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STRUCTURAL AND THERMAL STUDY OF ALUMINUM HYBRID COMPOSITE ALLOY REINFORCED WITH SILICON CARBIDE AND RICE HUSK ASH FOR AUTOMOBILE BRAKE DRUM

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Abstract: The reduction in weight of a vehicle in any possible way without changing its basic functionality is very important in increasing mileage, thereby increasing fuel efficiency. This project concentrates on reducing the weight of the Cast Iron brake drum used in rear wheels which is usually heavier, so it is suggested to replace the existing cast iron drum with aluminum hybrid composite reinforced with SiC and Rice Husk Ash (RHA) for improved mechanical, thermal and tribological properties. The composite is done by stir casting method for uniform distribution of reinforcement after procurement of individual materials and then making a list of properties required for brake drum and thereafter producing various specimens for different tests and which are done using various equipment. Then, the suitable composite is chosen from the list, tracked down with help of most important parameters. A comparison is made between the chosen composite and cast iron with that, a decision is made whether cast iron can be replaced.
Keywords: Aluminium composite, RHA (Rice Husk Ash), SiC (Silicon Carbide), Stir Casting

1. INTRODUCTION

Brake drum plays a vital role in the braking system and it is the most important component. A typical large truck brake drum weighs about and it is usually made by cast iron because of its low cost and desirable properties such as low melting point, good fluidity, better damping properties, and excellent machinability. Although the cast iron brake drums perform satisfactorily, there are some short comings like increased weight which contributes to a larger proportion of its total weight and susceptibility to heat checking which may lead to thermal cracks. To overcome these limitations, engineers are constantly striving hard to improve it's working performance by increasing their fatigue life and reducing its weight to a considerable level, by replacing the conventional cast iron brake drum with metal matrix composite(MMC). These MMC's find their application in brake drum because of their exceptional properties such as lower density, better corrosion resistance, good wear resistance, lower thermal expansion, higher thermal conductivity and higher thermal diffusivity. Weight of the brake drum has become increasingly important to the vehicle manufacturer because it affects the mileage efficiency. With due note to this, government has seriously stressed all the automobile manufacturers to reduce weight requirements on even the smallest automobile component. Automobile manufacturers are trying to reduce the weight of the brake drum by replacing it with lighter material such as aluminum and aluminum alloys .Hence this use of lighter materials reduces the internal yield strength, to overcome this aluminum alloy composites are used .

2. LITERATURE SURVEY

Zhang[1]et al. made comparison of friction and wear performance of brake materials Al matrix composites. Studies made on differing in amounts of zirconium silicate (0, 4, 8, 12 wt% $ZrSiO_4$) on brake materials sliding against the Al-MMC's drum performed on chase machine. Results show that brake material containing 8 wt% $ZrSio_4$ had the best wear resistance and higher friction level.

Zhao[2] et al. presented a discussion about frictional wear and thermal fatigue behaviours of biomimetic coupling materials prepared by laser surface melting and laser coating technology. Biomimetic coupling material and gray cast iron are compared. The results indicate at frictional wear resistance and thermal fatigue resistance of biomimetic coupling sample is better than that of untreated sample, and among the biomimetic samples, laser coating treated sample has superior resistance to wear and thermal fatigue comparing with laser melting treated sample

Rehman[3]et al. investigated the analysis of stir die cast Al-SiC composite brake drum based on coefficient of friction a brake drum dynamometer test rig was developed for the purpose. Al–SiC MMC was reinforced with 10% and 15% SiC particle by weight. The effect of heat treatment of the Al–SiC MMC brake drum was also studied. Performance was mainly evaluated on the basis of brake drum coefficient of friction .Scanning electron microscope was also used to study the effect of braking on the sliding surface of the brake drum. It was found that the coefficient of friction narrowly changed with applied braking load and speed for brake drums of any material. The coefficient of friction of the composites is found to be higher than cast iron brake drum. Higher coefficient of friction of heat treated Al–SiC MMC suggests a limited scope of its use in smaller load carrying automobiles. It is of interest to note that brake drum and brake shoe

Sallit[4]et al. made a study about coupling of MMCs with hypereutectic alloys composing brake disks/brake pads. It was carried out to define a characterization methodology, so as to identify the wear mechanisms of the tribological couple, and to evaluate the behaviour of the new materials. One of the features of this couple is the constitution of a transfer layer on the disk, because this has an important effect on the behavior of this couple. The results show that the heat treatment has a beneficial effect on the wear of the disk. The effect of the heat process on the hardness of hypereutectic alloys is relatively higher than it is on the hardness of Duralcan alloys.

A. Daoud[5]et al. depicts the effect of wear and friction behaviour of sand cast brake rotor made of A359-20 vol% Sic particle composites sliding against a friction material under the load range of 30–100 N and speed range of 3–12 m/s. A pin-on-disc type apparatus was used to investigate the dry sliding frictional and wear behaviour. The rotating disc is made of A359-20 vol% SiC particle composite, while the friction material was used as a pin. The wear and friction behaviour of commercially used cast iron brake rotor were studied and compared with the observed results. The results showed that the wear rate of the composite disc decreased with increasing the applied load from 30 to 50 N and increased with increasing the load from 50 to100 N. However, the wear rate of the composite disc decreased with increasing the sliding speed at all levels of load applied in the present work. For all sliding speeds, the friction coefficient of the composite disc decreased with applied load. The worn surfaces as well as wear debris were studied using scanning electron microscopy (SEM), energy dispersive X-ray (EDX) analyzer and X-ray diffraction (XRD) technique. At load of 50 N and speed range of 3–12 m/s, the worn surface of the composite disc showed a dark adherent layer, which mostly consisted of constituents of the friction material. This layer acted as a protective coating and lubricant, resulting in an improvement in the wear resistance of the composite.

Peter J. Blau[6]et al. says titanium alloys and their composites have the potential to reduce truck disc brake component weight and improve their resistance to road-salt corrosion. A titanium alloy rotor can weigh approximately 37% less than a conventional cast iron rotor with the same dimensions, while offering good high-temperature strength and much better resistance to corrosion from road-dicing salts. Friction coefficients and temperature rise data were obtained for two commercial Ti alloys, four experimental Ti-based hard particle composites, and a thermally spray-coated Ti alloy. Several commercially produced lining materials were used as counterfaces. Using a flat block pressed against a rotating disc, tests consisted of repetitive on-and-off drags at sliding speeds from 2 to 15 m/s, using nominal contact pressures of 1.0 or 2.0 MPa. Friction coefficients were affected by the choice of counterface (semi-metallic versus highly metallic lining composition) and by the friction-induced wear track temperature, which at times exceeded 800◦C[8]. The wear rates of the Ti metal matrix composites exceeded that of the reference cast iron, but were significantly better than that of two Ti alloys.

C.Blanco[7]et al.describes numerous studies relating structure and composition of (C/C) disc brakes to wear mechanisms and performance. He points out the disadvantages of cast iron brake drums relating to weight percentages, mechanical properties and tribological characteristics with respect to the advantages in c/c composites. He identifies the reason for changing the existing brake drum.

M. Senthilkumar[10]et al. have done the liquid metallurgy method for reinforcement of Rice husk ash of three different particle size ranges a 3,6,9,and 12% by weight with an aluminum alloy (AlSi10Mg) The dry sliding wear behavior of the composites in the cast conditions is examined using the pin-on-disc tribotesting machine for three different loads (20, 30, and 40 N) with three different sliding velocities (2, 3, and 4 m/s) by them. They concluded that The results reveal that the composite reinforced with the coarse rice husk ash particles exhibits superior wear resistance compared to the fine rice husk ash particles. The wear rate of the composite decreased with an increase in the weight percentage of rice husk ash particles for all size ranges. Finally, the wear mechanism was investigated with the worn surface using a scanning electron microscope.

M. Senthilkumar[11]et al. say that Artificial Neural Network (ANN) model was developed to predict the wear rate and coefficient of friction for the Rice Husk Ash (RHA) reinforced aluminum alloy composite. The composite was fabricated using the stir cast route and their tribological behaviour was tested using Pin on Disc wear tester. The experiments were conducted based on Orthogonal array (L27) generated through the Taguchi Technique and their results were used to train the ANN model. The input parameters assigned to develop an ANN model are applied load, sliding speed, RHA particle size and weight percentage of RHA reinforcement. A four layer perception network having 4-7-8-2 architecture was found to be the optimum network. Finally, confirmation test was done to verify the predictive model with the experimental results and also the wear surface morphology of the wear pin was analyzed using the scanning electron microscope.

S.D. Saravanan[12] et al. say that Rice Husk Ash (RHA) of three different particle size ranges (50–75 μm), (75–100μm) and (100–150μm) in 3, 6, 9 and 12 % by weight was reinforced with the aluminium alloy using stir cast route. The microstructure and mechanical properties of the fabricated composites were analyzed. The results reveal that the tensile strength, compressive strength and hardness of the aluminum alloy composites decrease with increase in particle size of RHA. But increase in the weight fractions of RHA particles decreases the ductility of the composite. Finally, the wear mechanism was investigated with the worn surface using a scanning electron microscope.

3. PREPARATION OF HYBRID COMPOSITE

The experimental work of this project is carried out, starting from material procurement through to various testing done on the specimens.

Figure 1. Stir Casting machine

The composite is made with Aluminum 2024, Silicon Carbide particles and Rice Husk Ash. The aluminium 2024 is chosen rather than any other alloy because it has high strength to weight ratio. Aluminium 2024 is Al-Cu alloy which has a further improvement in conductivity and good strength when compared to other aluminium alloys. SiC is added to improve the mechanical properties of the composite and RHA is added to reduce weight of the composite. The Aluminium 2024 matrix is reinforced with SiC and RHA through Stir casting. For obtaining a good composite mixture the operating parameters such as Stirring speed, Stirring temperature, Reinforcement preheat temperature, Stirring time, Preheated Temperature of Mould, Powder Feed Rate, Pouring temperature have to be controlled properly. Totally four different composites are made:

≡ Al 2024 + 5% SiC + 2% RHA
≡ Al 2024 + 10% SiC + 2% RHA
≡ Al 2024 + 15% SiC + 2% RHA
≡ Al 2024 + 20% SiC + 2% RHA.

4. MICROSTRUCTURE

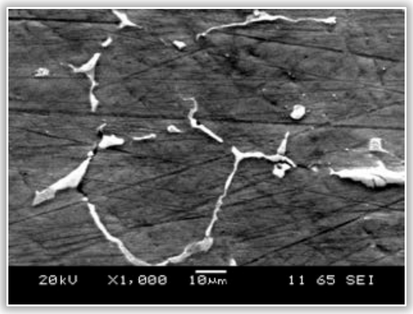

Figure 2. Microstructure of 1000X magnified image of Al 2024 + 20% SiC + 2% RHA

The low magnification images of the samples are shown in figures 2 to 6. The lighter region in the images corresponds to the SiC and darker region corresponds to the Aluminum base. At low magnification it can be seen that SiC form a network but on greater magnification like 1000x, they form a non-continuous network of which can be seen in Figure 2. In the composite with 20% SiC, the Silicon Carbide is more clustered compared to other compositions and they form a very good network, which is shown in Figure 3. In the composite with 10% SiC, SiC is more evenly spread compared to 20% SiC. The network is moderately formed when compared with 20% SiC as shown if Figure 4. The network formation is at the starting and the network formation is localized since the SiC content is very less as shown Figure 5. Pores are visible in the 15% SiC mixture, which may be due to improper mixing but the SiC is evenly spread as shown in Figure 6.

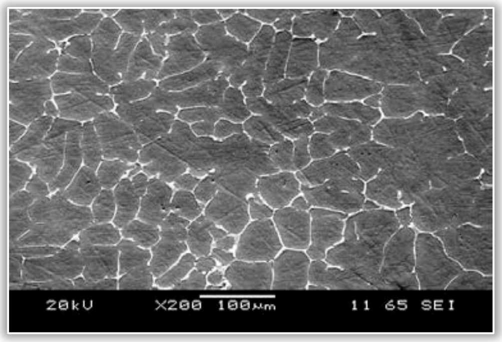

Figure 3. Microstructure of Al 2024 + 20% SiC + 2% RHA

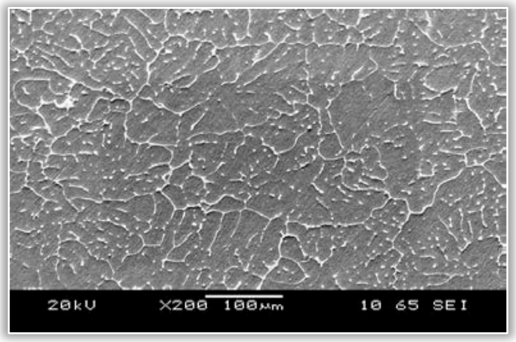

Figure 4. Microstructure of Al 2024 + 10% SiC + 2% RHA

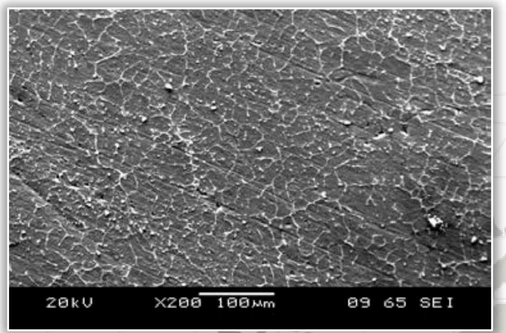

Figure 5. Microstructure of Al 2024 + 5% SiC + 2% RHA

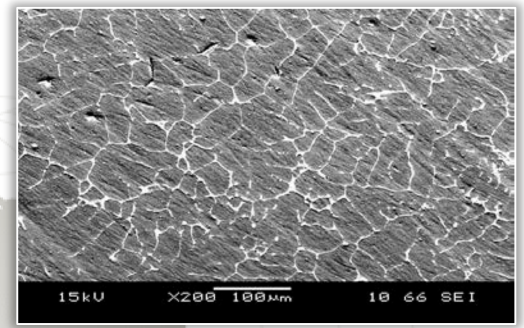

Figure 6. Microstructure of Al 2024 + 15% SiC + 2% RHA

5. MECHANICAL TESTING OF COMPOSITES

Tensile testing

The tensile testing is done to find out the various tensile properties such as yield point, ultimate tensile strength, failure point etc. The standard used for tensile testing of aluminium and its alloys is ASTM E8/E8M – 09. Since the test specimen is small, cutting by means of machine tools are tedious. Hence, wire EDM machine is used. The table 1 compares the tensile properties of different composites with three specimens each.

Table 1. Tensile Properties of Aluminium composites

Specimen	UTS(MPa)	% elongation
Al 2024 + 5% SiC + 2% RHA	291.32	5.27
Al 2024 + 10% SiC + 2% RHA	216.33	3.68
Al 2024 + 15% SiC + 2% RHA	198.64	1.80
Al 2024 + 20% SiC + 2% RHA	71.96	3.40

Figure 7. Tensile Specimens using EDM

Compression testing

Compression testing is used to find the compressive strength of the material. For our composite it is necessary because when the brake disc is pressed against the drum while braking, compressive force acts on the inner walls of the drum. It should have a property in such a way that it should withstand the compressive force. The standard followed for test specimen is ASTM E9-09. The specimen is a cylinder with 30mm height and 20 mm diameter.

The universal testing machine is used to find the compressive properties of various composites with three samples in each composite. The table 2 compares the compressive properties of different composites with three specimens each.

Figure 8.Specimen before Compressive Failure

Table 2. Compressive Properties of Aluminium composites

Specimen	CompressiveStrength (Mpa)
Al 2024 + 5% SiC + 2% RHA	421
Al 2024 + 10% SiC + 2% RHA	413
Al 2024 + 15% SiC + 2% RHA	436
Al 2024 + 20% SiC + 2% RHA	345

Impact Testing

The impact testing is used to find the toughness of the material under an external load. It is necessary to do impact testing because the brakes can be applied suddenly, when the driver wants to stop contrary to gradual application of brake. In that case impact strength places an important role for the brake drum. ASTM E23 is used. Charpy impact testing machine is used.

In this, Type A specimen size is used for the testing. The specimen is made with the help of wire EDM machine. The impact test is carried out using Charpy impact machine.

Figure 9. Specimen for Impact Test

Table 3. Impact Energy Absorbed by the specimen

Specimen	Impact Energy(J)
Al 2024 + 5% SiC + 2% RHA	50
Al 2024 + 10% SiC + 2% RHA	42
Al 2024 + 15% SiC + 2% RHA	36
Al 2024 + 20% SiC + 2% RHA	32

Hardness Testing

The hardness testing is used to find resistance to external indentation or scratch or wear of the material under action of external factor. It is essential to do hardness testing because when brakes are applied the brake disc rubs against the drum. The drum should be hard enough to provide resistance to wear. In that case, hardness plays an important role for the brake drum. The specimen used for hardness test is a Rectangular block as shown in Fig 10. The hardness is calculated with the help of Rockwell hardness tester machine.

The table 4 differentiates the values of hardness tested in Rockwell hardness tester by the different composites.

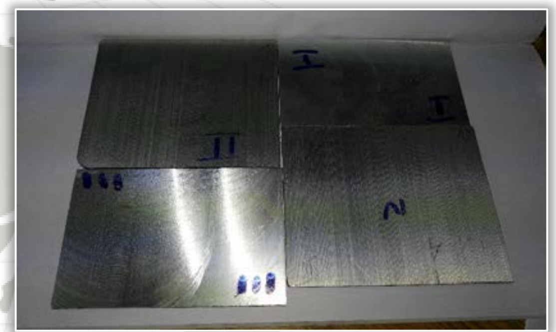

Figure 10. Specimen for Hardness Test

Table 4. Hardness Value

Specimen	Hardness (HRB)
Al 2024 + 5% SiC + 2% RHA	28
Al 2024 + 10% SiC + 2% RHA	31
Al 2024 + 15% SiC + 2% RHA	35
Al 2024 + 20% SiC + 2% RHA	40

6. TRIBOLOGICAL TESTING

In tribological testing, both wear rate and coefficient of friction is found out. Even though high hardness is required for the brake drum, it will wear out over time. So wear rate should be calculated. The coefficient of friction contributes to the wear rate. If the coefficient of friction is very low, there may not be any braking action and if it is very high then there may be material loss due to wear. Hence it should be optimum. The pin on disc experimental setup is used to find the parameters.

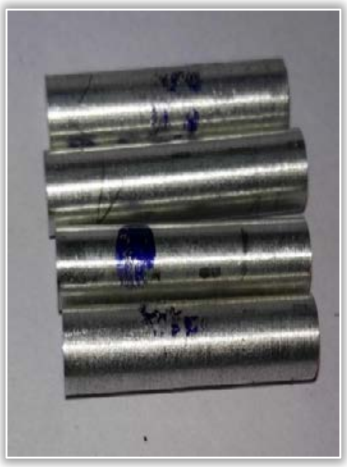

Figure 11. Composite Pins

Since asbestos is the commonly used friction material in the brake disc, the disc is made out of asbestos sheet and is fastened to the apparatus, while cylindrical pins are made from the different composite materials.

For the experiment, the input parameters are time to which the disc should rotate and the speed at which it is to rotate. To find the data, sliding speed is taken as 25 kmph and the distance is taken as 3000 m. Effective diameter is taken as 80 mm[9].

$$T = \frac{S}{U} \quad (1)$$

where T = time taken (S), S = sliding distance (m), U = velocity (m/s)

$$T = 428 \text{ s}$$

$$N = 60000 * S/(\pi * D) \quad (2)$$

$$N = 1671 \text{ rpm}$$

Table 5. Wear Rate and Friction Coefficient

Specimen	Wear Rate (μm)	Coefficient of Friction
Al 2024 + 5% SiC + 2% RHA	550.22	0.54
Al 2024 + 10% SiC + 2% RHA	538.59	0.49
Al 2024 + 15% SiC + 2% RHA	520.17	0.48
Al 2024 + 20% SiC + 2% RHA	523.63	0.50

7. THERMAL CONDUCTIVITY TEST AND COEFFICIENT OF HEAT TRANSFER

In thermal testing, both thermal conductivity and heat transfer rate is found out. The material should have high thermal conductivity because to transfer heat as soon as possible once it is generated due to braking. The transient plane source method is used to calculate the thermal conductivity. The specimens are made using the milling and grinding machines which has dimensions of 90x90x10 mm.

The temperature, voltage and current is taken as output variables from the experiment and the thermal conductivity is calculated using the equation (3).

$$K = \frac{P}{5.56 * r * T} * \beta \quad (3)$$

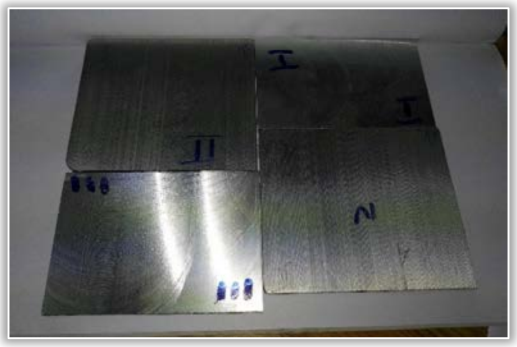

Figure 12. Specimens

where, K = thermal conductivity (W/m/K),P= power (W),r = radius (m), Radius = 50mm

The voltage reading is 6.6 V and current reading is 2.06 A.

Table 6. Thermal Conductivity

Specimen	Temperature(^{0}C)	Conductivity(W/M/K)
Al 2024 + 5% SiC + 2% RHA	67	88.4
Al 2024 + 10% SiC + 2% RHA	70	86.9
Al 2024 + 15% SiC + 2% RHA	75	85.7
Al 2024 + 20% SiC + 2% RHA	82	84.02

Table 7. Heat Transfer Coefficient values

Specimen	Conductivity (W/m/K)	Heat Transfer Coefficient (W/m^2/K)
Al 2024 + 5% SiC + 2% RHA	88.4	49.17
Al 2024 + 10% SiC + 2% RHA	86.9	49.15
Al 2024 + 15% SiC + 2% RHA	85.7	49.13
Al 2024 + 20% SiC + 2% RHA	84.02	49.12

The convective heat transfer should also be high because the heat generated should be transferred to the atmosphere. It can calculated using the equation (4).

$$\frac{1}{U} = \frac{t}{k} + \frac{2}{h} \quad (4)$$

where U - heat transfer coefficient, t – thickness, k – thermal conductivity, h- fluid heat transfer coefficient, thickness = 0.03 m, heat transfer coefficient of air is 100 W/m^{2}K.

8. RESULTS AND DISCUSSIONS

Selecting the suitable material

The comparisons are made with the respective properties of the different composites with the respective base metal and alloy in the Table 8.

Table 8. Comparison between Materials

Specimen	Tensile strength (MPa)	Compressive strength (MPa)	Impact strength (J)	Hardness (HRB)	Wear rate (μm)	Coeff. of friction	Thermal conductivity (W/m/K)	Heat transfer coeff. W/m2K
Aluminium	90	250	10	15	-	-	114	49.35
Aluminium 2024	185	400	20	7.17	-	-	121	49.39
Al 2024 + 5% SiC + 2% RHA	291.32	421	50	28	550.22	0.54	88.4	49.17
Al 2024 +10% SiC + 2% RHA	216.33	413	42	31	538.59	0.49	86.9	49.15
Al 2024 + 15% SiC + 2% RHA	198.64	436	36	35	520.17	0.48	85.7	49.13
Al 2024 + 20% SiC + 2% RHA	71.92	345	32	40	523.63	0.50	84.02	49.12

The figure from 13 to 17compares the values of different materials

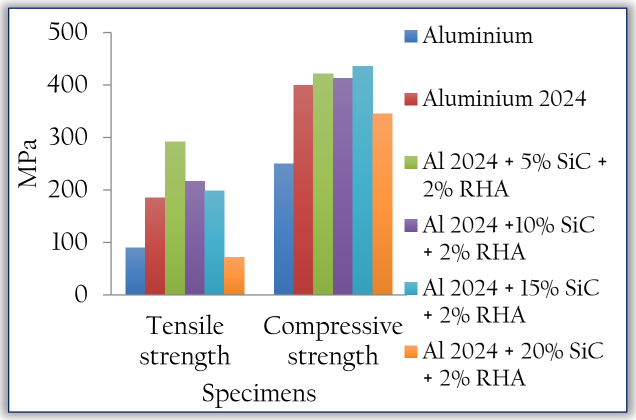

Figure 13. Variation of tensile strength and compressive strength

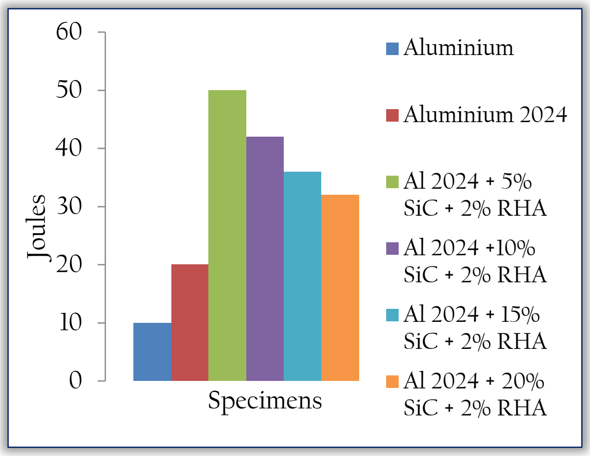

Figure 14. Variation of impact energy absorbed

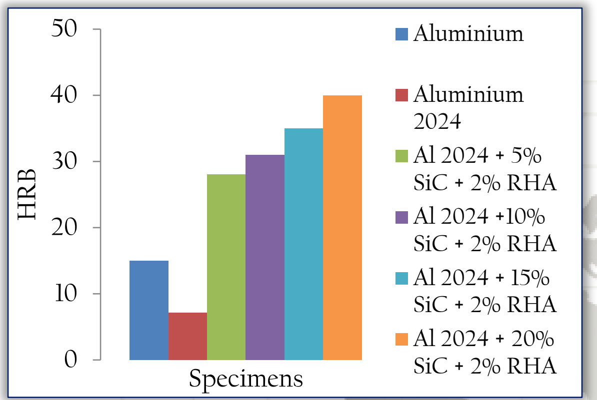

Figure 15. Variation of hardness

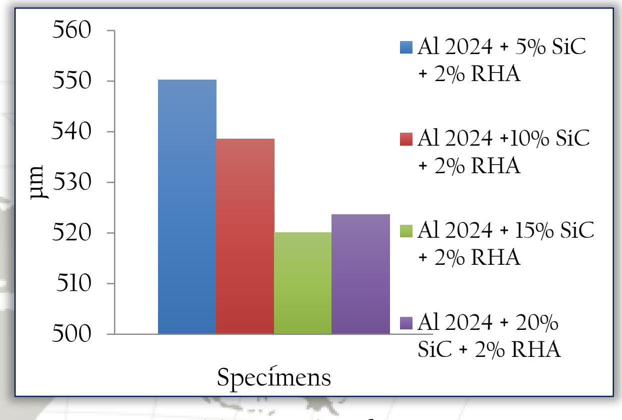

Figure 16. Variation of wear rate

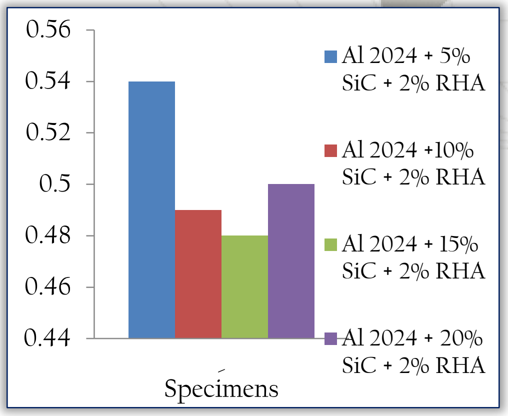

Figure 17. Variation of coefficient of friction

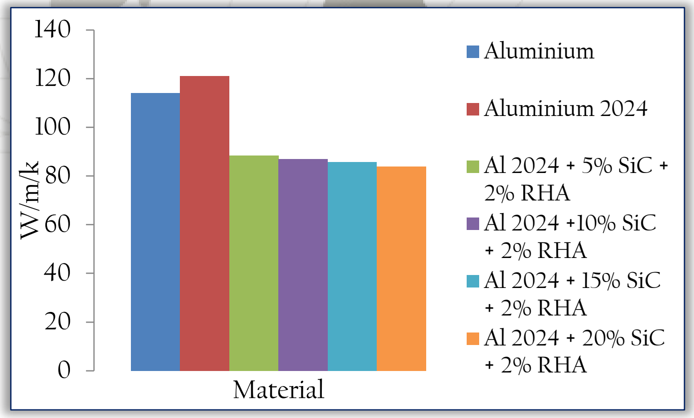

Figure 18. Variation of thermal Conductivity

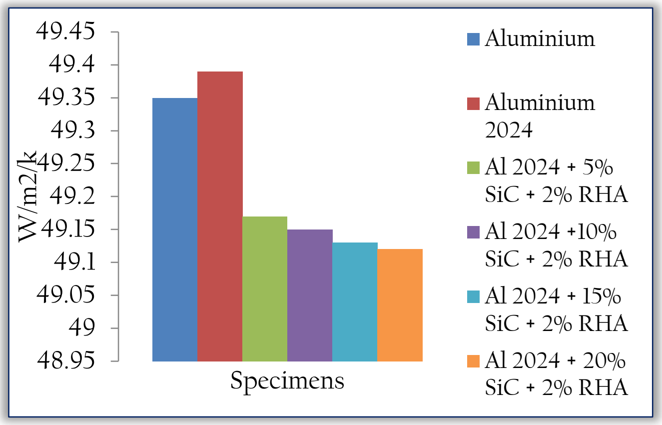

Figure 19. Variation of heat transfer coefficient

Al 2024 + 20% SiC + 2% RHA is eliminated because of its very low tensile properties and Al 2024 + 5% SiC + 2% RHA is eliminated because of its very low hardness properties when compared to cast iron[7]

Both Al 2024 + 15% SiC + 2% RHA and Al 2024 + 10% SiC + 2% RHA have intermediate properties among the composites, their values are comparably good against cast iron and Al 2024 + 15% SiC + 2% RHA is chosen over the other because it has high hardness which is a very major influencing parameter[7].

Comparison between Cast Iron and selected material

The following table is the comparison between cast iron and composite. The following chart provides comparison between the selected material and cast iron

Table 9. Comparison between Cast Iron and Composite

Specimen	Tensile strength (MPa)	Compressive strength (MPa)	Impact strength (Joules)	Hardness (HRB)	Wear rate (µm)	Coeff. of friction	Thermal conductivity (W/m/K)	Heat transfer coeff. W/m²K
Cast Iron	150	400	20	75	380.46	0.56	35	47.94
Al 2024 + 15% SiC + 2% RHA	198.64	436	36	35	520.27	0.48	85.7	49.13

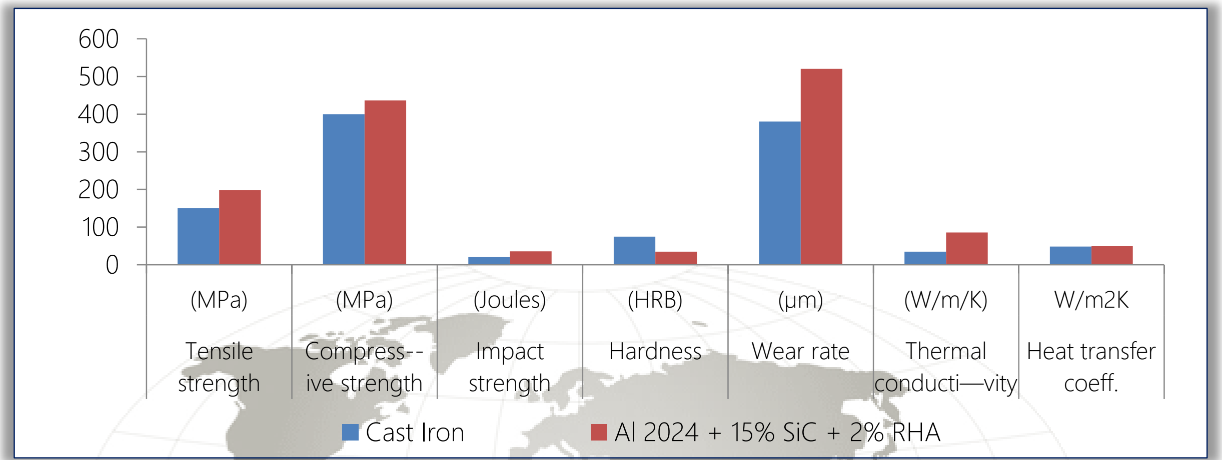

Figure 20. Comparison between Cast Iron and Composite

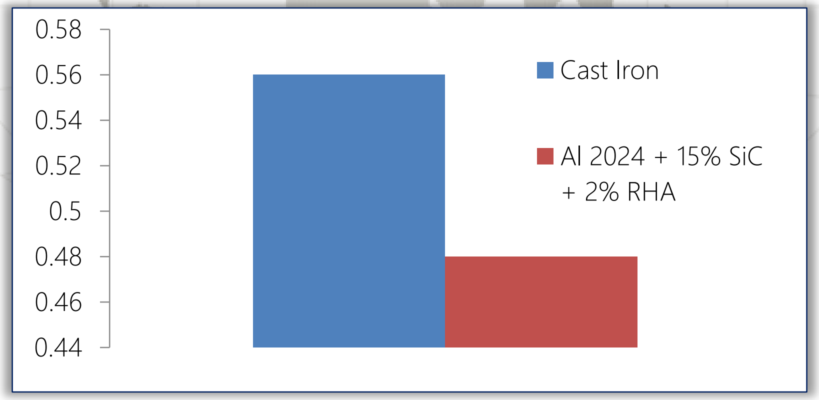

Figure 21. Comparison of Coefficient of friction between Cast Iron and Composition

9.CONCLUSIONS

The following conclusions are made:

- Al 2024 + 5% SiC + 2% RHA has high tensile, compressive and impact strength. It has least hardness value and high friction and wear rate. It has high thermal properties when compared to other three.
- Al 2024 + 10% SiC + 2% RHA has intermediate properties compared to other composites
- Al 2024 + 15% SiC + 2% RHA also has intermediate properties compared to other composites
- Al 2024 + 20% SiC + 2% RHA has low tensile, compressive and impact strength. It has highest hardness value and low friction and wear rate. It has low thermal properties when compared to other three.
- Al 2024 + 20% SiC + 2% is eliminated because of its very low tensile properties when compared to cast iron.
- Al 2024 + 5% SiC + 2% is eliminated because of its very low hardness properties when compared to cast iron.

Both Al 2024 + 5% SiC + 2% and Al 2024 + 10% SiC + 2% have intermediate properties among the composites, their values are comparably good against cast iron and Al 2024 + 15% SiC + 2% is chosen over the other because it has high hardness which is a very major influencing parameter.

The composite (Al 2024 + 15% SiC + 2% RHA) have better strength (tensile, compressive and impact) compared to cast iron. Since it is less dense than cast iron, it will reduce the weight of brake drum. Reduction of the weight has many advantages like improving mileage. It has thermal conductivity and heat transfer coefficient better than cast iron leading to the conclusion that heat is dissipated sooner which in turn reduces the thermal stresses. One of the disadvantages of the composite is its tribological properties, which is also manageable. The future scope of this project is fabrication of brake drum using both composite and cast iron; and comparing their functionality in rotor chase machine.

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