THE EFFECT OF CARBON BLACK GRADES IN TYRE TREAD COMPOUNDS

Mohd Bijarimi[1], Zulkafli Hassan[2], M. Dalour Beg[3], Zainal Abidin[4]

[1,2,3,4]Faculty of Chemical and Natural Resources Engineering, Universiti Malaysia Pahang

Email: bijarimi@ump.edu.my

ABSTRACT

In this study carbon black filler was added to the various formulations of tyre tread compounds. The carbon black grades chosen were N339/N375 and N550/N660. The compounds were characterised with respect to their rheological and physical properties. It was found that the carbon black grades of N375 and N339 could be substituted readily with minimal effects to the hardness, rebound resilience, tensile and tear strength. On the other hand, the carbon black of N550 could not be directly substituted with N660 as it affects the hardness and resilience of the vulcanizate.

KEYWORDS*: carbon black, hardness, tensile, tears, resilience*

1.0 INTRODUCTION

Rubber being a versatile material is widely used in many applications such as automotive, civil and electrical engineering. It has been well established that rubber without filler materials have very low physical strength and of no practical use.

Fillers are compounding ingredients added to a rubber compound for the purpose of either reinforcing or cheapening the compound. Despite that, fillers can also be used to modify the physical properties of both unvulcanized and vulcanized rubbers. Typical filler materials include carbon black, calcium silicate, calcium carbonate and clay. Fillers can be classified as black or white (non-black) fillers. Black fillers are more widely used in the rubber industry than white fillers. It is used in tyres, hoses and cable industries. Meanwhile white fillers are used in the footwear, general rubber goods and automotive industries.

Carbon black is the most popular filler added into the rubber compound due to its ability to enhance the strength properties of rubber vulcanizate as compared to gum vulcanizate; where no filler added (Medalia et al., 1994). Generally there are various types of carbon black grades used in the rubber industry such as N-200 ISAF (Intermediate Super Abrasion Furnace), N-300 HAF (High Abrasion Furnace), N-500 FEF (Fast Extruding Furnace) and N-660 GPF (General Purpose Furnace) series. However, the choice of carbon black grades for any given rubber formulation must take into account the desired physical properties of the end products, processing methods and costs.

Numerous studies have been done on the addition of carbon black in the rubber compounds (W.F Busse, 1934), (Lake *et.al*., 1988), (Mullins, 1959), (Gent *et.al*., 1967), (Busse, 1934), (Greensmith, 1956), (Rattanasom, 2009), (Mostafa *et.al*., 2009) and (Sam *et.al*., 2008). However the effect of carbon black grades in the tyre tread compound has not been widely studied. This study reports the rheological and physical properties of rubber vulcanizates with different grades of carbon black.

2.0 MATERIALS AND METHODS

2.1 Materials

In this study, natural rubber (NR) and NR/styrene butadiene rubber (SBR) blend was used to investigate the effect of cure characteristics and mechanical properties of rubber compounds. The carbon black grades chosen were N339/N375 and N550/N660 supplied by Cabot Corporation. Table 1 shows the typical tyre tread compounds. Formulations A1, B1 and C1 are standard recipes meanwhile recipes A2, B2 and C2 are variants. The effects of carbon black N550/N660 and N339/N375 were investigated in the formulations A1/A2 and B1/B2 & C1/C2 respectively.

TABLE 1
Compound formulations

Ingredients	A1 pphr	A2 pphr	B1 pphr	B2 pphr	C1 pphr	C2 pphr
NR	100.0	100.0	80.0	80.0	72.0	72.0
SBR	-	-	20.0	20.0	28.0	28.0
N375	-	-	57.0	-	55.0	-
N339	-	-	-	57.0	-	55.0
N550	53.0	-	-	-	-	-
N660	-	53.0	-	-	-	-
Zinc Oxide	5.0	5.0	4.5	4.5	3.0	3.0
Stearic Acid	2.0	2.0	2.0	2.0	4.0	4.0
Antioxidant	2.0	2.0	1.0	1.0	0.5	0.5
Antiozonant	1.0	1.0	2.0	2.0	2.0	2.0
Aromatic Oil	-	-	-	-	10.0	10.0
Sulphur	2.5	2.5	2.0	2.0	1.9	1.9
Accelerator	1.5	1.5	0.8	0.8	0.8	0.8
Retarder	0.4	0.4	0.20	0.20	0.4	0.4
Total	167.4	167.4	169.5	169.5	177.6	177.6

2.2 Compounding

Compounds were prepared in a two-step process; preparation of the masterbatch in a 1.6L Banbury internal mixer (BR1600) and addition of curatives on a two-roll mill. The mixing cycles of compound are given in the Table 2.

TABLE 2
Mixing cycles

Mixing steps	Ram down time(s)	Step instructions
1	0	1st addition: Rubber
2	50	2nd addition: Chemicals
3	100	3rd addition: Carbon black
4	150	4th addition: Chemicals
5	210	Brush/sweep
6	230	Discharge

As shown in the Table 2, the rubber was broken down in the internal mixer for 50 seconds at 60 rpm. Half of the masterbatch ingredients were later added and mixed for another 50 seconds. Subsequently, the carbon black was added and followed by the remaining ingredients. Finally the compound was dumped and weighed. The compound was cooled to room temperature for 3 hours before mixing with sulphur and accelerator. The mixing was carried out on a two-roll mill with roll speed of 30 rpm. After the addition of sulphur and accelerator, the rubber band was cut and folded several times to ensure uniform and homogeneous mixing. Total milling time was about 10 minutes. The compound was stored at room temperature for 24 hours before moulding.

The rheological properties of all compounds were determined by using an oscillating disc Monsanto Rheometer MDR 2000 and Mosanto Viscometer VM2000. The rheological such as cure characteristics and physical properties of the rubber vulcanizates were measured according to the ISO standards.

Cure characteristics at 150°C

- ML, dNm
- MH, dNm
- TC (10), mins
- TC (40), mins
- TC (90), mins
- TC (95), mins
- Mooney Scorch at 130°C
- t5, mins
- t35, mins

For physical properties, all compounds were cured to their respective TC (95) at 150°C.

- Physical Properties
- Hardness (Shore A)
- Rebound Resilience
- Tensile strength, MPa
- Tear strength (N/mm)

3.0 RESULT AND DISCUSSIONS

3.1 Rheological Properties

TABLE 3
Rheological properties at 150°C

	A1	A2	B1	B2	C1	C2
ML (dNM)	2.23	1.92	3.43	3.91	2.46	2.27
MH (dNM)	23.26	20.59	20.12	20.99	13.53	12.95
TC(10),min	6.48	4.77	4.73	5.27	8.38	6.85
TC(40),min	7.63	5.77	6.88	7.77	12.28	10.08
TC(90),min	12.02	9.37	14.82	17.37	22.87	18.55
TC(95),min	14.14	11.08	18.28	22.00	27.02	21.58
ML 1+4 (100°C)	64.3	55.1	81.3	92.1	54.5	51.2
Scorch (130°C)						
t5 (mins)	12:16	12:23	12:51	14:20	23:11	21:22
t35 (mins)	14:18	14:25	14:49	16:38	27:49	25:06

The Mooney properties and cure characteristics for all the compounds at 150°C are presented in Table 3. In compound A2 where a low structure carbon black filler i.e. N660 was used, the maximum torque (MH) decreased as compared to A1. This could be attributed due to higher structure of N550 in the formulation A1. Nevertheless, this is not the case for compounds B and C where the MH values are very close to each other. It was also observed that the scorch times were not much affected by the carbon black grades tested in this experiment.

3.2 Physical Properties

It has been well established that the incorporation of carbon black into rubber compound generally improved the strength, extensibility, fatigue resistance and abrasion. In this experiment we are concerned with hardness, rebound resilience, tensile strength and tear strength only.

TABLE 4
Physical properties cured to TC (95) at 150°C

	A1	A2	B1	B2	C1	C2
ML (dNM)	2.23	1.92	3.43	3.91	2.46	2.27
MH (dNM)	23.26	20.59	20.12	20.99	13.53	12.95
TC(10),min	6.48	4.77	4.73	5.27	8.38	6.85
TC(40),min	7.63	5.77	6.88	7.77	12.28	10.08
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TC(95),min	14.14	11.08	18.28	22.00	27.02	21.58
ML 1+4 (100°C)	64.3	55.1	81.3	92.1	54.5	51.2
Scorch (130°C)						
t5 (mins)	12:16	12:23	12:51	14:20	23:11	21:22
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3.3 Hardness

Hardness is a measure of the resistance to a reversible deformation of the rubber by a rigid indentor and widely used as a quality control measure. In this experiment, the results are shown in Figure 1 where the hardness is plotted against compounds. In compound A2, the hardness value was lower by 3 units as compared to A1 due to the substitution of carbon black N550 to N660. This softness could be due to relatively lower carbon black structure of N660 as compared to the N550. Structure describes the number of particles that fuse to form an aggregate. The more particles in the aggregate, the more complex in the shape and greater void volume created. These voids can be filled with polymer [2]. In contrast, the substitution of N375 to N339 shown the result an increase of hardness value by 3 units. Similarly, this can also be explained that the N339 has higher structure as compared to N375. However, the opposite phenomenon was found to be occurred in the compounds C1/C2 where the hardness decreased by 3 units even though the relatively higher structure of black i.e. N339 was used. This can be explained by the addition of oil in the compound C1/C2 probably has influenced the hardness value. In the absence oil, it was observed that the use of relatively higher structure of carbon black has contributed to a certain extent of higher hardness value. In addition, the maximum torque is correlated with hardness and modulus. From Table 3, the maximum torque was higher in A1 and hence the increase of hardness was expected.

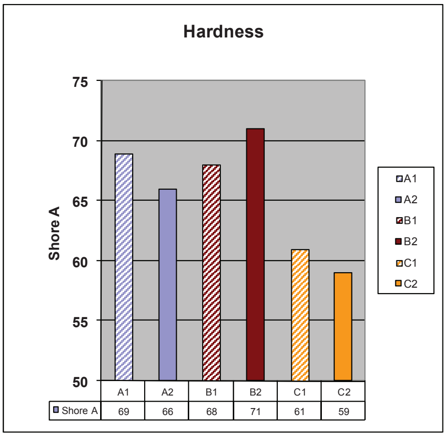

FIGURE 1
Variation of hardness with formulation

3.4 Rebound Resilience

Rebound resilience is the ratio of the energy of the indenter after impact to its energy before impact expressed as a percentage. Generally, the rebound resilience values did not show significant effect on different carbon black grades tested in this experiment. However this could only be true in the B1/B2 and C1/C2 compounds. In compound A2 where the carbon black grade was substituted from N550 to N660, the resilience increased by about 6 units. Perhaps this could be due to the drop of hardness value hence contributed to the higher value of rebound resilience.

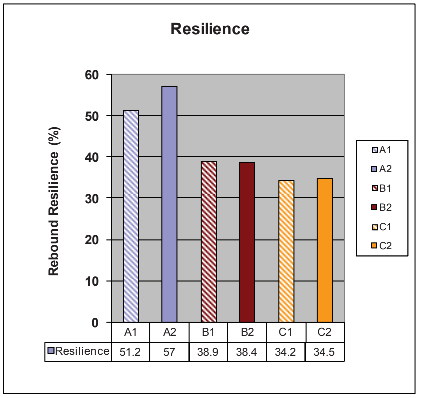

FIGURE 2
Variation of resilience with formulation

3.5 Tensile strength

Figure 3 shows the effect of different carbon black grades tested against the tensile properties in the tread compounds. Surprisingly, the tensile strength values showed almost no effect due to the substitution of N375/N339 and N550/N660 carbon black in all the formulations. However, according to Kraus, it is known that at a fixed loading (50phr) a low structure carbon black gives a higher tensile strength and higher elongation than a high structure carbon black of the same surface area (Denstaedt, 1990) and (Kraus, 1971). However, the elongation at break of the low structure carbon blacks i.e. N660 and N375 showed relatively higher values as compared to N550 and N339 respectively.

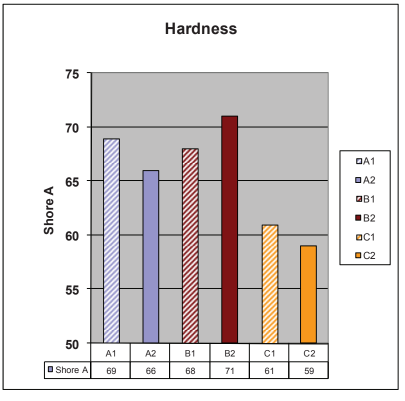

FIGURE 3
Variation of tensile strength with formulation

3.6 Tear strength

Figure 4 shows the tear strength of compounds with different compounds. There are very minimal effect to the compounds A1/A2 and B1/B2. However, in compound C2 the tear strength value increased by 4 units. Unlike the tensile strength values, the compounds C1/C2 appeared to having very much higher tear strength than A1/A2 and B1/B2. Perhaps this could be due to the presence of rubber crumb in the filler-rubber matrix which delays the tearing process.

4.0 CONCLUSIONS

From the observations and results obtained, the following conclusions can be drawn:

- The carbon black grades of N375 and N339 can be substituted directly into the tyre tread compound. It was shown that the hardness, rebound resilience, tensile strength properties were not very much affected. N375 carbon black grade is the more favourable option as it is relatively cheaper than N339.

- The carbon black N550 and N660 could not be directly substituted in the tyre tread compound as it decreases the hardness property. In order to achieve a similar hardness value, the loading of N660 needs to be increased.

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