The Effect Of Sliding Speed On Wear Behaviors Of Hybrid Mg Alloy Composites Reinforced With Carbon Nanotube and Cerium

*[1]Mehmet Baki Karamış, [2]F.Nazlı Sarı, [3]Yahya Kaya
[1,3]Composite Materials Research Laboratory, Department of Mechanical Engineering, Erciyes University, Turkey
[2]Faculty of Engineering, Department of Mechanical Engineering Aksaray University, Turkey

Abstract :

Although Magnesium is one of the lightest metals, it can not be used widely because of its some unfavorable mechanical properties. Because of that reason, the mechanical properties of magnesium need to be improved for exploiting its specific weight in future industrial applications such as low energy consumption in aircrafts and vehicles. Carbon nanotube (CNT) is regarded as an ideal candidate especially with its specific weight close to magnesium for a reinforcing material to improve magnesium's properties.

This study focuses on the effect of sliding speed on friction and wear behaviors of hybrid Mg alloy composites reinforced with Multi Walled Carbon Nanotube (MWCNT) and Cerium (Ce) rare earth element. Wear tests on twenty Mg alloy composite samples with different proportions of MWCNT and Ce were carried out using the pin-on-disk configuration at room temperature under dry conditions . In all tests, while stationary pin (ball) was loading on the samples under an constant applied load of 20 N, disc was rotated in four different sliding speeds (50, 100, 200 and 300 rpm) separately for each of the tests which corresponds to totally 80 wear tests. Wear behavior of Mg alloy composites were evaluated as weight loss and the variation of the frictional forces of the samples. The worn surfaces of samples were also examined by Scanning Electron Microscope (SEM) and it is concluded that developed hybrid composites have better wear characteristic under higher sliding speeds and more suitable to use high speed wear conditions.

Key words: Mg hybrid composites, Carbon nanotube, Cerium, wear properties

1. Introduction

Magnesium and its alloys are promising materials for significant weight reduction because they are among the lightest of the industrial metals. It is obvious that their mechanical and tribological properties must be improved when they are employed as structural parts or components. They are, however, poor to the mechanical properties, such as Young's modulus, tensile strength, hardness and heat resistance. In particular, when applying them to friction materials, the wear or seizure phenomena easily occur by contacting with the counter materials [1-3]. Therefore, the additives of hard particles and lubricants are effective to improve the mechanical and tribological

*Corresponding author: Address: Composite Materials Research Laboratory, Department of Mechanical Engineering, Erciyes University, 38039, Kayseri TURKEY. E-mail address: karamisb@erciyes.edu.tr, Phone: +903522076666 Fax: +904375784

properties of the conventional magnesium alloys [4-7]. In addition to that, carbon nanotubes (CNTs), showing excellent characteristics such as high tensile strength, high elastic modulus, and high hardness, have been considered as useful and attractive additives to organic materials [8,9], bulky metals [10,11] and metallic coatings [12,13] for tribological and structural applications.

On the other hand, the main problem in the use of CNTs as an industrial reinforcement for composites is their poor mixing in the matrix. This is caused by agglomerates that easily occur due to strong van der Waals forces, which are attractive or repulsive interactions between carbon atoms [14,15]. Many studies on the uniform distribution of CNTs were carried out using conventional mechanical milling and melting processes [16,17]. Unfortunately, homogeneous microstructures having uniformly dispersed CNTs could not be fabricated by these methods. A unique approach employing the mixing of CNTs in ethanol has been used to prepare composite particles coated with nanotubes [18,19]. Ultra-sonic vibration was used to disperse the agglomerated CNTs in ethanol, followed by dipping the metal powders into the ethanol.

As a result of reviewing studies in literature an ultra-sonic vibration mixing method was chosen suitable for dispersing the agglomerated CNTs in Isopropanol (IPA)

2. Materials and Method

2.1. Materials and composites preparation

In this study AZ41M Mg alloy powder with average size of 266 μm was used as matrix material. CNTs were used as reinforcement particles. The CNTs have an outer mean diameter of 5-20 nm , inner mean diameter of 4 nm and their length is 1- > 10 μm. The volume fractions of the reinforcements materials can be seen in Table 1.

Table 1. The volume fractions of reinforcement materials with sample numbers

Sample Number	% CNT	% Ce	Sample Number	% CNT	% Ce
8	0,0422	-	17	-	0,0129
10	0,0352	-	19	-	-
13	0,05	-	23	-	0,0037
14	-	0,02	25	0,0247	-

The powder CNTs were ultrasonically treated by Sonics VCX 750 processing for 7 min. to separate agglomerations and then they were mixed by AZ41 powders. After ultrasonic mixing, the solution was evaporated to remove solvent and pre-compacted in a steel die. Some of the composites have cerium as a second reinforcement. Cerium was added to solution after evaporating in atmosbag. They were also mixed by a mechanic mixer for 1 hour. Next, the mixed powder was cold pressed afterwards, it was hot extruded as a rod. The specimen was prepared from the rod. All wear specimen surfaces were polished for wear testing.

2.2. Wear tests

Wear tests were performed using the pin-on-disk configuration at room temperature under dry conditions. In all tests, while stationary pin (ball) was loading on the samples under a constant applied load of 20 N, disc was rotated in four different sliding speeds (50, 100, 200 and 300 rpm) separately for each of the tests. The frictional forces were recorded by a computer with software compatible with the testing. Wear was evaluated as weight loss and the variation of the frictional forces of the samples.

After each of the wear test, the samples were cleaned ultrasonically. The counter face was also cleaned before each test. All wear test samples were weighed prior to and after each test. After the wear tests, the characterization of the worn surfaces was made by optical and scanning electron microscopes (SEM) examinations.

3. Result and Discussion

3.1. Microstructure characterization

Figure 1 shows the microstructures of the AZ 41 alloy and the composite. The microstructures are examined by a SEM (Quanta Feg 250). As seen in Figure 1, it is observed that reinforcement particles are dispersed homogenously. It is clearly seen that CNTs are around the Ce particles.

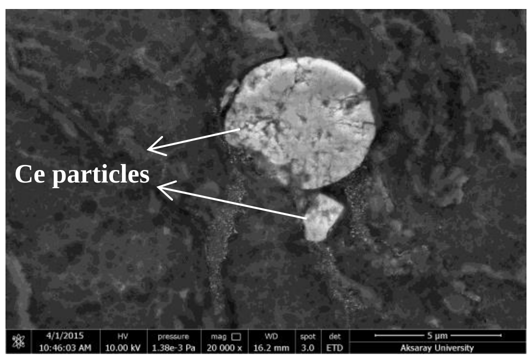


Figure 1. The microstructures of the Az41 alloy matrix composite.

3.2. Frictional characteristics of the samples

The variations of sample weight losses with sliding speeds were observed under constant load of 20 N. Figure 2 shows the changes in weight loss with the sliding speed. But all samples show similar decreasing tendency after sliding speed of 100 rpm, while they have different variations before 100 rpm under dry test conditions. At speed of 100 rpm, the weight losses of the samples reinforced by Ce and CNT separately are lower than that of unreinforced sample, although these samples show different behaviors before and after the test speed of 100 rpm. Some of the values are very close to each other at 50 rpm. However, the weight losses of all samples, generally, show decreasing with test speed.

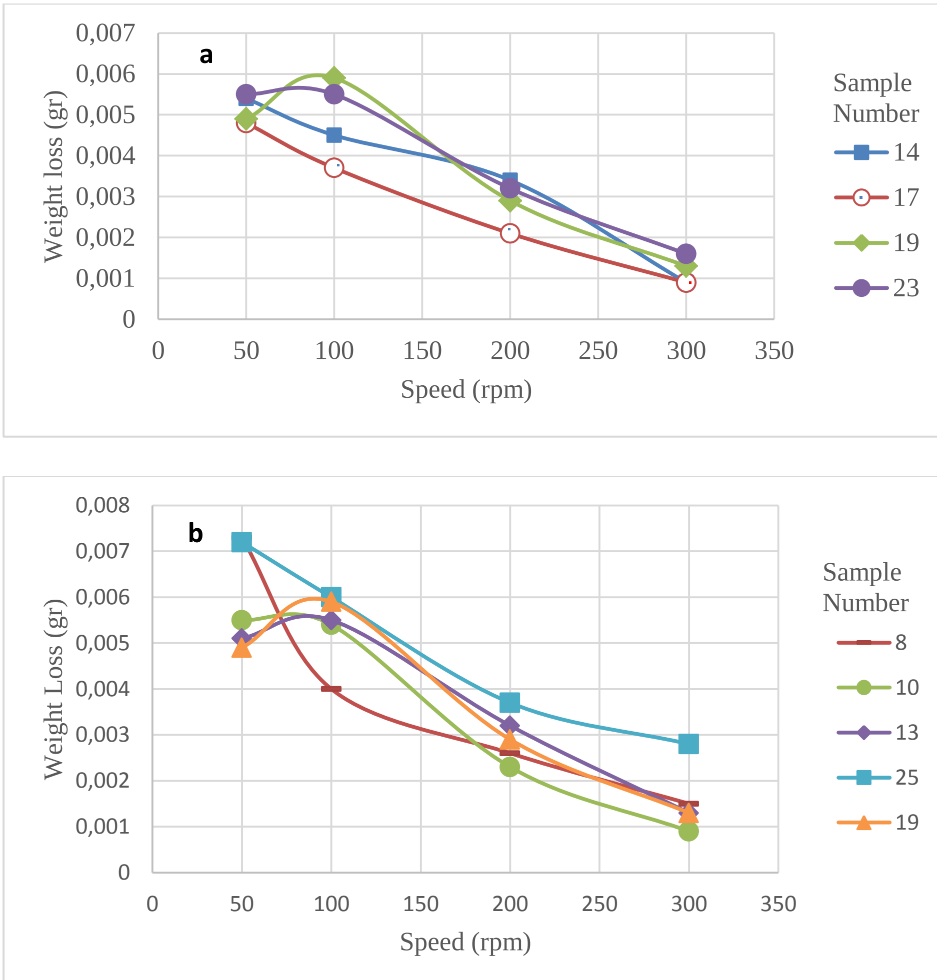


Figure 2. Weight loss of samples versus to sliding speed

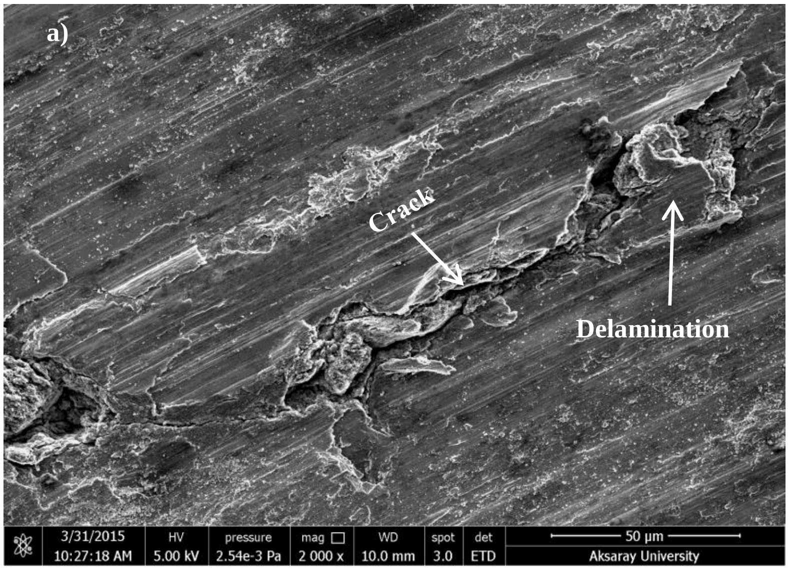
a) The samples reinforced by Ce

b) The samples reinforced by CNT

It can be seen from Figure 2 a that the samples having Ce give lesser weight losses than that of unreinforced sample (no 19) up to test speed of 200 rpm. After that they show similar decreasing slope up to 300 rpm. Similarly, the higher weight loss is observed for samples having CNT than that of unreinforced sample (no. 19) at test speed of 50 rpm, whereas they have similar decreasing tendency to each other after 100 rpm.

The maximum weight loss is observed for the sample 25 as seen in Figure 2 b. It is interesting that the weight loss of the sample 25 is higher than that of unreinforced sample at all test speeds. All samples having CNT have different behaviour than those of each other and unreinforced sample at different test speeds. Therefore, it is determined that there is no systematic relationship between reinforcements and sliding speed.

The worn surfaces of the sample 25 is shown in Figure 3. It can be seen from Figure 3 a that some cracks generated from surface fatigue caused by hertzian stress are observed on the surface. On the other hand, some delamination layer is also occurred near at edge of the crack. These situations say that the surface of the sample is not only brittle but it is also suitable to plastic yielding. The wear traces occurred in parallel to the sliding direction can be seen in Figure 3 b.



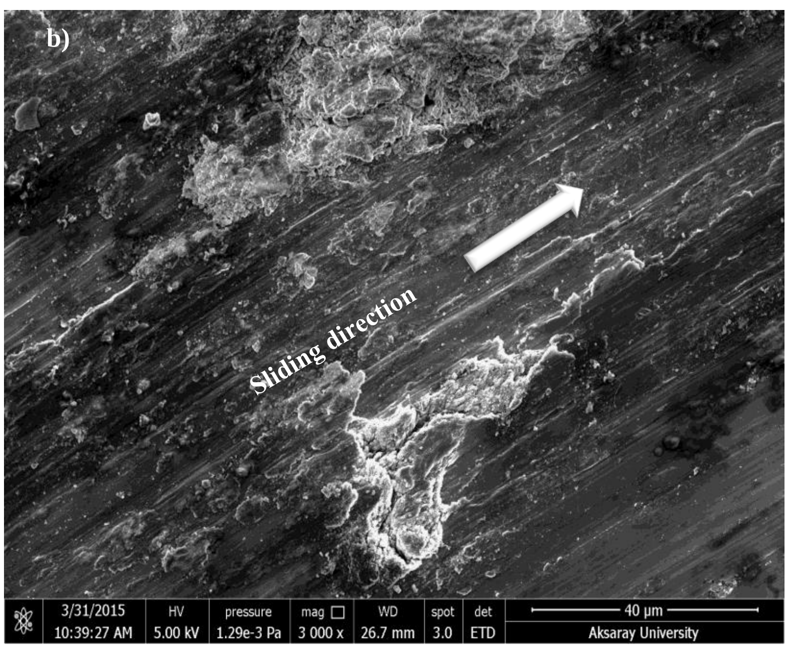


Figure 3. Worn surface of the composites at 50 rpm

a) For sample 25
b) For sample 13

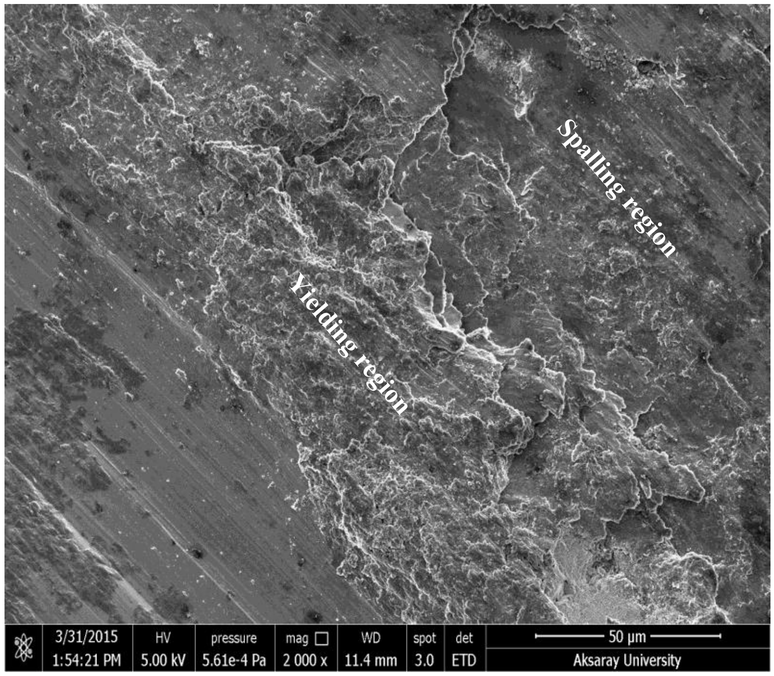
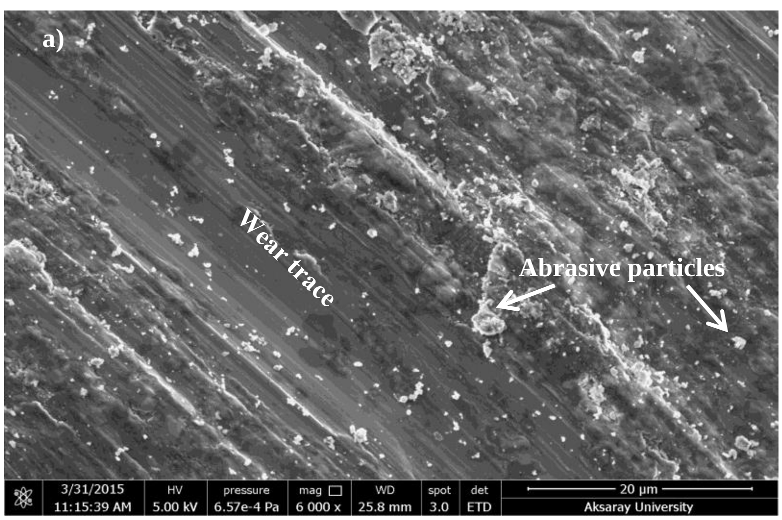


Figure 4. Worn surface of the reinforced composite (no. 10) at 100 rpm sliding speed

Figure 4 shows the worn surface of the reinforced composite under dry condition at 100 rpm sliding speed. It is understood that, the waving tendency of the variation in weight losses are caused by yielding plastically and spalling of surfaces.



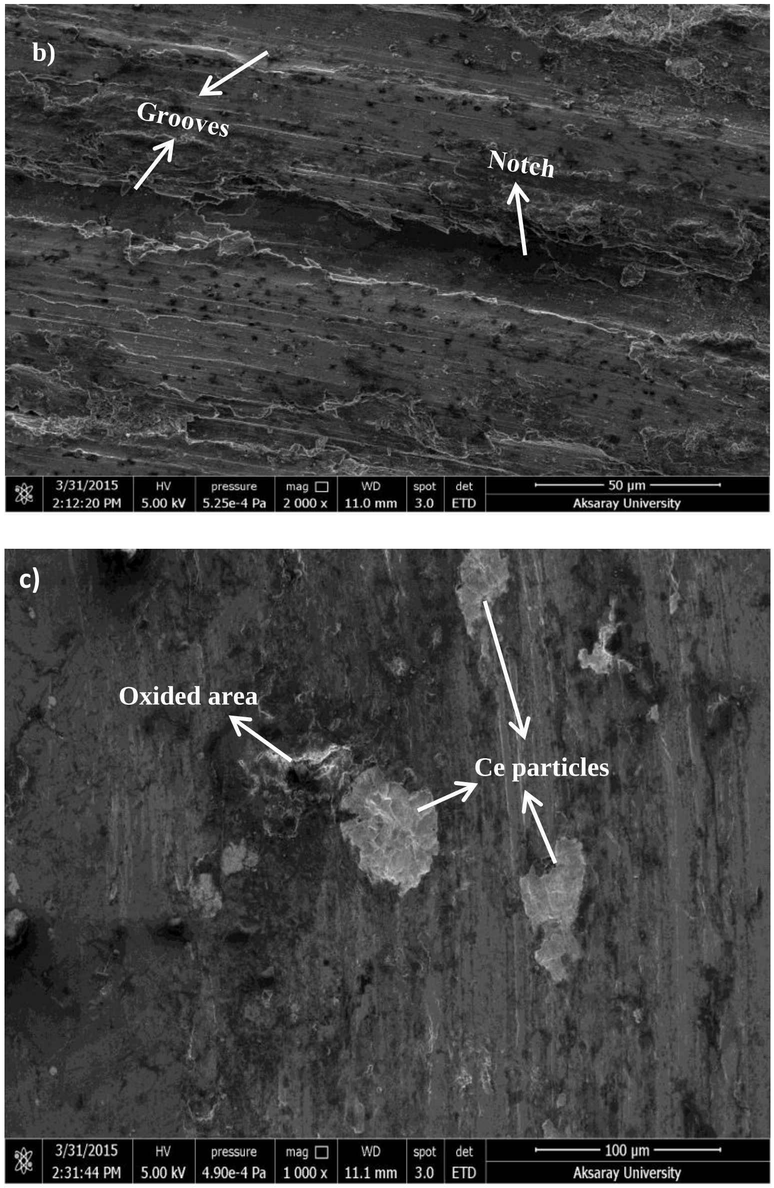


Figure 5. Worn surfaces of the reinforced composite (no. 14) tested at speeds of ;
a) 100 rpm b) 200rpm c) 300 rpm

On the other hand, the wear mechanism is changed from adhesive to abrasive mode by spalling particles having abrasive effect (Figure 5 a). The reason of the yielding is excess heat generated from long term friction affecting to the surface and it causes to softening of the surface. It is also observed that the abrasive particles generated from spalling of the surface layer caused to some grooves and notches on the surface (Figure 5 b). Some Ce particles can be seen on the surface with some oxided area (Figure 5 c).

4. Conclusion

In this study, the effect of sliding speed on wear behavior of the hybrid Mg alloy composites was examined. The following conclusions were derived from this study;

1. The reinforcements such as Ce and CNT have an increasing role for wear resistance of Mg alloy at speed of 100 rpm.
2. The weight losses are decreased by sliding speed for unreinforced and reinforced Az 41 matrix samples.
3. It is determined that there is no systematic relationship between reinforcements and sliding speed related to wear behavior of Az 41 matrix composites reinforced with CNT and Ce.
4. The wear mechanism is occurred as mixing of adhesive and abrasive modes. However, among the wear mechanisms such as adhesive and microcutting, abrasive wear mechanism is occurred predominantly on the Az 41 surface reinforced by CNT and/or Ce.

Acknowledgements

Authors would like to thanks to Scientific and Technological Research Council of Turkey (TUBITAK) due to their financial support for this study with project numbers: 112M780.

References

[1] Weijiu Huang, Bin Hou, Youxia Pang, Zhongrong Zhou. Fretting wear behavior of AZ91D and AM60B magnesium alloys. Wear 2006;260:1173–1178.
[2] J. An, R.G. Li, Y. Lu, C.M. Chen, Y. Xu, X. Chen, L.M. Wang. Dry sliding wear behavior of magnesium alloys. Wear 2008;265:97–104.
[3] Naing Naing Aung,Wei Zhou, Lennie E.N. Lim. Wear behaviour of AZ91D alloy at low sliding speeds. Wear 2008;265:780–786.
[4] C.Y.H. Lim, D.K. Leo, J.J.S. Ang, M. Gupta. Wear of magnesium composites reinforced with nano-sized alumina particulates. Wear 2005;259:620–625.
[5] S.C. Sharma, B. Anand, M. Krishna. Evaluation of sliding wear behaviour of feldspar particle-reinforced magnesium alloy composites. Wear 2000;241:33–40.
[6] Q.B. Nguyen, M. Gupta. Enhancing compressive response of AZ31B magnesium alloy using alumina nanoparticulates. Compos. Sci. Technol. 2008;68:2185–2192.
[7] X.J. Wang, X.S. Hu, K. Wu, K.K. Deng, W.M. Gan, C.Y. Wang, M.Y. Zheng. Hot deformation behavior of SiCp/AZ91 magnesium matrix composite fabricated by stir casting. Mater. Sci. Eng.: A 2008;492:481–485.
[8] X.H. Men, Z.Z. Zhang, H.J. Song, K. Wang, W. Jiang. Functionalization of carbon nanotubes to improve the tribological properties of poly(furfuryl alcohol) composite coatings. Compos. Sci. Technol. 2008;68:1042–1049.
[9] L.C. Zhang, I. Zarudi, K.Q. Xiao. Novel behaviour of friction and wear of epoxy composites reinforced by carbon nanotubes. Wear 2006;261:806–811.

[10] S.M. Zhou, X.B. Zhang, Z.P. Ding, C.Y. Min, G.L. Xu, W.M. Zhu. Fabrication and tribological properties of carbon nanotubes reinforced Al composites prepared by pressureless infiltration technique. Composites: Part A 2007;38:301–306.
[11] K.T. Kim, S.I. Cha, S.H. Hong. Hardness and wear resistance of carbon nanotube reinforced Cu matrix nanocomposites. Mater. Sci. Eng. A 2007;449–451:46–50.
[12] W.X. Chena, J.P. Tub, L.Y. Wang, H.Y. Gana, Z.D. Xua, X.B. Zhang. Tribological applications of carbon nanotubes in a metal-based composite coating and composites. Carbon 2003;41:215–222.
[13] L.Y. Wang, J.P. Tu, W.X. Chen, Y.C. Wang, X.K. Liu, Charls Olk, D.H. Chengd, X.B. Zhang. Friction and wear behavior of electroless Ni-based CNT composite coatings. Wear 2003;254:1289–1293.
[14] T. Hertel, R.E. Walkup, P. Avouris. Deformation of carbon nanotubes by surface van der Waals forces. Phys. Rev. B 1998;58:13870–13873.
[15] L.Y. Jiang, Y. Huang, H. Jiang, G. Ravichandran, H. Gao, K.C. Hwang. A cohesive law for carbon nanotube/polymer interfaces based on the van der Waals force. J. Mech. Phys. Solids 2006;54:2436–2452.
[16] D.K. Lim, T. Shibayanagi, A.P. Gerlich. Synthesis of Multi-walled CNT reinforced Aluminium alloy Composite via Friction Stir Processing. Mater. Sci. Eng. A 2009;507:194–199.
[17] Q. Li, A. Viereckl, C.A. Rottmair, R.F. Singer. Improved processing of carbon nanotube/magnesium alloy composites. Compos. Sci. Technol. 2009;69:1193–1199.
[18] Q. Li, M. Zaiser, V. Koutsos. Carbon nanotube/epoxy resin composites using a block copolymer as a dispersing agent. Phys. Status Solidi A 2004;201:R89–91.
[19] I. Bright, V. Koutsos, Q. Li, R. Cheung. Carbon nanotubes for integration into nanocomposite materials. Microelectron. Eng. 2006;83:1542–1546.