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THE EFFECT OF DC CONDUCTION IN ISOBUTYLENE ISOPRENE RUBBER LOADED WITH FAST-EXTRUSION FURANCE BLACK (FEF)

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ABSTRACT:

The effect of current-voltage characteristics of samples of isobutylene isoprene rubber (IIR) loaded with fast-extrusion furance black (FEF) carbon black has been studied at different temperatures in the voltage range 3-10 Kv. The conduction mechanism was found to follow the conventional band approach followed by the hopping model for (IIR) mixed with 40 phr of (FEF) carbon black.

1- INTRODUCTION

The aim of this work was the investigation of the current-voltage characteristics at different temperature for isobutylene isoprene rubber (IIR) loaded with fast-extrusion furance black (FEF) carbon black. According to Hashem et al., the interaction between carbon balck and polymer plays an important role in the electrical conductivity of the composite [1]. The space-charge limited current is encountered for the compsite. Therefore, the wealth of information that is obtained from the space charge limited current enables us to describe the condition mechanism in the compositie by the conventional band model. This mechanism is based upon the interaction between (FEF) carbon black and (IIR).

2. EXPERIMENTAL:

Samples of isobutylene isoprene rubber (IIR) loaded with fast-exctrusion furance black (FEF) carbon black was prepared according to Table I. The specification of the (FEF) carbon balck used is given in Table II [2]. The mixture was left for at least 24h before vulcanization. The samples were vulcanized at 150 ± 2 °C inside pressure of about 4o Kg/cm^2 for 30 min. The samples were shaped in the form of disc of 1.5 cm in diameter and 0.3 cm thick.

The electrode was silver paste covering the opposite surface of the sample over a circular area of 1 cm in diameter. The sample were thermally aged at 90 °C for 35 days to attain reasonable stability.

3. RESULTS AND DISCUSSION:

Figure (1) show the current-voltage (I–V) characterstic on a log-log scale for IIR loaded with 40 phr (FEF) carbon balck at different temperatures. I find that the conductionn is ohmic ($I \alpha V$) at low field. At intermediate fields, a square law region ($I \alpha V^2$) is obtained. The current density (J) in the square law region is given by the relation [3–6].

$$J = \frac{9 \in \in_o \mu_o V^2}{8a^3} \qquad (1)$$

where μ_o is the free carrier mobility; $\in_o$, the permittivity of free space; $\in$, the dielectric constant of the sample material ($\in = 17$ for 40 phr (FEF) composite) [7] ; and a, the sample thickeness.

Figure (2) show the plot of ($I-V^2$) for FEF composite at different temperature. The ($I-V^2$) plot fit stright lines at different temperatures, indicating the formation of space-charge in the composite. The formation of space-charge is due to the existence of traps within these composite that can occur at particular molecular sites and chain folds [8]. When a trap level exists, the electron mobility is reduced by $1/\theta$, and the effective electron drift mobility (μ_e) in an insulator with traps is, therefore,

$$\mu_e = \mu_o \theta \qquad (2)$$

where θ is the trapping factor.

$$\theta = N_c / N_t \exp(-E_t / kT) \qquad (3)$$

where N_c is the effective density of states in the conduction band and N_t is the shallow trap density at energy E_t below the conduction band edge, K is the Boltzmann constant, and T is the absolute temperature. Therefore, in the trap-square law region, which is our case, the relation between J and V^2 becomes [4,6]

$$J = \frac{9 \in \in_0 \ \theta \mu_0 \ V^2}{8 a^3} \tag{4}$$

The free current carrier mobility (μ_0) can be calculated at different temperatures using the experimental value of θ and the slope of $(I-V^2)$ plots. Experimentally, θ is the ratio between the current densities at the beginning I_1 and the end I_2 of the trap-square law region [5]. Again, θ is the ratio between the free electron concentration n_0 in the conduction band to the total electron density (n_0+n_t), n_t being the density of the trapped electrons. Thus,

$$I_1 / I_2 = \theta = n_0 / (n_0 + n_t) \tag{5}$$

Figure (3) shows the variation of the calculated μ_0 with temperature which we found that μ_0 decreases with increasing temperature and reaches a minimum value at 333 K. The behavior of μ_0 with temperature was identical with that observed for the electrical conductivity (σ) with temperature (in the ohmic region), as illustrated in Figure (4).

Using the experimental values of θ at different temperatures in Eq.(3); E_t, can be determined by plotting log θ against $^1/_T$, and this illustrated in Figure (5). From the slope, E_t , was found to be 0.09 eV.

The equilibrium concentration of the charge carrier in the conduction band n_0 can also be obtained using the relation [5].

$$n_0 = \left(\frac{\in \in_0 \ \theta}{q a^2} \right) V_{tr} \tag{6}$$

where q is the electron charge and V_{tr} is the voltage at which the transition from the ohmic to square law region takes place. The free carrier density n_0 may be used in Eq.(5) to determine the values of n_t, the trap carrier density.

For one type of current carrier, the conductivity is given by

$$\sigma = q\, n_o\, \mu_o \qquad (7)$$

Using the calculated values of n_o and μ_o in this equation, we found that the calculated values of σ agreed with the values determined from the ohmic region.

The Fermi level E_f measured from the bottom of the conduction band can be given by

$$n_o = N_c \exp(-E_f / kT) \qquad (8)$$

Figure (6) shows a plot of log n_o against 1/T. Comparing this figure with Figure (4), we found that the behaviour of n_o with 1/T is the reverse of the σ – 1/T plot.

Fermi energy can be determined from the slope of log n_o against 1/T. The Fermi level E_f was found to be 0.15 eV. Table III give the calculated parameters for FEF composite.

Comparing Figures 3,4 and 6, we found that the variation of σ with T follows the variation of μ_o with T rather than n_o with T.

It was established that if μ_o is greater than 1.0 $cm^2\ V^{-1}\ S^{-1}$ and varies with T^{-n} the conduction mechanism is a convertional band model, while if it is less than 1.0 $cm^2\ V^{-1}\ S^{-1}$ and varying as exp(-Eu/kT), where E_u is the mobility activation energy, the conduction mechanism is the hopping mechanism [3,4]. In our FEF composite , μ_o is greater than 1.0 $cm^2\ V^{-1}\ S^{-1}$ (3.28 $cm^2\ V^{-1}\ S^{-1}$) at room temperature and decrease with increasing temperature (see Figure 3) up to 333 K. Therfore, one can conclude that the conduction mechanism in the FEF composite is a conventional band model up to 333 K.

Finally we can concluded that IIR mixed with 40 phr of FEF carbon black, the conduction mechnism is a conventional band approach followed by the hopping model at a certain temperature.

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Table I. Composite formulation

Ingredients	(phr)*
IIR	100
Steric acid	2
Zinc oxide	5
Processing oil	10
FEF	40
MBTS **	2
PBN ***	1
Sulphur	2

* Parts per hundred parts rubber by weight.

** Dibenzthiaryle disulfide.

*** Phenyl- βnaphthylamine.

Table II. Specification of FEF carbon black

ASTM	Particle Diameter Arithmetic Mean (A°)	Surface Area m^2/g	Oil Absorption (cc /g)
N 550	360	55	1.34

Table III. Parameters for FEF composite at various temperatures

Temp. (°C)	$\sigma_{\text{measd.}} \times 10^{10}$ ohm^{-1} cm^{-1}	$\sigma_{\text{calc.}} \times 10^{10}$ ohm^{-1} cm^{-1}	$\theta \times 10^{2}$	μ_o (cm^{2}V^{-1}S^{-1})	μ_e (cm^{2}V^{-1}S^{-1})	$n_o \times 10^{-9}$ cm^{-3}	$n_t \times 10^{-10}$ cm^{3}	E_t (eV)	$N_t \times 10^{-11}$ cm^{-3}
25	3.8	5.2	4.40	3.28	0.14	0.96	2.08	0.09	2.07
40	1.8	4.3	4.40	2.05	0.10	1.30	2.46		2.07
60	0.5	1.5	5.75	0.51	0.03	1.80	2.90		2.40
90	7.8	21.0	8.23	5.45	0.45	2.43	2.70		1.76
100	15.0	71.0	7.54	23.61	1.78	1.90	2.30		1.60

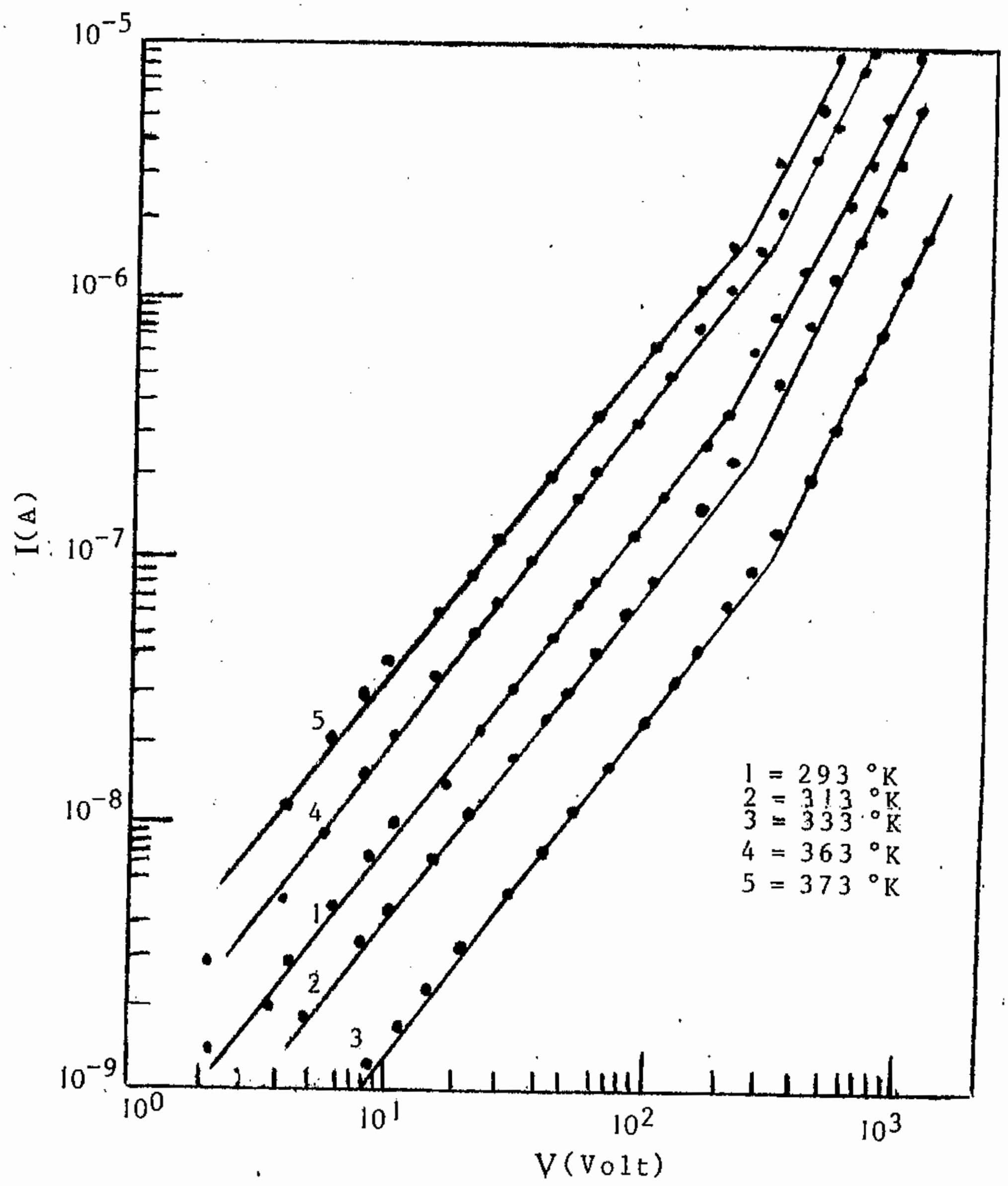

Figure 1: I–V characteristics on log-log scale for FEF composite

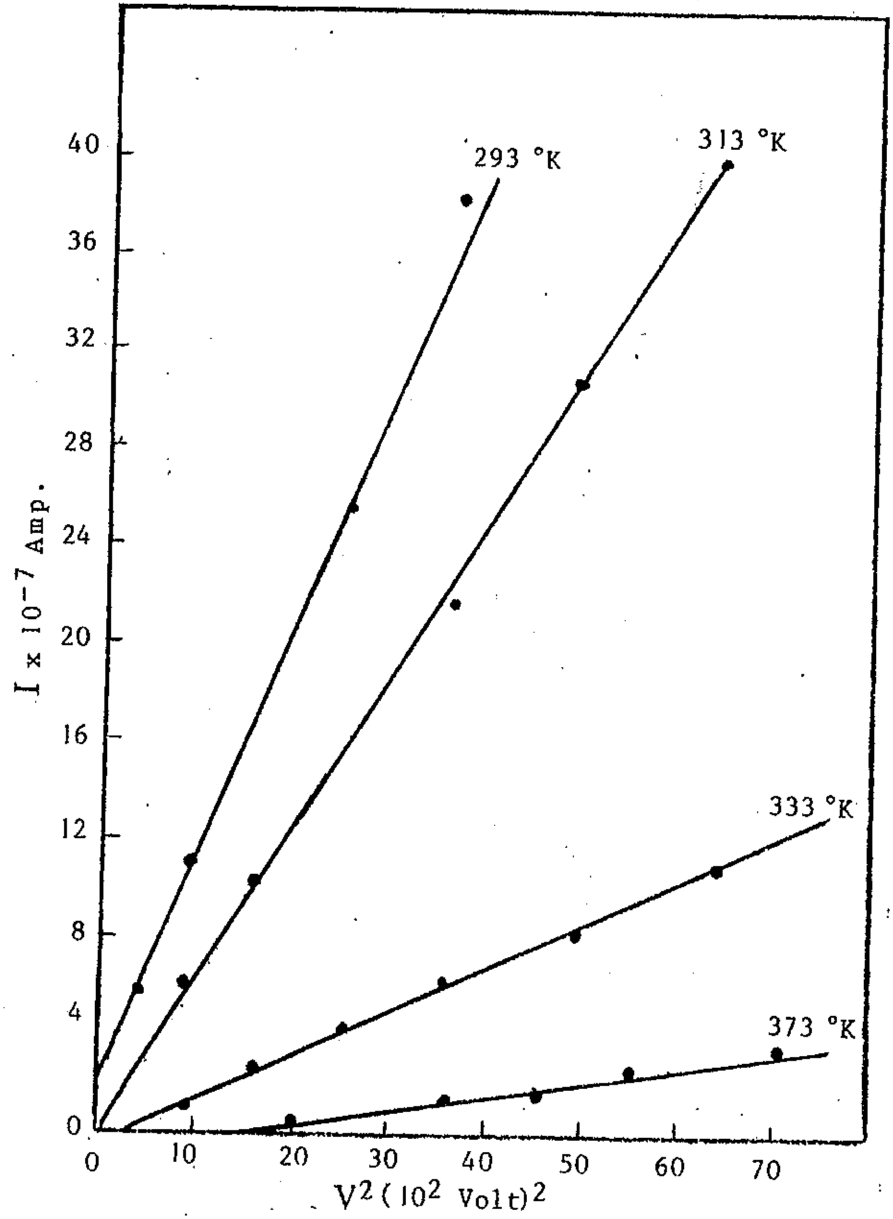

Figure 2: I–V^2 plot for FEF composite in the square law region at different temperatures.

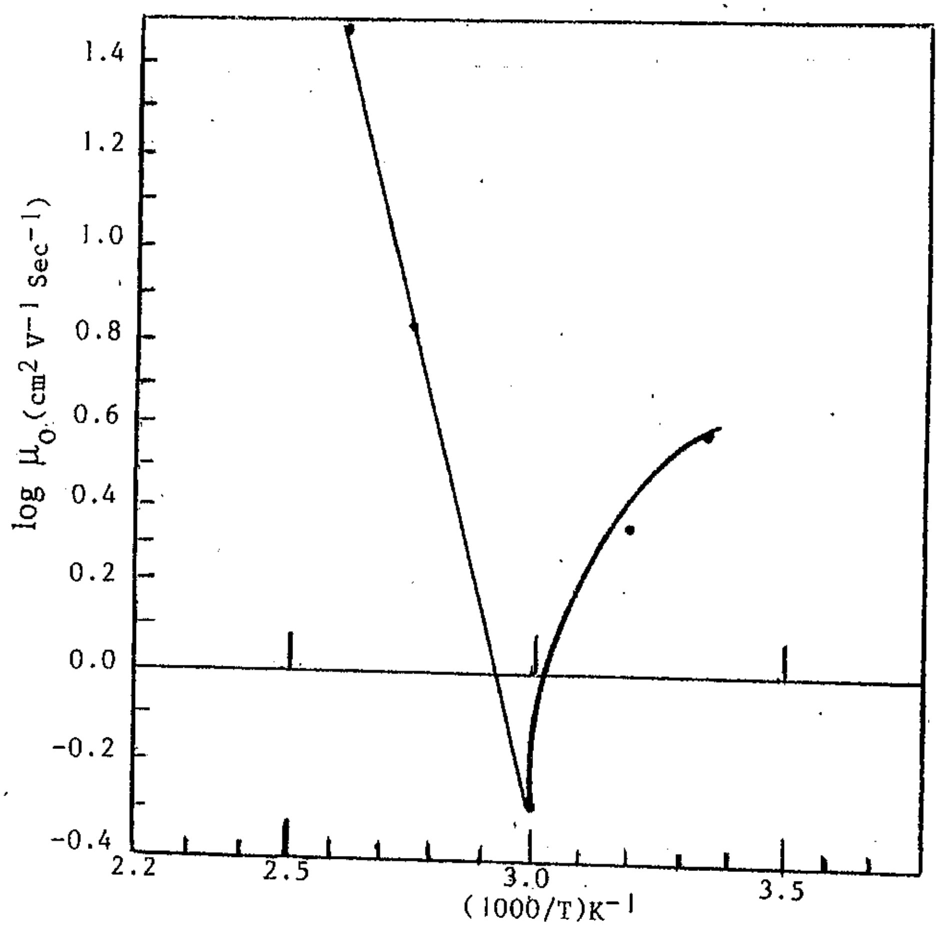

Figure 3: log $\mu_o - 1/T$ plot for FEF composite .

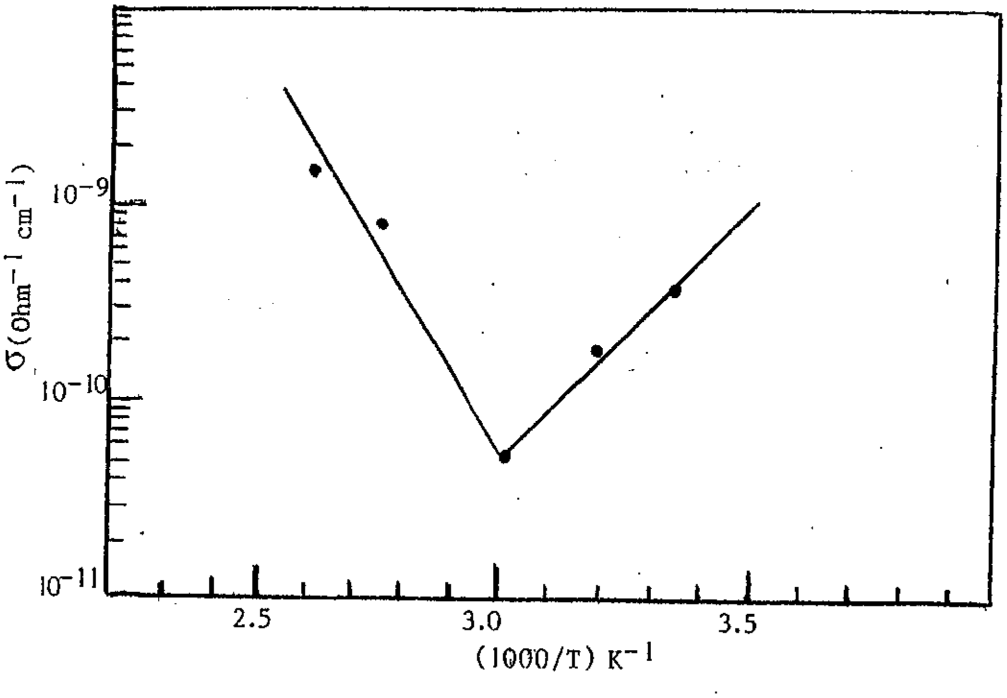

Figure 4: $\sigma - 1/T$ on a semilog scale for FEF composite.

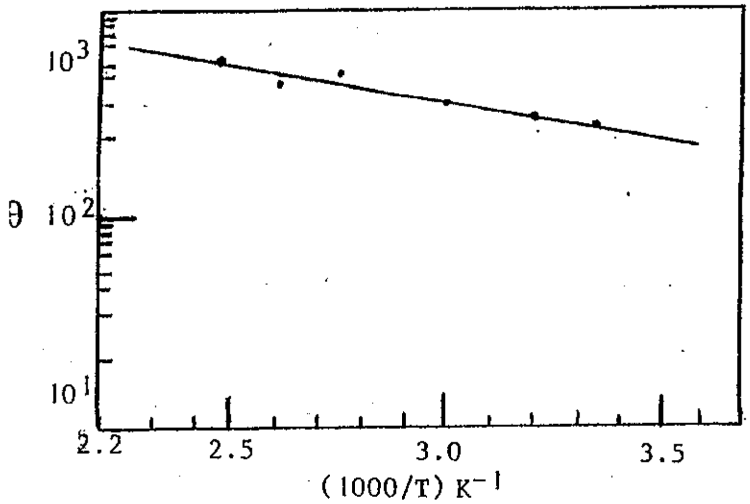

Figure 5: θ−1/T plot on a semilog scale for FEF composite.

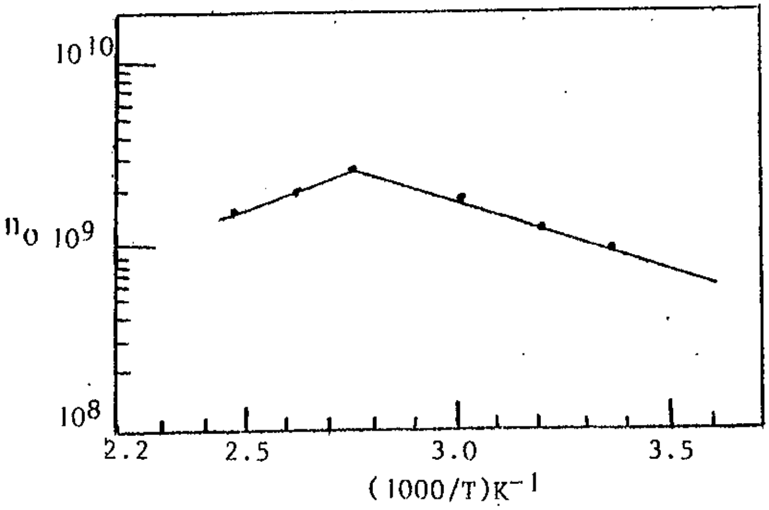

Figure 6: n_0 −1/T plot on a semilog scale for FEF composite.

تأثير توصيل التيار المستمر على مطاط الأيزوبيوتيلين أيزوبرين المضاف اليه بثق الكربون الأسود الفوار السريع

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ملخص البحث :

لقد قمت بدراسة التأثير المميز للتيار والجهد المستمر على مطاط الأيزوبيوتيلين أيزوبرين المضاف اليه بثق الكربون الأسود والفوار السريع عند درجات الحرارة المختلفة وذلك لمدى من الجهد بين ٣ الى ١٠ كيلوفولت. ولقد وجد أن ميكانيكية التوصيل تتفق مع السلوك المرعيه لحزم التوصيل والتى تطيع نموذج الوثب لمطاط الأيزوبيوتيلين أيزوبرين المضاف اليه ٤٠ جزء لكل ١٠٠ جزء من المطاط بالوزن من بثق الكربون الأسود الفوار السريع.