthened by the particles from the snail shell powder, that was calcium carbonate (CaCO$_3$) using a stir casting process. This research also explored the mechanical properties and microstructure that were obtained experimentally.

2. Method
This experimental research consisted of various specimens with different stirring durations: 1 minute, 2 minutes, and 3 minutes. The Al-Si alloy added with snail shell powder has a percentage of 0.05 wt% was the first step of this research. Snail shells were prepped, cleaned, and dried naturally using the sunlight, then crushed using ball mill for 6 hours in 300 ml capacity. Then, the powder was sintered at 1000°C for 1 hour. The next step was preparing the casting material from a used piston. The used piston was put into the furnace for 3 hours until it melted and produced 1.5
kg of liquid aluminium silicone. Sprinkled the snail shell powder into the liquid aluminium silicon at 850°C and stirred following the variations using the stirring device (Bosch). Then, the mixture was put into a cylindric mould and cooled in the air for 24 hours. Next was turned the casting specimens using lathe device (Magnum Tech FEEL-1640 GCY) to obtain the ASTM A370-16 standardised specimen for the tensile test. After, the specimens were ready for mechanical test using Torsée’s universal testing machine (UTM) Tokyo Testing Machine MFG with a maximum load of 50 kN. The microstructure of Al-Si was observed using a metal microscope in 650 enlargements from Nikon camera while the macrostructure pictures were taken using the DSLR camera (Canon 1200D).

3. Result and Discussion
The tensile test was conducted to gain the mechanical property such as tensile strength by pinning the specimen in the tensile test machine then loaded until the specimen broke. The test was performed based on the ASTM A370-16 standard. Figure 1 shows the results chart.

![Figure 1. Al-Si tensile strength in various stirring time](image)

The tensile strength in Figure 1 displays a decrease in the sample with 2 minutes stirring time due to porosity that was caused by the trapped hydrogen from the high temperature (16). Meanwhile, the specimen with 3 minutes stirring time has an increase in its tensile strength due to homogeneously distributed reinforcement material (17). Microstructure observations were carried out using a microscope with a magnification of 996.5x and etching was done to clarify the surface structure of objects (18). Microphotographs of all variations are shown at Figure 2. Figure 2a shows an unevenly distributed particle with granular and small dendrite. Figure 2b displays particle distribution in which the particle is uniform with different sizes. Figure 2c presents quite evenly distributed particle with larger size compared to Figure 2a and size that tends to be uniform. Figure 2d shows a uniform and distributed particles and dendrite structure have the smallest particle compared to other variations with an evident intergranular fracture (3,14,19). Smoother, smaller, and evenly distributed granular means improvement in the tensile strength (18). The macro images were aimed to analyse the fracture results after tensile strength. This analysis aimed to observe that Al-Si alloy with snail shell powder reinforcement carefully. The macrostructure shows the particle size distribution in Al-Si specimen clearly.
Figure 2. Al-Si microstructure with snail shell powder (SSP) reinforcement (a) Al-Si with 2 minutes stirring time, (b) Al-Si + SSP with 1 minute stirring time, (c) Al-Si + SSP with 2 minutes stirring time, (d) Al-Si + SSP with 3 minutes stirring time

Figure 3a shows a brittle fracture, some parts able to reflect the light and has many smooth grains. Figure 3b has a brittle fracture, some parts able to reflect the light, and only some smooth grains. Figure 3c has brittle fracture as proved by its ability to reflect the light (shiny), can be reassembled and have a high porosity. Compared to the tensile strength, this specimen has a lower tensile strength than other variations. Figure 3d shows a brittle fracture that reflects light, has an uneven surface, has fine grains, and higher tensile strength compared to other variations.
Figure 3. Fracture morphology of Al-Si with snail shell powder reinforcement (a) Al-Si with 2 minutes stirring time, (b) Al-Si + SSP with 1 minute stirring time, (c) Al-Si + SSP with 2 minutes stirring time, (d) Al-Si + SSP with 3 minutes stirring time

4. Conclusion
The results of research on Al-Si alloys with snail shell powder with a percentage of 0.05 wt% using a variation of the stirring time of 1 minute, 2 minutes, and 3 minutes had the following conclusions. Among the three specimens, the results of Al-Si + SSP castings with a stirring time of 3 minutes had the highest tensile strength values of 21.04 kg/mm² compared to other specimens. These results were supported by macro images that show that metal grains that are owned are uniform, smaller and denser, and there is no visible porosity on the fracture surface. Microstructure photographs also showed that specimens with a stirring time of 3 minutes show smaller granules, clearly visible grain boundaries, grains were evenly distributed, and smaller dendritic structures. Also, the finer the granules were spread evenly. The smaller the granular shape, the better the mechanical tensile strength.

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6. References
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