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Thermal reliability of Al-Si eutectic alloy for thermal energy storage

Zhengyun Wang[a,b], Hui Wang[c], Mei Yang[b], Wenwen Sun[b], Guangfu Yin[a,*], Qinyong Zhang[b,*], Zhifeng Ren[c,*]

[a] College of Materials Science and Engineering, Sichuan University, Chengdu, Sichuan 610065, China
[b] Key Laboratory of Fluid and Power Machinery of Ministry of Education & Center for Advanced Materials and Energy, Xihua University, Chengdu, Sichuan 610039, China
[c] Department of Physics and TcSUH, University of Houston, Houston, TX 77204, USA

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ABSTRACT

The thermal reliability of Al-Si eutectic alloy as phase change materials (PCMs) was investigated through vacuum thermal cycling 250, 500, 750, and 1000 times going through the solid-liquid phase change. The changes in thermal properties of Al-Si eutectic alloy, including melting point, latent heat, specific heat, thermal diffusivity and thermal conductivity, were investigated using differential scanning calorimetric (DSC) and laser flash apparatus. The results revealed that, with increasing the number of cycles, the melting point and latent heat of fusion of the Al-Si eutectic alloy showed almost no changes. Moreover, the thermal conductivity showed an outstanding stability after 1000 thermal cycles. Therefore, it is concluded that the thermal reliability of Al-Si eutectic alloy is more than adequate for long-term performance as a phase change material for thermal energy storage (TES) applications.

1. Introduction

In order to slow down the increasing of the global warming gas emissions, various sources of renewable energy have been studied [1–9], for which the so-called low-grade waste heat or solar generated heat, is being considered as promising [2,8–12].

Among the various ways of solar energy utilization, concentrating solar power (CSP) technology, which uses phase change materials for thermal energy storage, is one of the most important options to produce electricity [2,8,11,13–15]. It is well known that because of the large amount of thermal energy stored by the phase transition materials with a constant temperature, the using of PCMs in CSP plants is capable to provide the electricity generation at the time when the peak demand of electricity comes in [16]. In terms of the economic benefits, successful implementation of the CSP plants also depends very much on the availability of low cost heat storage solutions, which allowing smoothing the operation of the solar generated plant over a long time period [17]. Therefore, the attractive technology of TES, especially the high temperature TES, would play a more and more important role in CSP plants even though it is one of the systems less developed.

Utilization of heat storage with high-temperature PCMs for the CSP applications, as many researchers believe, will considerably increase the efficiency of solar energy utilization [18]. The thermal-physical properties of several perspective metals and alloys have been reported when they were used as high-temperature PCMs [19–24]. In the past a few decades, because of the suitable phase change temperature, high solid-liquid latent heat density, Al-Si eutectic alloy was intensely investigated as PCM in high-temperature TES systems [25–27]. However, as the high-temperature PCMs used in CSP, the influence of thermal cycling on the thermal-physical properties of Al-Si eutectic alloy were indispensable but have been rarely reported. Therefore, it is necessary to study the performance reliability of Al-Si eutectic alloy upon thermal cycling for the long life span of CSP plants.

Five Al-Si eutectic samples as high-temperature PCMs were prepared by arc-melting for thermal cycling test. The main objective of this paper is to investigate the change of important physical properties of the material in detail, including the melting temperature, the latent heat of the solid-liquid phase transition, and the temperature-dependent thermal conductivity. Combined with microstructure and SEM morphology analysis, the long-term thermal cycling performance of Al-Si eutectic alloy under the simulated conditions of CSP plants was studied.

* Corresponding authors.
E-mail addresses: nic0700@scu.edu.cn (G. Yin), bohr123@163.com (Q. Zhang), zren@uh.edu (Z. Ren).

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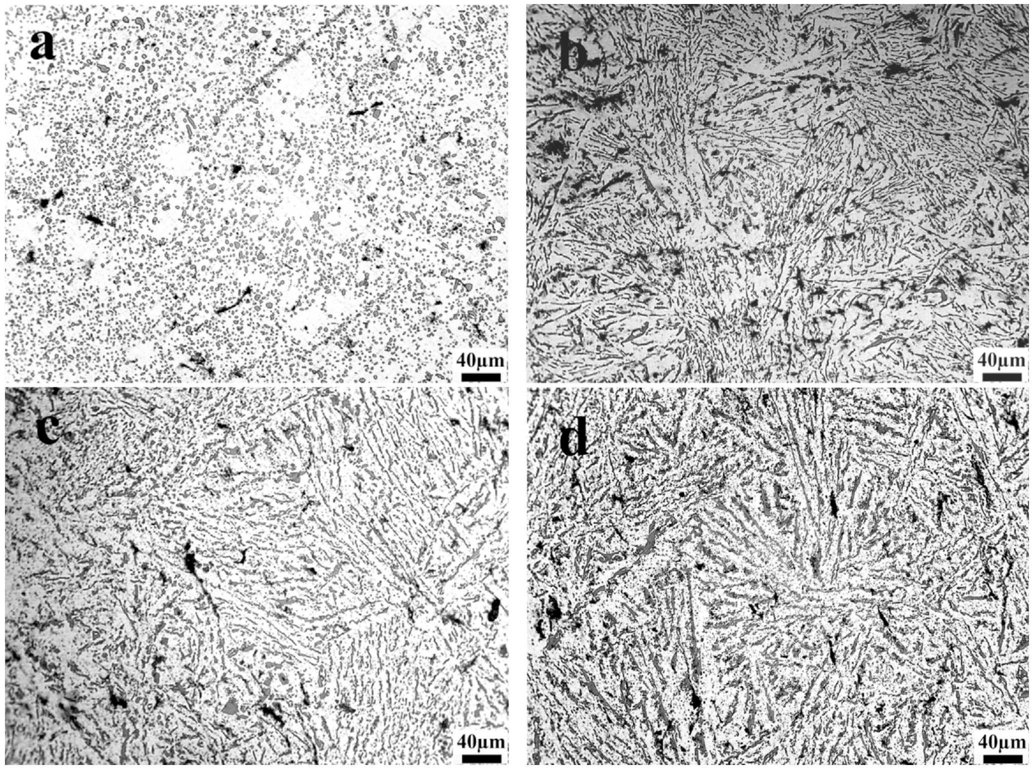

Fig. 1. The microstructure of Al-Si eutectic alloy after different number of thermal cycles: (a) 0 time, (b) 250 times, (c) 500 times, (d) 1000 times.

2. Experimental description

2.1. Preparation of samples

Al-12.2Si eutectic alloy (atomic ratio) was prepared by arc-melting, and then the samples were used for thermal cycling test. Pure Al (shot, 99.999%, Alfa Aesar) and pure Si (bulk, 99.9999%, Alfa Aesar) were weighed accordingly. In order to ensure the composition homogeneous, each sample was melted for five times by arc-melting. The whole arc-melting process was conducted under the protection of argon gas. Before the thermal cycling test, the as-melted samples were vacuum-sealed in quartz tubes and annealed for 100 h in a muffle furnace at 550 °C. Then the five annealed samples were heated from 500 °C to 650 °C with

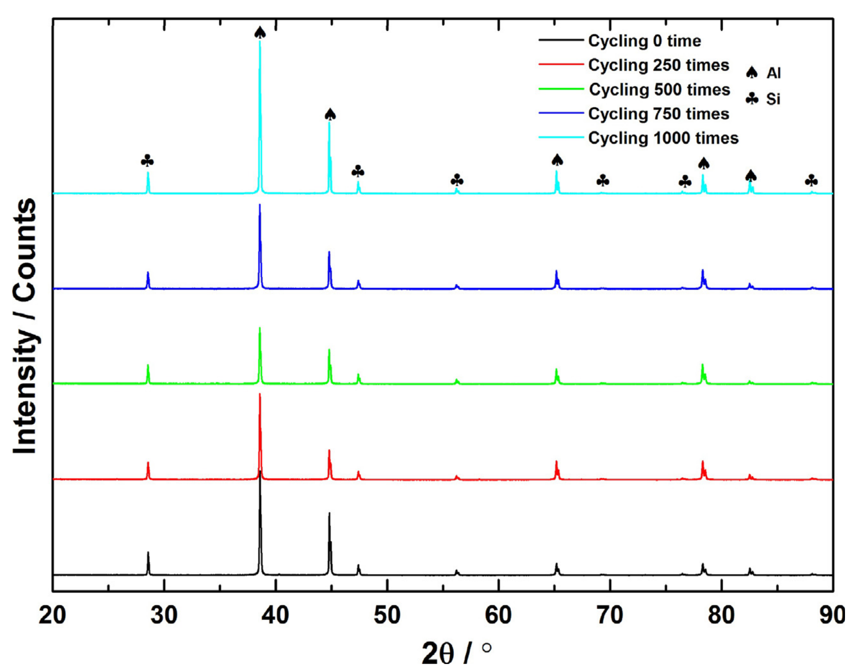

Fig. 2. The crystalline phase of Al-Si eutectic alloy analyzed by XRD after cycling of 250, 500, 750, and 1000 times.