Wear 313 (2014) 106–116

Contents lists available at ScienceDirect

Wear

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

Dry sliding wear of aluminium-high silicon hypereutectic alloys

F. Alshmri [a,1], H.V. Atkinson [b,*], S.V. Hainsworth [b], C. Haidon [c], S.D.A. Lawes [d,2]

[a] Department of Engineering, University Road, Leicester LE1 7RH, UK
[b] Department of Engineering, University of Leicester, University Road, Leicester, LE1 7RH, UK
[c] Department of Geology, University of Leicester, University Road, Leicester LE1 7RH, UK
[d] Department of Engineering, University Road, Leicester LE1 7RH, UK

ARTICLE INFO

Article history:
Received 16 August 2012
Received in revised form
29 January 2014
Accepted 13 February 2014
Available online 20 February 2014

Keywords:
Sliding wear
Wear testing
Non-ferrous metals
Electron microscopy
Aluminium-high Si alloys

ABSTRACT

One of the main limitations on using aluminium-high silicon (with silicon contents greater than about 20 wt%) alloys is the formation of coarse, brittle silicon particles under conventional solidification conditions. However, an increase in silicon content generally gives an improvement in wear properties so there is a drive to produce the high silicon alloys with relatively fine microstructures. Rapid solidification processing (RS) is very effective in limiting the coarsening of primary silicon due to the high cooling rate. Here flakes of material produced by chopping melt-spun ribbon have been degassed, consolidated, hot isostatically pressed and then extruded. The resulting material has been subjected to dry sliding reciprocating multi-pass wear testing at room temperature against a steel ball bearing at 10N and 100N load. The alloys compared can essentially be characterised as ‘low in silicon (around 21 wt%), high in intermetallic-forming elements (Fe, Cu, Ni)’ and ‘high in Si (around 30 wt% Si), low in intermetallic forming elements’. The wear results show that extruded bar with composition Al 21Si 3.9Cu 1.2 Mg 2.4Fe 1.4Ni 0.4Zr has higher hardness, and hence wear resistance, than extruded bar with composition Al 29.8Si 1.3Cu 1.4 Mg 0.3Fe 0.3Ni 0.3Zr, despite the higher Si content. It is thought that, at the higher Si content, there may be silicon particle pull-out which may subsequently lead to a three-body abrasive wear mechanism. In addition, for the lower Si alloy, the higher amounts of intermetallic-forming elements are thought to be contributing to the wear resistance.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Aluminium-high silicon alloys are generally defined as those where the silicon content is over about 17 wt%. They are sometimes categorised as metal matrix composites because the silicon particles act as reinforcing high hardness particles in the tough aluminium matrix. There is a drive to process such high silicon alloys because of the high specific stiffness and strength, good hot strength, low thermal expansion coefficient and excellent wear resistance. However, if conventional solidification routes are used, the primary silicon forms as large, brittle particles and the material has low toughness. Rapid solidification [1] presents a route for producing the alloy with the silicon initially in a very fine form. The processing route (e.g. via spray forming or melt spinning) must then be designed to minimise coarsening so that the Si particle size can be kept relatively small e.g. [2–4].

Secondary alloying elements in the composition play an important role in determining the properties. The elements we are concerned with here are copper, magnesium, iron, nickel and zirconium. In general [5], iron can modify the silicon phase by forming several Al–Fe–Si intermetallic phases whilst magnesium strengthens the alloy through the precipitation of Mg_2Si. Copper improves corrosion resistance and gives precipitation strengthening with $CuAl_2$; it may additionally strengthen the alloy by altering the brittle Al–Fe–Si phases. Nickel can enhance elevated temperature strength and hardness when combined with copper. If intermetallic phases are too coarse though the properties of the alloy will be degraded. In addition, intermetallic formation may denude the matrix of alloying elements, such as magnesium which would otherwise be available for precipitation strengthening.

The alloys considered here are high in silicon with the silicon level well above the eutectic. In previous work in the literature on the wear of aluminium–silicon alloys, there are conflicting findings about the effect of silicon content and contact pressure [6]. In dry sliding, two main wear regimes exist [7]. Mild wear occurs by surface oxidation and the formation of tribological transfer layers

---

[*] Corresponding author. Tel.: +44 116 22 31019; fax: +44 116 252 2525.
E-mail addresses: eng_fraj@hotmail.com (F. Alshmri), hva2@le.ac.uk (H.V. Atkinson), svh2@le.ac.uk (S.V. Hainsworth), ch230@le.ac.uk (C. Haidon), s.lawes@nottingham.ac.uk (S.D.A. Lawes).

[1] Now at P.O. Box 59874, Riyadh 11535, Saudi Arabia.

[2] Now at Faculty of Engineering, University of Nottingham, Room A43 Coates, University Park, Nottingham NG7 2RD, UK.

http://dx.doi.org/10.1016/j.wear.2014.02.010
0043-1648 © 2014 Elsevier B.V. All rights reserved.

by a process of mechanical mixing. Severe wear is characterised by considerable surface damage and deformation and often large scale material transfer. In the mild wear regime, there is evidence that the wear resistance does not vary appreciably with Si content [7]. Above the eutectic, further increase in Si also increases the wear resistance [8,9]. In contradiction with this, a maximum wear resistance region was found at around the eutectic level [10]. Various researchers have investigated the effects of silicon particle size and shape but find no consistent trends [11–14]. Hutchings et al. [15] identify a transition load for the transition from mild to severe wear. At this transition, a small quantity of aluminium adheres to the steel disc. Gross plastic deformation and fracture of the aluminium alloy pin then occurs as the test progresses. During mild wear, material removal occurs as a result of subsurface crack propagation through a composite transfer layer of aluminium and crushed silicon particles. With severe wear, subsurface cracking of silicon particles occurs in the highly deformed wear zone. Silicon particles released from the matrix then abrade the steel countersurface, increasing the proportion of steel and ferrous oxides in the mechanically mixed debris. Mahato et al. [16] have identified a 'post severe oxidative wear regime'. The wear is principally oxidative and occurs at pressures greater than 30 MPa. In a real engine, where the combustion products and lubricant contain substantial amounts of dissolved oxygen, this regime may be relevant.

Table 1 summarises the work in the literature [8,17–19] on wear rates in alloys with relatively high silicon percentages (i.e. as close to the regime 20–30% silicon which we are examining here as could be found). It shows the paucity of relevant work with data which can be converted to wear rates. All rates have been converted to the same units. This requires the area of the contact and hence the diameter *D* of the pin is given in the left hand column. The data shows that there is no systematic correlation between the Si content or the contact pressure and the wear rate and that the wear performance of these materials is a complex function of the microstructure and mechanical properties. None of these workers have examined the effect of secondary alloying elements. With respect to the effect of secondary alloying elements on wear rates in aluminium-high silicon alloys, the addition of 1.2 wt% Fe to cast LM28 alloy (which contains 17.5 wt%Si) increased the wear rate due to the formation of needle-like beta intermetallics [20] but introducing an additional 0.6 wt% Mn altered the intermetallics to alpha-phase ($Al_{15}(Fe,Mn)_3Si_2$) which reduced the detrimental effect of Fe. Where Mg_2Si, $CuAl_2$ or other intermetallics hardened the matrix, either as a result of heat treatment or indeed the temperature rise at the wearing surface due to friction, wear resistance was improved [21–23]. Chen et al. [24] have examined the behaviour of an alloy with a similar microstructure to those examined here (Al–25Si–2.5Cu–1Mg prepared by powder metallurgy followed by thixocasting) and proposed a model for the formation of the mechanical mixing layer (MML) generated by plastic deformation of a heavily loaded worn surface (Fig. 2) with the MML containing Si, Fe and Al_2O_3 phases embedded in an α-Al matrix.

In the work described here we investigate the dry sliding wear behaviour of aluminium-high silicon alloys (Si > 20 wt%) containing intermetallic-forming secondary alloying elements. The materials are made by rapid solidification to form ribbon, followed by consolidation of flakes of ribbon with hot isostatic pressing and extrusion, so the silicon particles are relatively fine in size. It is not possible to compare the rapidly solidified alloy with a 'control' of the same composition made by a 'conventional' route as cast aluminium–silicon alloys with these silicon levels tend to be extremely brittle because the silicon is so coarse. However, an A390 piston alloy with 17% silicon has been included for comparison.

2. Experimental materials and methods

2.1. Materials

The material was supplied by RSP Company in The Netherlands. Flakes are produced by chopping melt spun ribbon. These are then

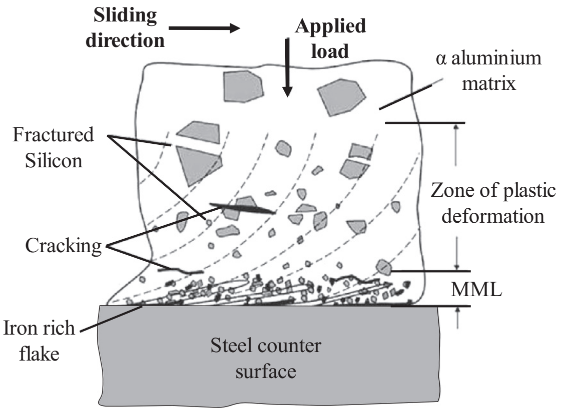

Fig. 1. Schematic cross section through the surface sliding under heavy load for the hypereutectic Al–Si alloys [24].

Table 1
Dry sliding wear rates from the literature for Al-Si alloys.

Methods and material	Material	Wear rate ($m^3\ m^{-1}$) × 10^{-12}				Wear rate ($m^3\ m^{-1}$) × 10^{-12}			Wear rate ($m^3\ m^{-1}$) × 10^{-12}				Wear rate ($m^3\ m^{-1}$) × 10^{-12}		
[8] Pin on a disc D=15 mm. Dry sliding on steel (50HRC). Pins are cast Al–Si alloys time 60 min. Area=1.8E-04 m^2		Contact pressure (kPa)				Contact pressure (kPa)			Contact pressure (kPa)				Contact pressure (kPa)		
		40	80	120	158	304	457	609	492	984	1476	1968	509	2038	3057
	Al-7%Si	0.9	1	3.5	5										
	Al-13%Si	0.5	2.2	1.5	2										
	Al-22%Si	0.9	1.9	3	4										
[17] Pin on a disc. Dry sliding on steel (50HR C). Pins are cast Al-Si alloys. Speed= 196 cms^{-1} Area=3.2E-05 m^2	Al-15%Si					0.0053	0.0076	0.0087							
	Al-16%Si					0.0076	0.0133	0.0133							
	Al-21%Si					0.0134	0.017	0.0229							
[18] Pin on a disc. D= 4.64 mm. Dry sliding on steel (50HR C). Pins are spray deposited AL-Si Alloys. Speed=0.48 m/s Distance=1.7 km. Area= 1.8 E-05 m^2	Al-12%Si								0.022	0.023	0.038	0.069			
	Al-20%Si								0.015	0.023	0.026	0.03			
	Al-25%Si								0.011	0.023	0.034	0.042			
[19] Pin on a disc. D= 5 mm Dry sliding on steel (50RC). Pins are cast Al-Si alloys. Area=2E-05 m^2	Al-12%Si												4	10	10
	15%Si												4	9	13

Download English Version:

https://daneshyari.com/en/article/617371

Download Persian Version:

https://daneshyari.com/article/617371

Daneshyari.com