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Investigating the Machinability of Al–Si–Cu cast alloy containing bismuth and antimony using coated carbide insert

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ABSTRACT

Surface roughness and cutting force are two key measures that describe machined surface integrity and power requirement evaluation, respectively. This investigation presents the effect of melt treatment with addition of bismuth and antimony on machinability when turning Al–11%Si–2%Cu alloy. The experiments are carried out under oblique dry cutting conditions using a PVD TIN-coated insert at three cutting speeds of 70, 130 and 250 m/min, feed rates of 0.05, 0.1, 0.15 mm/rev, and 0.05 mm constant depth of cut. It was found that the Bi-containing workpiece possess the best surface roughness value and lowest cutting force due to formation of pure Bi which plays an important role as a lubricant in turning process, while Sb-containing workpiece produced the highest cutting force and highest surface roughness value. Additionally, change of silicon morphology from flake-like to lamellar structure changed value of cutting force and surface roughness during turning.

1. Introduction

Aluminum–silicon alloys are increasingly being employed in the aerospace industry, satellite bearing and inertial navigation systems [1]. They are notable materials owing to the fine thermal conductivity, low expansion coefficient and good corrosion resistance. Among Al–Si cast alloys which comprise over 80% of cast aluminum alloys, hypo-eutectic alloy is additionally appealing because of the low material cost and excellent castability [2]. The inherent brittle nature of Si restricts its alloy applications in automotive and aerospace components which is related to mechanical stresses, ductility and high fatigue strength. Therefore, melt treatment with the addition of elements like strontium and sodium is generally used to alter the morphology of Si and meet these requirements [3].

Modification melt treatment in Al–Si cast alloys leads to a change in the morphology of eutectic silicon from coarse brittle flake-like to fine fibrous morphology, resulting in improved mechanical properties [4,5] especially ductility and fatigue life. By the addition of certain elements to the melt prior to solidification, chemical modification can be achieved [6]. Elements such as Na, Sr and Ba show marked effect on the eutectic silicon when added to

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molten Al–Si alloys by changing its morphology to fibrous appearance. Other elements such as Sb and Yb can refine the silicon morphology and alter its structure into partially modified or lamellar structure [7–9].

It has been reported that antimony (Sb) transforms the morphology of Si from flake to lamellar structure and consequently enhances the mechanical properties [3,10] along with wear resistance [11].

Machovec et al. [12] reported a relatively minor effect of Bi addition on the silicon morphology of Al–Si alloys in 319 type aluminium alloy. It was found that the addition of 1 wt.% Bi refines rather than modifies the Si structure and improved tensile strength, elongation and the absorbed energy for fracture of near eutectic Al–Si alloys. Moreover, Bi-refining effect intensified with increasing cooling rate [13].

In terms of machinability, chip breakability evidently improves at higher Si content when turning Al–Si alloy with a carbide cutting tool (K10) at a constant feed rate of 0.1 mm/rev, cutting depth of 0.5 mm and cutting speed between 0.5 and 2 m/s [14]. Basavakumar et al. [15] noted an improvement in machinability and surface characteristics of Al–Si cast alloy treated with combination of Sr modifier and Al–3Ti–B grain refiner at a constant feed rate of 0.2 mm/rev, cutting speed of 26 m/min and 0.4 mm depth of cut with PVD and polished CVD diamond-coated tools. It has additionally been reported that surface quality enhances when the cutting parameters are optimized [16]. Ciftci et al. [17] were investigated the evaluation of tool wear when machining SiCp-reinforced Al-2014 metal matrix composites (MMCs). They have found that coated cutting tools performed better than uncoated cutting tools in terms of tool wear for all the materials machined. The better performance of them can be attributed to the coating and a larger and more stable built-up-edge (BUE) formation. Ozben et al. [18] have been attempted to the Investigation of mechanical and machinability properties of SiC particle reinforced Al-MMC. They have reported that machinability of MMC is very different from traditional materials because of abrasive reinforcement element. This is due to abrasive element causes more wear on cutting tools. Flank wear of cutting tool are also increased with increase in reinforcement ratio. Reportedly, at greater cutting speeds the cutting temperature rises when machining eutectic and a hypereutectic Al–Si alloy. A linear relationship was identified between them, as primarily attributed to increased heat localization. Surface roughness was found to decrease at higher cutting speeds due to the reduced tendency for build-up-edge formation [19,20]. Irrespective of several papers studied on microstructure and mechanical properties of Al–Si alloy, very few data on the effect of Bi and Sb additions have been found in the literature that extensively address the influence of these elements on machinability characteristics of Al–Si–Cu cast alloy when dry turning. Therefore, having an understanding of these alloys' machinability is imperative when it needs to fabricate of some industrial products which produce by casting process. The aim of this work is to investigate the machinability of Al–Si–Cu alloys containing bismuth and antimony when dry turning using coated carbide inserts. Our findings help in the comparison of the results and afford a better understanding the features of the machinability of Al–Si system.

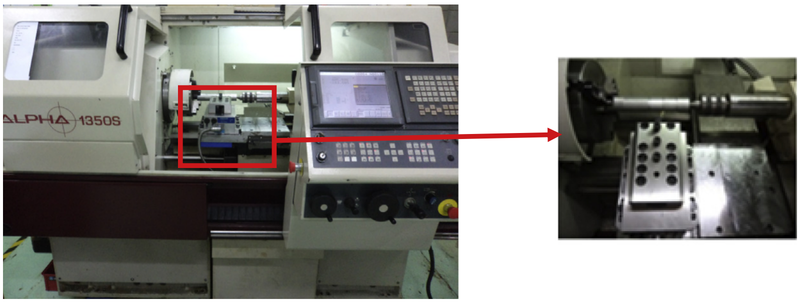
2. Experimental details

A turning investigation was accomplished on Al–11.3Si–2Cu cast alloy with 80–90 HV hardness, 125–140 MPa yield strength (YS) and 130–160 MPa ultimate tensile strength (UTS) using the CNC machine (ALPHA 1350S). Experimental setup (dynamometer) shown in Fig. 1. Particulars regarding the cutting tool are given in Table 1. Kennametal inserts with 35° rhomboid geometry with nose radius 0.2 mm and Relief angle (α) 5° on a Kennametal holder SVJBL-1616H11 were used. All machining conditions were selected according to the tool maker advice.

To fabricate the workpiece a commercial Al–11.3Si–2Cu ingot was melted and prepared using an induction furnace. Pure Bi shots and pure Sb granules at concentrations of 1 wt.% Bi and 0.5.% Sb were added to melt according to the optimum concentration for each additive which was determined by computer aided cooling curve thermal analysis (CA-CCTA) and microscopic inspection observed depression in eutectic growth temperature in previous

Table 1
Details of the cutting tool.

Tools/ grade	Coating composition	Process type	ISO catalog number
KU10	TiN	PVD	VBGT110302F



(CNC machine) (Dynamometer)

Fig. 1. Experimental set up.