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Optimization of Mechanical Properties and Wear Parameters of Al alloy-B_4C Composite Using Taguchi Technique: A Review

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Abstract*: Metal matrix composites (MMCs) have proved their viability as good alternatives to conventional alloys in high strength and stiffness application in industries like automobile, aerospace and mineral processing. Al metal matrix composites (MMCs) are being considered as a group of advanced materials for their lightweight, low coefficient of thermal expansion, and good wear resistance properties. The optimization of parameter has been done by using different techniques like Taguchi, DOE and their results were verified by ANOVA. Signal-to-noise ratio and Analysis of variance (ANOVA) were used to investigate the influence of parameters on the wear rate. Based on various papers the conclusion of this review paper is to study the influence of applied load, sliding speed and sliding distance on the various parameter such as optimum wear and co-efficient of friction of Al alloy-B4C composite to enhance the quality of product and suggest the best combination of wear parameter which helps to reduce the wear of product with the help of Taguchi method. The wear resistance of the composite was found to be considerably higher than that of the matrix alloy and increased with increasing particle content. The major observation based on reviewed papers is that the major factor in determining the wear rate is load applied followed by distance and sliding velocity whereas distance affects the coefficient of friction to a large extent followed by load and sliding velocity.*

Keywords: Metal matrix composite (MMCs), Taguchi Method, ANOVA, Optimization

1. Introduction

Metal matrix composites (MMCs) have proved their viability as good alternatives to conventional alloys in high strength and stiffness application in industries like auto-mobile, aerospace and mineral processing. Al metal matrix composites (MMCs) are being considered as a group of advanced materials for their lightweight, low coefficient of thermal expansion and good wear resistance properties. Mechanical properties of Al alloys can be greatly enhanced by incorporating reinforcing particles, forming composite. Among all particle-reinforced composites, the most interest is observed for those reinforced with hard ceramic particles because of controlling their mechanical properties by optimizing volume percentage, size, and distribution of the reinforcing particles in the matrix. A wide range of potential reinforcements have been considered, including SiC, Al2O3,B4C, ZrO2 and TiB2. Attention has been paid to boron carbide (B4C) to be used as reinforcement for MMCs due to its lower density, comparable mechanical and thermal properties to SiC and Al2O3 as common reinforcement. However, in the practice of making MMCs, the selection of reinforcement depends on the application, manufacturing methods, and material cost. Al-B4C composites have the potential to combine the high stiffness and hardness of B4C with the ductility of Al, and without defeating the goal of obtaining a strong and low-density material. The Taguchi technique is a powerful design of experiment tool for acquiring the data in a controlled way and to analyze the influence of process variable over some specific variable which is unknown function of these process variables and for the design of high quality systems. This method has been successfully used by researchers in the study of wear behavior of aluminium metal matrix composites. The aim of this technique is to make the products that are robust with respect to influencing parameters. This method significantly reduces the number of trials that are required to model the response function compared with the full factorial design of experiments(DOE). The most important benefit of this technique is to find out the possible interaction between the factors. In view of the above article, an assessment is made to investigate the outcome of sliding speed, load, sliding time and volume fraction of reinforcement on the dry sliding wear behavior of the particulate reinforced Al alloy with a varying range (3,5,10%) of B4C particulate composites using taguchi method. The Analysis of variance was used to find the percentage contribution of various process parameters and their correlations on dry sliding wear of the hybrid composite materials. These composites were endowed with good tribological properties due to the presence of hard reinforcements. Aluminium Metal Matrix Composites (AMMCs) gained importance due to their enhanced tribological properties that replaces their monolithic counterparts primarily in automotive, aerospace and energy applications [1]. Their resistance to wear added with strength and modulus characteristics made them crucial for many engineering situations, where sliding contact can be expected. Besides the work on abrasive wear behavior, an extensive review on dry sliding wear characteristics of aluminium alloy based composites was carried out [2,3].Reviews were indicating the tribology of AMMCs as a function of the applied load, reinforcement volume fraction, sliding velocity, distance and nature of the reinforcing phase [4,5,6].Interaction between load and sliding velocity over wear of a material was reported by several researchers [6,7]. High wear resistance of particulate reinforced AMMCs was due to presence of the ceramic particle content, which protects the metal matrix from wear. For AMMCs reinforced with ceramic particles, increased particle content enhances the wear resistance [8]. Investigation on influence of process parameters on hybrid AMMCs was successfully done using Taguchi's technique [9]. Extensive usage of particle reinforced AMMCs in automotive and aircraft industries was found for pistons, brake pads, etc. where tribological properties of the material should be taken care [10]. The type of reinforcement also has a significant role in determining the mechanical and tribological properties of the metal matrix composites. The effect of different type of reinforcements such as Silicon Carbide (SiC) whisker, Alumina (Al2O3) fiber and SiC particle on the properties of Metal Matrix Composites (MMCs), fabricated by powder metallurgy has been investigated. It was found in results that, there existed a strong dependence on the kind of reinforcement and its volume percentage. The results revealed that the particulate reinforcement was most beneficial for improving the wear resistance of MMCs [11].

2. Taguchi's technique: Materials

The main trust of Taguchi's technique was the use of parameter design that determines the parameter settings which produces the best levels of a quality characteristic with minimum variation. Taguchi's technique was best suited for manufacturing problems [12]. This methodology acquires data in a controlled way through limited number of experiments which gives the accurate nature of the process. Further depending on the number of factors, interactions and their level, an orthogonal array was selected. Taguchi method follows Signal-to-Noise (S/N) ratio as the quality characteristic of choice[21].S/N ratio in Taguchi's technique indicates the ranking of parameters based on their influence. Plan of experiments was done using Taguchi's technique and L27 orthogonal array was opted for getting the best results with minimum number of experiments. Wear rate of the specimen and the average coefficient of friction were the two responses evaluated using S/N ratio and Analysis of Variance (ANOVA). Experiments were conducted by considering three parameters; applied load, sliding velocity and sliding distance, each of these varied for three levels. Based on Taguchi method when we consider the wear rate, load was the major parameter which had its influence followed by distance and velocity. Taking coefficient of friction into account, distance was ranked first for its influence on it, followed by applied load and the sliding velocity. ANOVA was used to determine the design parameters significantly influencing the wear rate and coefficient of friction (response). The wear rate of the composite specimen on varying load (10 N, 20 N, 30 N) was compared in a graph. Considering the sliding velocity of 2 m/s and distance of 1500 m as constant, wear rate was calculated for all the three levels of load. These values were compared on a single scale which interprets the directly proportional relation between applied load and wear rate[22].

3. Manufacturing Method

Stir casting technique is one of the popular Liquid Metallurgy Route (LMR) and also known as a very promising route for manufacturing near net shape hybrid metal matrix composite components at a normal cost. Mechanical stirring is a key element of this process. Composites with up to 30% volume fractions can be suitably manufactured using this method [13,14]. A recent development in stir casting process is a double stir casting or two-step mixing process. In this process, first the matrix material is heated to above its liquidus temperature. The melt is then cooled down to a temperature between the liquidus and solidus points to a semi-solid state. At this point the preheated reinforcement particles are added and mixed. Again the slurry is heated to a fully liquid state and mixed thoroughly. In double stir casting the resulting microstructure has been found to be more uniform as compared with conventional stirring. The potency of this two-step mixing method is mainly due to its ability to break the gas layer around the particle surface which otherwise impedes wetting between the particles and molten metal. Thus the mixing of the particles in the semi-solid state helps to break the gas layer because of the abrasive action due to the high melt viscosity. They designed a new three step stir casting method for fabrication of nano particle reinforced composite. First the reinforcement and Al particles are mixed using ball mills to break the initial clustering of nano particles. The composite powder is then incorporated into the melt with along with mechanical stirring[16].

4. Mechanical and Wear properties

The mechanical properties of a composite depend on many factors such type of reinforcement, quantity of reinforcement, shape, size etc. The proper understanding of the mechanical behaviour is thus essential as they are employed in different areas [19]. The author have produced Al (6061-T6)/B4C composite and investigated its mechanical properties. They observed that the tensile strength of the composite is linearly increasing with increasing weight percentage of the B4C particulate [20]. Applied load is the wear factor that has the highest physical properties as well as statistical influence on the dry sliding wear rate of the composites among the other factors such as sliding speed and sliding distance. The wear rate is dominated by different parameters in the order of applied load, sliding speed, sliding distance. The ANOVA test concluded that as applied load increases the wear rate also increases significantly [21]. It was observed that both wear rate and coefficient of friction increases when applied load increases. From 10 N to 20 N, marginal increase of wear rate was observed, whereas drastic increase from 20 N to 30 N. This trend can be attributed to the plastic deformation of the material. At low loads (10 N and 20 N), temperature rise over the sliding surface had less effect on the plastic deformation. Increased load i.e. (30 N) on the specimen leads to increase in temperature over the sliding surface even at low sliding velocities. Due to this high temperature, plastic deformation of the surface occurred leading to the adhesion of pin surface onto the disc. This adhesion results in more material removal, thereby drastically increasing the wear rate. The author observes that the load factor has greater influence on wear rate. Hence applying load is an important control process parameter to be taken into account while wear process. Applied load is further followed by sliding speed, and sliding distance [23].

The graph below shows the effect of Applied load and Sliding speed on the Wear rate:

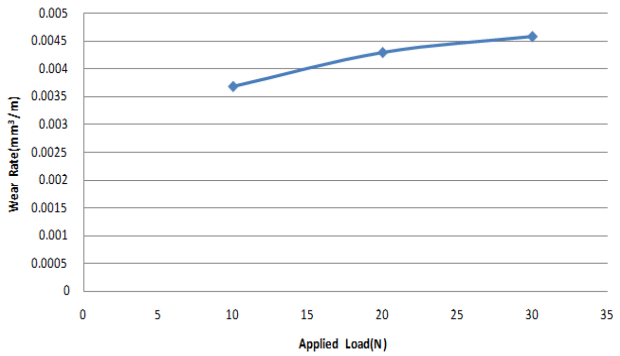

Figure 1: Variation of wear rate with change in Applied Load

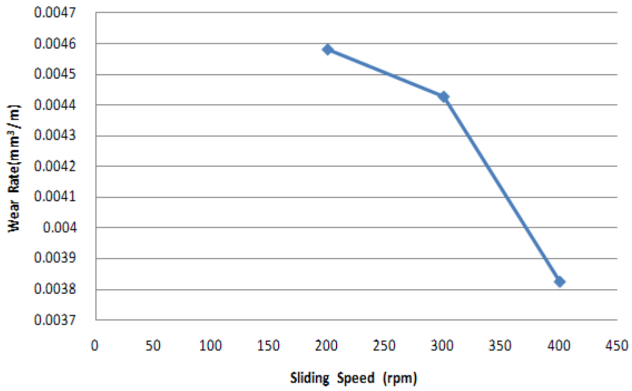

Figure 2: Variation of wear rate with change in Sliding Speed (when load applied is 30N)

This graph clearly shows that the influence of load is more than sliding speed on wear rate. Similarly the influence of sliding distance is less as compared to load and sliding speed on wear rate.

5. Conclusions

The major conclusions derived from the prior works carried out can be summarized as below:-

1) Optimum wear rate of the hybrid metal matrix composite materials was obtained from the experiment using Taguchi's method.
2) The wear rate is dominated by different parameters in the order of applied load, sliding speed, sliding distance. The ANOVA test concluded that as applied load increases the wear rate also increases significantly.
3) The wear rate and coefficient of friction has a direct relation with the load, whereas inverse with the sliding speed and distance.
4) Load was the major factor in determining the wear rate followed by distance and sliding velocity whereas distance affects the coefficient of friction to a large extent followed by load and sliding velocity.
5) Optimum conditions for obtaining good tribological characteristics were low load along with high sliding velocity and distance.
6) Addition of alumina, SiC, B4C etc. particles in aluminum improves the hardness, yield strength, tensile strength while ductility is decreased.

This investigation of wear and frictional behavior can be efficiently used for sorting out the best materials required for the automotive field, where sliding contact is expected. Replacement of conventional automotive parts like pistons, piston liners, brake rotors, cylinder heads etc. with these AMMCs can be done for having a better life of the components.

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