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# Effect of surfactants on the properties of rubber composites prepared from pyrolytic carbon black/natural latex via wet blending method

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Pyrolytic carbon black (CBp) is the main by-product of waste tire pyrolysis. CBp has high ash content and poor surface activity which leads to the composites reinforced with CBp has lower performance than composites reinforced with commercial carbon black, making it difficult to meet the requirements of tire. In order to realize the application of CBp in tires, the effect of surfactants on the properties of rubber composites prepared by wet mixing of CBp/natural latex was investigated. In the experimental process, sodium stearate ( $C_{17}H_{35}COONa$ ), sodium dodecylbenzene sulfonate ( $C_{18}H_{29}NaO_3S$ ), and sodium p-styrenesulfonate ( $C_8H_7NaO_3S$ ) were used to improve the surface activity and uniform dispersion of the CBp in the natural rubber matrix. The experimental results showed that the dispersity of  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  modified CBp in rubber matrix has [X] and [Y] values of 7.5 and 7.9, and 9.3 and 9.5, respectively, and the dispersion of these rubber composites is significantly better than that of  $C_{17}H_{35}COONa$ . The rubber composites prepared by  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  surfactants has the better physical and mechanical properties. The rubber composite prepared by  $C_{18}H_{29}NaO_3S$  has the highest tensile strength of 25.63 MPa, which increment in tensile strength is 15.6% compare to the rubber composite prepared by  $C_{17}H_{35}COONa$ . Meanwhile the dynamic mechanical properties of rubber composites prepared by modifying CBp with  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  are better than CBp with  $C_{17}H_{35}COONa$ . The  $C_8H_7NaO_3S$  modified CBp/rubber composite has the lowest loss factor ( $\tan\delta$ ) value at 60°C, and the  $C_{18}H_{29}NaO_3S$  modified CBp/rubber composite has the highest  $\tan\delta$  value at 0°C.

## KEYWORDS

waste tires, pyrolytic carbon black modification, surfactants, wet blending, rubber composite

## 1 Introduction

A lot of tires must be made each year as car items have become a necessity in people's life (Zhang et al., 2020). As a result, there are more used tires ending up in landfills every year. Tire waste poses major environmental risks since its components are not decompose in the natural environment (Aboelkheir et al., 2019). One of the most efficient processes for dealing with waste tires is thermal pyrolysis, which may transform scrap tires into tire pyrolysis oil (TPO), pyrolysis carbon black (CBp), and steel (Tian et al., 2021; Tian et al., 2022a; Tian

TABLE 1 Formulation of the rubber composites (phr<sup>a</sup>).

Component	Formulation [phr]	Suppliers
NRL (60%)	100	Taihu Rubber Public Co., Ltd (Thailand)
CBp	50	\
Zinc oxide	3.5	Hebei Shijiazhuang Zinc Oxide Factory
Stearic acid	2	Fengyi Grease Technology (Tianjin) Co., Ltd
Anti-aging agent 4,020	2	Shandong Shanghao Chemical Co., Ltd
Sulphur	1.2	ChaoyangTianming Industry and Trade Co., Ltd., Beijing, China
Wax	1.5	Rhein Chemie Rheinau GmbH, Mannheim, Germany
Plasticizer A	2	China Sunshin Chemical Holdings Ltd., Heze, China
TMQ <sup>b</sup>	1.5	China Sunshin Chemical Holdings Ltd., Heze, China
Accelerator CZ	1.3	Shandong shangshun Chemical Co., Ltd., Weifang, China

<sup>a</sup>Phr (parts per hundreds of rubber) is the number of additives per 100 (by mass) of rubber.

<sup>b</sup>TMQ, is the abbreviation of 2,4-diamino-5-methyl [(3,4,5-trimethoxyanilino)methyl] quinazoline.

et al., 2022b). TPO can be converted into high-value chemical materials or fuels after treatment and it is the main product of waste tire pyrolysis (Williams, 2013; Mohan et al., 2019). Regulating the quality of pyrolysis oil through the pyrolysis process is the main goal of waste tire pyrolysis treatment.

The second by-product of the pyrolysis of scrap tires is CBp. The composition of CBp is significantly complex, which contains the original carbon black, inorganic compounding fillers (SiO<sub>2</sub>), and vulcanization aids (ZnO) including their processing-related derivatives (ZnO transformed to ZnS) (Berki and Karger-Kocsis, 2016). Many researchers have explored the differences in the performance of different types of rubber composites reinforced by CBp and commercial carbon black (Norris et al., 2014; Moulin et al., 2017; Sagar et al., 2018; Martinez et al., 2019; Verma et al., 2019; Lai et al., 2020). CBp has high ash content and poor surface activity which leads to the composites reinforced with CBp has lower performance than composites reinforced with commercial carbon black, making it difficult to meet the requirements of tire. A novel approach which is atomization dispersion and high-temperature sputtering drying to achieve uniform dispersion of CBp in rubber matrix has been made by Wang (Tian et al., 2021) for improving the properties of CBp rubber composite materials through processing methods. Meanwhile, some researcher modify the CBp surface using surfactants as reported to enhance the interaction between CBp and rubber matrix. Zhou Jie (Jie et al., 2010) found that the treatment of CBp with titanate coupling agent resulted in a strong interaction between the treated CBp and the polyisoprene chain. Berenice (González-González et al., 2020) found that the surface area of CBp treated with sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) increased, while the oxygen content of CBp treated with potassium hydroxide (KOH) increased.

In this study, in order to realize the reapplication of CBp in rubber composites, a variety of surfactant, namely, sodium stearate (C<sub>17</sub>H<sub>35</sub>COONa), sodium dodecylbenzene sulfonate (C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S), and sodium p-styrene sulfonate (C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S), was used to improve the surface activity of CBp. Meanwhile, the degree of dispersion of the modified CBp in the rubber composite could be improved by wet blending of natural latex and CBp. The

main objective of this study is to investigate the effect of surfactants on the properties of rubber composites prepared from CBp/natural latex *via* wet blending method.

## 2 Materials and methods

### 2.1 Materials

C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S, C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S, and C<sub>17</sub>H<sub>35</sub>COONa were used to treat CBp in the experimental process to investigate the best surface activator for CBp, and then the treated CBp was used to prepare rubber composites by wet blending method. Table 1 shows the components, suppliers, and formulation of the rubber composites.

### 2.2 Preparation of CBp/natural latex masterbatch

In this paper, the wet mixing of natural latex and CBp was used to improve the homogenous dispersion of CBp in rubber matrix (Tian et al., 2021). This method mainly includes two processes: Preparation of CBp/natural latex masterbatch and preparation of CBp/rubber composite. The specific experimental process is shown in Figure 1.

#### 2.2.1 Pretreatment of CBp and natural latex

The CBp and nature latex were treated to achieve uniform dispersion of CBp in the process of preparation of CBp/natural latex masterbatch.

Pretreatment of the CBp: The grounded CBp and surfactant were added in deionized water with 1:5 surfactant to CBp ratio. The suspension was stirred with an ultrasonic dispenser (VCY-1500, Shanghai Yanyong Chaosheng Equipment Co., Ltd., Shanghai, China; experimental parameters: ultrasonic power, 1000 W) for 5 min.

Pretreatment of the natural latex: Natural latex and deionized water were mixed in the ratio of 1:1 and stirred with an ultrasonic dispenser for 3 min.

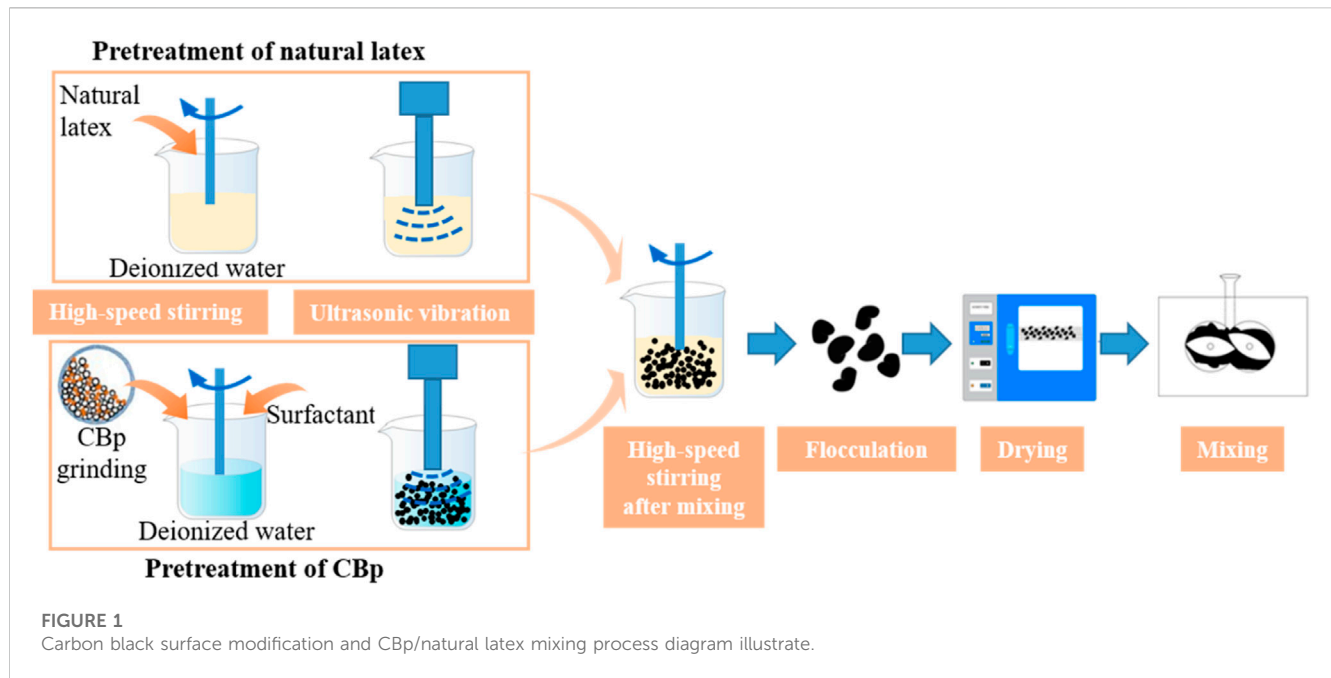


FIGURE 1 Carbon black surface modification and CBp/natural latex mixing process diagram illustrate.

TABLE 2 Preparation process of the rubber composite (Tian et al., 2020a).

Working procedure	Instrument	Processing parameters		Process
		Parameter	Value	
Mixing	Internal mixer (X(S) M-0.3 L)	Filling Factor	0.7	1) The CBp/natural latex masterbatch was blended in the internal mixer.
		Rotor speed	80 rpm	2) After 50 s, ZnO, stearic acid and others were added to the internal mixer.
		Temperature Controller	90°C	3) The rubber composite was discharged when the mixing time reaches 6 min
	Mill (XK-160)	Roller temperature	50°C	The rubber composite was added into the two-roll mill, The sulphur and accelerator CZ were added when the rubber composite was wrapped on a roller
Vulcanization	Vulcanizer (QLB-D400 × 400×2)	Temperature	150°C	The vulcanization time was set according to the experimental data measured by the Rotorless vulcanizer
		Pressure	10 MPa	

### 2.2.2 Mixing of CBp/natural latex

The natural latex and CBp slurry was mixed with a high-speed disperser (T 25 easy clean digital, German IKA company, Staufen im Breisgau, Germany; rotation rate: 400 rpm) for 5 min. A 5% concentration of acetic acid solution was prepared and added slowly into the CBp/natural latex slurry to flocculate the CBp/natural latex mixture.

After flocculation, the CBp/rubber compound were cut and placed in an oven at 70°C for 4 hours. Subsequently, the CBp/rubber compound was flattened with an open refiner, and placed in an oven at 60°C for 8 h.

### 2.2.3 Characterization of CBp/rubber compound

#### 2.2.3.1 Mooney viscosity

Mooney viscosity of the CBp/rubber compound was tested by the Mooney viscometer (Mooney viscometer, PremierMV, Alpha

Technology Co., Ltd., Akron, United States) according to the standard ISO 289-1: 1994, and the temperature was set at 100°C. After the actual temperature reached the set temperature, the sample was put in and tested after closing the mold.

#### 2.2.3.2 Rheological properties

Rheological properties of the CBp/rubber compound were tested by a rotorless rheometer according to the standard ISO 6502:1991, and the temperature was set at 150°C.

## 2.3 Preparation of CBp/rubber composite

CBp/rubber composite were made by adding fillers such as zinc oxide to the masterbatch of CBp/natural latex through the internal mixer, which produces a strong shearing effect on the rubber by the

**TABLE 3** Vulcanization characteristics of CBp/rubber compound modified by different surfactants.

Test project	C <sub>17</sub> H <sub>35</sub> COONa	C <sub>18</sub> H <sub>29</sub> NaO <sub>3</sub> S	C <sub>8</sub> H <sub>7</sub> NaO <sub>3</sub> S
t10/[min]	3.38	4.78	4.65
t50/[min]	5.32	7.2	7.16
t90/[min]	9.12	11.49	11.35
ML/[dN·m]	1.23	1.11	1.34
MH/[dN·m]	15.6	13.52	16.29
(MH-ML)/[dN·m]	14.37	12.41	14.95
ML (1 + 4)	42.42	35.37	39.34

rotor of the internal mixer to achieve uniform dispersion of the CBp in the rubber matrix. Then, the CBp/rubber composite was prepared by vulcanization. The specific process was shown in Table 2.

## 2.4 Characterization of CBp/rubber composite

### 2.4.1 Dispersion properties

Dispersion of the filler was measured using carbon black dispersity analyzer (DisperGRADER, Alpha Corporation America) according to ISO 11345. The dispersion calculation threshold was set to 23 μm and the exposure time was set to 40 ms.

### 2.4.2 Payne effect

The Payne effect of the composite was tested by a rubber processing analyzer (Rubber Processing Analyzer, RPA 2000, Alpha Technologies, Inc., Akron, United States). The frequency was 1Hz, the strain range was between 0.28% and 40%, and the temperature was set at 60°C.

### 2.4.3 Physical and mechanical properties

Shore A hardness was tested using a shore hardmeter (LX-A, Shanghai Liuling Instrument Factory, Shanghai, China) according to ISO 7619-2: 2004. The sample was tested after stacking three tensile specimens. The tensile specimens shape is a dumbbell shape, with a length of 115 mm and a width of 25 mm.

The tensile and tear properties of the vulcanized rubber were tested using a universal testing machine (TS 2005 b, GOTECH TESTING MACHINES CO., Ltd., Taichung, Taiwan) at a drawing rate of 500 mm/min according to the standards ISO 37: 2005 and ISO 34-1: 2004, respectively. Five specimens were tested for each sample type.

The abrasion of the rubber vulcanizates were evaluated using a DIN wear machine (GT-2012-D, GOTECH TESTING MACHINES CO., Ltd., Taichung, Taiwan) according to GB/T 1689-1998.

### 2.4.4 Dynamic mechanical thermal analysis (DMTA)

The viscoelastic mechanical properties of the vulcanizates were evaluated using a dynamic thermomechanical analyzer (EPLEX-OR-150N, Gabo Qualimeter Testanlagen GmbH, Ahlden, Germany), in which the test temperature range was -65°C t

**TABLE 4** The value of [X] and [Y] of CBp/rubber composite with different surfactants.

	C <sub>17</sub> H <sub>35</sub> COONa	C <sub>18</sub> H <sub>29</sub> NaO <sub>3</sub> S	C <sub>8</sub> H <sub>7</sub> NaO <sub>3</sub> S
[X]	6.6	7.5	7.9
[Y]	8.3	9.3	9.5

o 65°C, the heating rate was 2 K/min, the vibration frequency was 10 Hz, the static strain was 5%, the static force was 70 N, the dynamic strain was 0.25%, and the dynamic stress was 60 N.

## 3 Results and discussion

### 3.1 Effect of surfactant-modified CBp on viscosity and rheological properties of CBp/rubber compound

Processability is an essential indicator of the properties of rubber compound (Tian et al., 2020a; Tian et al., 2020b). It is usually characterized by Mooney viscosity and rheological properties. Among them, t10 is the scorch time of the rubber compound; t90 is the positive vulcanization time of the rubber compound; MH and ML represent the highest torque and the lowest torque of the rubber compound, respectively. Table 3 presents the processing performance data of CBp/rubber compound with different surfactants.

The three rubber composite with surfactant-modified CBp have sufficient scorch time, which can ensure the safety of rubber compound processing. The positive vulcanization time of C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S and C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S is longer than that of C<sub>17</sub>H<sub>35</sub>COONa modified rubber composite. C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S and C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S are sulfonates. The sulfonic acid reacts easily with the amine ion in the amine accelerator, reducing the reactivity of the accelerator and thus increasing the positive vulcanization time of the CBp/rubber composite (Wang et al., 2019). The MH-ML value of the rubber composite prepared by C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S modified CBp is the largest, indicating that the rubber composite has the highest crosslinking degree. Meanwhile, the ML of the rubber composites prepared by C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S modified CBp is the smallest, indicating that the CBp/rubber compound has better fluidity and low Mooney viscosity.

### 3.2 Effect of surfactant-modified CBp on dispersion properties

The CBp/rubber composite prepared by treating CBp with surfactant are tested by carbon black dispersity analyzer. The value of [X] represents the degree of dispersion of carbon black, and the value of [Y] represents the degree of dispersion of large particles of carbon black. The larger the value of [X] and [Y], the better the dispersion of carbon black in the rubber compound. Table 4 presents the value of [X] and [Y] of CBp/rubber composite with different surfactants.

From Table 4, the dispersion of C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S and C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S modified CBp in the rubber composite matrix is significantly better

TABLE 5 The value of  $\Delta G'$ .

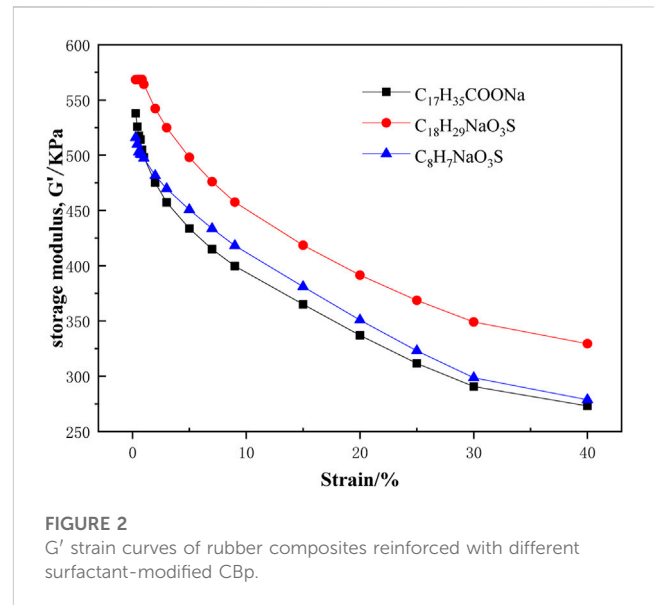
	$C_{17}H_{35}COONa$ (kPa)	$C_{18}H_{29}NaO_3S$ (kPa)	$C_8H_7NaO_3S$ (kPa)
$G'$ (0.28%)	537.84	568.34	515.98
$G'$ (40%)	273.14	329.45	278.71
$\Delta G'$	264.7	238.89	237.27

than that of  $C_{17}H_{35}COONa$ .  $C_{18}H_{29}NaO_3S$  has been found to be effective in dispersing carbon black, and the lower the degree of sulfonation function, the better the dispersion of carbon black. Lignosulfonate mainly enhances colloidal stability by electrostatic repulsion, and the likely mechanism of stabilization is a combination of electrostatic repulsion and steric hindrance (Subramanian and Øye, 2021).  $C_8H_7NaO_3S$  and  $C_{18}H_{29}NaO_3S$  have the same functional groups, but the molecular weight of  $C_{18}H_{29}NaO_3S$  (348.47 g/mol) is larger than that of  $C_8H_7NaO_3S$  (206.19 g/mol) (Kurt et al., 1995). By adding the same mass of surfactant, the number of effective functional groups of  $C_{18}H_{29}NaO_3S$  will be less than that of  $C_8H_7NaO_3S$ , making the dispersion effect of CBp in rubber matrix slightly lower than that of  $C_8H_7NaO_3S$ .

### 3.3 Effect of surfactant-modified CBp on Payne effect of CBp/rubber composites

According to Table 5, the  $\Delta G'$  values of  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  modified CBp composites are 238.89 kPa and 237.27 kPa, respectively. These values are lower than the  $\Delta G'$  value of 264.7 kPa for the  $C_{17}H_{35}COONa$  modified CBp rubber composite. A smaller  $\Delta G'$  value indicates a better interaction between CBp and rubber, with reduced CBp-CBp interaction (Tian et al., 2021). This suggests that CBp is more effectively dispersed in the rubber composite. The addition of  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  surfactants improves the wettability and uniform dispersion of CBp in natural latex, reducing the CBp-CBp interaction (Zhu et al., 2020).  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  are sulfonates and exhibit higher activity compared to  $C_{17}H_{35}COONa$  (Subramanian and Øye, 2021). Although  $C_8H_7NaO_3S$  and  $C_{18}H_{29}NaO_3S$  possess the same functional groups, the molecular weight of  $C_{18}H_{29}NaO_3S$  (348.47 g/mol) is greater than that of  $C_8H_7NaO_3S$  (206.19 g/mol) (Kurt et al., 1995). When the dosage is the same,  $C_8H_7NaO_3S$  has a higher number of hydrophilic functional groups than  $C_{18}H_{29}NaO_3S$ , resulting in a stronger surface modification effect on CBp. The enhanced dispersion of CBp in the presence of  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  is supported by higher [X] and [Y] values, as reported in Table 4.

Figure 2 illustrates that the  $C_{18}H_{29}NaO_3S$  modified CBp rubber composite exhibits the highest modulus.  $C_{17}H_{35}COONa$ ,  $C_{18}H_{29}NaO_3S$ , and  $C_8H_7NaO_3S$  belong to metal soap salts derived from fatty acids. These compounds consist of hydrophilic functional groups and hydrophobic carbon chains (Kerenkan et al., 2016). The hydrophobic carbon chains align to form micelles within the rubber, providing internal lubrication. The hydrophilic functional groups react with the surface groups of pyrolytic carbon black, serving as a means of surface modification (Wang et al., 2017).  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$ , which are sulfonic acid



metal soap salts, exhibit higher activity than  $C_{17}H_{35}COONa$  (Subramanian and Øye, 2021). The modification of CBp using  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  improves CBp dispersion and enhances CBp-rubber interaction. Additionally, the presence of a benzene ring in  $C_{18}H_{29}NaO_3S$  reduces the flexibility of its molecular chain, resulting in a more effective internal lubrication effect compared to  $C_8H_7NaO_3S$  (Shahabuddin et al., 2021). The combined effects of these factors contribute to the highest modulus observed in rubber composites containing  $C_{18}H_{29}NaO_3S$ -modified CBp.

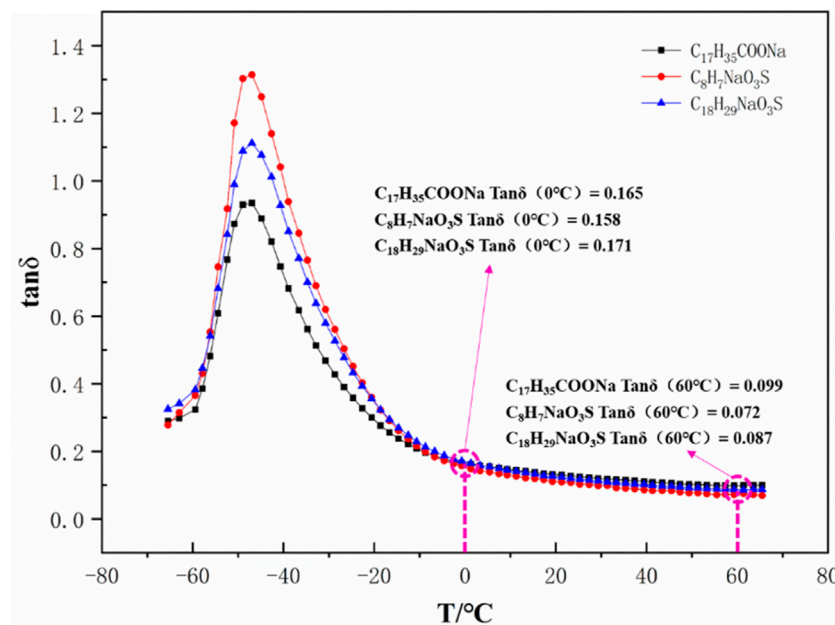
### 3.4 Effects of surfactant-modified CBp on physical and mechanical properties of rubber composites

Table 6 shows the physical and mechanical properties of CBp/rubber composites modified by different surfactants.

The  $C_{18}H_{29}NaO_3S$  surfactant-modified CBp/rubber composite has the highest tensile strength of 25.63 MPa, followed by  $C_8H_7NaO_3S$  and  $C_{17}H_{35}COONa$ , with 24.74 MPa and 22.17 MPa, respectively. The  $C_{18}H_{29}NaO_3S$  surfactant-modified CBp/rubber composite has 15.6% increment in tensile strength compared to  $C_{17}H_{35}COONa$  surfactant-modified CBp/rubber composite. There are three surfactants used in this study, the functional group of  $C_{17}H_{35}COONa$  is carboxyl group, while the functional group of The  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  is sulfo group. From Table 6, surfactants with sulfo functional group have higher tensile

**TABLE 6** Physical and mechanical properties of CBp/rubber composites modified with different surfactants.

Test project	C <sub>17</sub> H <sub>35</sub> COONa	C <sub>18</sub> H <sub>29</sub> NaO <sub>3</sub> S	C <sub>8</sub> H <sub>7</sub> NaO <sub>3</sub> S
Shore A hardness/[°]	67	59	65
100% constant elongation stress/[MPa]	2.43	1.86	2.4
300% constant elongation stress/[MPa]	10.28	8.97	11.57
M300%/M100%	4.23	4.82	4.82
Tensile strength/[MPa]	22.17	25.63	24.74
Tear strength/[KN·m <sup>-1</sup> ]	84	104	120
Elongation at break/[%]	519.6	585.3	522.7
Resilience/[%]	62.37	67.21	65.42
DIN abrasion/[cm <sup>-3</sup> ]	0.177	0.180	0.168



**FIGURE 3** Graph of tan delta versus temperature for CBp/rubber composite produced from different surfactant-modified CBp.

strength compare to carboxyl functional group surfactant. The presence of sulfonate group increases the water solubility of the C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S and C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S, and its surface charged functional groups contribute to the uniform dispersion of CBp in natural latex (Zhu et al., 2020), which enhances the compatibility of CBp with rubber and thus increases the tensile strength of rubber composites. In general, the more uniform the dispersion of CBp and the stronger the CBp-rubber interaction, the greater the tensile strength of the composite (Alex et al., 2013). This is also the main reason for the high tear strength and resilience value of the C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S and C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S surfactant-modified CBp/rubber composites. The C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S surfactant-modified CBp/rubber composites has the lowest hardness of 59°, followed by C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S and

C<sub>17</sub>H<sub>35</sub>COONa, with 65° and 67°, respectively. The hardness of rubber composites generally related to the dispersion of the modified CBp and the degree of crosslinking of CBp/rubber composite. Typically, the higher MH-ML value and the more uniform the dispersion of CBp, the higher the crosslinking degree of the rubber composite (Shan et al., 2023). The higher degree of crosslinking enhanced the mechanical properties of rubber composite (Sun et al., 2022). This could be the primary contribution of the higher hardness values of the C<sub>8</sub>H<sub>7</sub>NaO<sub>3</sub>S and C<sub>17</sub>H<sub>35</sub>COONa surfactant-modified CBp/rubber composites. These findings show that the CBp can be uniformly dispersed in natural latex after being treated with C<sub>18</sub>H<sub>29</sub>NaO<sub>3</sub>S, resulting in better comprehensive mechanical properties of the composite.

### 3.5 Effects of surfactant-modified CBp on dynamic mechanical properties of rubber composites

The dynamic mechanical properties of the composites refer to the mechanical response of composites under the action of alternating force. Usually, the dynamic mechanical properties of composites are studied through the changes in storage modulus and loss modulus under the influence of temperature and vibration frequency. Loss factor ( $\tan\delta$ ) refers to the ratio of loss modulus  $G''$  to storage modulus  $G'$ , which is an essential parameter of rubber composites and directly reflects the internal friction of rubber compounds. To a certain extent, it can characterize the dispersion of fillers in the rubber compound, the network degree of fillers, and the rolling resistance and wet skid resistance of the rubber compound. Typically, the higher the peak value of the loss factor ( $\tan\delta$ ), the better the dispersion of the filler and the lower the degree of networking of the filler (Tian et al., 2021).

It can be seen from Figure 3 that the rubber composite prepared by  $C_8H_7NaO_3S$  modified CBp has the highest  $\tan\delta$  peak, followed by  $C_{18}H_{29}NaO_3S$  modified CBp composite, and  $C_{17}H_{35}COONa$  modified CBp composite has the lowest  $\tan\delta$  peak. This shows that  $C_8H_7NaO_3S$  modified CBp has the best dispersibility in rubber composite and the weakest filler network effect, this is also in agreement with the payne effect and the dispersion properties of the composite. Besides, the  $C_8H_7NaO_3S$  modified CBp/rubber composite has the lowest  $\tan\delta$  value at  $60^\circ C$ , and the  $C_{18}H_{29}NaO_3S$  modified CBp/rubber composite has the highest  $\tan\delta$  value at  $0^\circ C$ . In the industry,  $\tan\delta$  at  $0^\circ C$  is commonly used to characterize the wet skid resistance of rubber composites. The larger the value, the better the wet skid resistance of the rubber composite. The rolling resistance of rubber composites is characterized by  $\tan\delta$  at  $60^\circ C$ . The smaller the value, the better the rolling resistance of the rubber composite (Tian et al., 2021). CBp modified by  $C_8H_7NaO_3S$  improves the surface activity of the CBp and makes it evenly dispersed in the rubber composite, thereby improving the dynamic mechanical properties of the rubber composite (Dong et al., 2017).

## 4 Conclusion

In this study,  $C_{17}H_{35}COONa$ ,  $C_{18}H_{29}NaO_3S$ , and  $C_8H_7NaO_3S$  were used to improve the surface activity and uniform dispersion of the CBp in the natural latex. The dispersity of  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  modified CBp in rubber matrix has [X] and [Y] values of 7.5 and 7.9, and 9.3 and 9.5, respectively, and the dispersion of these rubber composites is significantly better than that of  $C_{17}H_{35}COONa$ . The rubber composite contain of  $C_{18}H_{29}NaO_3S$  surfactant-modified CBp has the highest tensile strength of 25.63 MPa, which increment in tensile strength is 15.6% compare to the rubber composite prepared by  $C_{17}H_{35}COONa$ . Moreover, the

$C_8H_7NaO_3S$  modified CBp rubber composite has the lowest  $\tan\delta$  value at  $60^\circ C$ , and the  $C_{18}H_{29}NaO_3S$  modified CBp compound has the highest  $\tan\delta$  value at  $0^\circ C$ . The above experimental results indicate that the mechanical properties and dynamic mechanical properties of CBp/natural latex composites prepared by modifying CBp with  $C_{18}H_{29}NaO_3S$  and  $C_8H_7NaO_3S$  have been significantly improved. The modified CBp is able to replace some of the commercial carbon black for reapplication in the tire preparation process. The reuse of CBp to prepare rubber composites can significantly reduce the production cost of rubber products and is of great significance to both resource conservation and environmental protection.

## Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## Author contributions

XT: Conceptualization, Methodology, Writing—Original Draft, Writing—Review and Editing. XS: Data Curation, Validation, Formal analysis. KW: Formal analysis. TS: Investigation, Data Curation. CW: Conceptualization, Methodology. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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