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Effect of Extrusion and Heat Treatment on Microstructure and Mechanical Properties of Hypereutectic A390-0.3wt%Nd Alloy

Bo Gao[a], Jidong He[a], Yingwei Zhou[a], Guanglin Zhu[a], Pengfei Xing[a]*

[a]*School of Metallurgy, Northeastern University, Shenyang, Liaoning Province, P.R. China*

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An hypereutectic aluminium alloy with a composition of 16-18wt%Si, 4-5wt%Cu, 0.45-0.65wt%Mg, 0.3wt%Nd and Al balance (A390-0.3wt%Nd alloy) was processed by extrusion and aging at 200ºC for 10 hours. The effect of the thermomechanical processing and heat treatment on microstructure and mechanical properties was investigated for A390-0.3wt%Nd alloy. It was shown that the eutectic structure disappeared after the processing and heat treatment. In the meantime, the morphology of Al(Si,Mg) solid solution was transformed from dendritic to equiaxed and the Si particles were refined to have fine sizes of 1-10μm and dispersed in the Al(Si,Mg) matrix. Some of the Si particles became globular in shape, which can reduce stress concentration. The tensile strength of the A390-0.3wt%Nd alloy increased by 14.8% (211MPa to 242MPa) after extrusion and aging, and the elongation to fracture increased significantly from 0.5% to 13.3%. Thus, the mechanical properties of extruded and heat-treated A390-0.3wt%Nd alloy were improved after the extrusion and aging. The fracture mode is transformed from brittle fracture of as-cast alloy to ductile fracture of extruded and heat-treated alloy.

Keywords: *Aluminium alloy, thermomechanical processing, heat treatment, mechanical properties.*

1. Introduction

Hypereutectic Al-Si alloys are important casting alloys and widely used in aerospace and automotive industries due to their advantages such as high specific strength, low shrinkage and hot-cracking tendency, good corrosion resistance and wear resistance.[1-3] A390 Al-Si alloy with a composition of 16-18wt%Si, 4-5wt%Cu, 0.45-0.65wt%Mg, and Al balance has a good potential as an aluminium casting alloy due to its overall performance.[4] However, several shortcomings of A390 alloy such as high brittleness and poor machinability hinder their wide applications. Mechanical properties of A390 alloy are highly related to the Si phase morphology and distribution. Therefore, it's essential to modify hypereutectic A390 alloy to improve shape, size and distribution of primary silicon particles aiming at enhancing mechanical properties of A390 alloy.[5-6]

A number of references[7-10] have reported that rare earth elements can modify the hypereutectic Al-Si alloys. However, the effects of thermomechanical processing and heat treatment on microstructure and mechanical properties of hypereutectic A390 alloy have not been investigated yet.

In this paper, the effects of extrusion and aging on the microstructure and mechanical properties of A390-0.3wt%Nd alloy was studied in detail. The aim of this work is to find out an effective way to achieve a mechanical property improvement in A390-0.3wt%Nd alloy.

2. Experimental

The basic alloy used in this work is A390-0.3wt%Nd alloy and the chemical composition of the alloy is shown in Table 1. The alloy was melted in an electric resistance furnace and then poured into a cast iron mould which had been preheated up to 200°C. The molten metal was stirred at 750°C for 10 min before pouring.

Table 1. Chemical composition of A390-0.3wt%Nd (mass fraction, %)

Si	Cu	Mg	Nd	Al
16.0~18.0	4.0~5.0	0.45~0.65	0.3	balance

The solution treatment of the samples was carried out at 515°C for 6h and all the samples were quenched in water kept at 44°C. The artificial aging temperature was 200°C with holding time of 10h. After aging, the samples were air cooled to room temperature. The extrusion was carried out after the sample was preheated at 450°C for 0.5h and the extrusion ratio was 8:1.

The microstructure was analyzed by X-ray diffractometry (XRD) (X'pert pro MPD/PW3040/60, Holland) with Cu Kα radiation (λ=0.154056nm) at 40kV with a graphite monochromator and scans at 0.02°/min. The samples for microstructure observation were cut from the profile of untreated and treated alloys respectively, re-grinding and polishing was carried out to the samples separately, then etched by 0.5wt%HF acid for 20s. The metallographic observation was carried using a Lecia MPS30 optical microscope. The microstructure and phase composition were analyzed by scanning electron microscopy (SEM)(SSX-550, Japan).

Tensile tests were performed using an electronic universal testing machine (CMT5105, Germany) at room temperature. All tensile samples were cylindrical with a diameter of 6 mm and a gauge length of 12 mm.

*e-mail: gaob@smm.neu.edu.cn

3. Results and Discussion

As shown in Figure 1, the microstructures of as-cast A390-0.3wt%Nd alloy consisted of coarse primary silicon particles with sizes in the range of 20-30μm, lamellar eutectic silicon, traces of α-Al dendrites and Al_2Cu phase (the white irregular phase in image) distributing along with the boundaries of α (Al) dendrites.

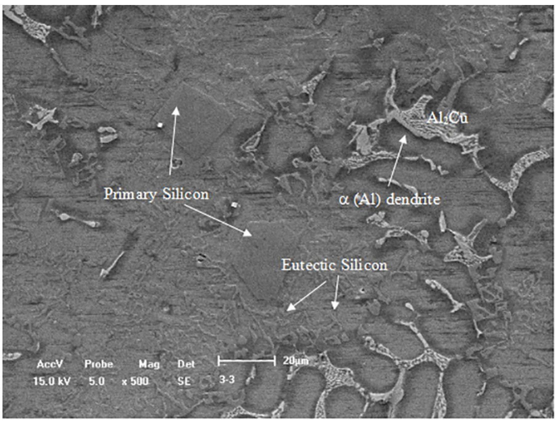

Figure 1. SEM image of A390-0.3wt%Nd alloy

After heat treatment, the plate-like eutectic Si disappeared and the primary Si particles became rounded, as shown in Figures2((a) and (b)). The morphology of α-Al solid solution was transformed from dendritic to equiaxed and the Al_2Cu phase was distributed along the grain boundaries. The high magnification SEM image (Fig.2(b))shows that some of the primary Si particles were granular, their sizes decreased to 1-5μm and part of the granular silicon distributed in the white bandy Al_2Cu phase. The distribution of white Al_2Cu phase presents more continuous compared to that of the as-cast A390-0.3wt%Nd alloy.

As shown in Fig. 3(a), the sizes for most of primary Si particles in the as-extruded sample became smaller(0.5μm to 2μm) than those of the primary Si particles in the as-cast sample due to fracture effect under extrusion stress. The refining effect is significant except for few coarse primary Si phase. After extrusion, the shape of Si particles was transformed into granular or short rod (Fig.3(b)) and few fine silicon particles (about several hundred nm) were distributed in the matrix. However, the reduction in grain size and uniform distribution of Al_2Cu phase was observed.

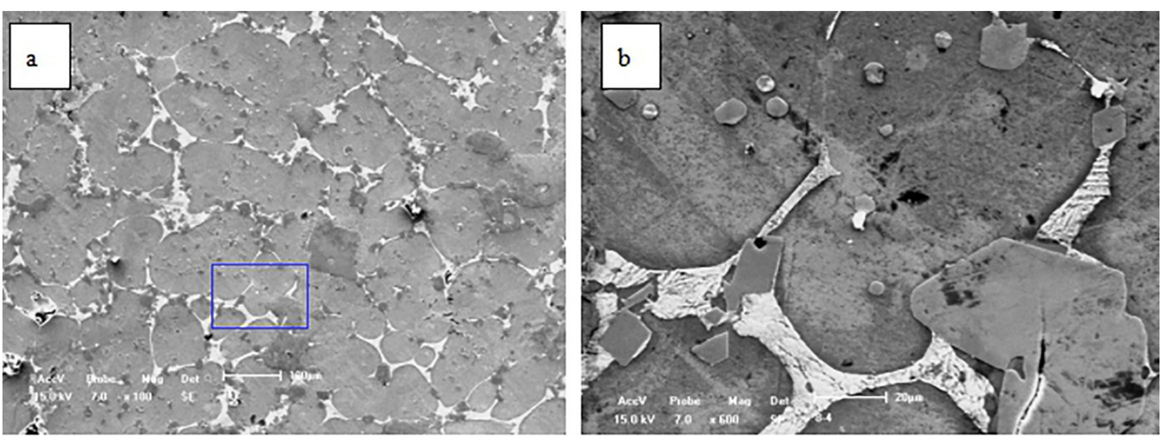

Figure 2. SEM images of A390-0.3wt%Nd alloy after heat treatment at different magnifications

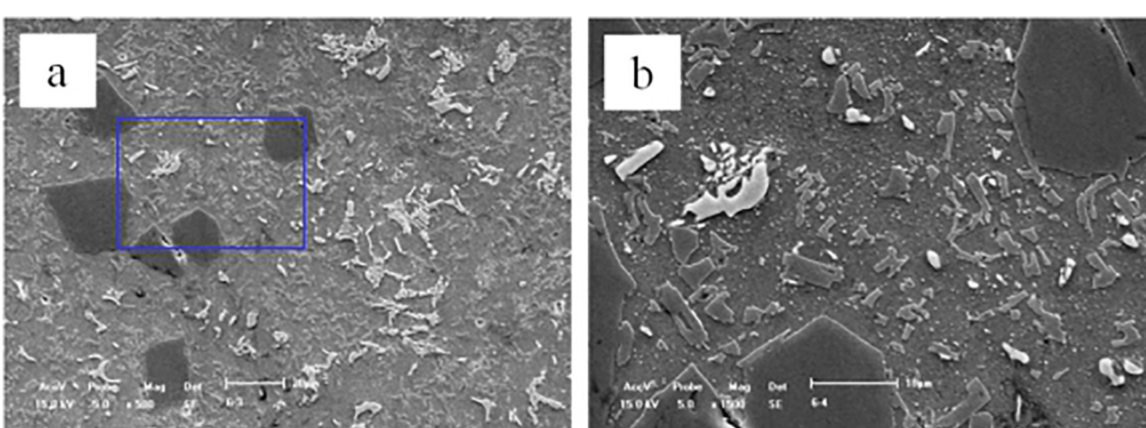

Figure 3. SEM images of A390-0.3wt%Nd alloy after extrusion at different magnifications

The mechanical properties of A390-0.3wt%Nd alloy before and after extrusion and heat treatment are shown in Fig.4. The properties of A390-0.3Nd alloys after extrusion and heat treatment are significantly improved. After extrusion and heat treatment, The tensile strength of A390-0.3wt%Nd alloy increased by 14.8% (211MPa to 242Mpa),while the elongation to fracture improved drastically from 0.5% to 13.3%.

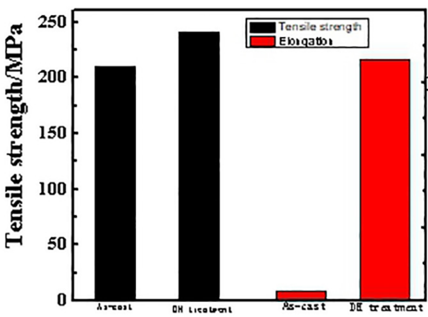

Figure 4. Variations in tensile strength, and elongation of as-cast A390-0.3wt.%Nd and extrusion and heat treatment samples

Fracture surfaces of as-cast and extruded and heat treated A390-0.3wt%Nd alloys are shown in Figures 5 (a) and 5(b), respectively. Due to few dimples for the as-cast sample (Fig.5(a)) the mode of fracture can be described as brittle fracture and further can be correlated because of only 0.5% elongation of as-cast sample. On the contrary, due to the abundance of dimples for extruded and heat-treated sample (Fig.5(b)), the mode of fracture can be described as ductile fracture and further can be correlated because of 13.3% elongation.

The mechanism could be explained as follows. Many silicon particles (second phase) distributed on substrate, when the plastic deformation happened, dislocations in substrate moved towards the second phase under the action of shear stress and lots of dislocations piled up to form dislocation loops around the substrate in the meantime. With the deformation degree further increase, the second phase particles will be filled with dislocation loops, from which the driving force of the dislocation source and the repulsive force of the second phase particle emerged. When the stress was big enough to push the interfacial dislocation to the interface of substrate and second phase, the dislocation loops moved towards the interface one by one, as a result, the interface will be separated in a certain direction to form a microvoid, the repulsive force of the second phase particle decreased as the microvoid appears, the dislocation source motivated again. Other microvoids emerged in the same way, resulting in formation of larger voids, and further developing into a tensile fracture in the end.

4. Conclusion

The morphology of α-Al solid solution in A390-0.3wt%Nd was transformed from dendritic to equiaxed and the Al_2Cu phase was distributed along the grain boundaries and the primary Si particles were granular, their sizes decreased to 1-5μm and part of the granular silicon distributed in the white bandy Al_2Cu phase after extrusion and heat treatment. The mechanical properties of as-cast A390-0.3wt%Nd improved significantly after extrusion and heat treatment. The tensile strength of A390-0.3wt%Nd alloy is increased from 211MPa to 242Mpa and the elongation to fracture improved drastically from 0.5% to 13.3%. The mode of fracture is transformed

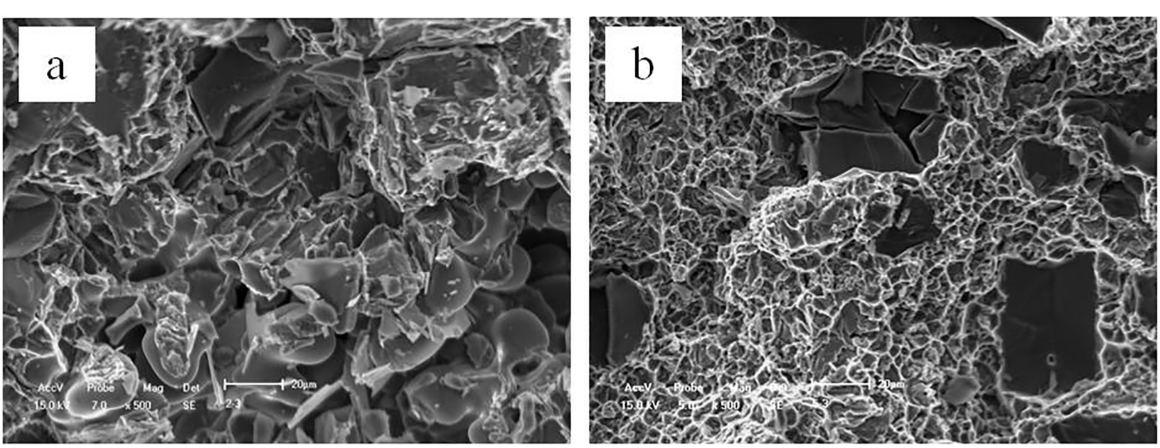

Figure 5. The SEM images of fracture surfaces of (a) as-cast A390-0.3Nd alloy sample; and (b)extruded and heat treated sample of A390-0.3wt%Nd alloy)

from brittle fracture of as-cast sample into plastic fracture of treated sample.

5. Acknowledgements

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