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Al based ultra-fine eutectic with high room temperature plasticity and elevated temperature strength

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ABSTRACT

Developments of aluminum alloys that can retain strength at and above 250 °C present a significant challenge. In this paper we report an ultrafine scale Al–Fe–Ni eutectic alloy with less than 3.5 at% transition metals that exhibits room temperature ultimate tensile strength of ~400 MPa with a tensile ductility of 6–8%. The yield stress under compression at 300 °C was found to be 150 MPa. We attribute it to the refinement of the microstructure that is achieved by suction casting in copper mold. The characterization using scanning and transmission electron microscopy (SEM and TEM) reveals an unique composite structure that contains the Al–Al_3Ni rod eutectic with spacing of ~90 nm enveloped by a lamellar eutectic of Al–Al_9FeNi (~140 nm). Observation of subsurface deformation under Vickers indentation using bonded interface technique reveals the presence of extensive shear banding during deformation that is responsible for the origin of ductility. The dislocation configuration in Al–Al_3Ni eutectic colony indicates accommodation of plasticity in α-Al with dislocation accumulation at the α-Al/Al_3Ni interface boundaries. In contrast the dislocation activities in the intermetallic lamellae are limited and contain set of planner dislocations across the plates. We present a detailed analysis of the fracture surface to rationalize the origin of the high strength and ductility in this class of potentially promising cast alloy.

1. Introduction

The growth of metal intermetallic in-situ composite through eutectic solidification is an elegant method for producing composite materials for high temperature applications. In this kind of composite, the fibers of intermetallics are grown inside the metallic matrix during solidification of the alloy [1–8]. Although well known for decades, their applications for aluminum alloys are limited often due to poor room temperature ductility [1–8]. Recently, it has been shown that eutectics at nano-length scale with micron size primary phase can exhibit high strength and plasticity [9–12]. The high strength in these cases is mainly due to nano/ultrafine eutectic while plasticity was derived from soft dendrites, which enhance dislocation activity [13–17]. Therefore, the strength and plasticity of the composites are strongly related through volume fraction, morphology and length scale of the eutectic phase constituents. For improvement in strength the volume fraction of the hard intermetallic must be maximized [2]. But high intermetallic fraction drops the ductility. To overcome the relatively poor ductility that is often observed in binary eutectic alloys, several ternary alloying additions have been attempted [13,18–22]. The ternary addition refines eutectic and forms small size colonies [18–21]. Under suitable conditions increasing ternary additions can yield a combination of two kinds of eutectics with two different spacings [22,23]. Synergy of these two eutectics and two length scales represent opportunity for alloy development.

There are several Al based eutectics with intermetallics (e.g. Al_2Cu, Al_3Ni and Al_3Zr) [1,2]. Among these, Al matrix with Al_3Ni fiber eutectic has widely been studied as model system for deformation and fracture behavior of fiber reinforced in-situ grown metal–matrix composites [2–8]. The eutectic microstructure in this case possesses excellent thermal stability upto 500 °C and the hardness of Al_3Ni fiber does not reduce significantly, notably up to 250 °C [2–8]. However, the eutectic alloy exhibits a low ductility and a yield strength of ~140 MPa at room temperature [2–8]. We therefore, explored the possibility of synthesizing a composite of two eutectics by adding ternary alloying elements. We have chosen Fe which is a natural impurity element in aluminum alloys and hence in general less welcome in common alloys [1,2]. In Al rich corner, it forms Al rich solid solution which coexists with Al_3Ni and Al_9FeNi intermetallics (Fig. 1(a)). The alloy

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composition studied was Al–3 at%Ni and 0.1 at%Fe. The results presented in this paper indicate reasonable ductility and superior strength at high temperatures for this alloy. The current paper also explains the role of microstructure and phases in improving the mechanical properties.

2. Experimental details

The alloy of Al (96.9 at%), Fe (0.1 at%)–Ni (3 at%) was prepared by arc melting the elements (99.9% purity) in required proportion under argon atmosphere. The alloy was re-melted at least 5 times

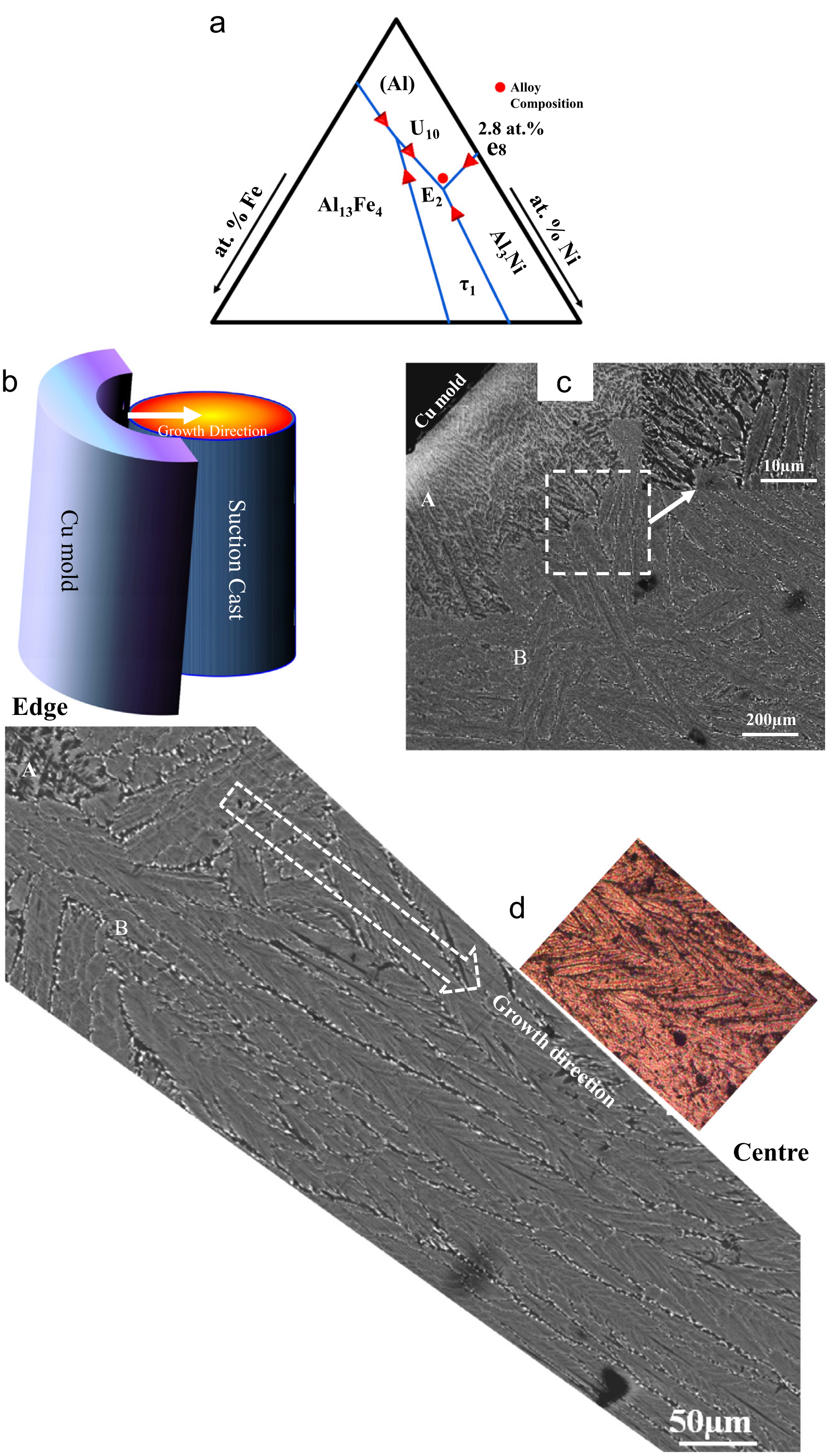

Fig. 1. (a) Ternary liquidus projection of Al rich Al–Fe–Ni phase diagram. The alloy composition is marked in the phase diagram. (b) The schematic of suction casting mold showing cooling directions. (c) SEM image in BSE mode and high magnification images as inset for suction cast sample. (d) A collage of images revealing the growth morphology of the eutectic dendrites from surface to the centre under suction casting condition. (e) SEM image of the central region of the sample in the same section at high magnification. A–B arrow indicates: central to edge region of a colony. (f)–(h) High magnification image of single colony showing the composite nature of the colony with rods at the centre and lamellae at the edge. (g) Schematic of the composite colony illustrating the composite morphology.