Dry Sliding Wear Behavior of Aluminum Al4032+ (ZrB_2 +TiB_2) Composites using Pin– on–Disc Machine

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Abstract: Aluminium based metal matrix composites (MMCs) offer potential for advanced structural applications when high specific strength and modulus, as well as good elevated temperature resistance, are important. In the present work, Aluminium matrix composites (AMCs) reinforced by ZrB_2 and TiB_2 particles were fabricated from Al 4032- x wt% ZrB_2 and TiB_2(x=0,2,4,6,8) by in situ reaction from mixtures of K_2ZrF_6 ,K_2TiF_6 and KBF_4 with molten Al alloy. The composite wear test were conducted using on pin – on disc machine materials possessing high wear resistance (under dry sliding conditions) are associated with a stable tribolayer on the wearing surface and the formation of fine equiaxed wear debris. For adhesive wear, the influence of applied load, sliding speed, wearing surface hardness, reinforcement fracture toughness and morphology are critical parameters in relation to the wear regime encountered by the material. The composite flakes was developed using Taguchi's method by considering the parameters of composite %, speed (rpm), load (N). The results indicate that the volumetric wear rate is decreased with the increase in the weight percentage of ZrB_2+TiB_2, while it is increased with the increase of the applied load. The SEM analysis of the wear scar indicates the fragmentation of ZrB_2+TiB_2 particles into smaller ones orienting themselves along the sliding direction.

Keywords: Aluminium Alloy, in-situ reaction, scanning electron microscope, Al4032

1. INTRODUCTION

Composite materials are composed of at least two phases; a matrix phase and a reinforcement phase. Matrix and reinforcement phase work together to produce combination of material properties that cannot be met by the conventional materials. In most of the composites, reinforcement is added to matrix –the bulk material to increase the strength and stiffness of the matrix.

The most common composites can be divided into three main groups:

1. Polymer Matrix Composites (PMC's): Polymer matrix composites are also known as FRP- Fibre Reinforced Polymers (or Plastics). These materials use a polymer-based resin as the matrix, and a variety of fibres such as glass, carbon and aramid as the reinforcement.
2. Metal Matrix Composites (MMC's): Metal matrix composites are increasingly found in the aerospace and automotive industry. These materials use a metal such as aluminium as the matrix, and reinforce it with fibres, particulates or whiskers.
3. Ceramic Matrix Composites (CMC's): Ceramic matrix composites are used in very high temperature environments. These materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.

1.1 WEAR

It is defined as a process of removal of material from one or both of two solid surfaces in solid contact. Wear is defined as "the damage to a solid surface, generally involving the progressive loss of material, due to relative motion between two moving surfaces". Such a process is complicated, involving time- dependent deformation, failure and removal of materials at the counterface. Research in this area is of vital importance from the economic point of view because it is a major problem and its direct cost is estimated to vary between 1% and 4 % of a nation's Gross National Product.

LITERATURE REVIEW

Tuti Alias and Haque has studied the wear behaviour of as-cast and heat treated Al-Si eutectic alloys. Wear tests on the alloys were performed on a pin on disk type wear testing apparatus and parameters were size and shape of the pin, load, speed and the material pairs.

Rajaram, Kumaran and Srinivas Rao have studied the tensile and wear properties of Al-Si alloys fabricated by stir-casting technique at temperatures ranging from ambient to 3500C. It is observed that the wear rate decreases with increasing temperature. This is because an oxide film is formed at high temperature which helps to avoid direct contact between alloy and the abrasive. Continuous sliding action removes this layer which facilitates direct contact of the alloy with the abrasive which results in decrement of wear rate at high temperature (~300^0C)

Xiaoming Wang have studied that In situ Al Ti particle reinforced aluminium metal matrix composites, with reinforcing particles dispersed in the aluminium matrix homogeneously, had strong ability to nucleate aluminium grains. This also made the interfacial bonding between these two phases strong. Particle size and morphologies were largely affected by the processing conditions, such as temperature, holding time and the composition of the flux. High temperatures and longer holding times resulted in the coarsening of the particles.

Kok developed 2024 aluminium alloy metal matrix composites reinforced with Al_2O_3 particles and found that the porosity in the composites increased with increasing weight fraction and decreasing size of Al_2O_3 particles. Moreover, the dispersion of the coarser sizes of particles was more uniform while finer particles led to agglomeration of the particles and porosity, the hardness and tensile strength of the composites increased with decreasing size and increasing weight fraction of particles.

Rajnesh Tyagi investigated the friction and wear characteristics of Al - TiC composites under dry sliding using a pin-on-disc wear tester. The wear rate decreased linearly with increasing volume fraction of titanium carbide, and coefficient of friction also decreased linearly with increasing normal load and volume fraction of TiC.

Shafaat Ahmed found that the metal matrix composites were of great interest in recent years as they could offer a better combination of properties not attainable in conventional alloys. Al - based MMCs have been attracting a lot of attention particularly for their desirable combination of high stiffness and low specific gravity. Recently, tribological properties of Al - MMCs have also drawn much interest.

Rao studied the dry sliding wear behaviour of aluminium alloy and aluminium alloy - SiC composite using pin-on-disc apparatus against EN32 steel counter surface, giving emphasis on the parameters such as coefficient of friction, rise in temperature, wear and seizure resistance as a function of sliding distance and applied pressure.

Ramesh have studied that increased contents of TiO_2 in Al 6061 – TiO_2 composites resulted in higher hardness and lower wear coefficient. The wear coefficient decreased at higher loads and larger sliding distance.

Jiang Xu and Wenjin Liu To improve the wear resistance of an aluminium alloy, an in-situ synthesized TiB_2 particulate reinforced metal matrix composite coating was formed on a 2024 aluminium alloy by laser cladding with a powder mixture of Fe-coated boron.

2. EXPERIMENTAL METHODOLOGY

3.1 Sample Preparation

Aluminium 4032 alloy were used as the base metal in this study and the composition of Al4032 is shown in the **table 3.1**. Three types of salt, namely K_2ZrF_6, K_2TiF_6 and KBF_4 were used to synthesize the ZrB2 and TiB2 reinforcement. Aluminium 4032 was melted in a graphite crucible and a stirrer is used to stir the melt. When the temperature of the melt reaches 850°C, the dried K_2ZrF_6, K_2TiF_6, KBF_4 salt powders with weight ratio x wt% (x=0,2,4,6,8) were added to the molten aluminium. The stirrer used was a mild steel stirrer coated with zirconium, to avoid possible contamination of the molten metal with iron. Chemical reaction between the inorganic salts and the molten Al took place to form in situ ZrB_2 and TiB_2 particulates in Al. Finally, the melt was degassed and deluged and the refined metal was poured into cylindrical mould (20 mm diameter and 300 mm length). After the mould was cooled down to the room temperature, the specimens were taken out and cut to required dimension

Table 3.1 Material Composition

Element	Si	Cu	Mg	Ni	Fe	Cr	Zn	Al
Wt%	11.0 - 13.5	0.50 - 1.30	0.8 - 1.30	0.50 - 1.30	1.0 max	0.10 max	0.25 max	Bal

3.2 Abrasive wear test

The dry sliding wear tests were conducted on a high temperature pin-on-disc wear testing machine according to the ASTM G99 G95a Standard. The cylindrical pins of size (10mm diameter and 25mm height) machined from the composite were used as test material. The counter facematerial used was the cast iron with hardness values 200- 220 BHN. Prior to the tests, all the contacting surfaces were polished, cleaned in acetone in an ultrasonic cleaner and dried. The weight of the pin and disk were recorded before and after the test through electronic balance with the accuracy of 0.001 mg.

The tests were carried out at room temperature, which correspond to load varies from I0N - 50N, for a period of 25 minutes. The sliding speed varies as (200, 400, 600, 800, 1000 rpm) and sliding distance was maintained constant 100 mm (track diameter), respectively varies for all the tests.

3.3 Wear parameters

The variables involved in the wear test are:

- % of Al4032 & (ZrB_2 and TiB_2) composition
- Normal load
- Sliding speed
- Sliding distance

3.4 Theoritical Wear Measurements

Wear rate was estimated by measuring the mass loss in the specimen after each test and mass loss, Δm in the specimen was obtained. We can calculate the mass loss by measuring the height loss (Δh) in each experiment, the area of cross section (A) of sample and the density (ρ) of the alloy by using the relation

$$\Delta m = \Delta h \times A \times \rho$$

Cares have been taken after each test to avoid interaction of wear debris in the specimen. Wear rate which relates to the mass loss (Δm) and sliding distance (L) was calculated using the

$$W = \Delta m / L$$

The friction force was measured for each pass and then averaged over the total number of passes for each wear test. The average value of co-efficient of friction, μ of composite was calculated from the expression,

$$\mu = Ff / Fn$$

Where Ff is average friction force and Fn is applied load. For characterization of the abrasive wear behaviour of the composite, the specific wear rate is employed. This is defined as the volume loss of the composite per unit sliding distance and per unit applied normal load. Often the inverse of specific wear rate expresses in terms of the volumetric wear rate as

$$Ws = Wv / Vs\ Fn$$

Vs are the sliding velocity.

3.5 Design of Experiments (DOE)

DOE is an important and power full statistical technique that evaluates the effect of multiple parameters simultaneously .Experiments have to be conducted in a sequence ,with a series of steps, so that the process performance is better understood a certain combinations of factors and levels are considered and varied in a strategic manner.

The results obtained are observed and analysed to find out the significant factors and preferred levels. The data can be a acquired in an orderly way by DOE based on taguchi process: (i) The planning phase (ii) Conducting phase and (iii) Analysis phase among the three listed phases planning phases is vital where the factors and levels are decided.

The results obtained from experiments are analysed for better understanding of the influencing factors.

3.5.1 Plan of Experiments

Wear tests of the base alloy and the composite specimen where conducted under dry sliding condition for three parameters composite, sliding speed(rpm) , and applied load(N).With the variation of five levels and the process parameter are shown in **table3.2** Experiments have planed based on of L25 orthogonal array (OA).

Table 3.2 Process Parameters Used in the Experiment

Level	Composite %	Speed (rpm)	Load (N)
1	0	200	10
2	2	400	20
3	4	600	30
4	6	800	40
5	8	1000	50

The process parameters are changed accordingly and the values are tabulated as shown. After the plan of experiments conducted the process moves on to the next stage of experimentation.

3.5.2 Experimental Design

3.5.2.1 ANOVA

Is a collection of statistical models used to analyze the differences between group means and their associated procedures (such as "variation" among and between groups), developed by R.A.Fisher. In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether or not the means of several groups are equal, and therefore generalizes the t-test to more than two groups. As doing multiple two-sample t-tests would result in an increased chance of committing a statistical type I error, ANOVAs are useful in comparing (testing) three or more means (groups or variables) for statistical significance.

3.5.2.2 Taguchi Design

Taguchi Orthogonal Array

Design L25 (5**3)

Factors: 3 Runs: 25

Columns of L25 (5**6) Array 1 2 3

Using mini tab we have to find out the best possibilities by taguchi method.

Table 3.3 Probabilities of variables using taguchi

S.NO	Composite%	Speed(Rpm)	Load (N)
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	1	5	5
6	2	1	2
7	2	2	3
8	2	3	4
9	2	4	5
10	2	5	1
11	3	1	3
12	3	2	4
13	3	3	5
14	3	4	1
15	3	5	2
16	4	1	4
17	4	2	5
18	4	3	1
19	4	4	2
20	4	5	3
21	5	1	5
22	5	2	1
23	5	3	2
24	5	4	3
25	5	5	4

3. RESULTS AND DISCUSSION

3.1. Wear test

The dry sliding wear experiments were conducted as per the OA and the wear rate is shown in **table 3.3**.The better understanding of the various factors have considered such that composite %, speed (rpm), L (applied load, in N) .and their interactions using MINITAB software. The analysis was carried out at confidence level of 1% **table3.3** , shows the ANOVA results for the wear rate of composites and based on the statistical analysis of variance (ANOVA), have identified contribution of each process parameter for wear test Reinforcement is influencing most contribution parameter than other parameter such that load applied. The p value is mention which plays a major role in wear contribution rate and has statistical significance. It can be observed from **table 3.3** the applied load has highest influence followed by sliding Taguchi design (also called an orthogonal array) A Taguchi design is a designed experiment that lets you choose a product or process that functions more consistently in the operating environment. Taguchi designs recognize that not all factors that cause variability can be controlled. These uncontrollable factors are called noise factors. Taguchi designs try to identify controllable factors (control factors) that minimize the effect of the noise factors. During experimentation, you manipulate noise factors to force variability to occur and then determine optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors. A process designed with this goal will produce more consistent output. A product designed with this goal will deliver more consistent performance regardless of the environment in which it is used.

A well-known example of Taguchi designs is from the Ina Tile Company of Japan in the 1950s. The company was manufacturing too many tiles outside specified dimensions. A quality team discovered that the temperature in the kiln used to bake the tiles varied, causing non uniform tile dimension. They could not eliminate the temperature variation because building a new kiln was too costly. Thus, temperature was a noise factor. Using Taguchi designed experiments; the team found that by increasing the clay's lime content, a control factor, the tiles became more resistant, or robust, to the temperature variation in the kiln, letting them manufacture more uniform tiles. Taguchi designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be assessed independently of all the other factors, so the effect of one factor does not affect the estimation of a different factor. This can reduce the time and cost associated with the experiment when fractionated designs are used. Orthogonal array designs concentrate primarily on main effects. Some of the arrays offered in Minitab's catalog let a few selected interactions to be studied. You can also add a signal factor to the Taguchi design in order to create a dynamic response experiment. A dynamic response experiment is used to improve the functional relationship between a signal and an output response. Session window output for a Taguchi design Minitab calculates response tables, linear model results, and generates main effects and interaction plots for: signal-to-noise ratios (S/N ratios, which provide a measure of robustness) vs. the control factors means (static design) or slopes (Taguchi dynamic design) vs. the control factors standard deviations vs. the control

Factors natural log of the standard deviations vs. the control factors Use the results and plots to determine what factors and interactions are important and assess how they affect responses. To get a complete understanding of factor effects, you should usually assess signal-to-noise ratios, means (static design), slopes (Taguchi dynamic design), and standard deviations. Ensure that you choose a signal-to-noise ratio that is appropriate for the type of data you have and your goal for optimizing the response.

If you suspect curvature in your model, select a design - such as 3- level designs - that lets you detect curvature in the response surface. Return to top. A comparison of Taguchi static designs and Taguchi dynamic designs

Minitab provides two types of Taguchi designs that let you choose a product or process that functions more consistently in the operating environment. Both designs try to identify control factors that minimize the effect of the noise factors on the product or service. Static response In a static response design, the quality characteristic of interest has a fixed level.

In a dynamic response design, the quality characteristic operates along a range of values and the goal is to improve the relationship between a signal factor and an output response. For example, the amount of deceleration is a measure of brake performance. The signal factor is the degree of depression on the brake pedal. As the driver pushes down on the brake pedal, deceleration increases. The degree of pedal depression has a significant effect on deceleration. Because no optimal setting for pedal depression exists, it is not logical to test it as a control factor. Instead, engineers want to design a brake system that produces the most efficient and least variable amount of deceleration through the range of brake pedal depression. Return to top Conduct a Taguchi designed experiment conducting a Taguchi designed experiment can have the following steps:

1. Before you start using Minitab, you need to choose control factors for the inner array and noise factors for the outer array. Control factors are factors you can control to optimize the process. Noise factors are factors that can affect the performance of a system but are not in control during the intended use of the

product. Engineering knowledge should guide the selection of control factorsand responses. You should also scale control factors and responses so that interactions are unlikely. When interactions between control factors are likely or not well understood, you should choose a design that is capable of estimating those interactions. Minitab can help you design a Taguchi experiment that does not confound interactions of interest with each other or with main effects. Noise factors for the outer array should also be carefully selected and might require preliminary experimentation. The noise levels selected should represent the range of conditions under which the response variable should remain robust.

Note: While you cannot control noise factors during the process or product use, you need to be able to control noise factors for experimentation purposes.

2. Go to Stat > DOE > Taguchi > Create Taguchi Design to generate a Taguchi design (orthogonal array). Each column in the orthogonal array represents a specific factor with two or more levels. Each row represents a run; the cell values identify the factor settings for the run. By default, Minitab's orthogonal array designs use the integers 1, 2, 3, to represent factor levels. If you enter factor levels, the integers 1, 2, 3, will be the coded levels for the design.

You can also use Stat > DOE > Taguchi > Define Custom Taguchi Design to create a design from data that you already have in the worksheet. Define Custom Taguchi Design lets you specify which columns are your factors and signal factors. You can then easily analyze the design and generate plots.

3. After you create the design, you can use Stat > DOE > Modify Design to rename the factors, change the factor levels, add a signal factor to a static design, ignore an existing signal factor (treat the design as static), and add new levels to an existing signal factor.

4. After you create the design, you can use Stat > DOE > Display Design to change the units (coded or uncoded) in which Minitab expresses the factors in the worksheet.

5. Conduct the experiment and collect the response data. The experiment is done by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, beside the factor settings for that run of the control factors in the inner array.

6. Use Stat > DOE > Taguchi > Analyze Taguchi Design to analyze the experimental data. You should analyze each response variable separately with Taguchi designs. Although Taguchi analysis accepts multiple response columns, these responses should be the same variable measured under different noise factor conditions.

7. Use Stat > DOE > Taguchi > Predict Taguchi Results to predict signal to noise ratios and response characteristics for selected new factor settings.

4.2 Analysis of Control Factors

The response table for wear rate of composite is presented in **table 3.3** ,to analyses the influence of the control factor analysis of control factor will give the additional important information about the nature of the process under consideration and the highest difference of control factors indicates the strongest influence on wear rate was composite %, speed(rpm),applied load (N). Fig 1` shows the interaction of plot for composites. Three levels (low, medium, high) are considered in the experimentation and a straight line can be drawn for second and third column. In the third column of fig 1(A and B) there is a sudden increase followed by sudden decrease which shows that applied load will affect the wear performance of the specimen .as the sliding speed increases the wear rate is increased.

Table 4.1 Smaller is better

Level	reinforcement	Speed (rpm)	Load (N)
1	71.68	80.71	79.47
2	76.89	79.95	79.24
3	79.16	79.29	79.03
4	81.68	78.57	79.44
5	87.09	78.00	79.34
Delta	15.42	2.71	0.44
Rank	1	2	3

The wear rate gradually decreases as the percentage of composite decreases. **Figure 2** shows the main effect plot for means of composite .On increased percentage of composite wear rate decreases, as gradually the speed increases wear rate increases. As the load has small increment value it results in slight increase of wear rate these are the main three effects plotted on the graph mention below these are the main effects identified along the graph

Table 4.2 Analysis of Variance (ANOVA)

Source	DF	Seq ss	Adj ss	Adj ms	F	P	Contribution
Reinforcement	4	0.000 0001	0.000 0001	0.00	193.6	0.000	100
Speed(rpm)	4	0.000 0000	0.000 0000	0.00	6.81	0.004	0
Load (N)	4	0.000 0000	0.000 0000	0.00	0.63	0.652	0
Error	12	0.000 0000	0.000 0000	0.00	0		
Total	24			0.0000001		100	

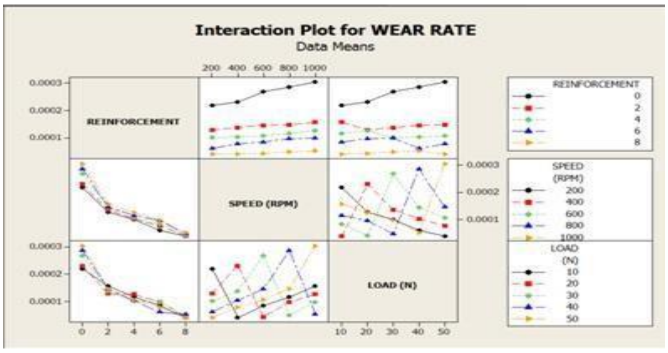

Fig 4.1 Interaction plot for wear rate

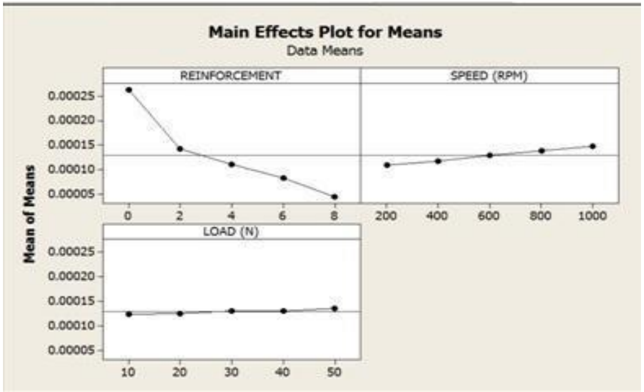

Fig 4.2 Main effects plot for means

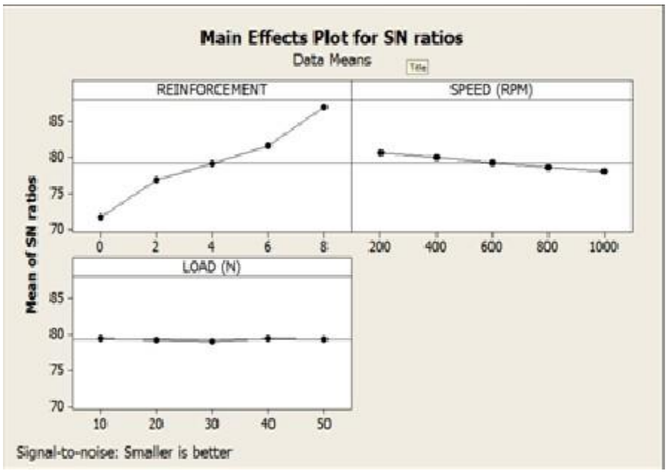

Fig 4.3 Main effect plots for SN ratio

Table 4.3 Experimental Design using L25 OA

SL.NO	Composite %	Speed	Load	Wear rate
1	0	200	10	0.0002196
2	0	400	20	0.0002313
3	0	600	30	0.0002689
4	0	800	40	0.0002876
5	0	1000	50	0.0003064
6	2	200	20	0.0001283
7	2	400	30	0.0001378
8	2	600	40	0.0001462
9	2	800	50	0.0001467
10	2	1000	10	0.0001576
11	4	200	30	0.0001005
12	4	400	40	0.000103
13	4	600	50	0.0001068
14	4	800	10	0.0001161
15	4	1000	20	0.0001261
16	6	200	40	0.0000603
17	6	400	50	0.0000781
18	6	600	10	0.0000844
19	6	800	20	0.0000973
20	6	1000	30	0.0000982
21	8	200	50	0.000039
22	8	400	10	0.0000401
23	8	600	20	0.0000425
24	8	800	30	0.0000479
25	8	1000	40	0.0000529

4.3 Scanning Electron Microscopy (SEM)

Have many applications across a multitude of industry sectors. It can produce extremely high magnification images (up to 200000x) at high resolution up to 2nm combined with the ability to generate localized chemical information (EDX). This means the SEM/EDX instrument is a powerful and flexible tool for solving a wide range of product and processing problems for a diverse range of metals and materials. LPD Lab Services has 2 SEM instruments and has extensive experience in using SEM/EDX analysis in many industrial sectors; electronics and semiconductors, pharmaceutical, petrochemicals, plastics and polymers, aerospace, automotive, medical devices, engineering, chemicals, materials and metallurgy.

4.3.1 Principle of SEM

An SEM is essentially a high magnification microscope, which uses a focused scanned electron beam to produce images of the sample, both top-down and, with the necessary sample preparation, cross-sections. The primary electron beam interacts with the sample in a number of key ways:-

Primary electrons generate low energy secondary electrons, which tend to emphasize the topographic nature of the specimen. Primary electrons can be backscattered which produces images with a high degree of atomic number (Z) contrast. Ionized atoms can relax by electron shell-to-shell transitions, which lead to either X-ray emission or Auger electron ejection. The X-rays emitted are characteristic of the elements in the top few µm of the sample and are measured by the EDX detector.

4.3.2 SEM Instruments

The scanning electron microscope is an instrument used for the imaging and analysis of a wide range of materials in a wide range of applications. The laboratory has 2 such instruments in house and 3 very experienced SEM analytical scientists. Additionally the company has access to higher resolution FEG (Field Emission Gun) instruments and environmental SEMs at trusted partner laboratories when required. SEM Instruments - Philips XL30 Scanning Electron Microscopes and EDAX

4.3.3 The main features and benefits of the SEM

Image magnification and resolution Magnification range X 15 - X 200,000 Resolution 2 nm Accelerating voltage

1 - 30 keV Secondary and backscatter electron imaging Stereo imaging and stereo height measurement EDX analysis of known or unknown materials. Qualitative and quantitative analysis for all elements from carbon upwards quantitative analysis of bulk materials and features ≥ 2 µm. Qualitative analysis of features ≥ 0.2µm

Detection limits typically 0.1 - 100 Wt % for most elements Multi-element X-ray mapping and line scans Multi- layer, multi-element thin film analysis - Thickness and composition Particle / Phase analysis - Detection, analysis, morphology and size Image Analysis Automatic particle counting and characterisation

4.3.4 Typical Applications

- Identification of metals and materials Particle contamination identification and elimination,
- classification of materials Product and process failure and defect analysis
- Examination of surface morphology (including stereo imaging)
- Analysis and identification of surface and airborne contamination Powder morphology, particle size and analysis
- Cleaning problems and chemical etching
- Welding and joining technology quality evaluation and failure investigation
- Paint and coating failure and delaminating investigation Paint, Adhesive, Sealant and Gasket Filler Fingerprinting Identification and elimination of corrosion and oxidization problems
- Contamination or stain investigation
- Reverse engineering of products and processes

By using this SEM process we are going to the next stage of project. We use the scanning electron microscope to calculate the wear rate. The worn out surface can be clearly scene in the SEM process.

4.3.5 SEM analysis:

Before wear the SEM images of various % (0, 2, 4, 6, and 8) are given as follows

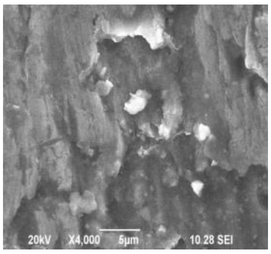

Fig 4.4 -0% before wears
wear

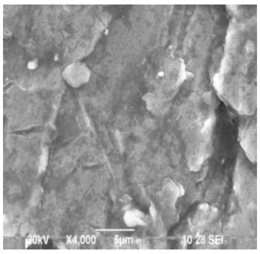

Fig 4.5- 2% before

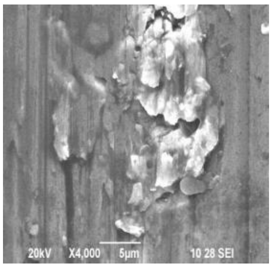

Fig 4.6- 4% before wears

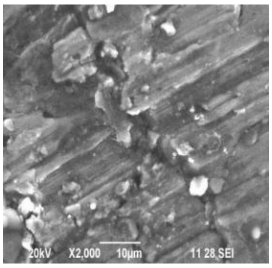

Fig 4.7-6% before wear

The composite mixture can be clearly seen by increasing magnification range of SEM testing process Image magnification and resolution Magnification range X 15 - X 200,000 Resolution 2 nm Accelerating voltage 1 - 30 keV Secondary and backscatter electron imaging Stereo imaging and stereo height measurement EDX analysis of known or unknown materials. Qualitative and quantitative analysis for all elements from carbon upwards quantitative analysis of bulk materials and features ≥ 2 µm.

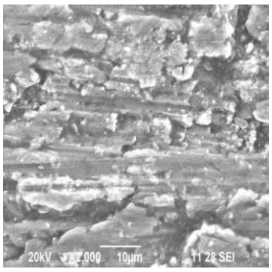

Fig 4.8- 8% before wear

After wear the weared surfaces are clearly seen in the following images. Detection limits typically 0.1 - 100 Wt

% for most elements Multi-element X-ray mapping and line scans Multi-layer, multi-element thin film analysis - Thickness and composition Particle / Phase analysis - Detection, analysis, morphology and size Image Analysis Automatic particle counting and characterization

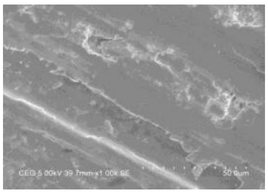

Fig 4.9- 0% after wears

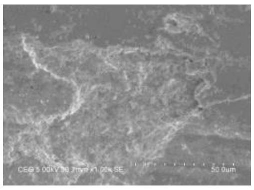

Fig 4.10- 2% after

wear Identification of metals and materials Particle contamination can also be seen identification and elimination, classification of materials Product and process failure and defect analysis are clearly shown

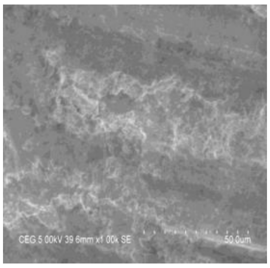

Fig 4.11- 4% after wears

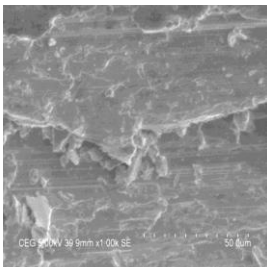

Fig 4.12- 6% after

wear

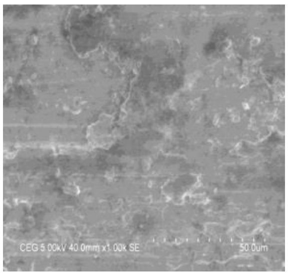

Fig 4.13- 8% after wear

SEM showing surface morphology of composite before and after long duration wears testing. High magnification observations indicated the presence of sharp, irregularly shaped particles on the wear tracks shows the surface appearance of composite with lower % before and after long duration wear testing, respectively. Examinations also revealed a higher percentage of composition on the wear track surface resulting from the sliding action. Observations on the wear track at high magnification showed de-bonding of reinforcement along with matrix fragmentation

5. CONCLUSION

The dry sliding behavior of Al4032 – (ZrB_2+TiB_2) in-situ composites have been analyzed and conclusion is

1) Wear rate of Al4032 reinforced with TiB_2 and ZrB_2 was highly influenced by applied load, speed and composite % respectively.

2) Wear rate decreases with increased in composite % also wear rate increases with the increase in sliding speed (rpm).

3) Simultaneously wear rate increase with increase in load.

4) Based on the taguchi and ANOVA the most influencing ranking process parameter and contribution have been identified.

5) By SEM results we can able to see the wear % variation with increase in composition.

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