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Effect of Seal Material on Leakage of MR Fluid for Brake Application

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Abstract—*Magnetorheological brake (MR) brake is an attractive option to replace the conventional disc brake by online control of friction force by using MR fluid. However, on initial experiments on MR brake, the leakage of MR fluid was observed. To understand the science, the images and elemental analysis of seal material was investigated by using the EDS technique and concluded the wear of seal material as the cause of leakage of MR fluid. To overcome this problem, seal having higher hardness and high temperature operability was proposed. Initially experiments using "Block on disc lubricity tester" was performed. The blocks of nitrile rubber, silicon rubber and Viton were used. The performance of the experiment was evaluated by measuring the weight loss of the blocks before and after the tests. To validate the results of Block on disc lubricity tester, experiments was performed on developed MR brake test set up for seals having nitrile rubber, silicon rubber, and Viton as seal material. The observe result are presented. The results of EDS as images and elemental analysis are presented.*

Keywords: *MR brake, MR fluid, Seal material, Block on disc setup.*

INTRODUCTION

The magneto-rheological fluid (MR) brake consists of rotating disks immersed in a MR fluid and an enclosed electromagnet. When current is supplied to the electromagnet, the MR fluid solidifies as its yield stress varies as a function of the magnetic field applied. This controllable yield stress produces shear friction on the rotating disks, generating the braking torque. Magneto-rheological fluids consist of stable suspensions of micron-sized carbonyl iron powder dispersed in a carrier medium such as silicon oil .The sealing of the MR fluid in MR brake is very important for automotive application. Since MR fluid is highly contaminated due to the iron particles in it, the risk of sealing failure has been increased. In addition, in the case of dynamic seals have been employed between the housing and the rotating shaft .MR fluid leakage would occur if the fluid was repetitively solidified (due to the repetitive braking) around the vicinity of the seals. Walowit and Pinkus (1) have discussed the tribological characteristics of magnetic –fluid seals under a magnetic field. Pinkus (2) has been carried out experimental investigations on the mechanism of seal operation and seal failure. Vardarajan and Radionobch, et al. (3,4) have been developed a unique wear test to simulate the wear of magnetic fluid seals. In addition, Ravaud, et al. (5) have been studied the mechanical properties of a magnetic fluid seal by using a three dimensional analytical approach based on the Colombian model of a magnet. Polevikov and Tobiska (6,7) have been derived a mathematical model to study the stability of magnetic fluid seals under the action of external pressure drop in the static case. Jun Liu (8) has been used a spectral finite difference scheme for numerical analysis of a secondary flow in the narrow gap of a magnetic fluid shaft seal, and the influence of magnetic fluid plug shape and centrifugal force on the maximum pressure drop was numerically investigated.

The goal of this work is to understand the wear resistance of various seal materials in contact with an MR fluid and to provide information on seal wear testing in MR fluids. The seal has been used in MR brake to prevent the leakage of MR fluid. The function of the seal is to seal around the shaft, keeping the MR fluid confined between the rotor and casing. Seal effectiveness depends on many factors, including seal material and seal design. Although seal design is a very important factor in the success of a seal, the wear resistance of the material becomes equally important for long performance in MR fluid application. In developing seals for MR fluids application, we have used three seal materials such as Nitrile, Viton and Silicone. However, the presence of iron particles in MR fluids can cause severe wear of these polymeric seals, leading to premature failure. Therefore, it is very important to study the wear resistance of seal materials to MR fluids in order to make a proper choice of seal material for an MR brake. It is also equally important to analyse the iron particle embedded in the seal material during MR fluid application. In this article, we have considered the three different seal to test the wear resistance of various seal materials when subjected to load in block on disk machine in the presence of an MR fluid. The results of this wear on different seal materials as weight loss of block and co-efficient of friction and SEM images of surface texture of different seal materials used in MR brake have been discussed. Also experiment is performed on the MR Brake experimental setup. However, EDX of three sample of seal materials have been done to find the impingement of iron particles on the surface of seal.

SAMPLE PREPARATION

To develop MR fluid, 80% of carbonyl iron particles with 1% of TAH, 0.25% of oleic acid and 18.75% of silicone oil were considered. To reduce the Van der Waals force among the particles, iron particles and TAH were mixed in the mechanical mixer. The mechanical mixer, shown in figure 1, contains a variable speed DC geared motor of 24Volts, 5 ampere power supply. To enhance the motor-torque, a speed reduction (6:1) gear assembly was attached at the end of the motor. The motor is capable to run at maximum rational speed of 500 rpm. The speed of the motor was controlled by using a 24V, 5A DC external DC power supply as shown in figure 1(b). Iron particle and TAH is added to the container and the mixture is mixed using a stirring vane. In the present work the mixture is mixed at 400 RPM for half an hour. The Oleic acid was then added to the mixture and stirred for half an hour. The silicone oil was segregated into six parts and added to the mixture after every five minutes (i.e. starting, 5 min., 10 min…… 30 min.) of stirring.

(a) Mechanical mixer

(b) DC power supply

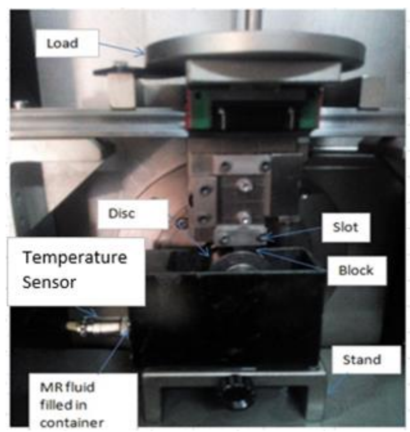
Fig. 1: Mechanical mixer with speed controller

EXPERIMENTAL TEST SETUP

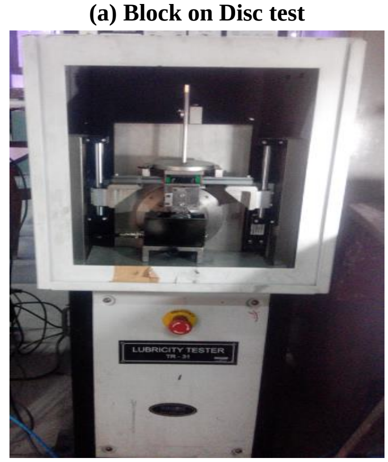
In the present work two type of experimental setups: (i) Block on Disc Setup and (ii) MR brake test setup, were utilized to find the effect of seal material for MR brake application. Since it is difficult and time consuming to remove the seal from the MR brake setup and replace with new disc, initial experiments were performed on block on disc setup. From this setup, the effect of hardness on wear and friction is determined and the validation of the finding was performed by conducting experiments on the developed MR brake setup. The discussion on the above mention test setups is presented in the following sub sections.

Block on disc lubricity tester

Block on disc setup (figure 2(a)) is an instrument used to measure the wear rate and frictional force between a stationary block and rotating cylinder. The maximum load of 100 N can be applied at a maximum rotational speed of 1200 rpm. The MR fluid is placed in a container and a thermocouple is used to sense the temperature of the fluid (figure 2(b)). The temperature can be varied from room temperature to 125^0C (maximum temperature is based on the lubricant used). The parameters: temperature, rpm and operating duration can be set with the help of the digital controller (figure 2(c)). The blocks of size 12x12x12 mm^3 having different material as (i) Nitrile Rubber (ii) Silicon Rubber (iii) Viton were fabricated.



(a) Block on Disc test



(b) Lubricity tester

(c) Digital control device

Fig. 2: Block on Disc test setup and digital controller

MR BRAKE EXPERIMENTAL TEST SETUP

To test the actual braking performance of the MR fluid, a brake setup as shown in figure 3 was developed. This setup consists of 3hp AC motor and the speed of motor is controlled using a frequency drive. The motor is connected to a MR brake using a jaw type coupling.

The MR brake consists of casing (figure 4(a)), rotor (figure 4(b)) and electromagnet (figure 4(c)). The MR fluid was filled in between the both sides of casing and the rotor. The electromagnet was powered using a variable DC power supply. To avoid the leakage of the fluid from the casing, the seals were provided in the casing. To measure current and voltage drawn from the motor at different rotational speeds of the motor and at different currents to electromagnet, ammeter and digital multi-meter were used. The torque of the system was estimated by using current and voltage of the motor.

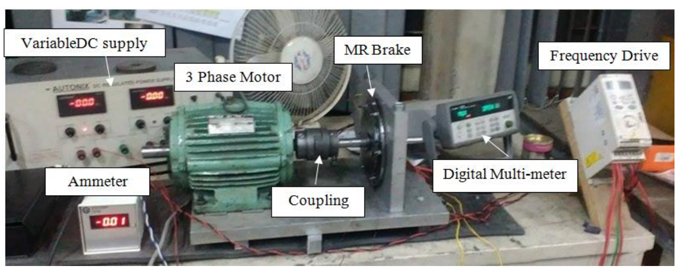


Fig. 4: MR brake test setup

(a) Casing

(b) Rotor

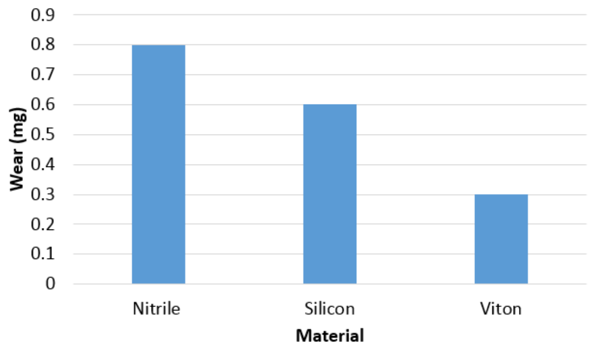
(c) Electromagnet

Fig. 5: Casing, rotor and electromagnet used in MR brake

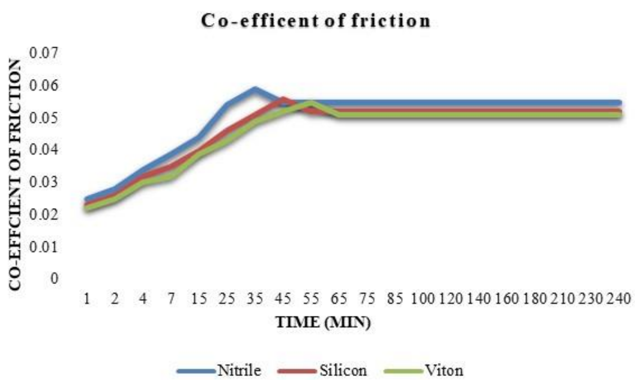
RESULTS AND DISCUSSION

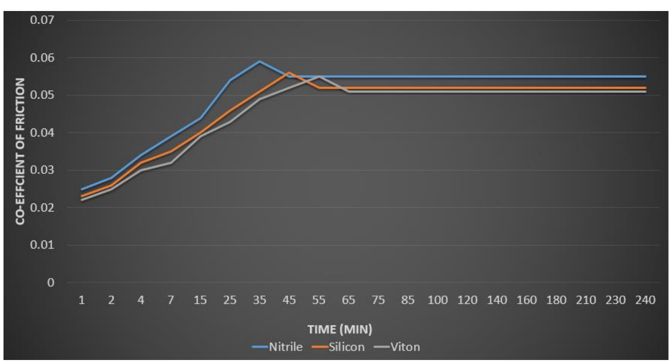
Experiments on block on disc were performed for Nitrile, Silicon and Viton blocks. The experiments were performed for 4 hr at the rotational speed of 400 RPM without load. The obtained values of wear and coefficient of friction are plotted in figure 5(a) and 5(b) respectively. From these figures it can be observed that wear and friction coefficient in case of Viton material is less as compared to other two material. The starting friction coefficient is increases rapidly for all the three cases but with time become constant due to the change in the surface morphology. Therefore it can be concluded that it is necessary to use Viton material seal as compared to nitrile rubber and silicon rubber seal.

To validate the above finding, second set of experiments was performed on the developed MR brake test setup. This experiment was performed for seals made up of different material as: (i) Nitrile rubber (ii) Silicon rubber and (iii) Viton. Experiments were performed at an operating speed of 250 rpm (40 km/hr) and 400 rpm (60 km/hr) which simulates the conditions of vehicle. The Supply of current for MR brake is constant for all the three cases as 1 amp and the time to failure of different material seal are listed in Table 1. From this table it can be concluded that Viton seal is not fail before 92.23 minute at 250 rpm Table 1(a) and 67.35 minute at 400 rpm Table 1 (b). This concludes that introducing the Viton material as seal material, the sealing problem of MR brake is reduced. This confirms the findings observed from the block on disc setup.



(a) Weight loss (mg)





(b) Co efficient of friction

Fig. 6: Wear and friction coefficient for different hardness block

Table 1: Time to failure of different seal (Experimental Set up result)

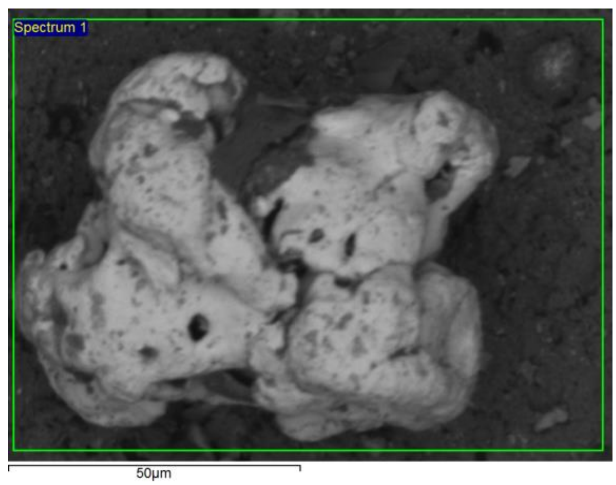
Seal material	Time to failure (min)
Nitrile Rubber	39.22
Silicon Rubber	68.41
Viton	92.23

250rpm

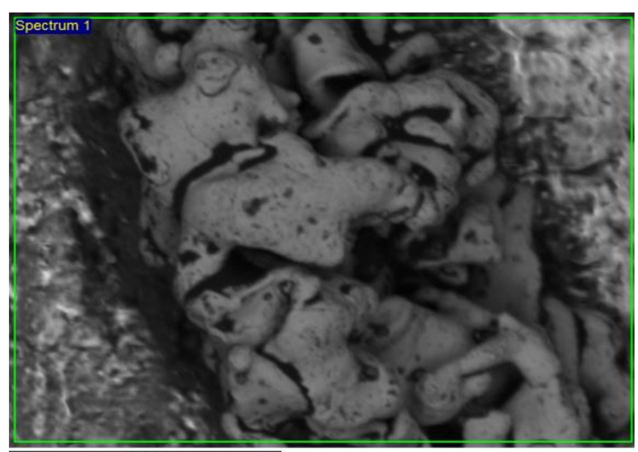
Seal material	Time to failure (min)
Nitrile Rubber	23.54
Silicon Rubber	42.31
Viton	67.35

(b) 400 rpm

To investigate the reason for the better performance of the seal material, the EDX analysis of blocks at 2000X and 5KV having (i) Nitrile (figure 6(a)) and (ii) Silicon (figure 6(b)) (iii) Viton (figure 6(c)) after performing experiments were analyzed. Also the element analysis of all seals blocks are done as shown in figure (7), figure (8), figure (9). From these figures, it can be observed that the blocks have impingement of iron particle as well as the surface cracks. However the cracks and iron particle impingement was found to be lesser in case of Viton seal material as compared to nitrile and silicon rubber material. From figure 6(c) and figure (9) it can be observed that Viton material has lesser impingement of iron particle and surface cracks which has led to solving the problem of MR brake sealing.



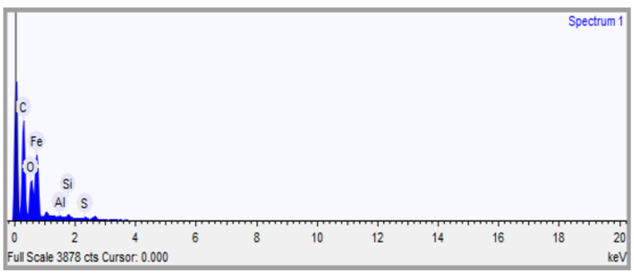
(a) Nitrile Rubber



(b) Silicon Rubber

(c) Viton

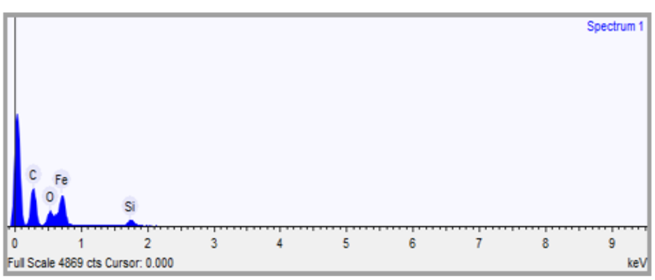
Figure 7: EDX Images of seal material



Summary results

Element	Weight %	Weight % σ	Atomic %
Carbon	26.735	0.519	55.940
Oxygen	8.973	0.305	14.095
Aluminum	0.310	0.118	0.289
Silicon	0.960	0.157	0.859
Sulfur	1.367	0.248	1.072
Iron	61.655	0.685	27.745

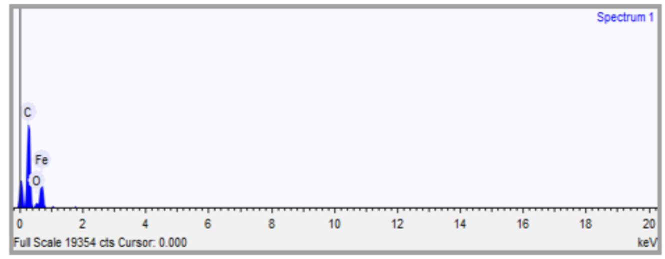
Figure 8: Elemental analysis of Nitrile rubber seal



Summary results

Element	Weight %	Weight % σ	Atomic %
Carbon	24.906	0.648	54.007
Oxygen	7.633	0.374	12.426
Silicon	4.568	0.280	4.237
Iron	62.893	0.857	29.331

Figure 9: Elemental analysis of Silicon rubber seal



Summary results

Element	Weight %	Weight % σ	Atomic %
Carbon	51.773	0.467	80.112
Oxygen	4.380	0.158	5.088
Silicon	0.631	0.073	0.417
Iron	43.216	0.497	14.382

Figure 10: Elemental analysis of Viton rubber seal

CONCLUSION

The material of the seal have an important role to reduce the leakage of MR fluid in MR brake. The Nitrile and silicon oil rubber seals failed earlier due to less hardness and low maximum temperature operability. To reduce the wear of seal, material having high hardness and maximum temperature operability is required. The Viton seal material has lesser impingement of iron particle and surface cracks compared to nitrile rubber and silicon rubber material seal. So seal material having hardness and maximum temperature operability leads to reduce the leakage of MR fluid in MR brake application.

ACKNOWLEDGEMENTS

The author declares that they have no conflict of interest.

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