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Design of Thermal Analysis Test Bench for Aluminum Metal Matrix Composite Disc Brake Rotor

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***Abstract*—An automotive disc brake is a device for slowing or stopping the motion of a vehicle. A disc brake consists of brake caliper and rotor. The widely used brake rotor material is cast iron (C.I.) for four wheeler application and stainless steel (S.S.) for two-wheeler application. Existing material posses problem of brake fading after repeated application of brakes. Which may result in fatal situations. Aluminum Copper Metal Matrix Composite (Al-Cu MMC) had shown better performance over SS rotor for two wheeler application when analyzed on ANSYS software. Performance of Al-Cu MMC depends on homogeneity of silicon carbide (SiC) particles in Al-Cu alloy, it depends on manufacturing process. Stir casting gives homogeneous mixture, and it is comparatively cheap process to manufacture Al-Cu MMC.**

Manufactured Al-Cu MMC rotor has to be analyzed experimentally to understand thermal behaviour of the material. Test setup was designed and fabricated to simulate driving condition. It was found that 0.5 hp motor, belt and pulley provides desired simulation conditions.

***Keywords*—Stir casting; SiC particle; Al-Cu MMC; Motor selection; Belt and pulley selection.**

I. INTRODUCTION

It is observed by Rupa Dasgupta that Al-Cu MMC performs in all types of wear applications[1]. Al-Cu MMC exhibits physical properties like good compressive strength, good specific heat and less density etc. which are desirable for disc brake rotor application. Current work emphasizes on finding solution for two wheeler braking problem. From reviewed paper it is observed that in software analysis Al-Cu MMC rotors perform better than existing material. Next step to it is manufacturing of rotor and designing of test setup. This paper focuses on best suited manufacturing process for Al-Cu MMC and designing of test setup.

Casting process is required to manufacture disc brake rotor. Metal casting process cannot manufacture homogeneous aluminum alloy metal matrix composites. Sir casting process is able to manufacture homogeneous aluminum alloy metal matrix composites, and it is cheaper process when compared with other manufacturing processes reviewed by C. Saravanan et.al.[2]. Ramesh B. T. et. al. presented paper on fabrication of stir casting setup and feeding parameters to manufacture aluminum alloy metal matrix composites[3]. Material homogeneity, weight percentage and particle size of reinforcement affects the properties and performance of the material. Material properties like good compressive strength, low wear rate, high specific heat and low density is desirable for brake rotor application. Al-Cu MMC posses all the mentioned properties. Which makes it a potential material to replace existing SS material.

Reviewed papers made it clear that, disc brake rotor made from Al-Cu MMC had shown good performance over existing material when analyzed on software. Validation of results require experimental analysis. This paper focuses on designing the test setup for two wheeler rear disc brake, which will simulate driving conditions. Readings for test parameters would be taken manually to keep the cost of the setup as less as possible.

II. MANUFACTURING OF AL-CU MMC ROTOR

In this paper, Al-Cu MMC material is finalized for manufacturing of the disc brake rotor for two wheeler application. The constituent material percentage decides physical properties of the material. Al-Cu MMC supplier named "Goodfellow" stated the physical properties on their website with weight percentage of constituent materials. It is considered for manufacturing, as the physical properties given by the supplier and desired physical properties are almost same. Studies carried out by Rupa Dasgupta suggested that constituent material weight percentage given by supplier shows the better performance in wear resistance applications[1].

Manufacturing of Al-Cu MMC with stir casting gives better homogeneity, quality and at comparatively low cost[2]. Ramesh B.T. et. al. presented the paper to fabricate the stir casting for Metal Matrix Composite[3]. Setup for stir casting is shown in Fig. 1.

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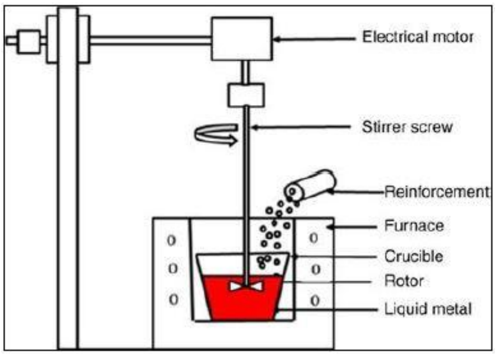

Fig. 1 Stir Casting schematic diagram

Constituent material in Al-Cu MMC are aluminium, copper, manganese, magnesium and silicon carbide. Weight percentage of constituent materials is shown in Table 1. Particle size of silicon carbide is finalized from study conducted by Omyma El-Kady, A. Fathy. Authors found that as weight percentage and particle size of SiC increase, the compressive strength of the metal matrix composite increases. Weight percentage of the SiC particle is taken around 17.8% therefore particle size is taken as 70 nanometre (nm)[4]. Graph of weight percentage of SiC against compressive strength for different particle size is shown in Fig. 2.

Disc brake rotor finished dimensions are O.D. of 230mm, I.D. of 146mm and thickness of 4mm require casting allowances to get finished dimensions after machining process. The pattern is made up of wooden material, dimension for it is finalized by thumb rules of the pattern making. Dimensions of the pattern is O.D. of 235mm, I.D. of 141mm and thickness of 12mm. Wooden pattern prepared for casting is shown in the Fig. 3.

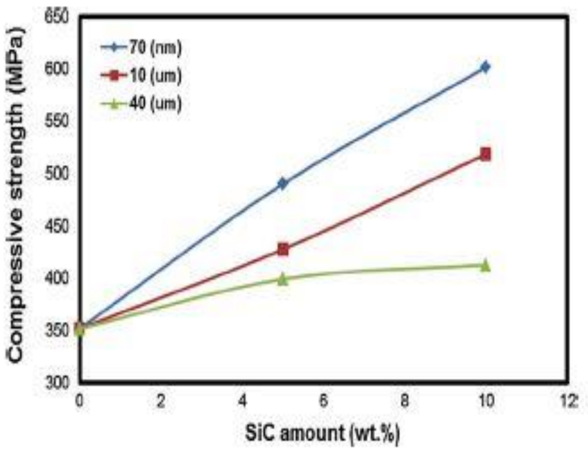

Fig. 2 Effect of particle size and weight percentage on compressive strength.

Moulds are prepared by using wooden pattern, which is made by considering shrinkage allowance, warpage allowance, draft allowance and machining allowance. Most of the constituent material is aluminium, therefore above mentioned allowances are kept as per thumb rules of the aluminium casting industry. Wooden pattern is used, so that casting quality would be better than polystyrene (thermocol) pattern. It increases machinability of the casting product.

FIg. 3 Wooden pattern

The weight of material required to manufacture single disc is around 1 kg. Casting process may incur problems in the final product like material warpage, porosity etc. It should not create any problem while machining phase, therefore 4 discs are manufactured as contingency if in case any problem occurs in few of the discs. Total weight of Al-Cu MMC material comes around 4 kg. Weight of each constituent material is given in table 1 below. Tolerance limit for weight percentage is around 1%.

Silicon carbide fine particle size decided is 70 nm for achieving better compressive strength than smaller size particles. It is important to look out which particle size is available in the market. It is better to go for higher particle size than 70 nm, as compressive strength increases with increase in particle size. The available size was 50 nm and 90 nm, so 90 nm particle size is selected for manufacturing. Grade of the silicon carbide fine powder specified by manufacturer is G320.

Table 1 Weight percentage of constituent material of Al-Cu MMC.

Sr. No.	*Material*	*Weight Percentage*	*Weight (kg)*
1.	Aluminum (Al)	77.9	3.116
2.	Copper (Cu)	3.3	0.132
3.	Magnesium (Mg)	1.2	0.048
4.	Manganese (Mn)	0.4	0.016
5.	Silicon Carbide (SiC)	17.8	0.712

Fig. 4 Casting of Al-Cu MMC rotor

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Melting point of Al is 650ºC, Cu has 1085ºC, Mg has 650ºC, Mn has 2146ºC and SiC has melting point of 2730ºC. SiC and Mn is used in powder form, SiC is used as a reinforcement, so it is not required to melt it. To get better wettability it is required to maintain the temperature at around 1100ºC. When all other constituent materials other than Mn and SiC gets completely melted then Mn and SiC powder is added to crucible. Stirrer is kept at 300 rpm[3] for 15 minutes and later the melted material is poured into the moulds. The casting product of the rotor is shown in Fig. 4.

Disc rotor after taking out the casting has runner and riser extensions as shown in above Fig. 4. It is then removed by grinding process. It is then taken for the finishing that means machining process. Minimum thickness that can be achieved with casting process of aluminium material is 12mm. So it has to be machined to 4mm thickness by milling or facing process. Holes are drilled to mount the rotor on wheel. Machined disc brake rotor of Al-Cu MMC is shown in Fig. 5.

Fig. 5 Al-Cu MMC rotor

Disc brake rotor is ready for experimentation. Test setup is designed to analyze rear disc brake rotor of the two wheeler.

III. DESIGNING OF TEST SETUP

It is required to design a stationery setup. So rear wheel of the bike is selected as a driven member in the setup, on which disc rotor is mounted. Brake assembly viz. brake lever, master cylinder, hydraulic hoses, brake caliper and brake pads of 200cc bike segment is selected as a force applying member. Electric motor is used as a driving member. V-belt is used as a means of transmitting the power to driven member. Fabricated stand of M.S. material is used to house all members of the test setup.

Design of test setup include induction motor selection, pulley selection, power transmission selection and stand to house all the components. Stand to house all the components is decided to be made from 40×40×1.5mm tube and 40×5mm angle. Stand base dimensions are 880×350×90mm. Wheel diameter is 600mm, so height of the wheel shaft centre is kept at 340mm from base of the square pipe stand. CAD model of the stand is shown in Fig. 6.

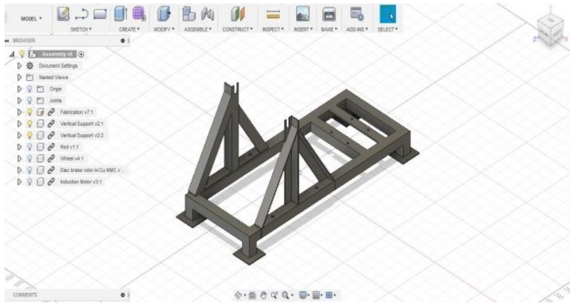

Fig. 6 CAD model of the wheel stand

Motor selection has a aspect viz. frictional torque, which helps to select appropriate motor for desired application. In this work motor has to overcome all frictional torque of the driven members. Maximum weight which motor has to drive is 10kg.

Therefore,

$$\text{Frictional torque (F.T.)} = \mu \times m \times g \times r \qquad (1)$$

Where,

μ = Coefficient of friction = 0.2

m = Maximum mass which has to be driven = 10kg

g = Acceleration due to gravity = 9.81m/s2

r = Radius of hub = 80mm = 0.08m

$$\text{F.T.} = 0.2 \times 10 \times 9.81 \times 0.08 = 1.5696 \text{ N.m}$$

Frictional power lost gives the motor ratings required.

$$\text{Frictional power lost (PL)} = \text{F.T.} \times \omega \qquad (2)$$

Where,

F.T. = Frictional torque

ω = Angular velocity = 144.96 rad/sec

= 60km/hr

$$\text{PL} = 1.5696 \times 144.96 = 227.5292\text{W} = 0.227\text{kW}$$

Motor required to have minimum of 0.227kW of power. Standard motor which have rating around required power is of 0.5hp which means 0.37kW and have 1440rpm. So both pulleys should be designed to have wheel speed of around 60km/hr.

Equation for determination of pulley diameter required to get desired speed is given below.

$$D/d = n/N \qquad (3)$$

Where,

D = Diameter of lager pulley

d = Diameter of smaller pulley

N = Speed in rpm of the lager pulley

n = Speed in rpm of the smaller pulley = 1440 rpm

Speed required at wheel is 60km/hr = 16.67 m/s

$$V = r \times \omega$$

Where,

V = Speed in m/s = 16.67 m/s

r = Radius of the wheel = 310mm = 0.31

ω = Angular speed in rad/sec.

$$16.67 = 0.31 \times \omega$$

$$\omega = 53.7742 \text{ rad/sec}$$

We know that,

$$N \text{ rpm} = \omega \text{ rad/sec}$$

$$1\,rpm = \frac{2\pi}{60}\ rad/sec$$

$$\therefore N = 513.5 \text{ rpm}$$

For ease in selection of pulley, larger pulley is considered having diameter of 150mm.

So smaller pulley will have diameter from Equation 3, given below.

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d = 53.54mm.

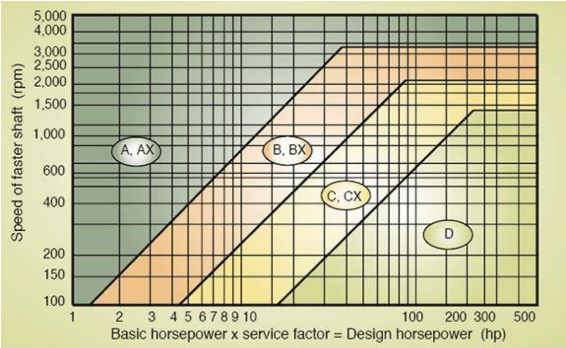

Fig. 7 Graph for selection of V-Belt section

V-belt is selected for our desired application, because of advantages like

1) V grooves provides good grip over same size of flat belt, because of larger contact surface.
2) Good grip enables it to have more transmission capacity.
3) Slip between pulley and belt is negligible.
4) Noise is less in V-belts, also it damps the vibration.
5) V-belt enables designer to achieve compactness.

V-belt with section A is appropriate as per chart for power transmission upto 1-3 hp and speed of 1440 rpm, graph for it is shown in Fig. 7[5].

Power transmission required is of 0.5 hp at 1440 rpm. Pulley for desired application is selected from standard dimensions. Larger pulley is selected of 8 inches diameter and smaller pulley of 6 inches diameter, to get higher speed at wheel. Belt length required is decided on centre distance and perimeter of pulley. As centre distance between wheel shaft and motor axis centre is 435mm, pulley diameter of 6 inches and 8 inches. Half perimeter of both pulley is added to twice the centre distance, therefore V-belt with specification A-56 is selected. A-56 specifies V-belt section is of type 'A' and length of the belt is 56 inch.

CAD model of the setup is prepared on Autodesk Fusion360. Wheel assembly and motor is mounted on the stand, CAD model of the setup assembly is shown in Fig. 8.

In fabricated test setup, a small fabricated panel is attached to one corner, which is used to house connection for electrical motor. Motor used is 3 phase induction motor, so fabricated panel houses the 4 pole MCB of 16 amp.(individual MCBs are used as power rating is low). Application of brake is done by brake lever, it is mounted on the side where electrical panel is mounted.

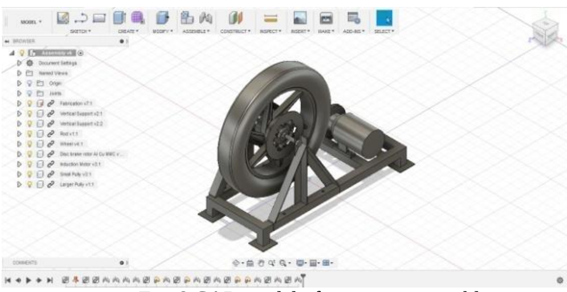

Fig. 8 CAD model of test setup assembly

Test setup is fabricated from material described above. It took 3 weeks to purchase, fabricate and commission the setup. Manufactured test setup is shown in Fig. 9.

Fig. 9 Test setup assembly

IV. CONCLUSION

Disc brake is a active safety system. Automotive industry requires to produces fast and faster vehicles. It is required to improve braking performance of the vehicles to ensure safety of the driver and passengers. Existing material of brake rotor leads to problem of brake fading after repeated brake applications. Reviewed research papers lead to conclusion that Al-Cu MMC helped to achieve better braking performance when analyzed on software.

This paper emphasizes on work related to manufacturing of Al-Cu MMC disc brake rotor and designing of test setup. It was observed that stir casting process helped to achieve homogeneous mixture with even SiC particle distribution. It also attributed to increase machinability of the material with minimum cost of manufacturing.

Fabricated test setup manages to simulate desired driving conditions, as considered in designing phase.

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