DOI: https://doi.org/10.24425/amm.2024.149782

M. KOLLI [1], S. NARESH DASARI [2], S. KOSARAJU [3*]

INVESTIGATION ON MECHANICAL PROPERTIES OF AGRO AND INDUSTRIAL WASTE REINFORCEMENT IN ALUMINIUM 7075 COMPOSITE WITH LIQUID METAL STIR CASTING ROUTE

Day-to-day life advanced composite materials usage is increasing continuously and replacing the existing monolithic materials. These composite materials are designed and fabricated for human needs with specific applications and also meet the standard requirements. In present study, the agro and industrial wastes derived ceramic reinforcements based Aluminium metal matrix composites, i.e. AA7075/welding slag and AA7075/Rice husk ash are fabricated through liquid metal stir casting route with varying the reinforcement contents from 2 to 12 (wt.%) in the matrix. Mechanical and microstructural characterization of the AA 7075 metal matrix composite were measured and compared to the base material. The results show an improved mechanical strength and high hardness in composites. Impact energy has also significantly improved at higher concentrations of reinforcement particles. Impact energy of the composites increases to 3 J for 9% and 12%, the maximum tensile strength obtained is 173 MPa for 12% Weld Slag MMC. The highest hardness achieved is 98 BHN for 12% Weld Slag MMC. Furthermore, the microstructural results reflect significant grain refinement with stir casting process with good interface characteristics in the matrix and uniform dispersion of agro reinforcement's particles.

Keywords: mechanical properties; industrial wastes; AA7075; agriculture wastes; microstacture analysis

1. Introduction

Nowadays, manufacturing scenario is changing in the usage of conventional materials as they have been replaced by the advanced materials. Metal Matrix Composites (MMCs) are one of such advanced materials that are playing a prominent role in manufacturing sector due to their properties like high specific strength, light weight, specific stiffness, wear resistance, corrosion resistance and elastic modulus mostly applicable for aerospace, automobile, marine, mining and mechanical structural applications [1]. Metal matrix composites (MMC's) are alloys combined with other materials that ultimately result in performance enhancement of the materials. Ever since their inception, Cu-, Al- and Mg- based MMC's have been significantly investigated [2]. In particular, Al based MMC's can broadly be categorized as synthetic ceramic, agro waste, and industrial waste derivatives [3]. Al- based MMC's are manufactured with many synthetic ceramic reinforcements due to their strength and desirable properties such as Silicon Nitride (Si_3N_4), Alumina (Al_2O_3), Aluminium Titanate (Al_2TiO_5), Zirconia ($ZrSiO_4$), Aluminium Nitride (AlN), Boron Carbide (B_4C), Silicon Dioxide (SiO_2) etc. due to their strength and desirable properties [4]. High cost and inadequate availability of conventional ceramic reinforcements in many developing countries prompted for a compulsory paradigm shift in the choice of selection for reinforcement particles [5]. Hence, usage of agro waste and industrial waste derived MMC's has gained prominence in recent past because usages of such reinforcements has mitigated the expensiveness of the reinforcements and are able to achieve properties on par with ceramic composites [6]. There have been numerous reports on Aluminium Industrial waste agro waste derived MMC's.The effect of alloying Bagasse ash particles in AA356 Alloy matrix has been investigated by kumar et al. [7] they have observed that the density of the composites decreases with increase in reinforcement particle alloying percentage and a significant improvement in hardness and compressive strength. The effect of BLA reinforcement into AA7075 material has been studied by Kolli et al. [8] by fabricating the composite using stir casting method. Hardness, tensile strength, elongation and toughness properties are considered as measuring characteristics of the composite when the addition

[1] LAKIREDDY BALI REDDY COLLEGE OF ENGINEERING, MYLAVARAM, ANDHRA PRADESH, INDIA
[2] R&D MECHATRONICS, DESIGN AND ENGINEERING, VEM TECHNOLOGIES PVT LTD, HYDERABAD, TELANGANA, INDIA
[3] GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY, MECHANICAL ENGINEERING, HYDERABAD – 500090, TELANGANA STATE, INDIA

* Corresponding author: satya.kosaraju@griet.ac.in

of BLA reinforcement's particles from 2 to 8% to matrix material. They have concluded that the addition of 6 to 8% of reinforcement material increase the hardness and tensile properties.

Kumar et al. have attempted to fabricate a high strength and low-density composite for automotive application with heat treatable Al-Mg-Si-T6 alloy and industrial waste fly ash and boron carbide particles as reinforcement [9]. They have concluded that the optimal composition of the reinforcements improved the tensile strength, hardness and compression strength of the material.Welding slag is a similar industrial by product of Arc Welding process produced during metal joining process across fabrication and construction industries. But, an effective recycling method of the slag has not been widely discussed [9]. Paranthaman et al. have studied the effect of weld slag particles on the AA6063 Alloy matrix they have observed that the tensile properties of the material increasing while wear rate decreases with increase in fraction of reinforcements [10].

Kolli et al. have investigated the effect of rock dust reinforcement in Al composite by FSP. They have fabricated FSP composites which are hairy an excellent appearance and calculated the mechanical wear properties. Rock dust particles vary from 0 to 10% and at 10% of reinforcement in Al, better results are found. It has been concluded that the rock dust particle addition to matrix material increases the wear resistance, impact strength, and micro hardness [11]. Anil kumar et al. have examined the mechanical properties of AA6061/FA with various reinforcement sizes. The stir casting method was used to fabricate the Al composite in a varied traction of FA from 10 to 20% and particle sizes 4-25 μm, 50 μm, and 100 μm. FA 15% contained in Al composite displays the highest UTS and hardness and less compressive strength than the AA6061 alloy. Smaller (4-25 μm) reinforced FA particles have resulted the best UTS as compared with those of the coarser FA particles (50 μm and 100 μm) [12]. Murthy et al. have examined the AA2024 alloy with FA and BFS composites. In their study, phase identification and structural analysis were performed, when FA and BFA with 5% of reinforcement added in AA2024 alloy by the stir casting technique. It has been observed that a uniform dispersion of FA and BFS particles in the matrix material generates a good bonding between matrix and powder particles. The mechanical properties indicated that both the composites have enhanced performance and reduced the density [13-14].

Electric Arc Furnace Dust (EAFD) is the solid waste generated in steel manufacturing process. AA7075 and 5% EAFD composites were prepared using the powder metallurgy method. 5% of EAFD and 2% of stearic acid were mixed correctly and processed using ball milling in order to reduce the particle size to 20 μm, further using the P/M technique to compact the samples. The AA7075/EAFD has shown better results with significant improvements i.e., 46% of hardness increases due to uniform distribution of the oxide particles and Al particles [15]. The MSA particles' synthesis considers the different heating conditions, best being 620-680°C. AA356/MAS composite wear resistance properties increase with MSA particles weight %. Al-12wt% MSA composites fabricated by a stir casting route on wear and mechanical characteristics were studied. AA6101/MAS results shows that the hardness improves from 47.9 to 74.7 VHN, CS from 160 to 201 MPa, elongation reduces from 8.3 to 5.5% and wear rate increases from 0.017 to 0.076 g/min. MAS particles have an excellent alternative to synthesis particles like Al_2O_3, SiC, TiC, Si_3N_4, B_4C, TiB_2, etc [16].

Correlation/data between the percentages of reinforcements, materials, tensile strength for various MMCS [17-20].

TABLE 1

Strength of various matrix material with varying percentage reinforcement through stir casting process

Matrix material	Reinfor-cement	Percentage of reinforcement	Processing route	Ultimate tensile strength MPa
Al7075	FA/E-glass short fibers	3% FA and 3% E-glass short fibers	Stir casting	160
Al6061	SiC/FA	7.5% SiC and 7.5% FA	Stir casting	173
Al7075	Bamboo leaf Ash	Gr2% BLA and 8% FA	Stir casting	163
LM 13	Snail Shell Ash	7.5% SIC and 7.5% SSA	Stir casting	161
Al 7075	Coconut shell ash	12% CSA	Stir casting	153

Al composites with industrial and agricultural waste are innovative materials. These features are used to replace the traditional ceramic reinforced particles composite materials. Automobiles, for example, manufactured different light weight components such as brakes, engine pistons, cylinder barrel, piston connecting rod, pushrods, battery grids, and chevlet corvette cardan shaft. Surface coating and cryogenic treatment are other applications for aluminium metal matrix composites. Therefore a pioneering attempt to use industrial and agriculture wastes as an economical route to process Al-based MMC. In the present study, weld slag particles and rice husk ash are used as reinforcements to produce AA7075 based particle reinforced MMC using liquid stir casting route. AA7075/WS and AA7075/RHA composites with varying powder particulate fraction are compared. Finally, the microstructural characteristics and mechanical properties of composite has been studied and analysed.

2. Experimental Methods

2.1. Matrix materials

AA7075 alloy is selected as the base material for this study due to its high ductility, strength, toughness and fatigue resistance. The AA7075 boasts a superior corrosion resistance than itsAA2000 series counterparts. These properties make the material trustworthy for highly stressed structural environments [21]. The typical composition of AA7075 alloy is given in the TABLE 2.

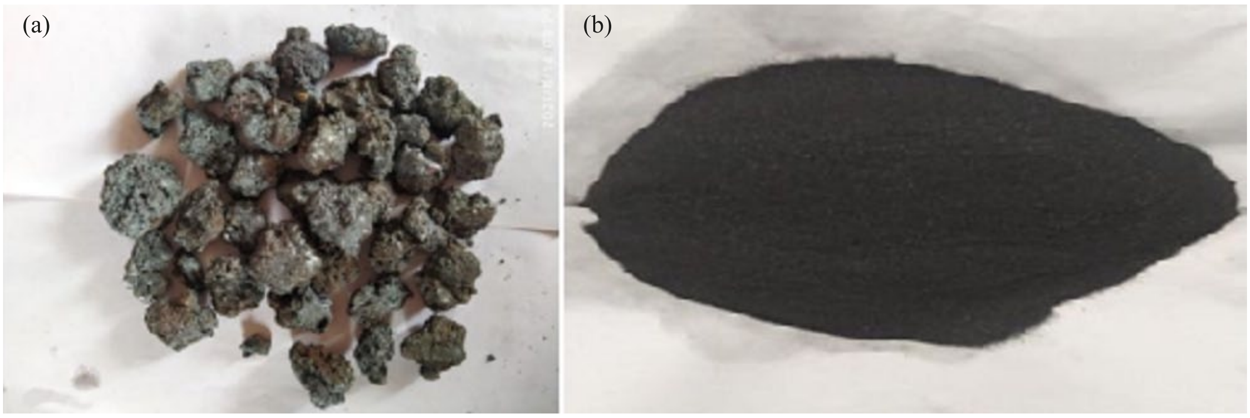

Fig. 1. Welding slag reinforcement preparation: (a) Weld Beads Grounded and (b) Weld Slag finely powdered and sieved

TABLE 2

Chemical Composition of Al 7075 Alloy

Elements	Zn	Mg	Cu	Si	Mn	Fe	Cr	Ti	Al
Wt%	5.56	2.71	1.42	0.33	0.21	0.34	0.27	0.12	Re-maining

2.2. Reinforcement Material

One of the agro waste materials like rice husk was collected from the Mangalagiri rural area, Guntur district region, Andhra Pradesh, India. The rice husk particles are converted to ash particles as per the guidelines of Kolli et al. and developed required shape and size. Further, industrial waste in the vein of welding slag that was collected from a Krishna district, Mylavaram local welding workshops as a by-product while joining steels by Arc Welding (Mild steel best arc 10 gauge 6013 (rod) and Mild steel (plates) were used as welding electrode and workpiece). The slag finely grounded using mills and the powder thus obtained sieved to an average of by-product 10-400 µm. The finely weld slag reinforcement is shown in Fig. 1.

The SEM images of the weld slag are shown in Fig. 2. The SEM analysis confirmes that the powdered particles are in the range of 60-70 µm. The results of EDS display the presence of Silicon (Si), Oxygen (O), Calcium (Ca), Potassium (K), Chlorine (Cl) and Magnesium (Mg) in their oxide forms (Fig. 3) in weld slag particles and are consistent with reports of several other investigations.

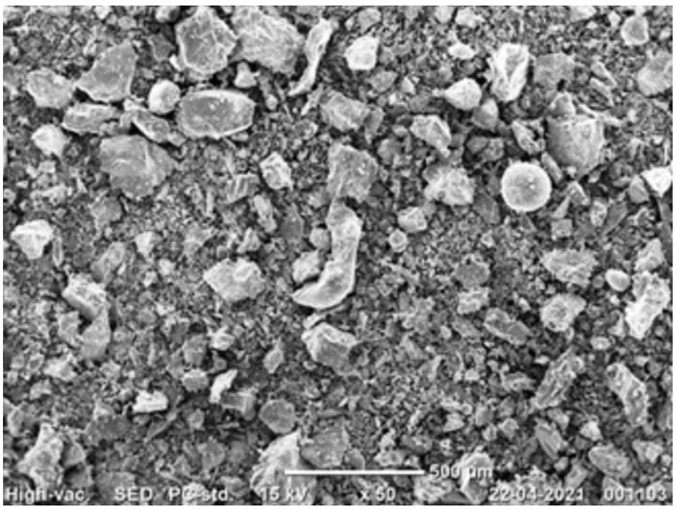

Fig. 2. SEM image of weld slag particles

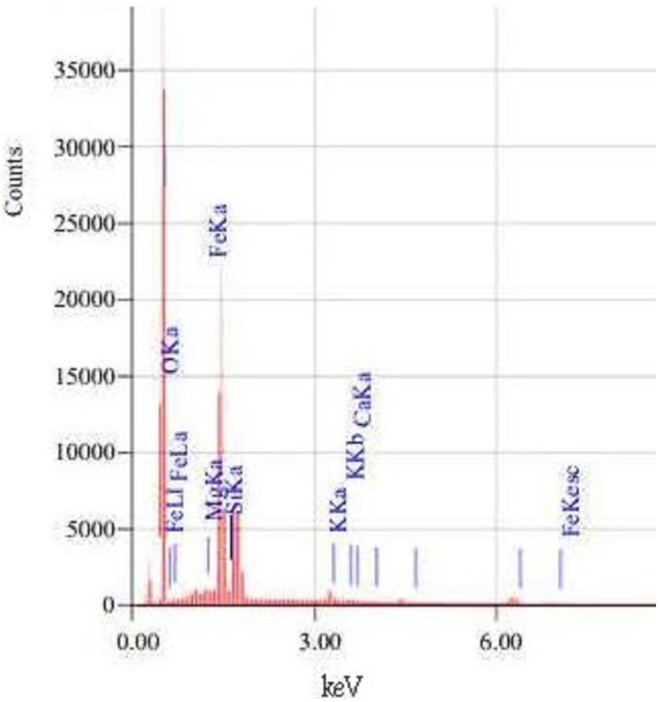

Fig. 3. EDX spectroscopy image of weld slag particles

The SEM and EDS profiles of BLA particulate matter are shown in Fig. 4 and 5, respectively. The EDS profile (Fig. 5) of BLA has displayed peaks of Silicon (Si), Oxygen (O), Calcium (Ca), Potassium (K), Chlorine (Cl) and Magnesium (Mg) along with the oxygen. This indicates that these are in oxide form. The results are consistent with the reports of several other investigations [22]. The Silicon Dioxide's (SiO_2) dominance in the chemical composition is confirmed from the highest peak in the EDS profile. This finding is well supported by the literature [22]. On the other hand, SEM image (Fig. 4) of BLA has portrayed that the average size is ~50-70 µm.

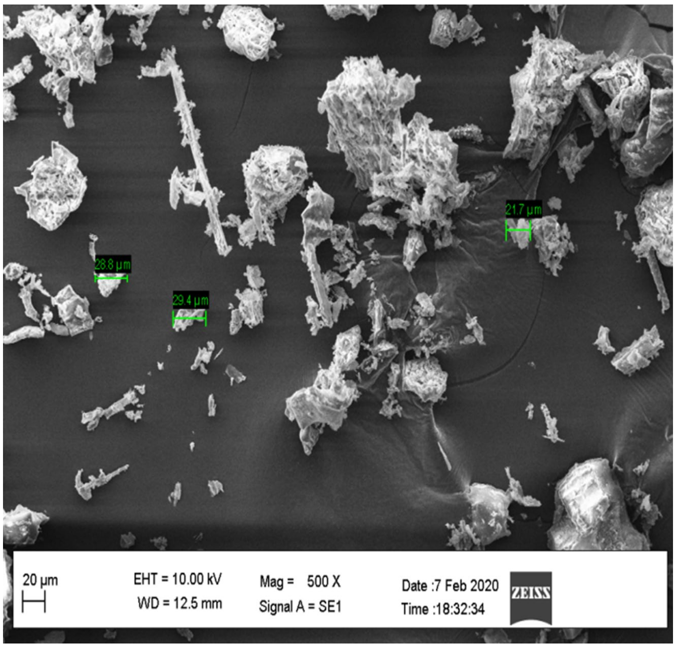

Fig.4. SEM image of rice husk ash particles

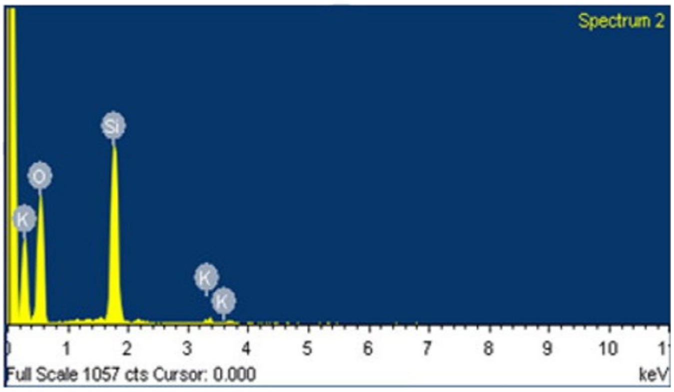

Fig. 5. EDX spectroscopy image of rice husk ash particles

2.3. Manufacturing Technique

The production of MMC is realized through stir casting process. A typical outline of the setup is shown in Fig. 6. Initially, AA7075 ingots are charged and furnace is heated up to 780°C for 30 Minutes. The mixture of metal matrix is constantly stirred at 800 RPM for duration of 20 minutes by simultaneously adding reinforcements which are preheated up to 325°C in order to improve wettability according to the 3, 6, 9 and 12 by wt% of the alloy AA7075. Enhancement of the stirring time improves the homogeneous distribution of the particles and decreased grain structure size. Subsequently, higher hardness values are achieved. However, excessive stirring caused serious increase in oxidation and impurities in the matrix of MMC. Hence, the selection of parameters from the literature for current study was carefully carried out for achieving optimum results. Further, the molten metal is poured into mould cavities, preheated up to 400°C for 3 hrs, are charged in to the metal matrix. The molten metal is then pressurized using mechanized die into the mould cavity.

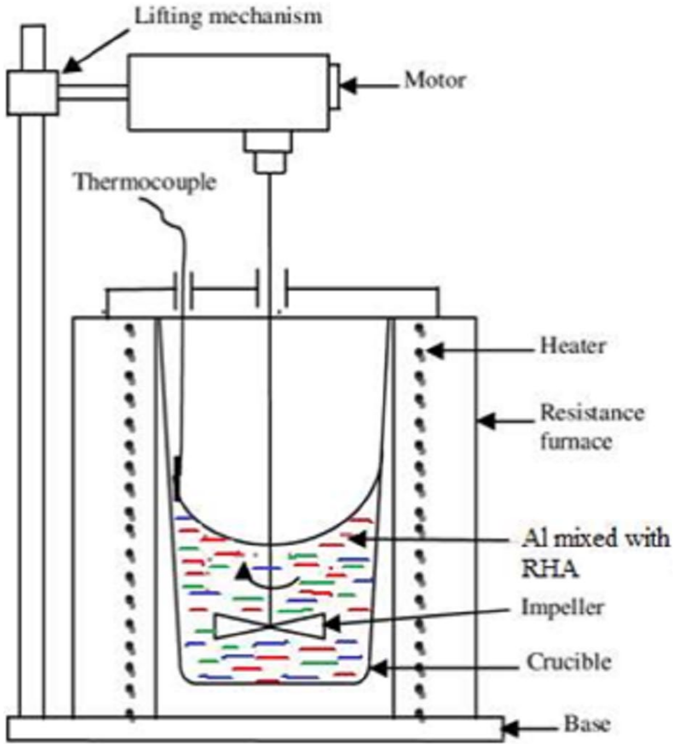

Fig. 6. Line diagram of stir casting setup

2.4. Performances characteristics measures

The influence of reinforced particulate in AA7075 and their varying compositions is evaluated by determining mechanical properties of the specimen viz. Yield Strength (YS), Ultimate Tensile Strength (UTS), Ductility, Hardness and Impact Energy. The specimens for Tensile Testing were cut and machined and tested as per ASTM E28 Standard [23].The standard specimens are cut using CNC Lathe. The tensile testing is done on Universal Tensile Testing Machine (FIE make, Model: UTE 40) with a maximum displacement of 200 mm. The Hardness specimens are cut and tested as per ASTM E28.06 Standard [24] on FIE Hardness Tester model B-3000H. The specimens are tested for Impact Energy as per ASTM E23-13 Standard of Testing [25]. The V-Notch Specimens are cut and Tested on Impact Energy Tester (Model: IT 30 of FIE make). The microstructures were studied using Olympus GX53 Inverted Metallurgical Microscope 1500× Magnification, matrix Vision 8 MP Camera.The grain refinement of the composites was studied. The samples are first ground with successive meshed grits of 1200, 1600 and 2000, respectively and the samples are then polished into a mirror like finish using diamond slurry and alumina paste on a polisher.

3. Results and discussion

3.1. Microstructural characterization

The interface characteristics and the microstructure of the composites reflect the properties exhibited by the alloys at large.

The results of the microstructural studies are shown in Fig. 7. All the microstructures of MMCs have revealed a significant grain refinement with addition of reinforcement particles. This is due to the fact that the distribution of the particles inside the matrix alloy has inhibited the devolvement of the α- grains during solidification [22]. The solidification has resulted in a grain refinement and non-homogeneous nucleation slag particles at center [25]. A clear and discernable dendritic microstructural propagation reflects unique and rapid solidification induced grain refinement [26]. The increased dislocation densities could be identified from the microstructures. The porosities are visible as the reinforcement's fraction increases.

The interface attributes and the associated microstructures of the composites in turn govern the properties displayed by the MMCs at large. The microstructures captured for the composites are shown in Fig. 8. All the microstructures of MMCs has

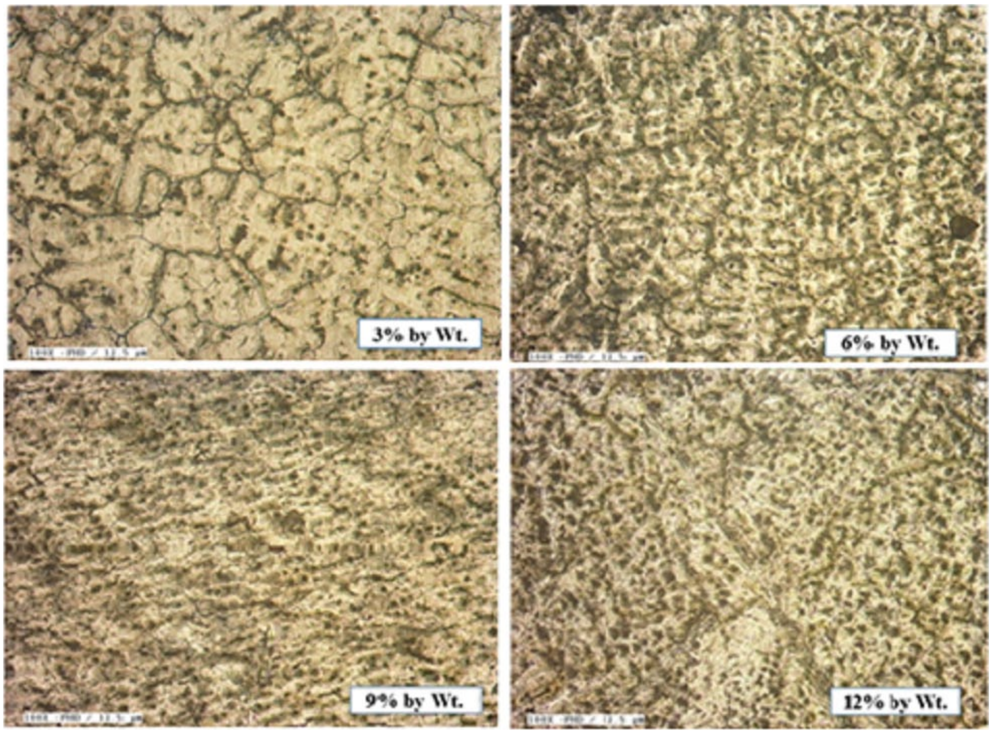

Fig. 7. Al 7075/Weld Slag MMC microstructure Images

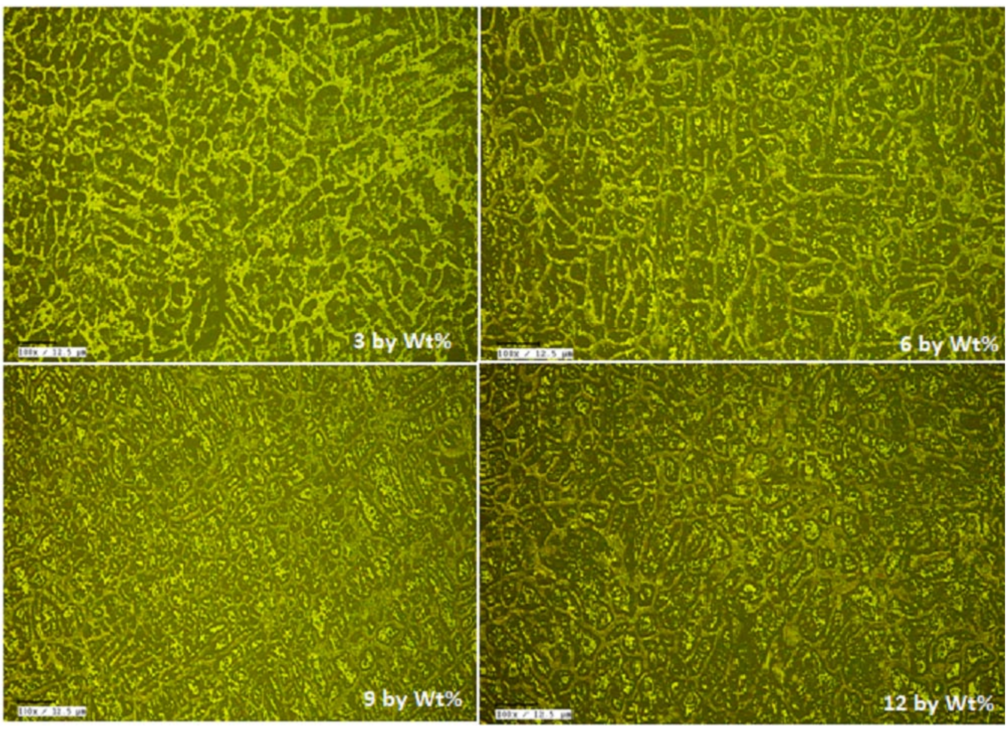

Fig. 8. Al 7075/RHA MMC microstructure Images

uncovered a critical grain refinement with the reinforcement particles acting as nucleation points. This is due to the effect of the distribution of the reinforcement particles within the matrix alloy to inhibit the improvement of the α-grains during solidification [22]. Dislocation densities are found to be higher in the microstructures of composites compared to AA7075 Alloy. The pinning down of the sharp WS particles is evident from the micrograph (shown by white arrow). The sharp WS particles (in red circles) in the Al composite matrix are shown in Fig. 7. The microstructure has shown a clear interface reaction boundary in the matrix confirming a good wettability of the reinforcement inside the matrix.

3.2. Tensile strength

The tensile strengths of the composites increases continuously as the fraction of weld slag reinforcements increases by weight (Fig. 9). These results are consistent with literature across numerous studies that concluded that alloying hard ceramic particles in soft metal matrix increases the strength of the MMC [27-29]. The strengthening of composites occurs by two mechanisms; one by the improved restriction to plastic deformation of matrix material when load is applied due to the direct transfer of load to reinforcement particles in the matrix at the interface boundaries of the reinforcements [30]. The other mechanism is by the efficient bonding of the reinforcement particles with matrix due to high wettability of the weld slag particles [31]. The weld slag metal matrix composites strength improves by these two mechanisms.

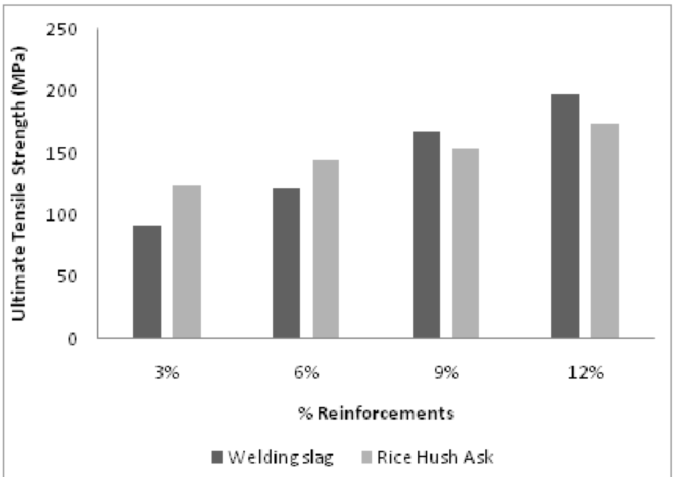

Fig. 9. Ultimate Tensile Strength (MPa) vs Reinforcement Percentage by wt

The tensile properties of compositesis better than that of the Al RHA composite and are represented in Fig.10. This strengthening of the MMC's is produced by two mechanisms; one is by the greater limitation of the plastic deformation of the matrix material under load by direct load transfer to the reinforcement particles in the matrix at the interfaces [32] and the other mechanism is based on the efficient binding of the reinforcement particles to the matrix due to the high wettability of the SSA-SiC particles [33]. The tensile strength of the composite increases as the SSA particle fraction increases. This is evident from the other studies as well [31,34] wherein, the tensile strengths of the composites increases as their particle reinforcement sizes increase but decrease beyond the optimum level. This may be due to the creation of excessive porosities and voids inside the matrix due to increasing particle size and reduction in interficial bonding between the particles and matrix.

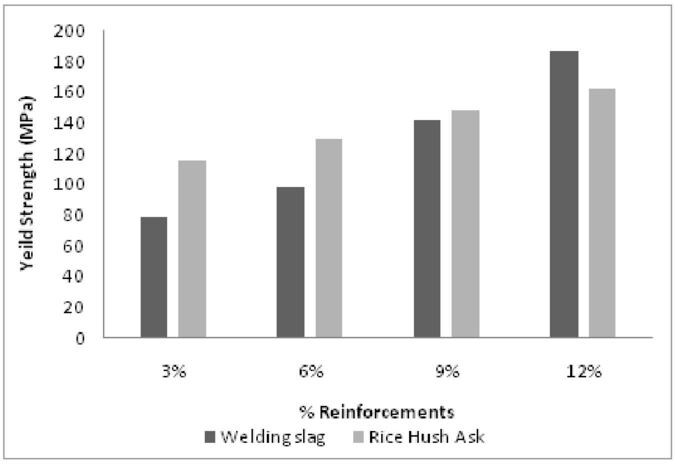

Fig. 10. Percentage Yield Strength (MPa) vs Reinforcement Percentage by wt

3.3. Impact strength

The fracture toughness of a composite is determined by the amount of energy absorbed by the specimen of fracture [35]. The impact energy responses of the composites are shown in Fig. 11. It can be confirmed that as the particulate fraction (wt%) increases in the matrix, the impact energy is retained first upto 6 by wt% and then increases. The primary reason for the improvement of the impact energy may be endorsed by the rich interface and good interfacial bonding amid the matrix and

Fig. 11. Percentage Impact strength vs Reinforcement Percentage by wt

the reinforcement. This effectively improves the load transfer capacity of matrix to the reinforcements [36]. However, impact energy can be negatively affected due to the barricading effect of reinforcements to the movement of dislocations inside the matrix. This result in the growing rate of work hardening causing decrease in fracture toughness [37]. The strengthening is more pronounced at higher reinforcement's percentages because of the presence of larger interface regions effectively mitigating the work hardening effect. In the composites with low alloying particulate fraction, both the effects nullify each other and impact strength remain unaltered.

3.4. Elongation

The ductility of the MMCs result reflects the reduced ductility. Additionally, SiC and Al_2O_3 increase the britility of the composites [31]. In the current study, the ductility of the composites are investigated and analyzed as a function of % elongation of the composites. The ductility of the composites increases gradually with increase in the reinforcement fraction (wt%) Fig. 12. This might be due to the fact that the Weld Slag particles are thermodynamically stable in the matrix and mitigate the embrittlement effects [32] of particles thus improving ductility of the composite.

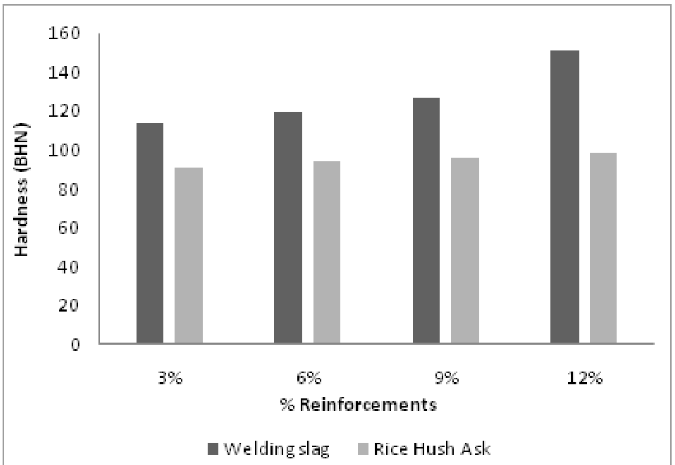

Fig. 12. Percentage Elongation vs Reinforcement Percentage by wt

3.5. Hardness

The hardness characteristics of the composites compared to as-cast samples are show in Fig. 13. The hardness of the MMC are higher than that of the base material. The hardness values are presented as an average of three taken at different locations on the specimens. The hardness of a MMC increases continuously as fraction reinforcement by wt% increases in the matrix [38] generally due to grain refinement, Hall-Petch mechanism and mismatch of particle coefficient of thermal expansion mechanisms. In the current study, as the fraction of reinforcements increases, the hardness of the MMC also increases. The hardness values of all the MMCs are higher than that of the base material. This is due to the good wettability of the weld slag reinforcement particles and good interface bonding between the matrix and the reinforcement particle.

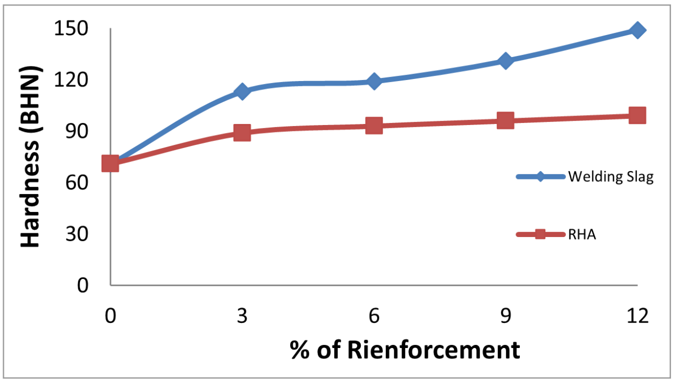

Fig. 13. Hardness vs Reinforcement Percentage by wt

Among the composites, the sample 02 (6%) has reflected a moderate but monotonic reduction in hardness than that of the sample 03 (9%). This may be due to the fact that the intrinsic hardness of the composite declines as the particle size decreases due to the segregation of the Mg to the interface and the formation of Mg_2Si interface compounds at the grain boundaries [32].

The key conclusions that can be drawn from the study are as below;

1. Industrially produced Weld Slag particles can be used as a viable reinforcement for producing Al-MMCs successfully.
2. The significant grain refinement has been obtained with stir casting process with good interface characteristics in the matrix and uniform dispersion of reinforcements.
3. The tensile strength of the composites increases as the reinforcement fraction progresses. The maximum tensile strength obtained is 173 MPa for 12% Weld Slag MMC.
4. The produced Al-Weld Slag MMCs exhibits superior hardness of the matrix and the magnitude of hardness increases as the action of reinforcements increases. The highest hardness value is ~98 BHN for 12% Weld Slag MMC.
5. The impact energy of the composites increases to 3J for 9% & 12% Weld Slag Composite.

REFERENCES

[1] W.S. Lee, W.C. Sue, C.F. Lin, Compos. Sci. Technol. **60** (10), 1975-1983 (2000).

[2] M.O. Bodunrin, K.K. Alaneme, L.H. Chown, J. Mater. Res. Technol. **4** (4), 434-445 (2015).

[3] A. Mortensen, J. Llorca, Annu. Rev. Mater. Res. **40**, 243-270 (2010).

[4] X. Zhang, Y. Chen, J. Hu, Prog. Aeronaut. Sci. **97**, 22-34 (2018).

[5] K. Shirvanimoghaddam, H. Khayyam, H. Abdizadeh, M.K. Akbari, A.H. Pakseresht, F. Abdi, M. Naebe, Ceram. Int. **42** (5), 6206-6220 (2016).

[6] N.E. Udoye, O.S.I. Fayomi, A.O. Inegbenebor, IOP Conf. Ser. Mater. Sci. Eng. 640 012066 (2019).
DOI: https://doi.org/10.1088/1757-899X/640/1/012066

[7] T.S. Kumar, S. Shalini, K.K. Kumar, R. Thavamani, R. Subramanian, Mater. Today: Proc. **5** (2), 7123-7130 (2018).

[8] M. Kolli, D.S. Naresh, K. Ravi Prakash Babu, Experimental studies on mechanical characteristics of bamboo leaf ash reinforcement with Aluminum 7075 alloy using rotary stir casting technique, International Conference on Advanced Manufacturing and Materials Processing, Malaviya National Institute of Technology Jaipur, Rajasthan, India, July 24-25, (2021).

[9] M.S. Kumar, M. Vasumathi, S.R. Begum, S.M. Luminita, S. Vlase, C.I. Pruncu, J. Mater. Res. Technol. **15**, 1201-1216 (2021).

[10] P. Paranthaman, P.M. Gopal, N. Sathiesh Kumar, Characterization of economical aluminium MMC reinforced with weld slag particles. In: S.Hiremath, N.Shanmugam, B. Bapu, (eds) Advances in Manufacturing Technology. Lecture Notes in Mechanical Engineering. Springer, Singapore (2019).
DOI: https://doi.org/10.1007/978-981-13-6374-0_2

[11] M. Kolli, S.N. Dasari, N.S. Potluri, A.V.S. Ramprasad, Aust. J. Mech. Eng. 1-10 (2020).
DOI: https://doi.org/10.1080/14484846.2020.1842299

[12] H.C. Anilkumar, H.S. Hebbar, K.S. Ravishankar, Int. J. Mech. Mater. Eng. **6**, (1), 41-45 (2011).

[13] I.N. Murthy, N.A. Babu, J.B. Rao, Journal of Minerals and Materials Characterization and Engineering **2**, 319-333 (2014).

[14] J.M. Kumar, N. Gopikrishna, Technol. **8** (11), 277-284 (2017).

[15] E.O. Alves, D.R.A Amaro, E.C.D.O. Silva, O.O.D. Araújo Filho, K.G.B. Alves, Mater. Res. **21** (6), e20170779 (2018).
DOI: https://doi.org/10.1590/1980-5373-MR-2017-0779

[16] J. Petrović, S. Mladenović, I. Marković, S. Dimitrijević, Mater. Technol. **56** (2), 115-122 (2022).

[17] S. Reddy, S.V. Chetty, S. Premkumar, H.N. Reddappa, Procedia Mater. Sci. **5**, 508-516 (2014).

[18] D.R.J. Selvam, D.R.I. Dinaharan, Energy Procedia **34**, 637-646 (2013).

[19] Murahari Kolli, Dasari Sai Naresh, K.Ravi Prakash Babu, Manufacturing and Processing of Advanced Materials 3-19 (2021).

[20] Murahari Kolli, J. Paulo Davim, Waste Residue Composites **16**, 2023, Walter de Gruyter GmbH & Co KG.

[21] M. Kolli, A.V.S. Ram Prasad, D.S. Naresh, SN Appl. Sci. **3** (7), 1-14 (2021).

[22] P.K. Bannaravuri, A.K. Birru, Results Phys. **10**, 360-373 (2018).

[23] ASTM E28.04. ASTM E8/E8M – 21 Standard Test Methods for Tension Testing of Metallic Materials. ASTM International, West Conshochcken, PA.)2018).
Available from: https://www.astm.org/Standards/E8.htm

[24] ASTM E28.06. ASTM E10 – 18 Standard Test Method for Brinell Hardness of Metallic Materials. ASTM International, West Conshochcken, PA. (2018).
Available from: https://www.astm.org/Standards/E10

[25] ASTM E28.07. ASTM E23 – 18 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials. ASTM International, West Conshochcken, PA. (2018).
Available from: https://www.astm.org/Standards/E23.htm

[26] L. Poovazhagan, K. Kalaichelvan, T. Sornakumar, Mater. Manuf. Processes **31** (10), 1275-1285 (2016).

[27] J. Zhang, R.G. Guan, D. Tie, X. Wang, X.H. Guan, B.C. Chen, Mater. Manuf. Processes **30** (3), 340-5 (2015).

[28] Y.T. Yao, L.Q. Chen, Mater. Manuf. Processes **31** (10), 1286-91 (2016).

[29] S. Aravindan, P.V. Rao, K. Ponappa, J. Magnesium Alloys **3** (1), 52-62 (2015).

[30] V. Balaji, N. Sateesh, M.M. Hussain, Mater. Today: Proc. **2** (4-5), 3403-8 (2015).

[31] B. Praveen Kumar, A. Kumar Birru, Kov. Mater. **56** (5), 325-37 (2018).

[32] X. Guo, Q. Guo, J. Nie, Z .Liu, Z. Li, G. Fan, D. Zhang, Mater. Sci. Eng. A. **711**, 643-649 (2018).

[33] B. Ravi, B.B. Balu Naik, J. Udaya Prakash, Mater. Today Proc. **2** (4-5), 2984-2990 (2015).

[34] R. Vinayagamoorthy, Polym. Polym. Compos. **28** (6), 410-420 (2020).

[35] H. Ghandvar, S. Farahany, M.H. Idris, Tribol. Trans. **61** (1), 88-99 (2017).

[36] V. Mohanavel, K. Rajan, S.S. Kumar, S. Udishkumar, C. Jayasekar, Mater. Today. Proc. **5** (1), 2938-44 (2018).

[37] C.U. Atuanya, A.T. Esione, F.A. Anene, J. Chin. Adv. Mater. Soc. **6** (4), 543-52 (2018).

[38] N.K. Bhoi, H. Singh, S. Pratap, J. Compos. Mater. **54** (6), 813-833 (2020).