Friction and Wear Properties of NBR/PVC Composites

Xinwu Huang,[1,2] Nong Tian,[1] Tingmei Wang,[1] Kun Wang,[1] Qunji Xue[1]

[1]*State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Science, Lanzhou 730000, China*
[2]*Graduate School of the Chinese Academy of Sciences, Beijing, 100049, China*

Received 10 March 2006; accepted 11 July 2006
DOI 10.1002/app.25316
Published online 30 July 2007 in Wiley InterScience (www.interscience.wiley.com).

ABSTRACT: Acrylonitrial butadiene rubber (NBR)/Polyvinyl chloride (PVC) composites with different PVC content were prepared. The effect of PVC content on the mechanical strength and tribological properties of the NBR/PVC composites was investigated. The morphologies of the worn traces and debris of NBR/PVC composites and worn traces of mating ball were observed using a scanning electron microscope (SEM). It was found that the friction and wear of NBR/PVC was lower than that of NBR without PVC. The NBR/PVC composite with 30% PVC content showed the best synthetic mechanical and tribological properties. The inferior elastic properties and the lesser deformation under the applied load of composites with PVC resulted in hysteric force and adhesion force decrease, which leading to a lower friction and wear of NBR/PVC composites. The frictional failure unit of NBR70/PVC30 composite being smaller should be an important reason of the wear of the composite being lowest. The lubricating effect of PVC played an important role in decreasing the friction coefficient and wear of NBR/PVC composites. © 2007 Wiley Periodicals, Inc. J Appl Polym Sci 106: 2565–2570, 2007

Key words: acrylonitrial butadiene; polyvinyl chloride; NBR/PVC composites; friction; wear; SEM analysis

INTRODUCTION

Friction and wear behavior is one of the most important properties of rubber and its composites. Therefore, many studies on friction and wear properties of rubber and its composites have been carried out. A scientific understanding of the mechanism of friction and wear is still lacking, because wear is complex phenomenon and its mechanism depends on many parameters like the chemical and physical properties of rubber bulk, composition, mating surface, load, and the velocity, etc.[1–9]. Research results have shown that Acrylonitrial butadiene rubber (NBR) and Polyvinyl chloride (PVC) are fairly compatible. The application of NBR/PVC composites come down to wire, hose, sealing joint strip, rubber-covered roller, and sole of shoes. However, the research for friction and wear properties of NBR/PVC is lacking.[10–12]

In this paper, NBR/PVC composites with different PVC content were prepared. The effect of PVC content on the mechanical strength and tribological properties of the NBR/PVC composites was investigated. The morphologies of the worn traces and debris of NBR/PVC composites and worn traces of mating ball were observed using a scanning electron microscope (SEM). The mechanism of the friction and wear behavior of NBR/PVC composites is also discussed.

Correspondence to: X. Huang (hxw9766@163.com).

EXPERIMENTAL

Materials

Acrylonitrial butadiene rubber (NBR) used in this study was N-32 (acrylonitrile content 32%, Mooney viscosity [ML 1 + 4] at 100°C : 46), which was kindly supplied by Lanzhou Chemical Industrial Co. Ltd of China. Polyvinyl chloride (PVC) was purchased from Shanghai Chlor-Alkaki Chemical Co. Ltd of China. Other materials, such as carbon black, zinc oxide, sulfur, stearic acid, etc., were commercial products.

Sample preparation

The NBR/PVC matrix was mixed in the following mass content of PVC with 0, 10%, 20%, 30%, 40%, and 50%. The carbon black, sulfur, promoter DM, stearic acid, and zinc oxide were 36 per hundred parts of (phr), 1.5 phr, 1.2 phr, 1.3 phr, and 4 phr, respectively. All the compounds were mixed in an internal mixer (SK-150) as per the standard procedure. The rubber specimens for mechanical and wear test were prepared by molding at 140°C for 45 min according to GB 6038-1993.

Evaluation of mechanical properties

The tensile strength and the elongation at break of NBR/PVC composites were determined using an INSTRON-1121 tester at room temperature according to GB528-1992. The shore A hardness of composites

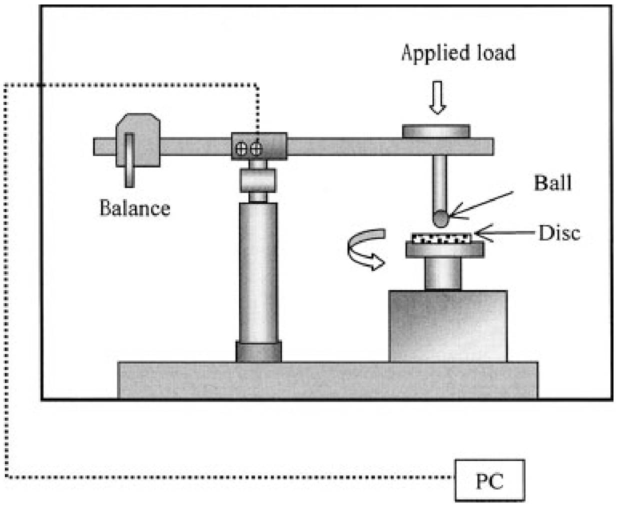

Figure 1 Diagram of pin-on-disk friction and wear test apparatus.

was determined by a HS-74 tester at room temperature according to GB531-1983.

Friction and wear test

Friction and wear behavior of the NBR/PVC composites were run in a friction–wear tester with a ball-on-disc configuration. The schematic diagram of the main apparatus of the wear tester is shown in Figure 1. As shown here, the surface of a rotating NBR/PVC composite disc was rubbed against a stainless steel ball. Friction coefficient was calculated by moment of friction force that was detected by BLK-50 load sensor. The wear rate W (g/m) of each specimen was calculated from the relationship: $W = (m_1 - m_0)/L$, where m_0 and m_1 are the mass losses before and after the test measured by a balance with accuracy of 0.001 mg, and L is the sliding distance.

The disc with a diameter of 45 mm and a thickness of 6 mm was made of NBR/PVC composite specimens. The disc was ultrasonically cleaned in ethanol before and after the experiments, and then dried in a convection oven at 60°C for 120 min. The mating ball was made of stainless steel (GCr15), with a diameter of 5 mm. The ball was cleaned with cotton dipped in acetone and dried in air prior to the commencement of the experiments. Friction and wear were carried out at an applied load of 59.8 N, sliding velocity of 0.11 m/s, and dry ambient condition at room temperature over a period of 60 min.

Morphological analyses

The morphologies of the worn traces and worn debris of NBR/PVC composites and worn traces of mating ball were observed using a JSM-5600LV scanning electron microscope (SEM). Gold palladium alloy was sputtered on the samples for further observation.

RESULTS AND DISCUSSION

Mechanical properties

Figure 2 shows the effect of the PVC content on the tensile strength and the elongation at break of NBR/PVC composites. It is seen that the tensile strength and the elongation at break of NBR/PVC composites are lower than that of NBR rubber without PVC. As the PVC content in the composites is 50%, the tensile and the elongation at break of composite decreases to 15.9 MPa, 97% from 21.3 MPa and 600% of the value of NBR rubber without PVC, respectively. Note that the tensile strength and the elongation at break of NBR/PVC composites show different change with increasing PVC content in composites. The elongation at break of NBR/PVC composites almost linearly decreased with the increase of PVC content. While as the PVC content in the composites was from 10 to 50%, the highest tensile strength of the composites is obtained at composite containing 30% PVC.

The variations of the shore A hardness of NBR and NBR/PVC composites are shown in Figure 3. It is seen that the shore A hardness of composites increases with the increase of the PVC content. As the PVC content is 30 and 50%, the shore A hardness of the composites rises by a factor 1.3 and 1.4 as compared to NBR without PVC.

To sum up, the best synthetic mechanical properties of NBR/PVC composites is got as the PVC content is 30%.

Friction and wear properties

Figure 4 shows the variations of the friction coefficient of NBR/PVC composites sliding against GCr15 stainless steel ball as a function of PVC content. It is seen that the friction coefficient of composites is

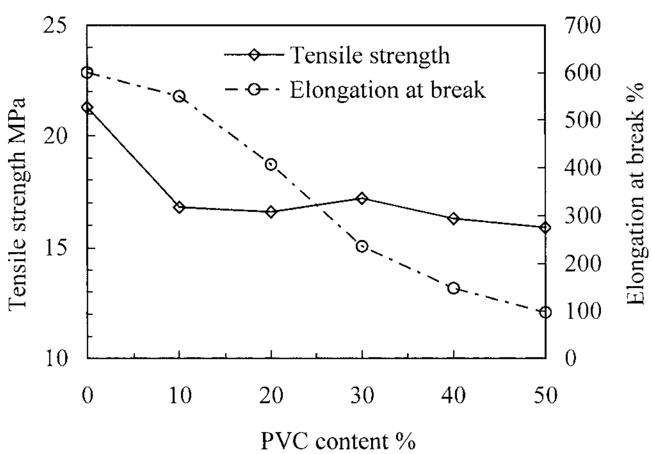

Figure 2 The effect of PVC content on the tensile strength and elongation at break of NBR/PVC composites.

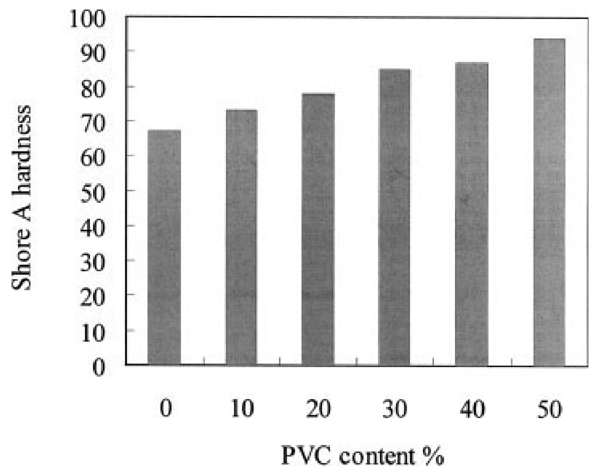

Figure 3 The effect of PVC content on the shore A hardness of NBR/PVC composites.

decreased sharply when PVC content is lower than 20%. Then the friction coefficient decreases gently with increasing PVC content to 50%. The lower friction coefficient of about 0.4 is got in this experiment when the PVC content from 30 to 50%.

The effect of the PVC content on the wear rate of NBR/PVC composites sliding against GCr15 stainless steel ball is shown in Figure 5. It was noted that the PVC-filled NBR composites exhibit a decreased wear rate in comparison to the unfilled one. But the wear rate does not linearly relate to the PVC content. The wear rate of the composites decreases with the increase in PVC content to 30%. Then the wear rate of the composites increases with the PVC content to 50%.

In the combination of tribological properties and mechanical strength, it could be recommended that the optimal content of PVC in the composite should be 30%.

SEM analyses

It is now widely accepted that the interface between two contact surfaces plays a crucial role in sliding resistance, thus the morphologies of the worn traces of NBR/PVC composites and mating ball were observed by SEM.

Figure 6 shows SEM photographs of worn surface of NBR and NBR/PVC composites after the experiments. There are obvious differences among the worn surface of NBR/PVC composites. It may be seen that a series of periodic parallel wear marks [Fig. 6(a)] perpendicular to the sliding direction are formed on the worn surface of NBR rubber without PVC. That is, the typical wear abrasion pattern of rubber materials is formed during sliding process in this condition.[3–6] Similar to the case of NBR rubber, the worn surface [Fig. 6(b)] of the NBR90/PVC10 composite consists of saw tooth ridges perpendicular to the sliding direction of composite too. While the PVC content reaches to 30% and 50%, the abrasion pattern phenomena could not be observed on the worn surface [Fig. 6(c, d)] in these conditions. There are some cracks and cavities on their worn surface, the size of cracks and cavities of NBR50/PVC50 composite is larger that those of NBR70/PVC30 composite.

The friction force between rubber and a hard surface has two contributions commonly described as the adhesion and hysteric components, respectively.[1] The friction force of rubber composite is expressed by the relationship: $F = F_{\text{ahe}} + F_{\text{hyst}}$, where F_{ahe} is

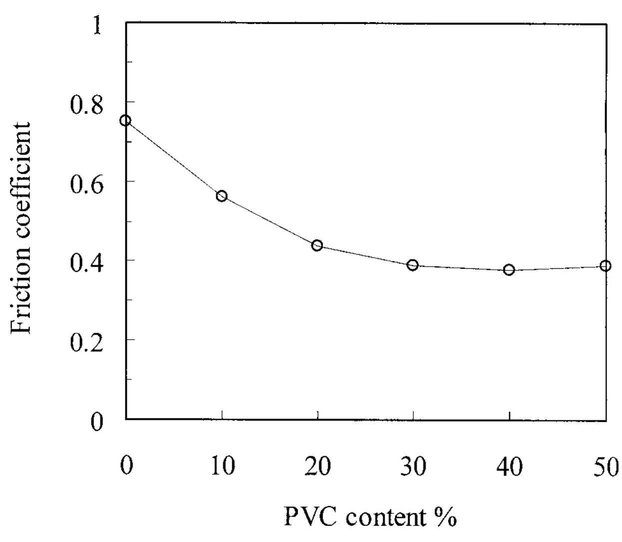

Figure 4 The effect of PVC content on the friction coefficient of NBR/PVC composites. (Load: 59.8 N, Velocity: 0.11 m/s, Time: 60 min)

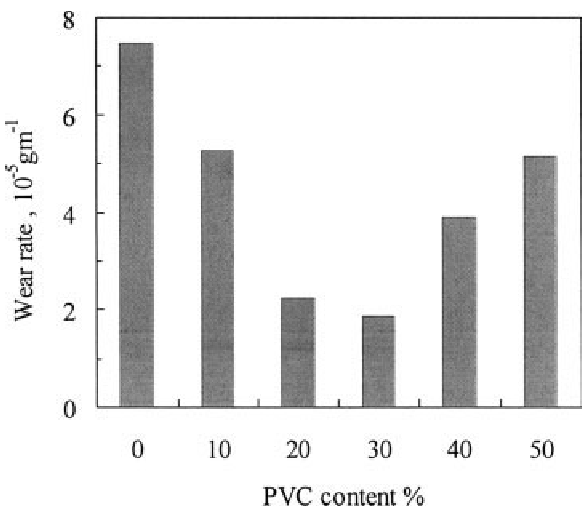

Figure 5 The effect of PVC content on the wear rate of NBR/PVC composites. (Load: 59.8 N, Velocity: 0.11 m/s, Time: 60 min)

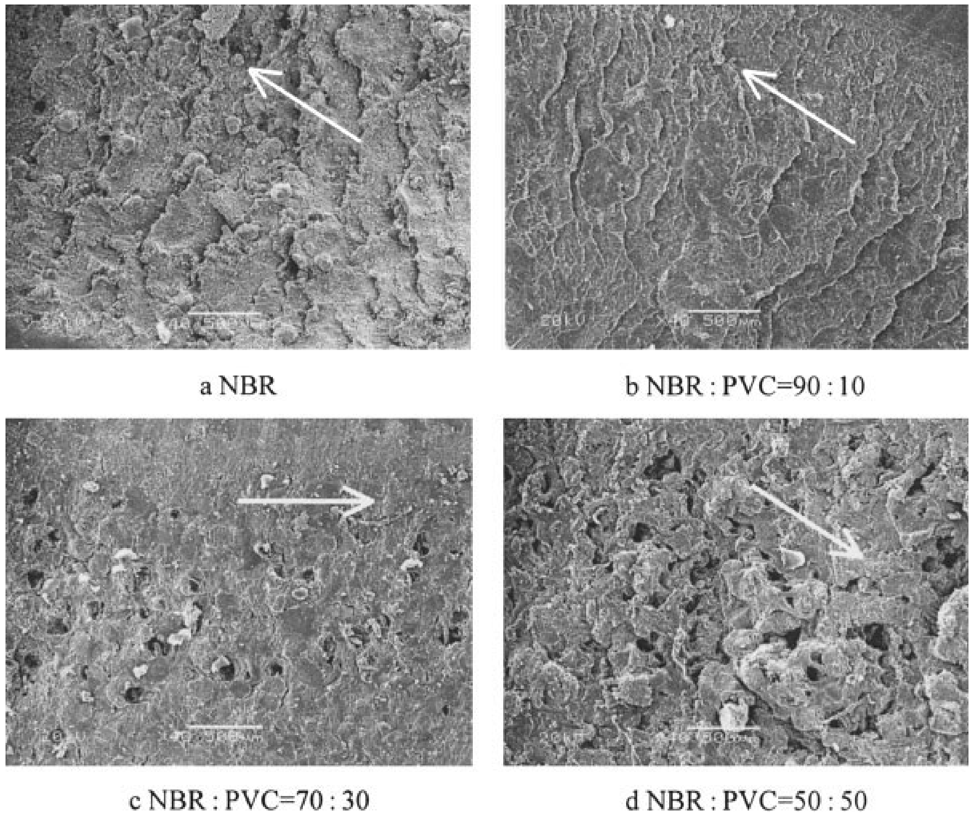

Figure 6 SEM photograph of worn surface of NBR and NBR/PVC composites after the experiments. The arrow indicates the sliding direction.

adhesion force, and F_{hyst} is hysteric force. In this paper, part of the friction coefficient comes from the adhesion F_{adh} between the NBR rubber composites surface and the stainless ball. The other contributions are due to the friction force F_{hyst} from the internal friction of the NBR rubber composites.

In the combination of tribological properties, mechanical properties, and SEM analyses, the friction and wear mechanism of NBR/PVC will be discussed as follows. The elongation at break of NBR/PVC composites decreases with the increase of the PVC content, it indicates that the elastic properties of composites decrease, while the plastic properties increase. This effect results in the decreasing of friction force F_{hyst} from the internal friction of the NBR rubber composites, which leads to a lower friction and wear. This effect is also the main reason for the disappearance of abrasion pattern of NBR when the PVC content is higher.

The shore A hardness of composites is increasing with increasing the PVC content, which means the higher the PVC content, the lower the deformation under the same applied load. Thus the area of real contact between NBR rubber composites and stainless ball is decreasing. Thus the adhesion F_{adh} becomes lower leading to the lower friction coefficient. The reason why the friction coefficient approaches constantly as the PVC content is above 30% may be because of the lubricating effect of PVC, discussed later. It is worth pointing out that the wear rate of NBR50/PVC50 composite is higher than that of NBR70/PVC30 composite, this could be related to the interfacial bonding of composites. That is, an excess amount of PVC leads to the weakening of interfacial bonding and more severe structural inhomogeneity of the composite (Fig. 5), and hence to higher wear rate.

Figure 7 shows SEM photographs of worn surface of mating stainless ball sliding against NBR and NBR/PVC composites after the experiments. It may be seen that a kind of transfer film that formed on the mating ball [Fig. 7(a,b)] sliding against NBR without PVC is rough, the scuffing is observed on the surface. Note that the NBR/PVC composite formed a smooth film [Fig. 7(c–f)] on the stainless ball counterface under the same conditions. The higher the PVC content, the smoother is the formation of transfer film. The smooth surface on the mating ball in the case of NBR/PVC composite may be the other reason for lower friction coefficient and lower wear rate than that of NBR without PVC. It can be inferred that PVC act as the lubricating agent in these conditions.

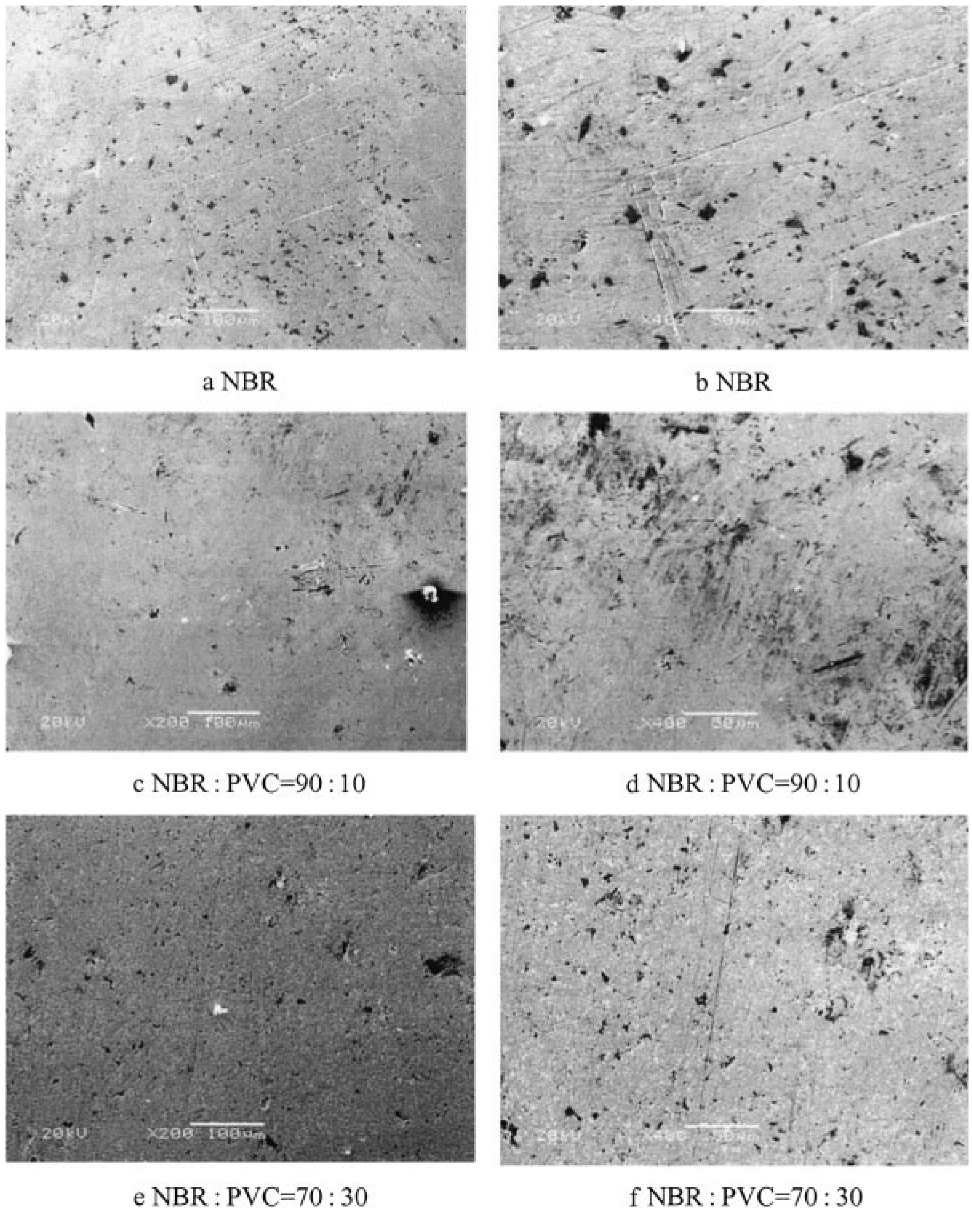

Figure 7 SEM photographs of worn surface of mating stainless ball sliding against NBR and NBR/PVC composites after the experiments.

Figure 8 shows SEM photographs of debris of NBR/PVC composites. It may be seen that the worn debris of the NBR/PVC composites show the similar morphologies compared with each other. That is, the dump-like debris formed in the sliding process in all cases. But the size of debris is different from each other, the smallest debris was got when the PVC content is 30% in the composites. It can be easily speculated that PVC play a part in reducing the size of the debris formed during the sliding process in this case leading to a lower wear. In other words, the frictional failure unit of NBR70/PVC30 composite being smaller should be an important reason of the wear of the composite being lowest.

CONCLUSIONS

From the above discussions, the following conclusion could be drawn. It was found that the friction and wear of NBR/PVC is lower than that of NBR without PVC. The NBR/PVC composite with 30% PVC content shows the best synthetic mechanical and tribological properties. The inferior elastic properties and the lesser deformation under the applied load of composites with PVC results in decrease in hysteric force and adhesion force, which leads to a lower friction and wear of NBR/PVC composites. The frictional failure unit of NBR70/PVC30 composite being smaller should be an important reason of the wear of the composite being lowest. The lubricat-

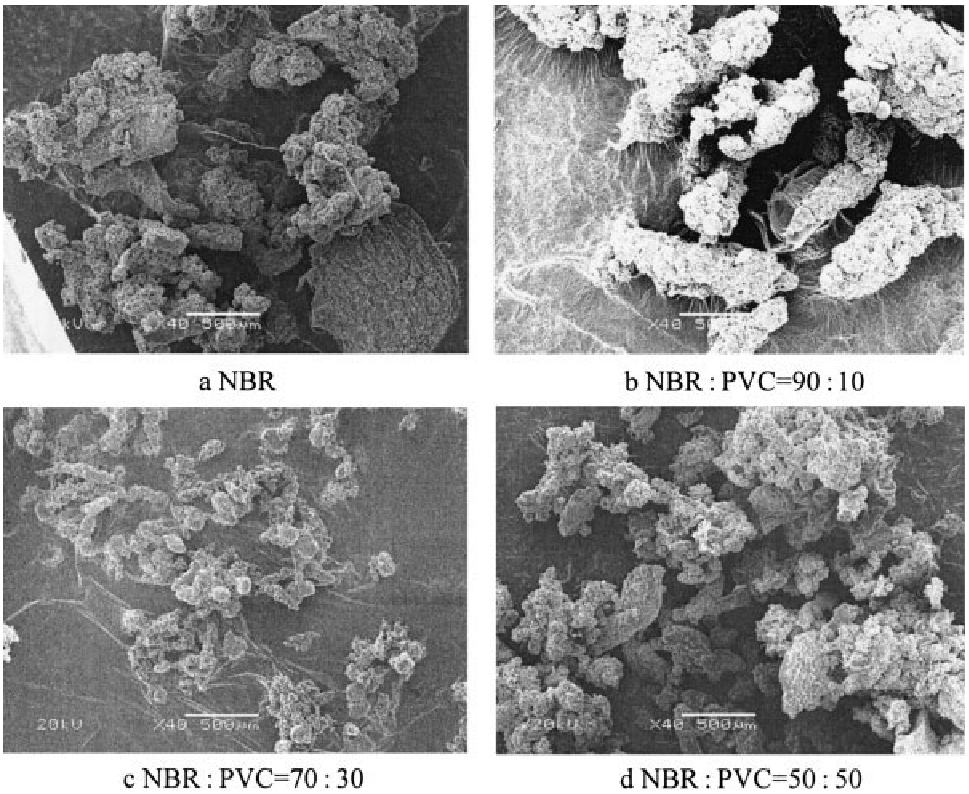

Figure 8 SEM photograph of debris of NBR and NBR/PVC composites.

ing effect of PVC played an important role in decreasing the friction coefficient and wear of NBR/PVC composites.

References

1. Persson, B. N. J. Surf Sci 1998, 401, 445.
2. Maeda, K.; Bismarck, A.; Briscoe, B. J. Wear 2005, 259, 651.
3. Iwai, T.; Chiyama, Y. U.; Shimosaka, K. Wear 2005, 259, 669.
4. Best, B.; Meijers, P.; Savkoor, A. R. Wear 1981, 65, 385.
5. Fukahori, Y.; Yamazaki, H. Wear 1994, 171, 195.
6. Fukahori, Y.; Yamazaki, H. Wear 1994, 178, 109.
7. Thavamani, P. P.; Bhowmick, A. K. J Mater Sci 1993, 28, 1351.
8. Bielinski, D. M.; Slusarski, L.; Affrossman, S.; Oneill, S. O.; Pethrick, R. A. J Appl Polym Sci 1997, 64, 1927.
9. Degrange, J. M.; Thomine, M.; Kapsa, Ph.; Pelletier, J. M.; Chazeau, L.; Vigier, G.; Dudrange, G.; Guerbe, L. Wear 2005, 259, 684.
10. Chen, W.; Yan, H.; Ke, Q.; Li, H. Plast Sci Technol 2002, 4, 15.
11. Senake Perera, M. C.; Ishinaku, U. S.; Mohd, Z. A. Eur Polym J 2001, 37, 167.
12. Kader, M. A.; Choi, D.; Lee, S. K.; Nah, C. Polym Test 2005, 24, 363.