TEST Engineering & Management

July/August 2020
ISSN: 0193-4120 Page No. 6818 - 6825

Marble Dust-Enhanced Friction Stir Processing of AA7075: Impacts on Mechanical and Material Characteristics

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Article Info
Volume 83
Page Number: 6818-6825
Publication Issue:
July/August 2020

Abstract - The study investigated the effect of adding Marble dust particles as reinforcement in different weight percentages (Wt.%) to AA7075 aluminum-based surface composites manufactured by Friction Stir Processing (FSP). The composites were produced by evenly distributing the Marble dust particles in the aluminum matrix through FSP, with a fixed set of input variables including a tool rotational speed (TRS) of 1250 rpm, a tool traverse speed (TTS) of 45 mm/min, and a tool tilt angle (TTA) of 1^{o}. The output response was analyzed, that the addition of marble dust particles resulted in increased ultimate tensile strength (UTS) in the aluminum matrix. However, the impact strength was reduced. To understand the surface morphology of the wear samples, scanning electron microscopy (SEM) was used. From the SEM observations, it was evident that the Marble dust particles were evenly distributed in the aluminum matrix, indicating good particle incorporation during the FSP process. Overall, the results suggest that the addition of Marble dust particles can significantly enhance the impact strength and UTS of aluminum-based surface composites produced through FSP.

Article History
Article Received :*25 April 2020*
Revised: *19 May 2020*
Accepted: *22 June2020*
Publication*: 23 August 2020*

Keywords:- Friction stir Processing, Marble dust, ultimate tensile strength, mechanical properties.

1. Introduction:

Aluminum is widely used due to its low weight and resistance to corrosion, and AA7079 is commonly employed in aerospace, aviation, and defense due to its superior strength-to-weight ratio. Nevertheless, casting defects like porosity and fractures make the base metal prone to localized corrosion. To control corrosion, experimental techniques like age hardening, particle reinforcement, and surface coatings must be used. The type of reinforcement used affects the strength and durability of the material. Particle reinforcement is considered an effective method for improving mechanical properties due to its wide range of applications. Stir casting, ultrasonic stir casting, and FSP are some of the particle reinforcement techniques used [1-3].

Recently, many researchers have turned their attention to FSP as a new and innovative route for producing aluminum-based surface composites. This method involves the use of a rotatable tool that is pressed downward and uniformly mixes the reinforcing phase throughout the matrix [4]. Pasha et al. [5] conducted a study using FSP to produce AA7075 Matrix Surface Composites (AMSC). They varied process parameters, such as TRS, TTS, and Number of Passes (NP), and found that doing so resulted in improved mechanical and microstructural properties for the AMSC billets. Their findings demonstrated that the average grain size of AMSCs was significantly refined, and the number of FSP passes had a substantial impact on the wear resistance of AMSCs. Butola et al. [6] studied how TRS, TPP, and reinforcement affect the microstructural properties and microhardness of AA7075 FSP. They found that the TRS is the most critical variables, followed by the type of reinforcement and the shape of the tool pin. The outcomes revealed that the microhardness of the AA7075/B_4C composite was 1.5–1.6 times higher than that of the substrate material, signifying that B_4C provides superior microhardness enhancement than SiC and RHA. Hussain et al. [7] conducted an experiment using various FSP tool profiles to produce a composite material made of AA7075-T651 reinforced with TiN particles. The study focused on the wear properties of the composite material. The findings of the experiment showed that the composite material had improved wear properties, suggesting that the use of FSP in the manufacturing process had a positive effect. Interestingly, only the threaded tool was used in the experiment, yet it still achieved an increase in hardness. Overall, the study highlights the potential benefits of using FSP in the production of composite materials for improving their wear properties. Bansal and Saini [8] studied a surface composite's mechanical and wear characteristics reinforced with SiC and SiC/Gr particles on the Al359 alloy's surface. The Al/ SiC/Gr composite was claimed to have higher hardness, UTS, and lower wear rate than the Al359 alloy. Many researchers have conducted many experiments on the tensile strength characteristics of AA7075, utilizing a wide range of reinforcing particles, to determine the manufactured samples' effectiveness under tensile loading[9–12].According to Ahamed et al. [13], AA6061 exhibits excellent toughness, wear, and strength properties when reinforced with marble dust. The stir casting process is used to create particulate MMCs that are reinforced with marble dust at wt% of 4, 8, 12, and 16. The experiment demonstrates that a 16 % rock dust sample has a high level of hardness and a lower rate of wear due to the higher limitations on localized matrix deformation. Soorya Prakash et al. [14] conducted a study to study the effect of rock dust reinforcement on the wear characteristics of AA6061. The samples were prepared using the stir casting process with rock dust content. The outcomes revealed that the mixing of rock dust reduced the wear loss of the AA6061 matrix. The wear loss was observed to decrease with an increase in the amount of rock dust, reaching a minimum value at 8 wt%.

Rockdust, which is a by-product of crushing rocks to make gravel, is being chosen as a reinforcement material for Advanced Materials Composites (AMCs). Typically, 25-30% of quarry dust is released into the atmosphere as waste material. Breathing in this polluted air for an extended period can cause respiratory problems and vision impairments. However, by using rock dust as a reinforcement material, AMCs can benefit from improved mechanical and wear properties, as well as lower production costs, which can help to mitigate these issues associated with quarry dust pollution.

The current study aimed to create surface composites of AA7075 alloy and marble dust using Friction Stir Processing (FSP). Different weight percentages of marble dust (3%, 6%, 9%, 12%, and 15%) were used as reinforcement while keeping the processing parameters constant. The specimens were cut according to ASME standards from the stir zone of the surface composite using a water jet cutting machine. The resulting specimens were then subjected to testing for mechanical characteristics like UTS, YTS, impact strength, and microhardness. Additionally, the SEM technique was used to study the speading of the reinforced particles in the microstructure of the specimens.

2. Experimental procedure

The production of a surface composite is 6mm thick AA7075 plates that are commercially available. The material constitutes of AA7075 is provided in Table 1. To reinforce the composite, marble dust particles that are ≤30µm in size are used in varying weights. The marble dust is processed through mechanical sieving, gradually reducing the sieve grit size from 100µm to 30µm, with each grit size reducing by 15µm. The material constitutes of the marble dust is displayed in Table 2.

2.1 Taguchi Method:

In the FSP, various process parameters are affected, mainly TPP, TRS, TTS. The previous literature selected the process parameters: Square TPP, 1250rpm TRS, 45mm/min TTS, and 1º TPP. The experimentation is conducted by using those process parameters. Before going to experiment, the design of experimentation is prepared using the Taguchi method in MINITAB-17 statistical software. A square tool profile is used for the FSP. For the current study, a square pin tool was used with a shoulder diameter of 20mm and a square TPP measuring 6x6mm and 5.8mm in height. Grooves were packed with marble dust at weight percentages of

3, 6, 9, 12, and 15% in five aluminum plates.

Table 1 AA7075 material constitutes.

Element	Si	Mn	Fe	Mg	Cr	Cu	Ti	Zn	Al
wt%	0.4	0.3	0.5	2.5	0.15	1.6	0.2	5.5	Balance

Table 2 Marble dust chemical composition

Element	SiC	Al_2O_3	Ca	Fe	MgO	K	S
wt%	59.62	15.39	6.44	10.5	6.5	1.2	0.35

The reinforced marble dust is stuffed into the circular holes based on the wt % 0, 3, 6, 9, 12, 15%. FSPed without pin profile tool is passed throughout the workpiece, and the holes are sealed using this process. After the sealed process, the square TPP with 1250rpm TRS and 45mm/min TTS, 1° TTA is used to conduct FSP, is performed using an FSW-3T machine shown in Figure 2. Marble dust reinforced stuffed work plates and FSPed plates are shown in Figures 3.

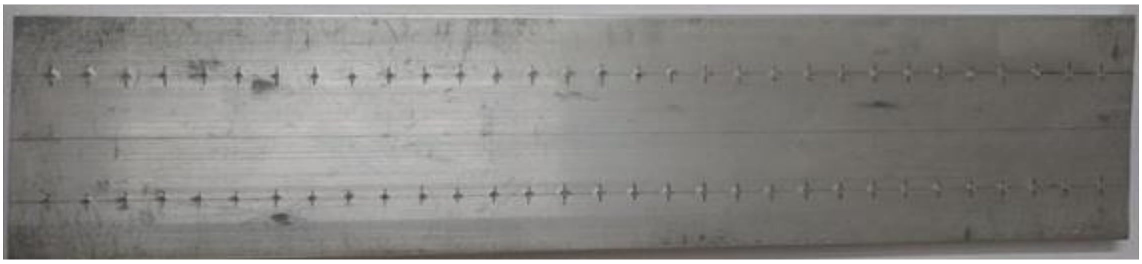

Fig 1 Work Piece after drillingholes

Fig.2 Experimental setup

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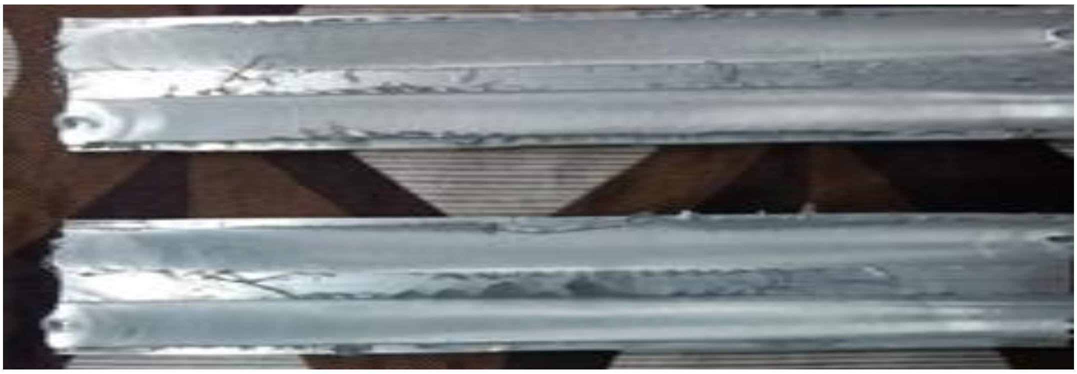

Fig 3. FSP plates

To prevent the reinforcement particles from escaping during processing, a tool with only a shoulder and no square pin was passed over the drilled holes initially. Samples were extracted from the stir zone of the resulting surface composites using a horizontal CNC milling machine, following ASME standards for both tensile and impact tests. The tensile strength of the specimens was determined using a UTM (TUE-C-200) with a maximum load capacity of 200 kN. The impact resistance was assessed using an impact testing machine (FIT 300(EN)) with a 'V' notch depth of 2mm. Microhardness testing was conducted using a Vickers digital microhardness tester (ECONOMET, Model: VH1MD, SR No: CH27497) with a load of 300gm applied for 15 seconds.

3. Results and Discussions

3.1 Microstructural characterization of AMMCs:

The Field Emission SEM graph (Fig. 4) shows the presence of marble dust particles in the composite AA7075, and there is uniform distribution throughout the matrix.

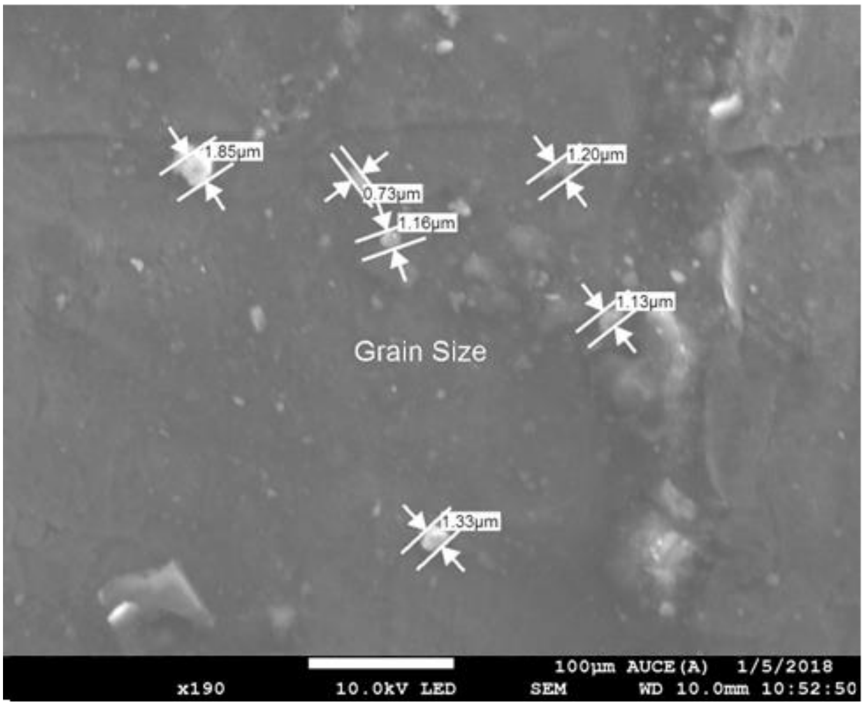

Fig. 4 High UTS specimen of AA7075 with 9 wt% of marble dust SEM analysis

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The presence of reinforcing particles is shown in the SEM micrograph as bright phases. To strengthen identification reinforcement, a sample of 9 wt.% marble dust was AA7075 composite illustration morphology of marble dust particles of 0.73 µm size was displayed in Fig. 4.

3.2 Effect of marble dust on Tensile Strength of AMMCs

The results obtained from the YTS and UTS tests on the composite materials. Figure 6 demonstrates that the YTS increases from 264 N/mm2 to 332 N/mm2 as the concentration of marble dust particles increases from 0 to 9 wt% in the AMMCs. This enhancement in YTS is because of the even distribution of the particles in the substance matrix. The UTS of the AMMCs also enhances with the incorporation of marble dust particles, up to a concentration of 9 wt%. This increase occurs because the marble dust particles have a higher load-bearing capacity than the aluminum matrix, which enables them to transfer induced loads more effectively, thereby enhancing the composite's strength. However, as the concentration of marble dust particles exceeds 9 wt%, the UTS begins to decrease due to the clustering of particles in the AMMCs. The paragraph points out that the composite's brittle nature is a limiting factor for enhancing UTS, as observed extensively in Figure 5. The occurrence of marble dust particles in the composite material makes it more brittle and reduces its UTS. Therefore, when incorporating marble dust particles, it is essential to consider the composite's brittle nature while selecting the appropriate concentration of marble dust particles.

3.3 Effect of marble dust on the Impact strength (IS) of AMMCs

The effect of the incorporation of marble dust particles on the IS of the manufactured composites. The IS was reduced by increasing wt% of marble dust up to 9 in the AMMCs. The IS of the marble dust is slowly reduced with enhanced reinforcement. Increasing the wt% of the marble dust in the matrix alone reduces the IS. With the occurance of marble dust particles in the composites, the nanocomposite material changed its nature to brittle and acted as stress concentration areas; because of that, the IS was reduced.

The IS of nanocomposites incorporation with agro wastes, such as coconut shell ash, rice husk, and bagasse ash, is similar to the IS of nanocomposites reinforced with marble dust particles. These materials are used as reinforcement to rise the mechanical characteristics of nanocomposites, but their incorporation can also cause some negative effects. For example, mixing marble dust particles in the nanocomposites diminishes their ductility, which is the ability to undergo plastic deformation without breaking. This reduction in ductility leads to the formation of stress concentration regions, which promote the creation of cracks and failure initiation.

Conclusion:

In the present work, an experimental study has been carried out to enhance the mechanical characteristics of AA7075 through reinforcing by Marble dust. The Marble dust has been reinforced with AA7075 through FSP, and an MMCs was formed. Various drill holes are created on the base metal of AA7075, an FSPed specimen reinforced by marble dust. Based on the experimental results, the following conclusions were drawn for the proposed set of process parameters:

1. The marble dust particles with 3-15% were evenly distributed throughout the Al matrix, indicating the effectiveness of the FSP in situ technique for fabricating composite materials.
2. The addition of marble dust reinforcements at percentages above 9 wt% caused a decrease in both the YTS and UTS of the base material.
3. The presence of marble dust in the composites resulted in an improvement in the impact strength of the material.

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