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Statistical Modeling of FSP of Al/Al_2O_3 Composite

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Abstract

In this research, FSP (friction stir processing) for producing Al/Al_2O_3 composite has been investigated. The mechanical and wear properties of the reinforced composite are compared with the processed and base materials. The response surface method has been used to determine the effect of the input parameters on the tensile strength and wear rate. Also, by using analysis of variance (ANOVA), the optimal levels of the parameters have been specified to achieve maximum tensile strength and minimum wear rate. The obtained results showed that adding the alumina powder significantly increases the tensile strength and wear resistance. In addition, by examining the optimal results, it was found that by selecting the rotational speed of 1200 rpm, the feed rate of 40 mm/min, and 0.6 g of alumina powder, the highest tensile strength and the lowest wear rate can be achieved for the processed composite sample.

Keywords:

Surface Composite, Aluminum Alloy, Alumina Powder, FSP.

1. Introduction

Powder-reinforced composites are extensively used in the aerospace and automotive industries. They exhibit high strength and good wear resistance compared to base materials. The FSP is one of the methods in which a plastic zone is created by rotating a solid tool inside the part, while the part is strengthened by moving the tool forward, as shown in Figure 1. Traditional approaches for predicting the properties of aluminum composites produced by FSP are usually based on trial and error. Nowadays, researchers have been able to significantly reduce the process cost and time by developing computational methods such as design of experiments (DOE) [1-4]. In this research, the effect of input parameters, on the tensile strength and wear rate was studied. Using central composite design (CCD), the influence and contribution of parameters were determined. Finally, the optimal levels of parameters for simultaneous optimization of tensile strength and wear rate of aluminum composites reinforced with alumina powder were determined.

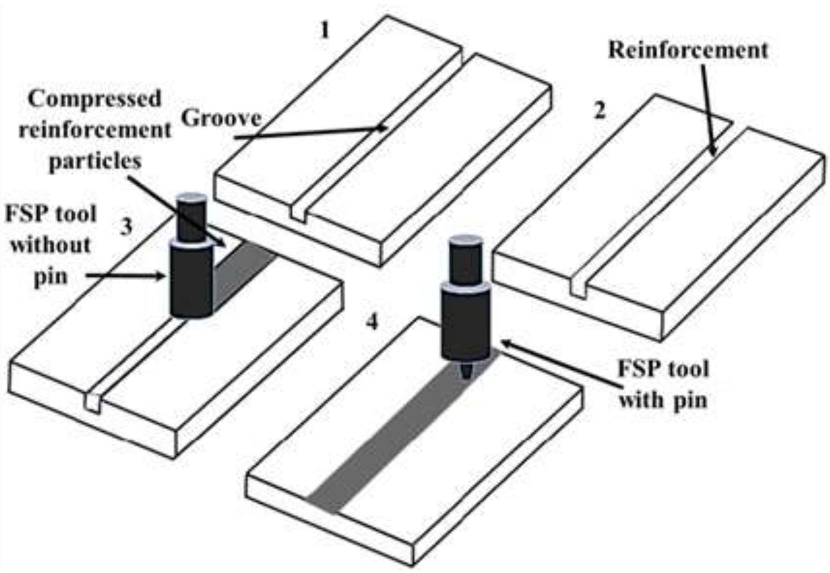

Figure 1. Schematic of the friction stir processing

2. Methodology

The sheet used in the experiments is made of AA1100. To perform the FSP tests, initial sheets with dimensions of 150×100×2 mm were prepared, and grooves were created in their middle by a milling machine. Then, the grooves were filled with alumina powder, and the process was carried out. A fixture was used to clamp the parts and also to position them correctly. To determine the tensile strength and wear rate, a tensile test according to ASTM-E8 standard and a wear test according to ASTM-G99 standard were used, respectively. To investigate the effects of process parameters on tensile strength and wear rate, a response surface methodology (RSM) with a central composite design (20 experiments) was designed and experimentally conducted. The parameters N, f, and W represent the tool rotation speed, tool feed speed, and alumina powder weight, respectively.

3. Discussion and Results

The contour plot of the effect of input parameters (N, f, and W) on tensile strength is shown in Figure 2. According to the figure, it is observed that to achieve the highest tensile strength, the tool rotation speed should be at its highest level, the feed rate of the tool should be at its lowest level, and the amount of alumina powder added in the stirring zone should also be at its highest level. Figure 3 demonstrates the contour plot of the effect of input parameters on the wear rate. It can be seen that to achieve the lowest wear rate (highest wear resistance), the tool rotational speed needs to be selected at its midpoint, the feed rate at its lowest level, and the amount of alumina added at its highest level.

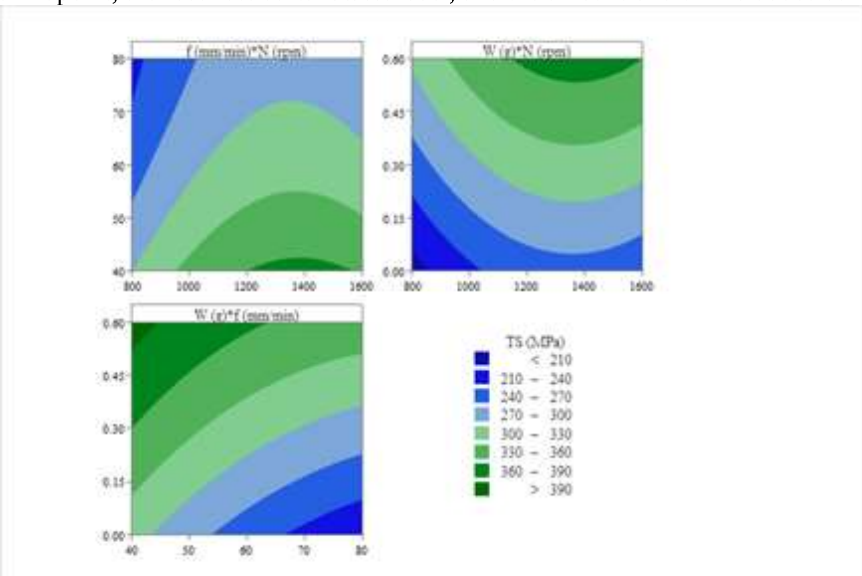

Figure 2. Contour plot of input parameters on tensile strength

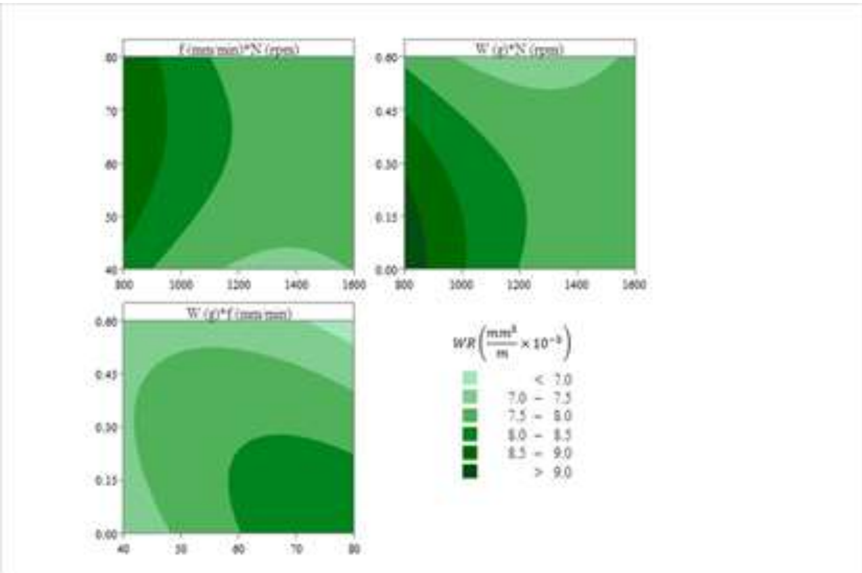

Figure 3. Contour plot of input parameters on wear rate

Figure 4 illustrates the optimal values for single-objective and multi-objective optimization. As can be seen, by choosing a tool rotation speed of 1204 rpm, a feed rate of 40 mm/min, and 0.6 g of alumina powder, a high tensile strength and a low wear rate can be achieved simultaneously. To validate the obtained results, an experiment was conducted with the optimal values. Comparing the optimal results with the confirmation experiment showed that the prediction error is less than 10% for both outputs (tensile strength and wear rate), which indicates the acceptable accuracy of the proposed optimization method.

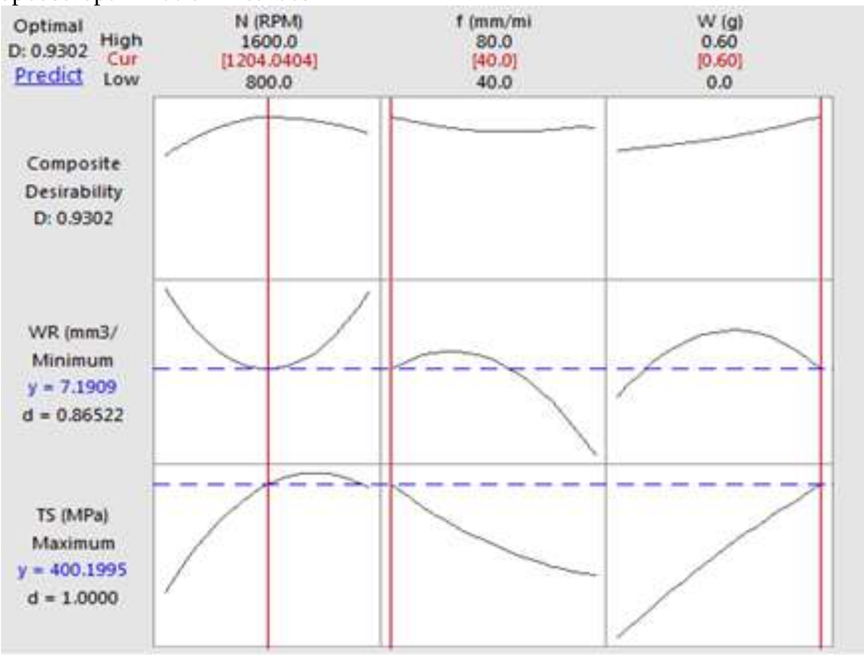

Figure 4. Optimization results

4. Conclusions

In this study, FSP (friction stir processing) was used to produce an aluminum composite reinforced with alumina particles. To investigate the effect of process parameters on tensile strength and wear rate, the RSM with central composite design was used. The tool rotation speed, tool feed rate, and alumina powder weight were considered as inputs. Using a multi-objective optimization method, the optimal process conditions were determined to achieve the highest tensile strength and lowest wear rate. The results of this study showed that adding alumina powder and applying FSP increased the wear resistance of the composite sample and reduced plastic deformation during wear.

5. References

[1] Malopheyev, Sergey S., Ivan S. Zuiko, Sergey Yu Mironov, and Rustam O. Kaibyshev. "Microstructural aspects of the fabrication of Al/Al_2O_3 composite by friction stir processing." Materials 16, no. 7 (2023): 2898.

[2] Orłowska, Marta, Florian Pixner, Andreas Hütter, Norbert Enzinger, Lech Olejnik, and Małgorzata Lewandowska. "Manufacturing of coarse and ultrafine-grained aluminum matrix composites reinforced with Al_2O_3 nanoparticles via friction stir processing." Journal of Manufacturing Processes 80 (2022): 359-373.

[3] Abbass, Muna Khethier, and NA Baheer Sharhan. "Characteristics of Al6061-SiC-Al_2O_3 surface hybrid composites fabricated by friction stir processing." Journal of Materials and Engineering 1, no. 4 (2023): 147-158.

[4] Modanloo, Vahid, Mohammad Dashti Kahnouei, and Amin Safi Jahanshahi. "Statistical modeling of energy absorption of grooved aluminum tubes under axial compression loading." Journal of Modeling in Engineering 23, no. 82 (2025): 157-166.