Effect of Agro Waste Reinforcements on the Mechanical Properties of Aluminium Composites

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Abstract Research on the development of cost-effective aluminium composites have led researchers to explore agricultural waste materials as potential reinforcements. Aluminium composites with such agro waste reinforcements have been reported to possess properties that are comparable to those with purely ceramic reinforcements. This paper specifically reviews the work done by these researchers and summarizes their fabrication details and the effect of agro waste reinforcements on the mechanical properties of aluminium composites. The corresponding improvement/reduction in their properties as compared to the base aluminium alloy has been tabulated.

Keywords Aluminium composite · Agro wastes · Reinforcements · Mechanical properties

1 Introduction

Ceramic-reinforced aluminium metal matrix composites have widely replaced traditional aluminium alloys in most domains. They are now the preferred material for engineering components due to their superior mechanical properties. However, their high costs have led researchers to explore alternate materials that can replace or partly substitute ceramics as reinforcements.

Agricultural wastes such as bamboo leaf ash (BLA), bean pod ash (BPA), coconut shell ash (CSA), corn cob ash (CCA), cow dung ash (CDA), eggshell powder (ESP), groundnut shell ash (GSA), lemon grass ash (LGA), locust bean waste ash (LBA), maize stalk particulates (MSP), melon shell ash (MSA), neem leaf ash (NLA), palm kernel shell powder (PKS), rice husk ash (RHA) and sugarcane bagasse ash (SBA),

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potentially offer a cost-effective replacement to the expensive synthetic ceramic reinforcements. Of late, researchers have increasingly focussed on the fabrication and characterization of properties of aluminium metal matrix composites reinforced with such agro wastes. The details of their fabrication and their overall impact on the mechanical properties are summarized in the subsequent sections.

2 Materials and Methods

Agro wastes which are used as reinforcements consist of naturally occurring ceramics and are therefore inexpensive when compared to the traditionally used synthetic ceramics. Researchers have therefore used various combinations and sizes of agro wastes along with ceramic particulates, for reinforcing aluminium composites. Table 1 summarizes the major constituents of agro waste reinforcements that were selected for this study.

These composites can be fabricated through various processes such as stir casting (SC), double stir casting and double layer feeding (DD), electromagnetic stir casting (ESC), squeeze casting (SQC), compo-casting (CC), sintering (SI) and friction stir processing (FSP). Reinforcements were preheated in some cases to increase the wettability.

Table 1 Agro wastes and their major constituents

Agro wastes	Al_2O_3	C	CaO	Fe_2O_3	K_2O	MgO	P_2O_5	SiO_2	TiO_2	References
BLA	4.13	4.2	6.68	–	5.62	–	–	76.2	–	[1]
CSA	21.84	–	0.67	18.45	–	12.37	–	41.26	–	[2]
CCA	5.64	–	2.45	2.97	–	1.71	–	77.05	–	[3]
CDA	–	–	6.92	–	7.29	5.79	8.57	67.39	–	[4]
GSA	–	–	29.72	17.07	9.81	6.76	–	18.79	–	[5]
LGA	0.17	–	6.45	–	29.73	3.55	–	57.93	–	[6]
LBA	14.98	–	1.08	0.28	–	0.09	–	55.38	–	[7]
MSA	3.54	–	2.11	1.3	4.7	–	–	84.3	–	[8]
PKS	9.43	–	11.21	–	9.71	4.85	–	55.69	–	[9]
RHA	–	–	0.379	0.287	1.759	0.394	–	96.319	–	[10]
SBA	97.4	–	0.8	0.6	–	–	–	–	1.2	[11]

3 Fabrication and Effect on Properties

Research studies on aluminium composites with agro wastes reinforcements and the fabrication processes employed are discussed in this section.

3.1 BLA Reinforcements

Bodunrin et al. [12] reinforced AA 6063 with silica sand (<75 μm) and BLA (<50 μm) particulates through stir casting. Five different composites with silica sand/BLA weight fractions as 10/0, 7.5/2.5, 5/5, 2.5/7.5 and 0/10 percentages were fabricated. The composite with 10/0% reinforcements had the highest hardness of around 64.6 VHN. The composite with 0/10% reinforcements had the lowest density of around 2.383 g/cc. Kumar et al. [1] reinforced Al-4.5%Cu alloy with BLA particulates through stir casting. Three different composites with BLA weight fractions of 2, 4 and 6 percentages were fabricated. The composite with 2% reinforcements had the highest percentage elongation of around 3.06%. The composite with 4% reinforcements had the highest hardness (Brinell) of around 99.3 BH, microhardness of around 104.4 MH, tensile strength of around 177.304 MPa and yield strength of around 133.19 MPa. The composite with 6% reinforcements had the lowest density of around 2.619 g/cc. Fatile et al. [3] reinforced Al–Mg-Si (0.396% Mg and 0.4% Si) alloy with SiC (30 μm) and BLA (<50 μm) particulates through stir casting. Four different composites with SiC/BLA weight fractions as 10/0, 8/2, 6/4 and 4/6 percentages were fabricated. The composite with 10/0% reinforcements had the highest microhardness of around 82 HV, ultimate tensile strength of around 164 MPa, yield strength of around 123 MPa and percentage elongation of around 26.1%. The composite with 4/6% reinforcements had the highest fracture toughness of around 10.2 $MPam^{1/2}$ and the lowest density of around 2.615 g/cc.

3.2 CSA Reinforcements

Panda et al. [13] reinforced AA 1200 with m-CSA particulates (i.e. modified CSA with CSA:graphite:Mg in the ratio 1:1:2.5) through compo-casting. Three different composites with m-CSA weight fractions of 2, 4 and 8 percentages were fabricated. The composite with 4% reinforcements had the highest hardness (Brinell) of around 77.7 BHN. The composite with 8% reinforcements had the lowest density of around 2.56 g/cc. Lakshmikanthan and Prabu [14] reinforced AA 6061 with CSA (<150 μm) particulates through stir casting. Five different composites with CSA weight fractions of 3, 6, 9, 12 and 15 percentages were fabricated. The composite with 6% reinforcements had the highest hardness (Brinell) of around 55.2 BHN and tensile strength of around 160.27 MPa. Bodunrin et al. [12] reinforced AA 6063 with CSA particulates

through stir casting. Four different composites with CSA weight fractions of 3, 6, 9 and 12 percentages were fabricated. The composite with 3% reinforcements had the highest modulus of elasticity of around 1.018 MPa. The composite with 12% reinforcements had the highest hardness of around 40.2 HRB and ultimate tensile strength of around 73.62 MPa, while it had the lowest density of around 2.59 g/cc. Kumar et al. [2] reinforced AA 6082 with ZrO_2 (<50 μm) and CSA (<75 μm) particulates through stir casting. Six different composites with ZrO_2/CSA weight fractions as 0/10, 2/8, 4/6, 6/4, 8/2 and 10/0 percentages were fabricated. The composite with 10/0% reinforcements had the highest hardness (Brinell) of around 64 BHN. The composite with 8/2% reinforcements had the highest tensile strength of around 202 MPa and yield strength of around 142 MPa. The composite with 2/8% reinforcements had the highest flexural strength of around 92 MPa. The composite with 0/10% reinforcements had the highest percentage elongation of around 13.8% and impact strength of around 15 J. It had the lowest density of around 2.63 g/cc. Mohanavel et al. [15] reinforced AA 7050 with CSA (60–70 μm) particulates through stir casting. Two different composites with CSA weight fractions of 4 and 8 percentages were fabricated. The composite with 8% reinforcements had the highest microhardness of around 78 HV and tensile strength of around 203 MPa. Subramaniam et al. [16] reinforced AA 7075 with B_4C (75 μm) and CSA (62 μm) particulates through stir casting. Five different composites with B_4C/CSA weight fractions as 0/3, 3/3, 6/3, 9/3 and 12/3 percentages were fabricated. The composite with 12/3% reinforcements had the highest hardness of around 169 BHN. The composite with 9/3% reinforcements had the highest tensile strength of around 189 MPa and impact strength of around 2.3 J. The composite with 0/3% reinforcements had the highest percentage elongation of around 13.5%. Table 2 summarizes details of aluminium alloys with BLA/CSA reinforcements.

Table 2 Aluminium alloys with agro wastes (BLA/CSA) as reinforcement

Authors	Alloy	Reinforcement		Process	References
		R1	R2		
Bodunrin et al.	AA6063	Silica sand	BLA	SC	[12]
Kumar et al.	Al-4.5%Cu	BLA	–	SC	[1]
Alaneme et al.	Al-0.396% Mg-0.4%Si	SiC	BLA	SC	[17]
Panda et al.	AA1200	m-CSA	–	CC	[13]
Lakshmikanthan and Prabu	AA6061	CSA	–	SC	[14]
Bodunrin et al.	AA6063	CSA	–	SC	[12]
Kumar et al.	AA6082	ZrO_2	CSA	SC	[2]
Mohanavel et al.	AA7050	CSA	–	SC	[15]
Subramaniam et al.	AA7075	B_4C	CSA	SC	[16]

3.3 GSA Reinforcements

Palanivendhan and Chandradass [18] reinforced AA 6063 with GSA particulates through stir casting. Three different composites with GSA weight fractions of 2.5, 5 and 7.5 percentages were fabricated. The composite with 2.5% reinforcements had the highest hardness of around 42.2 HV and tensile strength of around 111.2 MPa. Venkatesh et al. [5] reinforced AA ADC12 with B_4C (7.78–10.40 μm) and GSA (<50 μm) particulates through squeeze casting. Three different composites with B_4C/GSA weight fractions as 2.5/7.5, 5/5 and 7.5/2.5 percentages were fabricated. The composite with 7.5/2.5% reinforcements had the highest hardness of around 115.6 BHN, yield strength of around 286.5 MPa, tensile strength of around 348.45 MPa and impact strength of around 3.41 J. The composite with 2.5/7.5% reinforcements had the lowest density of around 2.525 g/cc. Refaai et al. [19] reinforced AA 8079 with GSA particulates through stir casting. Six different composites with GSA weight fractions of 3, 6, 9, 12, 15 and 18 percentages were fabricated. The composite with 3% reinforcements had the highest impact strength of around 0.9 J/mm^2. The composite with 18% reinforcements had the highest hardness (Brinell) of around 60.1 BHN and the lowest density of around 3.34 g/cc. Alaneme et al. [20] reinforced Al–Mg–Si (0.5% Mg and 0.45% Si) alloy with SiC (28 μm) and GSA (<50 μm) particulates through stir casting. Five different composites with SiC/GSA weight fractions as 10/0, 7.5/2.5, 5/5, 2.5/7.5 and 0/10 percentages were fabricated. The composite with 10/0% reinforcements had the highest hardness of around 63.5 HRV, yield strength of around 129 MPa and tensile strength of around 158 MPa. The composite with 5/5% reinforcements had the highest percentage elongation of around 12.8%. The composite with 0/10% reinforcements had the highest fracture toughness of around 7.7 MPam$^{1/2}$.

3.4 RHA Reinforcements

Dinaharan et al. [21] reinforced AA 6061 with RHA (8 μm) particulates through friction stir processing. The volume fraction of the reinforcements was 18%. The composite had an ultimate tensile strength of around 285 MPa. Alaneme and Sanusi [22] reinforced AA 6063 with Al_2O_3 (30 μm) and RHA (<50 mm) particulates through stir casting. Five different composites with Al_2O_3/RHA weight fractions as 10/0, 7.5/2.5, 5/5, 2.5/7.5 and 0/10 percentages were fabricated. The composite with 7.5/2.5% reinforcements had the highest percentage elongation of around 12.7%. The composite with 10/0% reinforcements had the highest hardness of around 68.7 VHN, ultimate tensile strength of around 133 MPa, yield strength of around 100 MPa and toughness of around 8.8 J/m^3. Arora and Sharma [10] reinforced AA 6351 with SiC and RHA particulates through stir casting. Three different composites with SiC/RHA weight fractions as 2, 4 and 6 percentages were fabricated. The composite with 6% reinforcements had the highest microhardness of around 72.5 VHN and ultimate

Table 3 Aluminium alloys with agro wastes (GSA/RHA) as reinforcement

Authors	Alloy	Reinforcement		Process	References
		R1	R2		
Palanivendhan and Chandradass	AA6063	GSA	–	SC	[18]
Venkatesh et al	ADC12	B_4C	GSA	SQC	[5]
Refaai et al	AA8079	GSA	–	SC	[19]
Alaneme et al	Al–0.5%Mg–0.45%Si	SiC	GSA	SC	[20]
Dinaharan et al	AA6061	RHA	–	FSP	[21]
Alaneme and Sanusi	AA6063	Al_2O_3	RHA	SC	[22]
Arora and Sharma	AA6351	SiC	RHA	SC	[10]
Verma and Vettivel	AA7075	B_4C	RHA	SC	[23]
Saravanana and Kumar	AlSi10Mg	RHA	–	SC	[24]

tensile strength of around 186 MPa. The composite with 2/6% reinforcements had the lowest density of around 2.63 g/cc. Verma and Vettivel [23] reinforced AA 7075 with B_4C (50 μm) and RHA particulates through stir casting. Three different composites with B_4C/RHA weight fractions as 5/0, 5/3 and 5/5 percentages were fabricated. The composite with 5/5% reinforcements had the highest hardness (Vicker's) of around 121.42 HV and compression strength of around 563.3 MPa. The composite with 5/0% reinforcements had the highest tensile strength of around 260.5 MPa. Saravanana and Kumar [24] reinforced AlSi10Mg alloy with RHA particulates through stir casting. Four different composites with RHA weight fractions of 3, 6, 9 and 12 percentages were fabricated. The composite with 9% reinforcements had the highest ultimate tensile strength of around 173 MPa. The composite with 12% reinforcements had the highest compression strength of around 524 MPa and hardness of around 80.9 BHN. The composite with 3% reinforcements had the highest percentage elongation of around 9.3%. Table 3 summarizes details of aluminium alloys with GSA/RHA reinforcements.

3.5 SBA Reinforcements

Harish et al. [25] reinforced AA 5056 with SiC (40 μm) and SBA particulates through stir casting. Three different composites with SiC/SBA weight fractions as 0/4, 3/2 and 3/4 percentages were fabricated. The composite with 3/4% reinforcements had the highest microhardness (Vicker's) of around 73.2 HV. Chandla et al. [11] reinforced

AA 6061 with Al_2O_3 (53 μm) and SBA (38 μm) particulates through vacuum-assisted stir casting. Four different composites with Al_2O_3/SBA weight fractions as 5/0, 5/4, 5/6 and 5/8 percentages were fabricated. The composite with 5/6% reinforcements had the highest tensile strength of around 151.1 MPa and microhardness of around 35.2 HV. The composite with 5/4% reinforcements had the highest percentage elongation of around 8.6%. The composite with 5/0% reinforcements had the highest impact strength of around 6.9 J. The composite with 5/8% reinforcements had the highest compression strength of around 411 MPa. The composite with 5/8% reinforcements had the lowest density of around 2.665 g/cc. Palanivendhan et al. [26] reinforced AA 6262 with SBA (40 μm) particulates through stir casting. Two different composites with SBA weight fractions of 2 and 5 percentages were fabricated. The composite with 5% reinforcements had the highest ultimate tensile strength of around 161.97 MPa. The composite with 2% reinforcements had the highest microhardness (Vicker's) of around 70.4 HV. Imran et al. [27] reinforced AA 7075 with graphite (20–60 μm) and SBA (0.1–100 μm) particulates through stir casting. Three different composites with graphite/SBA weight fractions as 1/2, 1/4 and 1/6 percentages were fabricated. The composite with 1/6% reinforcements had the highest ultimate tensile strength of around 294.2 MPa, hardness (Brinell) of around 88.3 BHN and yield strength of around 184.93 MPa. The composite with 1/2% reinforcements had the highest percentage elongation of around 6.7%. Subramanian et al. [28] reinforced Al-Si10-Mg alloy with SiC (<25 μm) and SBA (<75 μm) particulates through stir casting. Four different composites with SiC/SBA weight fractions as 0/9, 3/9, 6/9 and 9/9 percentages were fabricated. The composite with 0/9% reinforcements had the highest percentage elongation of around 2.615%. The composite with 9/9% reinforcements had the highest tensile strength of around 161.73 MPa, hardness of around 129.7 BHN and impact strength (Charpy) of around 0.039 Jmm^2.

3.6 CCA, MSA, PKP, CDA and LBA Reinforcement

Odoni et al. [29] reinforced AA 6063 with CCA particulates through stir casting. Six different composites with CCA weight fractions of 2.5, 5, 7.5, 10, 12.5 and 15 percentages were fabricated. The composite with 2.5% reinforcements had the highest impact energy of around 0.87 J/mm^2 and tensile strength of around 196 MPa. The composite with 15% reinforcements had the highest hardness (Brinell) of around 58 BHN and the lowest density of around 2.44 g/cc. Fatile et al. [3] reinforced Al–Mg-Si (0.396% Mg and 0.4% Si) alloy with SiC (50 μm) and CCA (<60 μm) particulates through stir casting. Five different composites with SiC/CCA weight fractions as 10/0, 9/1, 8/2, 7/3 and 6/4 percentages were fabricated. The composite with 10/0% reinforcements had the highest microhardness of around 93 HVN, ultimate tensile strength of around 185 MPa, yield strength of around 144.2 MPa and percentage elongation of around 24%. The composite with 6/4% reinforcements had the highest fracture toughness of around 12 $MPam^{1/2}$ and the lowest density of around 2.6 g/cc. Suleiman I et al. [8] reinforced Al-12%Si alloy with MSA (50 μm) particulates

through stir casting. Four different composites with MSA weight fractions of 5, 10, 15 and 20 percentages were fabricated. The composite with 15% reinforcements had the highest hardness of around 103.5 HRC and tensile strength of around 207.1 MPa. The composite with 5% reinforcements had the highest impact strength of around 17 J and percentage elongation of around 27.6%. Edoziuno et al. [30] reinforced AA 6063 with PKP particulates through stir compo-casting. Six different composites with PKP weight fractions of 2.5, 5, 7.5, 10, 12.5 and 15 percentages were fabricated. The composite with 7.5% reinforcements had the highest yield strength of around 192 MPa, ultimate tensile strength of around 187 MPa and modulus of elasticity of around 14,014 MPa. The composite with 12.5% reinforcements had the highest percentage elongation of around 39.6%. The composite with 2.5% reinforcements had the highest hardness of around 612 BHN. The composite with 10% reinforcements had the highest impact energy of around 31.96 Manikandan et al. [4] reinforced AA 7075 with B_4C (50–70 μm) and CDA (40–60 μm) particulates through stir casting. Five different composites with B_4C/CDA weight fractions as 0/10, 2.5/7.5, 5/5, 7.5/2.5 and 10/0 percentages were fabricated. The composite with 10/0% reinforcements had the highest hardness (Brinell) of around 152 BHN. The composite with 0/10% reinforcements had the highest impact strength (Charpy) of around 3 J. The composite with 2.5/7.5% reinforcements had the highest flexural strength of around 358 MPa. The composite with 7.5/2.5% reinforcements had the highest tensile strength of around 288.38 MPa. Usman et al. [7] reinforced AA A356 with LBA (<75 μm) particulates through stir casting. Five different composites with LBA weight fractions of 2, 4, 6, 8 and 10 percentages were fabricated. The composite with 2% reinforcements had the highest impact energy of around 33.5 J. The composite with 10% reinforcements had the highest tensile strength of around 0.84 GPa and hardness of around 15.1 HRB. Jose et al. [6] reinforced AA 6061 with LGA (50–250 μm) particulates through compo-casting. Three different composites with LGA weight fractions of 3, 5 and 7.5 percentages were fabricated. The composite with 7.5% reinforcements had the highest microhardness of around 155 HV and tensile strength of around 195 MPa. The composite with 3% reinforcements had the highest percentage elongation of around 11.7%. Table 4 summarizes details of aluminium alloys with SBA/CCA/MSA/PKP/CDA/LBA reinforcements.

The percentage increase/decrease in tensile strength (TS), hardness—Brinell (H), percentage elongation (PE), microhardness (MH), yield strength (YS), flexural strength (FS), impact strength (IS) and density (D) have been given in Table 5. These values were computed only for composites whose base alloy properties were determined experimentally by the corresponding researcher.

4 Conclusion

There exists an increasing trend among researchers to fabricate aluminium composites with agro wastes and their combinations. They have successfully reinforced aluminium alloys with agro wastes such as BLA, CSA, RHA, GSA

Table 4 Aluminium alloys with other agro wastes as reinforcement

Authors	Alloy	Reinforcement		Process	References
		R1	R2		
Harish et al	AA5056	SiC	SBA	SC	[25]
Chandla et al	AA6061	Al_2O_3	SBA	SC	[11]
Palanivendhan et al	AA6262	SBA	–	SC	[26]
Imran et al	AA7075	Graphite	SBA	SC	[27]
Subramanian et al	Al-Si10-Mg	SiC	SBA	SC	[28]
Odoni et al	AA6063	CCA	–	SC	[29]
Fatile et al	Al-0.396%Mg -0.4%Si	SiC	CCA	SC	[3]
Suleiman et al	Al-12%Si	MSA	–	SC	[8]
Edoziuno et al	AA6063	PKP	–	CC	[30]
Manikandan et al	AA7075	B_4C	CDA	SC	[4]
Usman et al	A356	LBA	–	SC	[7]
Jose et al	AA6061	LGA	–	CC	[6]

Table 5 Percentage increase/decrease in composite properties

Composite	TS	H	PE	MH	YS	FS	IS	D
Al-4.5%Cu/BLA	17.8	37.2	− 11.6	24.4	11.7	–	–	− 4.9
AA1200/m-CSA	–	19.9	–	–	–	–	–	5.3
AA6061/CSA	129	35.1	–	–	–	–	–	–
AA6063/CSA	− 7.2	–	–	–	–	–	–	–
AA6082/ZrO_2/CSA	23.2	45.5	− 6.8	–	26.8	9.5	− 3.8	− 1.5
AA7050/CSA	33.6	–	–	38.1	–	–	–	–
AA7075/B_4C/CSA	65.8	33.1	− 2.2	–	–	–	283	–
AA6063/GSA	− 2.7	–	–	–	–	–	–	–
ADC12/B_4C/GSA	13.1	17.4	–	–	17.4	–	− 3.1	− 7.5
AA8079/GSA	–	140	–	–	–	–	–	− 3.7
Al–0.5 Mg–0.45Si/SiC/GSA	53.4	–	− 52.1	–	63.3	–	–	–
AA6061/RHA	29.5	–	–	–	–	–	–	–
AA6063/Al_2O_3/RHA	− 4.3	–	16.5	–	− 2.9	–	–	–
AA6351/SiC/RHA	7.5	–	–	12.6	–	–	–	− 3.1
AA7075/B_4C/RHA	30.2	–	–	73.3	–	–	–	–
AA6262/SBA	62.1	–	–	3.1	–	–	–	–
AA6063/CCA	− 18	123	–	–	–	–	–	–
Al-12%Si/MSA	69.1	–	− 21.8	–	–	–	− 2.9	–
AA6063/PKP	78.1	79.5	428	–	86.4	–	147	–
AA7075/B_4C/CDA	56	38.2	–	–	–	11.9	− 6.3	–
A356/LBA	52.7	–	–	–	–	–	− 7.8	–

and SBA through various processes. Of the composites selected for the study, a high tensile strength of around 348.45 MPa was observed in the composite ADC12/7.5%B_4C/2.5%GSA, hardness (Brinell) of around 169 BHN was observed in the composite AA7075/12%B_4C/3%CSA, percentage elongation of around 39.6% was observed in the composite AA6063/12.5%PKP, microhardness of around 121.42 HV was observed in the composite AA7075/5%B_4C/5%RHA, yield strength of around 286.5 MPa was observed in the composite ADC12/7.5%B_4C/2.5%GSA, fracture toughness of around 12 $MPam^{1/2}$ was observed in the composite Al-0.396 Mg-0.4Si/6%SiC/4%CCA, flexural strength of around 358 MPa was observed in the composite AA7075/2.5%B_4C/7.5%CDA, impact strength of around 33.5 J was observed in the composite A356/2%LBA, compression strength of around 563.309 MPa was observed in the composite AA7075/5%B_4C/5%RHA and a low density of around 2.383 g/cc was observed in the composite AA6063/10%BLA. Aluminium composites reinforced with a combination of agricultural wastes and ceramics thus offer a cost-effective alternative to those reinforced with synthetic ceramic reinforcements.

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