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# Al-Si alloy for thermal storage applications-a review

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**Abstract-**
In regions that experience abundant sunshine, solar radiation emanating from the sun constantly generates significant thermal energy which has been an established potential source of harvestable clean energy. But an enormous amount of this form of renewable energy reaching the earth's crust gets re-emitted back into the space at sunset period without being harnessed. There is a special need for researches to further develop thermal storage alternatives with high thermal capacity, good thermal transfer rate, portable, cost effective and durable. From literature, aluminum and silicon alloys have proved to be one of the most efficient thermal storage materials for medium to high temperature storage applications. It has been shown that different combinations of these gives different results depending on the application the alloy is to be used for. This paper reviews the application of Al-Si alloys for thermal storage with superior properties to Al-Cu, Al-Mg, Al-Cu-Zn, Al-Si-Mg and Al-Si-Cu alloys. The making of Al-Si for thermal storage through liquid and solid metallurgical processes were also highlighted.

**Key words:** Al-Si alloy, thermal storage, sensible heat, thermal conductivity, casting

## 1. Thermal storage overview

Thermal energy is one of the components of solar radiation coming from the sun. A huge amount of this reaches the earth's crust every day and gets re-emitted back to space at night as waste energy. Industries are as well a huge source of thermal energy waste. For this reason, it is of high importance for researchers to come up with a thermal storage system with high thermal capacity, good thermal transfer rate, portable, cost effective and durable, [1]. There are three different modes of thermal storage and these are: sensible thermal storage, latent thermal storage and chemical thermal storage.

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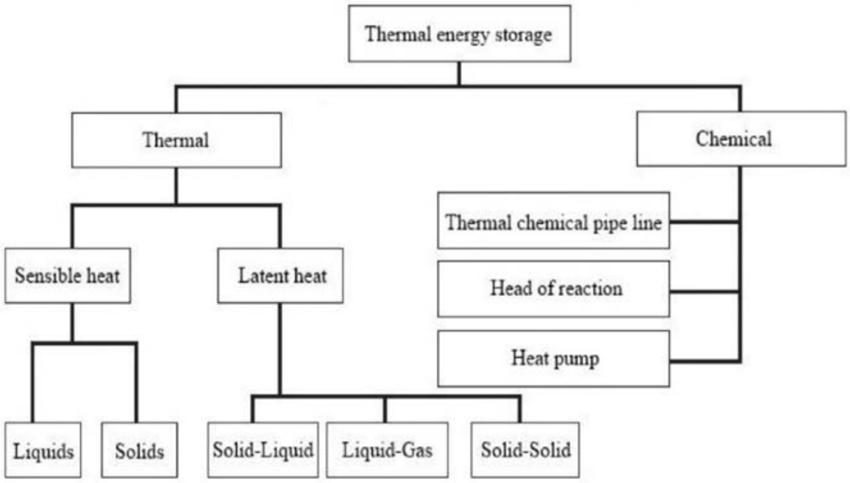


Figure 1**:** Modes of thermal energy storage [2]

In Figure 1, the details of the modes of thermal energy storage is shown. A sensible heat material stores or releases energy when its temperature rises or falls respectively. Sensible heat storage can occur at the solid, liquid and even gas phase.

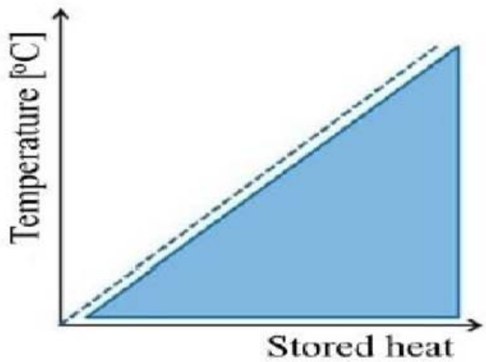


Figure 2**:** Method of thermal energy storage by sensible heat material showing relationship between temperature and heat stored [2]

## 2. Sensible and latent heat storage

Figure 2 graphically depicts the behavior of a sensible heat storage material. Their specific heat is relatively low but they have relatively good thermal conductivities. They are generally low-cost materials. It is relatively cheaper to get a large amount of these materials but the drawback is that a larger volume or mass of these materials are needed to store the same amount of thermal energy compared to material in the other categories thus bringing the issue of portability into light [3]. Commonly used sensible heat materials are concrete, cast iron, cast steel and sand-rock minerals.

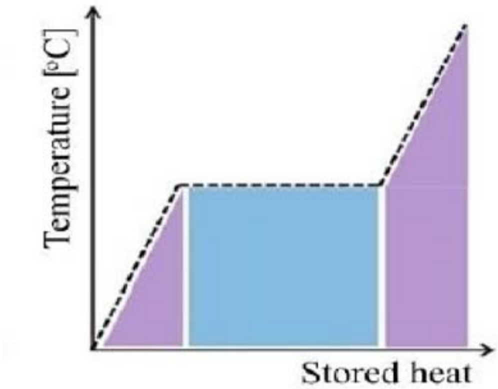


Figure 3**:** Method of thermal energy storage by latent heat storage materials [2]

## 3. Metal alloys as thermal heat storage

Over a few decades now, researchers have employed various means and types of materials for both sensible and latent heat storage. At the early stages of thermal storage, the sensible thermal storage method was the main area of focus. As time went on, researchers discovered the advantages of latent heat storage and this led to the further exploration of this type of storage. Of all the different type of materials and composites used for thermal storage, metal alloys proved to be the best in terms of their advantages [4]–[7]. These advantages are: small volume change during phase change, low density variation, negligible amount of sub-cooling, no phase segregation, low vapour pressure, chemical stability and compatibility with containers. Metallic alloys in general have a large latent and specific heat, a high thermal conductivity and good thermal stability. With all these properties, a key ingredient that should be considered is cost and weight since they are metal alloys [8]. Reference [8] from the metallurgical angle assessed the drawbacks of employing metal alloys for thermal storage as phase change materials. They investigated the effect of heat treatment of these alloys on their microstructures and how it affects their overall thermal properties. Some of the drawbacks they identified are as follows: for pure metals, some have high vapour pressure and undercooling with homogeneous or heterogeneous nucleation whereas in alloys, the heat transfer fluid to be used must have the property that will enable it work with the high heat transfer coefficient of the metal alloy. Another issue is the difference in thermal expansion coefficient of the alloy versus that of the container. There is need for further research on the effect of thermal cycling on the microstructures of the alloy, expansion to encapsulate metal alloys and the possible reaction between the metal alloy and the container. Reference [9] investigated different atomic rations of Si, Al, Fe and Ni as possible phase change materials for thermal storage. They found that an increase in the silicon (Si) content increased the latent heat of the Al-Si alloy. Thermal diffusivity decreased with increase in temperature. It also decreased with the increase of Si.

Ten (10) alloys were fabricated by [10] by utilizing compositions of Al-Si, Al-Cu, Al-Mg and Al-Cu-Zn alloys. The melting point of an alloy was reduced by adding Cu, Zn and Si and on the other hand, the latent heat was enhanced by adding Cu and Zn. They concluded that thermal treatment may have had a major role in determining the thermal properties of an alloy. Reference [11] examined the effect of adding Cu to Al and the resultant latent heat energy storage capacity. Cu in the range of 7.3-52.8% in Al-Si alloys were reported to be advantageous for thermal energy storage application. Reference [12] worked on the storage/discharge behavior of three Al-Si alloy samples in vacuum. After twenty (20) thermal cycles, the sample containing Al-25wt%Si escaped oxidation. The Al-25wt%Si sample was also noted to be the most stable of the three samples. Reference [13] worked on the performance of cast aluminum alloy for thermal storage. They worked on the solid and liquid phase of Al-Si, Al-Si-Mg and Al-Si-Cu. They found that the Al-Si alloy was the most suitable for thermal storage applications. They also discovered that an increase in the silicon content of the Al-Si increased the latent heat of the alloy but reduced the specific heat. The increase in latent heat with the increase in the silicon content was as well confirmed by Reference [9]. Reference [13] concluded that the grain size of the alloy determines to a large extent the latent heat of the alloy. They in agreement with [8] also pointed out that thermal treatment affects the grain size which in turn affects the latent heat of the alloy.

A high temperature heater was built by Reference [14]. They characterized two samples of different compositions of Al-Si alloy. One of the alloys (12%wtAl) with superior thermal properties was chosen to be the phase change material for the device. The 12%wtAl alloy had the following physical properties: solid state specific heat of 1.038 kJ/kg K, liquid state specific heat of 1.741 kJ/kg K, melting temperature of 576 ºC, latent heat of 560 kJ/kg, density of 2700 kg/m$^3$ and thermal conductivity of 160 W/m ºC. On the other hand, the other sample (20%wtAl) had a melting point of 585 ºC and latent heat of 460 kJ/kg. Reference [15] carried out a test of performance of Al-12%Si in a thermal storage device. A mathematical model for the thermal system was then built and compared to the data gotten from the device. There was a good correlation between the model and the experimental data. According to them, further tuning of the model and improved material testing procedures would improve the correlation. 1200 thermal cycles were made on Al-17wt%Si by [16] in order to test its thermal stability as a phase change material. They observed a 4.1% reduction in latent heat of the alloy at the end of the cycles. However, the melting temperature increased from 576.2 ºC at 0 thermal cycles to 577.9 ºC after 1200 thermal cycles. Reference [9] experimentally observed the change in thermal properties of five different compositions of Al-Si alloys after 1000 thermal cycles. From their results, they observed no significant change in the thermal properties of all the samples. The excellent thermal properties of Al-Si alloys also make them suitable for electronic packaging and heat dissipating materials [17] though Al-SiC could also be used for the same purpose [18].

## 4. Synthesis of Al-Si Alloys

While application of Al-Si alloys for thermal application cannot be over flogged, making the alloy should not be trivialized. Both liquid and solid metallurgical routes have been used by researchers to produce Al-Si alloys. Al-Si alloy phase diagram is shown in Figure 4, while Figures 5, 6 and 7 shows microstructure for hypoeutectic alloy (<12.6 wt% Si), eutectic alloy (12.6 wt% Si) and hypereutectic alloy (>12.6 wt% Si) respectively. The phase diagram and microstructures were as reported by [19].

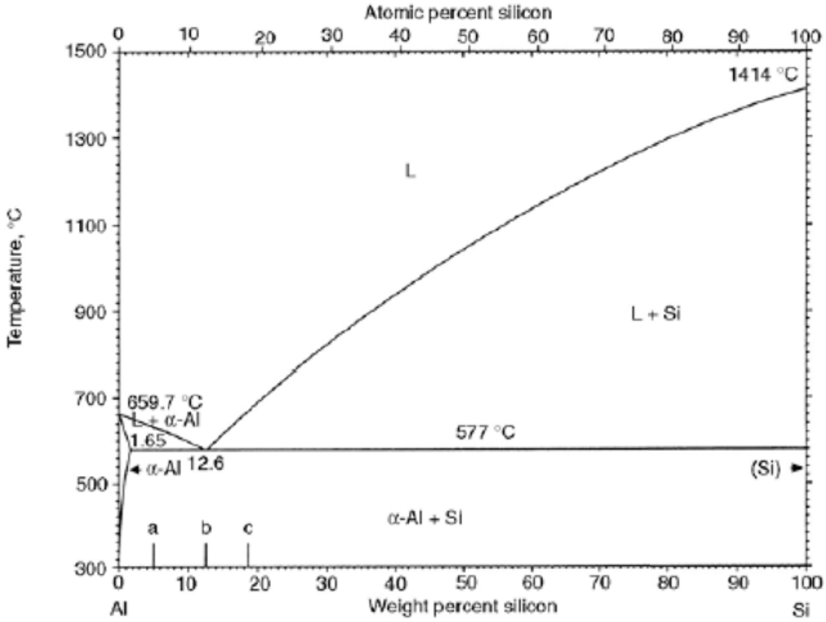


Figure 4**:** Al-Si phase diagram showing the different melting temperature ranges based on different percentage weight of silicon [19]

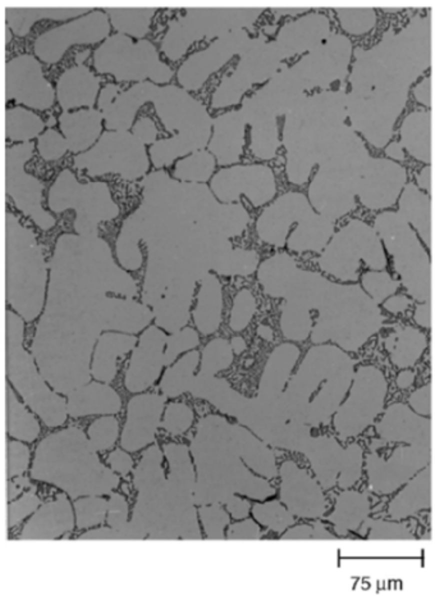


Figure 5**:** Microstructure for Al-Si hypoeutectic alloy (<12.6 wt% Si) [19]

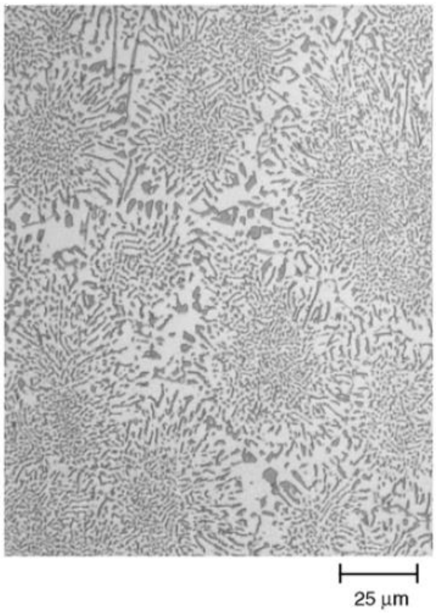


Figure 6: Microstructure for Al-Si eutectic alloy (12.6 wt% Si) [19]

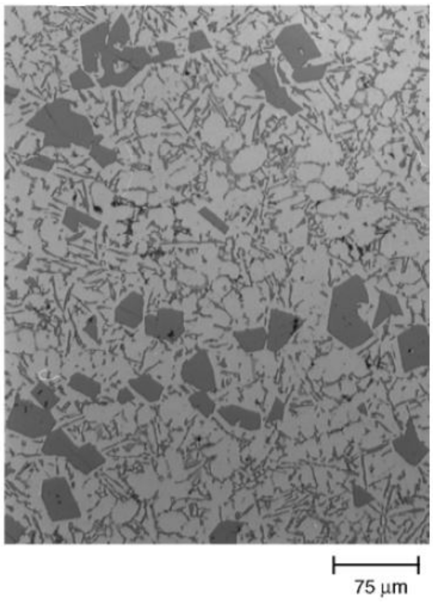


Figure 7: Microstructure for Al-Si hypereutectic alloy (>12.6 wt% Si) [19]

Reference [17] reported the use of spray deposition, powder metallurgy, semi-solid thixoforming, and suspension casting. Reference [18] and Reference [21] produced Al-Si alloy with the used of electrical resistance furnace having graphite crucible. Reference [22] reported oil-fired tilting furnace with graphite crucible to produce metal alloys and composites of aluminium, iron, gold, lead, magnesium, copper and tin. The set up used by Reference [20] is shown in Figure 8. Reference [23] used liquid metallurgy to make Al-Si alloy which were high-pressure die cast to produce specimens for various tests. This [23] conventional method of melting Al-Si alloy in crucible was also used by [24]. However, complex shear flow casting (CSFC) treatment apparatus (Figure 9) was used on the melt until final solidification level. Liquid metallurgical route was also used by [25]. Reference [26] on their part used solid metallurgy route. Atomised Al was mixed with monocrystalline silicon and compacted to produce Al-Si alloy. Also, [27] used mechanical alloying (MA) method to produced Al-Si alloy from pure Al and Si powder with the use of planetary ball mill for between 2h to 50h at ambient temperature.

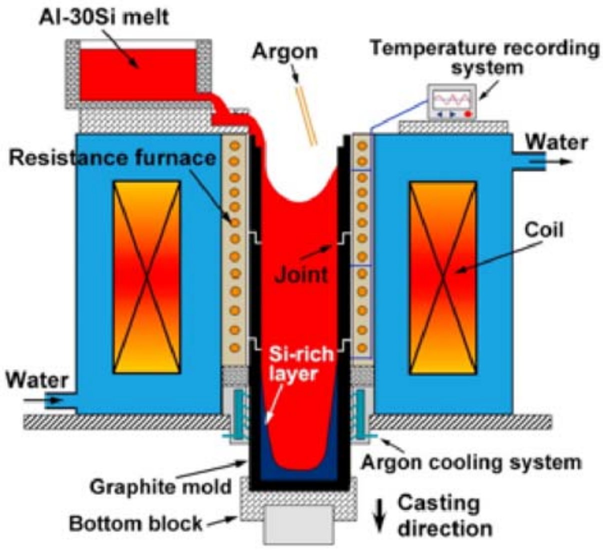


Figure 8: Typical liquid metallurgical route of producing Al-Si [20]

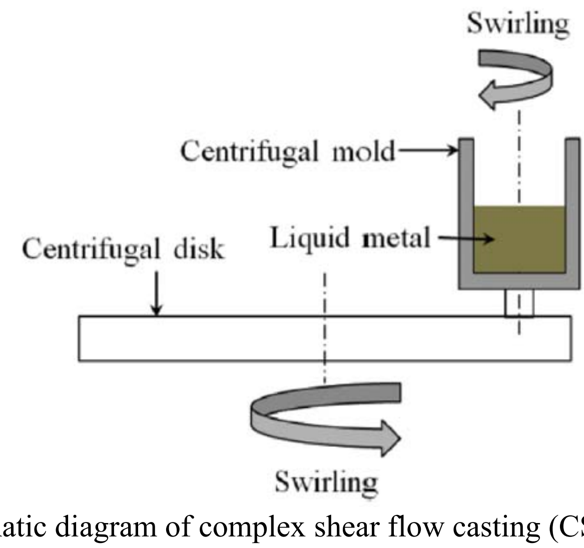


Figure 9: Schematic diagram of complex shear flow casting (CSFC) system [24]

Today, liquid structure of Al-Si alloy could be studied using software to simulate molecular dynamic of atom arrangement and also visualise the atoms [28].

## 5. Conclusion

This paper reviewed the use of superior Al-Si alloy as thermal storage material over other alloys such as Al-Cu, Al-Mg, Al-Cu-Zn, Al-Si-Mg and Al-Si-Cu. Fabrication methods for such alloys were also highlighted. This paper also recommends the use of Al-Si alloy for thermal storage based on its thermal properties [29].

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