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PREPARATION AND PROPERTIES OF RUBBER NANOCOMPOSITES BASED ON NATURAL RUBBER/ ETHYLENE PROPYLENE DIENE MONOMER REINFORCED WITH NANOSILICA, CARBON BLACK AND BARIUM SULFATE

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Abstract. In this work, rubber nanocomposites based on natural rubber/ethylene propylene diene monomer (NR/EPDM) blends and reinforced with nanosilica (NS) in combination with carbon black (CB) and barium sulfate (BS) were prepared by melt blending method in a Brabender internal mixer. The appropriate contents of NS and CB for reinforcing the rubber nanocomposites based on NR/EPDM are 10 and 30 phr (parts per hundred rubber), respectively. The NR/EPDM nanocomposites material reinforced with 10 phr NS and 30 phr CB has the best mechanical properties that with the enhancement of tensile strength over 117% and 40 % compared to that of the NR/EPDM nanocomposite material unreinforced and reinforced with only 10 phr NS, respectively. The appropriate content of BS for replacement of CB in the NR/EPDM blend is 6 phr. The rubber nanocomposite based on NR/EPDM (60/40) blend reinforced with 10 phr NS, 24 phr CB and 6 phr BS has a tight structure, high mechanical properties, and especially, high alkali resistance and heat resistance, abrasion resistance and low endogenous heat due to rotation and friction. This material may be used to manufacture technical rubber products that require heat resistance and stability in alkaline environments, such as conveyor belts used in the cement industry.

Keywords: nanocomposite, NR/EPDM blend, nanosilica, carbon black, sulfate barium

Classification numbers: 2.2.1, 2.2.2

1. INTRODUCTION

From the past few decades, polymer nanocomposite materials in general and rubber nanocomposites in particular have received strong attention from researchers worldwide as well as in Viet Nam [1, 2]. Nano-size fillers such as nanoclays, nanosilica, carbon black, carbon nanotubes, graphene, etc. were usually used to fabricate rubber nanocomposites [3, 4]. Recently, different combinations of nano-fillers, especially between carbon black and other nano-fillers, have been used to reinforce rubber nanocomposites [3 - 5]. The obtained results showed that the reinforcement with a combination of nano-fillers could improve many physical–mechanical and technical properties of the materials compared to the material reinforced with a single nano-filler [1,4,5]. However, there have not been many publications on the combination of nano-fillers with carbon black and other micro-fillers in order to integrate the advantages of each to improve the mechanical properties of the materials [1, 3]. On the other hand, for reinforcing rubber materials, until now, carbon black is still the leading reinforcing agent because it can increase most of the mechanical and technical properties of rubber materials and it has low cost [6, 7]. Along with carbon black, silica has been used as the main reinforcing filler to increase the usefulness of rubber. In particular, nano-sized silica can enhance the physical and mechanical properties of rubber due to its uniform dispersibility in the rubber matrices much better than other fillers [2, 3, 7, 8]. Besides, barium sulfate (BS) is commonly used as a filler to enhance the alkali resistance of polymeric materials in general and rubber in particular [7, 9, 10]. Thus, if using these 3 types of reinforcing agent at the same time with an appropriate ratio, it will increase the mechanical, technical properties and alkali resistance of rubber materials. The disadvantage of natural rubber (NR) is that it is less stable to heat and the environment (oil and grease, acid, alkali, ozone, etc.). Thus, from the past few decades, natural rubber has been combined with synthetic rubbers or thermoplastics to create rubber blends that improve abrasion, oil and grease resistance and environmental durability, such as blends of natural rubber with butadiene rubber (BR), styrene butadiene rubber (SBR), nitrile butadiene rubber (NBR) or chloroprene rubber (CR) [11, 12]. In particular, rubber blends based on natural rubber/ethylene propylene diene monomer (NR/EPDM) have also been studied extensively and have shown outstanding properties such as high thermal resistance and good environmental durability [11, 13 - 16]. However, there are almost no publications on manufacturing rubber blend materials based on NR/EPDM with many simultaneous features such as high mechanical strength, thermal and alkali resistance. Therefore, rubber nanocomposite materials based on a blend of NR/EPDM reinforced with nanosilica (NS), carbon black (CB) and barium sulfate (BS) were studied. This study may be useful for the production of technical rubber that requires high mechanical properties, thermal resistance and alkali resistance.

2. MATERIALS AND METHODS

2.1. Materials

Natural rubber (NR) was a type of SVR-3L (Dong Nai Rubber Corporation); ethylene-propylene-diene-monomer (EPDM) rubber had a grade of NDR 37060 (Dow Chemical Company). Nanosilica (NS) was a type of Reolosil (Akpa chemical company (Turkey)) with specifications such as specific surface area of 200 ? 20 m^2/g and grain size of 12 - 50 nm. The anti-aging agents were TMQ and 4020 (Lanxes, Germany). VLP compatibilizer was obtained from Mitsui Chemical America, Inc. Other fillers included technical carbon black (CB) which had a grade of HAF N330 (China) with bulk density of about 330 kg/m^3, oil absorption of 102 ± 7 mL/100 g, grain size of 38 - 42 nm; barium sulfate (BS) had a grade of B-L909 (Hubei Hoyonn Chemical Industry Co., Ltd - China) with specific gravity of 4 g/cm^3, oil absorption of ≤

22 mL/100 g; bis(3-trietoxysilyl propyl) tetrasulfite (TESPT) used as a silane coupling agent; stearic acid; zinc oxide; sulfur; dicumyl peroxide; accelerators (dibenzothiazole disulfide - MBTS (DM) and tetrametyl thiuram disunfit (TMTD)); and other chemicals available on the market.

2.2. Methods

2.2.1. Preparation of rubber nanocomposites

The rubber mixtures were prepared in a Brabender internal mixer at a temperature of 80 °C and a rotation speed of 50 rpm as follows: small pieces of natural rubber (NR) were added first, followed by VLP compatibilizer, ethylene-propylene-diene-monomer (EPDM) rubber, stearic acid, and anti-aging agents 4020 and TMQ; then, the mixture was mixed for 30 seconds, followed by the addition of a reinforcing additive-nanosilica (NS) previously mixed with TESPT in a porcelain mortar. For samples with CB, CB was added after mixing NS for 30 seconds. For samples containing all NS, CB and BS, after mixing NS for 30 seconds, BS which was previously ground thoroughly in a porcelain mortar was added, followed by mixing for another 30 seconds, then CB was added and the mixture was further mixed for 30 seconds. Finally, zinc oxide was added and mixed for 5 minutes in a temperature range not exceeding 120 °C for uniform dispersion of the components. After that, the mixture was allowed to cool down below 50 °C, followed by adding theaccelerators, sulfur and dicumyl peroxide, and mixing for 3 minutes at a temperature not exceeding 90 °C. The rubber mixture was left to stand for 24 hours at room temperature and then vulcanized in a Mini-test Press (Toyoseiki, Co., Tokyo, Japan) at a temperature of 145 ± 2 °C under a pressure of 6 kg/cm^2 for 20 minutes (for samples with a thickness of 2 mm). By investigations, the NR/EPDM ratio of 60/40 (w/w) with high mechanical properties of the material was chosen from previous studies [17, 18]. The composition of the rubber nanocomposites is given in Table 1.

Table 1. Composition of the rubber nanocomposites.

No.	Materials and chemicals	Contents (phr)	No.	Materials and chemicals	Contents (phr)
1.	Natural rubber – SVR3L	60.0	9.	TESPT (Si69)	0.5
2.	EPDM	40.0	10.	Carbon black N330	vary
3.	VLP compatibilizer	2.0	11.	Barium sulfate	vary
4.	Stearic acid	2.0	12.	Accelerator DM	1.0
5.	Zinc oxide	5.0	13.	Accelerator TMTD	1.0
6.	Anti-aging agent TMQ	1.0	14.	Sulfur	1.0
7.	Anti-aging agent 4020	1.0	15.	Dicumyl peroxide	2.0
8.	Nanosilica	vary			

Note: phr (parts per hundred rubber)

2.2.2. Determination of the structure and properties of materials

Mechanical properties including tensile strength and elongation at break were determined according to TCVN 4509:2006 (ISO 37-2006) on a GOTECH AL - 7000M Electromechanical Universal Testing Machine (Taiwan). The hardness of the materials was determined according to TCVN 1595-1:2007 (ISO 7619-1:2004) using a TECLOCK hardness meter (Shore A, Jis

K6301A - Japan). The abrasiveness of the materials was determined according to TCVN 1594-87 on a YG634 machine (Ying hui machine (Taiwan)).

The morphological structure of the materials was studied using a Field Emission Scanning Electron Microscope (FESEM) on a Hitachi S-4800 machine (Japan). The thermal properties of the materials were determined by thermogravimetric analysis (TGA) on a TGA Labsys 1600 thermal analyzer, SETARAM (France) at a heating rate of 10 ^{o}C/min in air. The alkali resistance of the materials was evaluated according to TCVN 7544:2005. The determination of endogenous heat due to rotation and friction was carried out on an Akron Abrasion Tester - JC1076 (China) with a cylindrical rubber specimen. The determination of rubber surface temperature characteristics was performed on a Smart AR330 Laser sensor (China).

3. RESULTS AND DISCUSSION

3.1. Effect of nanosilica content on mechanical properties of NR/EPDM/NS nanocomposites

In the rubber formulation (Table 1), the nanosilica (NS) content varies. The effect of nanosilica content on the mechanical properties of NR/EPDM/NS nanocomposites is given in Table 2.

Table 2. Effect of nanosilica content on the mechanical properties of NR/EPDM/NS nanocomposites.

Content of nanosilica (phr)	Tensile strength at break (MPa)	Elongation at break (%)	Residual elongation (%)	Abrasiveness (cm^3/1,61 km)	Hardness (Shore A)
0	8.9	405	18.9	0.90	52
2	9.8	416	18.7	0.91	53
4	10.6	428	18.5	0.91	53
6	11.5	439	18.3	0.92	54
8	12.7	453	18.2	0.92	54
10	13.8	465	18.0	0.92	54
12	13.0	458	18.3	0.93	55
14	11.9	450	18.8	0.94	55

As seen in Table 2, as the nanosilica content increases, the tensile strength at break and elongation at break increase from 8.9 MPa to a maximal value of 13.8 MPa and from 405 % to a maximal value of 465 % at an NS content of 10 phr, respectively. By further increasing the NS content, both the tensile strength at break and the elongation at break decrease. In contrast, the residual elongation decreases gradually from 18.9 % to 18 % at an NS content of 10 phr. By further increasing the NS content, the residual elongation increases again. This can be explained that at low nanosilica content, a uniform dispersion of nanosilica in the rubber matrix is obtained, which improves the mechanical properties of the material. When the amount of nanosilica exceeds an appropriate content, the residual nanosilica particles will aggregate into a separate phase and it hinders the interaction between rubber macromolecules. Thus, it will reduce the mechanical properties of the material. Particularly, the hardness and the abrasiveness still increase gradually but not by much because NS is a soft filler [19]. From the obtained results, we chose the NS content of 10 phr for further investigations.

3.2. Effect of CB content on the mechanical properties of NR/EPDM/NS/CB nanocomposites

The effect of CB reinforcement on NR/EPDM/NS rubber blend nanocomposites is presented in Table 3.

Table 3. Effect of carbon black content on the mechanical properties of NR/EPDM/NS/CB nanocomposites.

Content of carbon black (phr)	Tensile strength at break (MPa)	Elongation at break (%)	Residual elongation (%)	Abrasiveness (cm^3/1,61 km)	Hardness (Shore A)
0	13.8	465	18.0	0.92	54
5	14.6	456	18.1	0.91	55
10	15.5	447	18.2	0.90	57
15	16.5	437	18.3	0.89	59
20	17.4	428	18.4	0.88	61
25	18.5	416	18.5	0.87	63
30	19.4	405	18.6	0.86	65
35	18.9	392	18.8	0.90	67

It can be seen that, as the CB content increases, the tensile strength of NR/EPDM/NS/CB nanocomposites also increases strongly and the residual elongation rises slightly, while the elongation at break and the abrasiveness of the material change insignificantly. Until the CB content exceeds 30 phr, the tensile strength and elongation at break of NR/EPDM/NS/CB nanocomposites decrease, but the residual elongation, abrasion and the hardness of the material increase. This can be explained that when the CB content is smaller than an appropriate level, CB is uniformly dispersed in the rubber matrix and a regular and tight structure is obtained. Thus, the mechanical properties of the material are improved. When the CB content exceeds this appropriate level, CB will aggregate into a separate phase that hinders the interaction of rubber macromolecules in the material, hence reducing the mechanical properties. From the obtained results, we chose the CB content of 30phr for further investigations.

3.3. Effect of BS content on the mechanical properties of NR/EPDM/NS/CB/BS nanocomposites

Table 4. Effect of BS on the mechanical properties of NR/EPDM/NS/CB/BS nanocomposites.

Content of Barium Sulfate (phr)	Tensile strength at break (MPa)	Elongation at break (%)	Residual elongation (%)	Abrasiveness (cm^3/1,61 km)	Hardness (Shore A)
0	19.4 ± 0.60	405 ± 11.95	18.6 ± 0.62	0.86 ± 0.026	65.0 ± 1.94
2	19.0 ± 0.53	402 ± 11.18	18.7 ± 0.54	0.87 ± 0.025	65.0 ± 1.81
4	18.7 ± 0.55	399 ± 11.21	18.8 ± 0.55	0.88 ± 0.029	64.9 ± 1.91
6	18.5 ± 0.36	396 ± 9.23	18.9 ± 0.40	0.89 ± 0.018	64.9 ± 1.51
8	17.8 ± 0.50	390 ± 9.52	19.1 ± 0.47	0.91 ± 0.025	64.8 ± 1.76
10	17.2 ± 0.42	382 ± 10.05	19.4 ± 0.49	0.95 ± 0.026	65.0 ± 1.74
12	16.5 ± 0.47	372 ± 10.19	19.8 ± 0.59	1.05 ± 0.029	64.8 ± 1.79
14	15.8 ± 0.46	363 ± 10.20	20.3 ± 0.58	1.11 ± 0.031	64.5 ± 1.75

The effect of BS on NR/EPDM/CB/BS is presented in Table 4. In this investigation, BS partially replaces the CB content in rubber nanocomposites.

It can be seen that, with increasing BS content the mechanical properties of NR/EPDM/NS/CB/BS nanocomposites are gradually reduced, especially the tensile strength. The reason is that with increasing BS content the CB content in the rubber nanocomposites decreases and the effect of CB reinforcement in the material is lower. However, closer observation shows that, when the BS content is less than 6 phr, the mechanical properties of the material only decrease slightly. This result shows that it is possible to replace the CB content with BS up to 6 phr while maintaining the mechanical properties of rubber nanocomposites. From the obtained results, we chose the BS content of 6 phr for further investigations.

3.4. Alkali resistance of NR/EPDM/NS/CB/BS nanocomposites

The alkali resistance of NR/EPDM/NS/CB/BS nanocomposites is evaluated according to TCVN 7544:2005. The test medium is 20 % (w/v) NaOH solution, the test time is 72 hours, and the test temperature is 27 ± 2 ^{o}C. The obtained results are given in Tables 5 and 6.

Table 5. Effect of BS content on the alkali resistance of NR/EPDM/NS/CB/BS nanocomposites by determination of tensile strength and elongation at break.

Properties / Content of BS (phr)	Tensile strength before testing (MPa)	Tensile strength after testing (MPa)	Fluctuation (%)	Elongation at break before testing (%)	Elongation at break after testing (%)	Fluctuation (%)
0	19.4 ± 0.60	16.6 ± 0.52	-14.4	405 ± 13.41	338 ± 10.95	-16.5
2	19.0 ± 0.58	16.5 ± 0.50	-13.2	402 ± 12.58	337 ±10.68	-16.1
4	18.7 ± 0.55	16.4 ± 0.49	-12.3	399 ± 12.01	343 ±10.05	-14.0
6	18.5 ± 0.46	16.4 ± 0.41	-11.4	396 ± 10.26	342 ±8.58	-13.6
8	17.8 ± 0.51	15.5 ± 0.50	-12.9	390 ± 11.39	325 ±9.65	-16.6
14	15.8 ± 0.46	13.4 ± 0.42	-15.2	363 ± 11.36	290 ± 9.69	-20.1

Table 6. Effect of BS content on the alkali resistance of NR/EPDM/NS/CB/BS nanocomposites by determination of hardness and weight.

Properties / Content of BS (phr)	Hardness before testing (Shore A)	Hardness after testing (Shore A)	Fluctuation (Shore A)	Weight before testing (g)	Weight after testing (g)	Fluctuation (%)
0	65.0 ± 2.01	65.5 ± 2.02	+0.5	45.51 ± 1.47	46.05 ± 1.46	+1.20
2	64.5 ± 1.98	65.0 ± 1.92	+0.5	48.22 ± 1.52	49.08 ± 1.43	+1.10
4	64.0 ± 1.89	64.5 ± 1.94	+0.5	46.17 ± 1.38	46.70 ± 1.38	+1.12
6	63.5 ± 1.59	64.0 ± 1.65	+0.5	44.91 ± 1.19	45.40 ± 1.21	+1.00
8	63.2 ± 1.83	63.5 ± 1.99	+0.7	45.45 ± 1.35	45.85 ± 1.41	+0.90
14	60.6 ± 1.78	61.2 ± 1.85	+0.6	48.45 ± 1.50	49.13 ± 1.59	+1.4

It shows that at BS content of 6 phr the rubber nanocomposite has the best alkali resistance. The tensile strength and the elongation at break decrease by about 11.4 % and 13.6 % after alkali resistance testing, respectively. In contrast, the hardness and the sample weight increase by 0.5 Shore A and by 1.0 %, respectively. This can be explained that CB is the best reinforcing material for rubber due to its good dispersion in the rubber matrix and thegood surface interaction between CB and rubber. Therefore, the material structure is more regular and tight, so the penetration of alkaline into the material is restricted. However, the additional BS content can neutralize the alkaline environment on the sample surface, making the environment less harsh and inhibiting the destruction of the material. Therefore, with the appropriate additive content of 10 phr NS, 24 phr CB and 6 phr BS, the material has both a tight structure, and high mechanical properties and alkali resistance. When the BS content is too high and the CB content is too low, the mechanical properties and alkali resistance decrease possibly due to poor structure of the material.

3.5. Morphological structure of nanocomposite materials

The morphological structure of the materials was determined by Field Emission Scanning Electron Microscopy (FESEM). The FESEM images of NR/EPDM/NS/CB/BS nanocomposites with different combinations of fillers are presented in Figure 1.

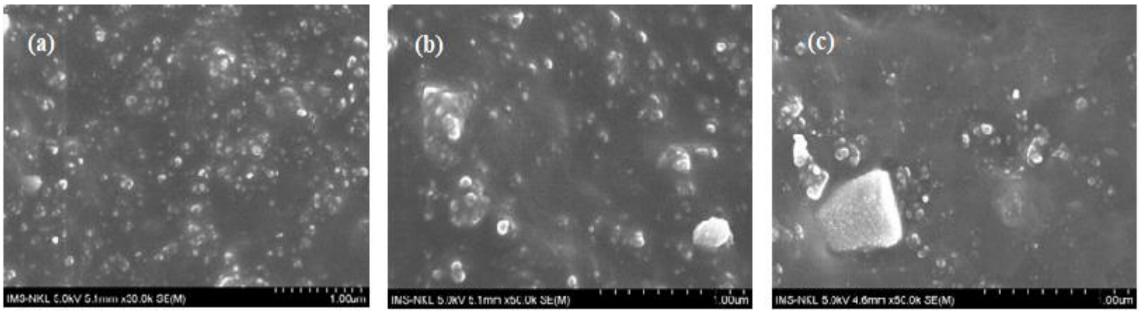


Figure 1. FESEM image of fractured surface of reinforced NR/EPDM blend material combining NS with CB and BS. ((a) 10NS+30CB; (b) 10NS+24CB+6BS; (c) 10NS+16CB+14BS).

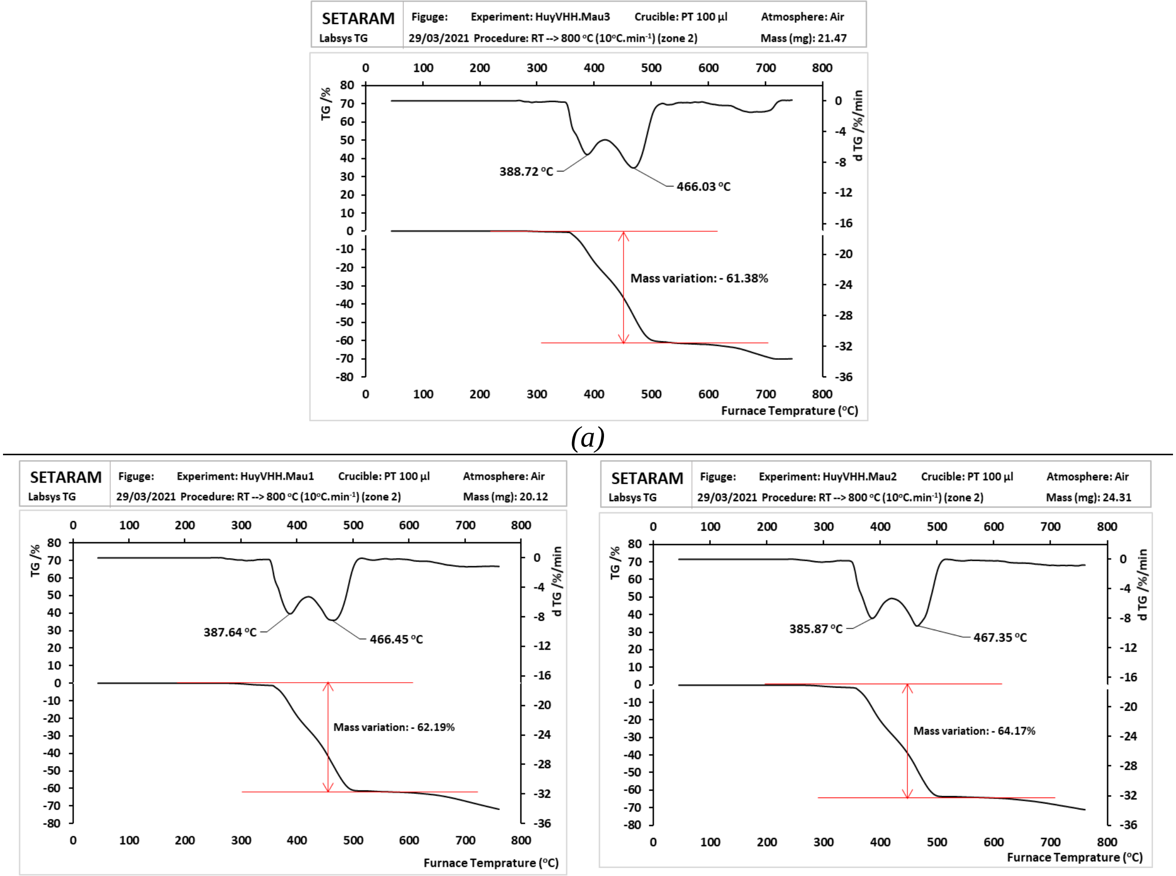
It shows that, for the blend rubber sample reinforced with 10 phr NS and 30 phr CB, the filler particles are uniformly dispersed in the rubber matrix; most of particles have size below 100 nm (Figure. 1a). When the CB replaced with BS up to 6 phr, there are some BS particles larger than 100 nm on the fracture surface of the material, but the material still maintains its regular and tight structure (Figure. 1b). Therefore, good mechanical properties and high alkaline resistance of the material are maintained. However, when the replaced CB content increases, especially when the BS content is up to 14 phr, that means the CB content is only 16 phr, quite large particles and aggregates (larger than 100 nm) can be seen on the fractured surface (Figure. 1c). This indicates that the structure of the nanocomposite material at NS content of 10 phr, CB content of 16 phr, BS content of 14 phr is not uniform and that is the reason for reducing the mechanical properties and alkaline resistance of the material.

3.6. Heat resistance of rubber nanocomposites

The thermal properties of rubber nanocomposites with different compositions are shown in Figure 2 and Table 7.

Table 7. Thermal properties of the rubber nanocomposites based on NR/EPDM (60/40) with different fillers.

Properties Samples	Starting degradation temperature [^{o}C]	Temperature range of maximal degradation [^{o}C]	Mass loss (up to 500 ^{o}C) [%]
NR/EPDM/10NS+30CB	359,17	388,72 – 466,03	61,38
NR/EPDM/10NS+6BS+24CB	358,36	387,64 – 466,45	62,19
NR/EPDM/10NS+14BS+16CB	354,24	385,87 – 467,35	64,17



(a)

(b) *(c)*

Figure 2. TGA diagram of the nanocomposite materials based on NR/EPDM (60/40).
(a) 10NS+30CB; (b) 10NS+24CB+6SB; (c) 10NS+16CB+14SB.

For NR/EPDM (60/40) reinforced with 10 phr NS and 30 phr CB, the first temperature of maximal degradation was 388.72 ^{o}C (corresponding to NR degradation) and followed by degradation of EPDM at 466.03 ^{o}C. When carbon black (6 phr) is replaced by barium sulfate (6 phr), the first temperature of maximal degradation of NR/EPDM/NS/CB/BS nanocomposites decreases but not significantly to 387.64 ^{o}C, while the degradation temperature of EPDM increases slightly to 466.45 ^{o}C. If further increasing the BS content up to 14 phr, which means that the NR/EPDM blend is reinforced with 10NS, 14BS and 16CB (calculated by phr), the first derivative peak temperature continues to decrease to 385.87 ^{o}C but the second derivative peak temperature increases to 467.35 ^{o}C.

On the other hand, the mass loss at 500 ^{o}C of the NR/EPDM blend sample reinforced with 10NS+30CB as well as the sample of 10NS+6BS+24CB is in the range of 61 - 62 %, while that of the samples reinforced with 10NS+14BS+16CB reaches 64.17 %. In addition, the beginning degradation temperature of the blend samples of 10NS+30CB and 10NS+6BS+24CB are 359.17 ^{o}C and 358.36 ^{o}C, respectively; while that of the blend sample of 10NS+14BS+16CB is only 354.24 ^{o}C. This can be explained that NS and CB are more suitable fillers for rubber reinforcement, thus making NR and EPDM components more compatible, and that makes the nanocomposite materials have a tighter structure. If a small CB amount (about 6 phr) is replaced by BS, the regular and tight structure of the material is still maintained as described above (section 3.5). Therefore, the maximum degradation tempratures of NR and EPDM also fluctuate slightly and are closer to each other (Figures 2a and 2b), the beginning degradation temperature of material samples is also higher and the mass loss to 500 ^{o}C is also lower than the sample of 10NS+14SB+16CB.

From the above results, it is shown that the nanocomposite materials based on NR/EPDM (60/40) blend reinforced with NS/CB as well as NS/CB/BS, when at appropriate ratios, have much higher heat resistance than non-reinforced NR-based materials as well as nanocomposite samples reinforced with only nanosilica or carbon black (the begining degradation temperature is only about 300 ^{o}C) [20].

3.7. Effect of the modification process on the heat generation due to rotation and friction of materials

One of the objectives of researching rubber nanocomposites based on NR/EPDM blend is to produce heat-resistant conveyor belts. In this application, endogenous heat due to rotation and friction is one of the factors that greatly affect the durability of the product. To evaluate this heat generation process, we investigated the heat generation on the surface of nanocomposite materials in the abrasion test of cylindrical rubber specimens. The obtained results are shown in Figure 3.

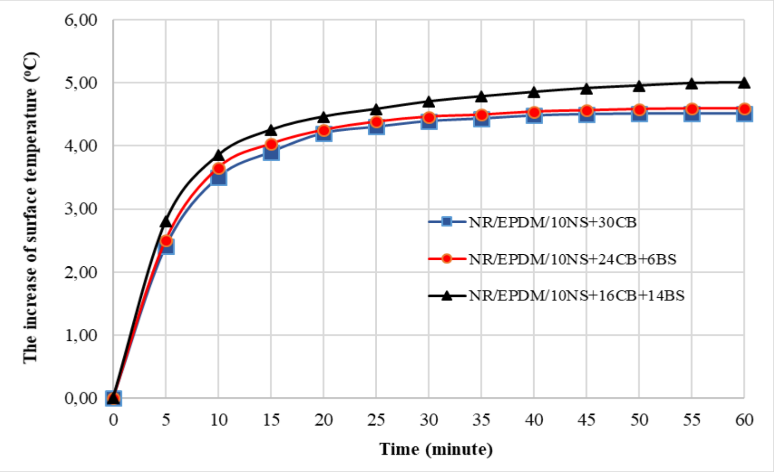


Figure 3. The increment of surface temperature due to rotation and friction of some nanocomposite materials based on NR/EPDM blends.

As can be seen from Figure 3, due to the rotation and especially the friction force on the contact surface between material samples and grinding wheel, the temperature on the surface of material samples increases. The process of heating up is fast at first, then slower and after about 25 minutes, the temperature on the surface of the material increases insignificantly. For the rubber material reinforced with 10NS+30CB (calculated by phr), after about 30 minutes, the increment of surface temperature is 4.39 ^{o}C; after about 50 minutes that is 4.51 ^{o}C and then almost no more increase is observed. For the material reinforced with 10NS+24CB+6BS, the increment of surface temperature is almost the same: after 50 minutes, the increment of surface temperature is 4.58 ^{o}C and then there is almost no more increase. Meanwhile, the samples reinforced with 10NS+16CB+14BS, after 50 minutes, the increment of surface temperature is 4.95 ^{o}C and still tends to increase slowly. This can be explained that the rubber nanocomposite reinforced with NS/CB has a higher thermal conductivity (due to its high CB content) and a tighter structure, so the heat generated will be quickly spread throughout the material as well as the surrounding environment, reducing heat accumulation on the sample surface. For the material reinforced with 10NS+16CB+14BS, due to less thermal conductivity of BS and less tight structure of the material, the increment of surface temperature is the highest. Thus, the increment of surface temperature of the rubber nanocomposite reinforced with 10NS+24CB+6BS is nearly equal to the material reinforced with 10NS+30CB and quite suitable for manufacturing rubber products subjected to friction and rotation.

4. CONCLUSION

Rubber nanocomposites based on NR/EPDM reinforced with NS, CB and BS were prepared by melt blending method using an internal mixer. The rubber nanocomposites show the best mechanical properties at NS content of 10 phr and CB content of 30 phr with the enhancement of tensile strength over 40 % compared to that of the rubber nanocomposite reinforced with only 10 phr NS.

The appropriate content of BS for replacement of CB in the NR/EPDM blend is 6 phr. The NR/EPDM (60/40, wt./wt.) blend reinforced with 10 phr NS+24 phr CB+6 phr BS has a tight structure, high mechanical properties, and especially, high alkali resistance and heat resistance, abrasion resistance and low endogenous heat due to rotation and friction. This material may be used to manufacture technical rubber products that require heat resistance and durability in alkaline environments under high friction and rotation conditions, for example conveyor belts used in the cement industry.

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CRediT authorship contribution statement. Tran Huu Quang: Methodology, Investigation, Formal analysis. Do Trung Sy: Formal analysis. Nguyen Tien Dung: Investigation. Tran Huu Huy: Investigation. Nguyen Thi Diep: Investigation. Pham Quynh Trang: Investigation. Pham Cong Nguyen: Investigation. Do Quang Khang: Methodology, Formal analysis, Supervision, Funding acquisition.

Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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