Influence of Static and Cyclic Compression on the Electrical Conductivity of FEF Black-Loaded Rubbers

The influence of static and cyclic compression on the electrical conductivity of 100 fast extrusion furnace (FEF) black-loaded rubber vulcanizates (SBR, NR, IIR, BR, and NBR) has been studied. It was found that the electrical conductivity is most pressure sensitive for the SBR and NR composites and exhibits a slight dependence upon the number of compression cycles. In addition, the temperature coefficient of conductivity for SBR shows a weak dependence upon the stress amplitude and the number of compression cycles.

INTRODUCTION

The correlation between electrical and mechanical properties is one of the major problems of polymer science and attracts the attention of many investigators,[1-9] since it has a great impact on modern technological applications. It has been shown that preextension should certainly modify the distribution and arrangement of carbon black particles or aggregates in the rubber matrix.[1] This behavior was interpreted in terms of the structure of the polymer and dispersed filler on the basis of an idealized model.[2]

On the other hand, there is strong evidence that static pressure largely affects electrical conductivity of SBR vulcanizate filled with different concentrations of FEF black.[6] The present work describes the influence of the static and cyclic compression on the electrical conductivity of several types of rubber: SBR, BR, IIR, NBR, and NR loaded with FEF.

EXPERIMENTAL

FEF black was introduced into the investigated types of rubber, namely, natural rubber (NR), butadiene rubber

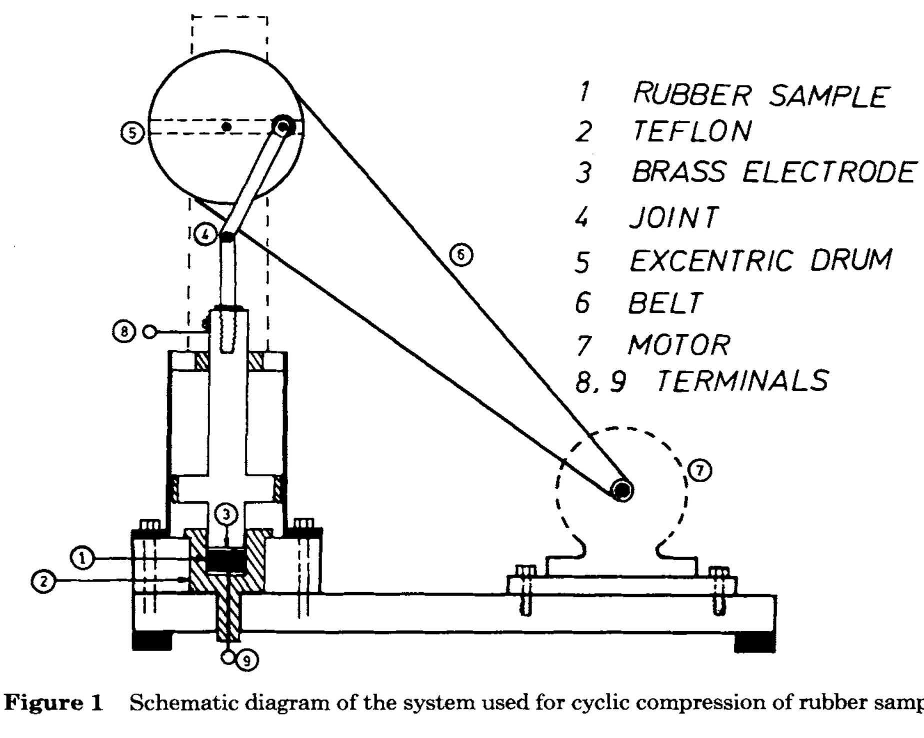

Figure 1 Schematic diagram of the system used for cyclic compression of rubber samples.

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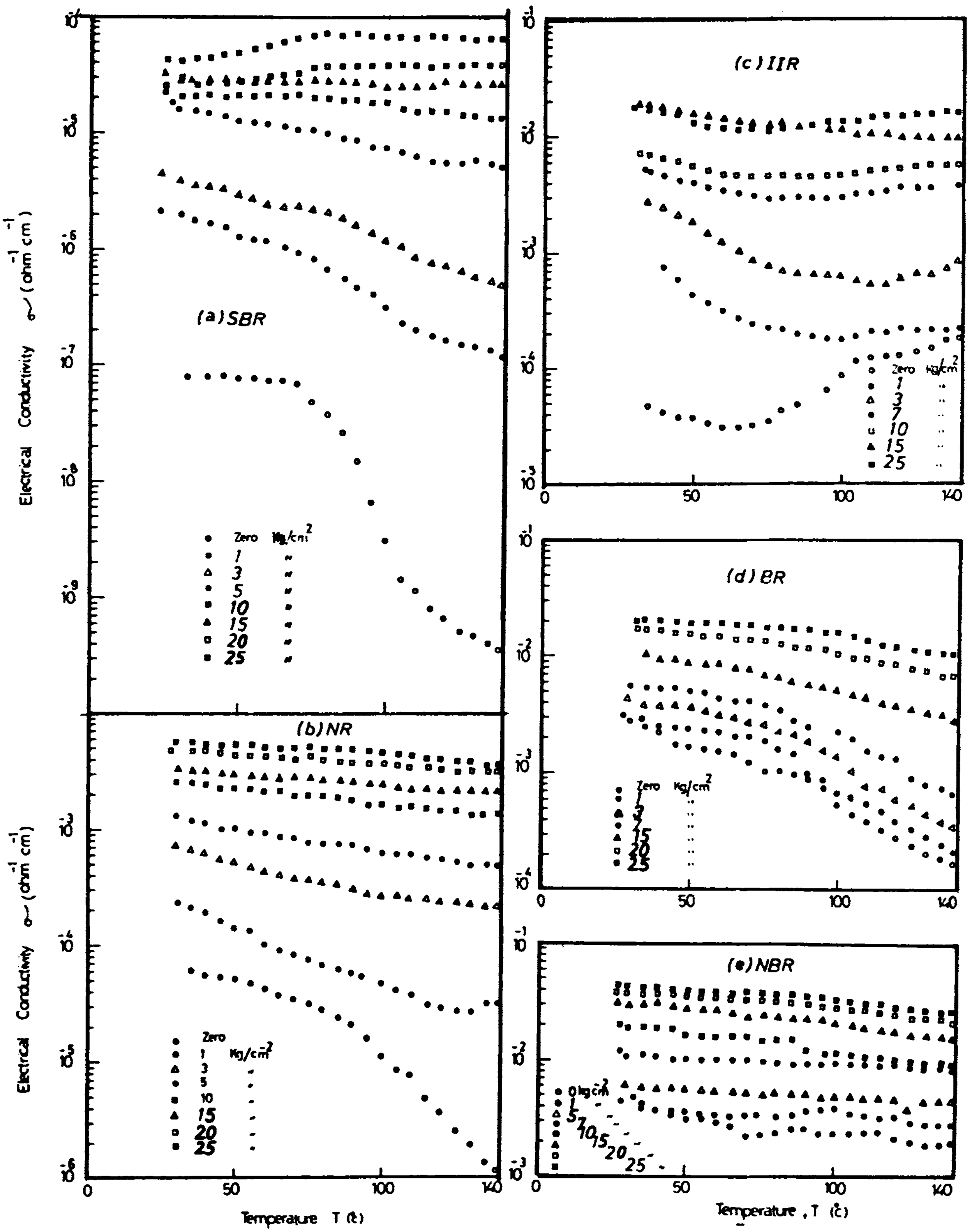

Figure 2 Effect of static pressure on the $\sigma(T)$ dependence for 100 phr black-loaded rubber composites: (a) SBR; (b) NR; (c) IIR; (d) BR; (e) NBR.

Table I Composition of the FEF Black-Loaded Rubber Composites

Ingredients (phr)[a]	Sample SBR	NR	IIR	BR	NBR
SBR-1502	100	—	—	—	—
NR	—	100	—	—	—
IIR	—	—	100	—	—
BR	—	—	—	100	—
NBR	—	—	—	—	100
Stearic acid	2	2	2	2	2
ZnO	5	5	5	5	5
Processed oil	10	10	10	10	10
FEF black	100	100	100	100	100
MBTS[b]	2	2	2	2	2
PBN[c]	1	1	1	1	1
S	2	2	2	2	2

[a] Parts per hundered part of rubber by weight.
[b] Dibenthiazyl disulphide.
[c] Phenyl-β-naphthylmine.

(BR), styrene butadiene rubber (SBR), butadiene acrylonitrile rubber (NBR), and butyl rubber (IIR) according to the recipe illustrated in Table I. The test samples were prepared on a two-roll mill of 170 mm diameter, working distance 300 mm speed of slow roll 18 rpm, and gear ratio 1.4. The rubber composites were left for 24 h before being vulcanized at 143 ± 2°C under a pressure of about 40 kg/cm^2 for 20 min.[7]

Test samples had the form of discs of radius 0.5 cm and thickness about 0.35 cm. The effect of static pressure, P, on the temperature dependence of electrical conductivity, $\sigma(T)$, was studied following a previously described method.[6] Since variation of mechanical properties of rubber with time represents an actual problem,[8] it was necessary to leave the test samples for a sufficiently long time (about 4 h) under the applied static pressure to ensure establishment of equilibrium.

Cyclic compressions of the rubber samples were carried out at a constant number of cycles, frequency, and stress amplitude using a locally made setup (see Fig. 1).

Table II Temperature Coefficient of the Conductivity for 100 FEF/SBR Uncompressed Sample at Different Numbers of Compression Cycles, *N*, and Stress Amplitude, *A*

N	TCC × 10^2 (°C^{-1}) A = 1 kg/cm^2	A = 4 kg/cm^2
100	2.4	7.2
1,000	1.96	4.3
5,000	4.37	0.5
10,000	1.75	2.25

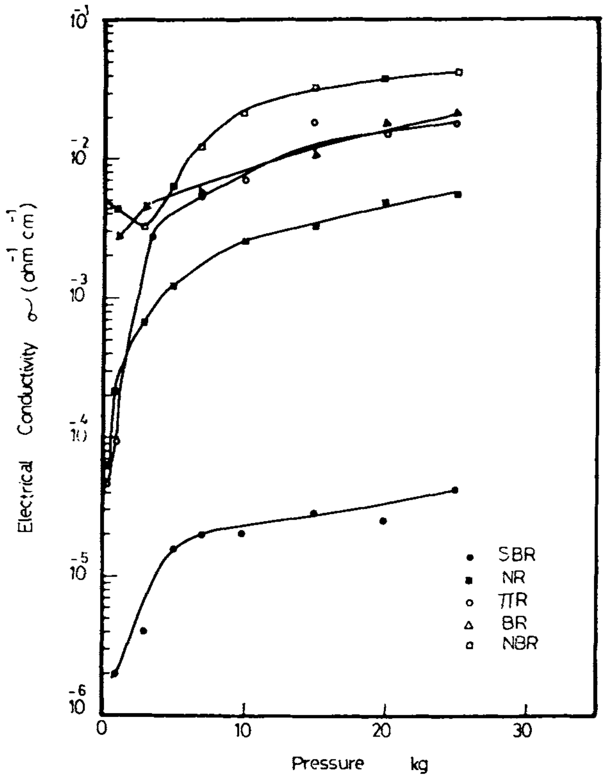

Figure 3 Dependence of electrical conductivity, σ, on static pressure at room temperature.

RESULTS AND DISCUSSION

The effect of static pressure on the $\sigma(T)$ dependence for 100 phr FEF black-loaded rubber samples is presented in Figure 2. It is noticed that each composite has its own behavior, although they all contain the same content of FEF.

σ is seen to increase with pressure, P, while the temperature coefficient of conductivity (TCC) decreases for all rubber samples. The increase of P leads to a decrease of the hopping paths between carbon black particles or aggregates[5] and, consequently, to the observed rise in σ. However, at a given pressure, as the temperature rises, these hopping paths begin to expand appreciably. This would imply that pressure and temperature have opposite effects on conductivity, and, hence, the observed value of σ is determined by competition of these two parameters.

Figure 3 represents the $\sigma(P)$ relation at room temperature for the investigated rubber composites. It is clear that the NBR sample has a somewhat peculiar behavior as compared to other composites. While the conductivity of the latter shows a monotonic increase with pressure, σ for the NBR composite decreases with P up to 3 kg/cm^2,

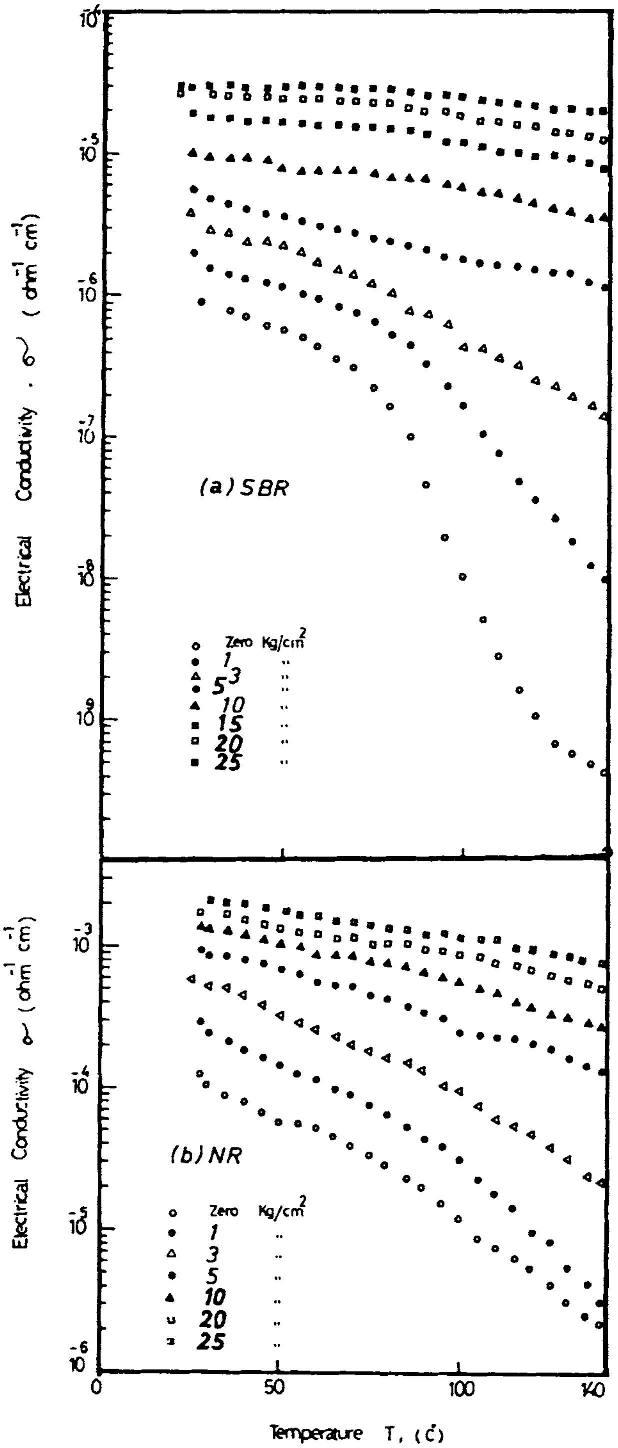

Figure 4 The $\sigma(T)$ dependence at different values of static pressure for rubber samples after being subjected to 100 compression cycles: (a) 100 FEF/SBR; (b) 100 FEF/NR.

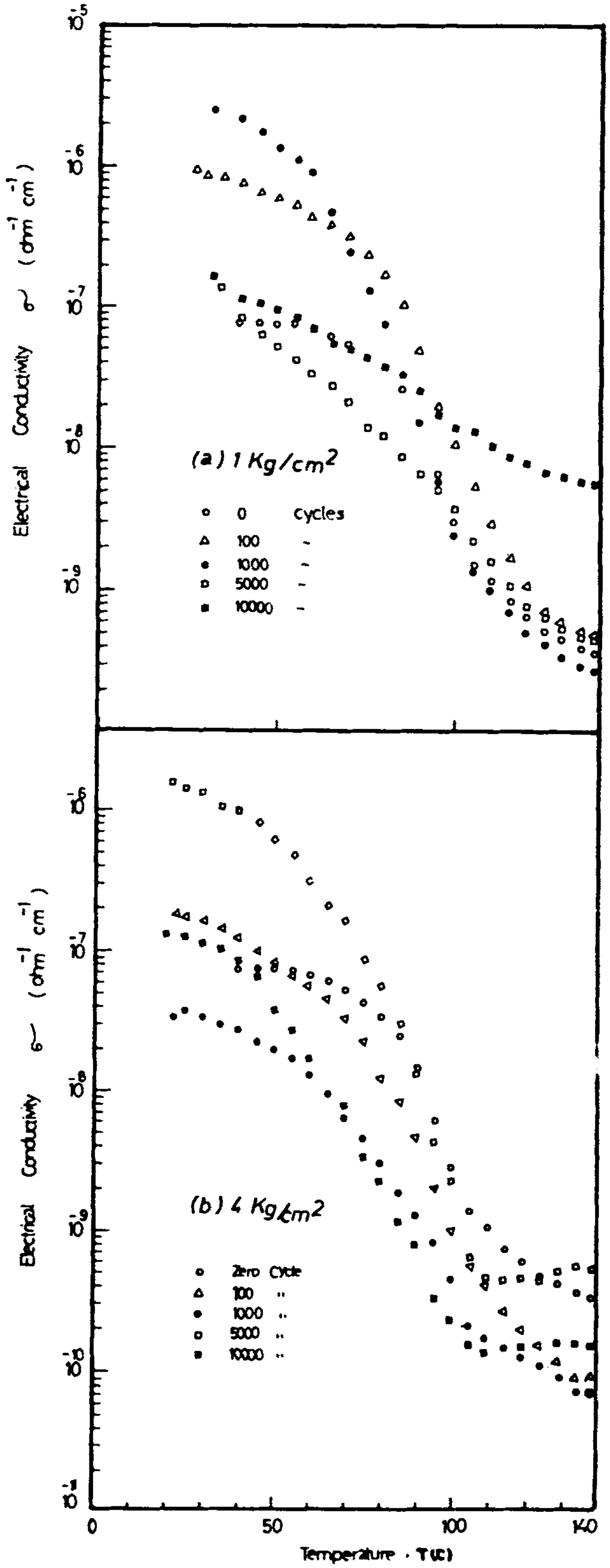

Figure 5 Effect of stress amplitude and number of compression cycles on the $\sigma(T)$ dependence for the 100 FEF/SBR composites: (a) 1 kg/cm^2; (b) 4 kg/cm^2.

after which it starts to increase. This may be explained by a breakdown of the carbon structure at low-pressure values and alignment of rubber chains in the direction of applied stress at higher pressures.

Figure 2 shows that NR and SBR composites are the most sensitive to static pressure. For this reason, it seemed reasonable to investigate the influence of cyclic compression on the $\sigma(T)$ dependence, namely, for these composites.

Figure 4 demonstrates the $\sigma(T)$ dependence at different values of static pressure for SBR and NR samples after being subjected to 100 compression cycles of constant amplitude at a rate of about 3.4 cycles/s. A comparison of Figure 2 (a) and (b) with Figure 4 (a) and (b) indicates that cyclic compression of NR and SBR samples leads to a slight decrease of conductivity, probably due to an increase of hopping paths between carbon particles or aggregates as they relax to more stable positions within the rubber matrix under the effect of the applied cyclic stress.

The fact that cyclic compression causes some decrease in the electrical conductivity of NR and SBR showed that it might be useful to study the effect of stress amplitude and number of compression cycles on the $\sigma(T)$ relationship for the FEF/SBR sample; the results are illustrated in Figure 5 and Table II.

As might be observed from Figure 5, increasing the stress amplitude or number of compression cycles causes some decrease in the electrical conductivity. Moreover, Table II shows that the temperature coefficient of conductivity decreases as the number of compression cycles increases at a constant stress amplitude and increases as the stress amplitude increases at a constant number of compression cycles.

Such a behavior of σ and TCC may be interpreted as a consequence of an increase of the percentage breakdown of carbon black structure under the effect of the applied cyclic compression. Qualitatively speaking, it may be said that this behavior is in agreement with the fact that the energy dissipated per second in the sample is proportional to the square of the stress amplitude.[9]

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