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A novel approach in fabrication of a hybrid green metal matrix composite using waste egg shells and snail shell ash as reinforcements

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Abstract: The effective utilization of biowaste is mandatory for sustainability of our society. The aluminum (Al) alloy is reinforced with different volume fractions of silicon carbide (SiC), waste carbonized eggshells (WCE) and snail shell ash (SSA) and fabricated by stir casting process. To manifest the global need of novel hybrid composites with reduced weight, high strength and cost effectiveness, this paper leads to the development of a new hybrid composite. Experimental results shows increased hardness, tensile and fatigue strength while decrease in fracture toughness, ductility and corrosion rate which is improved by heat treatment. The optimum values are obtained at 12.5 wt. % of WCE and 7.5 wt. % SiC+SSA. The samples are kept stable and non-reactive at most favorable temperature. Mono-ethylene glycol (MEG) in aqueous solution is used for the experiments. The hardness is augmented to a maximum value at 7.5 wt. % SiC+SSA addition and gets decremented at 10 wt. % SiC+SSA addition. Microstructures of composites show uniformity in interfacial bonding and distribution of WCE. Density and overall cost of the composite are decreased which infer improvement of mechanical properties with the addition of WCE particulates.

Keywords: Wettability, porosity, interfacial bonding, tensile strength, hardness

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1. Introduction: Various industrial sectors use AMC **[1, 2]** for their improved tribo mechanical properties. Modern improvements in development of hybrid composites embraced by stir casting route were performed by Daoud et. al. **[3]**, powder metallurgy **[4, 5]**, spray-atomization by Wu et. al. **[6]**, plasma spraying as done by Tiwari et. al. **[7]**, squeeze-casting as experimented by Kim et. al. **[8]** and compo-casting **[1, 9].** Recent trends in AMC includes various ceramic reinforcements **[1, 5]**, but here, we have used egg shells (ES), waste carbonized egg shells (WCE), snail shell ash (SSA), silicon carbide (SiC) and boron carbide (B_4C) with varying weight fractions by stir casting at squeezed pressure and optimum controlled conditions which is a novel approach. The main objective of this research is to flourish a novel hybrid green composite by recycling and reutilizing the hazardous wastes using liquid casting route for mass production at cheap rate.

Current trends involve recycling of different industrial wastes for environmental sustainability. Chemical affinity, shape and size of the reinforcements directly affect their microstructure and physio tribo-mechanical properties. Improper wettability is originated by the occurrence of oxide formation and adsorbed contaminants on the surface of the alloy. Strong interfacial bonds are a must criteria for improved wettability. Therefore, addition of different metallic coatings like magnesium and calcium and by heat treatment method is essential for improvements. Better tribomechanical characteristics are attained with incremented percentage of WCE than ES by Hassan et. Al. **[10]** and obtained a huge decrement in the impact energy. Toro et. al. **[11]** used different proportions of ES in polypropylene composite with various proportions and obtained improved Young's modulus with greater connotations of ES. Bootklad et. al. [12] used molding in high compression and prepared thermoplastic starch and investigated the nano-indentation technique in hybrid composites. Alaneme et. al. [13, 14] found higher corrosion rate of AMC reinforced with rice husk ash and alumina with increased reinforcement percentage weight.

After identifying the gaps in the literature, it was mandatory to develop a novel hybrid green AMC by obtaining superior physio-mechanical properties. An investigation was conducted to prove the feasibility of producing Al matrix/WCE green metal matrix composites by using stir casting process which proved the feasibility of a better hybrid green composite.

2. Experimental Setup

2.1. Materials and equipment: The material library is shown in Table (1) and mechanical properties in Table (2). Spherical SEM morphology of ES particles is shown in Figure (1e) and flaked shape morphology is shown in Figure (1f). Experimental samples with detailed specifications are shown in Figure (2).

Table (1): Material composition

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Cr	Al
wt.%	0.7	0.5	4.3	0.6	0.5	0.25	0.2	0.1	0.1	Balance

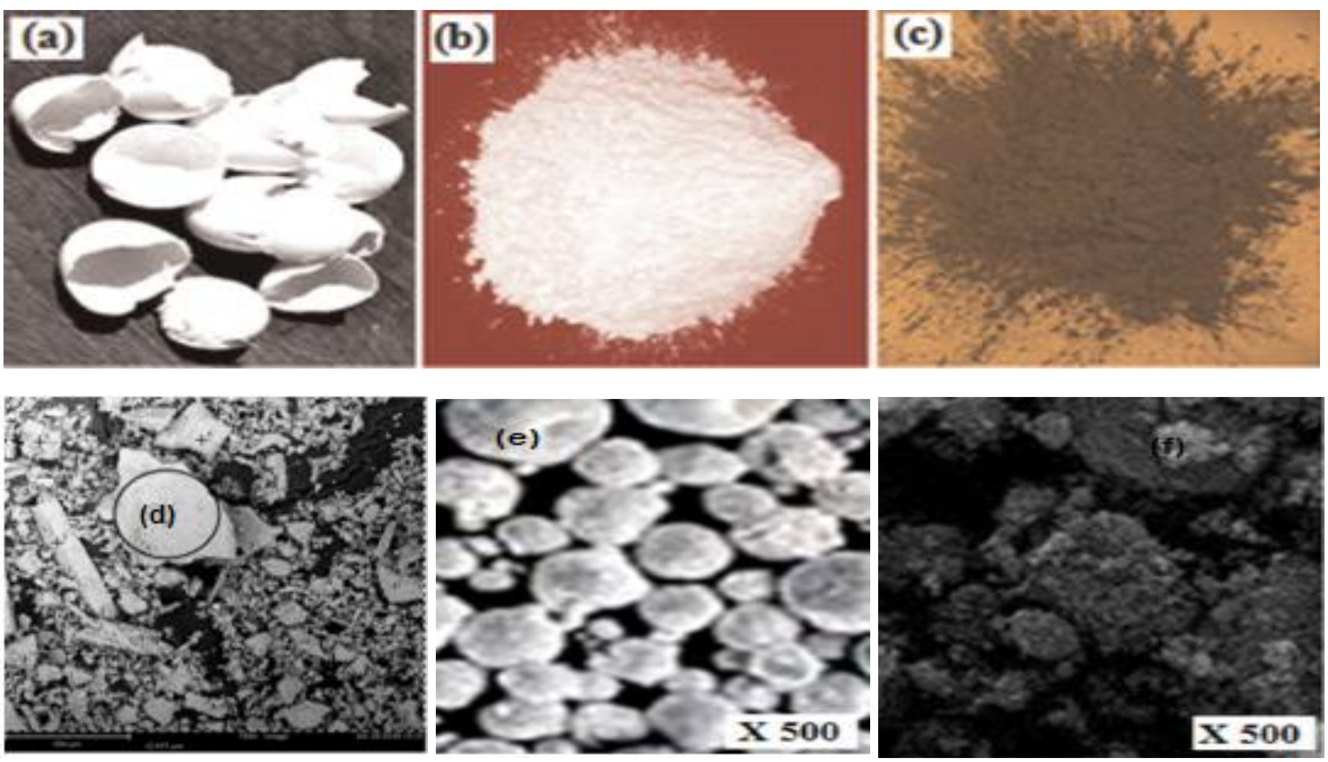


Figure (1): Pictures of (a) eggshells, (b) ES powder, (c) WCE powder, (d) SEM morphology of SiC+SSA, (e) SEM morphology of ES, (f) SEM morphology of WCE.

Table (2): Measured mechanical properties by Alaneme et. al. [14].

Melting point	640 ^{0}C
Density (g/cm^3)	2.8
Tensile strength (MPa)	185
Hardness (BHN)	60
Toughness (J)	12
Ductility (percentage elongation)	13
Fatigue strength (MPa) 1 x 10^7 cycles	90

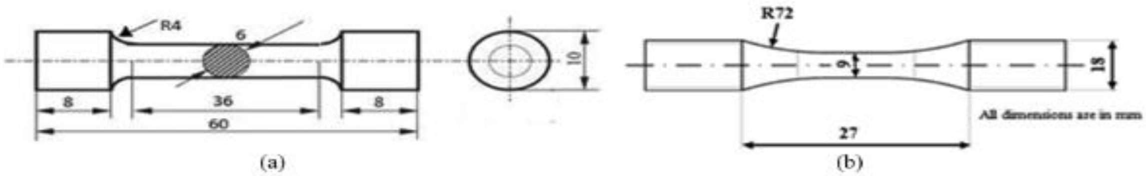
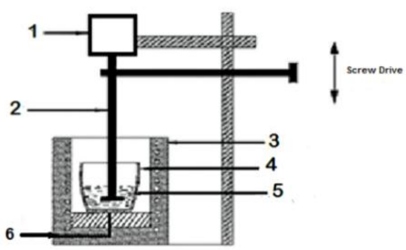


Figure (2): (a) Tensile and (b) fatigue sample.

2.2. Composite advancement: Al matrix was heated to a temperature of 780 °C, melted in a furnace and then cooled approximately to 600°C as shown in Figure (3). It was then superheated to 800 °C and manually stirred at 300 rpm for 12 minutes and a current of 10 Ampere. The mixture varying the wt. % (0, 2.5, 5, 7.5, 10, 12.5 and 15) of reinforcements before and after heat treatment was then solidified into the mould.



1. Motor
2. Stirrer
3. Furnace
4. Graphite Crucible
5. Molten Metal
6. Thermocouple

Figure (3): Experimental set up by stir casting route.

2.3. Analysis of porosity: To find the experimental densities, Archimedes principle was used. Material properties are highly influenced by porosity and compactness. Porosity was calculated as the accumulative ratio of both the densities of the composites as obtained by Dwivedi et. al. [16]

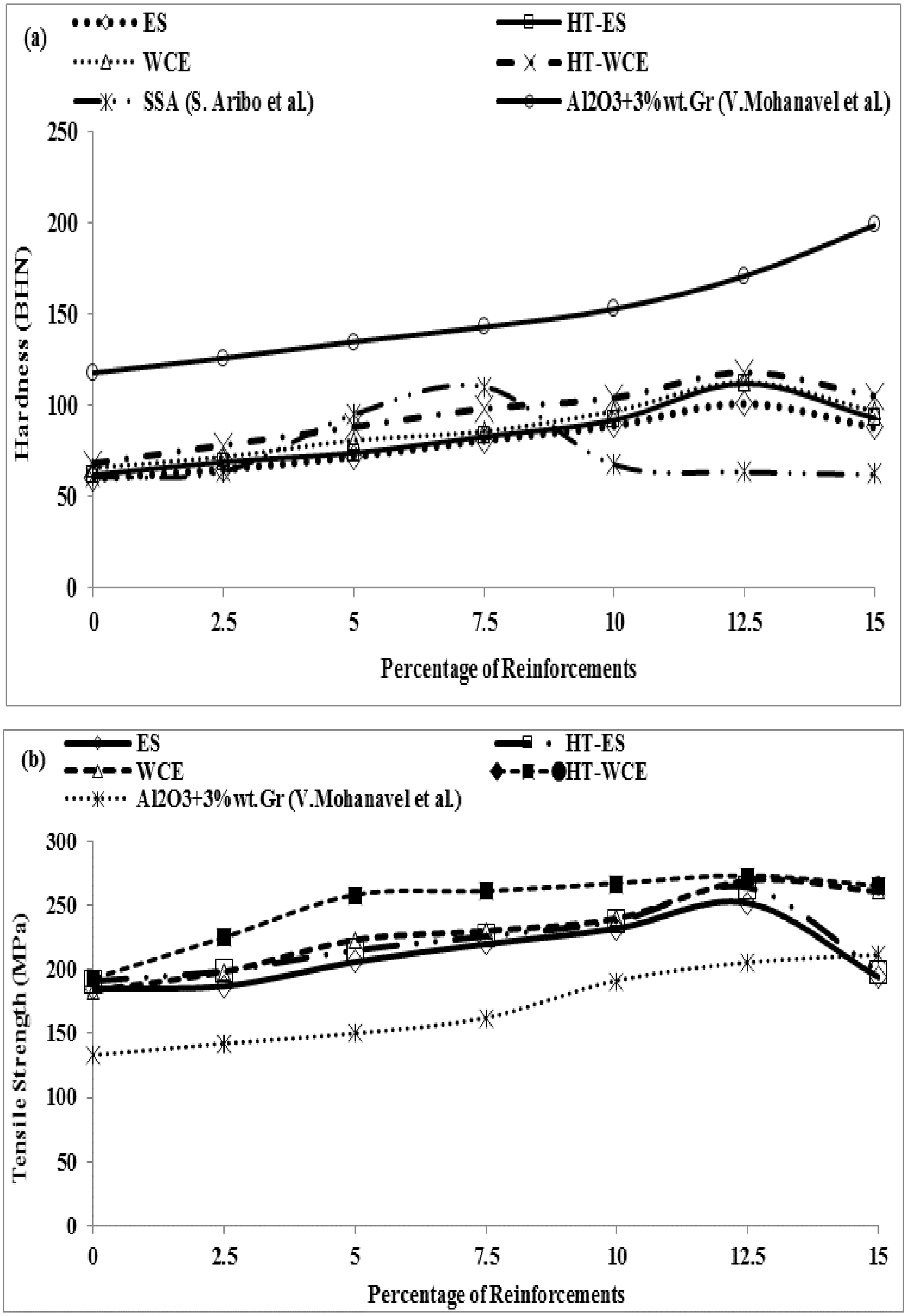
$$P = 1 - \frac{\rho exp}{\rho theo} \text{ x } 100\% \quad (1)$$

2.4. Analysis of corrosion rate: High alkaline container was used where the composites were kept for 5 days at room temperature in 3 wt.% NaCl solution. Uniform corrosion was assumed, where K = 8.75 × 10^4, A = 9 cm^2, t = 120 hours as observed by Dwivedi et. al. [16]

$$CR = \frac{WxK}{\rho xAxt} \quad (2)$$

3. Experimental result analysis

3.1. Assessment of mechanical properties: In this research, the hardness of AMC amplified from 60 BHN (0 wt. %) to 102 BHN for ES and 114 BHN for WCE (12.5 wt. %), respectively, and 61 BHN (0 wt. %) to 111 BHN (7.5 wt. %) of SiC-SSA according to S. Aribo et. al. [17], and then decreased as shown in Figure (4a).



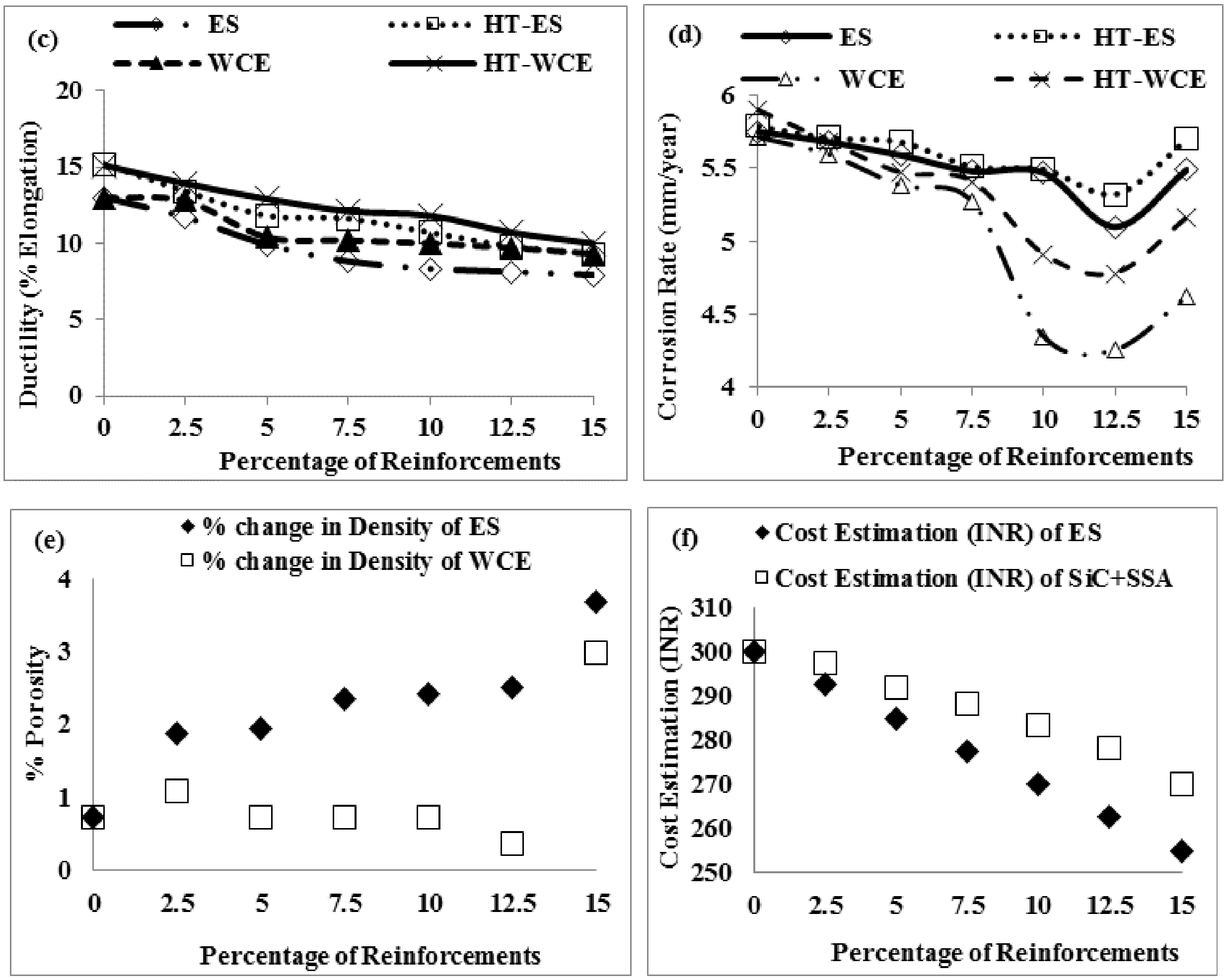


Figure (4): Tribo-mechanical properties of hybrid green AMC.

The increment was because of existence of brittle phases of the eggshell particles and then got decremented which might be due to the air entrapment indicating larger pore formation resulting in decrease in mechanical properties. Hardness of WCE and ES was enhanced to 120 BHN and 113 BHN, respectively after heat treatment. But, Mohanavel et. al. [18] indicated increase in the hardness with graphite (Gr) addition resulting in brittle fracture. Figure (4b) indicates improvement in tensile strength up to 12.5 wt.% in the Al alloy. Tensile strength improved from 186 MPa (0 wt.%) to 253 MPa and 271 MPa for ES and WCE (12.5 wt.%), respectively because uniform eggshell particles were distributed in the Al alloy matrix and then decreased due to weak particle-matrix interaction. Mohanavel et al [18] clearly indicated that increase of addition Al_2O_3 and Gr increased the tensile strength upto 206 MPa and then decreased. The decrement in ductility and corrosion rate occurred with the reinforcements' addition as shown in Figure (4c) and Figure (4d).

3.2. Microstructure analysis: The microstructure of Al+12.5 wt. % WCE showed an improved result with respect to porosity as shown in Figure (1e, f).

3.3. Porosity analysis: Figure (4e) shows the percentage change in density of composites and calculation of porosity. Experimental density of composite = mass of composite/volume. Porosity of Al matrix / 12.5 wt. % WCE (P) = (1 - 2.69/2.70) × 100 = 0.37 % which was found to be the best result on comparing with that of ES.

3.4. Cost analysis: The initial cost of the material was set to be approximately 300 INR. The eggshell particles are readily available free of cost. Cost of Al matrix+12.5 wt. % ES is predicted to be 263.5 INR which is much lower than SiC-SSA which is 277 INR as shown in Figure (4f).

4. Conclusion: Eggshell and snail shells' dust are highly injurious to health which needs to be properly recycled and reutilized. The novel approach is to fabricate AMC with stir casting which is the easiest casting technique for mass production with fewer limitations. Eggshell particles are much favorable as a reinforcement material than SiC-SSA at higher wt. %. Very few researchers fabricated AMC using SSA, so the new approach is to reutilize SSA and ES, WCE and to obtain the best experimental result. Hardness is first increased and then decreased resulting in an optimum level, which indicates increase of hard and brittle phases of the reinforcements. Addition of MEG to the composite results in high resistance to the solution, low current and low material loss due to erosion-corrosion. The corrosion rate decreases from 5.78 mm/year to 4.28 mm/year with WCE reinforcement at 12.5 wt. % after heat treatment. Minimum porosity is 0.37 % for Al matrix / 12.5 % WCE which is the best result. Cost of AMC with 12.5 wt. % WCE is 5.89 % lower than that with other reinforcements.

5. Nomenclature:

CR	Corrosion Rate	ρ	Density of the alloy (g/cm^3)
A	Area exposed (cm^2)	P	Porosity percentage
t	Time exposed (hours)	ρexp	Experimental density
K	Proportionality constant	ρtheo	Theoretical density
W	Weight loss (g)	BHN	Brinell Hardness Number

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