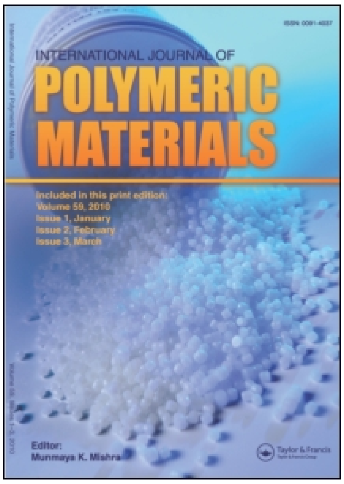

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# The Magnetism Properties and Surface Microstructure of NBR/$Fe_3O_4$ Composites

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# The Magnetism Properties and Surface Microstructure of NBR/$Fe_3O_4$ Composites

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For preparing the good magnetism properties of rubber, NBR/$Fe_3O_4$ composites are prepared. In the experiment, the surface microstructure of NBR/$Fe_3O_4$ and distribution of nano-$Fe_3O_4$ particles are analyzed. The results showed that after the addition of nano-$Fe_3O_4$, the surface microstructure of NBR/$Fe_3O_4$ is greatly improved. The interface bonding of nano-$Fe_3O_4$ and NBR are close-knit. With adding different mass fractions of nanoparticles, the maximum elongation 300% stress at definite elongation and the tensile strength of composites are decreased, but the shore A hardness of composites is improved. The magnetic property of composites can only rely on mass fraction of nano-$Fe_3O_4$, while uncorrelated to the degree of scatter of nano-$Fe_3O_4$.

**Keywords** magnetic properties, nano-$Fe_3O_4$, NBR, physical-mechanical properties, surface microstructure

## INTRODUCTION

Magnetic rubber is prepared by filling magnetic materials in rubber and vulcanization molding. Magnetic rubber has fair magnetism and maintained the advantages of rubber [1–5]. The traditional metal magnetic materials are replaced by magnetic rubber because its own characteristics, such as high saturation magnetic induction, low coercivity, high permeability, low

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high-frequency loss and so on, can be widely used in the automobile, petroleum and chemical industries. Nitrile rubber (NBR) has an excellent resistance to oil, burning oil, aromatic solvents, heat and corrosion due to the polar hydrogen in a molecule of NBR. Therefore NBR was widely used in the seal products. Rubber is filled with nanoferrite particles with low relative density and is suitable to be processed into products with high precision and complex shape [6–8]. The application scope of NBR composites was expanded due to its special properties when there is a need for reliability and performance [9–11].

In this paper, in order to further study on the properties of magnetic rubber, NBR/$Fe_3O_4$ was prepared by mixing nano-$Fe_3O_4$ particles, which have good magnetic properties, in the widely used NBR. The surface microstructure, physical-mechanical properties and magnetic properties of NBR/$Fe_3O_4$ were studied, and the relationship of micro-structure and the magnetic properties of composites was investigated.

## EXPERIMENTS

### Material Preparation

The size of nano-$Fe_3O_4$ particles was $50 \sim 100$ nm because they could be well-distributed during compounding. The magnetic powder size was small and had a large specific surface area. The magnetic density of magnetizing products was well-proportioned and not demagnetized when nanoparticles were uniformly dispersed in rubber. NBR and all accessory ingredients were mixed in the XK-150 mixing machine at 50 ± 5°C for 26 min. The basic formulation was unvulcanized NBR(N41) 420 ± 0.2 g; ZnO 20 g; sulfur 6 g; accelerant DM 4 g; stearic acid 4 g; black carbon 160 g. Meanwhile, 15, 20, 25 and 30% mass fraction of nano-$Fe_3O_4$ particles were added by contrasting with the mass of material used. After the completion of mixing, the specimens were put on a smooth and clean metal plate for 6 h before vulcanization. Last, the specimens were vulcanized in the Y33-50A plate vulcanizing press at 145.0 ± 0.5°C, 10 Mpa for 45 min. The curing time of NBR/$Fe_3O_4$ composites and standard rubber was the same while has nothing to do with the content of magnetic powder.

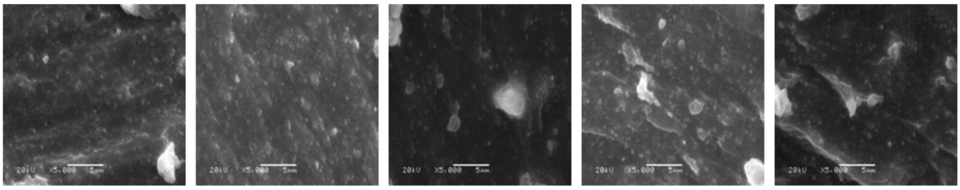
### Performance Test

The environmental temperature was 23 ± 2°C, and the relative humidity was $30\% \sim 50\%$. The surface microstructure of NBR/$Fe_3O_4$ and distribution of nano-$Fe_3O_4$ particles were analyzed by using a JSM-5600LV electron microscope and energy dispersive X-ray spectrometer. The tensile strength, maximum elongation and 300% stress at definite elongation of the specimens was measured after they were vulcanizated with a DXLL-10000 electronic tensile tester. The shore A hardness was characterized using a MC010-TH200 rubber durometer. Mooney viscosity were measured by Mooney Viscometer. The magnetic property was tested by using a U5-10 magnetizer, and magnetization time was 20 min.

# RESULTS AND DISCUSSION

## Surface Microstructure

Because the molecular chain of NBR has strong polarity and a low degree of flexibility, which causes bad compatibility of the polymers, the surface of ordinary NBR is rough with obvious surface defects and much pits as seen in Figure 1(a). After adding nano-$Fe_3O_4$ particles, the surface microstructure is smoother with less surface defects and pits in Figure 1(b). This is because the nano-$Fe_3O_4$ particles have good chemical and thermal stability and a large specific surface area [9,13]. Thus, we can know that nano-$Fe_3O_4$ particles have a high-energy surface, while NBR has a low-energy surface. When mixing the two materials, the low-energy surface of NBR is inclined to be strongly adsorbed on the high-energy surface of nano-$Fe_3O_4$ particles. This kind of adsorption can compensate the imbalance force field on the high-energy surface [8,9,11]. At the same time, nano-$Fe_3O_4$ particles can fill surface defects of NBR, which represents that nano-$Fe_3O_4$ particles can better reinforce the NBR. And the two-phase interface of NBR and nano-$Fe_3O_4$ are fuzzy in the NBR matrix, which indicates nano-$Fe_3O_4$ particles and NBR matrix had good affinity in Figure 1. The polymer mixed process is completed in a sticky flow condition which can be seen as nano-$Fe_3O_4$ dissolves in rubber. Through comparison, we can know that the surface structure of NBR/$Fe_3O_4$ composites is better when the mass fraction of nano-$Fe_3O_4$ is 15%. However, with increasing the level of filling, the surface properties gradually reduced and there was a more granular convex body which means greater roughness in Figures 1(c)–(e). This is because the integration degree of NBR and nano-$Fe_3O_4$ particles



(a) 0% (b) 15% (c) 20% (d) 25% (e) 30%

**Figure 1:** SEM pictures of NBR with a different mass fraction of nano-$Fe_3O_4$ (5000×).

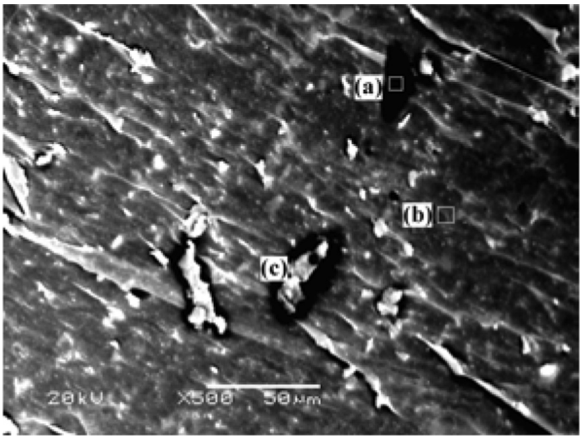


**Figure 2:** Microscopic surface backscattered image (mass fraction of nano-$Fe_3O_4$ particles 25%).

decreased, and the irregular phase structure increased due to the bond strength variation of the two-phase interface, which led to the composites strength reduction when the addition is over 20%.

In order to accurately study the distribution of nano-$Fe_3O_4$ particles, components of the surface elements were analyzed. Microscopic surface backscattered image of the NBR/$Fe_3O_4$ composites is shown in Figure 2. As in Figure 2, we selected areas a, b and c to analyze the distribution of nano-$Fe_3O_4$. The results are shown in Table 1.

We can see from Table 1 that the percentage composition, atom percentage composition of Fe, and counting rate of x-ray are basically in line with the addition of nano-$Fe_3O_4$. There are minute differences between different regions owing to the inhomogenous mixing. Surface microstructure of area c has more defects due to more nano-$Fe_3O_4$. However, in terms of overall effect, the mixing is relatively uniform.

## Physical-Mechanical Properties

The change curve of 300% stress at definite elongation, tensile strength and maximum elongation of the NBR/$Fe_3O_4$ composites filled with different mass fraction of nano-$Fe_3O_4$ in Figure 3.

**Table 1:** The distribution of Fe elements of composites.

| Surveyed area | Line | Weight % | Cnts/s | Atomic % |
|---|---|---|---|---|
| a area | Ka | 22.03 | 42.83 | 12.27 |
| b area | Ka | 23.17 | 45.27 | 13.17 |
| c area | Ka | 27.32 | 53.88 | 17.91 |

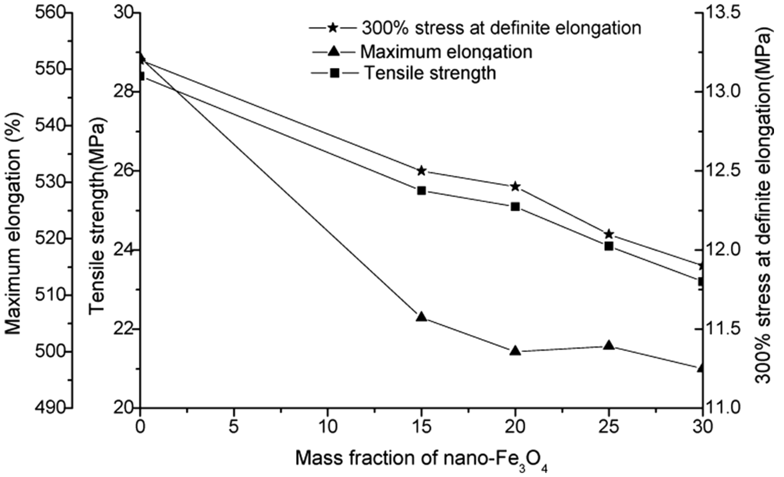


**Figure 3:** Change curve of 300% stress at definite elongation, tensile strength and maximum elongation of the NBR/ $Fe_3O_4$ with a different mass fraction of nano-$Fe_3O_4$..

It can see from Figure 3 that 300% stress at definite elongation, tensile strength and maximum elongation of NBR/$Fe_3O_4$ composites are slightly lower than ordinary NBR. In order to obtain better strength for polymer composites, a key factor is the uniformity dispersion of nano-particles; the other is the interface structure of rigid particles surface in the matrix [3,5,9]. With the addition of nano-$Fe_3O_4$ particles increasing for composites, interfacial thickness is decreased due to the spacing of particle are reduced between the particles. The wrapped degree of nano-particles is weakened in the NBR matrix, and bond strength of two-phase interface is breaked up, imbalance force is concentrated to cause strength of composites is decreased. With addition of nano-$Fe_3O_4$ increasing, the homogeneous degree of nano-particles gradually declined and agglomeration increased. Binding force is decreased due to be a large area of phase interface existing between agglomeration of nano-$Fe_3O_4$ particles and the rubber matrix in Figure 1.

The change curve of shore A hardness of NBR/$Fe_3O_4$ composites filled with different mass fraction of nano-$Fe_3O_4$ in Figure 4. It can be observed that shore A hardness of NBR/$Fe_3O_4$ composites is larger than ordinary NBR. Shore A hardness of unfilled NBR was 63 degrees, while the shore A hardness of NBR/$Fe_3O_4$ composites was 74 degrees when the mass fraction of nano-$Fe_3O_4$ was 30%. The reason for the increase of hardness, on one hand, was that the hardness of nano-$Fe_3O_4$ was bigger than that of unfilled NBR, which deservedly increased the hardness of the composites [4,12,14], nano-$Fe_3O_4$ particles filled the cavity of NBR, which increased the hardness of NBR/$Fe_3O_4$ composites as well; on the other hand, the good interfacial bonding and a certain thickness of the interfacial layer exist around evenly distributed rigid particles

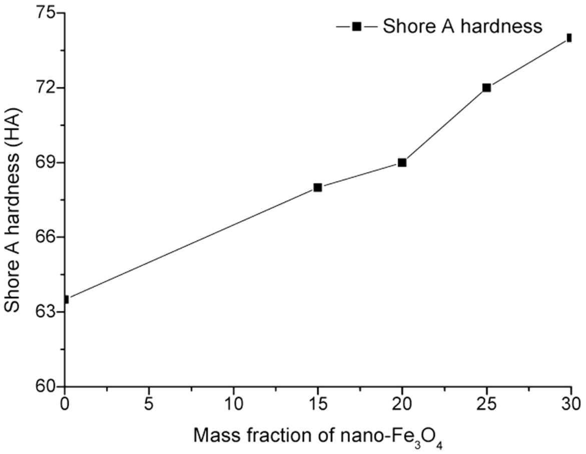


**Figure 4:** Change curve of shore A hardness of NBR/$Fe_3O_4$ with a different mass fraction of nano-$Fe_3O_4$..

which causes craze when damage are produced [1,15], which causes a large amount of impact to be consumed and suffer stress is well-transmited.

The change curve of Mooney viscosity of NBR/$Fe_3O_4$ composites filled with different mass fraction of nano-$Fe_3O_4$ is in Figure 5. The Mooney viscosity of NBR was slightly increased after adding nano-$Fe_3O_4$ particles, but the processing was affected little. From the above analysis we can know that the low mass fraction of nano-$Fe_3O_4$ and the change of physical-mechanical properties was small.

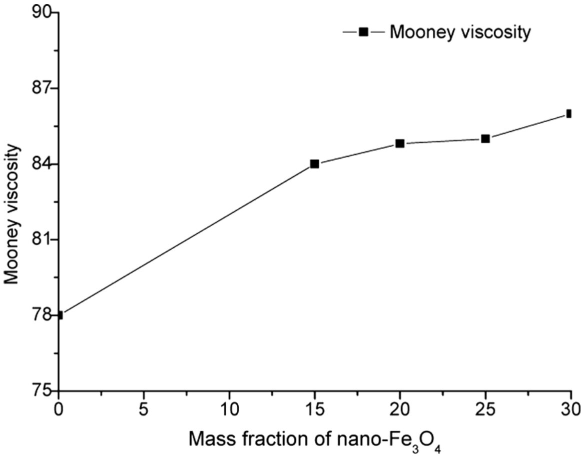


**Figure 5:** Change curve of Mooney viscosity of NBR/$Fe_3O_4$ with a different mass fraction of nano-$Fe_3O_4$..

## Magnetic Properties

The magnetic hysteresis loops of NBR/$Fe_3O_4$ composites are shown in Figure 6. Clearly, by increasing the mass fraction of nano-$Fe_3O_4$, magnetic properties of the NBR/$Fe_3O_4$ composites monotonously increase, and the saturation magnetization strength of the composites increases constantly. The composites show typical characteristics of paramagnetism. Due to internal defects in rubber materials, wall energy is reduced and the effect of magnetization is influenced, so the magnetic density needed during the magnetization process is relatively larger [8,9]. With the magnetic intensity increasing, saturation magnetization strength of the NBR/$Fe_3O_4$ composites increases due to the microstructure of composites weakened with the addition of nano-$Fe_3O_4$ increasing. When the magnetic strength increased to 10,000 (Oe), the value of saturation magnetization strength tends basically to steady.

The changing curve of saturation magnetization strength (*Bs*), residual magnetic flux density (*Br*), and coercive force (*Hc*) with different mass fraction of nano-$Fe_3O_4$ particles are shown in Figure 7. As seen in Figure 7, *Hc* of the NBR/$Fe_3O_4$ composites is small. When the mass fraction of nano-$Fe_3O_4$ is 15%, the value of *Hc* is 14 emu/g which is relatively smaller. *Bs* and *Br* keep good linear relationship with the mass fraction of nano-$Fe_3O_4$. By increasing the mass fraction of nano-$Fe_3O_4$, *Bs* and *Br* continuously become larger. This is because magnetic properties of the NBR/$Fe_3O_4$ composites do not depend on the way nano-$Fe_3O_4$ particles scatter, and also do not depend on physical processes between particles and substrate or particles and particles [4,8,12], but only depend on the mass fraction of nano-$Fe_3O_4$. Meanwhile, nano-$Fe_3O_4$

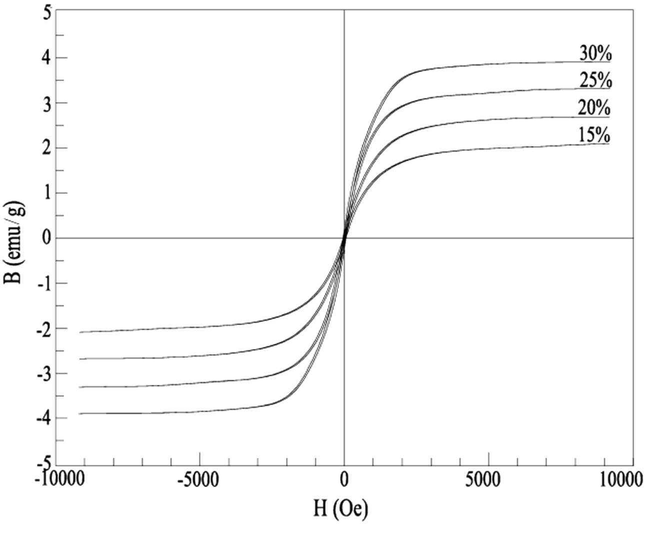


**Figure 6:** Magnetic hysteresis loops of NBR/$Fe_3O_4$ composites.

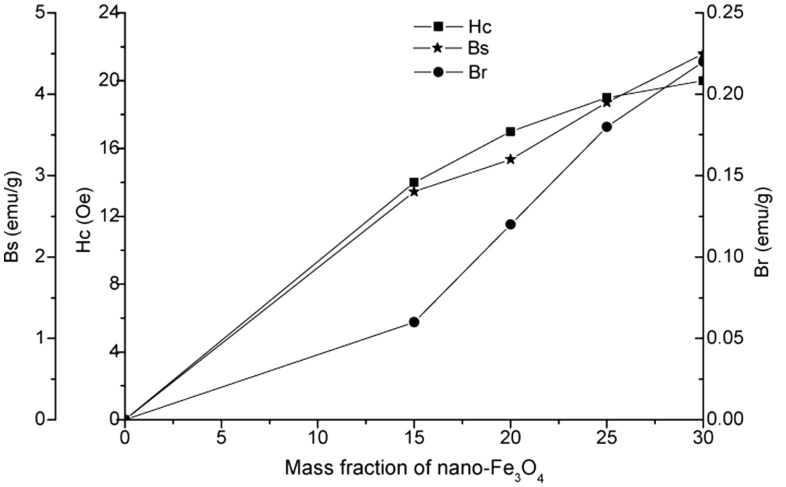


**Figure 7:** Changing curve of saturation magnetization strength (*Bs*), residual magnetic flux density (*Br*) and coercive force (*Hc*) with different mass fraction of nano-$Fe_3O_4$..

particles are ferrimagnetics which have typical characteristic of high frequency, therefore hysteresis losses are lesser. Compared with [8], we can see that NBR/$Fe_3O_4$ has good soft magnetism performance. These all lay a foundation for further application of NBR/$Fe_3O_4$ composites.

## CONCLUSIONS

1) The NBR/$Fe_3O_4$ was prepared by blending. Surface microstructure of NBR/$Fe_3O_4$ was improved due to the addition of nano-$Fe_3O_4$ and was smoother when the addition of nano-$Fe_3O_4$ was 15%.

2) Nano-$Fe_3O_4$ particles were well-inoculated in the NBR matrix, and the distribution of nano-$Fe_3O_4$ was well-proportioned. With increasing the mass fraction of nano-$Fe_3O_4$ 300% stress at definite elongation, tensile strength and maximum elongation of the NBR were decreased while shore A hardness was increased.

3) With the addition of nano-$Fe_3O_4$ increasing, the microstructure of composites has more pits which lead to saturation magnetization strength increasing. The magnetic properties of composites can only rely on the mass fraction of nano-$Fe_3O_4$ particles, while uncorrelated to the degree of scatter of nano-$Fe_3O_4$ particles. The NBR/$Fe_3O_4$ shows good soft magnetism performance.

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