JOURNAL OF MATERIALS PROCESSING TECHNOLOGY 209 (2009) 798–804

journal homepage: www.elsevier.com/locate/jmatprotec

Solidification behaviour, microstructure and mechanical properties of high Fe-containing Al–Si–V alloys

K.L. Sahoo[a,*], *B.N. Pathak*[b]

[a] *National Metallurgical Laboratory, Jamshedpur 831007, Jharkhand, India*
[b] *Department of Mechanical Engineering, BRCM College of Engineering & Technology, Bahal, Bhiwani 127028, Haryana, India*

ARTICLE INFO

Article history:
Received 29 August 2007
Received in revised form
11 February 2008
Accepted 24 February 2008

Keywords:
Al–Fe–V–Si alloy
Silicides
Mechanical properties
Thermomechanical treatment
Rolling

ABSTRACT

The paper deals with effect of Fe on the solidification behaviour and mechanical properties of unmodified and modified Al–V–Si alloys. Effect of thermo-mechanical processing on the mechanical properties of these alloys was also reported. The solidification proceeds through several invariant reactions, the first one corresponds to formation of Al_3(Fe,V,Si)-type phase. Modification with Ni–Mg master alloy changes the morphology, size and distribution of the primary as well as interdendritic phases. The modified alloys show an increase in first invariant reaction temperature and decrease in final invariant reaction temperature when compared with unmodified alloy, probably due to action of phase modification. In comparison to untreatable alloy, appreciable improvement in mechanical properties occurs on modification by Ni–Mg treatment. Hot rolling further improves the mechanical properties of the alloy.

1. Introduction

Al–Si based alloys are mostly used in automotive application because of their high strength to weight ratio, low coefficient of thermal expansion and good abrasion resistance. Solidification rate and alloy composition control the grain size and phase distribution that, in turn, influences the properties of cast alloys. The principal alloying elements in Al-based cast alloys are Si, Cu, Zn, Mg, Mn, Cr and Ti (ASM, 1990). These alloys are used up to the operating temperature of about 180 °C (Das et al., 1989). Beyond this temperature, the mechanical properties deteriorate owing to the coarsening of the precipitates. An aluminium-transition metal system has the potential to go to relatively higher temperatures and is likely to be suitable for use in aerospace and automobile sectors (Jones, 1986). In particular, Al–Fe–V–Si alloys belonging to this system have attracted considerable interest amongst the researchers. However, a high Fe content in Al-alloys is considered to be harmful to the mechanical properties due to formation of needle and angular shaped Fe-bearing phases. The phases formed in Al–Fe alloys are Al_6Fe, Al_7Fe_2, $Al_{19}Fe_6$, Al_3Fe, etc. that depend on the chemical composition and cooling rate (Rivlin and Raynor, 1981; Adam and Hogan, 1972). The phase mixture of Al–Al_3Fe forms at 1.8 wt.% Fe and 655 °C in Al–Fe alloys under equilibrium conditions (Adam and Hogan, 1972). The structure of the Al–Al_3Fe eutectic consists of plates of Al_3Fe intermetallic in an Al matrix, the plates being highly branched at low temperature gradients in the order of 1 K mm^{-1} (Adam and Hogan, 1972). Higher Fe contents in the Al–Fe alloys result in the growth of primary Al_3Fe prisms. Depending upon the cooling rate and pressure during the solidification various morphological shapes of Al_3Fe is formed. Sahoo et al. (2000a,b) have

* *Corresponding author*. Tel.: +91 657 2271709; fax: +91 657 2270527.
E-mail address: klsah@nmlindia.org (K.L. Sahoo).
0924-0136/$ – see front matter
doi:10.1016/j.jmatprotec.2008.02.043

Table 1 – Compositions of the experimental alloys

Alloy designation	Chemical composition (wt.%)				Treatment condition (wt.%)
	Fe	V	Si	Al	
A1	4	1	1	*Balance*	Untreated
A2	4	1	1	*Balance*	Treated with 1% of Ni–20Mg
B1	5	1	1	*Balance*	Untreated
B2	5	1	1	*Balance*	Treated with 1% of Ni–20Mg
C1	6	1	1	*Balance*	Untreated
C2	6	1	1	*Balance*	Treated with 1% of Ni–20Mg
D1	8	1	1	*Balance*	Untreated
D2	8	1	1	*Balance*	Treated with 1% of Ni–20Mg

reported the occurrence of ten-armed star-shaped phases in conventional cast Al–Fe–V–Si alloys. They have also reported that the chemical treatment of Al–Fe–V–Si alloys by elemental Mg or Mg-bearing master alloys changes these phases into more favourable compact forms and thereby improves the mechanical properties.

The present paper reports the effect of Fe content on the solidification behaviour, microstructure and mechanical properties of Al–Fe–V–Si alloys. The paper also reports the effect of modification treatment on these aspects. The effect of thermomechanical treatment has also been discussed.

2. Experimental

The experimental alloys (Table 1) were prepared by melting high purity Al (99.9%), Al–21Fe, Al–10Fe–5V and Al–20Si master alloys (all compositions are in wt.%) in graphite crucibles coated with alumina in an electric resistance heating furnace. To avoid oxidation during melting the melt was covered with flux. Required quantities of Al and master alloys were added in the crucible. The melt was intermittently agitated with a graphite rod for complete mixing. After melt down, sufficient time was allowed for complete homogenization of the melt. The melt was then degassed with dry argon. The melt was treated with 80% Ni–20% Mg master alloy, as a modifier, for modification studies. Small pieces of modifier wrapped in thin Al foil was first heated to 250 °C and then plunged into the melt at a temperature ranging from 840 to 900 °C depending upon the alloy composition. The degassed unmodified as well as modified melts were poured into permanent moulds in the form of rods and plates (cooling rate 14 K/s). Cooling curves were recorded with the help of a strip chart recorder attached to a temperature recorder/calibrator of ±0.4 K accuracy and a chromel–alumel thermocouple of 0.4 mm in diameter. The thermocouple was placed at the centre of the mould. Quenching experiments were carried out to study the transformation occurring at different temperatures. Initially, several cooling curves were taken to determine the transition temperatures. For quenching experiments, the melts were poured at a temperature of 1173 K into a resin bonded sand cup fitted with chromel-alumel thermocouple. When the temperature dropped to the specified level, the cup was quickly quenched in a tank containing sufficient ice-brine solution. The quenched and cast specimens were polished and etched with a modified Keller's reagent (2 ml HF and 3 ml HCl in 175 ml water) for microstructural study. The specimens were examined under scanning electron microscope (SEM) fitted with an energy dispersive X-ray (EDX) analysis system. The EDX analysis was done at 20 keV, and the results reported are the averages of minimum 10 readings for each phase. The number and size-distribution of precipitates were estimated with the help of image analyser. X-ray diffraction (XRD) analysis was carried out with a PHILIPS diffractometer equipped with a Co target. In order to determine the tensile strength, standard Hounsfield specimens (no. 15) were prepared from the as cast samples and tested at a strain rate of 3×10^{-3} s^{-1}. The 20 mm plate was homogenized at 450 °C for 36 h prior to rolling in a four high mill with reverse rolling facility. Rolling temperature was maintained at 350 °C.

3. Results and discussion

Cooling curves were recorded for all the samples. A representative cooling curve of unmodified Al–8Fe–1V–1Si alloy is shown in Fig. 1. The time required for cooling the test piece from the pouring temperature to the final liquidus invariant reaction temperature has been considered to determine the average cooling rate. A number of kinks were noted in the cooling curves, which indicate that various phases precipitate during solidification. A quaternary Al–Fe–V–Si alloy phase diagram (Skinner, 1988) is reproduced in Fig. 2(a) and (b) for an assessment of the results of the present investigation. The diagram reveals the existence of silicide phases of general composition $Al_{12to14}(Fe,V)_3Si_{0.9–1.29}$. It also indicates the equilibrium phase relationship within the Al–Fe–V alloy system. According to the published phase diagram of an Al–Fe–V alloy at 748 K (Skinner, 1988), the equilibrium solid phase is approximately Al_3(Fe,V). Reddy and Sekhar (1989) reported

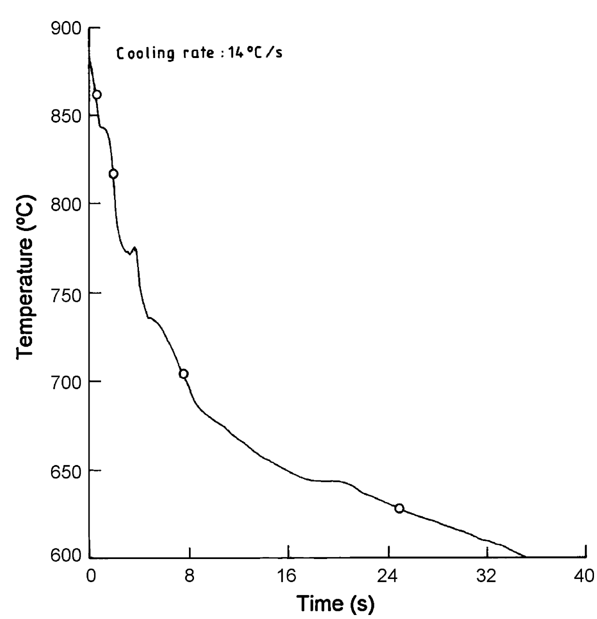

Fig. 1 – Cooling curve of unmodified Al–8Fe–1V–1Si alloy at a cooling rate of 14 K/s.