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Mechanical and sliding wear of SBR vulcanizates as a function of carbon black loading

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ABSTRACT

Mechanical and tribological properties of N330 carbon black filled Styrene butadiene rubber (SBR) vulcanizates were evaluated when rubbed against austenitic stainless steel at various filler loading. It has been found that the tensile properties of the vulcanizates were improved with filler loading compared to the control recipe. Friction coefficient of the unfilled SBR vulcanizates was higher than the filled counterpart. Wear properties derived from pin on disk, fretting fatigue and Taber abrading machine were found to decrease with filler loading. The observed trends were attributed to the rubber-filler interaction as well as the type of crosslinks produced.

KEYWORDS

Sliding wear;
Friction coefficient;
SBR.

INTRODUCTION

As a kind of highly elastic materials rubber has some favorable properties such as high resistance to wear compared to metals and some other polymeric materials. Rubber friction differs in many ways from the frictional properties of most other solids due to the very low elastic modulus of rubber and the significant internal friction of rubber in a wide frequency range. Earlier reports by Grosch[1] revealed that the rubber friction is linked with the internal friction of the rubber molecules. Therefore, all rubber compounds forwarded for tribological applications must satisfy some requirements, such as a given friction coefficient and wear properties[2-3]. Polymer based frictional materials contain fillers (either particulate or fibrous) as well as various solid lubricants[2]. The physical processes occurring during the sliding wear of rubbers have two major components commonly related as adhesion and hysteritic components, respectively[4]. The hysteritic component arises from the internal friction of the rubber. During the sliding process the rough counterpart substrate exerts oscillating forces on the rubber surface which leads to cyclic deformation of the rubber and energy dissipation via the internal damping of the rubber. Simultaneously the role of adhesion between the elastomer and the substrate is expected to participate to the deformation process during the sliding wear. This is attributed to the interaction between the surfaces which gives an additional contribution to the sliding friction. In the knowledge of the hysteritical and adhesional components together with the structural characteristics of the rubbers, their tribological behavior is predictable. During wear, four possible mechanisms are expected to occur at the sliding surface. These include adhesion of the rubber to the counterpart succeeded by cohesion failure of the former; scratching of the rubber due asperities of the sliding counterpart producing debris; thermomechanical fatigue of the rubber causing its which detaches some part of the material from the surface; and finally pyrolysis or oxidation which results in gas formation[4,5]. The sliding conditions(load, speed and duration) are known to influence these above mechanisms; however the most important aspect is the inherent structure of rubber (crosslinking type and degree, filler type and amount). In this work we report on the influence of carbon black loading on the sliding behavior of Styrene-Butadiene Rubber(SBR) vulcanizates. Attempts were made to correlate the wear characteristics with structural ones and to trace relationships between wear and mechanical properties.

EXPERIMENTAL

Rubber compounds and their curing

SBR vulcanizates were delivered by the Deutche Institut Für Kautschuktechnologie e.v (Hanover, Germany). The mixing recipe used was as follows (in parts) SBR 100 parts; zinc oxide; 3 stearic acid 1; CBS 1.5; and carbon black(N330) : variable(from 0 up to 60). As the addition in rubber recipes are traditionally indicated in parts per hundred parts rubber (phr, see above) the carbon black(CB) loading is given in this unit furtheron, the cure characteristics were determined at 160^0C by a Monsanto moving die rheometer (MDR2000EA-1) at 1.667Hz and 0.5^0C arc. These included scorch time(t_5), the optimum cure time (t_{90}) and the difference between the maximum and minimum torque(MH-ML). Note that MH-ML is often traced as state of cure. Sheets of 2mm thickness were produced by compression moulding using a Satim machine(constructeur, France) at 160^0C and 70 bar pressure according to their $t_{90,}$ as read from the MDR curemeter curves. The rubbers were characterized by the swelling index. Circular discs with a thickness of 2mm and 20mm diameter were immersed in toluene for 72h, swelling index was measured as :

$$\text{Swelling Index=Final mass/Intial mass} \qquad (1)$$

As the swelling index is an indirect indication of the crosslink density[7].

Testing

Tensile properties

Tensile tests were carried out on 2mm thick dumbbells at ambient temperatures on Zwick 1445 universal testing machine at a deformation rate of 50cm/min with respect to ASTM D412. Five specimens were tested and the median value was determined for each rubber formulation.

Hardness

Circular discs of 2mm thickness were tested on ASTM shore A hardness tester in International Rubber Hardness Degrees (IRHD) according to ISO 48(1979).

Wear

The friction and sliding wear were assessed on a home built pin-on-disc wear tester under dry conditions (ambient temperature of 21^0C and relative humidity of 50-70%). Stainless steel pin over a period of 6h in circular rotation was pressed against the rubber disc. The rubber disc was fixed by a metal frame. Pin is made of Austenitic stainless steel 316L (17-12 Mo), metal powder produced by Atmix Co., Japan, the pin was injection moulded by Taisei Kogyo Co., Japan, ρ=7.95g/cm^3 , H_u=2.15 GPa and H_v=1.81 Gpa, Tests were carried out at a speed of 0.25 m/s and 3 N load. This corresponds to a pressure $\times$ speed term of 5.95×10^{-5} MPa.ms^{-1}. The torque was also measured by a torque measuring shaft in order to qualify the frictional forces expressed as friction coefficient(μ). The mass loss determined by weighing was converted to wear volume(volume loss by considering the density of the rubber according to the following equation :

$$\text{Volume loss, mm}^3 = \frac{\text{Mass Loss, g}}{\text{Density, g/ml}} \times 1000 \qquad (2)$$

The density was determined according to DIN 53479 method A the data are shown in TABLE 1. The specific wear rate was calculated according to the following equation :

$$Ws = \frac{m_a - m_e}{\rho F_n . S} \qquad (3)$$

$$S = 3600 . v . t \qquad (4)$$

where W_s is the specific wear rate (mm^3/N.m); m_a is the initial weight (g); m_e is the final weight ;F_N is the normal load(N); v is

TABLE 1: Network-related and tensile properties of SBR vulcanizates as a function of carbon black content(phr)

CB content (phr)	0	30	45	60
Swelling index	4.15	2.87	2.73	2.46
Shore A hardness	55	65	71	75
T.strength (MPa)	2.8	19.2	24.5	35.2
M300(MPa	1	3.3	4.6	6.4
%EB	656	1056	719	674
Density(ρ)(g/ml)	0.98	1.23	1.27	1.43

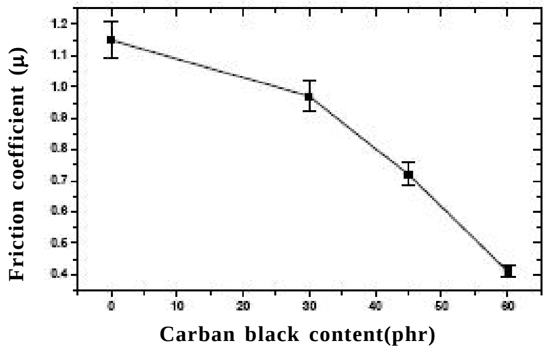


Figure 1 : Course of friction coefficients as a function of CB content

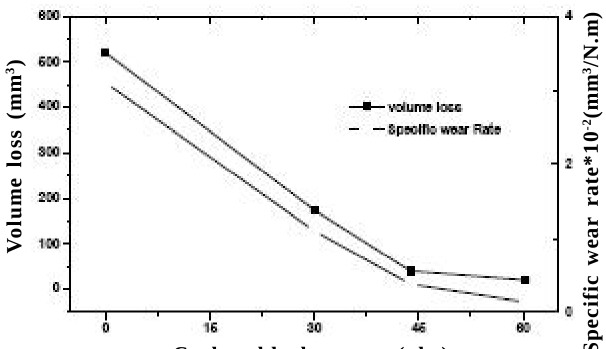


Figure 2 : Volume loss (v) and specific wear rate (k) as a function of CB content of the SBR vulcanizates

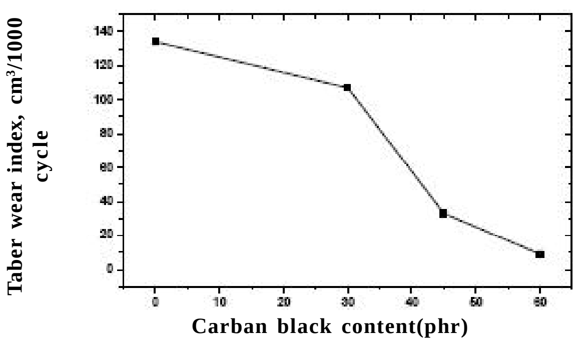


Figure 3 : Change in the taber wear index as a function of the CB content of the SBR vulcanizates

the sliding velocity (m/s); S is the sliding distance; t is the duration time(h) and ρ is the density (mg/ml).

Abrasion resistance

The abrasion test was carried out on Taber® Abraser Model 5130 with digital counter (Taber Industries, NY, USA). Specimen of 100100mm^2 were adhered to S-36 mounting card and abraded against H-18® wheels calibrade with 1000g load for 5000 cycle. The Taber wear index was expressed as volume loss in mm^3/1000 cycles of abrasion.

Failure mode

The worn surfaces of the pin-on-disc test was inspected with scanning electron microscope (SEM) type JSM5400 (geol Toleyo, Japan). Prior to scanning the specimens were sputtered with Au-Pd alloy.

RESULTS AND DISCUSSIONS

Cure characteristics and tensile properties

TABLE 1 lists both network related and tensile properties for the SBR green and it vulcanizates filled various amounts of carbon black (CB). Both modulus and tensile strength increase profoundly with CB content. This is due to the large specific area of the CB used (mean particle size of N330 CB is ca. 30nm) favoring rubber filler interactions. Increasing CB content is accompanied with a substantial decrease in the swelling index and increase in apparent crosslink density. The elongation at break passed through a maximum as a function of CB content. This can be due to incomplete filler network formation the break up of which was accompanied with a ductility increase.

Wear characteristics

Figure 1 shows the course of the friction coefficient as a function of CB content. Note that the friction coefficient represents an average value recorded during the test of 6 h duration. Claiming that the softer the rubber the larger is the actual contact area and thus the corresponding friction coefficient.

Both volume loss and specific wear rate decrease with increasing CB content (cf. Figure 2).

So increasing crosslink density and filler/rubber interactions improve the resistance of sliding wear of rubber. This is fruit usual for rubbers at least to a given threshold CB content. Considering the reinforcing effect of CB as reflected by the tensile data and sliding

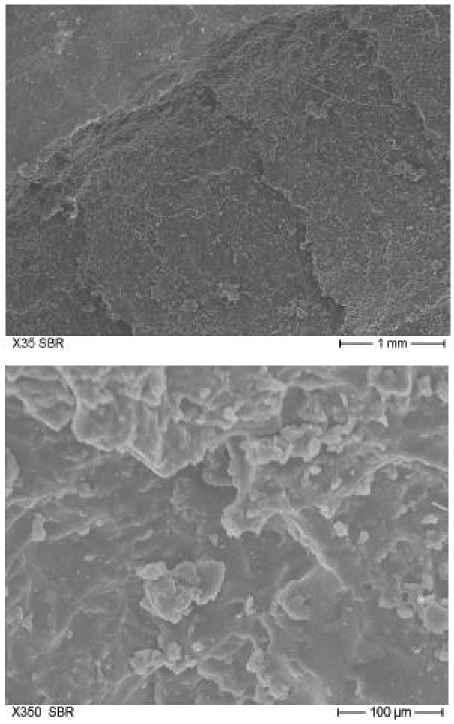
(a)
(b)


Figure 4 : SEM worn surfaces for unfilled SBR vulcanizates at two different magnification modes

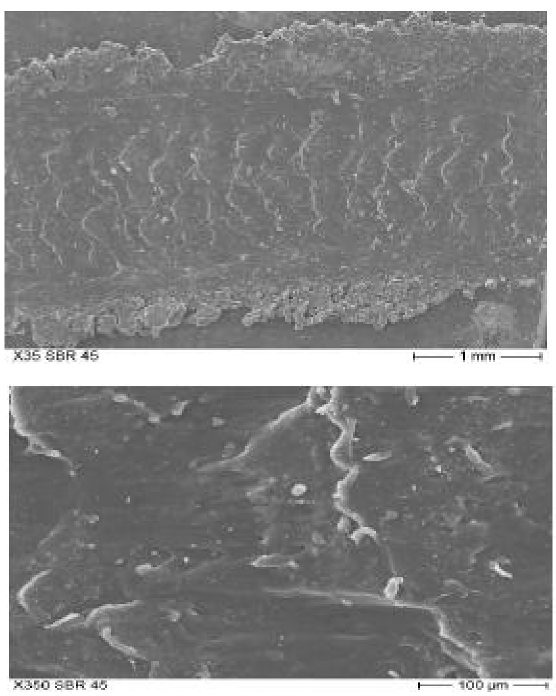
(a)
(b)


Figure 5 : SEM worn surfaces for unfilled SBR vulcanizates at two different magnification modes

wear characteristics. The trend reported in this study concords earlier reports on the wear resistance of various reinforced rubber composites[8-11].

Taber abrasions

The taber wear index decreases obviously with increasing CB content (cf. figure 3). This behavior is analogous with that of the sliding wear (cf. figure 1). As a consequence the corresponding failures modes should also be similar.

Fracture mode

Sliding wear

SEM pictures taken from the worn surfaces of the neat SBR rubber are displayed in figure 4a and b respectively. Some type patterns, i.e. ribs transverse of the sliding directions can be observed in figure 4a.

On the other hand the failure is mostly caused by micro cutting and slipping (cf Figure 4b). This failure is supported by low crosslink density and low tensile performance of this SBR. The wave patterns are well resorted for the SBR with 45 phr CB in figure 5a.

The edges of the Schallamach waves end in rolls. They detach in rather small transverses due to the enhanced stiffness and strength of this vulcanizates. The overall surfaces is smeared suggesting a low wear rate (cf figure 5b) of some craterliice features on the surface indicate that secondary cracking might be at work.

CONCLUSIONS

The following conclusions can be drawn from this study.

The mechanical performance of the vulcanizates were improved as such. The value of wear loss of SBR containing carbon black decrease progressively with the increase of filler loading. This was attributed to the increase in crosslink density as well as the reinforcing role exerted by the carbon black used in this study.

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