

EXPERIMENTAL INVESTIGATION OF DRY SLIDING WEAR BEHAVIOUR OF STIR CASTED AZ31 MAGNESIUM ALLOY-CASIO₃ METAL MATRIX COMPOSITES

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Abstract

Metal matrix composites (MMCs) became one of the obligatory material in the transportation sector where Magnesium MMCs are in high demand due to their exclusive properties like low density, good weldable, recyclable, and casting. In the present work, wear behavior of AZ31 magnesium alloy added by calcium silicate (CaSiO₃) as additive of various compositions of its weight percentage from 0 to 8% is determined and tested under dry sliding condition. After experimentation, results revealed that the sample S-3 which comprises 4% CaSiO₃, shows the minimum pin temperature of 33.1 °C. In terms of frictional force, sample S-4 which has 6% CaSiO₃, shows a least frictional force of 4.81 N. The sample S-2 formed by 2% CaSiO₃ shows the highest value of 14.1 N of frictional force. By comparing the coefficient of friction value, the specimen sample S-4 displays the least friction value of 0.160 μ and sample S-2 exhibits the highest value as 0.470 μ. Wear occurred between pin and disc is observed as 292 μm for sample S-2 which is low compared to sample S-4 of 324 μm. By consolidation of results, the sample S-4 shows better performance in terms of force, coefficient of friction, and pin temperature concerning time.

Keywords: MMC, Magnesium Alloy, Wear, Calcium Silicate, Ambient temperature

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INTRODUCTION

MMCs plays a vital role in the fields of aerospace, automobile, marine and sports due to its light weight ratio. Calcium silicate which is available in powder form and acts as an anti-cracking agent is added with magnesium alloy to avoid the initiation of flaws due to internal or residual stress or varying loads which is most desirable aspect where these MMCs are preferred. Now a days, these are also preferred in medical field as implants due to its high wear resistance and light weight property.

In the present work, as reinforcement the effect of calcium silicate is experimentally determined by wear test conducted at

dry sliding condition under ambient temperature. AZ31 Magnesium alloy is taken as base alloy material and calcium silicate from 0% to 8% in its weight percentage added to base alloy which is shown in Table 1 and fabricated by stir casting process (Fig- 1, Make: M/s. Swam Equip, Chennai, India) under controlled atmosphere with Argon inert gas in a bar shape shown in Fig- 2. Later these bars are machined to the required sample size for wear test (Fig- 3 and Fig- 4) on Automatic Feed Lathe machine (Make: Banka 35).

Table-1 Weight Percentages of AZ31 and CaSiO₃ in Samples

Sl. No.	Sample No.	Percentage of AZ31 Magnesium Alloy	Percentage of CaSiO ₃
1	S-1	100%	0%
2	S-2	98%	2%
3	S-3	96%	4%
4	S-4	94%	6%
5	S-5	92%	8%



Fig- 1 Bottom Pouring Type Stir Casting Furnace (Received authorised certificate by corresponding author from M/s. Swam Equip, Chennai, India for using their furnace)



Fig- 2 AZ31-CaSiO₃ Composite Bars before Machining



Fig- 3 Machined AZ31-CaSiO₃ Composite Bars for wear test



Fig- 4 AZ31-CaSiO₃ Composite Samples for Wear test

Dai Nakama et al. [1] investigated about the effects on surface conditions and mechanical properties when AZ31 magnesium alloy plate was used as substrate and coated with AZ91 magnesium alloy consumable rod deposited by automatic friction welding machine. The result shows that the hardness, wear resistance and microstructure was improved for coated sample compared to substrate AZ31 magnesium alloy sample. **Y Fouad and M El Batanouny [2]** performed a wear test on surface treated AZ31 wrought magnesium alloy samples where ball burnishing, and shot peening surface treatment techniques used on samples. Shot peening is done with two pressure loads of 0.1 and 0.3bar pressure. The results show that worst wear results are observed on cast sample at 0.1 bar and sample which is surface treated with shot pining also shows the higher wear results and surface treated with swaged technique sample shows higher hardness value compared to other samples.

H. Hornberger et al. [3] comprehensively reviewed about the coatings and their role on magnesium alloy samples when they act as a biomedical implant. the results of the review states that corrosion resistance was increased when the samples are coated with calcium phosphate. but the crack propagation in the material is still existing which needs more concentration, other mechanical properties shows the better results. **M. Heydarzadeh Sohi et al. [4]** made an attempted by experimentation to analyse the microstructure, wear, hardness of AZ31 magnesium alloy by applying a alloyed layers of Aluminium using Tunsten inert gas (TIG) process as heat source, and better results are observed with increase in hardness, microstructure and reduction in wear rate. **Jie Xu et al. [5]** compared the results of as-received AZ31 magnesium alloy and AZ31 magnesium alloy which is processed by equal-channel angular pressing (ECAP). Wear behaviour of both samples was observed by conducting test using ball on disc apparatus and the test result show that ECAP processed magnesium alloy sample shows better results than as-received in terms of wear rate and volume loss which are reduced. Improvement in coefficient of friction was also observed.

HE Huan -ju et al. [6] conducted experimentation on AZ31 magnesium alloy to evaluate wear rate using hopkinson pressure bar which is done at high strain rate and observed that wear property was improved upto suitable strain rate but at high strain rate the material gets inactivated. Two types of wear mechanisms are observed which are grain abrasion and adhesive wear. **C. Liang et al. [7]** performed test on AZ31 magnesium alloy using pin on disc apparatus at different loads from 5-360 N at sliding ranges from 0.1-4.0 m/s. The wear rate was observed in two regimes which are mild wear and severe wear. when wear extends from mild to severe a substantial strain hardening which originates large plastic deformation was observed on surface which plays a key role. Different wear mechanisms are observed like oxidation, abrasion and delamination, thermal and surface melting in two regimes which are responsible for wear of material. **J Weiczorek et al. [8]** tested the AZ31 magnesium alloy samples which are coated with methods of anodising and

electroless plating. The quality of coating on samples was tested with scratch test. The results shows that the anodised coated sample-B shows better results at applied load of 7.5N and also best wear resistance was observed on Sample-B, but a poorest erosion resistance was observed on sample-D which was coated by electroless plating technique.

Sankalp Agarwal et al. [9] reviewed about the usage of magnesium alloys as biodegradable medical implant as orthopedic applications and especially focused on surface modifications of alloys, and known th fact that by the addition of other elements like Zn, Al, Mn, and Ca to base metal always improves the mechanical properties especially improvement of corrosion resistance was observed. It is also observed that synthetic and sol-gel aliphatic polyesters based coatings shows more corrosion resistance compared to conventional magnesium alloy. **Mohammad Ansari et al. [10]** investigated about the mechanical properties like microhardness, corrosion and wear resistance of AZ31 magnesium alloy which is surface alloyed with pulsed Nd:YAG laser surface with nichel 5% aluminium powder and results shows that microhardness, corrosion resistance and wear resistance has been raised and shows better results compared with base magnesium alloy. **Karakere Rangaraju Gopi and Hanumanthappa Sivananda Nayaka [11]** conducted an experiment on AZ70 magnesium alloy to find the wear behaviour when the alloy is processed with equal-channel angular pressing (ECAP). Loads of 30 and 40 N are applied to conduct wear test. Results shows that wear resistance was decreased for ECAP sample compared to conventional magnesium alloy sample and also reduction in mass loss and coefficient of friction (CoF) was also observed.

Nurettin Sezer et al. [12] reviewed about the usage of magnesium alloy as bio implants in human body but it has disadvantage of degradableness which means the alloy dissolves in body fluid. By addition of other elements and surface coatings by different techniques can enhance the mechanical, microstructural properties of magnesium alloy. Most of the researchers worked and made suggestions by various synthesis routes and checked the properties of alloy through in-vivo, in-vitro and in-silico with various studies and experimentations. **Faruk Mert [13]** conducted experiment to find the wear resistance of as-cast and hot rolled AZ31B magnesium alloy using pin-on-disc apparatus with a sliding distance of 1500 m with various sliding velocities as 0.25, 0.5, 1.00 and 2.00 m/s under applied loads of 10,20,40 and 80N. the result shows that hot rolled magnesium alloy samples shows better wear resistance and found an ultra-severe wear mechanism at high sliding velocity at high loads. Hardness of alloy was also improved for hot rolled magnesium alloy sample compared with as-cast sample. **Lijia Fang et al. [14]** examined the antiwear and anticorrosion enhanced properties of AZ31 magnesium alloy when an aluminium-silica as protective layer deposited using cold spray, and observed that improved silica content enhanced adhesion, antiwear and microhardness of alloy. Even distribution of silica in

coating shows an altered wear regimes which are adhesive and abrasive. Babu P.S et al. [15,16] found that 98% AZ31-2% CaSiO₃ Composite showed good hardness and 90% AZ31-6% CaSiO₃ composite showed less corrosion rate when matched to composites of other percentages of same combination. D.Suneel and Babu P.S [17] examined that nano composite of A356 base metal with 0.5% of SiC nano particles with 50nm size shows progress in wear resistance by using pin on disc apparatus under

ultrasonic cavitation at 30N and 40N loads compared to other percentages of SiC particles.

Experimentation

Pin on Disc Apparatus, the name itself describes that the machine is designed in such a way that the pin mounts in perpendicular direction on a circular disc. The disc rotates with desired speed in revolutions per minute (rpm) chosen by the user.



Fig- 5 Length of Pin sample



Fig- 6 Pin on Disc Apparatus

In present work, Pin on Disc apparatus (Make: Ducom, Bangalore) shown in Fig- 6 is used to conduct test and analysed the wear results on the magnesium alloy specimens shown in Fig- 4. Individual sample is shown in Fig- 5 which is fixed in holder and attached to apparatus and tested with selected parameters. The chosen parameters for the test are speed as 400rpm, duration of run as 16min, Distance covered as 1 km and Track diameter as 50mm.

Calculation of Time to conduct Test

To find out the time required to run the test is as follows,

Distance covered by Pin	=	1 km (Say)
Track Diameter (D)	=	50mm
Pin Diameter	=	10mm
Pin Length	=	40 mm (minimum)
Circumference of Circle	=	$\pi D = 3.141 \times 50\text{mm}$
	=	157.079mm
Speed of Disc	=	400 rpm (say)
No. of Revolutions	=	Total distance
travelled by Pin / Circumference of circle	=	$1\text{km} \times 1000 \times 1000$
		$\text{mm} / 157.079\text{mm}$

	=	$10^6 \text{ mm} / 157.079 \text{ mm}$
	=	6366.223 rev.
Therefore, Time to Run the Apparatus is given as No. of Revolutions / Speed of Disc	=	$6366.223 / 400 =$
	=	15.91 minutes
	=	Approximately 16min of time.

Assumed parameters and data to conduct the test on magnesium alloy samples are, Pin diameter as 10mm, Speed as 400rpm, applied load as 3kg or 30N, distance covered by pin is taken as 1 kilometre and plate is made of Steel (EN31) with a hardness of 62HV. From calculation the time of run to conduct wear test is 16min.

METHODOLOGY

The experiment is conducted to find the wear rate of magnesium alloy in microns (μm) which occurs due to external load application on Pin. By providing the selected parameters to the control unit shown in Figure 7, the test is conducted at 30N or 3 kg applied load for a duration of 16min.



Figure 7 Control Unit of Pin on Disc Apparatus

By this experiment, wear rate, pin temperature, coefficient of friction and force applied on pin is evaluated and the graphs are plotted between Time versus (vs) Wear rate, Time vs Coefficient of friction, Time vs Pin temperature and Time vs Force. Details of

all specimens include their weights, lengths and diameters are shown Table 2.

Table 2 Details of Sample Pins

Sl. No	Sample Number	Weight	Length	Diameter
	Units	(gms)	(mm)	(mm)
1	S-1	5.7174	43	10
2	S-2	6.4554	47	10
3	S-3	5.3425	44	10
4	S-4	5.6733	47	10
5	S-5	5.3423	40	10

RESULTS

In the present test, all samples are tested to find wear rate, Coefficient of Friction (CoF), Force and Pin temperature. The concerned graphs are plotted between Time versus (vs.) Wear,

Time vs. Coefficient of Friction, Time vs. Force and Time vs. Pin temperature. These are all shown from Fig- 8 to Fig-11.

Time vs. Wear Graphs

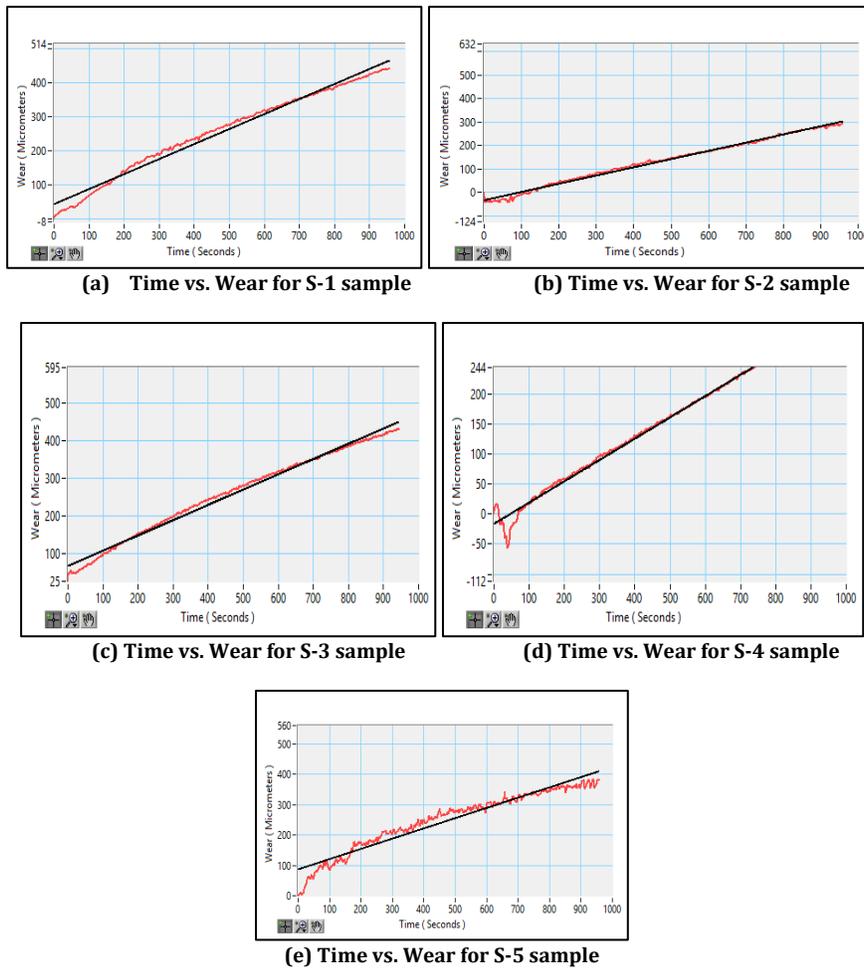


Fig- 8 Wear test results of all samples

Time vs. Coefficient of Friction (CoF) Graphs

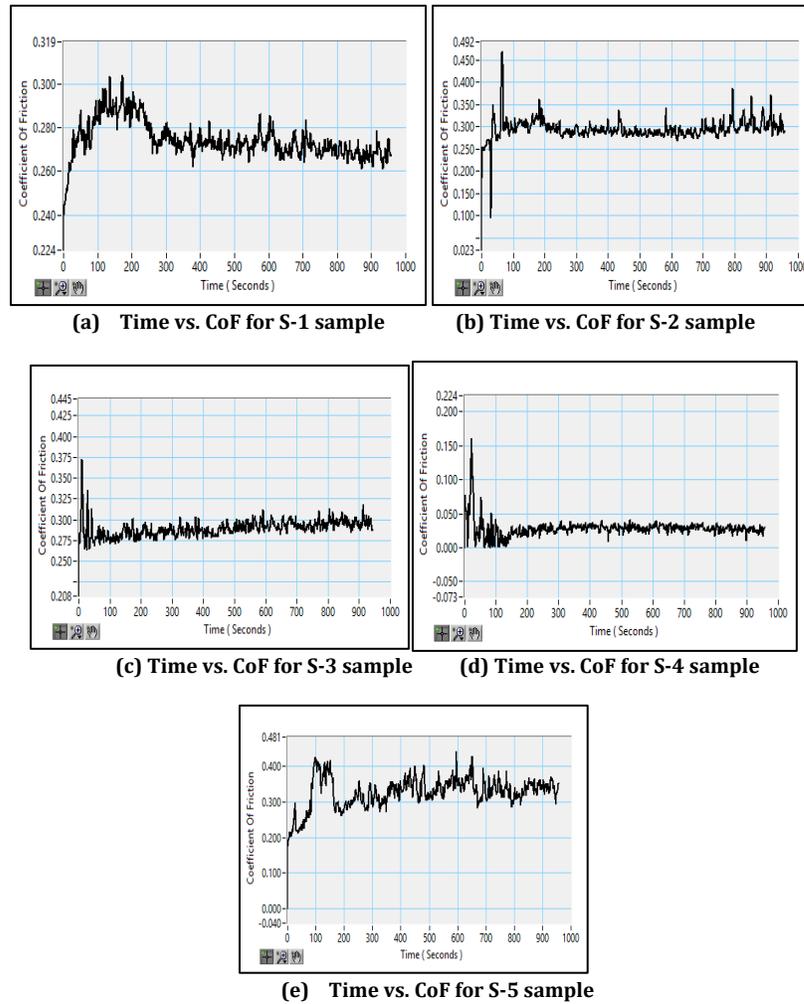
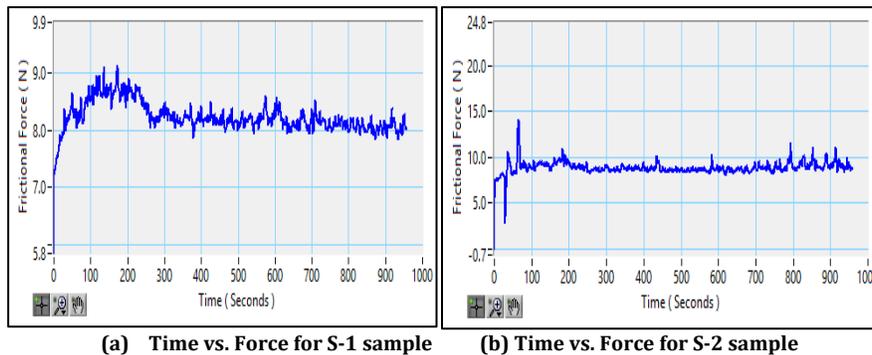


Fig-9 Co-efficient of Friction test results of all samples

Time vs. Frictional Force Graphs



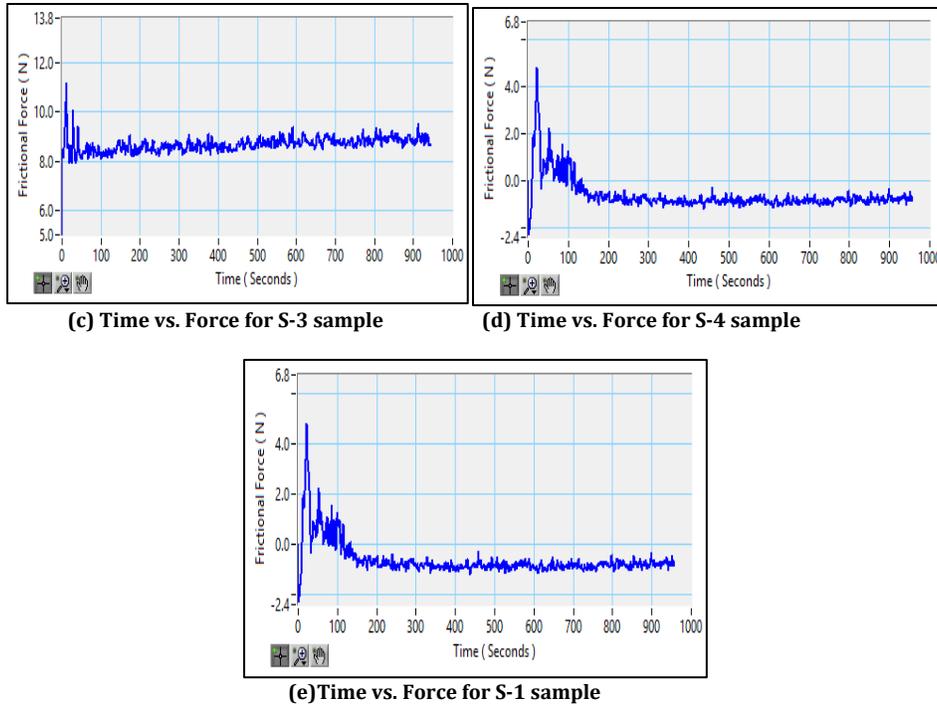
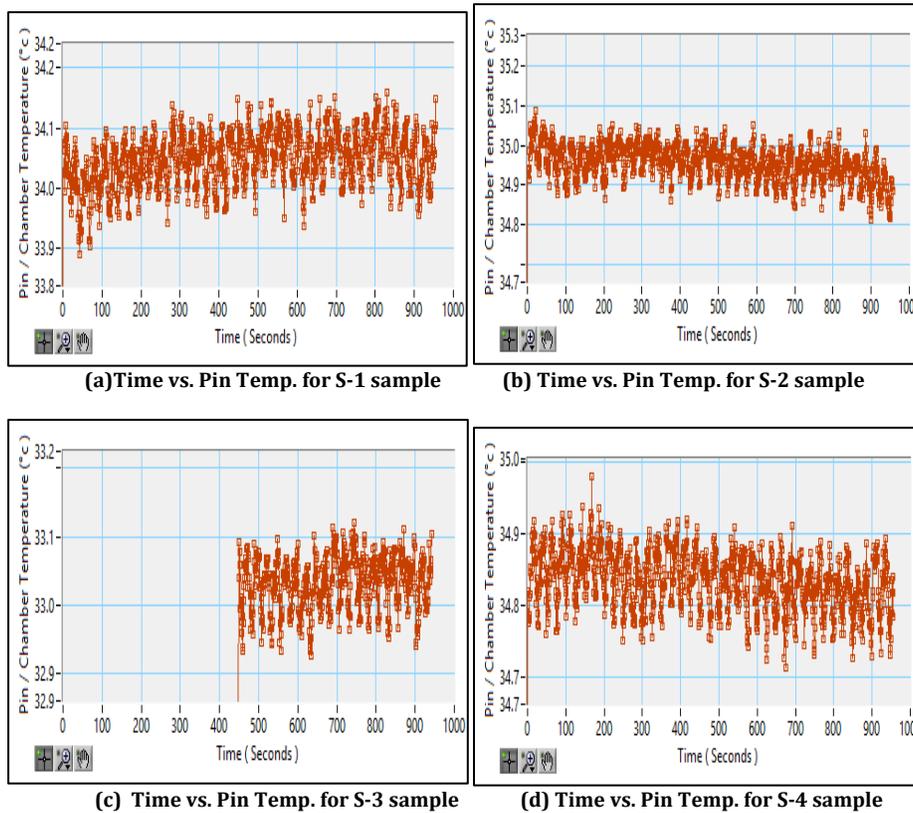
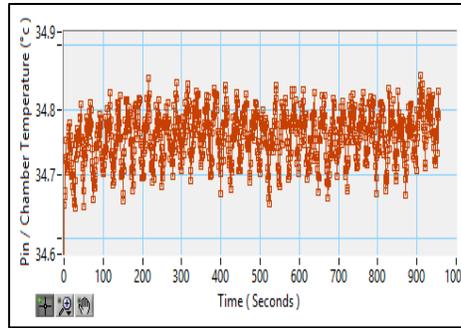


Fig- 10 Friction test results of all samples

Time vs. Pin Temperature Graphs





(e) Time vs. Pin Temp. for S-5 sample

Fig- 11 Pin Temperature test results of all samples

Table-3 Consolidated Results of samples after experimentation

Sl. No	Sample Number	Pin Temperature (°C)	Force (Newtons, N)	Coefficient of Friction (μ)	Wear (micrometers, μm)
		Max.	Max.	Max.	Max.
1.	S-1	34.1	9.25	0.304	441
2.	S-2	35.1	14.1	0.470	292
3.	S-3	33.1	11.1	0.372	432
4.	S-4	35.0	4.81	0.160	324
5.	S-5	34.85	13.1	0.430	381

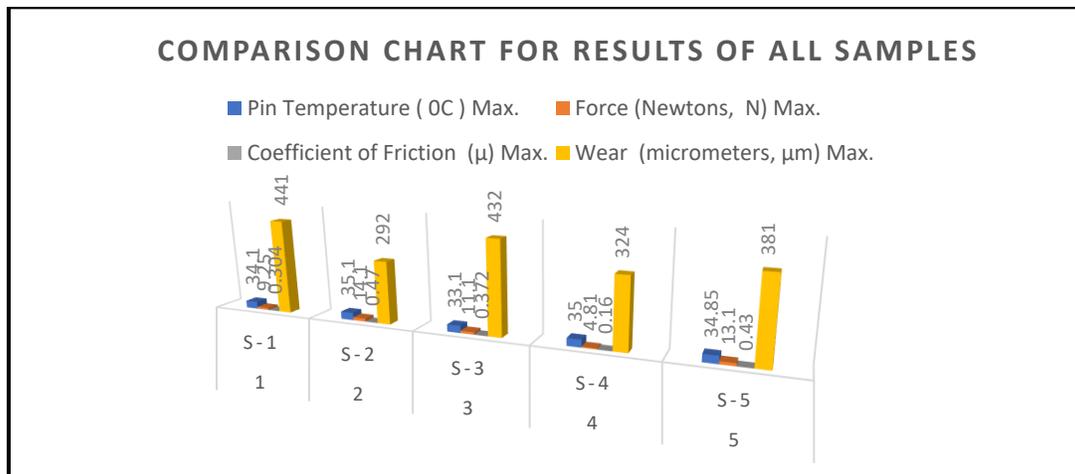


Figure 12 Comparison chart for results of all the AZ31-CaSiO₃ Composite samples

DISCUSSION

By observing all the results which are tabulated in Table 3 and drawn the chart as Fig- 12, it is found that the pin temperature reached 35°C for sample S-4 which have the composition of 6% of calcium silicate with AZ31magnesium alloy against the Force applied on pin is very least for the same sample. By comparing other parameters also S-4 sample exhibits better results compared to other samples.

CONCLUSIONS

After completion of experimentation with AZ31 Magnesium alloy samples added by calcium silicate as additive in different weight percentage from 0 to 8% (with increment of 2%) are tested to find the Wear rate, Pin temperature, Coefficient of friction and Force under the load of 3kg with a speed of 400rpm. The following conclusions are derived

- ❖ The sample S-2 composition shows a Pin temperature of maximum of 35.1 °C, the sample S-3 shows minimum of 33.1 °C.
- ❖ The sample S-4 shows Frictional force of least value of 4.81 N, but the sample S-2 shows the highest value of 14.1 N
- ❖ By comparing the coefficient of friction value, the specimen S-4 shows the least friction value of 0.160 μ and sample S-2 shows highest value of 0.470 μ
- ❖ Due to friction occurred between plate and pin, the Wear occurred between them is observed as 292 μ m for sample S-2 which is less compared to sample S-4 is 324 μ m.

Finally, the sample S-4 shows better results in terms of force, coefficient of friction and pin temperature with respect to time and sample S-2 shows less wear rate of 292 μ m compared to other samples.

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