Experimental study of cooling water temperature on properties of short fiber and rubber composites

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Abstract: Cooling water temperature is one of the important factors, which effects the mixing process and cooling water temperature of SFRC greatly. The effects of different cooling water temperature on mixing process of SFRC have been researched by experiments. In the paper, the cooling water temperature was changed from 20°C to 50°C respectively. Also the addition of short fibers was about 0phr~6phr. The experimental results indicated that SFRC had better physical and mechanical properties as cooling water temperature was about 40°C, and the addition of short fibers was about 3phr.

1. Introduction

Short fiber-rubber composite material (SFRC) is a kind of composites, which could be manufactured by the way of mixing rubber, short fibers and other fillers such as N330, SiO2, 4010NA. Because SFRC has good performances, it has been used in almost all kinds of rubber products in recent years [1~10]. Especially, SFRC has been applying to all parts of tires, such as antiseismic engineering. While mixing is the first step and one of the most important steps of manufacturing SFRC, because mixing quality influences the coming process and products performances directly. Due to cooling water temperature is an important factor which influences the mixing quality and physical and mechanical properties of SFRC, so the effects of cooling water temperature on mixing process and physical and mechanical properties has been researched by experiments in this paper.

2. Experiments

2.1. Materials and Formulation (unit: phr).

The materials and formulation for manufacturing SFRC are shown as following, Natural Rubber (NR),100.0, Polyester Short Fibers (3~5mm, slenderness ratio 120), 0~6.0, Carbon Black (N330),38.5, White Carbon Black (SiO2),15.0, Antioxidant (4010NA),2.0, Zinc Oxide (ZnO),3.5, Stearic Acid (SA),2.0 Coupling Agent (CA), 3.0, N-Oxidiethylene-2-Benzothiazolyl Sulfonamide (NOBS), 1.5, Sulfur (S),1.0.

2.2. Equipments.

X(S)M-1.7 Internal Mixer, X(S)K-160 Open Mixer, QLB-D400×400×2 Flat Vulcanizing Machine, XD-1 Electronic Microscope, TS2005b Testing Machine, QP-16 Slicing Machine, KS-DR-S Plasticity.
Testing Machine, LX-A Rubber Durometer, MM4130C Vulka Meter without Rotors and DG1000NT Carbon Dispersion Testing Machine.

2.3. Experimental conditions.  
Addition of short fiber is 0phr~6phr, cooling water temperature is 20℃~50℃, fill factor is 0.6, top ram pressure is 0.6MPa, vulcanization condition is 150℃×25 (min) ×10MPa(oil pressure), testing speed for physical and mechanical properties is 50mm/min, and rotor speed is 70rpm.

2.4. Orientation of short fibers.  
The way of making short fibers get orientation is tablet forming the mixed rubber of SFRC on the open mixer. The method is setting the open mixer roller space to 4mm, and making the mixed rubber pass through the roller space for 5~10 times at the same direction in order to make short fibers orientated at a certain direction. Afterwards, the roller space of the open mixer was to 2mm, through which making the mixed rubber pass at the same direction, also about 5~10 times. As a result, short fibers would get orientation.

2.5. Testing samples.  
The samples for performances testing were made in the following way. Pay attention to the orientation of short fibers during the vulcanization process of mixed rubber, then the samples should be made along the orientation of short fibers as shown in the Figure 2 and Figure 3.

3. Results and discussion  
The cooling water temperature was changed as 20℃, 30℃, 40℃ and 50℃ for researching the effects of cooling water temperature on the mixing process and physical and mechanical properties of SFRC. Also, the addition of short fibers was changed as 0phr, 1phr, 3phr, 5phr and 6phr in the experiments. And the other experimental conditions were not changed.

The experimental results have been shown in Figure 4 and Figure 5, in which, ● cooling water temperature was 20℃, ▲ cooling water temperature was 30℃, ■ cooling water temperature was 40℃, ▼ cooling water temperature was 50℃.
3.1. Mixing process

3.1.1. The effects of cooling water temperature on mixing process
To cool the mixing room and mixer rotors during the mixing process is necessary with cooling water, because if the temperature is too high would be make rubber materials get scorching. As shown in the Figure 4, if the cooling water temperature increased, then the maximum energy consumption and the unit energy consumption would decrease while the discharging temperature would increase with the condition which was the short fibers addition was the same. The reason is that, with a low cooling water temperature, there would be some dew on the surfaces of mixer rotors and mixing room. Because the temperature in the mixing room was higher than inside of mixer rotors or mixing room, and the air humidity in the mixing room. As a result, the rubber materials would sliding on the surfaces of mixer rotors or mixing room, which made the mixing process need more energy to mix the rubber material. And obviously, a lower cooling water temperature would make the discharging temperature get lower, because it would take away more quantity of heat. Otherwise, if increasing the cooling water temperature, the viscosity of rubber would get lower. This would be easy for the mixing process, and the maximum energy consumption and the unit energy consumption would decrease. But the cooling water would take away less quantity of heat, so the discharging temperature got higher.

3.1.2. The effects of fibers addition on mixing process
As what has been shown in the Figure 4, during the mixing process of SFRC, the maximum energy consumption, unit energy consumption and the discharging temperature would increase along with increasing of short fibers addition. The reason is that, the flow ability of the mixed rubber with short fibers would get worse due to the short fibers modulus was larger than that of rubber matrix. As a result, the frication between the surfaces of mixer rotors and mixing room would increase, leading to
more energy needed for mixer rotors turning, also more quantity of heat would be generated because of higher shearing force. So the maximum energy consumption, unit energy consumption and the discharging temperature would increase.

3.2. Physical and mechanical properties

![Graphs showing physical and mechanical properties](image)

Figure 5. Experimental results for physical and mechanical properties

3.2.1. The effects of cooling water temperature on physical and mechanical properties

As vividly shown in the Figure 5, on the condition of same adding amount of the short fiber, the physical and mechanical properties including strength at 300% elongation, tensile strength, tear resistance, maximum elongation, permanent set at break and hardness of the mixed SFRC would be best if the cooling water temperature was 40℃ (shown as ■). The reason is that, if cooling water temperature was lower, the rubber materials would sliding on the surfaces of mixer rotors or mixing...
room, resulting in the rubber materials could not be mixed well with fillers such as carbon black, short fibers etc. Therefore, the physical and mechanical properties of the SFRC would be worse. But if the cooling water temperature was higher, the viscosity of rubber would get lower, which also made rubber materials could not be mixed well with fillers. Moreover, short fibers could not combine with rubber matrix well, so, the physical and mechanical properties of the SFRC would also be worse. As what has been shown in the Figure 5, the proper cooling water temperature was 40℃.

3.2.2. The effects of fibers addition on physical and mechanical properties
As what has been vividly shown in the Figure 5, comparing the mixed rubber without short fibers and SFRC, the physical and mechanical properties of SFRC including strength at 300% elongation, tensile strength, tear resistance, maximum elongation, permanent set at break and hardness were better, which mean the short fibers had played a role in the reinforcing action. But if the short fibers addition was more than 3phr, the tensile strength, tear resistance, maximum elongation, permanent set at break would get worse, while strength at 300% elongation and hardness would get better and better. The reason is that, if more short fibers were added, due to modulus of short fibers was larger than that of rubber matrix, on one hand the flow ability of the mixed rubber would get worse, on the other hand, more short fibers couldn’t disperse well in rubber matrix. So in general, it is not the more short fibers added, the physical and mechanical properties of SFRC are better. Therefore, according to the experimental results, the proper addition of short fibers is 3phr.

4. Conclusions
Cooling water temperature impacts the mixing process and quality of mixed rubber greatly. During the mixing process, the maximum energy consumption, unit energy consumption and the discharging temperature would increase if cooling water temperature increased or of short fibers addition increased. While the physical and mechanical properties would get better if the cooling water temperature or the short fibers addition was proper. Therefore, according to the experimental results, the proper cooling water temperature is 40℃ and addition of short fibers is 3phr.

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