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TECHNICAL PAPER

Wear Behaviour of ZA27-Based Composite Reinforced with 5 wt% of SiC Particles and Processed by Multi-directional Forging

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Abstract Zinc aluminium-based alloys (ZA/27) are widely used in bearing application, but due to its density and higher level of porosity of cast component, it limits the usage of these alloys in automobile industries. Stir casting technique followed by squeeze process was adopted. ZA27-based silicon carbide particles (SiC_P)-reinforced composite was subjected to multi-directional forging (MDF) at 100 °C and 200 °C up to three and six numbers of passes to a total strain of 0.54 and 1.09, respectively. Wear behaviour of ZA27/SiC_P was investigated using pin-on-disc test rig. Distributions of SiC_P were fairly uniform. Average grain size of 200–250 nm and 1–2 µm was achieved for three passes at 100 °C and six passes at 200 °C of MDF processed samples. Vickers hardness value increased by incorporation of SiC_P. Better wear resistance was observed for MDF processed sample at 100 °C up to three passes. Wear mechanisms of the samples were validated through characteristics of worn surfaces.

Keywords ZA27/SiC · Vickers hardness · Density

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1 Introduction

ZA27 alloy has become a suitable substitute for conventional counterpart materials like bearing bronzes, brass and copper-based alloys with lower density and higher mechanical properties [1]. The presence of optimum copper content in ZA27 alloy further improves the wear properties [2]. MMCs are the best way to achieve low density material with improved properties. Stir casting is one of the promising route for fabrication of metal matrix composites, especially for particle type of reinforcement to achieve uniform distribution. Additionally, it has some advantages like simplicity and applicability to bulk productions and large-sized components [3]. The addition of ceramic reinforcement to a metal matrix improves strength and stiffness, but at the expense of ductility [4]. The presence of porosity in cast component can be overcome by adopting severe plastic deformation process. Multi-directional forging is one the important process for producing ultrafine grain structure in bulk materials. MDF processed samples under plane strain condition shows improvement in mechanical and tribological properties [5]. It has been reported by Auras et al. [6] that wear resistance increased with addition of SiC_P. Investigation of Babic et al. [7] shows the improvement in wear behaviour after the incorporation of alumina particles under dry sliding condition. Purcek et al. [8] explained in their work that ECAP process influenced the toughness and improved the ductility by grain refinement. Aim of the present work is to investigate the influence of SiC_P in composites and grain refinement caused by MDF process on wear rate and to know the effect of different loading conditions with varying sliding distance at constant sliding velocity.

2 Materials and Experimental Details

Commercially available ZA27 alloy used as matrix material with a chemical composition of 27% Al, 2.5% Cu, 0.38% Fe, 0.02% mg and balance is zinc. SiC_P in 5 wt% was used as reinforcing material for preparation of composites. Stir casting technique followed by squeezing process was adopted for fabrication. Ascast samples were solutionized at 365 °C for 5 h and quenched in water; heat-treated sample was further machined to required dimension of 30 × 30 × 25 in millimetres. MDF process was carried out up to three passes at 100 °C and six passes at 200 °C using square channelled die with 40 ton hydraulic press. Die induced total cumulative strain of about 0.54 and 1.09 for three passes at 100 °C and six passes at 200 °C, respectively. The lowest possible temperature is desired during compression to control the grain growth. Molybdenum disulphide (MoS_2) paste was used as lubricant to avoid frictional effects. Work piece was pressed in such a way that entire volume of work piece was confined within the die and plastically deformed in nearly the same way of plane strain condition. Sample was rotated by 90° in two different directions for every pass so that samples should be forged from all sides. Microstructure observations were carried out on both processed and unprocessed samples using scanning electron microscope (JEOL-JSM-6380LA). Nital 3% was used as an etchant for etching to reveal the microstructure. CARL Zeiss-FESEM (Oxford Instruments EDS) was used to analyse the composition of composite. Archimedes's principle was used to measure the density of alloy and composites. Vickers microhardness was measured at an applied load of 1.961 N with a dwell time of 20 s at room temperature. Wear test was performed by using pin-on disc (DUCOM) wear testing machine in accordance with ASTM G99 standard. Wear specimen dimension was 28 mm in length and 6 mm in diameter. EN 31 hardened steel with an average hardness of 65BHN was used as counter surface, and 110 mm of track diameter was kept constant throughout the experiment. Worn surfaces were examined by SEM.

3 Results and Discussions

Microstructure and dispersion of reinforcing particles have a prominent role in improvement in properties of ZA27/SiC composites. Figure 1a, b shows the elemental mapping by energy-dispersive spectroscopy with respect to ZA27 composition and confirmation of particle's presence in the composites.

ZA27 alloy reveals a coarse dendritic structure with primary aluminium-rich α-phase surrounded by eutectoid $\alpha + \eta$ in the interdendritic region along with some intermetallic copper-rich ε-phase [9]. SEM micrograph of ZA27/SiC_P composites at different conditions is shown in Figs. 2 and 3. The sample, after solution heat treatment, breaks into dendritic structure and forms a grain-like structure which is shown in Fig. 2b. X-ray diffractogram of the ZA27 material shows that α, η, β and ε exist in solutionized condition as shown in Fig. 1c. Supersaturated β-phase in as-quenched specimen later transforms to α, ε and η phases [10, 11]. It is clear from the SEM micrographs of Fig. 3a, b that there is a substantial refinement in grain size after MDF process up to three and six numbers of passes at different temperatures. A coarse-grained structure in unprocessed sample can be observed with the grain size of 20–25 µm. MDF processed up to three passes at 100 °C shows ultrafine grains with an average grain size of 200–250 nm as shown in Fig. 3a. Approximately, 1–2 µm of grain size with homogeneous grain structure is achieved for MDF processed samples up to six passes at 200 °C. Formation of ultrafine grain structure can be attributed to very large strain deformation. Density and Vickers hardness value of ZA27 alloy and its composites are given in Table 1. Results show that after solutionized heat treatment, there is an increase in density, but on addition of SiC_P, density value decreases in considerable amount; further processing leads to complete elimination of remaining porosity which shows increase in density. The hardness value increases from 134 to 148 with the incorporation of SiC_P. This improvement in hardness of composite is attributed to thermal strain mismatch between the SiC particle and ZA27 matrix during casting process.

These thermal strain values decrease as the distance between reinforcement and matrix interface increases [12]. The presence of particles acts as an obstacle to the movement of dislocation, and these dislocations are generated during cooling process due to difference in thermal expansion coefficient between the matrix and ceramic particles. Further processing leads to increase in hardness to 170Hv and 166Hv for material processed at three and six numbers of passes, respectively. The increase in hardness of processed sample is due to the grain refinement with increased volume of grain boundaries which occur during plastic deformation.

Wear behaviour of the alloy and its composites have been tested with varying applied load (39.24 N, 49.05 N and 58.86 N) and sliding distance (2000 m and 4000 m) at a constant sliding velocity of 1 ms^{-1}. Wear rate increases for samples tested with 4000 m of sliding distance as compared with 2000 m, and it is shown in Fig. 4. Applied load has a major influence on wear rate than that of sliding distance. Wear resistance of the material decreases with increase in applied load and sliding distance. The presence of SiC particles improve the wear resistance of ZA27 alloy

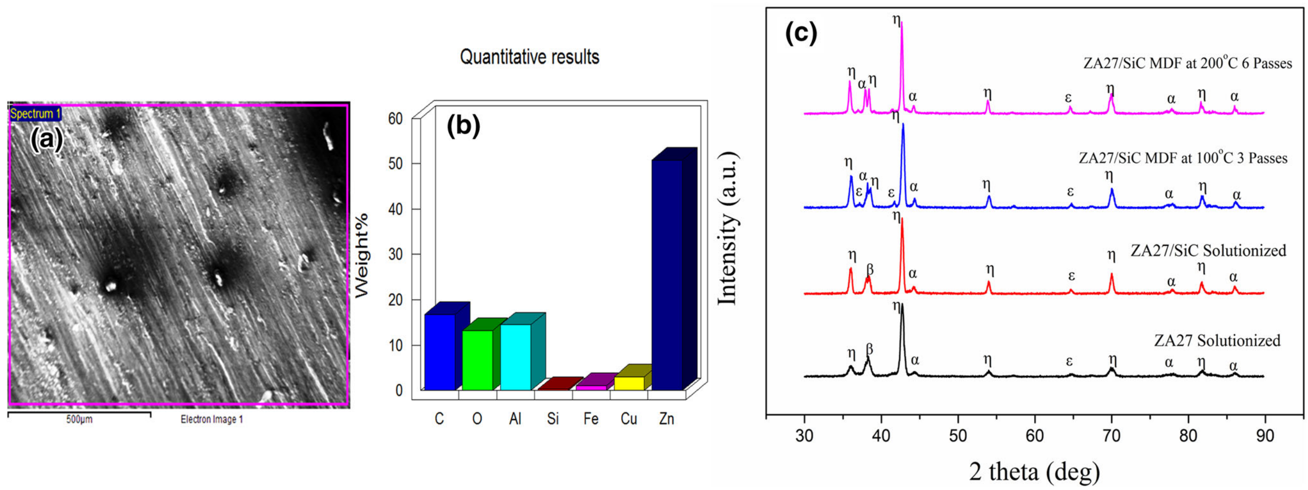

Fig. 1 **a** EDS micrograph showing distribution of SiC particles. **b** ZA27/SiC composition. **c** XRD patterns of ZA27 alloy and composite sample MDF processed at different temperatures

Fig. 2 SEM image of ZA27 composites **a** ZA27 ascast. **b** ZA27/SiC$_P$ solutionized

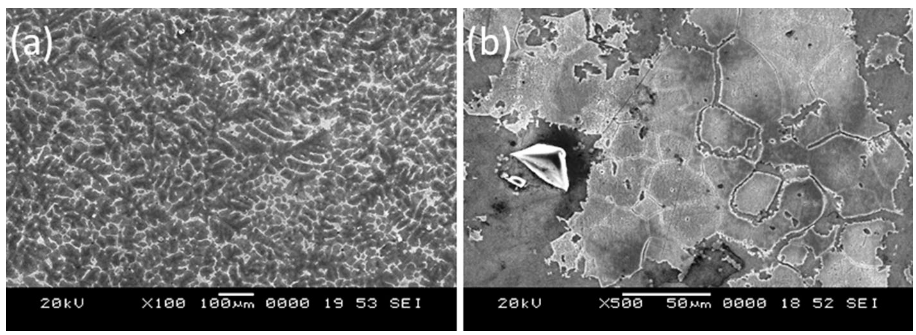

Fig. 3 SEM of ZA27 composites **a** MDF three pass at 100 °C. **b** MDF six pass at 200 °C

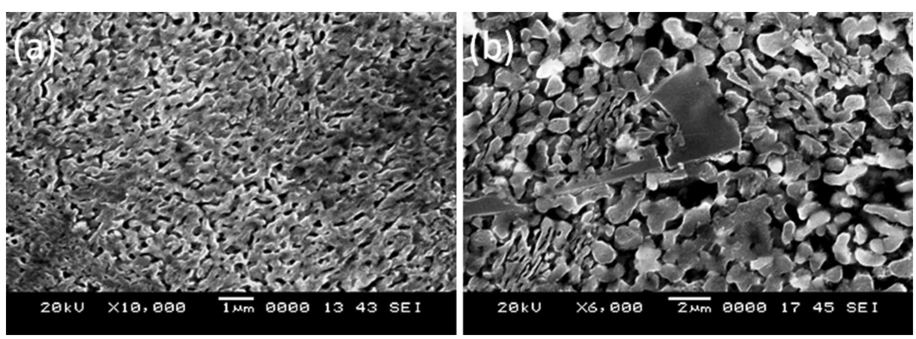

Table 1 Variation of density and Vickers hardness value as a function of material condition

Sl. no.	Material condition	Density [g/cm^3]	Vickers hardness
1	ZA27 ascast	5.2189	117
2	ZA27 solutionized	5.2521	134
3	ZA27 + 5% SiC	5.0783	148
4	ZA27 + 5% SiC + MDF 3P at 100 °C	5.1104	170
5	ZA27 + 5% SiC + MDF 6P at 200 °C	5.1222	166

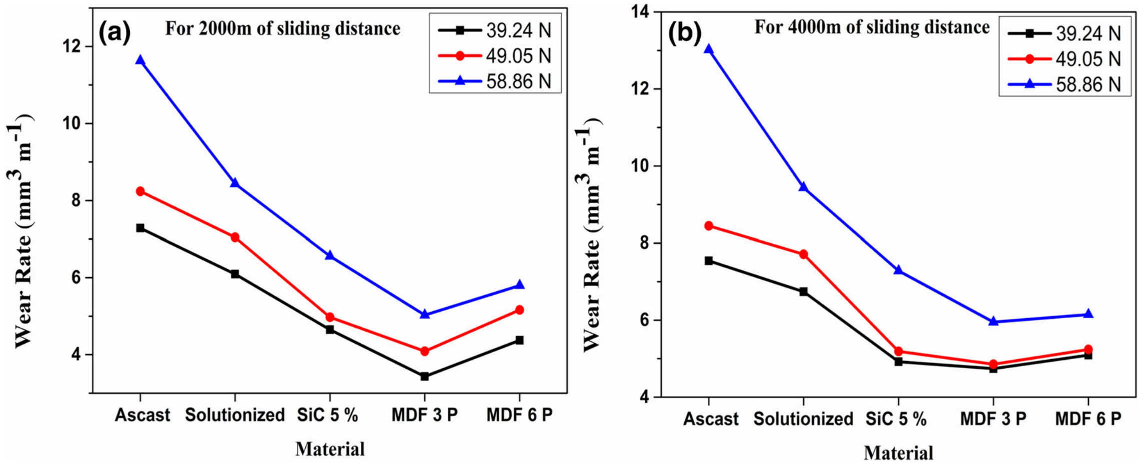

Fig. 4 Wear rate of material **a** 2000 m of sliding distance. **b** 4000 m of sliding distance

as it is correlated with hardness by Archard equation [8]. The positive effect of SiC towards enhancement of the wear behaviour of the ZA27 material was confirmed by Mitrovic et al. [4]. MDF processed sample has shown better wear resistance as compared with unprocessed composite. The improvement in wear behaviour of processed samples is due to the enhanced mechanical properties of the ZA27/SiC material. MDF processed up to three passes at 100 °C has maximum wear resistance due to the presence of micro-constituents and by formation of ultrafine grain structure. For brevity and convenience, only few micrographs have been presented in Fig. 5 which shows the worn surface morphology of ZA27 alloy and its composite. Wear surface of ZA27/SiC_P samples tested at 39.24 N and 2000 m with a constant sliding velocity of 1 ms^{-1} reveals some scratches and grooves caused by abrasive action of hard ε particle in the form of debris removed from the sample surface, and these particles caught in between the mating surface result in abrasion which shows that the main wear mechanism is abrasive type for lower load and shorter sliding distance condition. The presence of SiC_P and debris of the base matrix material shown in Fig. 5c has a major influence on wear behaviour of material. Some micro-cracks are observed in Fig. 5d. At

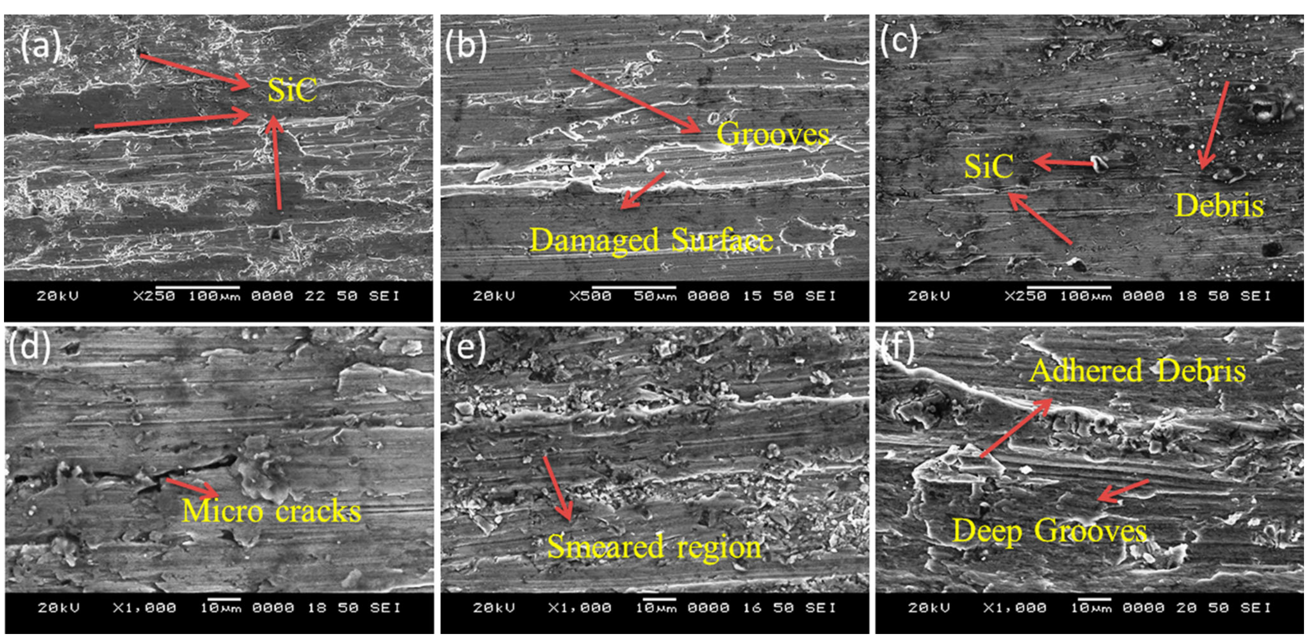

Fig. 5 Wear surface of ZA27 alloy and its composites under varying load and sliding distance **a** ZA27/SiC sol-39.24 N and 2000 m. **b** ZA27/SiC-MDF three pass 49.05 N and 2000 m. **c** ZA27/SiC-MDF six pass 58.86 N and 2000 m. **d** ZA27/SiC sol-39.24 N and 4000 m. **e** MDF three pass- 49.05 N and 4000 m. **f** MDF six pass- 58.86 N and 4000 m

higher applied load and sliding distance, the debris gets smeared and adhere to the surface of the pin which in turn increases the temperature between the pin and disc causing lower wear resistance with an adhesive type of wear mechanism. In mentioned research [1], the observations indicated that severe adhesive wear took place by material transfer from the pin to the steel ring, and detachment of long arc shaped metallic debris from the pin material were seen. Similar type of observation was made by other researchers showing particle reinforced composites performing better as compared with unreinforced ones with dual type of wear mechanism [13].

4 Conclusions

After successful fabrication of ZA27/SiC_p with 5 wt%, stir casting technique followed by squeezing was further processed up to three passes at 100 °C and six passes at 200 °C by MDF processing. Porosity was reduced by squeezing the molten metal during solidification; additionally, density of composite decreased with the addition of SiC particles. Fair distribution of SiC_P was observed in SEM micrographs with few clusters. Grain size reduced to 200–250 nm for MDF processed at 100 °C up to three passes, and at 200 °C, up to six passes showed 1–2 μm of average grain size. Significant increase in hardness was achieved from 117 to 170 and 166Hv for MDF processed samples at 100 °C for three passes and six passes at 200 °C, respectively. As applied load and sliding distance increased, the wear rate of the material also increased. Samples tested with lower load and sliding distance showed abrasive type of wear mechanism, but as the applied load and sliding distance increased, mechanism changed to adhesion type. Due to the rise in temperature between the interface of pin and disc, material detached from the pin as debris got adhered to the surface of pin which influenced the mode of mechanism to switch from abrasion to adhesion. MDF processed ZA27/SiC_p for three passes at 100 °C showed better wear resistance with fine grains and higher hardness.

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