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Machinability Characterization of Ecodesigned Hybrid Aluminium Composites

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Machinability is expressed as the ease with which a material can undergo machining operations with gratifying surface finish and persistent material removal rate. In general, alumiAnium composites are observed to be difficult to machine due to infusion of hard reinforcement particles into metal matrix. In present study, machinability attributes of Al7075-T6/ Eggshell/SiC/Al_2O_3composites (Al7075-T6 as matrix material infused with three reinforcement materials: eggshell particles with average particle size ~ 60 µm; wt. % 0.5, 1and 1.5, Silicon Carbide particles with average particle size ~ 65 µm; wt. % 1, 1.5 and 2, and Aluminium Oxide particles with averageparticle size ~90 µm; wt. % 1.5, 2 and 2.5,) synthesized through electromagnetic stir casting route, have been investigated with fixed machining parameters (Cutting speed : 6 m/min, Depth of cut: 1mm, Feed rate: 0.3 mm/second and Test duration: 30 seconds). With enhanced mechanical attributes, the machinability of synthesized aluminium composites was realized to remain uninfluenced in terms of proportionate material removal rate (material removal rate of specimen S8: 0.0040g/sec and of specimen S0: 0.0043g/sec) and comparable surface roughness (average surface roughness of specimen S8: 1.02 µm and of specimen S0: 1.15µm). Disposal of eggshells has been listed worldwide as one of the worst environmental problems, hence eggshell powder has been used as one of the reinforcement in order to synthesize ecodesigned hybrid aluminium composites.

Keywords: Stir casting, hybrid composites, reinforcements, machinability, material removal rate, average surface roughness

1 Introduction

In recent years, material science research has predominantly culminated into evolution of composites materials. These materials are unquestionably advantageous while analysing cost–performance equation in component production. Aluminium metal matrix composites with augmented attributes have emerged as revolutionary materials for various engineering aspects. Aluminium/ aluminium alloys with low density, high strength, exquisite thermal and electrical characteristics and cost effectiveness are infused with distinctive reinforcements such as titanium boride, titanium carbide, silicon carbide, tungsten carbide, graphite, red mud, fly ash, bamboo leaf and rice husk *etc.*, to synthesize composite materials according to the anticipated applications. Aluminium composites exhibit modifiable characteristics depending upon matrix material, reinforcement material, reinforcement content, processing route and processing parameters. Although traditional aluminium composites demonstrate improved characteristics as compared to the unreinforced base metal, but with a negative repercussion on many other properties, which are crucial to retard the premature failure of mechanical components[1, 2]. Composites, synthesized using matrix material and two or more reinforcement materials with different traits, causing enhancement in various characteristics within composites and diminishing the disagreeable traits of reinforcements are known as hybrid composites. Hybrid composites display consolidation of characteristics discordant to the traditional composite materials and have humongous capabilities for modifications in their attributes for distinct requirements. SiC and Al_2O_3 blended with Al 6061 alloy exhibited enhanced hardness and tensile strength and reduced impact strength and ductility[3]. Composites prepared with an amalgamation of rice husk ash, aluminium oxide and aluminium displayed enhanced strength, increased fraction toughness, decreased density and reduced hardness[4]. Hybrid aluminium composites fabricated by mixing SiC particles and bamboo leaf ash with Al-Mg-Si alloy demonstrated improved corrosion resistance and fracture toughness. Other essential characteristics of

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these aluminium composites such as tensile strength, density and hardness were degraded[5]. Reduced density and improved tensile strength were realized for Al6061/SiC/Gr composites[6].Aluminium metal matrix composites with upgraded hardness and tensile strength were synthesized by infusing titanium oxide and graphite particles into Al6061 alloy matrix[7]. AA6082/Si_3N_4/Gr hybrid composites demonstrated augmented tensile strength and hardness[8]. Hybrid aluminium composite with silicon carbide and rice husk ash as reinforcements and A356.2 alloy as base metal exhibited improved hardness, enhanced tensile strength, reduced density and decreased thermal coefficient of expansion in comparison of base alloy[9]. Al8090/SiC/calcinated fly ash hybrid aluminium composites offered resistance to chemical degradation in extreme environmental conditions[10]. Al/Zn/Al_2O_3 composites exhibited enhanced thermal stability[11]. Aluminium alloy Al6063 infused with aluminium oxide (Al_2O_3) and zircon sand ($ZrSiO_4$) to prepare composites, demonstrated increased hardness and tensile strength[12]. Hybrid composite LM25/SiC/Gr displayed augmented hardness with remarkable wear properties[13].

Though there are certain complexities associated with the phenomena of hybridization during development of hybrid composites, such as hybrid mode, hybrid ratio, reinforcements tendencies, interfacial bonding between reinforcement and preform phases, processing parameters, component design and strength concept, however hybrid aluminium composites are observed to be cost effective materials with outstandingly improved physical, mechanical, thermal and electrical attributes in comparison of the conventional composites and unreinforced alloys[14]. Though, particulate reinforced aluminium composites can be synthesized through numerous processing techniques, however vortex techniques (stir casting) is realized to be the simplest and cost effective with certain associated complications such as insufficient wetting due to weak interfacial bonding between matrix material and reinforcement particles and inconsistent distribution of reinforcement particles due to the centrifugal force of rotating molten aluminium. To surmount these difficulties in present study, electromagnetic stir casting technique has been adopted for synthesis of hybrid aluminium composites. In accordance with the design layout of experiment based on Taguchi orthogonal array L9, nine aluminium hybrid composite specimens were synthesized and evaluated for machinability.

2 Experimental Details

Al7075-T6 with elemental composition as specified in Table 1 has been used as base metal for composite fabrication in this experiment.

Disposed eggshells are strikingly serious hazard to our environment, as they straight away contribute to pollution in terms of odour generation and microbial growth and there is no certain time limit for decomposition of eggshells in soil. In present experimental investigation egg shells have been recycled as shown in Fig. 1 and used as natural particulate reinforcement (density: 2.15 g/cc, average particle size ≈ 60 microns) with commercially available silicon carbide particles (density: 3.21 g/cc, average particle size ≈ 65 microns) and aluminium oxide particles (density: 3.95 g/cc, average particle size ≈ 90 microns) for synthesis of hybrid aluminium composites with distinctive characteristics.

Present study includes preparation of nine hybrid aluminium metal matrix composites with Al7075-T6 as metal matrix and varying weight percentage of fillers as per Taguchi L9 orthogonal array as shown in Table 2.

To prepare hybrid aluminium composites, cleaned and weighed ingots of Al7075-T6 were heated in a graphite crucible up to 900 °C in the electric furnace of mechanical stir casting setup as shown in Fig. 2a, followed by infusion of preheated (at 500 °C for 1 hour) reinforcements into molten aluminium alloy at 850 °C. The preheated mechanical stirrer rotating at 150 rpm was used to stir the molten base metal and reinforcement mixture in inert atmosphere.

In order to trounce the agglomeration and uneven dispersion of reinforcement particles in base metal

Table 1 — Composition of Al7075-T6[15]

Sl. No.	Component	Weight %	Sl. No.	Component	Weight %
1.	Aluminium	87-91	6.	Manganese	>0.3
2.	Chromium	0.18-0.28	7.	Silicon	>0.4
3.	Copper	1.2-2	8.	Titanium	>0.2
4.	Iron	>0.5	9.	Zinc	6
5.	Magnesium	2.1-2.9	10.	Others	Balance

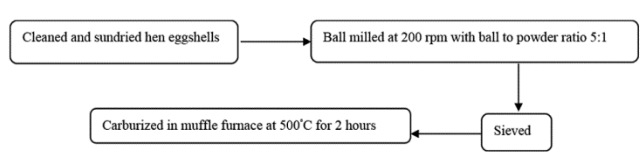

Fig. 1 — Recycling of hen eggshells

Table 2 — Design of experiment for composite synthesis as per orthogonal array L9

Hybrid aluminiumcomposite specimen number (S1 to S9)	Eggshell weight percentage	Silicon Carbide weight percentage	Aluminium Oxide weight percentage	Mechanical Stirring Time (minutes)
S1	0.5	1	1.5	2
S2	0.5	1.5	2	4
S3	0.5	2	2.5	6
S4	1	1	2	6
S5	1	1.5	2.5	2
S6	1	2	1.5	4
S7	1.5	1	2.5	4
S8	1.5	1.5	1.5	6
S9	1.5	2	2	2
S0	As-cast Al7075-T6 specimen (Base metal with no reinforcement)			

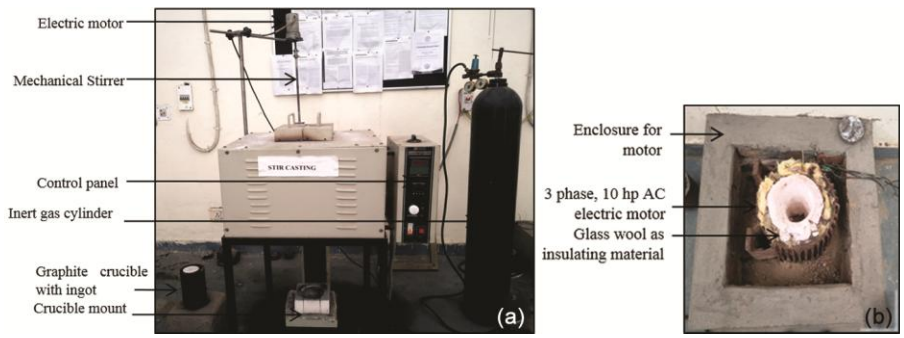

Fig. 2 — (a) Conventional mechanical stir casting setup (b) electromagnetic stirrer

melt, the crucible containing composite amalgam was placed on the electromagnetic stirrer (a 10 horse power, 3 phase AC motor) rotating at 960 rpm in inert atmosphere, for 30 seconds, as shown in Fig. 2b.

The casted hybrid aluminium composites were solidified in the crucible itself and specimens were prepared on wire cut EDM for various characterizations. As-cast base metal and synthesized composites specimens, as shown in Fig. 3a were evaluated for machinability on a conventional lathe machine (Model No. SG: 2, Electric motor: 2HP, Speed 50-1200 rpm, Distance between centres: 125 mm) with tungsten carbide cutting tool (tool material harder than reinforcement materials to ascertain the acceptable performance during machining) as shown in Fig. 3b.

3 Results and Discussion

These synthesized composite specimens were previously assessed for various characteristics and it was observed that hybrid aluminium composite specimen S8 (Al7075-T6/1.5 weight percentage of eggshell/1.5 weight percentage of silicon carbide/1.5 weight percentage of aluminium oxide) demonstrated multi fold intensification in physical and mechanical attributes in comparison of the unreinforced as-cast

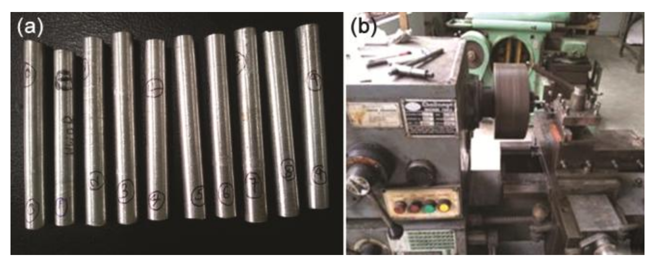

Fig. 3 — (a) Specimens for machinability study (b) Lathe machine for machinability study

Al7075-T6 specimen S0. Augmented characteristics of advance engineering materials can be of exhaustive utilization, when consolidated with reasonable machinability. Aluminium composites are contemplated as state-of-the-art functional materials with improved mechanical attributes, yet sometimes the presence of abrasive reinforcement materials, contribute significantly in their strenuous machining, increasing the product cost and restraining their widespread applications in industry. Machinability is described as the extent of ease with which a material is machined with justifiable surface finish and consistent material removal rate. In present experimental study, specimens were evaluated for their machinability in terms of material removal rate, average surface roughness and types of chips formed, with fixed machining parameters as mentioned below:

- Cutting speed: 6 m/min
- Depth of cut: 1mm
- Feed rate: 0.3 mm/second
- Test duration: 30 seconds

Material removal rates of as-cast Al7075-T6 specimen S0 and various hybrid aluminium composite specimens are shown in Table 3.

It displays that the material removal rate reduced insignificantly in synthesized hybrid aluminium metal matrix composites as compared to their unreinforced counterpart (as-cast Al7075-T6) and this may be attributed to the phenomenal uniform dispersion of reinforcement particles into matrix material through electromagnetic stir casting technique.

Table 4 demonstrates, average surface roughness of machined specimens Ra (arithmetic mean roughness value).

As the tungsten carbide cutting tool machined synthesized hybrid aluminium composite specimens and interacted with the hard reinforcement particles present, two possibilities emerged influencing the surface finish of machined specimens. When cutting tool came in contact with the reinforcement particle and the particle was sheared, improved surface finish was observed and when the reinforcement particle was dislocated and pulled out by the cutting tool, pits and cracks were conceived at the component surface contributing towards inferior surface finish in comparison of unreinforced base metal. Figure 4 displays a combined depiction of material removal rate and surface finish of evaluated specimens.

Chips formed during machining of specimens were analysed and it was realized that longer chips were obtained for as-cast unreinforced Al7075-T6 alloy due to its ductile nature, whereas semi continuous (saw toothed segmental) chips were acquired for hybrid aluminium compositesdue to micro-ploughing and reinforcement particle fracture, as shown in Fig. 5.

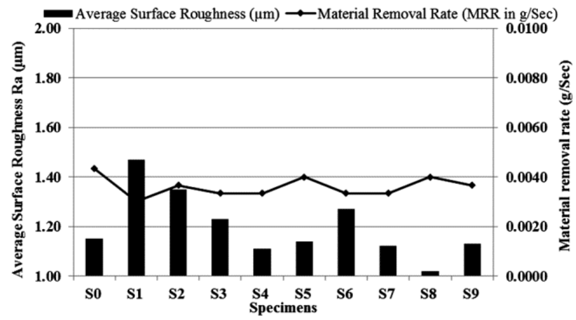

Fig. 4 — Material removal rate and surface roughness of specimens

Fig. 5 — Chips formed during machining of as-cast Al 7075 and composite specimen

Table 4 — Surface roughness of specimens

Specimen name	Average surface roughness Ra (µm)
S0	1.15
S1	1.47
S2	1.35
S3	1.23
S4	1.11
S5	1.14
S6	1.27
S7	1.12
S8	1.02
S9	1.13

Table 3 — Material removal rate of specimens during machinability study

Specimen name	RPM	Initial weight of specimen (g)	Final weight of specimen (g)	Material removed from specimen (g)	Material removal rate of specimen (MRR in g/sec)
S0	195	18.87	18.74	0.13	0.0043
S1	195	16.53	16.44	0.09	0.0030
S2	195	18.62	18.51	0.11	0.0037
S3	195	18.91	18.81	0.10	0.0033
S4	195	18.05	17.95	0.10	0.0033
S5	195	17.47	17.35	0.12	0.0040
S6	195	16.18	16.08	0.10	0.0033
S7	195	17.95	17.85	0.10	0.0033
S8	195	17.22	17.10	0.12	0.0040
S9	195	17.04	16.93	0.11	0.0037

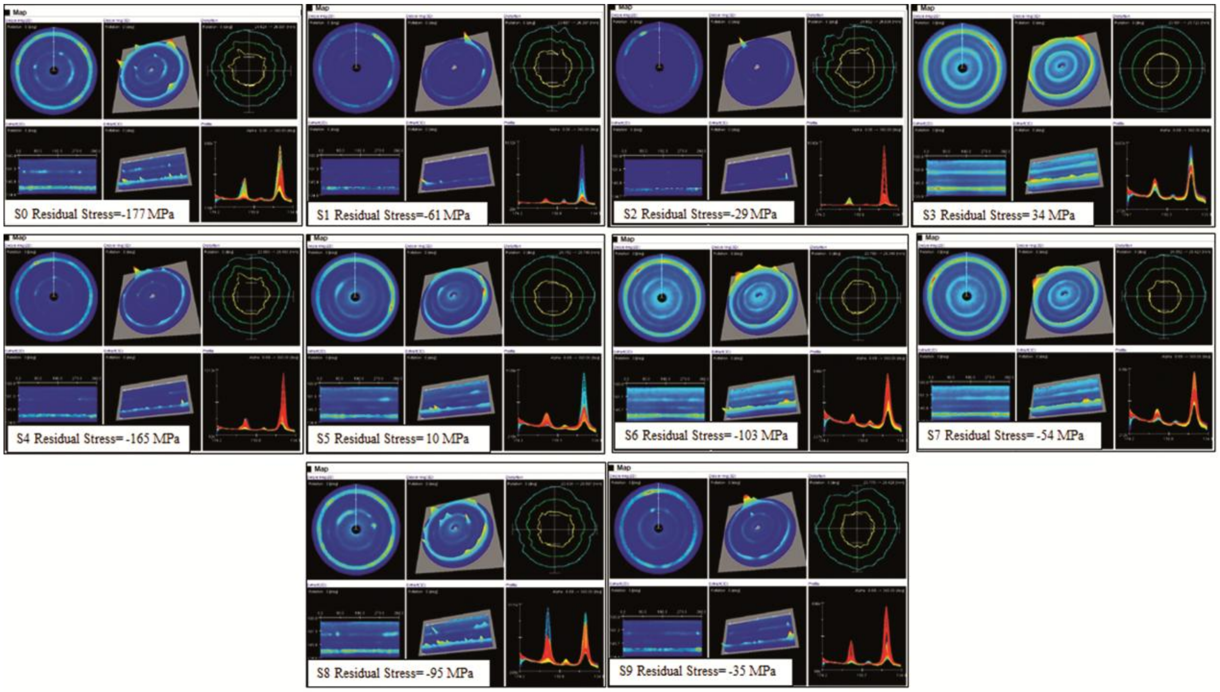

Fig. 6 — Residual stress in machined specimens

The present experimental investigation endorses wide industrial applications of synthesized hybrid aluminium composites with reasonable machinability and significantly augmented attributes due to uniform dispersion of reinforcement particles into Al7075-T6 matrix through electromagnetic stir casting route. Additionally, residual stresses of machined specimens were also measured using a non-destructive X-ray analyzer (μ-X360) through X-ray diffraction technique, as shown in Fig. 6.

4 Conclusion

In general, machining of hybrid aluminium composites has been observed to be troublesome in comparison of as-cast Al7075-T6 due to hard reinforcement particles infused into aluminium matrix, resulting into unstable material removal rate, degraded surface finish and increased tool wear. Usually the total manufacturing cost of a component is enhanced by 20% due to its machining cost, therefore moderate machinability is desirable in hybrid aluminium composites besides enhanced mechanical and physical characteristics.

In this experimental study, nine Al 7075-T6/ Eggshell/SiC/Al_2O_3 hybrid composites were prepared via electromagnetic stir casting technique. On infusion of reinforcement particles, various mechanical and physical properties were enhanced appreciably whereas machinability of synthesized hybrid aluminium composites was realized to remain unblemished in terms of consistent material removal rate (material removal rate of composite specimen S8: 0.0040g/sec and of as-cast base metal Al7075-T6 specimen S0: 0.0043g/sec) and commensurate surface finish (average surface roughness of composite specimen S8: 1.02μm and of as-cast Al7075-T6 specimen S0: 1.15μm). The chips formed during machining of hybrid aluminium composite were curled and semi-continuous. It was substantiated that by adding a diminutive reinforcement content (weight percentage) the attributes of synthesized hybrid composites were improved considerably with justifiable machinability, advocating them as plausible alternatives for diverse advance engineering applications.

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