Journal of Manufacturing Processes 23 (2016) 130–134

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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

Technical Note

Enhancing the machinability of hypereutectic Al-30Si alloy by friction stir processing

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ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form 11 June 2016
Accepted 13 June 2016
Available online 28 June 2016

Keywords:
Chip
Hypereutectic
Aluminum silicon alloy
Cast
Friction stir processing
Machinability

ABSTRACT

Chip formation ability and chip characteristics during machining in as-cast as well as friction stir processed hypereutectic Al-Si alloy are investigated. The effect of microstructural refinement by friction stir processing on chip size, shape and morphology are characterized using optical microscopy and scanning electron microscopy techniques. It was observed that with the increase in number of FSP passes morphology of chips transformed from an irregular brittle powder to regular curly ductile chips with the corresponding decrease in the surface roughness values, thus enhancing the machinability. The change of chip behavior in cast and that after FSP was primarily due to the reduction in diameter and uniform redistribution of primary silicon.

1. Introduction

Machinability can be defined as the ease of cutting operation with which materials can be machined. It is rather a relatively complex phenomenon involving many variables like tool life, surface roughness, chip formation, cutting force, power consumption, etc. [1,2]. Presently, efforts are being undertaken to minimize the machining cost, and correspondingly new tools are being developed to extend the tool life used for machining operations. Therefore, machinability is one of the important factors to be considered for design and selection of materials for intended application [3].

Hypereutectic aluminum-silicon (Al-Si) alloys are advanced engineering materials extensively used for electronic packaging and thermal management applications due to their low coefficient of thermal expansion (CTE), good electrical conductivity and lightweight. The microstructure of hypereutectic Al-Si alloy comprises of hard silicon particles dispersed in soft and ductile aluminum matrix and, therefore, it is considered as in situ composite material. The main disadvantage of this cast alloy is the presence of large primary silicon particles with casting porosities, which makes the alloy brittle coupled with low strength, low toughness and poor machinability [4,5].

Particulate composite materials are known for having poor machinability due to the high tool wear and poor surface finish arising from the abrasive hard particles, which act as small cutting surface thus resulting in poor surface finish [6–11]. Farid et al. [12] reported the effect of feed rate and cutting speed on chip morphology of hypereutectic A383 (Al-11.5 Si) alloy by high speed drilling operation. The chips morphology gets transformed from continuous to classical continuous fragmentary chips on increasing the cutting speed and feed rate. The effect of 2–20% silicon content on machinability and chip characteristic was studied by Kamiya and co-workers [13], according to which particularly for hypereutectic Al-Si alloy, increasing the silicon content resulted in improvement of chip breakability with simultaneous decrease in tool life and surface finish. Also, the surface roughness and tool wear is increased by the cracking of primary silicon and contact between fractured primary silicon and tool. Tanaka and Akasawa investigated the machinability of the Al-25Si alloy produced by powder metallurgy (PM) and ingot metallurgy (IM) casting routes and reported an enhanced machinability of the former processed alloy due to primary silicon refinement. The chips produced during machining of IM alloys is broken type, however, the continuous ribbon type chips was the characteristics of PM alloy [14]. In most of the published works, investigation is focused either on the tool wear or on the tool surface finish but the effect of microstructural refinement on the chip characteristics is not investigated significantly. The

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http://dx.doi.org/10.1016/j.jmapro.2016.06.008
1526-6125/

hypereutectic alloy consist of three phase that is alpha aluminum, eutectic and primary silicon and their size effect on machinability is subject of interest for industrial applications. Therefore, the motive of present investigation is to study the mechanism of chips formation and enhancement of machinability of as-cast hypereutectic Al-30Si alloy by multipass friction stir processing (FSP).

2. Materials and experimental details

The fabrication of cast hypereutectic Al-30Si alloy was carried out by melting pure aluminum ingot and silicon nuggets in box type electrical resistance furnace. The raw materials were thoroughly cleaned using alcohol to remove dirt and oil and melting was carried at 950 °C. After melting, sodium based fluxing agent and standard chlorine based degassing tablets were used for removing oxides from the surface of molten metal and removing entrapped gas before casting into rectangular metallic mold of size 300 mm × 300 mm × 12 mm. The cast plates were subjected to FSP in which a rotating tool with shoulder and pin is inserted in the base metal. The material is exposed to thermo-mechanical deformation due to the friction between the tool and the plate and is responsible for the microstructural refinement during FSP. The steps involved in the FSP process, that is the tool which is rotated at 900 rpm is inserted in the cast alloy and translated throughout the length of the plate at 16 mm/min (Fig. 1(a)). Fig. 1(b) displays the FSP machine with tool and cast plate clamped in the machine bed and Fig. 1(c) illustrate the H13 steel tool profile used in the experiment. Hypereutectic Al-30Si bars of 8 mm in diameter and 140 mm long in as-cast condition as well as after FSP were produced for dry machining test. Dry lathe turning tests were performed using eight feet lathe machine, 'Hindustan Machine Tool model Vikram'. The tool holder used for dry turning operation was having a positive 5° rake angle and 15° relief angle. Prior to the machining tests, the above bars were subjected to turning at a low cutting speed (∼300 m/min) by using uncoated WC–Co cermet inserts. This step was used to give a standard uniform surface for the dry turning tests. The parameters used for turning operation are listed in Table 1.

Table 1
Parameters used for generation of chips during turning operation in lathe machine.

Parameters	Condition
Cutting speed	1200 rpm
Feed rate	0.125 mm/rev
Depth of cut	0.5 mm
Coolant	None

Microstructural analysis of the as-cast and friction stir processed Al-30 Si alloy and their machined chips were carried out using optical and scanning electron microscopy (SEM). Sample preparation for the optical and SEM studies was carried out by mechanical polishing of longitudinal crossection of FSP stir zone. The final stage polishing was carried out with diamond paste. These samples were etched with 0.5% hydro fluoric acid and microstructure characterization was done by Carl Zeiss make M2m® model upright metallurgical microscope. The machined chips were also polished in the same way, but the main difference was that the chips were dispersed and mounted on carbon conductive bakelite. Polishing of chips could be performed by taking extra care at each stage. The morphology and shape of chips were examined in SEM attached with energy dispersive spectroscopy (EDS) system of Carl Zeiss Supra® 55 FESEM with Oxford's X-Max® detector.

The hardness test was conducted on the polished cast and FSP samples, and their chips with a load of 200 g and dwell time of 15 s on Leco make micro-hardness tester as per ASTM E92 standard. Inter-particle region was selected for hardness measurement as the hardness of primary silicon particle is much higher than that of the matrix. However, due to the increase in volume fraction of silicon particles, after the overlap FSP, it was difficult to locate the inter-particle region for hardness measurement. The surface roughness value (Ra) on the surface of cast machined samples as well as after one and three pass FSP machined samples were measured by stylus. The surface roughness measurements were made at three different locations and the average values are reported here.

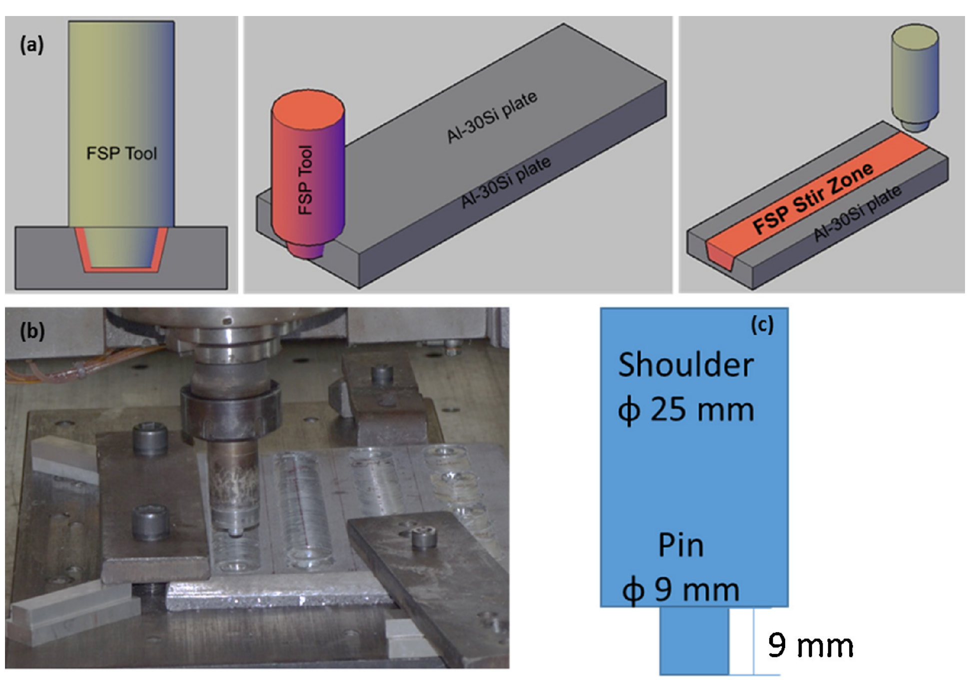

Fig. 1. (a) Schematic representation of FSP showing FSP tool insertion and translation thus creating refined FSP zone, (b) FSP setup showing FSP machine, tool and Al-30Si plate clamped on machine bed, and (c) tool profile used for carrying out FSP.