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Study of Factors Influencing Sliding Wear Behaviour of Aluminium Based Composites

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Abstract— Aluminium ceramic composites is considered as an important material where high strength and wear resistant components are of key importance, predominantly in the aerospace and automotive engineering sectors. In recent years aluminium metal matrix composites(AMMCs) have been used in the applications of cylinder liners, brake drums, crankshafts, and the aerospace and automotive industries because of their greater strength to weight ratios and high temperature resistance . In most of the studies on wear behaviour of Aluminium based hybrid composites powder metallurgy process is using. It also possess low wear resistance property, so additional reinforcements must be added. Ceramic materials like SiC, Al2O3, B4C, TiC, and AlN will provide wear resistance and mechanical strength. Then lubricants will provide extra wear resistance and lubrication property. Usually MoS_2 or graphite lubricants are using in different compositions. In order to test the wear property, pin-on-disc equipment is used. In order to test the wear behaviour pin on disc equipment is using. There are a lot of factors we need to consider while testing the wear behaviour. Factors like applied load, sliding speed, sliding distance, reinforcement content, ball milling timing, process what we are doing etc. It is essential to identify the major factor which influence the wear behaviour, which is the main criteria of this review. Most of the reported research focussed on the effect of either one or two factors on the dry sliding wear behaviour of hybrid composites. In most of the studies composites are produced by using powder metallurgy method, which is one of the economic and commonly used methods in metallurgy. An additional advantage of powder metallurgy is the uniformity in the reinforcement distribution. Matrix and reinforcement phase work together to produce combination of material properties that cannot be met by the conventional materials.

I. ALUMINIUM CERAMIC COMPOSITES

Aluminium ceramic composites is considered as an important material in the aerospace and automotive engineering sectors due to its high strength and wear resistant components. At the present time, aluminium metal matrix composites (AMMCs) have been well recognised and steadily improved because of their advanced engineering properties, such as their improved wear resistance, low density, specific strength and stiffness. It also possess low wear resistance property, so additional reinforcements must be added. Ceramic materials like SiC, Al_2O_3, B_4C, TiC, and AlN will provide wear resistance and mechanical strength. These aluminium-based ceramic composites require not only good strength and good wear resistance but also self-lubrication properties [1, 2]. In order to test the wear behaviour pin on disc equipment is using. There are a lot of factors we need to consider while testing the wear behaviour. Factors like applied load, sliding speed, sliding distance, reinforcement adding, ball milling timing, process what we are doing etc [3,4]. It is essential to identify the major factor which influence the wear behaviour. In most of the studies composites are produced by using powder metallurgy method, which is one of the economic and commonly used methods in metallurgy. An additional advantage of powder metallurgy is the uniformity in the reinforcement distribution. Most of the reported research focussed on the effect of either one or two factors on the dry sliding wear behaviour of hybrid composites.

In some of the studies they have optimized factors using taguchi methods. In that most papers used taguchi method as their optimization tool. An orthogonal array, the signal-to-noise ratio and analysis of variance were used to study the optimal testing parameter using Taguchi design of experiments. They have considered wear and coefficient of friction in their work [5, 6]. A number of studies have done their work on the dry sliding wear behaviour of aluminium composites reinforced with various ceramic particles [7, 8]. Widely and well known lubricants are MoS_2, BN, Gr and CaF_2. Lubricants also influence the wear behaviour and coefficient of friction properties [9].

II. TAGUCHI METHOD

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently applied to engineering, biotechnology, marketing and advertising. It is one of an optimization technique used now a days. The Taguchi's method [3] is a powerful method for designing high quality systems based on orthogonal array (OA) experiments that provide much reduced performance for the experiments with an optimum setting for process control parameters. This method achieves the integration of design of experiments (DOE) [10] with the parametric optimization of the process yielding the desired results. Design of experiment is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously and involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance. All designed experiments require a certain number of combinations of factors and levels be tested in order to observe the results of those test conditions. Taguchi approach relies on the assignment of factors in specific orthogonal arrays to determine those test conditions. Analysis of the experimental setup results uses a signal to noise (S/N)

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ratio to aid in the determination of the best process designs which are logarithmic functions of desired output to serve as objective functions for optimization. The S/N ratio takes both the mean and the variability into account and is defined as the ratio of mean (Signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product / process to be optimized. The three categories of S/N ratios are used: lower the better (LB), higher the better (HB), and nominal the best (NB). For the case of minimization of wear, LB characteristic needs to be used. This technique has been successfully used by researchers in the study of dry sliding wear behavior of composites [7]. These methods focus on improving the design of manufacturing process.

A product can be designed and manufactured based on a set of specifications demanded by the customer. Each specification has a required parameter value or values, which the manufactured product must be able to satisfy. Thus, the manufacturing process must be capable of producing the designed parameters, which is termed as the targeted value, according to the customer's specifications. Unfortunately in reality, manufacturing processes are far from ideal. A product manufactured tends to give a distribution that has a mean value slightly different from the targeted value. Thus, one of the main techniques used in Taguchi's quality control is to reduce the variation around the targeted value. According to Taguchi, the quality of a group of products can be improved by achieving its end product specifications distribution as close to the target value as possible.

This concept can be realised by designing and building the quality into the product itself. Hence, Taguchi employs design experiments using specially constructed table, known as "Orthogonal Arrays (OA)" to treat the design process, such that the quality is build into the product during the product design stage. Discussions of the various aspects of Orthogonal Arrays (OA) can be found in the following links.

A. The Approach of Orthogonal Arrays

An experiment during the product design stages, involves the materials used in manufacturing the experimental product which affects the final quality outcome. Factors such as variations in the chemical ratio, the level of ingredients used, and how the product is formed together, will contribute to the variation in the targeted value of the final product.

Orthogonal Arrays (OA) are a special set of Latin squares, constructed by Taguchi to lay out the product design experiments. By using this table, an orthogonal array of standard procedure can be used for a number of experimental situations. Consider common 2-level factors OA as shown in table 3.1 below:

TABLE 1. Orthogonal Array of L8 (2^7)

TRAIL NUMBERS	A	B	C	D	E	F	G
1	0	0	0	0	0	0	0
2	0	0	0	1	1	1	1
3	0	1	1	0	0	1	1
4	0	1	1	1	1	0	0
5	1	0	1	0	1	0	1
6	1	0	1	1	0	1	0
7	1	1	0	0	1	1	0
8	1	1	0	1	0	0	1

The array is designated by the symbol L8, involving seven 2-level factors, zeros and ones. The array has a size of 8 rows and 7 columns. The number (zeros/ones) in the row indicate the factor levels (be it a fluid viscosity, chemical compositions, voltage levels, etc.) and each row represents a trial condition.

The vertical columns represent the experimental factors to be studied. Each of the assigned columns contain four levels of zeros (0), and four levels of one (1), these conditions, can combine in four possible ways, such as (0,0), (0,1), (1,0), (1,1,), with 27 possible combinations of levels. The columns are said to be orthogonal or balanced, since the combination of the levels occurred the same number of times, when two or more columns, of an array are formed. Thus, all seven columns of an L array, are orthogonal to each other. The OA facilitates the experimental design process by assigning factors to the appropriate columns. In this case, referring to table 1, there are at most seven 2-level factors, these are arbitrarily assigned factors A, B, C, D, E, F, and G to columns 1, 2, 3, 4, 5, 6, 7 and 8 respectively, for an L8 array. From the table, eight trials of experiments are needed, with the level of each factor for each trial-run as indicated on the array. The experimental descriptions are reflected through the condition level. For example, 0 may indicates the factor is not applied, and 1 represents the factor that is fully applied. The factors may be variation in chemical concentration, material purity, and mechanical pressure and so on. The experimenter may use different designators for the columns, but the eight trial-runs will cover all combinations, independent of column definition. In this way, the OA assures consistency of the design carried out by different experimenters. The OA also ensures that factors influencing the end product's quality are properly investigated.

III. WEAR TESTING & FACTORS CONSIDERING IN WEAR TEST

Dry sliding wear tests were performed in accordance with the ASTM G99-05 (reapproved 2010) test standards [10] for the pin-on-disc equipment. Prior to testing, the pins and disc surface were cleaned with acetone. All the tests were performed on different factors like applied load, sliding distance, sliding speed. Values will differ for each process. After each test, the specimen and counter face disc were cleaned with organic solvents to remove traces of composite. Wear rate and coefficient of friction can be noted for each combinations. Each experiments will be repeated, in order to get the average result. Aluminium materials have a lot of applications in various industries, but it has less wear resistant property. So additional ceramic particles needs to be added in order to improve its properties. In this work I am giving importance to the factors that have been used in various journal papers.

A. Applied load

In this paper they have used Al 2024 with 5 % SiC weight percentage in constant and graphite content from 0-10%. Load varies from 10, 15, 20 newton [10]. In this tribological behaviour of aluminium alloy (Al-Si10Mg) reinforced with alumina (9%) and graphite (3%) fabricated by stir casting process was investigated. Applied load ranges from 20, 30, 40 newton [11]. In aluminum based red mud metal matrix composite material they have applied loads from 10, 30, 50 newton [4]. Investigation on the effect of Cu addition in Aluminium powder performs on their dry sliding behaviour loads are applied from 10, 15 and 20 newton [12].

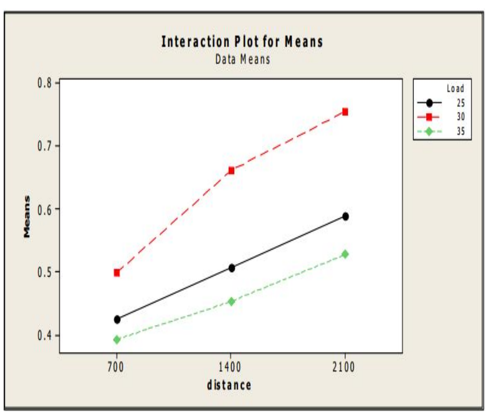

Fig. [5] Interaction plot between Load and Sliding Distance [5].

Tribological behaviour of aluminium alloy Al6061T6 reinforced with silicon carbide and alumina oxide particles (10%weight percentage of SiC and Al2O3 particles) fabricated by stir casting process they have distributed loads from 10, 20 and 30 newton. Optimization of tribological performance parameters of Al-6061T6 alloy reinforced with SiC, Al2O3 15% and graphite particulates of weight percentage of 10 % are adding loads were applied from 25 to 35 newton. In most of the cases applied load plays vital role in wear formation. As applied loads increases wear rate increases and then decreases. Tribological studies of red mud reinforced Al metal matrix composites take load from 10-30 newton [6]. In another study on red mud reinforced Al metal matrix composites load varies from 10, 30 and 50 [4].

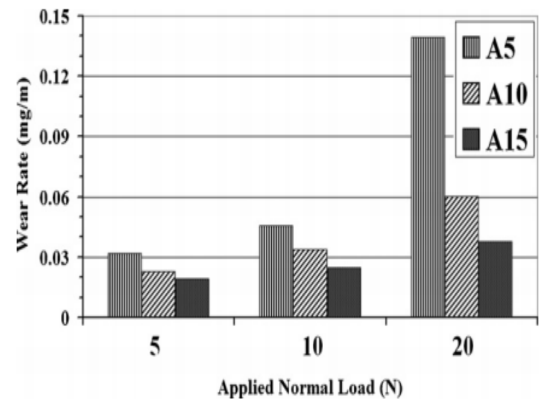

Fig. [13] The variation of wear rate as a function of normal load for the A5, A10 and A15 samples.

B. Sliding speed

In this study the mechanical properties of Al–12% Si matrix composite reinforced by various amounts of Titanium Carbide (TiC) and Titanium Nitride (TiN) particles, the wear behaviour was investigated using a pin-on-disc wear testing machine with varying parameters in that sliding speed was 150 and 225 rpm. Results shows that wear rate increases due to sliding speed [8]. In Al 6061 T6/ 15% SiC/15% Al_2O_3/ 10% graphite sliding speed varies from1.5, 2, 2.5 m/sec [5]. In Al 7075 alloy with addition of Silicon Carbide, 1 m/sec sliding speed is applied [14]. In Al 2219/ 15 SiCp and graphite sliding speed varies from 3 m/sec to 8 m/sec [7]. Tribological studies of red mud reinforced Al metal matrix composites we take sliding speed from 2, 3 and 4 m/sec [6]. In another study on red mud reinforced Al metal matrix composites sliding speed varies from 2, 3 and 4 m/sec [4].

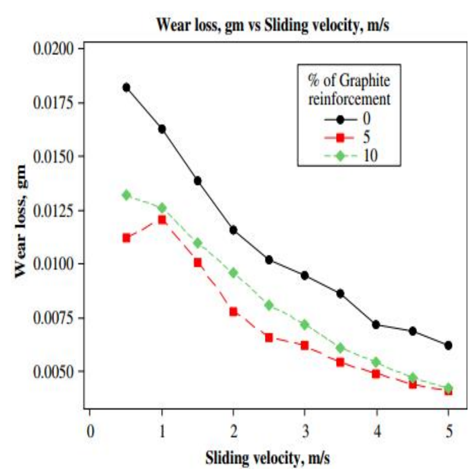

Fig. [10] Variation of wear loss against sliding velocity at constant load of15 N for a constant sliding distance of 5000m

C. Reinforcement content

Al–12% Si matrix composite reinforced by various amounts of Titanium Carbide (TiC) and Titanium Nitride (TiN) particles, the wear behaviour was investigated using a pin-on-disc wear testing machine Al-12Si matrix reinforced by 5%, 10%, 15% of TiC particles. Results shows that reinforcement adding improves the wear resistance [8]. The dry sliding wear behaviour of aluminum matrix nano composites containing various amounts of Al2O3–AlB12(5, 10 and 15 wt.%) particles was investigated. Results shows improvement of wear properties due to addition of nano particles [3]. In Al 7075 alloy with addition of Silicon Carbide, different proportions of ceramic particles varying from 0, 10 and 40% are adding [14].]. In Al 2219/ 15 SiCp different percentages of graphite is adding. Graphite provides additional wear resistant and lubrication property [7]. Tribological studies of red mud reinforced Al metal matrix composites red mud is reinforcing in 15, 20, 25 weight percentages [6]. In another study on red mud reinforced Al metal matrix composites red mud varies from 3, 4 and 5 in weight percentages [4].

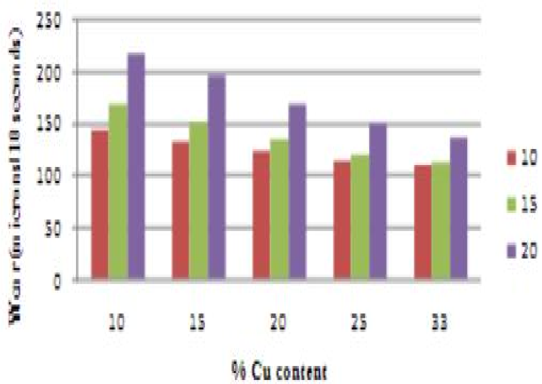

Fig. [12] Variations in wear at different applied loads for various weight % of Cu contents

D. Sliding distance

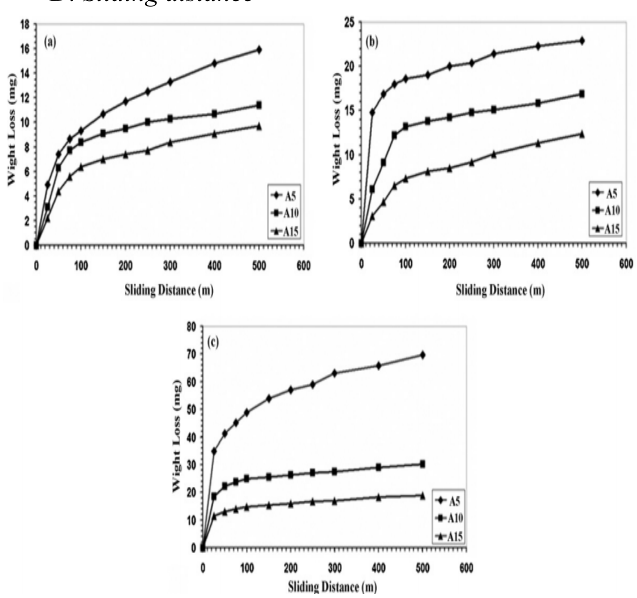

Fig. [13] shows Variation of wear mass loss as a function of sliding distance for all nano composite samples at applied loads of (a) 5 N, (b) 10 N, and (c) 20 N

In Al 6061 T6/ 15% SiC/15% Al_2O_3/ 10% graphite sliding distances are applied from 700 to 2100 meters. Results shows that sliding distance has influence in wear behaviour of hybrid composites [5]. In Al 2219/ 15 SiCp different percentages of graphite is adding in that sliding distance is kept constant at 5000 meters [7]. Tribological studies of red mud reinforced Al metal matrix composites uses sliding distance from 3000 to 5000 meters [6]. In all cases as sliding distance increases wear rate will also increase, so it will must fixed in a correct value.

E. Ball milling process

In all process ball milling process is carrying out. If time taken in doing ball milling is high, proper mixing of powder particles will takes place. Mechanical alloy by high energy ball mill RETSCH PM 400 for 2 hours have been done with a rotation speed of 30 to 400 rpm [15].

Table 2. Showing Different Factors And Their Combinations From Journals

Combination	Load (N)	Sliding speed (m/s)	Sliding distance (m)	Process	Findings
Al 6061 T6/ 15% SiC/15%Al_2O_3/ 10% Gr	25-35	1.5-2.5	700-2100	Powder metallurgy process	Applied load and sliding distance have significant role in wear behaviour
Al 6061 T6/ 10% SiC/10% Al_2O_3/	24.5-34.5	2-2.5	1000-2000	Stir casting process	Wear rate is highly influenced by sliding distance, applied load and sliding speed
Al and Al2O3–AlB12(5, 10 and 15 wt.%) nano particles	5-15	Not considering	800-1200	Powder metallurgy process	Wear rate decreases by adding reinforcement content. Wear loss increases with sliding distance and applied load.
• Al pure • Al(7075)+ SiC 10% • Al(7075)+ SiC 40%	Up to 220	1	Not mentioned	Powder metallurgy process	There is a strong relation between reinforcement addition and wear rate. Reinforcement decreases the wear rate

IV. RESULTS

- In this review about different factors considering in dry sliding wear behaviour, almost all factors are vital. Sliding distance, Sliding speed, applied load, Reinforcement content, Ball milling timing etc.
- Reinforcement content increases the wear resistance there by increasing the property of the composite.
- At higher load wear content will be less.
- Sliding distance and sliding speed increases means wear loss will also be high.
- Ball milling timing improves quality of the powder there by improving wear resistant property.

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