Utilizing Rotary Friction Welding for Joining Aluminum Composite Materials by Omani Waste Marble Reinforcement

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Aluminum composite materials consist of a base material created from an aluminum alloy (AL-Si12Fe) and reinforcement elements made from marble waste (MW). The stir-squeeze casting technique is employed to cast these components together. Composites consisting of an aluminum alloy and 5% MW were subjected to mechanical testing. The study demonstrated that the addition of MW reinforcements significantly improved the mechanical properties of the composite materials. The AL-Si12Fe +5%MW and AL-Si12Fe +5%MW-weld composites exhibited an ultimate tensile strength (UTS) that was 16% and 52% respectively higher than that of the AL-Si12Fe aluminum alloy. Friction welding is a technique that can be used to improve and recrystallize crystals, in addition to being a technique for super-deformation.

Keywords: AL-Si12Fe alloy, aluminum composites, rotary friction welding, marble wastes.

1. Introduction

The current research focuses on the potential application of friction welding to join Aluminum Composite Materials (ACM). Generally, to enhance the mechanical properties of aluminum alloys, they can be reinforced with materials such as graphite or glass fibers, creating ACMs. In recent years, the increasing use of ACMs in the automotive and aerospace sectors has prompted the need for effective joining techniques [1]. Friction welding, specifically solid-state welding, is a preferred technique due to its low heat input, absence of filler materials, small heat affected zones, reduced distortion and residual strains, and enhanced material properties. The utilization of rotary friction welding (RFW) is highly appealing in aluminum alloys due to its ability to match material properties and process capabilities effectively [2].

Recycling and reusing waste is a widely recognized strategy in many countries. The Sultanate of Oman is known for its natural marble exports [3]. However, the manufacturing process of marble results in a significant amount of waste that needs proper disposal in sanitary landfills, which can be expensive [4]. To tackle this issue, Omani marble is now being recycled to reinforce metal, effectively reducing industrial waste. This approach aligns with the concept of recycling and is a significant step towards sustainability [5].

2. Methods and Methodology:

Our research aims to analyze the microstructure and mechanical properties of standard and experimental materials used for aluminum composite reinforcement. These materials consist of an AL-Si12Fe as basic metal and a mixture of 5% MW, which is created through stir squeeze casting and joined using the RFW method. We will evaluate the properties of the resulting materials. Table 1 displays the chemical composition of MW.

Table 1. Chemical Composition of MW [6].

Composition	Wt. %
SiO2	0.29
Al2O3	0.05
Fe2O3	<0.04
MgO	0.36
CaO	55.86
TiO2	<0.01
P2O5	<0.01
MnO	<0.01
Cr2O3	0.002
LOI	43.49

Sultan Qaboos University in Oman used stir squeeze casting to make AMC. The casting machine merged and consolidated materials using hydraulic forging and casting as shown in figure 1. To ensure that moisture and particle clumping were prevented, the preheater chamber of the stir squeeze casting machine heated the reinforcement particles to a temperature of 300°C. The warmed reinforcement particles were then mixed gently with AL-Si12Fe molten metal for a specified duration to ensure that the dispersion in the matrix phase was uniform. The mixture was pressed hydraulically to make the samples. The casting parameters are listed in Table 2.

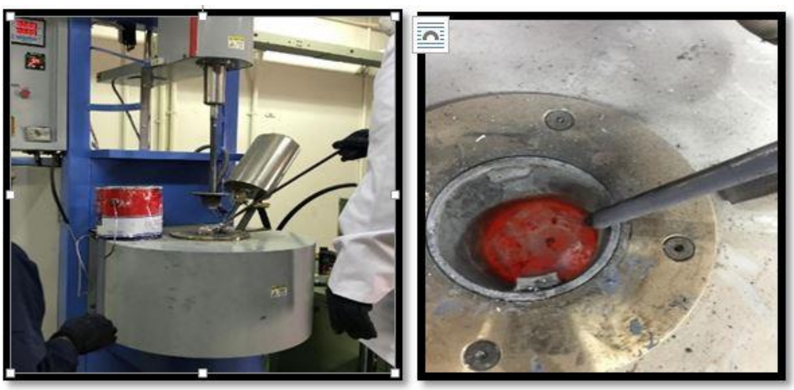

Figure 1. Molten Aluminum Matrix Composite.

Table 2. Process Parameters of Stir Squeeze Casting Process.

S. No	Process Parameters	Range (Values)
1	Stirring temperature	740 ºC
2	Stirring speed	600 rpm
3	Stirring time	10 mins
4	Preheat temperature of reinforcement particles	300 ºC
5	Preheat temperature of the permanent die	250 ºC
6	Squeeze pressure	75 MPa
7	Matrix material (AL-Si12Fe)	95%
8	Reinforcement material (MW)	5%

RFW machines are advanced industrial tools that assemble many materials precisely and efficiently. They forge pieces without melting by rotating one part at high speeds and forcing it against another fixed part, creating heat through friction. Rotary friction welding is ideal for complex material combinations in e-mobility, aerospace, and automobile industries due to its strong, reliable connection. The basic RFW machine layout is shown in Figure 2. The welding process involved 1400 rpm spindle speed, 150 Mpa upsetting pressure, 230 Mpa upset pressure, and 200 seconds of friction time.

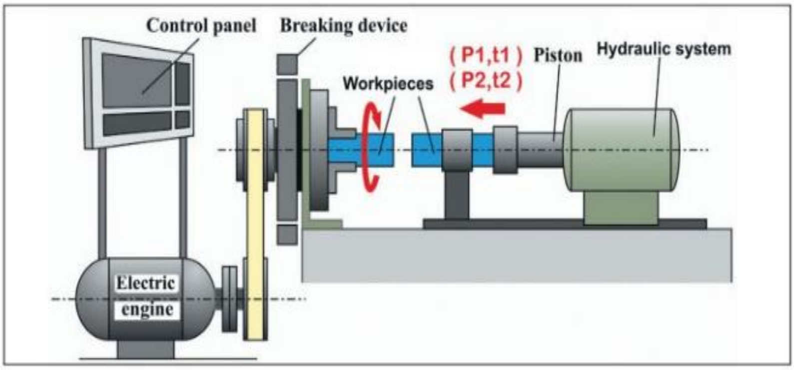

Figure 2. Shows the Layout of FRW [7].

3. Result and Discussion:

The results that have been presented showcase various mechanical and physical properties. The test samples that were studied consisted of four materials: (A) the base material AL-Si12Fe, (B) A+5%MW, (C) A-welded (by rotary friction welding processes), (D) A+5%MW-welded.

a) Mechanical Characterizations of Composites.

All samples were prepared according to ASTM standard E-8 and the uniaxial tensile testing was carried out. Then UTS and % ductility values were measured for each and then averaged. Figure 3 shows the stress-strain curves and average UTS value for four samples of A, B, C, and D. Table 3 presents the % increase in UTS and ductility for all samples.

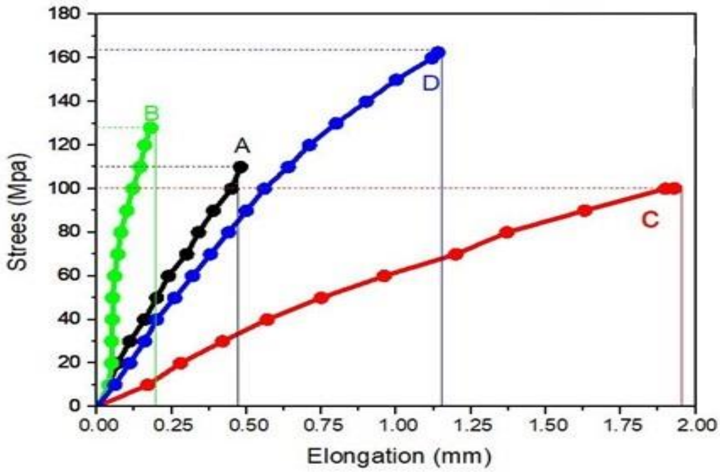

Figure 3. Stress-Strain Curves for Samples A, B, C and D.

Table3. UTS and Ductility Values of Samples from Tensile Testing.

Sample ID	UTS (MPa)	% UTS	Elongation	% Ductility
A	110	-	0.48	--
B	128	16%	0.28	- 41%
C	100.2	-9 %	1.93	302%
D	162.6	52%	1.14	137%

Friction welding is a severe plastic deformation (SPD) technique that can be employed to enhance the crystal microstructure. This refers to the process of generating fine-sized materials, which is necessary to meet the conditions for super-plasticity. It can also be referred to as thermomechanical processing, which involves recrystallization in the AMC. We noticed a substantial rise in the percentage of ductility in the welded samples, reaching a maximum of 300%.

Vickers hardness testing was conducted to determine the hardness profile across the composite samples. Sample types used for hardness testing were (C) and (D) samples. Individual hardness value was measured for samples, as shown in Figure 4.

In RFW processes, the material hardness in the welding zones decreases compared to the parent metal due to the recovery and recrystallization or removal recrystallization process [8].

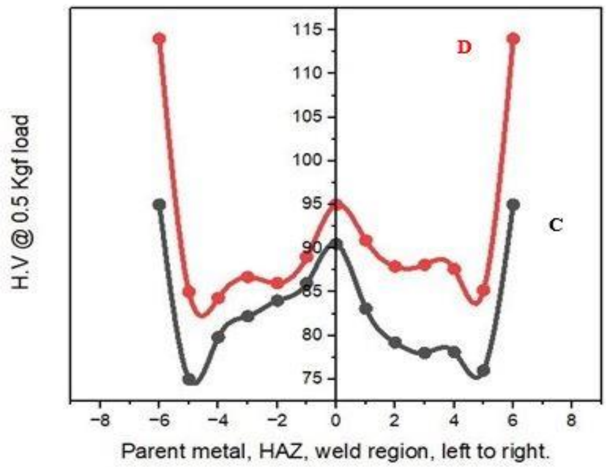

Figure 4. Results of Vickers Hardness Testing

Figure 5 displays the energy absorbed by four samples prepared following ASTM A370.

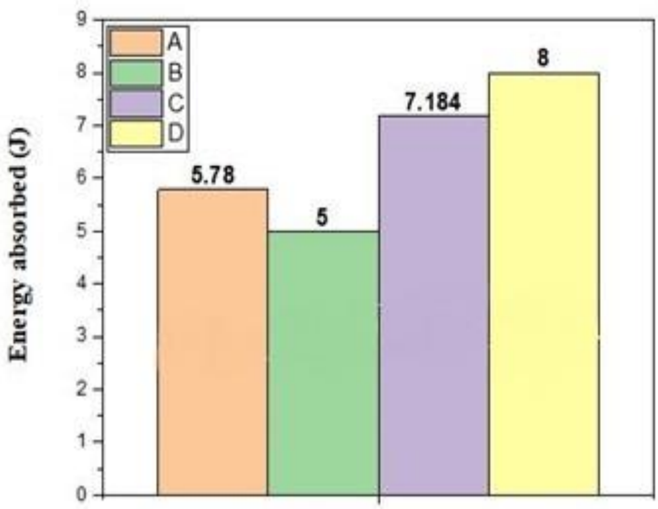

Figure 5. Energy Absorbed by Samples During Impact Testing.

b) Physical Characterizations of Composites.

In Figure 6. we can see the microstructural image of aluminum alloy (AL-Si12Fe). It contains an aluminum solid solution and an inter-dendritic network of aluminum-silicon eutectic.

In Figures 7. and 8, we can see the microstructural image of the heat-affected zone (HAZ) and welding region. Upon observation, we found that the size of the particles in the crystals decreased from the HAZ to the welded area. This suggests that the crystals began to recrystallize in the weld area due to super-deformation resulting from friction welding processes [8], [9].

As part of the EDS testing, we observed the visible presence of Al, Si, O, C, Fe and Mg elements in the composite. The elemental maps in Figure 9.

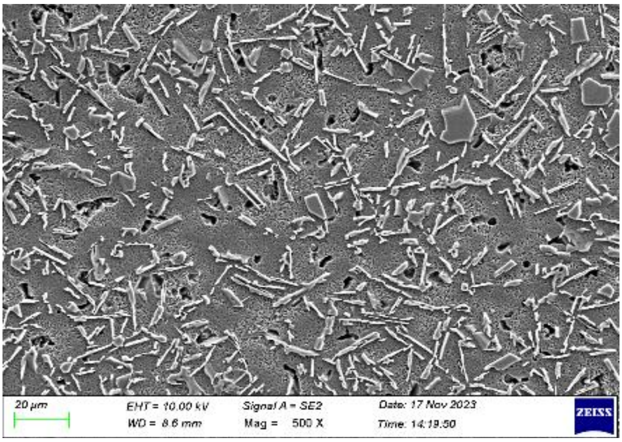

Figure 6. Microstructural Image of (AL-Si12Fe).

Figure 7. Sample (C) HAZ.

Figure 8. Sample (C) Welding Region.

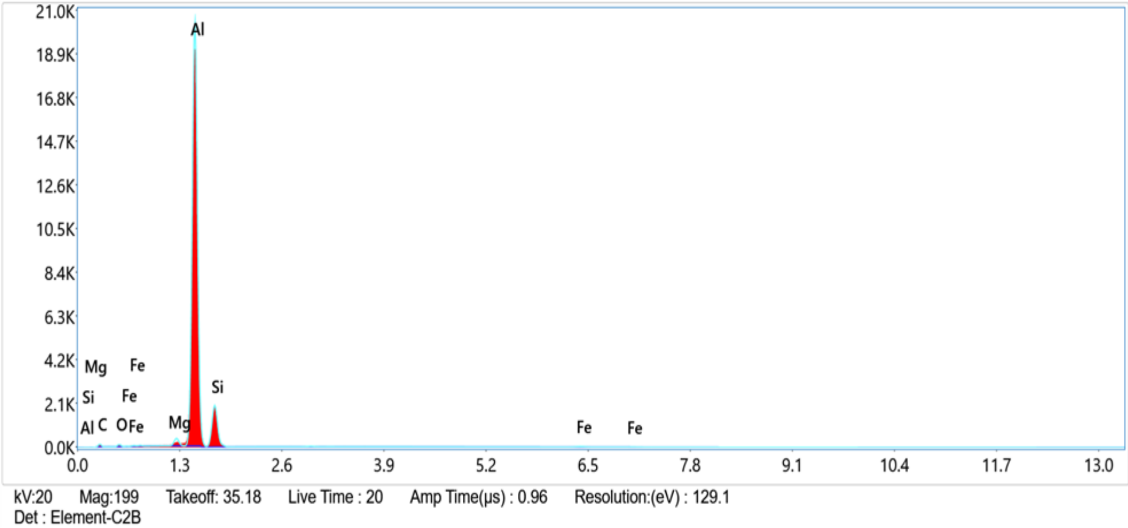

Figure 9. EDS Map of Sample (C) Weld Composite.

Microstructural images of sample (D) HAZ and welding regions are shown in Figures 10 and 11. We found that crystal particles shrank from the HAZ to the welded area after careful analysis. These data suggest that friction welding super-deformation triggered crystal recrystallization in the weld area. EDS revealed Al, Si, O, C, Fe and Mg elements. Figure 12 shows elemental mapping.

Figure 10. Sample (D) HAZ.

Figure 11. Sample (D) Welding Region.

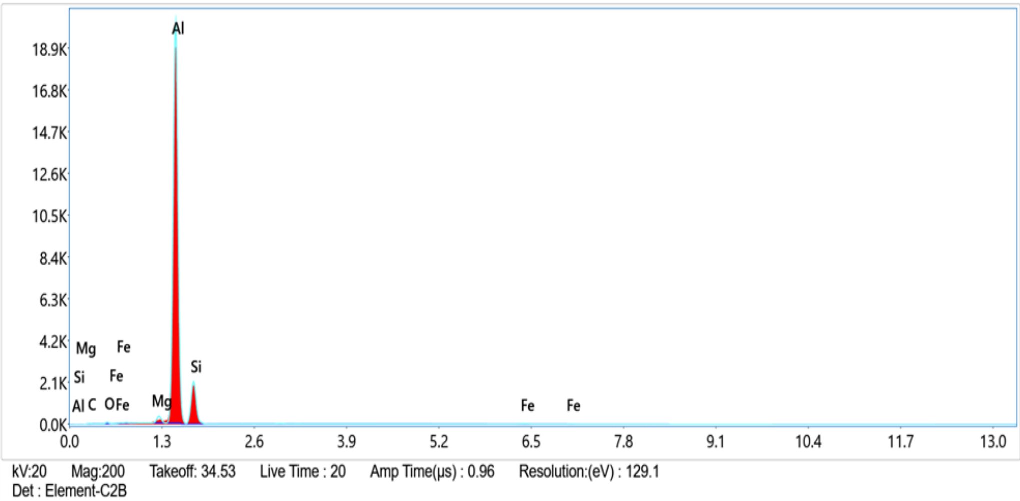

Figure 12. EDS Map of Sample (D) Weld Composite.

4. Conclusion:

- The mechanical tests were conducted on AL-Si12Fe alloy and its composites with 5% reinforcements of MW. The results and analysis showed that the addition of MW reinforcements significantly enhanced the mechanical properties of the composites. Specifically, the ultimate tensile strength (UTS) value of AL-Si12Fe+5%MW and AL-Si12Fe+5%MW-weld composites increased by 16% and 52%, respectively, compared to base aluminum alloy.

- The degree of strengthening of the AL-Si12Fe alloy was determined by evaluating micrographs and EDS maps obtained from the morphological characterization of AL-Si12Fe samples belonging to user +5%MW, as well as AL-Si12Fe-welded samples of the same user. It was concluded that the chemical composition, particle size, and particle size concentration of the reinforcing phase materials played a significant role in this determination. Upon observation, it was found that the size of the particles in the crystals decreased from the HAZ (heat-affected zone) to the welded area. This suggests that the crystals began to recrystallize in the weld area due to super-deformation resulting from friction welding processes.

- The process of rotary friction welding is a technique that can be used to improve and recrystallize crystals, in addition to being a technique for super-deformation.

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