Proceedings of the
International Conference on Mechanical Engineering 2007
(ICME2007) 29- 31 December 2007, Dhaka, Bangladesh

ICME07-AM-72

DRY SLIDING WEAR BEHAVIOR OF HYBRID MMCS WITH VARYING ORIENTATIONS AND HYBRID RATIOS

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ABSTRACT
The dry sliding wear behavior of Al_2O_3 fiber and SiC particle hybrid metal matrix composites (MMCs) fabricated by squeeze casting method was investigated using a pin-on-disk wear tester. The test results showed that the wear behavior of MMCs varied with fiber orientation and hybrid ratio. Hybrid reinforcement was effective in planar-random (PR)-MMCs. In the case of Al_2O_{3f} single reinforced MMCs, normal (N)-MMCs showed a higher wear resistance than PR-MMCs, however, the wear resistance of hybrid MMCs was contrary. The wear resistance of PR-MMCs increased with an increase of SiC_p ratio, however, that of N-MMCs decreased with an addition of SiC_p. The coefficient of friction was not affected by hybrid reinforcement.

Keywords: Dry sliding, Hybrid metal matrix composites, Wear

1. INTRODUCTION
In recent decades, the method of mixing a few lightweight structural materials with Aluminum Metal Matrix Composites (MMCs) has drawn increasing attention because of its specific stiffness and strength [1]. Due to good thermal stability and high wear resistance which produce the bottle-neck, the break disk used in friction can be obtained from some definite materials. We take raw materials in different species (SiC, Al_2O_3 etc.) and shapes (fiber, particle, crystal whisker etc.) of MMCs reinforcement materials. Generally, mechanical strength and wear resistance are improved by fiber and particle reinforcement materials respectively with remarkable effects. Consequently, there are a lot of researches about MMCs on the development of new reinforcement materials that are provided with multiple characteristics.

Besides MMCs single fiber/particle reinforcement materials, there are also some studies of hybrid reinforced MMCs materials. Hybrid reinforcement has excellent properties of good damage tolerance factor and low thermal expansion coefficient that are also found in single reinforcement [2-3]. The wear resistance of peculiar hybrid reinforcement already became a very active research field [4-8]. Park [5] reported that hybrid reinforcement materials Al_2O_{3f}/SiCw/Al, compared with Al_2O_{3f}/Al and SiCw/Al, had a higher wear resistance. Gurcan and Baker [6] also obtained that Al_2O_{3f}/SiCw/Al has an advantage in wear resistance. According to Fu et al. [7], it is found that under dry sliding wear the behavior of Al_2O_{3f}/SiCw/Al compared with Al_2O_{3f}/Al and SiCw/Al shows the most excellent advantage in wear resistance [8]. And the solid lubrication performance researches of carbonized hybrid MMCs reinforcement materials were carried on [5, 7-8]. In despite of the wear resistance researches indicated that fiber/particle reinforcement materials were classic, but, the most of the researches focused on the evaluations of different reinforcement materials.

In this paper we study the wear behavior of fiber/particle hybrid reinforcement materials fabricated by squeeze casting method with known hybrid ratio and fiber directions in metal.

2. EXPERIMENTAL
2.1 Metal Matrix Composites (MMCs) Preparation
Cast Aluminum Alloy A356 Al-Si of known materials was used and Al_2O_3 fibers/SiC particles (Saffil) were used for the reinforcement materials. Table 1 shows the different kinds of the preforms which were used in this experiment. The reinforcement ratios of preforms were approaching to 20 vol. %, and hybrid ratio was found through 4 different vacuum casting methods and produced in MMCs squeeze casting method. Procedure declaration of MMCs after rough treatment is similar to reference literatures [2, 8]. T6-heat treatment on MMCs is for 4 hours at 540?, and then water quenching, at last 4 hours artificial aging at 155? air cooling.

Table 1: The preforms fabricated in this work

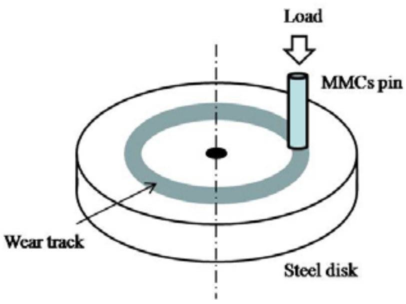
Preform	Vol.%			Hybrid ratio
	Total	Al_2O_{3f}	SiC_p	
F20	20	20	0	Fiber only
F13P7		13	7	2 : 1
F10P10		10	10	1 : 1
F3P13		7	13	1 : 2

2.2 Wear testing

The wear tests of the MMCs were performed according to fiber/particle hybrid ratio in the planar-random (PR) and normal (N) orientations sliding against a counter steel disk at a fixed speed under different loads.

Fig. 1 shows apparatus and schematic of pin-on-disk which is used under dry sliding condition. The dry sliding wear behavior of Al_2O_3 fiber and SiC particle hybrid metal matrix composites (MMCs) fabricated by squeeze casting method was investigated using a pin-on-disk wear tester.

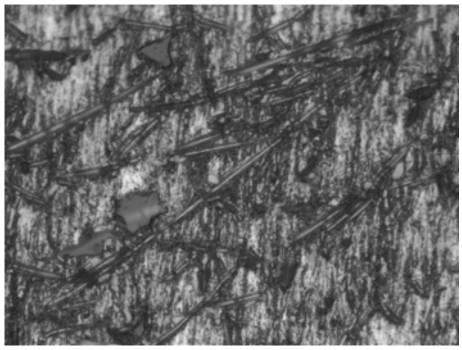
(a) Wear test machine



(b) Schematic of pin-on-disk wear-test setup

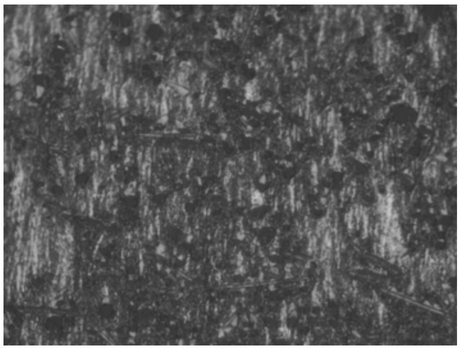
Fig 1: Apparatus and Schematic of pin-on-disk:(a) wear test machine, (b) schematic of pin-on-disk wear-test setup.

Fig. 2 shows the specimen's optical micrographs which are in different orientations of planar-random (PR) and normal (N) and with a hybrid ratio of 13% fibre and 7% particle. In Fig. 2(a), we can easily observe the fiber and the orientation of that. In Fig. 2(b), because the fiber is not easily observed, accordingly, we can infer that the fiber has a Normal orientation.



(a)

F13P7 PR-MMCs



(b) F13P7 N-MMCs

Fig 2: Optical Microstructures of PR- and N-orientation MMCs:(a) F13P7 PR-MMCs, (b) F13P7 N-MMCs.

Fig. 3 shows schematic of squeeze cast MMCs ingot in cross section. Along the direction of fiber length, the pins of planar-random (PR) orientation and normal-random (N) orientation were machined with the size of Φ6mm × 20mm. Counter steel disk was made of SCM440 and machined to be Φ30mm × 7mm. The surfaces of Pins and disk were washed by acetone after that were respectively polished by sand paper of the standard 800, and then they was used in the experiment of wear testing [9]. We weighed the pins whose weights were changed in experiment by precision electronic balance with the measurement accuracy of 0.1 mg. Sliding speed was constant at 0.36 m/s, applied loads were 3,5,8 kgf and total sliding distance was 2.5 km.

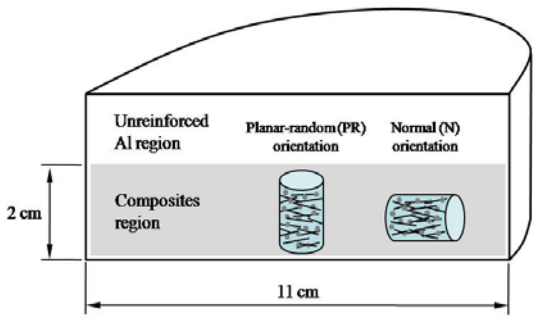


Fig 3: Schematic of squeeze cast MMCs ingot in cross section

3. RESULTS AND ANALYSIS

3.1 Wear behavior of different fiber orientations

Fig. 4 shows comparisons between the wear losses of PR- and N-MMCs according to normal load. From the comparison of the curves F20PR and F20N, we found that the wear loss of F20PR is higher than that of F20N. Therefore, the wear resistance of N-MMCs is higher than that of PR-MMCs for Al_2O_{3f} single reinforcement materials, however, it is just the opposite of the hybrid reinforcement materials when we compared the other two curves.

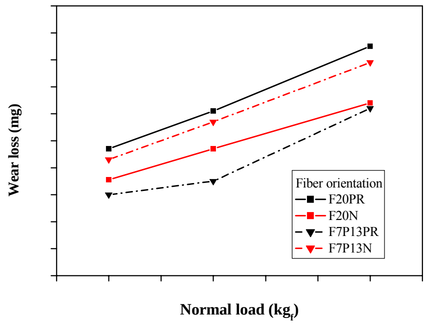


Fig 4: Comparisons between the wear losses of PR- and N-MMCs according to normal load.

The wear resistance of N-MMCs is higher than that of PR-MMCs for fiber single reinforcement materials which were already confirmed in many other investigations [10]. But, the particles on the direction of fiber may be holdback the wear resistance in the case of particles hybrid reinforcement materials, it is the possible reason for the poor wear resistance. Accordingly, we need to analyze the subsurface of wear surface and do some relative researches to find out the real causes.

Fig. 5 shows the schematic diagram of wear mechanism of F20 MMCs with different fibers' orientations. We found that although the fiber of PR-MMCs was not consumed away after the wear testing, the rest part was automatic spalling off, consequently, on the surface of PR-MMCs specimens we could find there was an obvious spalling character, of the N-MMCs, the rest part was always on tight junction of the pins.

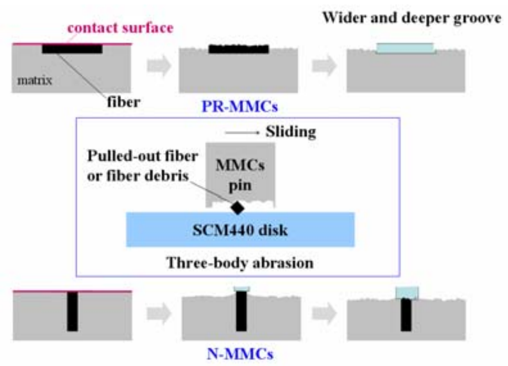
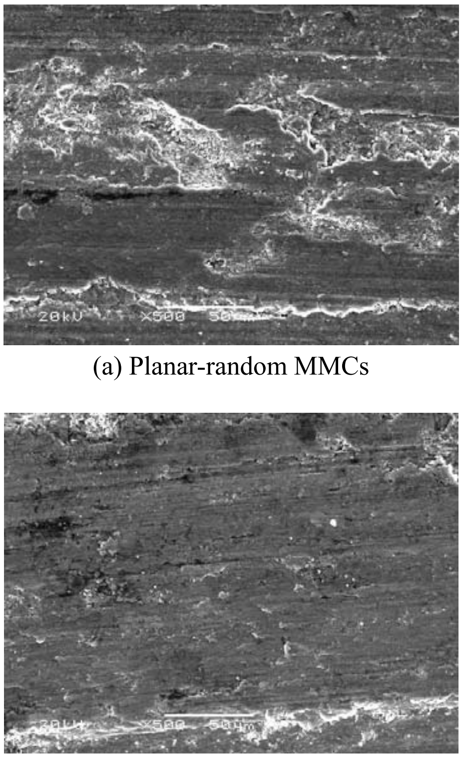


Fig 5: Wear mechanism of F20 MMCs

Fig. 6 shows the worn surfaces of F20 PR- and N-MMCs with normal load of 3 kgf. Comparison of Figs. 6(a) and 6(b) shows that the worn surface of PR-MMCs has a higher surface roughness than that of N-MMCs which is coincident with the wear loss results of experiment and the wear mechanism.

In Fig. 6 (b) we can also find the spalling character, because in the N-MMCs specimen, all the fibers' orientations are not perfect in the normal direction, there are few defects inside.



(a) Planar-random MMCs

(b) Normal MMCs

Fig 6: Worn surface of F20 MMCs with normal load of 3 kgf: (a) Planar-random MMCs, (b) Normal MMCs

Fig. 7 shows the schematic diagram of wear mechanism of hybrid MMCs with different fibers' orientations. We can synthetically consider the interaction between fiber and particle.

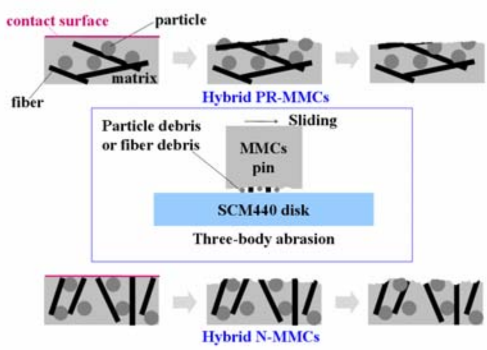
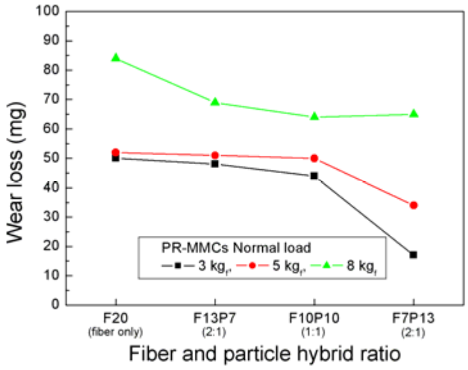


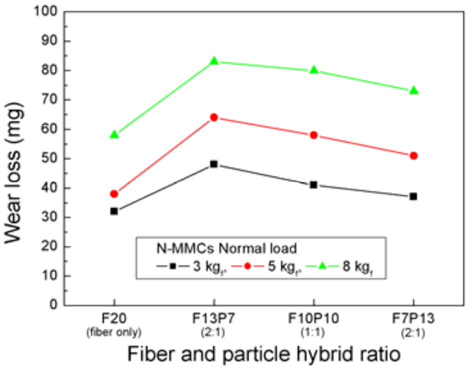
Fig 7: Wear mechanism of hybrid MMCs

3.2 Wear behavior of different fiber/particle hybrid ratios

Fig 8(a) shows Effect of hybrid ratio on wear loss of the PR-random MMCs. Compared with Al_2O_{3f} single reinforcement materials, we can observe that hybrid reinforcement materials have a higher wear resistance. Wear resistance increases evidently also with the increasing ratio of SiCp. Under the high load, we can confirm the outstanding wear resistance of hybrid reinforcement materials.



(a) Planar-random orientation



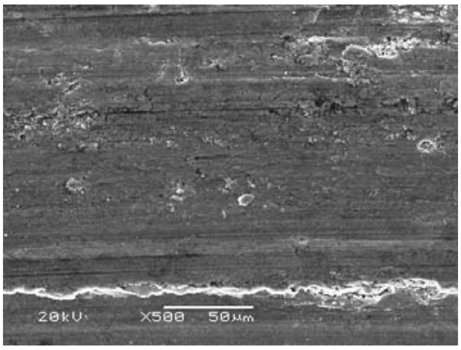
(b) Normal orientation

Fig 8 Effect of hybrid ratio on wear loss of MMCs: (a) planar-random orientation, (b) normal orientation.

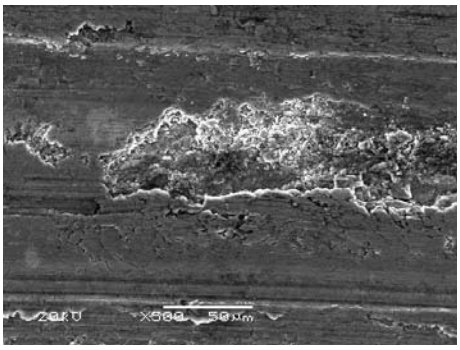
Fig. 8(b) shows Effect of hybrid ratio on wear loss of the N-random MMCs. Compared with Al_2O_{3f} single reinforcement materials, the wear resistances of PR MMCs and hybrid MMCs of different hybrid ratios are smaller. However, wear resistance increases also with the increasing ratio of SiCp.

Fig. 9 shows the worn surface of hybrid MMCs (F13P7) according to hybrid ratio of 2:1 with different orientations.

We can observe smaller spalling character in Fig. 9(a) because of the existent particle. And in Fig. 9(b), the spalling character has an obviously increasing trend.



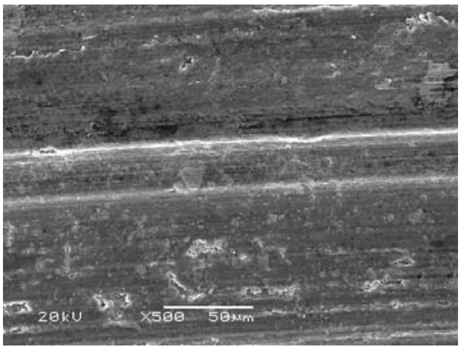
(a) Planar-random MMCs



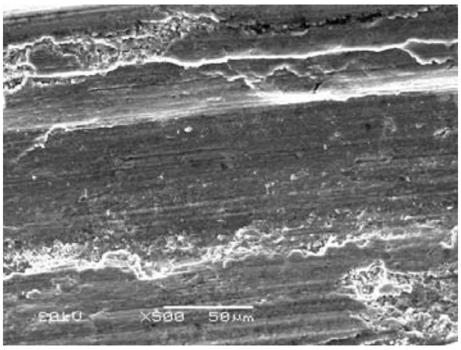
(b) Normal MMCs

Fig 9: Worn surface of hybrid MMCs (F13P7) according to hybrid ratio of 2:1: (a) Planar-random MMCs, (b) Normal MMCs

Fig. 10 shows the worn surface of hybrid MMCs (F10P10) according to hybrid ratio of 1:1 with planar-random and normal orientations respectively.



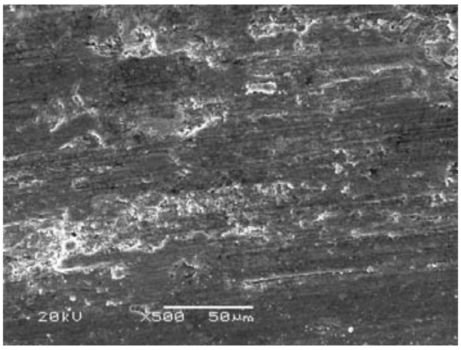
(a) Planar-random MMCs



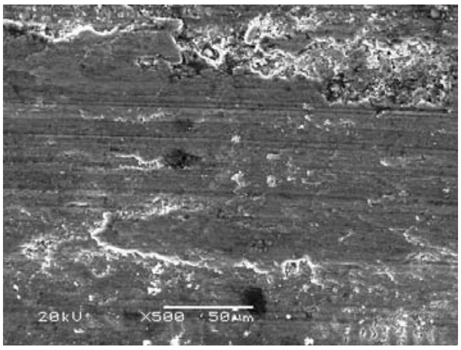
(b) Normal MMCs

Fig 10: Worn surface of hybrid MMCs (F10P10) according to hybrid ratio of 1:1: (a) Planar-random MMCs, (b) Normal MMCs

Fig. 11 shows the worn surface of hybrid MMCs (F7P13) according to hybrid ratio of 1:2. Compared with the fiber only specimens, we found that there are some differences of the sub surfaces between fiber/particle and fiber only PR-MMCs of the wear testing. The subsurface of hybrid PR-MMCs is much more smooth, the wear resistance of hybrid PR-MMCs is higher than that of fiber only PR-MMCs.



(a) Planar-random MMCs



(b) Normal MMCs

Fig 11: Worn surface of hybrid MMCs (F7P13) according to hybrid ratio of 1:2: (a) Planar-random MMCs, (b) Normal MMCs

For the hybrid N-MMCs, their behaviors were just the opposite, so we need more subsurface analysis for that.

From the comparison of Figs. 9(a), 10(a), and 11(a), when hybrid ratio was increasing, we observed that the spalling character disappears gradually, weight loss gradually decreases and it has significant difference too. The result is also coincident with the experiment.

From Figs. 9(b) 10(b), and 11(b), we also observed the results similar to Figs. 9(a) 10(a), and 11(a) with the increasing hybrid ratio, but the wear resistances of them were always smaller than that of the fibre only N-MMCs specimen.

For the hybrid specimens, because of the existent particles, the wear resistance was affected, and on the worn surface we can find many extrusive defects which were made by particles.

From fiber/particle hybrid MMCs reinforcement materials, we can know that fiber orientation and hybrid ratio of reinforcement materials have an effect on the wear resistance. In fiber/particle hybrid reinforcement materials, compared to fiber normal orientation, the wear resistance of planar-random orientation is better, while the wear resistance of SiCp is better than Al2O3f.

3.3 Coefficient of friction

The coefficient of friction μ was calculated by the following formulation:

$$\mu = \frac{\tau_c A}{F_N} \qquad (1)$$

F_N is normal applied load.

Fig. 12 shows coefficient of friction of PR- and N-MMCs according to different hybrid ratios of fiber/particle MMCs. It shows little change in coefficient of friction for the same load and different hybrid ratios. As seen in Fig. (12), the coefficients of friction are 2.69~2.75, 1.65~1.71, and 1.08~1.12 that correspond to the applied loads of 3, 5, and 8 kgf respectively. The coefficients of friction decreased with the increase of the applied loads in the given range of values.

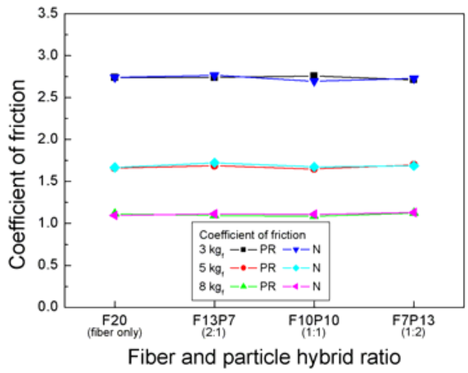


Fig 12: Friction coefficients of PR- and N-MMCs according to hybrid ratios.

4. CONCLUSIONS

The fiber/particle MMCs are fabricated by squeeze casting method where the fiber's random orientations are different. Through the above calculation, analysis and comparison with the results of test, the following can be concluded:

(1) In the case of Al_2O_{3f} single reinforced MMCs, wear resistance N-MMCs is higher than that of PR-MMCs, however, the wear resistance of hybrid MMCs showed a reverse behavior.

(2) In the case of PR-MMCs, the hybridization of fiber and particle protects the pull-out of the fiber. As a result, the wear resistance is increased.

(3) The coefficient of friction of hybrid MMCs was not affected by hybrid reinforcement in MMCs.

5. ACKNOWLEDGEMENT

The authors of this paper were partly supported by the Second Stage of Brain Korea21 Project.

6. REFERENCES

1. D. B. Miracle, "Metal matrix composites – From science to technological significance", Compos. Science Technology, Vol. 65, No. 65, (2005), pp. 2526-2540.
2. K. H. Oh and K. S. Han, "Short-fiber/particle hybrid

reinforcement: Effects on fracture toughness and fatigue crack growth of metal matrix composites", Composites Science and Technology, Vol. 67, No. 7-8, (2007), pp. 1719-1726.

3. J. I. Song and K. S. Han, "Effect of volume fraction of carbon fibers on wear behavior of $Al/Al_2O_3/C$ hybrid metal matrix composites", Journal Composites Material, Vol. 31, No. 4, (1997), pp. 319-344.
4. J. I. Song, Y. C. Yang and K. S. Han, "Squeeze casting conditions of Al/Al_2O_3 metal matrix composites with variations of the preform drying process", Journal Composites Material, Vol. 31, (1996), pp. 2615-2621.
5. H. C. Park, "Wear behavior of hybrid metal matrix composite materials", Scripta Metallurgica et Materialia, Vol. 27, No. 4, (1992), pp. 465-470.
6. A. B. Gurcan and T. N. Baker, "Wear behavior of AA6061 aluminium alloy and its composites", Wear, Vol. 188, No. 1-2, (1995), pp. 185-191
7. H. H. Fu, K. S. Han and J. I. Song, "Wear properties of Saffil/Al, Saffil/Al_2O_3/Al and Saffil/SiC/Al hybrid metal matrix composites", Wear, Vol. 256, No. 7-8, (2004), pp. 705-713.
8. Z. M. Du and J. P. Li, "Study of the preparation of $Al_2O_{3sf}\cdot SiC_p/Al$ composites and their wear-resisting properties", Journal of Materials Processing Technology, Vol. 151, No.1-3, (2004), pp. 298-301.
9. B.K. Prasad, "Sliding wear response of a cast iron under varying test environments and traversal speed and pressure conditions", Wear, Vol. 260, No. 11-12, (2006), pp. 1333-1341.
10. Y. Sahin, "Wear behavior of planar-random fibre-reinforced metal matrix composites", Wear, Vol. 223, No 1-2, (1998), pp. 173-183.