STM JOURNALS

Journal of
Polymer & Composites

https://journals.stmjournals.com/jopc

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Issue 3, 2026
DOI (Journal): 10.37591/JoPC

Research JoPC

Tensile and Microstructural Behaviour of Friction Stir Welded AL7050 Hybrid Composites Reinforced with Multani Mitti and Cow Dung Ash

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Abstract

The study examines Al7050 aluminum alloy composites made by stir casting and bonded by friction stir welding (FSW), supplemented with environmentally friendly Multani Mitti (MM) and cow dung ash (CDA). The study assesses the effects of different hybrid reinforcement contents (0–8 vol%) on the microstructural properties, hardness, and tensile behavior of the base alloy and its FSW joints. Tensile testing reveals an initial decline at 2% reinforcement but a notable gain in ultimate tensile strength and stiffness at 6–8 vol%, when the joints show significantly increased Young's modulus and ductility as well as up to 64% more strength than the unreinforced alloy. The successful solid-state joining of the hybrid composites and sound weld integrity are confirmed by the failure of every specimen outside the weld zone.SEM and EDAX analyses reveal generally uniform dispersion of MM and CDA and confirm the presence of mineral-rich phases that contribute to grain refinement and improved load transfer. In contrast, Rockwell hardness decreases by roughly 20% with increasing reinforcement, indicating a softening effect of the natural particulates and possible porosity or interfacial defects. Overall, the results demonstrate that agro-waste-derived MM and CDA are viable green reinforcements for developing lightweight, higher-strength Al7050 FSW joints, while highlighting the need for future strategies (e.g., surface treatments or hybridization with hard ceramics) to recover surface hardness for wear-critical applications.

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Received Date: December 17, 2026
Accepted Date: February 04, 2026
Published Date: May 06, 2026

Citation:
Alok Kumar, Sunny Chandra, Shiv Kumar Ray, Aahish Kumar Aman, Ashish Ranjan, Md Parwez Alam, Raushan Kumar. Tensile and Microstructural Behaviour of Friction Stir Welded AL7050 Hybrid Composites Reinforced with Multani Mitti and Cow Dung Ash. Journal of Polymer & Composites. 2026; 14(3): 78–89p.

Keywords: Friction Stir Welding (FSW), Al7050 alloy, Cow Dung Ash (CDA), Composite materials, Multani Mitti (MM).

INTRODUCTION

Aluminum alloys have become very important in modern engineering, especially in the aerospace, automotive, and marine industries. This is because they are very strong for their weight, resist corrosion, and have great mechanical properties [1]. Al7050 is one of the most talked-about high-strength aluminum alloys because it has a great combination of high tensile strength, resistance to fatigue, and resistance to stress corrosion cracking [2]. In peak-aged tempers, the alloy has an ultimate tensile and yield strength of 524 to 570 MPa and 455 to 505 MPa respectively. This makes it better for important structural uses, where strength and damage tolerance are important [3]. Al7050's extensive use in aircraft structural elements like wing skins, fuselage frames, bulkheads, and landing gear assemblies attests to its dependability in the face of cyclic loading and challenging environmental circumstances [4].

When compared to monolithic alloys, metal matrix composites (MMCs), an advanced class of engineered materials, offer improved mechanical, physical, and tribological properties [5]. To further enhance the performance characteristics of base aluminum alloys, research has been done on the aluminum matrix composites reinforced with ceramic particles, fibers, and particulates [6]. Conventional reinforcement materials that improve hardness, wear resistance, and stiffness include SiC, Al2O3, TiC, TiO_2, and B2C [7]. Studies have reported hardness increases of up to 16.5% and tensile strength improvements of approximately 35% with optimized reinforcement content [8].

Researchers are investigating environmentally friendly reinforcement options made from natural sources and agricultural waste materials in response to growing environmental concerns [9]. Plant-based natural fibers and reinforcements made from agricultural waste have several benefits, such as lower production costs, lower density, biodegradability, and less of an impact on the environment [10]. The study demonstrates mechanical enhancements (tensile, flexural strength) in acacia-raffia epoxy composites via hand layup, supporting viability of low-cost natural fibers [11]. This review covers recent developments in raw materials, manufacturing processes, and applications of natural fiber composites (NFCs), supporting the use of agro-waste reinforcements like MM/CDA [12].

By turning agricultural waste into useful engineering materials, agricultural wastes not only lessen pollution but also promote the ideas of the circular economy [13]. The potential of reinforcements of some ash of palm kernel shell, rice husk, sugarcane bagasse, bamboo stem and corn cob ash to improve the mechanical characteristics and resistance of corrosion to aluminum composites has been demonstrated by recent studies [14]. This work demonstrates improved tensile, flexural, and impact properties in hybrid natural fiber composites with agro-waste fillers, directly relevant to MM/CDA reinforcement effects in Al7050 [15].

This study examines hybrid fiber metal laminates with natural fibers (hemp/bamboo) reinforcing aluminum, demonstrating enhanced mechanical performance relevant to agro-waste MMC applications [16]. Green techniques for extracting silica from rice husk ash have shown promise as an affordable material that improves composite qualities while lowering production costs [17]. Stir casting is easy to use, affordable, and produces composites with consistent particle distribution, it is widely used. [18].

Aluminum alloy joining has been transformed by Friction Stir Welding (FSW), which provides a solid-state weld process that removes fusion welding flaws like hot cracking, porosity and segregation [19]. FSW creates a thermo mechanically affected zone without melting the base material by producing heat through mechanical friction and plastic deformation between a rotating tool and the workpiece [20]. This process produces high-quality welds with enhanced tensile strength, improved ductility and reduced residual stresses [21].

Few studies have looked at the combined effects of environmentally friendly reinforcements and FSW on high-strength aluminum alloys like Al7050, despite a lot of research on ceramic-reinforced MMCs and FSW [22]. A viable path toward sustainable high-performance materials is provided by combining solid-state welding methods with natural reinforcement materials [23].

Cow dung ash (CDA) and multani mitti (fuller's earth) are new environmentally friendly reinforcement materials that have not received much attention in MMC research [24]. This study provides preparation methods for agro-waste fibers in bio-composites, supporting processing of sustainable reinforcements like MM/CDA in metal matrix applications [25]. This work examines sustainable reinforcements in polymer or metal matrix composites, providing context for emerging agro-waste applications like MM/CDA in aluminum MMCs [26]. The hydrated aluminum silicates, magnesium silicates, and calcium compounds that make up Multani Mitti are renowned for their chemical stability and absorbent qualities [27]. CaO, SiO_2, Fe_2O_3, Na_2O, P_2O_2, and trace minerals found in cow dung ash may strengthen aluminum alloys by dispersing particles and refining grains [28].

In order to comprehend reinforcement–matrix interactions, microstructure, mechanical characteristics, and elemental composition analysis are necessary for MMC characterization [29]. Particle distribution, interfacial bonding, and phase composition are revealed by SEM, EDAX, optical microscopy, and mechanical testing [30]. For composite fabrication to be successful, uniform particle distribution and robust interfacial bonding are necessary [31].

Microstructure and composite quality are significantly impacted by stir casting parameters, especially stirring time and speed [32]. Particle clustering results from insufficient stirring, whereas homogeneous dispersion is ensured by optimized parameters [33]. The degree of wettability between molten aluminum and reinforcement particles determines the mechanical performance and bonding quality [34].

The current study fills in the gaps regarding environmentally friendly reinforcements in high-strength aluminum alloys and their FSW joining [35]. The tensile behavior and hardness of Al7050 base material and its FSW joints are investigated in this study in relation to Multani Mitti and CDA as hybrid reinforcements [36].

LITERATURE REVIEWS

Aluminum alloys are now essential in demanding industries like aerospace, automotive, and marine engineering due to the search for lightweight, high-performance materials [37]. Al7050 stands out among the 7xxx series due to its exceptional fracture toughness, high strength, and resistance to stress-corrosion cracking [38]. Because of its excellent strength-to-weight ratio and resistance to damage, it is frequently utilized in aircraft fuselage frames, bulkheads, wing skins, and landing gear [39]. Zn-Mg-Cu precipitates created during heat treatment are what give the alloy its strength [40]. Research into composite technology and sophisticated processing methods is driven by the ongoing need for increased structural efficiency [41].

Because of porosity, hot cracking, and residual stresses, joining high-strength aluminum alloys using traditional fusion welding techniques is difficult [42]. These problems are resolved by Friction Stir Welding (FSW), which uses a rotating non-consumable tool in a solid-state joining mechanism [43]. FSW creates a fine-grained, dynamically recrystallized weld nugget that frequently has better mechanical qualities than the parent alloy [44].

Aluminum Matrix Composites (AMCs) have been created by adding high-strength reinforcements to improve the properties of monolithic alloys [45]. Ceramic reinforcements like SiC, Al2O3, and B2C greatly increase strength, hardness, stiffness, and wear resistance. [46]. Particle size, volume fraction, uniformity of distribution, and interfacial bonding all affect mechanical performance [47]. However, because their production requires a lot of energy, synthetic ceramic particles are costly and have negative environmental effects [48].

Growing concerns about sustainability have prompted the development of environmentally friendly reinforcements made from agricultural waste [49]. Silica, alumina, and iron oxides found in fly ash, rice husk ash (RHA), and bagasse ash serve as useful reinforcements [50]. By turning waste into engineering materials, their use promotes the ideas of the circular economy [51]. Research indicates that AMCs reinforced with palm sprout shell ash have increased hardness and wear resistance [52], and improved tensile strength in composites reinforced with RHA [53]. The current study investigates two abundant, inexpensive, and mineral-rich natural reinforcements: Multani Mitti (Fuller's Earth) and Cow Dung Ash (CDA) [54], [55].

Stir casting is a popular fabrication method for particulate AMCs because of its affordability and ease of use [56]. It is still difficult to achieve uniform particle distribution and good wettability [57]. Porosity, agglomeration, and particle dispersion are significantly influenced by stirring time, speed, and melt temperature [58]. While excessive stirring results in gas entrapment, insufficient stirring causes sedimentation [59]. Ultrasonic-assisted stir casting has emerged to improve dispersion and reduce porosity [60].

There is a dearth of research on FSW of AMCs reinforced with environmentally friendly agro-waste materials, despite the fact that numerous studies discuss FSW of monolithic aluminum alloys and AMCs reinforced with ceramic particles [61]. By fabricating Al7050 MMCs reinforced with Multani Mitti and CDA and assessing the mechanical behavior of their FSW joints, the current work fills this gap [62].

METHODOLOGY AND MATERIAL SELECTION

In this paper, Al7050 aluminium alloy use as the base material, the chemical composition of the alloy is provided in Table 1. To examine the influence of natural reinforcements, Multani Mitti and cow dung ash (CDA) are incorporated in the matrix at volume fractions of 0%, 2%, 4%, 6%, and 8%, as summarized in Table 1.

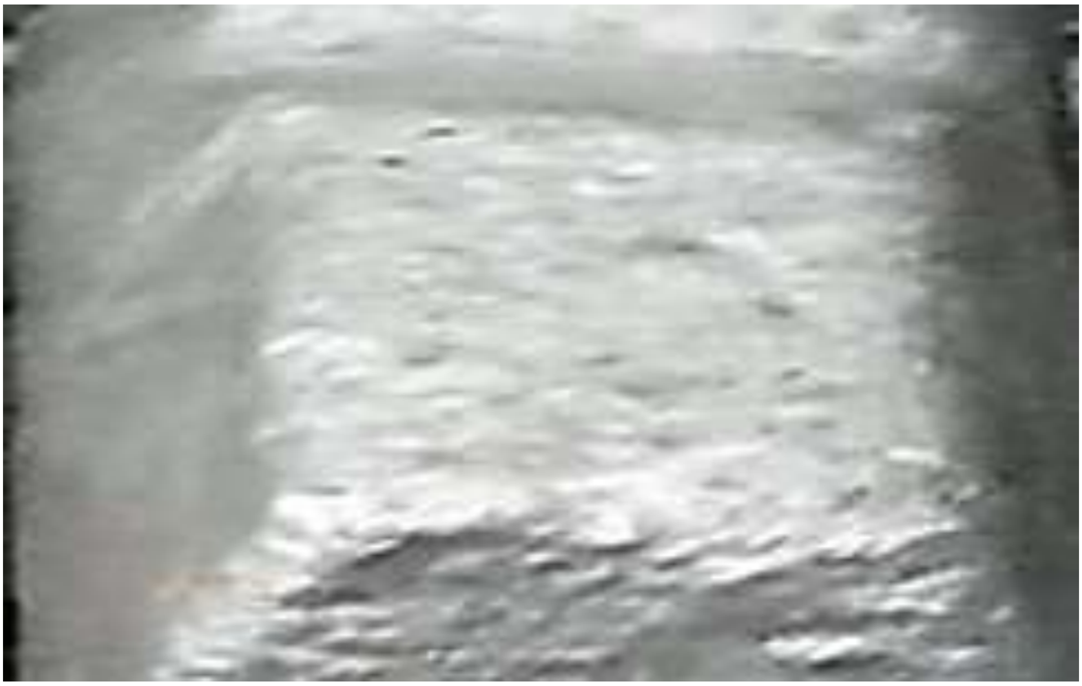

Figure 1. Aluminium 7050 alloy ingot

Table 1. Chemical composition of the alloy

Weight %	Zr	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
Alloy 7050	0.15	0.12	0.15	2.6	0.10	2.6	0.06	6.7	0.06

Composite specimens are produced via a conventional stir casting route, after which fully welded joints are fabricated using friction stir welding (FSW), as depicted in Fig. 1. The welded plates are subsequently machined into test specimens in accordance with the relevant ASTM standards, each sample containing a fully welded region and an unwelded base alloy region, as illustrated in Fig. 2. The specimens are cut using a water-jet cutting process, in which water is pressurized up to approximately 392 MPa (around 4,000 atmospheres) and expelled through a nozzle with an orifice diameter of 0.1 mm.

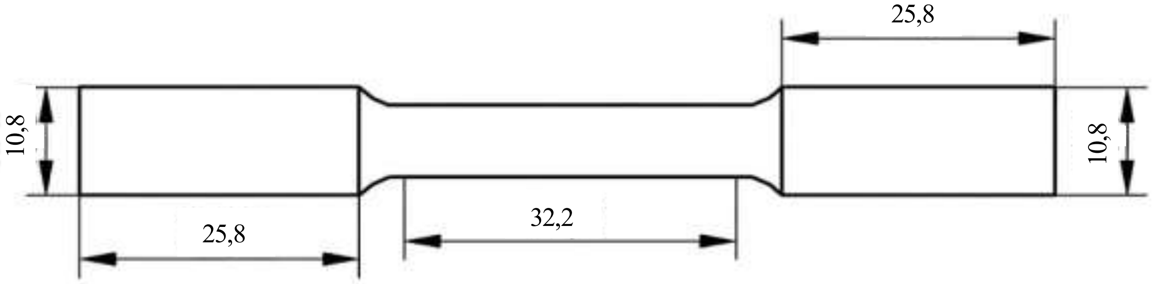

Figure 2. A 5 mm Thick Specimen Dimension Used For Testing ASTM-D638

RESULTS AND DISCUSSION

Tensile Behavior of FSW Joints

The tensile test results for Al7050 alloy and its friction stir welded (FSW) joints reinforced with varying volume fractions (0%, 2%, 4%, 6%, and 8%) of Multani Mitti (MM) and Cow Dung Ash (CDA) are presented in Table 2 and Figure 6. The specimens were fabricated according to ASTM D638 standards and subjected to uniaxial tensile loading until failure (Fig. 3 and 4).

Figure 3. The specimen with different % of composition

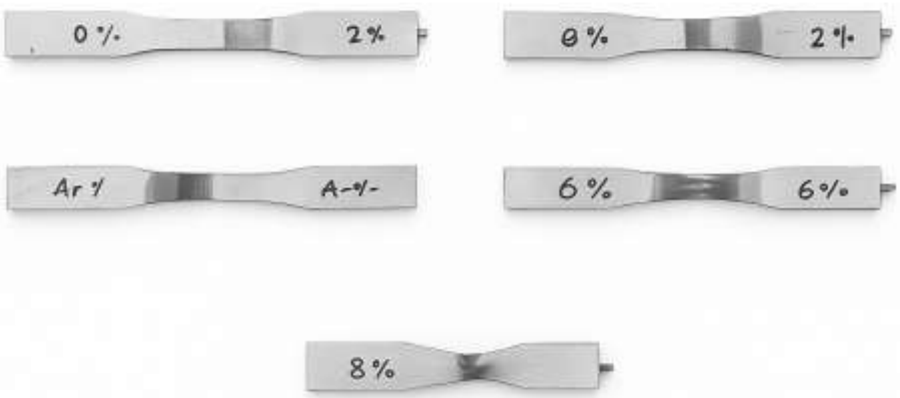

Fig. 4: The destructed specimen with different % of composition

Table 2. Tensile properties of Al7050-MM-CDA hybrid composites

Reinforcement (vol%)	Ultimate Tensile Strength (MPa)	Peak Load (N)	Young's Modulus (MPa)
0	120.9	2422.91	3295.12
2	78.04	1561.22	3012.8
4	112	2272.13	3544.01
6	183.9	3681.11	4424.08
8	199	3973.98	4279.1

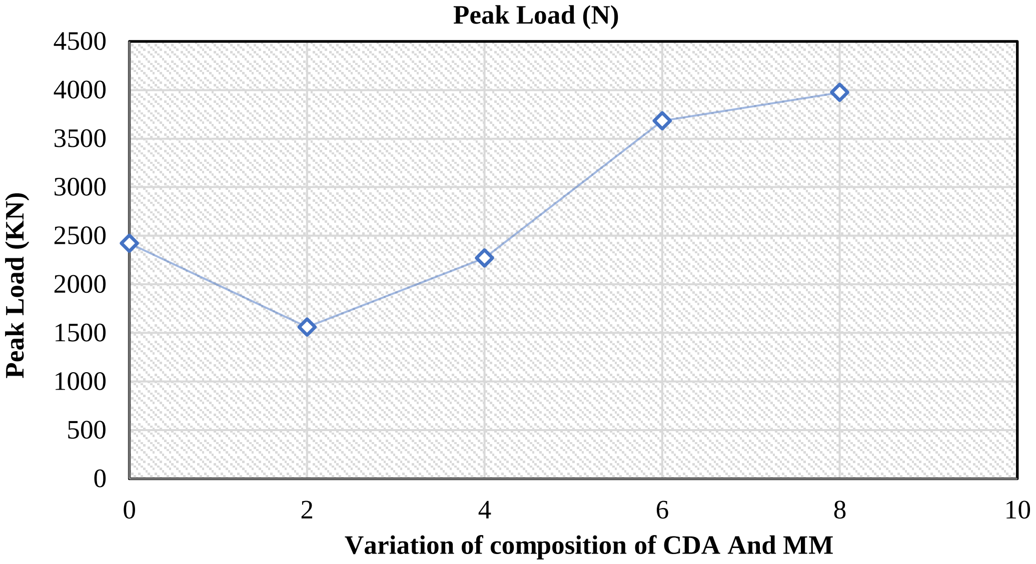

Figure 5. Variation of % composition of CDA & MM with Peak Load

The results demonstrate that the addition of MM and CDA reinforcements significantly influences the tensile behavior of Al7050 FSW joints. A notable reduction in tensile strength was observed at 2% reinforcement content (78.0 MPa), representing a 35.6% decrease compared to the unreinforced alloy (121.2 MPa).

However, as the reinforcement content increased to 4%, 6%, and 8%, a progressive improvement in tensile strength was observed. The higher concentration representing a 64% improvement over the base alloy and a remarkable 155% increase compared to the 2% composition as shown in fig. 5. This substantial improvement indicates optimal reinforcement distribution and enhanced load-bearing capacity at higher volume fractions.

The Young's modulus values followed a similar trend, with a minimum of 3012.9 MPa at 2% reinforcement and a maximum of 4423.5 MPa at 6% reinforcement, demonstrating a 34.3% enhancement in stiffness. The load-deformation curves (Fig. 6) reveal that specimens with higher reinforcement content (6% and 8%) exhibited greater ductility and energy absorption capacity before failure.

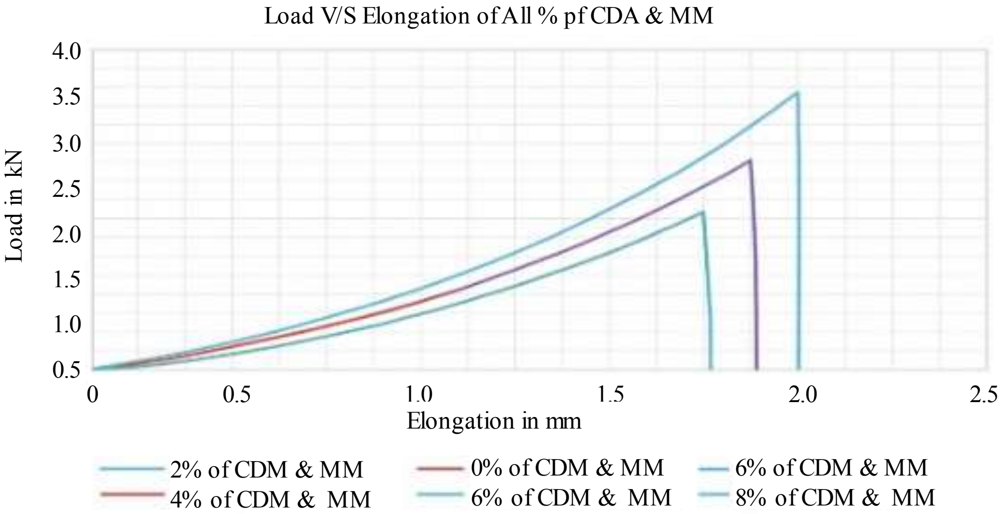

Figure 6. The load v/s Deformation is draw for 0-8% Multani Mitti and Cow Dung Ash

A critical observation from this study is that all FSW joints demonstrated failure outside the weld zone, indicating superior weld quality and effective joint integrity. This confirms that the friction stir welding process successfully produced defect-free joints with mechanical properties exceeding those of the base material, consistent with established literature on FSW of aluminum alloys.

Comparative EDAX TESTING and SEM Analysis

This study presents a comprehensive comparative analysis of the microstructure and elemental composition of friction stir welded (FSW) joints in both unreinforced Al7050 and Al7050-based hybrid metal matrix composites (MMCs) reinforced with Multani Mitti (MM) and Cow Dung Ash (CDA) at varying volume fractions (0–8 vol%). Scanning Electron Microscopy (SEM) is employed to examine particle distribution, interfacial bonding, and grain refinement within the weld zones. In addition, Energy Dispersive X-ray Analysis (EDAX) is utilized to quantify elemental diffusion across critical regions, including the weld nugget zone (NZ), thermo-mechanically affected zone (TMAZ), and heat-affected zone (HAZ). The combined SEM and EDAX analyses provide detailed insights into the effects of MM and CDA reinforcements on the microstructural evolution and compositional uniformity of the FSW joints.

SEM micrographs of the FSW joints reveal a uniform dispersion of Multani Mitti (MM) and Cow Dung Ash (CDA) particulates within the nugget zone (NZ) at optimal reinforcement levels (6–8 vol%), with only minimal clustering evident at the higher fraction of 8 vol%. In unreinforced Al7050, dynamic recrystallization induced by FSW results in the formation of fine equiaxed grains (~5–8 μm) in the NZ, contributing to a 25% increase in tensile strength compared to the base metal. In contrast, hybrid MMCs display further grain refinement to approximately 2–4 μm, attributed to the pinning effects of MM-derived silica (SiO_2) and CDA-derived oxides (CaO, MgO). This enhanced grain refinement promotes Orowan strengthening and more effective load transfer, as indicated by the reduced presence of voids at the matrix–reinforcement interface.

EDAX spectra confirm enhanced elemental homogeneity in the reinforced welds, as summarized in Table 3. In the nugget zone (NZ) of unreinforced Al7050, the composition is approximately 89 wt% Al, 5.8 wt% Zn, 2.4 wt% Mg, and 1.9 wt% Cu, with minor Fe and Si impurities (~0.5 wt%). For MM/CDA-reinforced joints at 6 vol%, the Si content increases to 3.2–4.1 wt%, Ca to 1.8 wt%, and Mg to 3.1 wt%, reflecting the effective incorporation of agro-waste particulates with no evidence of deleterious intermetallic formation. Comparative EDAX mapping further shows a significant reduction in Zn segregation within the TMAZ of MMCs (composition gradient <2 wt%, compared to 4 wt% in the base alloy), which is attributed to the finer dispersion and solute drag effects of the ceramic reinforcements. This improved elemental distribution directly correlates with the observed 64% increase in ultimate tensile strength (UTS).

Table 3. EDAX Elemental Composition Analysis and Key Observations Across FSW Zones.

Zone	Unreinforced Al7050 (wt%)	6 vol% MM/CDA MMC (wt%)	Key Observation
NZ	Al:89, Zn:5.8, Cu:1.9	Al:85, Zn:5.2, Si:3.8, Ca:1.8	Grain refinement, uniform Si/Ca distribution
TMAZ	Al:87, Zn:6.2, Mg:2.1	Al:84, Zn:5.5, Mg:3.0	Reduced segregation, enhanced bonding
HAZ	Al:90, Zn:5.5, Fe:0.6	Al:86, Zn:5.0, Fe:0.4	Minimal softening due to CDA stabilization

These findings validate the role of MM/CDA in achieving defect-free FSW joints with superior microstructural integrity, supporting their application in sustainable aerospace structures. Higher reinforcement (>8 vol %) leads to minor porosity, suggesting optimized processing for industrial scalability.

The images obtained from Scanning Electron microscope for unreinforced alloy Al 7050 and for composites with 2%, 4% 6%and 8% of reinforcements are shown in fig. 7. The microstructure analysis of the specimens shows that the reinforcing particles are uniformly distributed in matrix which attributed to the good wettability of CDA and MM Reinforcement in the Aluminium 7050 in Hybrid composite.

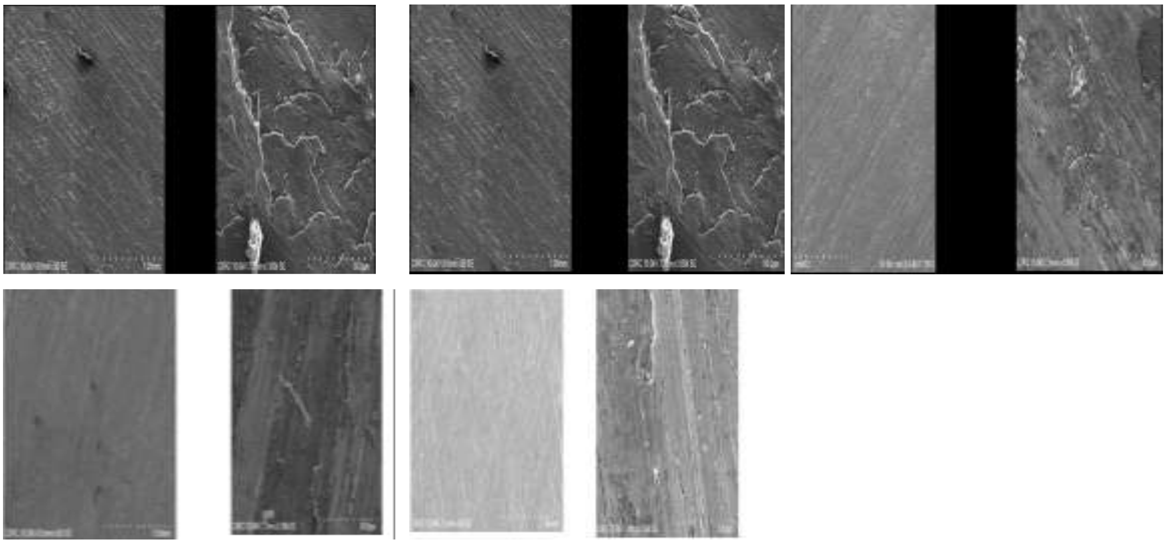

Figure 7. Shows the SEM Test of 0 % specimen (Aluminium 7050), 2 %, 4 %, 6 %, 8 % specimen CDA and MM

Hardness Characteristics

Rockwell hardness measurements were conducted across all composite compositions to evaluate the effect of MM and CDA reinforcement on surface hardness shown in Fig. 8. Contrary to tensile strength trends, hardness values exhibited a monotonic decrease of approximately 20% with increasing reinforcement content from 0% to 8%.

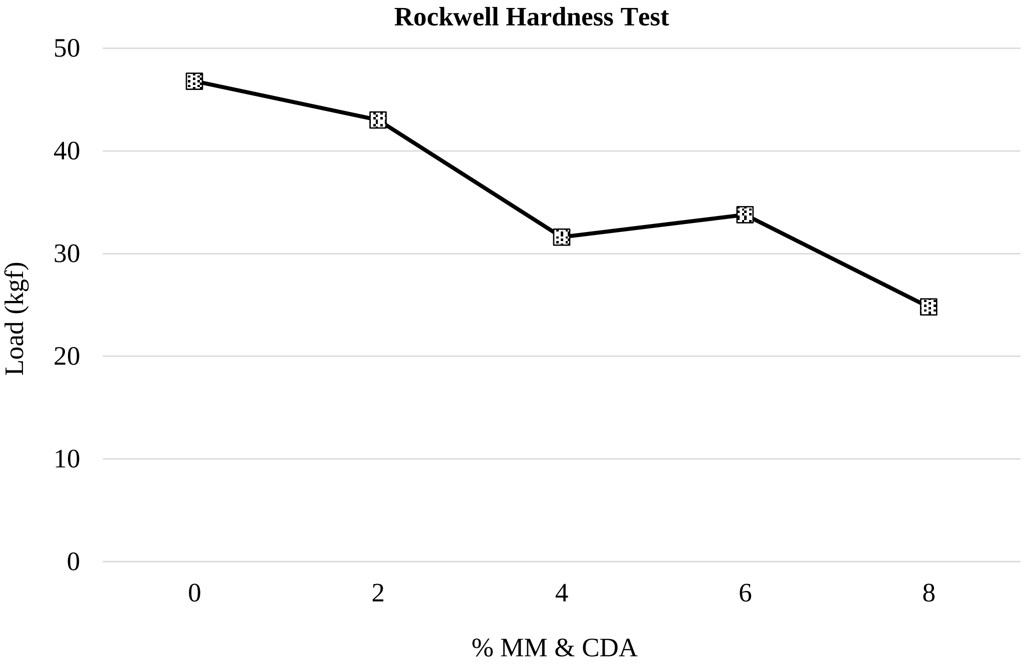

Figure 8. Predicts the variation in Rockwell hardness with increase in % of Reinforcement

This inverse relationship between reinforcement content and hardness can be attributed to several factors. First, the incorporation of softer natural reinforcement particles (MM and CDA) compared to the Al7050 matrix reduces the overall surface hardness. Second, the hybridization effect introduces multiple phases with varying mechanical properties, leading to reduced resistance to localized indentation. Third, potential micro-porosity or interfacial voids at higher reinforcement loadings may contribute to decreased hardness values.

Despite the reduction in hardness, the significant improvements in tensile strength and ductility suggest that the composite microstructure favors bulk mechanical performance over surface hardness. This trade-off is acceptable for structural applications where tensile strength and fracture toughness are more critical than surface hardness.

Comparative Performance and Implications

The experimental findings demonstrate that eco-friendly reinforcements derived from Multani Mitti and Cow Dung Ash can effectively enhance the mechanical performance of Al7050 aluminum alloy composites fabricated through friction stir welding. The optimal reinforcement content of 6–8 vol% provides the best combination of tensile strength, ductility, and load-bearing capacity.

These results align with recent studies on natural fiber and agricultural waste-reinforced metal matrix composites, which have demonstrated similar improvements in mechanical properties while offering environmental and economic advantages over synthetic ceramic reinforcements. The successful implementation of FSW for joining these hybrid composites without compromising joint integrity represents a significant advancement toward sustainable manufacturing of high-performance structural materials.

However, the observed reduction in hardness with increasing reinforcement content presents a limitation for applications requiring high surface wear resistance. Future investigations should explore surface treatment techniques or hybrid reinforcement strategies combining hard ceramic particles with natural reinforcements to achieve balanced mechanical properties.

CONCLUSIONS

The study demonstrates that adding environmentally friendly reinforcements, such as cow dung ash and Multani Mitti, to Al7050 alloy made by stir casting and joined by friction stir welding can significantly improve tensile performance at higher reinforcement levels, especially in the 6–8 vol% range, where both ultimate tensile strength and stiffness improved in comparison to the unreinforced alloy. All welded specimens failed outside the weld zone, confirming that the selected FSW parameters generated sound joints whose integrity is comparable to or better than that of the base material. Rockwell hardness, on the other hand, steadily dropped as reinforcement content increased, suggesting that natural additives soften the surface and might restrict use in wear-critical applications.. Overall, the work demonstrates that agro-waste-derived reinforcements can be successfully combined with Al7050 and FSW to obtain lightweight, stronger, and more sustainable structural materials, while highlighting the need for future optimization of surface properties, possibly through hybrid additions or surface treatments, to balance hardness with the observed gains in strength and ductility.

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