International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 05 | May 2020 www.irjet.net p-ISSN: 2395-0072

Wear Behaviour Analysis of Silicon Carbide based Aluminium Metal Matrix Composites

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Abstract - *The group of light weight and high-performance aluminium centric material systems are referred as Aluminium Matrix Composites (AMCs). The properties of this metal can be enhanced by reinforcement of TiC,B4C,Al_2O_3, SiC, and graphite in volume fractions ranging from a few per cent to 60% in AMCs. Silicon Carbide (SiC) particles have been found to have an excellent compatibility with the aluminium matrix and can be obtained at low cost. The major part of applications of AMCs includes moving and sliding parts, hence the investigation of tribological properties of these materials is very important to understand the behaviour of composite materials while in service application. Therefore, present study focused on tribological properties (wear behaviour) of AA380 – SiC composite. The proposed AA380-SiC composites are to be fabricated by stir casting method with 15 % volume fraction of SiC particles and pin of 10 x 30 mm diameter and height are to be cut. The wear behaviour tests are to be carried at table 2 conditions using pin-on disc wear testing equipment. From the proposed result effect of test parameters on aluminium matrix alloy and silicon carbide-based aluminium metal matrix composites are to be studied. Further by using Taguchi's technique the results are to be tabulated in Minitab – 17 software to analyse the effect of each input parameter on the wear rate.*

Key Words*:* Aluminium metal matrix, reinforcement, silicon carbide (SiC), wear, stir casting, Taguchi method, Minitab 17 software.

1. INTRODUCTION

The selection of materials is a difficult engineering challenge for the material engineer and, if done with perfection, can be a success for proper implementation and subsequent operation of the design. There are tremendous types of materials available to the designer, but choosing a correct material is an achievement in making a design. Materials selected should be able to perform on the basis of designer's expectation and should possess right properties in any working environment. Light-weight materials will most likely not possess sufficient strength, and brittle materials will not necessarily be good in fatigue resistance, stiffness or toughness. It is also almost impossible to find all the required material properties in a single material composition which fulfil the criteria of work to be performed. Moreover, material properties are greatly affected by the working environment (such as temperature, pressure, humidity, etc.) and the nature of loading (gradual, fluctuating, impact, fatigue, etc.), therefore two or more materials are combined to form alloys or composites to utilize the Aluminium Alloys and Composites which possess different useful properties for different use.

Aluminium alloys and composites have, in many applications, displayed better execution analysed than other metals. . The preference of aluminium compounds and composites gets from one significant quality of aluminium metal—lightweight. Light-weight converts into numerous significant results in designing applications. In the automobile industry, it implies less dead weight, lower fuel utilization, lower emissions, expanded payload (for travellers and cargo) and simple to handle. In the aviation and airplane industry, it converts into more payload (freight), less fuel and lower emissions. There are comparative points of interest in all territories where aluminium is used—marine, rail, packing, thermal administration, building and development, sports and entertainment, and many more. Aluminium's acceptable electrical and thermal conductivity have seen its expanded use in electrical conveyors, electronic packing and thermal administration. These days, aluminium is seen as a significant material for vitality preservation and natural assurance. Present day innovation targets fulfilling the market whose guidelines are increasing in value. The market requests quicker, progressively agreeable and easy transportation, increasingly conservative and lighter machines and instruments, progressively strategies for power production, etc. Most built materials can without much of a stretch meet or outperform structure particulars that would not have been imagined a couple of years back. The present materials are exposed to increasingly basic loads, more stress and progressively serious working conditions in a situation never experienced. In a shuttle, for instance, the working conditions experienced are very one of a kind and require uncommon sorts of materials to withstand the serious burdens forced on the rocket during take-off and support in the circling space. Customary materials have been discovered needing in meeting these working conditions and subsequently the need to strengthen innovative work (R&D) endeavours in new and propelled materials for explicit applications and proficiency improvement. . Among the propelled materials on the R&D, the main is the metal matrix micro and non composites. Metal matrix composites (MMCs) are metals or metal compounds that join particles, stubbles, filaments or empty microballons made of an alternate material and offer remarkable chances to tailor materials to explicit plan needs. . In automobile applications, for instance, these materials can be customized to be light-weight and with different other helpful properties including high explicit quality and explicit firmness, high hardness and wear resistance, high thermal conductivity, high vitality assimilation and a damping limit and low coefficients of friction and thermal development. In this manner, more opportunities are offered for more extensive utilizations of materials by controlling their preparing to suit the imperative properties under various workplaces. . The design of composite materials with explicit properties can, additionally, be practiced with the utilization of limited component demonstrating procedures. It is conceivable to foresee the properties of a specific material of indicated organization by utilizing these strategies. Similarly, it is conceivable to structure materials to offer determined properties by the utilization of these methods.

1.1 Objective

- To find better alternative material than cast iron for brake rotor application.
- Compare the wear loss proposed composite material.
- To find out influence of each control factor on wear of the selected alloy.

2. EXPERIMENTAL PROCEDURE

2.1 Design of Experiment

The procedure of spreading out the states of analyses including different variables was first proposed by the Englishman, Sir R. A. Fisher. The strategy is famously known as the factorial plan of analyses or design of experiments. A full factorial structure will recognize every conceivable blend for a given arrangement of elements. Since most mechanical trials as a rule include a large number of variables, a full factorial design plan brings about an enormous number of investigations. To decrease the quantity of investigations to a practical level, little small set from all the potential outcomes is chosen. The strategy for choosing a limited number of analyses which delivers the most data is known as a partial fraction experiment. Despite the fact that this strategy is notable, there are no broad rules for its application or the investigation of the outcomes acquired by performing the trials. Taguchi developed a unique arrangement of general design rules for factorial tests that spread numerous applications.

The design of experiment of a test includes following steps:

1. Choice of independent factors
2. Determination of number of level settings for every independent factor
3. Determination of orthogonal array
4. Allocating the independent factors to every segment
5. Performing the experiment
6. Data analyzing
7. Deduction

2.2. Materials required

In the current investigation, AA-380 alloy having composition shown in Table.1 was picked as the base matrix since its properties can be custom fitted through heat treatment process. The reinforcement was SiC 15%, and there are adequate written works clarifying the improvement in wear properties through the expansion of SiC. Due to the property of high hardness and high thermal conductivity, SiC after mixing into delicate malleable aluminium base matrix, upgrades the wear resisting behaviour of the Al/SiC metal matrix composite.

Table - 1: Composition of AA-380

Alloy	Si	Fe	Cu	Mn	Zn
AA380	8.220	0.686	3.586	0.189	0.952

Alloy	Cr	Ni	Ti	Pb	Al
AA380	0.018	0.124	0.037	0.0806	Bal.

2.3. Stir casting fabrication method

Among the variety of processes available for discontinuous metal matrix composites, stir casting is commonly acknowledged, and is right now practised commercially. Its preferences are its simplicity, adaptability and appropriateness to large scale production and, because it allows a conventional metal processing to be utilized, and its low cost. This fluid metallurgy technique is the most practical of all the available routes for metal matrix composite production, permits large sized components to be manufactured, and can continue high efficiency rates. The expense of getting ready composites materials using a casting method is around one-third to half portion than that of a competitive technique, and for high volume production, it is anticipated that costs will fall to one-tenth. Generally Stir casting of MMCs includes production of melt of the selected matrix material, followed by the introduction of a reinforcing material into the melt, acquiring a suitable dispersion through stirring. The following step is the solidification of the melt containing suspended particles to acquire the desired distribution of the dispersed phase in the cast matrix. In composites produced by this technique, particle distribution will change significantly relying upon process parameters during both the melt and solidification phases of the procedure. The increment of particles to the melt drastically change the consistency of the melt, this has suggestions for implication of casting process. It is significant that solidification happen before considerable settling has been permitted to occur.

The most significant requirement when using a stir casting technique is consistent stirring of the melt with a motor driven agitator to prevent settling of particles. If the particles are denser than the host alloy, they will normally sink to the base of the melt. This implies some technique for stirring the melt must be acquainted before casting to guarantee that the particles are evenly distributed all throughout the casting.

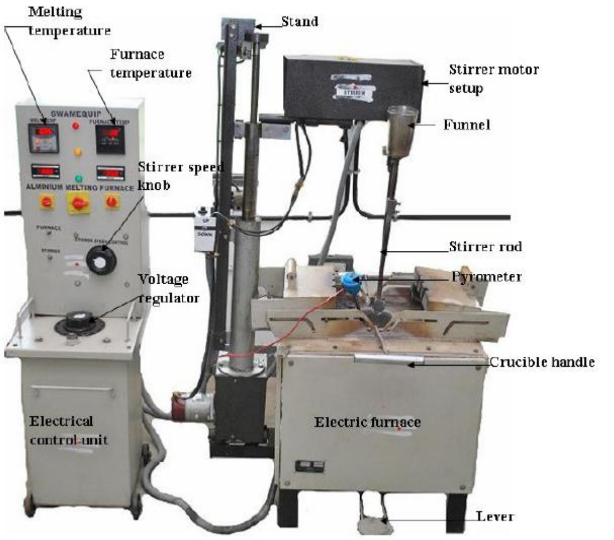

Figure - 1: Experimental setup for fabrication of material (*Stir casting setup*)

2.4. Wear test on Pin-on disc setup

Dry sliding wear tests for various number of specimen was performed by utilizing a Pin-on disc machine. In this investigation, Pin-on Disc testing technique was utilized for tribological portrayal. The test strategy is as per the following:

- At first, pin surface was levelled such that it will support the load over its entire cross-section called first stage. This was accomplished by the surfaces of the pin test ground utilizing emery paper (80 coarseness size) before testing.
- Run-in-wear was performed in the following stage/second stage. This stage maintains a strategic distance from starting turbulent period related with friction and wear curves.
- Last stage/third stage is the genuine testing called constant (steady state wear). This stage is the dynamic rivalry between material exchange processes (moving of material from pin onto the disc and development of wear debris and their removals). Prior to the test, both the pin and plate were cleaned with ethanol doused cotton. Prior to the beginning of each investigation, preparatory advances were taken to ensure that the load was applied normal way.
- Figure 2. Represents a schematic view of Pin-on-Disc setup.

Figure - 2: Pin-on disc sliding wear testing machine with integrated system.

3. RESULT AND ANALYSIS

The aim of the experiment plan is to locate the significant factors and factors of elements impacting the wear procedure to accomplish the minimum wear rate. The experiments were created dependent on orthogonal array, with the aim of relating the impact of sliding velocity, applied load and sliding distance. These design parameters are particular and inborn element of the procedure that impact and decide the composite execution. Taguchi suggests analyzing the S/N ratio utilizing theoretical methodology that includes charts of the impacts and visually recognizing the significant factors.

3.1. Taguchi method

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has built up a technique dependent on "Orthogonal Array" tests which gives a reduced "fluctuation" for the investigation with "ideal settings" of control parameters. In this way the combination of Design of Experiments with enhancement of control parameters acquire best outcomes was accomplished in the Taguchi Method. "Orthogonal

Arrays" (OA) give a lot of even (least) analyses and Dr. Taguchi's Signal-to-Noise ratio (S/N), which are log elements of desired yield, fill in as target capacities for streamlining, help in information examination and forecast of ideal outcomes.

The Taguchi procedure includes lessening the variation in a procedure through robust Design of Experiments (DOE). Multiple linear regression equation has been gotten through MINITAB 17. The general goal of the strategy has been delivering great item requiring little to no effort. Taguchi technique has been the least difficult strategy contrasted with many advanced exploratory strategies like response surface technique which is a mix of statistical experiment design basics, regression modelling method and optimization techniques. Significant downside of every one of these strategies has been their inability to include the effect of uncontrollable factors like ecological conditions, etc. Taguchi technique has been viewed as the best technique than recently developed calculation techniques, which in numerous events require less human impact. Taguchi technique is a scientific mechanism used for assessing and actualizing enhancements in items, procedures and facilities. The technique is appropriate over a wide scope of engineering fields that incorporate procedures like manufacturing of materials, tuning the sub-systems in engineering operations or in administration part. Taguchi technique independently ascertains the individual or fundamental impacts of independent variables on performance parameters, while different designs give an aggregate impact of variables regarding conditions or three dimensional curves or contour diagrams, which are frequently hard to comprehend and interpret. The general objective of the technique has been creating high quality item requiring little to no effort.

3.2. Formation of L9 orthogonal array

The orthogonal array has the accompanying extraordinary properties that reduce the number of trails to be conducted.

- The vertical section under every independent variable has an extraordinary blend of level settings. All the level settings seem an equivalent number of times. For L9 array under factor 4, level 1, level 2 and level 3 shows up thrice. This is known as the adjusting property of orthogonal arrays.
- All the level estimations of independent variables are utilized for conducting the tests.
- The arrangement of level values for directing the trials will not be changed. This implies one cannot lead experiment 1 with variable 1, level 2 arrangement and experiment 4 with variable 1 , level 1 arrangement. The purpose behind this is the arrays of each factor columns are commonly orthogonal to some other column of level values. The inward result of vectors relating to loads is zero. If the above 3 levels are standardized between - 1 and 1, at that point the weighing factors for level 1, level 2 , level 3 are - 1 , 0 , 1 respectively.

3.2.1. Selection of orthogonal array

The determination of Orthogonal array relies upon three things arranged by priority, viz., the number of factors and their interactions, number of levels for the factors and the desired experimental resolution or cost restrictions. Sums of 9 investigations were performed dependent on the run order generated by the Taguchi model [Table 2]. The response for the model is wear rate .The general format of L9 symmetrical exhibit is appeared in Table 3.Experimental design with a L9 orthogonal array as recommended by Taguchi has been utilized to carry out experiments regarding three input sources parameters and for three levels of individual parameters. The response for the model is wear rate .The general layout of L9 orthogonal array is shown in Table 3.Experimental design with a L9 orthogonal array as suggested by Taguchi has been used to carry out experiments with three inputs parameters and for three levels of individual parameters. The input parameters utilized are Load (L), Sliding speed(S) and Sliding distance (D). According to Taguchi experimental structure theory a set of three levels assigned out to each procedure parameter has two degrees of freedom (DOF). This gives a sum of six DOF for three procedure parameters selected in this work. The closest three level orthogonal array accessible and fulfilling the rule of choosing the Orthogonal Array is L9 having 26 DOF. The details of investigations with parameters and levels are given in Table 4.

Table - 2: Selected factors and levels

Controllable factor	A: Load, L (N)	B: Sliding speed, S(m/s)	C: Sliding distance, D(m)
Level 1	10	1.5	900
Level 2	20	2.5	1500
Level 3	30	3.5	2100

Table - 3: L9 Orthogonal Array

Experiment No.	Column 1	Column 2	Column 3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table - 4: L9 Orthogonal array for this experiment

Sr.No.	Load (N)	Sliding speed(m/s)	Sliding distance(m)
1	10	1.5	900
2	10	2.5	1500
3	10	3.5	2100
4	20	1.5	1500
5	20	2.5	2100
6	20	3.5	900
7	30	1.5	2100
8	30	2.5	900
9	30	3.5	1500

3.3. Results of Statistical Analysis of experiment

The outcomes for different combination of parameters were obtained by conducting the examination according to the orthogonal array. The measured outcomes were investigated utilizing the commercial software MINITAB 17 explicitly used for design of experiments applications. Table 5 shows the experimental results of L9 orthogonal array for 15% SiC of wear rate. To quantify the quality attributes, the experimental values are changed into signal to noise ratio. The impact of control parameters, for example, load, sliding speed, and sliding distance on wear rate has been examined using signal to noise response table.

The ranking of different parameters using signal to noise ratios acquired for various parameter levels for wear rate are given in Table 6 and Table 7 individually for 15% reinforced SiC MMCs. The control factors are statistically significant in the signal to noise ratio and it could be seen that the sliding distance is a prevailing parameter on the wear rate followed by applied load and sliding speed.

Table - 5: Results of L9 orthogonal array for 15% SiC

Sr. No.	Load	Sliding Speed (m/s)	Sliding distance(m)	Wear rate (mm^3/m)	S/N ratio wear(dB)
1	10	1.5	900	0.00480	46.44729
2	10	2.5	1500	0.00374	49.19350
3	10	3.5	2100	0.00156	55.65043
4	20	1.5	1500	0.00425	47.63914
5	20	2.5	2100	0.00199	54.33389
6	20	3.5	900	0.00365	48.9725
7	30	1.5	2100	0.00282	51.18191
8	30	2.5	900	0.00315	49.19339
9	30	3.5	1500	0.00243	52.43225

Table - 6: Average effect response for mean values of wear for 15% SiC

Level	Load (A)	Sliding velocity(B)	Sliding distance(C)
1	0.003367	0.003957	0.003987
2	0.003297	0.003080	0.003473
3	0.002920	0.002547	0.002123
Delta (Δ)	0.000447	0.001410	0.001863
Rank	3	2	1

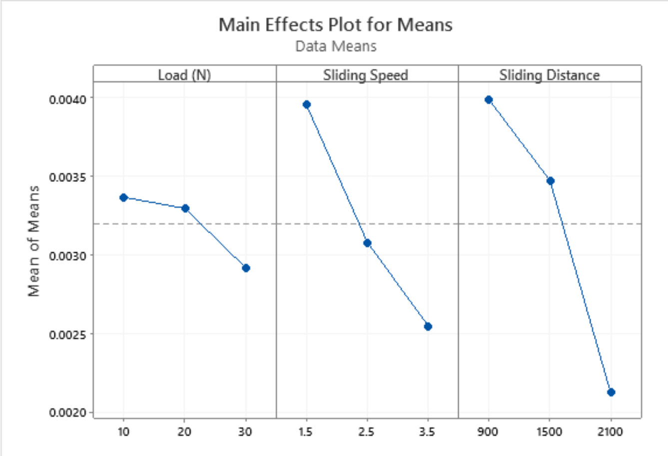

Figure - 3: Response graph for mean values of wear of 15% SiC

Table - 7: Average effect response for S/N ratio for wear 15% SiC

Level	Load (A)	Sliding velocity(B)	Sliding distance(C)
1	51.07	49.27	49.07
2	49.98	51.55	50.42
3	51.48	54.39	54.72
Delta (Δ)	0.72	4.13	5.61
Rank	3	2	1

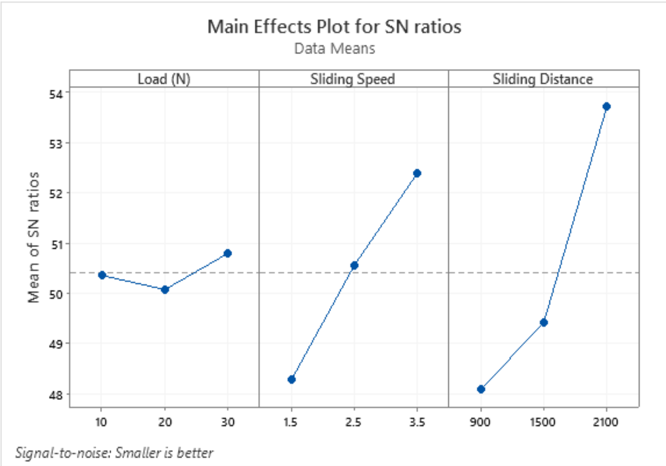

Figure - 4: Response graph for S/N ratio of wear for 15% SiC

4. CONCLUSIONS

The need of lightweight and superior materials in the aerospace and automobile industries has prompted broad research and endeavours in the advancement of aluminium metal matrix composites. The composite material in this project has been utilized for brake rotor application guaranteeing that less weight of vehicle decreases the fuel utilization and consequently low discharges along these lines greatly affecting nature for an enormous.

In this project, tribological properties of Aluminium alloy(AA-380) + Silicon carbide(SiC) composite with 15% of reinforcement are considered and it is been seen that with the increase in load, sliding velocity and sliding distance, wear rate gradually decreases. The samples were fabricated by Stir Casting process. The wear properties of the metal matrix composites are studied by dry sliding wear test utilizing a pin-on disk wear tester. Further so as to decide the parameter like wear rate, Taguchi technique is utilized to choose the number of trails dependent on factors like load, sliding speed, and sliding distance.

The percentage contribution of different control factors, for example, applied load, sliding speed and sliding distance on wear rate is determined by using ANOVA technique. Signal to noise ratio is used for advancement of working condition. Maximum estimation of signal to noise ratio in S/N ratio plot gives us the optimum condition.

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