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Optimization of Machining Parameters of Hybrid Metal Matrix Composites Using Design of Experiments

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Abstract

The design and construction of an aluminum composite infused with magnesium and SiC are the subjects of this work. Nominal cost composites with reduced weight have been developed in response to industrial demands for enhanced hardness and tensile strength. Composites with different amounts of reinforcement are cast using the stir casting method. In this study, a hybrid MMC was made utilizing the In-Situ process with magnesium (Mg), silicon carbide (SiC), and aluminum 7075 as the matrix and reinforcements. While maintaining Mg at 2 weight percent, the proportion of Sic content was adjusted in increments of 2. Using a carbide-tipped tool in a turning operation, later machining features, like thrust force, were ascertained by adjusting speed and feed for the created hybrid MMC. In this investigation, a lathe machine equipped with an IEICOS-652 dynamometer for cutting force analysis was used to optimize the machining parameters using a second-order statistical model developed using ANOVA. The optimization speed ranges are 71, 112, 180, 280, and 450 rpm, and the feed ranges are 0.18, 0.2, 0.24, 0.25, and 0.28 mm/rev.

Keywords: Anova, Turning, Silicon Carbide, Feed, Speed.

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Introduction

Because of its remarkable strength-to-weight ratio, aluminum matrix composites, or AMCs, have grown in popularity over the last 20 years. Additionally, qualities including hardness, corrosion resistance, wear resistance, and temperature resistance have improved. The use of reinforcements, among other things, makes the final composites more durable. Due to this property, studies have demonstrated that the machinability of composite materials is decreased by the addition of these strong ceramic reinforcements (Ajithkumar & Xavior, 2019). Hybrid composites are extremely relevant because of the increasing demand for lightweight structural materials in the transportation, aerospace, and healthcare industries (Lakshmanan et al., 2021). Magnesium matrix composites are now the most advanced material available due to its high strength to mass ratio, low density, and better corrosion resistance (Ajithkumar & Xavior, 2019). Aluminum's limited high strength, creep resistance at higher temperatures, high degree of shrinkage upon solidification, and strong chemical reactivity limit its industrial use (Ononiwu et al., 2021). A new generation of engineering materials with superior properties to unreinforced alloys, such as a lower coefficient of thermal expansion, a higher strength to weight ratio, improved resistance to corrosion and wear, increased hardness, and increased resistance to thermal shock, are produced when ceramic materials are reinforced in aluminum alloys (Akhtar et al., 2021). Machinability, regardless of the method being discussed, is the ease with which the materials removal process can be completed. Machinability is a general term used to describe some elements referred to as outputs or dependable variables. Researchers have worked hard to understand how the input elements affect specific parameters of the final product through machinability analysis in order to address the uncertainty difficulties in making AMC components (Kannan et al., 2020). Dry machining turning techniques have been the subject of the majority of this field's research. This often leads to the "worst-case scenario" results. Turning is a machining operation that removes metal from a rotating work component using a single-point cutting tool in order to meet the necessary design requirements for the final product. Turning is a rather easy and versatile machining method that may create a variety of products (Raof et al., 2020).

Research Method

The aluminum alloy Al7075 with SiC (2, 4, 6, 8, 10 weight percent) and magnesium (2 weight percent) reinforcement was made by stir casting. Magnesium increases the composite's moisture-absorbing ability. The melting point of magnesium is around 7500 C. For thirty minutes, mechanical stirring was conducted at an average speed of 350 rpm. Al7075 alloy's chemical makeup is presented. The stir casting apparatus shown in Fig. 1 is used to create composite materials. Al7075, SiC, and Mg hybrid composite work pieces in the shape of circles were employed for testing.



Fig. 1: Material

For evaluating cutting forces during turning operations, a 2-channel multi-component digital force indicator called the IEICOS-652 was put on the lathe. Displays the process variables. With varying feed rates of 0.18, 0.2, 0.24, 0.25, and 0.28 mm/rev, turning operations were performed in the current study at five distinct spindle speeds of 71, 112, 180, 280, and 450 rpm. Shows the hybrid MMC with SiC 2, 4, 6, 8, and 10% with 2% Mg. Experiments were conducted using a carbide-tipped tool coupled to a lathe tool dynamometer. The thrust force was measured during the turning operation using a two-channel IEICOS-652 (Model: 652: two-channel multi-component digital force indicator, Make: IEICOS). The IEICOS carbide-tipped cutting tool multicomponent piezoelectric dynamometer and digital force indicator are shown in Fig. 1 depicts the tested specimen during turning of a dia 18.3 mm 6wt% SiC+2 wt% Mg hybrid MMC specimen.

Materials Used

Two scenarios were examined in this study. First, we used a dynamometer to measure the forces while varying the feed rate while keeping the spindle speed constant. In order to continue the optimization process, we used Minitab to tabulate the results after measuring the forces with a dynamometer and adjusting the spindle speed while maintaining a constant feed. The tool force measurement, or tool dynamometer, is a crucial instrument for theoretical cutting process analysis. The remaining results are then applied to shop floor issues such tool performance and load demands on the machine and jigs and fixtures.

Experimental Setup

The Taguchi technique is typically applied to analyses that take into account several variables. When there are more than two components combined, there will be additional experiments, and the Taguchi technique will then be employed to find a solution. A methodology of cost-driven quality engineering known as Taguchi Methods places more emphasis on the efficient implementation of engineering strategies than on sophisticated statistical methods (Ramakrishnan et al., 2019). Upstream and shop floor quality engineering are also a part of it. Small-scale tests are effectively used in upstream approaches to minimise variability and develop affordable, reliable designs for the marketplace and large-scale manufacturing. Shop floor methods offer cost-based, real-time ways to assess and maintain production quality.

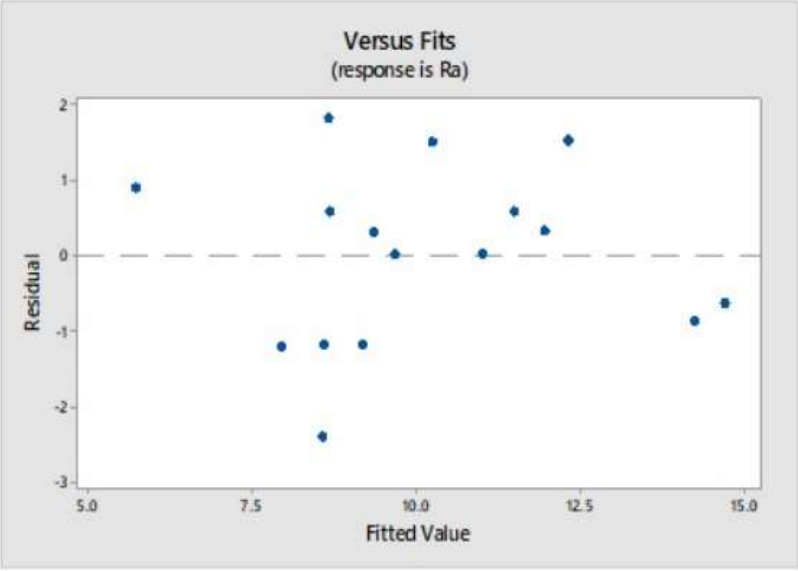


Fig. 2: Constant Variance

The Taguchi Methods assist a company in quickly and accurately gathering technical knowledge to develop and deliver low-cost, extremely reliable products and processes. Its most advanced applications enable engineers to construct adaptable technology for the design and production of families of high-quality products, greatly cutting down on the time required for delivery, development, and research. Constant Variance shown in Fig. 2.

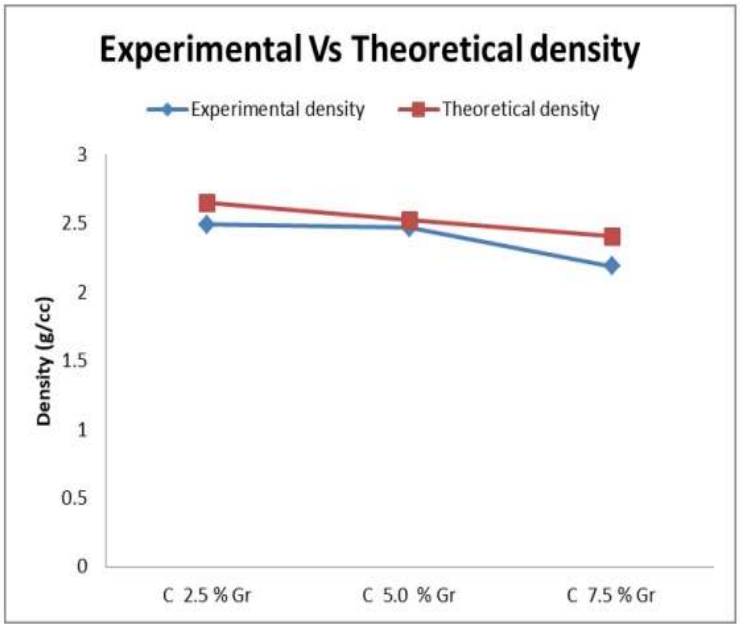


Fig. 3: Density Plot

The study of the relationship between the response and factors is the main goal of DOE. Experimental data is required to study the relationship between the response and self-governing factors. The diameter of the specimen, the feed rate, and the speed were chosen to evaluate the impact of various factors on thrust force. Density Plot shown in Fig. 3.

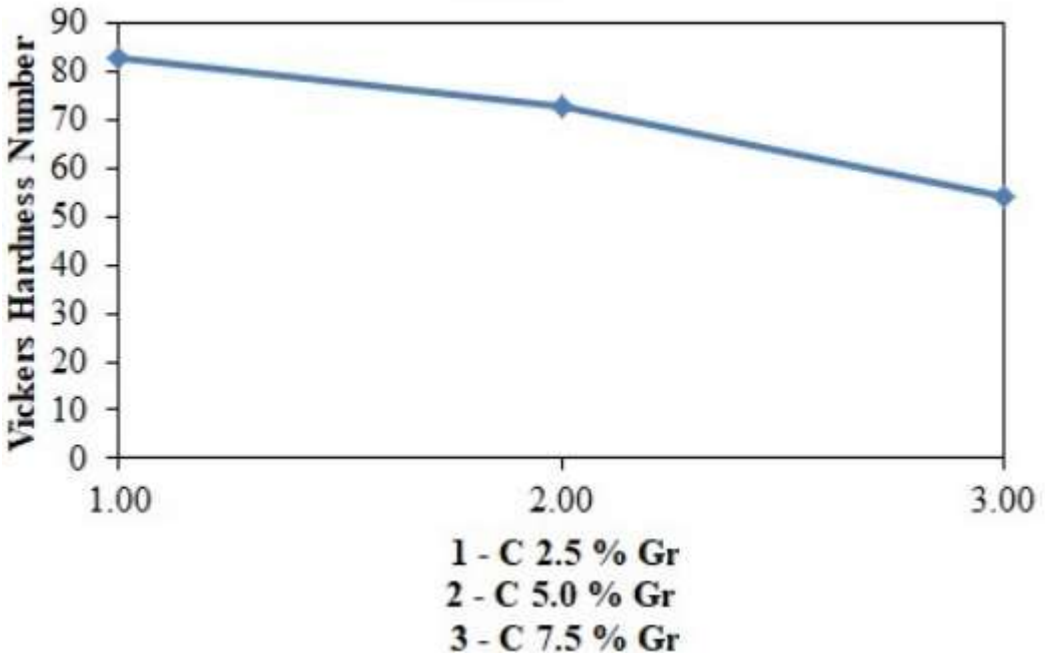


Fig. 4: Variation of Micro Hardness with Graphite Content

The experiment will be designed using the Taguchi technique, and a suitable orthogonal array will be chosen by taking the design variable into account. With the aid of the Minitab 15 programme, a Taguchi orthogonal array is planned with three tiers of rotating parameters. Four design variables—tool material (T), depth of specimen cut (D), feed rate (F), and spindle speed—are chosen to be orthogonal arrays (S). To determine the optimal machining conditions and the percentage contribution of each factor for 2wt% to 10wt% SiC hybrid MMC, the effects of deviation in the input

process variables will be planned on one response variable, and the experimental statistics will be analyzed using the Taguchi method. Variation of Micro Hardness with Graphite Content shown in Fig. 4.

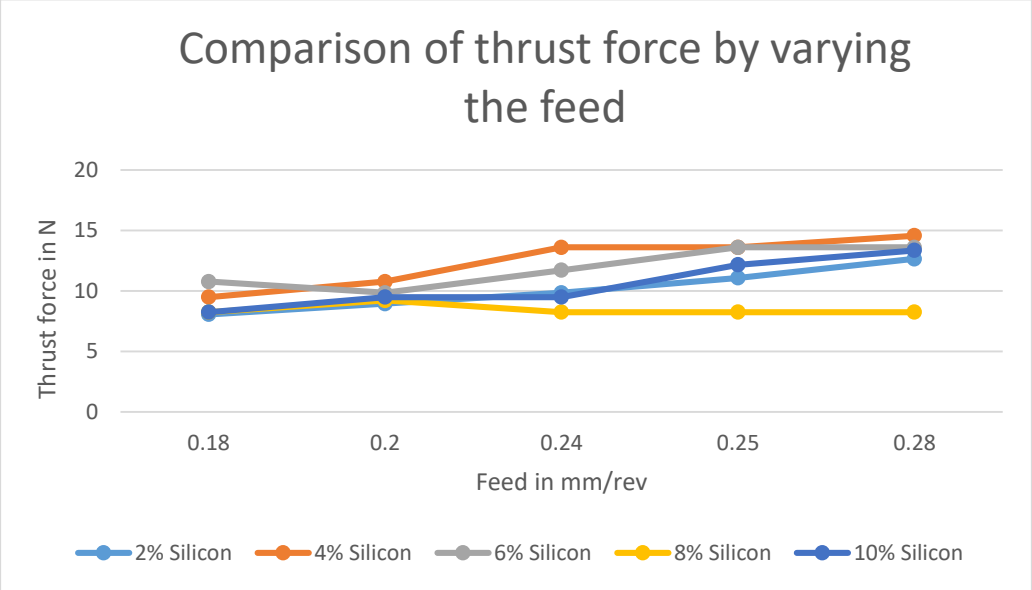


Fig. 5: Comparison of Thrust Force by Varying the Feed

Graphs are made using the data collected from the tests. Surface roughness also increases with speed, as shown in Fig. 5. But as feed increases, surface roughness decreases. However, when surface roughness values increase, so does the depth of cut.

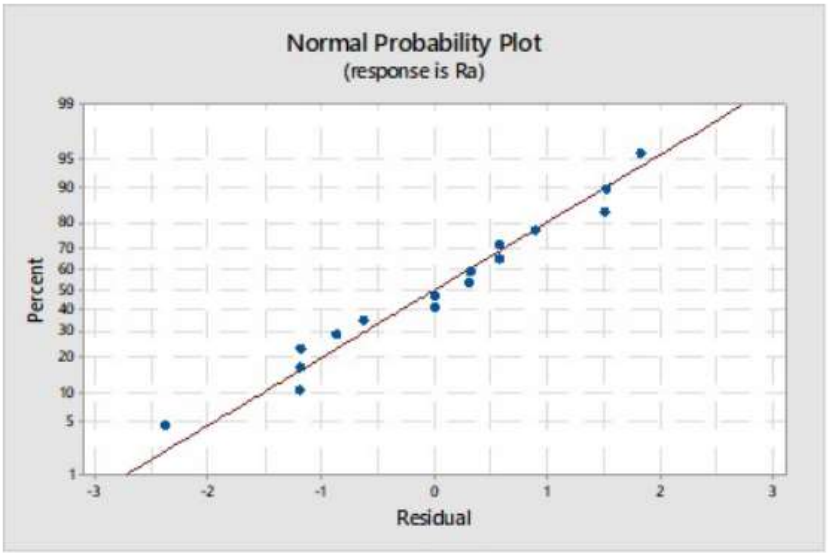


Fig. 6: Normality

As cutting speed increases, surface roughness increases in relation to SN ratios. But as the feed rate decreases, so does the surface roughness value. On the other hand, the surface roughness value does not increase as the incision depth does. Interaction plots for means and SN ratios are displayed. Normality shown in Fig. 6.

Conclusion

In this work, the Taguchi approach is applied to determine the optimal machining parameter. The thrust force for the test results was calculated using the Taguchi technique. Cutting speed (V) and feed rate (f), two machining parameters, are tuned to achieve the goals. The study's findings include the experimental investigation of the impact of Sic on

Al7075 physical, mechanical, and machining behavior-induced Aluminium alloy MMC hybrid composites. Using ANNOVA, a static model was created to calculate the hybrid MMC's thrust force. The second order polynomial regression equations were created and may be utilised to forecast the thrust force for turning operation for HSS tool material, feed rate and spindle speed.

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