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Effect of reinforcement and heat treatment on the friction performance of Al Si alloy and brake pad pair

Amit Telang*[1], Ameenur Rehman[1], Gajendra Dixit[1] and Satyabrata Das[2]

[1] Maulana Azad National Institute of Technology, Bhopal, M.P., India
[2] Advanced Materials Processes Research Institute, Bhopal, M.P., India

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ABSTRACT

In the present work the effect of SiC particle reinforcement and further its heat treatment on Al alloy (ADC12) is studied in the application of automobile brake discs. ADC 12 is synthesized by stir casting process and its composite with silicon carbide (SiC) in weight percentage of 10% as the hard particle and its heat treated variety. The candidate materials have been compared with tests on a rig developed for testing of brake discs under variety of operating conditions. The brake disc test set-up is a facility developed for simulating on road brake disc operating conditions. The brake disc test procedure for performance evaluation has been developed and formulated based on the Bureau of Indian standards (IS-14664:1999) for the acceptability of results. For evaluation the performance has been compared with the conventional steel brake disc with an emphasis on brake torque. In general it is observed that the average brake torque for ADC12 alloy at all velocities and brake force is lower than steel. The brake torque of the composites is higher than steel, the addition of SiC particles increased material hardness and its brake torque. Heat treatment of the composite material further increased the brake torque.

Key words: Aluminum silicon alloy, composite, brake force, brake torque.

INTRODUCTION

The need of reducing weight in automobiles has led to both considerable changes in design and search for lightweight materials. Particulate reinforced aluminum metal matrix composites (AMCs) are promising candidate for automobile applications since they offer high specific stiffness and strength, good wear resistance and thermal properties.[1]. The advantages of the composites can be categorized as those related to materials and those concerned with the application parameters/conditions/modes, methodology and application conditions. They include applied load, sliding distance, speed, environment, wear mode, test configuration etc. AMCs find potential applications in automobile. The first category of the factors include microstructural features e.g. shape, size, content and morphology of the microconstituents. The second category of parameters pertain to the testing components like piston, cylinder liner, brake drums ,crankshafts, etc.[2].A series of brake stops at a variety of operating condition were performed and the observed values of coefficient of friction were averaged to provide a single value which is referred for analysis.[3]. The automotive braking, for both large or small machines is the most complex and sensitive area of study. Brake performance is influenced by brake disc material-brake pad pair, rubbing speed, applied force. Frictional behavior of the material pairs is very complex due to additional factors like, temperature ,prior usage history [4] and the asperities, wear debris, surface contact percentage of drum-liner rubbing surface.[5]. The friction coefficient stability under different operating conditions have been targeted and the performance with Al-SiC composite brakes have been reported in terms of stability of friction coefficient, surface temperature and wear resistance [6].The effect of normal load and system stiffness on the interaction between friction, wear and vibration using two dissimilar surfaces, steel rubbing on cast iron have been studied from materials point of view[5].

MATERIALS AND METHODS

Composite Preparation

In the present investigation , three identical size brake discs were manufactured of; Al-Si alloy, Al-Si composite with 10% SiC as particulates and Al-Si Alloy 10% SiC composite (heat treated) as per the size of conventional steel brake disc of *Bajaj Pulsar* motorcycle.. Aluminum-Silicon (ADC-12) alloy was used as the matrix alloy. The chemical composition of the alloy in percentages was: 10.29 Si, 1.98 Cu,0.8 Ni,0.75Fe,0.47 Mg, 0.12 Mn and rest Al.. The ADC 12-10 wt % SiC composite was prepared by dispersing SiC particles (10 wt%) which were sieved using standard sieving practice with an aim to get particle in the size range of 40-80 μm. The alloy and the composite melt were then solidified in cast iron disc moulds. The heat treatment of the composites was done by solutionising at 495^0C for 6hr and quenched in water. The samples were tempered at 175^0C for 6 h followed by air cooling.

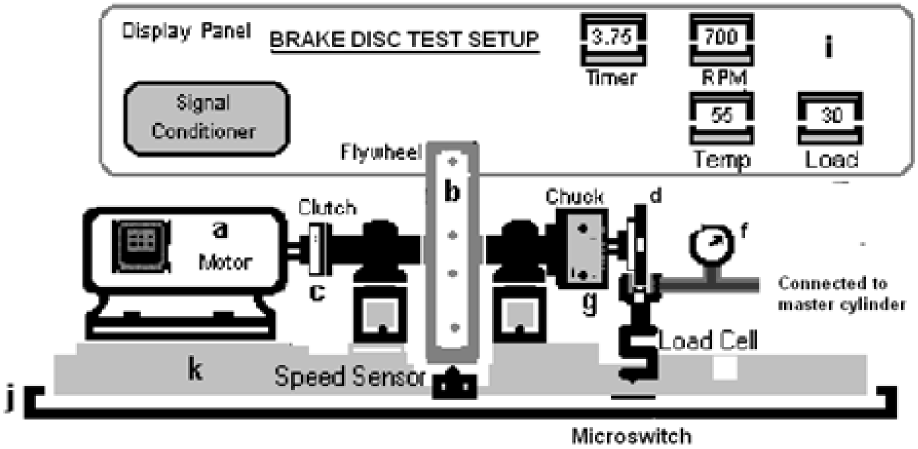
Test Set-up

The *Bajaj Pulsar* motorcycle had been selected as a sample vehicle for analysis of brake discs with alternative material. The performance of the above mentioned three materials have been evaluated with the steel disc against the commercial brake pads. These four pairs are tested on a test setup Power source used is A.C. motor from *Kirloskar* of 3.6 KW at 1440 rpm was selected with a variable speed drive for AC motor from L&T for speed variation close in range of the test vehicle. Electromagnetic clutch is fitted for transmission from the motor shaft to the flywheel. The clutch of magnetic capacity was matched with the motoring maximum torque and flywheel inertia capacity. The flywheel is designed so as to obtain a specified amount of speed regulation close in range of the test vehicle.

The primary sensing elements for picking up events from the machines were identified based on uncertainty analysis, and the requirements of the data needed for analysis of the performance. Then a logical sequencing of signal transfer was designed.

Fig.1 shows the schematic diagram of brake disc test set up. Fig.2 shows the schematic loading diagram. Fig.3 shows that brake force is applied to the brake caliper through the master cylinder to which pressure is applied by the means of hand lever of the motorcycle. This lever is pulled by wire which is connected to a loading pan on which weights are kept. Initially the pan is lifted and at predetermined time is allowed to fall with weights. Fig. 4 shows a complete picture of the set up along with computer interface with the machine on the left and a control panel on the right. The test setup, as detailed in figure 1 comprises of main frame j fabricated out of heavy mild steel channel and base plate *k* made of cast iron. Base plate is bolted on the channel base and the test facility is fitted with bolts on the base plate.

Fig.1 : Brake Disc Test Setup (schematic diagram)



The set up has the following units.

AC Motor	**: a**	Flywheel unit	**: b**
Electromagnetic Clutch	**: c**	Brake disc plate	: **d**
Pressure Gauge	: **f**	Chuck To hold Disc	**: g**
Display panel	**: i**	Main Frame (MS Channel)	**: j**
Base Plates bolted on **j**	**: k**	Control Panel	**:** not in figure

Fig. 2: Brake disc loading (schematic)

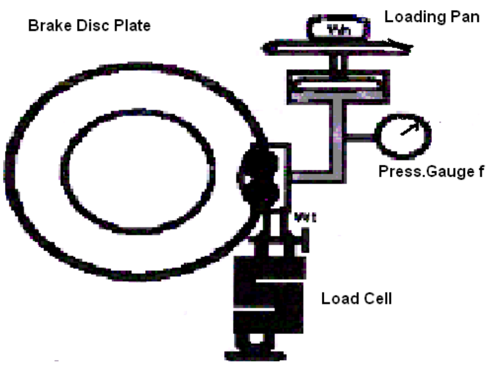


Fig.3: Brake force application by weights through hand lever

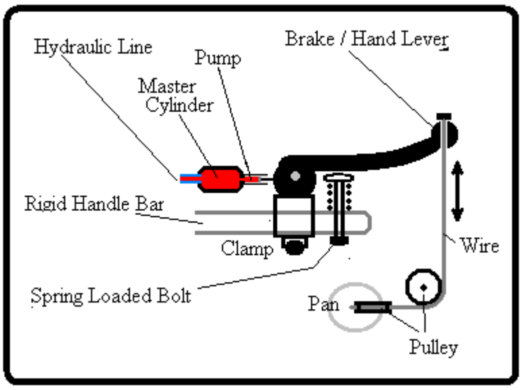
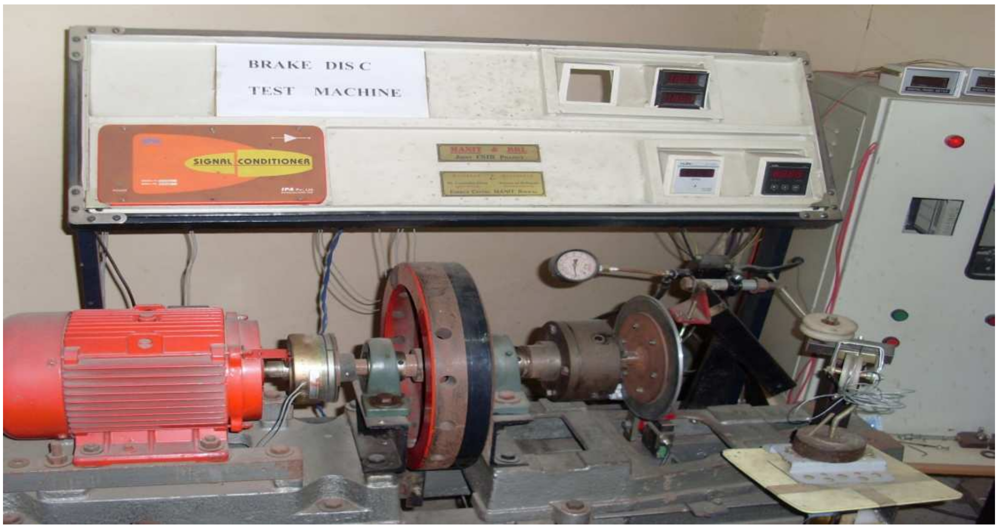


Fig. 4: Brake disc test set up (photo)



For selecting a suitable material for brake disc the simulation of brake disc operations is the best way to predict material suitability on the road. The test set-up has been designed for evaluating brake disc performance simulated operating conditions. Set up has been interfaced with computer with data acquisition facility to store data for subsequent systematic detailed analysis.

Experimental Parameters

The following performance tests were conducted:

Performance test sequence: Preburnish Test, Burnish Test & Final Testing

Evaluation of the performance was based on the following test parameters: Effect of brake force, velocity on coefficient of Friction.

The performance test was done with***:***

***** Test velocities : 40, 60, 80,100 km/hr.

* Actuating Brake Forces 246 N, 492 N, 738 N, 984N,1230N

* Brake disc test material: The following materials including Al. Alloy and SiC composites have been used to cast the sample brake drums for testing. They have been referred to as follows during the course of discussion:

S.No.	Test Samples	Referred as
1)	Steel (Pulsar Brake Disc)	Steel
2)	Aluminium silicon alloy	ADC 12
3)	ADC 12-10 wt% SiC composite	ADC 12-10 SiC
4)	ADC12-10 wt% SiC Composite – Heat Treated	ADC 12-10 SiC (HT)

RESULTS AND DISCUSSION

The results have been plotted in the form of graphs indicating the results of various parameters and their interdependence. The results are given under following heads-

Effect of brake force on brake torque

Figs.5 to 8 show the variation of brake torque with the applied brake force for the candidate materials for different test velocities which are 40,60,80 and 100 km/hr. It is visible from the graph that the brake torque for applied brake force and velocities is lowest for ADC-12 (lower than steel) and highest for ADC 12-10SiC HT. The brake torque values vary in a narrow scatter band. The average value for ADC 12 varies from 9.8 to 12.6 Nm, ADC 12-10 SiC from 18.4 to 24.6 Nm and ADC 12 -10 SiC HT from 23.4 to 35 Nm (against brake pad material) if the velocity is increased from 40 km/hr to 100 km/hr. The brake torque for the conventional steel against brake pads varies from 15.6 to 22 Nm for the same variation of velocity.

Brake torque being the product of rotor radius and frictional force will show the same behaviour as frictional force. It is seen that for a particular velocity increase in applied force causes increase in the values of frictional force and this is in agreement with the work reported in the literature. The average brake torque reported for ADC 12 Al alloy disc brake at all brake force values is lower than steel. Adding SiC particles to form Al MMC increases the material hardness which increases the brake torque [7]. There is improvement in wear resistance of 10% Al alloy composite than Al alloy because of SiC addition [8]. In all observations of wear behavior of Al MMCs sliding against automobile friction material frictional force of the Al matrix composite has been found to be greater than the steel and at higher loads the frictional force is higher because of more contact area at the frictional material surface [9].

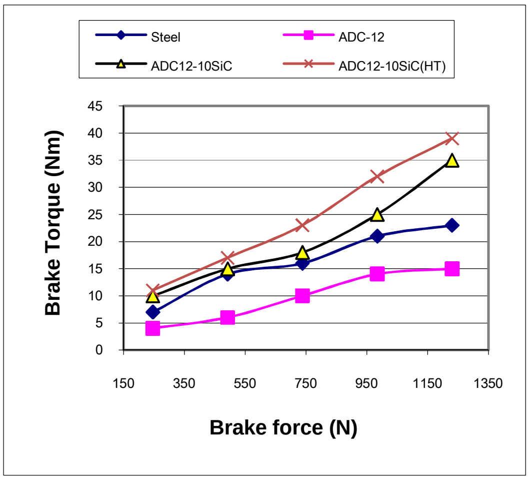


Fig. 5:Effect of brake force on brake torque at 40 km/hr

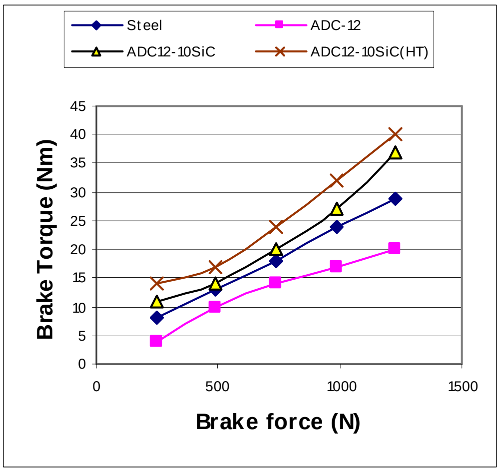


Fig. 6: Effect of brake force on brake torque at 60 km/hr

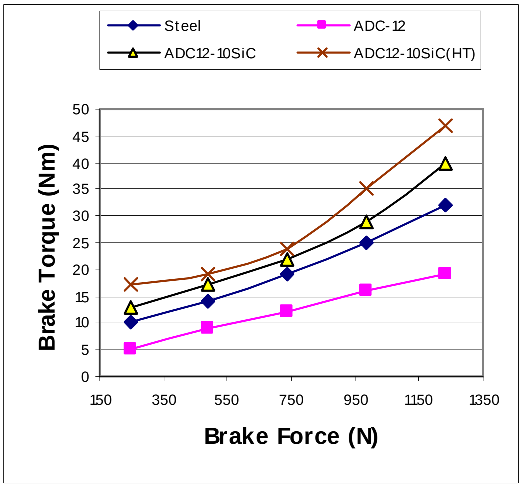


Fig. 7:Effect of brake force on brake torque at 80 km/hr

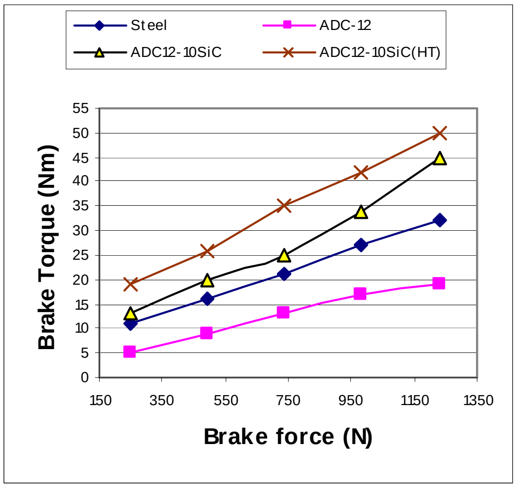


Fig.8:Effect of brake force on brake torque at 100 km/hr

Effect of velocity on brake torque

Figs.9 to13 show the variation of brake torque with velocity for the candidate materials for different brake forces ie 246 N, 492 N, 738 N, 984N and1230N. It is seen from the graphs that the brake torque values for tested velocities and brake forces are lowest for ADC-12, lower than steel and highest for ADC 12-10SiC HT. The average value for ADC 12 varies from 12.5 Nm to 19.4 Nm, ADC 12-10 SiC from 17.5 Nm to 23 Nm and ADC 12 -10 SiC HT from 19.5 Nm to 26.7 Nm if the brake force is increased from 246 N to 1230 N. The brake torque for the conventional steel material against brake pads varies from 16 Nm to 21.5 Nm for the same variation of force. The brake torque increases as the speed is increased from 40 km/hr to 100 km/hr for a particular applied force.

It has been reported in literature in studying the wear behavior of Al MMC composites sliding against automobile friction material for all loads the frictional force (which will have show same variation as brake torque) is found to increase with sliding speed [9] ,because at low velocity there is less formation of transfer film at the interface and the frictional force is 20% more in MMC than cast iron. At higher velocities the formation of transfer film is fast [6]. It is observed [10] that higher sliding velocity leads to higher friction coefficient for MMCs. Formation of a compact transfer layer has been identified in the matrix region of the worn surface of the MMCs. The transfer layer mostly consists of constituents of the phenolic pad material which acted as counterbody. The amount of the constituents of the counterbody in the transfer layer is seen to increase as sliding velocity increases. It is suggested that the transfer layer on MMC acts as a protective cover and helps reduce wear rate and increasing the friction coefficient and thus frictional force. The brake torque reported for ADC 12 Al alloy drum brake at all velocities is lower than cast iron. [7]

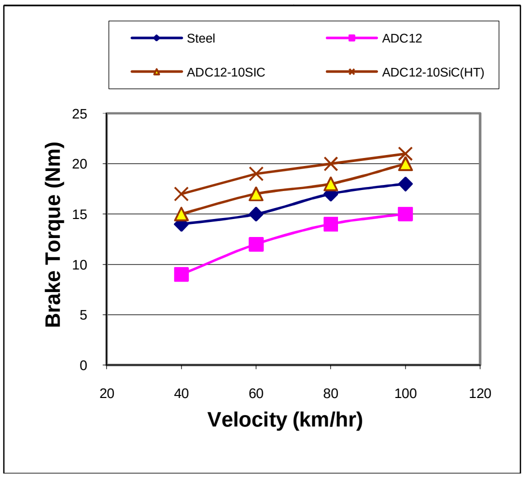


Fig. 9: Effect of velocity on brake torque at 246 N brake force

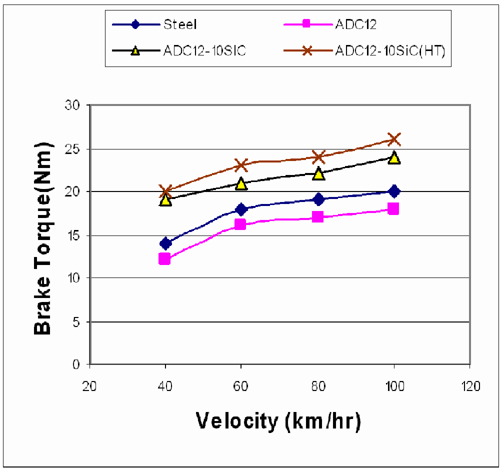


Fig. 10: Effect of velocity on brake torque at 492 N brake force

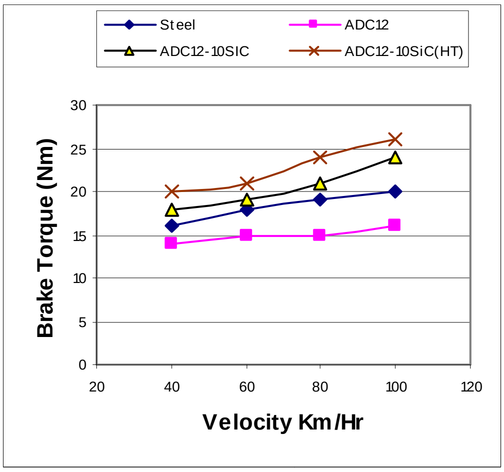


Fig. 11: Effect of velocity on brake torque at 738 N brake force

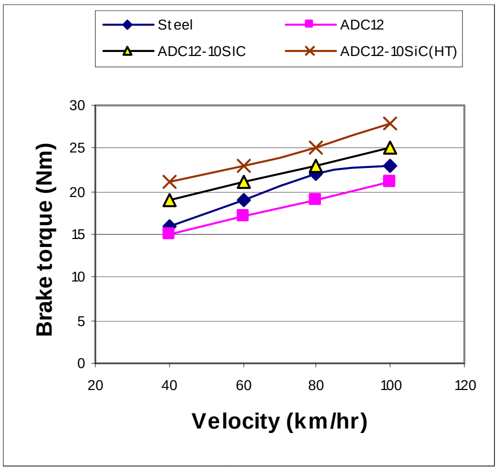


Fig. 12:Effect of velocity on brake torque at 984 N brake force

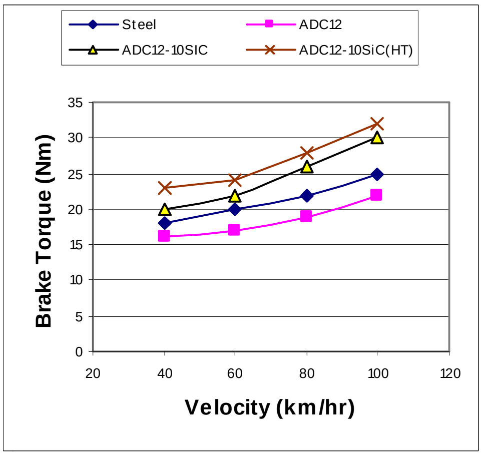


Fig. 13 :Effect of velocity on brake torque at 1230 N brake force

CONCLUSION

By observing the graphs following conclusions can be drawn-

- ✓ The apparatus simulates the actual operating condition of the brakes and provides an opportunity to the designer to evaluate the operating performance of the disc brakes in similar operating condition at the design stage more accurately before the brakes are put in actual operation.
- ✓ The average brake torque for ADC 12-10 SiC is 14.3% better than steel where as ADC 12-10 SiC (HT) gives 54 % higher value than steel for the tested brake force and the coefficient of friction of ADC 12 is inferior by 40.5% on an average to the steel For the tested velocities the average brake torque for ADC 12-10 SiC is 16% better than steel where as ADC 12-10 SiC (HT) coefficient of friction gives 24% higher value than steel for the tested velocities, while the coefficient of friction of ADC 12 is inferior by 13% on an average to the steel
- ✓ By observing the graphs it is visible that the performance of ADC 12-10 SiC and ADC 12-10 SiC (HT) brake discs is better than the steel and that of ADC 12 is inferior to the steel with respect to brake torque; comparison of the experimental test data agrees with such tests reported earlier in literature thus supporting the correctness of the system
- ✓ The facility helps in comparative analysis of the different brakes material in the simulated condition which helps in selection of right material for a wide range of input parameter values.

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