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Elevated re-aging of a piston aluminium alloy and effect on the microstructure and mechanical properties

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ABSTRACT

T6 heat treated piston aluminium alloy (Al-13Si-4Cu-2Ni-1Mg-0.25Mn) were further aged at 350 °C and 420 °C, respectively, for various time (0–1000 h). The microstructures of the re-aged alloy were analyzed using optical microscope (OM, Nicon300) and transmission electron microscope (TEM, JEM-2010). The tensile strengths at room and 350 °C, as well as high cycle bending fatigue of the alloy were tested. The results show that the $Al_{11}Cu_5Mn_3$ nanoparticles will precipitate during the elevated re-aging process. The volume fraction formed during re-aging at 420 °C is higher than that formed at 350 °C. Both room temperature (RT) and 350 °C tensile strengths, as well as the high cycle fatigue life of the alloy after being re-aged at 420 °C are higher than those of re-aged at 350 °C due to the notable precipitation strengthening effect of nano particles $Al_{11}Cu_5Mn_3$.

1. Introduction

Piston is one of the most vital and key components in internal combustion engines because it transfers the driving force and withstands complex and high thermal–mechanical loads when performing high-speed reciprocating motion [1–3]. Piston materials endure a complex working condition of high thermal stresses and high temperature mechanical cycles responsible of fatigue cracking in the weakest zone, especially in areas facing the combustion chamber [4]. The local temperature at piston head is up to 400 °C in high density diesel engine, the combustion pressure of which is up to 20 MPa [5–7].

Among various piston alloys, eutectic Al-Si alloys containing elements Cu, Ni, Mg, Mn are widely used in high-temperature applications [8,9] because of their high strength and excellent resistance to abrasion and fatigue at ambient and elevated temperatures, as well as excellent fluidity due to their near zero solidification range [5].

The most common heat-treatment temper for Al-Si piston alloys is T6, which is comprised of solution heat treatment and quenching, followed by artificial aging [10]. The precipitation hardening through heat treatment will precipitate the alloying elements in the form of fine coherent particles inside the aluminium grains during the aging stage to harden the alloys [11]. Coherent particles that have been reported to precipitate during aging of Al-Si-Cu-Mg-Ni alloys (depending upon the chemical composition) are Al_2Cu, Mg_2Si, $Al_5Cu_2Mg_8Si_6$, and Al_2CuMg phases [12]. This system piston aluminium alloys are usually dissolved between 480 °C and 525 °C. The as-quenched alloys are either naturally aged at room temperature (commonly referred to as T4 temper) or artificially aged at a temperature between 150 °C and 240 °C. The main aging precipitated phase is Al_2Cu.

However, the actual service temperature of the piston head is significantly higher than the conventional heat treatment temperature. The microstructure and properties of normal aging heat treatment alloys will inevitably change. Extended operations at elevated temperatures will adversely affect the microstructure and properties of the piston alloys, which are vital to the overall life-span of the engines [13–16]. Therefore, understanding the effects of elevated heat treatment on the piston alloy is of considerable theoretical and practical importance. However, few studies have been reported on this topic yet.

In this study, the microstructure and mechanical properties of a eutectic piston aluminium alloy were measured after re-aging the alloy to 350 °C and 420 °C respectively in order to understand the microstructure and mechanical properties evaluation in close to actual working conditions of the piston.

2. Experimental procedure

The piston alloy is eutectic Al-Si alloy (Al-13Si-4Cu-2Ni-1Mg). The alloy was prepared using ingots of pure Al (99.95 wt%), pure Mg (99.9 wt%), pure Si (99.9 wt%), Al-50 wt% Cu, Al-10 wt% Ni and Al-10 wt% Mn master alloys with trace amounts of elements Fe and Ti. All samples for tensile properties and fatigue testing were machined from the permanent gravity cast piston crowns after heat treatment T6

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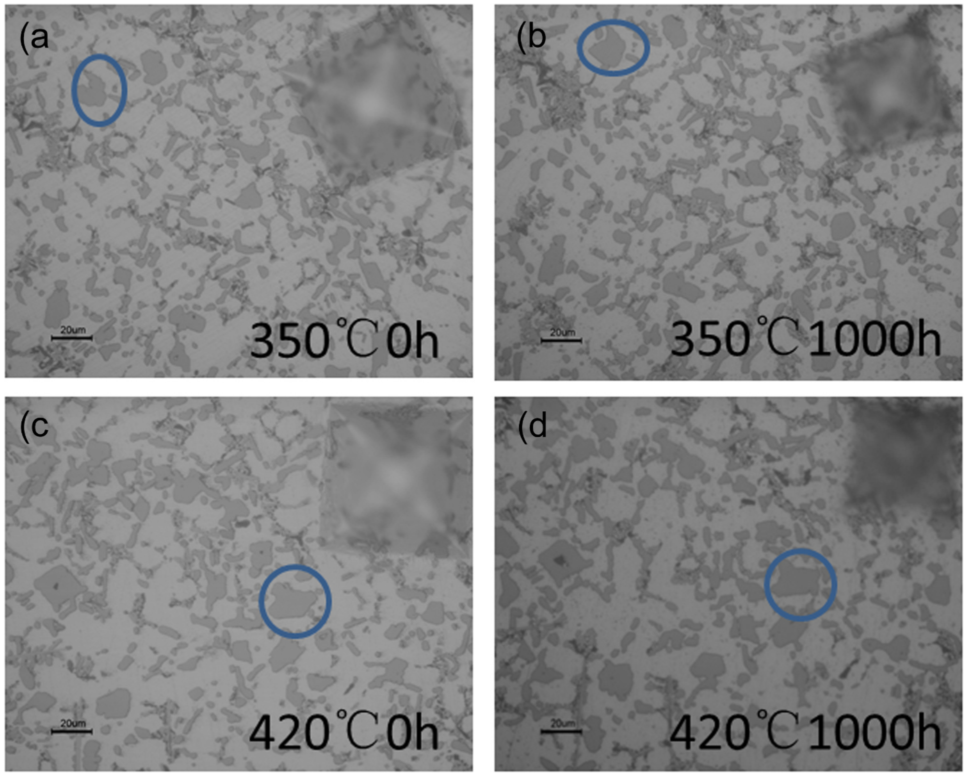

Fig. 1. The OM photographs of the alloy with different re-aging temperatures and times: (a) 350 °C, 0 h, (b) re-aging at 350 °C, 1000 h, (c) 420 °C, 0 h, (d) re-aging at 420 °C, 1000 h.

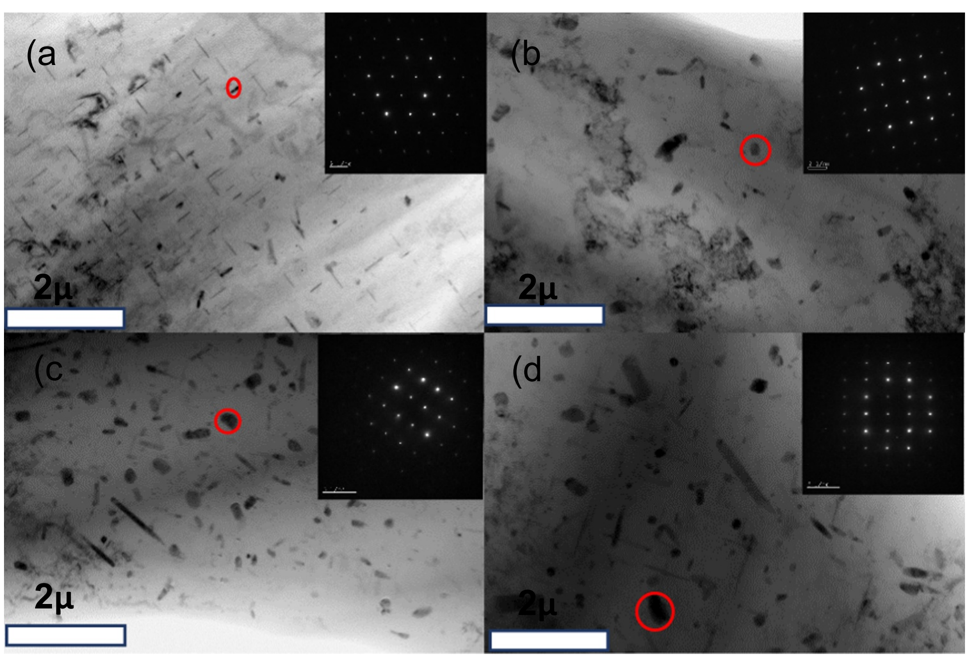

Fig. 2. TEM images of the alloy re-aged at 350 °C for different times (a) 0 h; (b) 10 h; (c) 15 h; (d) 100 h.