Microstructures and Wear Behavior of Spray-Formed Al-22Si-4Cu-1.7Mg Alloy

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***Abstract*-In the present work Al–22Si–4Cu-1.7Mg alloy has been spray formed and subsequently hot pressed for densification. Hardness and wear behavior of spray formed and secondary processed alloys have been evaluated individually and compared with that of as-cast alloy. The microstructure of spray formed Al-22Si-4Cu-1.7Mg alloy consisted of globular shaped Si particles, fine Q-Al-Si-Mg-Cu phase and θ-Al_2Cu precipitates spread around the boundaries and junctions of grains in α-Al matrix. The microstructure is further refined by hot pressing and the size of Si particle size varies from 2-10 µm. The Q- phase and θ phase have been further broken down to smaller fragments. In contrast the microstructure of as-cast alloy consisted of coarse primary and eutectic Si with Chinese script like coarse θ-Al_2Cu precipitates and Q-Al-Si-Mg-Cu phase in α-Al matrix. The primary Si size varies from 20–200 µm. The spray formed and hot pressed alloy exhibited a higher hardness value of 149 VHN compared to the as-cast alloy that has a value of 98 VHN. The wear behavior of the alloys, under dry sliding conditions at a sliding velocity of 1.4m/s and sliding distance of 1020 m, showed an increase in the wear rate with an increase in the load. Spray formed and hot pressed alloy exhibited maximum wear resistance, while as-cast alloy showed minimum wear resistance for a range of applied loads varying from 10 - 50 N. The high wear resistance of spray formed and hot pressed Al-22Si-4Cu-1.7Mg-alloy is explained in terms of its microstructural modifications induced during spray forming and subsequent hot pressing and also the topographical features of worn out surfaces.**

Keywords- Al-Si alloy, Spray deposition, Hot pressing, Hardness, Wear rate.

I. INTRODUCTION

Al and its alloys occupy third place among the commercially used engineering materials. In commercial aluminum casting alloys, Al–Si base alloys are perhaps most common particularly due to very attractive characteristics such as high strength to weight ratio, good workability, excellent cast ability, good thermal conductivity and corrosion resistance. Addition of Silicon to Aluminum gives, low thermal expansion coefficient and high wear resistance. These alloys also show improved strength and wear properties as the silicon content is increased beyond eutectic composition [1].

Hypereutectic Al-Si alloys have an excellent potential for applications in automotive and aerospace industries due to their high strength to weight ratio. In order to improve the mechanical properties of hypereutectic Al-Si alloys, a modification in composition is necessarily made by adding alloying elements like Cu, Mg and Fe to these alloys. Addition of Cu and Mg increases the strength of the alloy through formation of intermetallic phases such as θ-Al_2Cu, Q-Al-Si-Mg-Cu, However, this also leads to a reduction in ductility [2]. The formation of coarse plate-like silicon particles, needle-like intermetallic phases in conventional casting methods, results in inferior mechanical properties. On the other hand heat treatment or addition of modifiers and refiners during the casting process has little success. More recently, spray forming has received considerable attention as an alternative route for the synthesis of a variety of structural materials. In the spray forming process, droplets are first atomized from a molten metal stream, quickly cooled by an inert gas, deposited on a substrate, and finally built up to form a low-porosity deposit with a required shape[3]. The objective of the present study was to utilize combined effects of high cooling rate solidification and the advantages of hypereutectic Al-Si alloy alloyed with the other elements such as Cu, Mg and Fe. In the present investigation Al-22Si-5Cu-1.7Mg alloy were spray deposited and hot pressed. The microstructural features of as cast and spray formed hot pressed alloys are studied.

II. EXPERIMENTAL PROCEDURE

The chemical composition of Al-22Si-4Cu-1.7Mg Alloy used as the base composition is as shown in Table 1 The schematic view of the spray forming set up as shown in figure 1 and the procedure generally adopted is described elsewhere [5]. The capability of the spray forming setup used was to handle 5 kg of Al melt. In the present investigation, the alloy was melted in a crucible to a superheat temperature of 120^{o}C. The molten alloy was atomized to a spray cone by a free-fall atomizer using nitrogen gas. Subsequently, the liquid droplets in the spray were cooled by the atomizing gas and accelerated towards a copper substrate (collector) and deposited to form a consolidated preform. The spray deposition processing parameters are summarized in Table 2. The round samples machined from the preform were hot-pressed at a temperature of 480°C after soaking for 60 minutes using a load of 50 KN. Wear tests were carried on

hot-pressed sprayed and as cast alloys using a pin-on-disc type wear testing machine (Model: TR-20, DUCOM). Wear specimen of size 30 mm length and 8 mm diameter were machined from differently processed samples. The contact surface of the specimen were polished up to 1200 mm grit size and tested against a rotating EN-32 steel disc with a hardness value of HRC 65. The wear tests were carried out at constant sliding velocity of 1.4 m/s for a fixed sliding distance of 1000 m at different normal loads (10, 20, 30, 40 and 50 N). The frictional force induced on the specimen was recorded constantly during the wear test by a load cell. The microstructural features, compositions of constituent phases and worn out surfaces of pins after the test were examined by using Optical microscope, Scanning Electron Microscope (Model: S-3400N Hitachi Model) the hardness was measured using Vickers Hardness Tester (Mattoon ATK-600) at an applied load of 300 g.

Table 1. Chemical composition of Al-22Si-4Cu -1.7Mg alloy (wt. %)

Si	Cu	Mg	Ni	Fe	Al
22	4	1.76	0.025	0.9	Bal

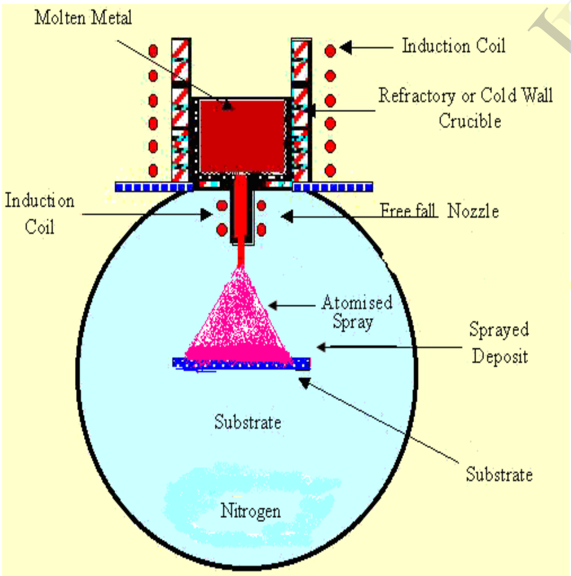

Fig.1. Schematic view of spray deposition set up

Table 2 Process variables in spray deposition process

Process variables	Value
Melt superheat	120 °C
Melt flow	2.3kg/min
Gas pressure	3.0 MPa
Diameter of nozzle	4 Mm

III. RESULTS AND DISCUSSION

Microstructural features

Fig. 2 (a) shows the microstructure of as-cast (AC) alloy. It consists of primary and eutectic Si phases in the α-Al matrix. The primary Si particles exhibited a plate like morphology with a size varying from 75–535 μm, while eutectic phase comprises of Si needles. The intermetallic Al_2Cu and Q-Al-Si-Cu-Mg phases are in the form of Chinese scripts distributed non uniformly in the Al-Matrix. The SEM microstructure of as cast alloy as shown in figure 2(b). It consists of block like Si particles, Al_2Cu intermetallic compounds appears in the form of Chinese and acicular shape of Q phase distributed non uniformly in the Al- matrix.

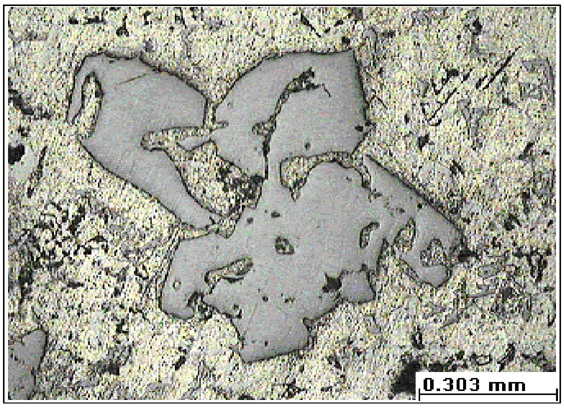

Fig 2(a) Optical micrograph of as cast alloy

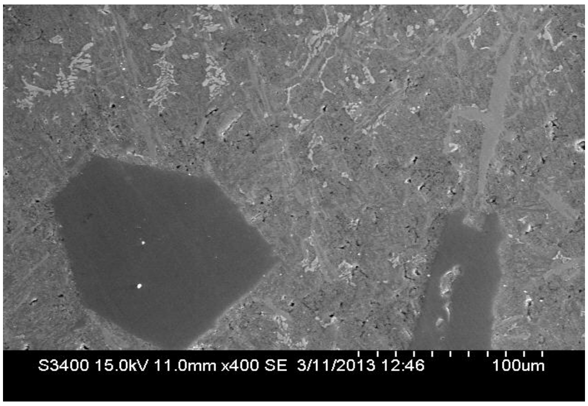

Fig 2(b) SEM micrograph of as cast alloy

Figure 3(a) depicts the optical microstructure of spray formed (SF) alloy. The microstructure consists of an equiaxed, nearly spheroidized grain morphology of α-Al matrix. The Si particles are very much refined, fine particulates of Al_2Cu (white contrast) and Q-Al-Si-Cu-Mg are uniformly distributed in the Al-matrix. A porosity of 18.4 % was observed in the spray formed alloy, which is an important and undesirable feature of spray formed alloys. The SEM microstructure of spray deposited alloy as shown in Fig.3 (b). It consists of primary Si particles having size in the range between 2 to15µm, Al_2Cu and Q- Al-Si-Mg-Cu phases exists in the form of fine precipitates and distributed uniformly in the Al–matrix. An equiaxed, homogeneous, and uniform distribution of primary Si phase and modified eutectic phase in Al-matrix of as-spray formed (SF) alloy can be obtained due to abundant nucleation of the melt due to rapid cooling in the flight and on deposition. The semi solid droplets are fractured due to inter particle collision in spray during flight and upon impinging on a substrate. Also due to remelting of the solid component of the spray in the top surface region of the deposit effectively break the Si particles that are formed prior to the deposition stage [6]. The presence of such Si phase leads to an increase in the density of nuclei in the top layer of the spray deposited alloy [4].

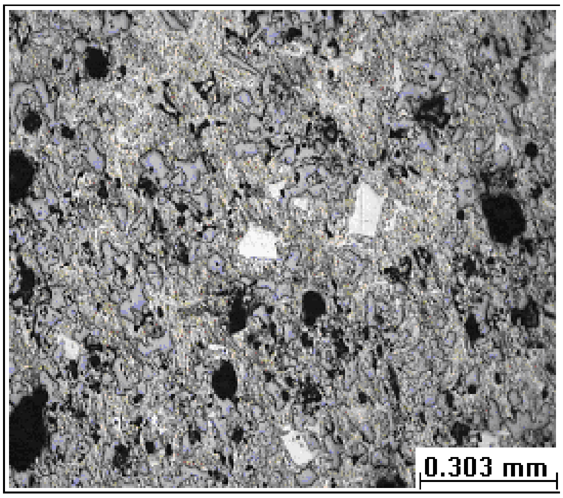

Fig. 3(a) Optical micrograph of spray deposited alloy

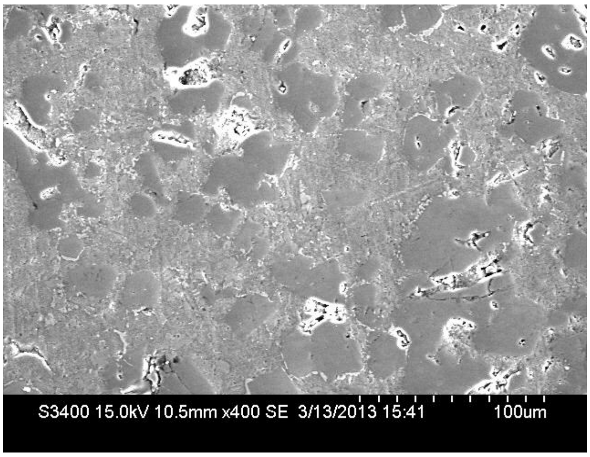

Fig. 3(b) SEM micrograph of spray deposited alloy

The microstructure of spray formed and hot pressed (SF + HP) alloy shown in Fig. 3 (c). After hot pressing, the alloy showed partially re-crystallized grains together with elongated grains. The fragmentation of Si and Al_2Cu phases and enhanced density of the alloy with reduction in of porosity of 7%.

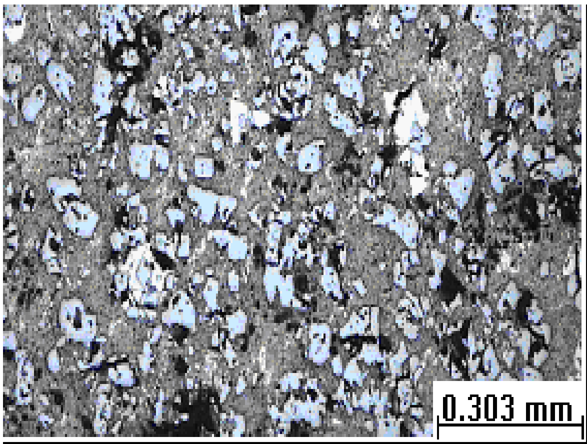

Fig. 3(c) Optical micrograph of SF+HP alloy

Hardness

The results of hardness values of SF+HP and as cast alloys are as shown in Fig 4. It is evident from the results that the hardness of SF+HP alloy is almost 1.5 times higher than that of as-cast alloy. The higher hardness of SF+HP alloy can be attributed to the microstructural refinement ,uniform distribution of primary Si phase and presence of fine dispersion of brittle intermetallic (Al_2Cu and Q phases) and reducedporosity[5].

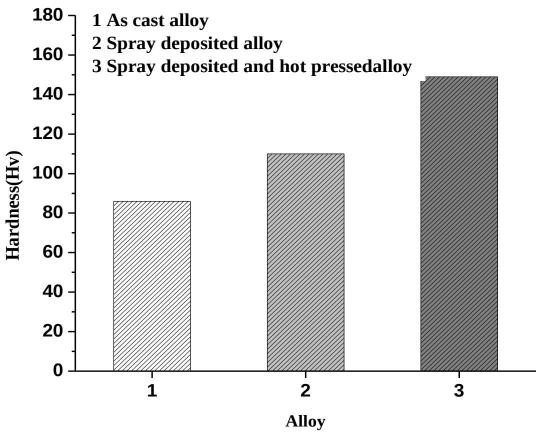

Fig.4. Hardness of investigated alloys

Wear characteristics

The wear rate of AC and SF+HP alloys for a range of loads at a sliding velocity of 1.4 m/s and a sliding distance of 1025 m are shown in Fig. 5. The load is varied from 10–50N. It is observed from the Fig. 5 that the wear rate is increasing with increase in the load for all the alloys irrespective of alloy processing condition. In the entire range of applied loads, among both the alloy compositions the spray formed + hot pressed alloy showed better wear resistance than the as-cast alloy [6].

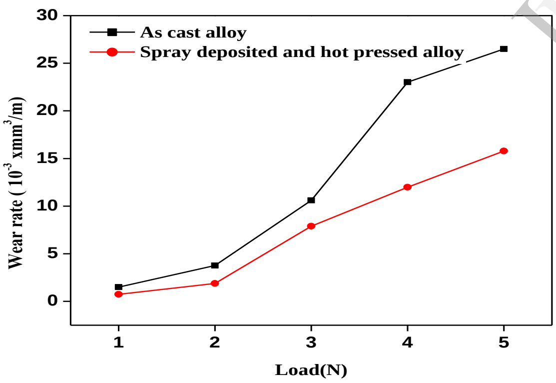

Fig .5 Volumetric wear rate with applied load

Topographical features of worn surfaces

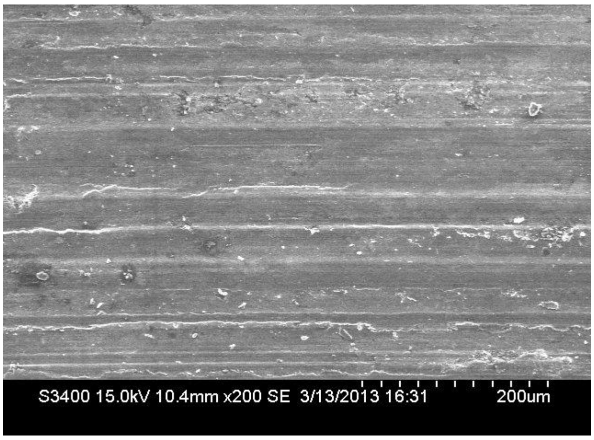

Fig.6. SEM worn out surface of as cast alloy at 5Kg load with sliding velocity 1.4m/s

Fig.6 depicts the SEM micrographs of worn–out surface of as cast alloy. The worn–out surface of cast alloy is more heavily scored with enlarged dimples. Alloy shows wider grooves and significantly causing severe damage to the surface. The presence of irregular plastic flow lines indicate the occurrence of extensive plastic deformation during wear run. Also the ploughing was severe, indicating a high wear rate in cast alloy. The worn-out surface of SF+HP alloy as shown in Fig. 7. The surface damage observed in spray formed and hot pressed alloy is lesser than that observed in as cast alloy. This is because of fragmentation of β and θ phases into finer particles and reduction of porosity due to hot pressing. No dimple is present on the worn–out surface of spray deposited and hot pressed alloy resulting in a low wear rate [7].

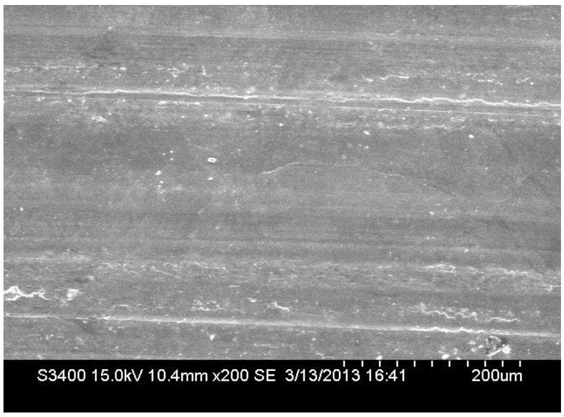

Fig.7 SEM worn out surface of SF+HP alloy at 5Kg load with sliding velocity 1.4m/s

IV. CONCLUSIONS

1. Spray forming is an effective in refining the microstructures of Al-22Si-4Cu-1.7Mg alloys. The microstructures of as-spray formed alloys are further refined and the porosity have been considerably reduced in the alloy by hot pressing. On the contrary the microstructures of as-

cast alloys are coarser with long platelets of primary Si and long needles of eutectic Si and θ-Al_2Cu phase in the form of Chinese script in α-Al matrix unevenly distributed in α-Al matrix.

2. The wear resistance and hardness are high for spray formed and hot pressed alloy and low for as-cast alloy. Worn–out surface and debris particle analyses clearly justified the effectiveness of spray deposition casting process.

REFERENCES

[1] Jung HK, Seo PK, Kang CG. "Microstructural characteristics and mechanical properties of hypo-eutectic and hyper-eutectic Al–Si alloys in semi-solid forming process", 2001.

[2] Lopez F, Reyes J, Campillo B, Aguilar-Sahagun G, Juarez-Islas JA." Rapid solidification of Cu alloys with high strength and high conductivity" J Mat Eng Perform 1997; 65:611–4.

[3] Dayanand M. Goudar, K. Raju, V.C. Srivastava, G.B. Rudrakshi. Effect of secondary processing on the microstructure and wear behavior of spray formed Al–30Mg2Si–2Cu alloy. Materials and Design (Elasevier) 47 (2013) 489–496.

[4] C. Cui, A. Schulz, K. Schimanski, H.-W. Zoch. "Spray forming of hypereutectic Al–Si alloys". Journal of Materials Processing Technology (2009) 5220–5228.

[5] E.R. Wang, X.D. Hui, G.L. Chen, "Eutectic Al–Si–C Fe–Mn alloys with enhanced mechanical properties at room and elevated temperature, Materials and Design" (2011).

[6] K. Raju, A.P. Harsha and S.N. Ojha. **"**Effect of processing techniques on the mechanical and wear properties of Al-20Si alloy**"**

[7] F. Wang, "Effect of Si content on the dry sliding wear properties of spray-deposited Al–Si alloy", Materials and Design, vol. 25, pp. 163–166, 2004.