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Current Perspectives

# Preparation of magnetic rubber with high mechanical properties by latex compounding method

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ABSTRACT

the magnetic rubber based on $Fe_3O_4$ nanoparticles and nature rubber were prepared by latex compounding method, in which stable $Fe_3O_4$ aqueous solutions were mixed with natural rubber latex and additives. This process was fast, versatile, reliable, safe, environmentally friendly and inexpensive. What's more, it was found that the magnetic and mechanical properties of magnetic rubber increased together with increase in doping content of $Fe_3O_4$ nanoparticles. Especially, it was demonstrated that the tensile strength (25.0 Mpa) of magnetic rubber was improved to be 478.0% comparing to neat natural rubber (5.2 Mpa), which was 5 times higher than maximal value reported in previous work. At the same time, the magnetic rubber revealed better thermal stability and solvent resistance comparing to the neat natural rubber, too. The work dose not only provides a new way to environmentally friendly preparation of magnetic rubber at low temperature, but also improve the mechanical and magnetic properties of magnetic rubber applied in industry.



## 1. Introduction

Magnetic rubber (MRE) have attracted intensive attention due to their many potential applications, such as large strain actuators, damping devices, bionic robot's artificial muscles, electromagnetic interference shielding and magnetic shape memory polymers [1,2]. Such materials were mainly fabricated from magnetic particles and rubber. It was noticed that the performances of MRE devices were very dependent on the magnetic and mechanical properties of MRE materials. The previous studies have been shown that the magnetic properties of MRE increased with increasing in doping content, but the mechanical properties decreased. The result was attributed to the weak adhesion and bad dispersion between magnetic fillers and rubber [3]. So, magnetic particles was modified by organic molecules to improve adhesion and dispersion between magnetic fillers and rubber. Unfortunately, in most cases, the magnetic powder with surface modification were doped into rubber matrix by mechanically blending, in which the magnetic particles tended to greatly decrease the mechanical properties of MRE [1–7]. The results was attributed to that the dispersion of magnetic particles in rubber matrix was difficult to be improved by the surface modification. The problem greatly precluded their practical application in industry. Therefore, a great challenge in this rapidly growing field was to find effective methods for improving dispersion of magnetic particles into rubber matrix and the mechanical properties of magnetic rubber. Recently, a relatively new approach to incorporate nanofillers in a nature rubber matrix was based on the use of the so-called latex technology, in which the nanofiller was directly mixed to the aqueous colloidal dispersion of the nature rubber (NR) latex [8–10]. This process was fast, versatile, reliable, safe, environmentally friendly and inexpensive. Also, the distribution of nanofiller in NR matrix was easily controlled by the process. However, to be our best knowledge, there were few works reporting the preparation of MRE using latex technology.

Based on the above considerations, we developed a facile latex compounding approach to synthesis MRE at room temperature. This approach offered a uniform dispersion of $Fe_3O_4$ in cross-linked NR. Owing to the well dispersion microstructures, the MRE exhibited high mechanical properties and comparable magnetic properties. Moreover, this paper was to discuss some mechanistic aspects of the physical process. The proposed discuss will give an explanation for the high mechanical properties of MRE in present work. Although, some parts of the explanation were reported earlier, here the whole explanation will be introduced to a broader community for the first time. It may be a help for further discussions and the development of better latex compounding process to prepare the MRE.

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## 2. Experimental section

### 2.1. Materials

NR latex dry rubber content 60 phr (per hundred rubbers) was supplied by Chengyi Rubber Company, Dongguan. $FeCl_3$ and $FeCl_2$ were supplied by Shanxi Wanhua cheminal Company, Potassium hydroxide (KOH), sodium hydroxide (NaOH) and Levelling Fatty alcohol polyoxyethylene ether (Agent O) were used as stabilizers and were also kindly provided by Wanhua cheminal Company, Sulfur (S) were used as vulcanizing agents; Zinc oxide (ZnO) were used as activator; Zinc diethyl dithiocarbamaate (ZDC) were used as accelerator, and all were purchased from Sichuan Haida Rubber Group.

### 2.2. Preparation of MRE by the latex technology

(1) Preparation of sulfur and additives suspension solution

The 20.0 g casein and 6.0 ml $NH_3$ solution (20.0%) were added to deionized water under stirring at 50 °C to form stable casein aqueous solution (10.0 wt%). 12.5 g KOH and 12.5 g alkyl polyoxyethylene ether were added to deionized water (50.0 ml) under stirring at 50 °C to form KOH and alkyl polyoxyethylene ether aqueous solution (20.0 wt%), respectively.

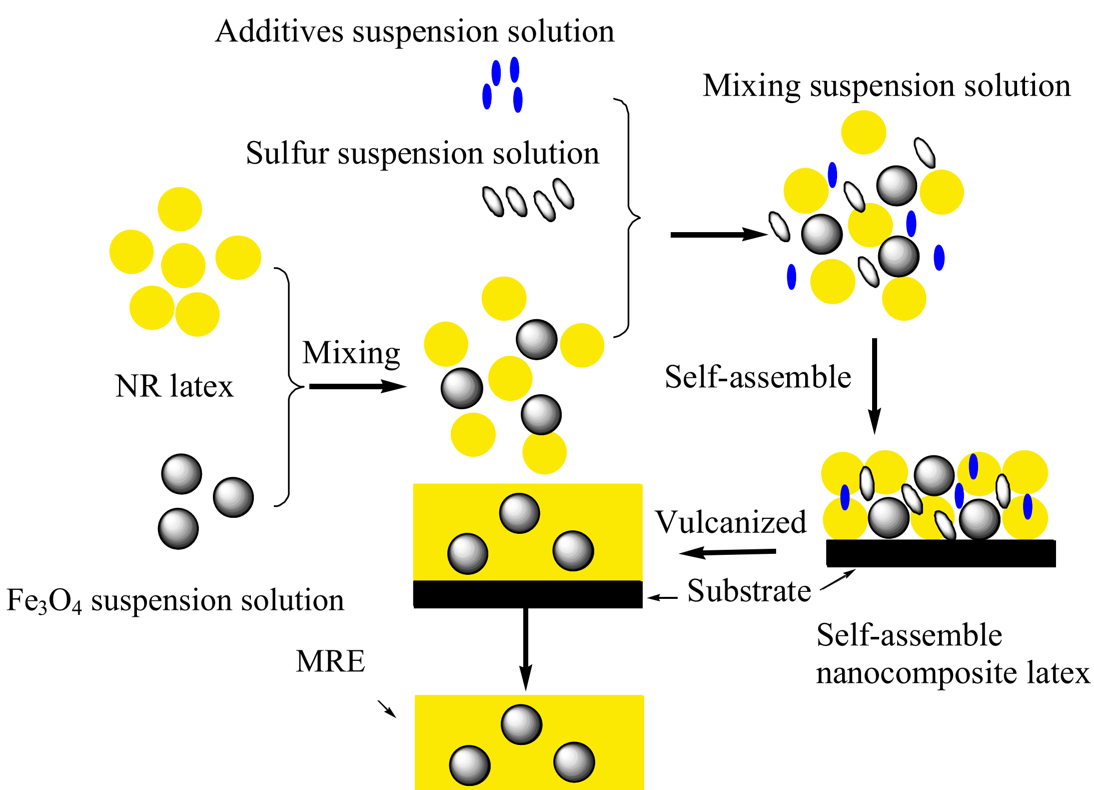
The 50.0 g sulfur, 20.0 ml casein aqueous solution and sand were added to deionized water under stirring for 12.0 h at room temperature. And the sand was separated and removed by sieve from mixing solution to form stable sulfur (S) suspension solution (50.0 wt%). 20.0 g Zinc oxide (ZnO), 3.0 g dispersing agent NNO (NF), 40.0 ml casein solution and sand were added to deionized water under stirring for 12.0 h at room temperature. And the sand was separated and removed by sieve from mixing solution to form stable ZnO suspension solution (40.0 wt%). 50.0 g Zinc diethyldithiocarbamate (ZDC), 1.15 g NF, 20.0 ml casein solution and sand was added to deionized water under stirring for 12.0 h at room temperature. And then the sand was separated and removed by sieve from mixing solution to form stable ZDC suspension solution (50.0 wt%).

(2) Synthesis of $Fe_3O_4$ suspension solution

Stable $Fe_3O_4$ suspension solution was prepared by co-precipitation method as shown in following: 3.58 g $FeCl_2 \cdot 4H_2O$, 6.08g $FeCl_3 \cdot 6H_2O$ were dissolved in 90.0 ml distilled water to form a mixing solution. Then 92.4 ml NaOH aqueous solution (53.0 mg/ml) was added drop-wise into the mixing solution under vigorous stirring. The reaction was continued for 90.0 min at 50.0 °C. Precipitated $Fe_3O_4$ nanoparticles were separated with a magnet and was washed for several times with deionized water to remove excess materials. And then the pure $Fe_3O_4$ nanoparticles were dispersed in deionized water to form stable $Fe_3O_4$ suspension solution (0.1 g/ml).

(3) Preparation of MRE

The MRE based on $Fe_3O_4$ nanoparticles and NR was prepared by a latex compounding method as shown in Scheme 1. In this process, the 25 ml NR latex was uniformly mixed with different amount of $Fe_3O_4$ suspension solution (0, 4.5, 10.5 or 15.0 ml) by mechanical agitating. And then, the 0.15 g ZnO, 0.15 g ZDC, 0.3 g S, 0.075 ml KOH and 0.075 ml Agent O suspension solution were added into the $Fe_3O_4$ and NR mixing latex. The mixing suspension solution was moved directly into the mold (20.0 mm × 10.0 mm × 1.0 mm) and pre-vulcanized at 50 °C for 90 min. And then, it was further dried at room temperature for 3d. For comparison, a sample of neat NR was prepared from NR latex by the same preparation conditions.




**Scheme 1.** Preparation of MRE.