THE EFFECT OF CARBON BLACK ON D.C. CONDUCTIVITY OF EPOXY RESIN

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Abstract:

D.C conductivity of epoxy composites was determined as a function of carbon concentration and temperature in the range (301-401) K .The samples were prepared by hand lay up method with diferent black carbon weight percentage ratios (2.5%,5%, 7.5% and 10%) as sheets of dimensions(30x20x2)mm^3 .The electrical conductivity has been measured as a function of temperature by using DC power supply PE-1540 ,digital electrometer Keithely 616 and electrical oven. It has been found that the increase in carbon concentration caused increase in DC conductivity at room temperatures (RT) to maximum value of $\mathbf{9.42x10^{-10}}$ $(\Omega.cm)^{-1}$ for carbon weight percentage of (10%). The Hall mobility and carrier concentration at laboratory temperature has been calculated, the Hall mobility values are increased from **1.41** cm^2/V.sec for the pure epoxy to **9.42**cm^2/V.sec for the composite with (10 wt %) C**,** and the carrier concentration values are increased from $\mathbf{4.2\ x10^4}$ cm^{-3} for the pure epoxy to $\mathbf{6.4\ x10^6}$ cm^{-3} for the composite with (10 wt %) C.

Key Words: Carbon black, DC conductivity, Epoxy Resin

Introduction

Much of the industrial progress is based on the use of organic materials such as polymers as insulators of heat and electricity. However, our modern lifestyle increasingly demands more from the polymers than their traditional role of insulators. With the rapid development of electronics industry, the demand for electrically conductive materials, such as electromagnetic wave interference shielding materials for personal computers and home electronic devices, flooring and ceiling materials, de-electrifying cloths and radar cross-section reducing protective fabrics for stealth technology has increased .This has led to the investigation and the subsequent commercial exploitation of organic polymers as conductors of electricity [1].

Conducting polymers have been the subjects of study for many decades as possible synthetic metals. However, the practical uses of conducting polymers are not very likely because of their poor mechanical properties and processability that rarely meet the industrial requirements. Thus, a unique combination of electronic and mechanical properties of composites of conducting polymers with conventional polymers seems to have great applications. The application of conducting polymers such as light emitting diode (LED)[2], Sensors[3], Photovoltaic cell[4], Field effect transistor (FET) [5], etc. The simplest example of the class of conducting polymers is polyacetylene $(CH)_x$, Which was the first conducting polymers its can be doped by electron donors or acceptors lead to n-type or p-type polymers respectively [6]. It consists of weakly coupled chains of CH units forming two type of lattice; the first is called trans-$(CH)_x$ which was the stable isomer and the other was called cis-$(CH)_x$ is isomer[7].

Most of the research works on the conductive polymers composites focus on modification of the electrical properties by subjecting their structures to various physical and chemical conditions to produce new systems with modified conductivity .In this work black carbon was added to epoxy polymer to improve its conductivity [8-11].

Experimental

Material used Preparation

The material used to prepare the test samples were Epoxy resin (EP) type (Leyco-Pox 635) with one type hardener formulated amine was supplied by leyco chem. Leyde industry ,and black carbon supplied by industrial chemical and resin CO.LTD,kingdom of Saudi Arabia.

The test samples were prepared by hand lay-up method with diferent weight percentage ratios and dimensions (30x20x2)mm^3 , highly conductive silver paste is used to produce electrodes for DC contacts . The details of the test samples presented in table (1).

Table (1) details of the test samples

Sample No.	Composites Ratios
1	**0% Black carbon +100 % epoxy**
2	**2.5% Black carbon + 97.5 % epoxy**
3	**5% Black carbon + 95 % epoxy**
4	**7.5% Black carbon + 92.51 % epoxy**
5	**10% Black carbon + 90 % epoxy**

Testing Procedure

For the dc- conductivity measurements, samples with plane geometry have been used .The electrical contacts are made of fine silver paste. Kethley (616) digital meter was used for resistance measurement in the temperature range of (301-401K) temperature was monitored during the measurement using a chromel-alumel thermocouple.

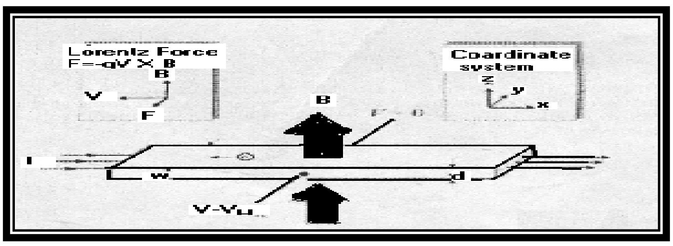
Dc conductivity of the samples as a function of temperature is studied. The rate of heating of the samples was controlled using an oven type (memert 854).The activation energy of the test samples is calculated, from the plot of Ln σ versus (10^3/T) and by using Stuke's equation [10].

$$\sigma = \sigma_0 \exp(-E_a / k_B T) \quad \text{..................(1)}$$

This equation is basically derived to give the change of the electrical conductivity with temperature .E_a denotes the thermal activation energy of electrical conduction (σ) which is a parameter that depends on the material nature, (σ_0) is defined as the proportionality factor which represents the conductivity when temperature approaches infinity, T is the absolute temperature and k_B is Boltizman's constant

As a current –carrying conductor is placed in a transverse magnetic field, the Lorentz force on moving charge pushes them toward one side of the conductor producing a charge separation and as a result, a voltage arises in the direction perpendicular to both the magnetic field and the current and called Hall voltage as shown in Fig. (1)[12].

Fig (1) Schematic diagram of Hall effect [6]



Hall effect has been measured by using the electrical circuit which contain (D.C power supply (0-40)V, when the samples carrying a current expose a constant magnetic field (B=0.254)Tesla perpendicular to the electric field then an e.m.f which is called Hall voltage(V_H) is set up across the sample, the current I and V_H were recording by using Keithly Digital Electrometer 616. The concentration and mobility of the carrier for the tested samples can be determined by the following equations [13].

The Hall coefficient (R_H) is found by:

$$R_H = \pm 1/ n q \text{……………………………}(2)$$

If V_H is the Hall voltage across the sample, I is the current and B is the applied magnetic field, then the Hall coefficient is:

$$R_H= t V_H/ I B \text{…………………………}(3)$$

Where t is the thickness of the sample. If the conduction is due to the one carrier type (e.g: electrons) then we can find the mobility from the equation [14].

$$\mu = \sigma / n q \text{……………………………}(4)$$

and $$\mu = \sigma (R_H) \text{………………………………}(5)$$

Results and Conclusion

Variation of d.c conductivity with temperature is the main tool in investigating the electrical properties of the composites by plots (lnσ) vs. (10^3/T), the activation energy can be measured from the slope of straight lines of (-ΔE/K).

The d.c conductivity σ for the composites has been determined as function of (10^3/T), it was noticed that at room temperature the d.c conductivity **($\sigma_{r.t}$)** increased with the increasing of carbon weight percentage as shown in table (2) .

Table (2): Variation of D.C conductivity $\sigma_{r.t}$ with black carbon content at RT.

Sample	$\sigma_{r.t}$ $(\Omega.cm)^{-1}$ x10^{-10}
0% Black carbon +100 % epoxy	1.41
2.50% Black carbon +97.5 % epoxy	6.23
5% Black carbon +95 % epoxy	6.86
7.5% Black carbon +92.5 % epoxy	8.11
10% Black carbon +90 % epoxy	9.42

Fig. (2) shows the variation of (lnσ) vs. (1000/T) for epoxy resin and its composites, it illustrates that the conductivity increased with the increasing of carbon weight percentage , The influence of temperature on the d.c conductivity has been explained by considering the mobility of charge carriers responsible for hopping. As temperature increases the mobility of hopping ions also increases thereby increasing conductivity. The electrons which are involved in hopping are responsible for electronic polarization in the composites [9,10].

The activation energy of epoxy resin and its composites were determined and listed in table (3).

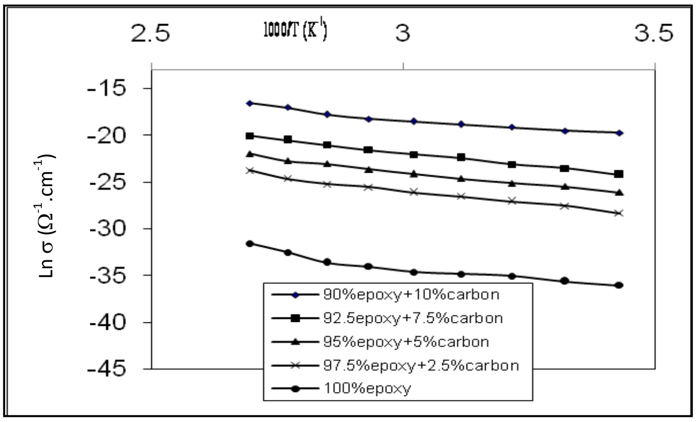


Fig. (2): Variation of ln σ (Ω^{-1} cm^{-1}) with 1000/T(K^{-1}) for epoxy resin and its composites

Table (2) The activation energy values E_a as a function of C content for epoxy resin and its composites

Sample	Ea(eV)
0% Black carbon +100 % epoxy	4.3
2.50% Black carbon +97.5 % epoxy	4.06
5% Black carbon +95 % epoxy	3.8
7.5% Black carbon +92.5 % epoxy	3.4
10% Black carbon +90 % epoxy	3.1

Figs.(3-7) show the variation of Hall voltage as a function of currents for pure epoxy and its composites .from which the Hall coefficients R_H were determined and listed in Table (3) .

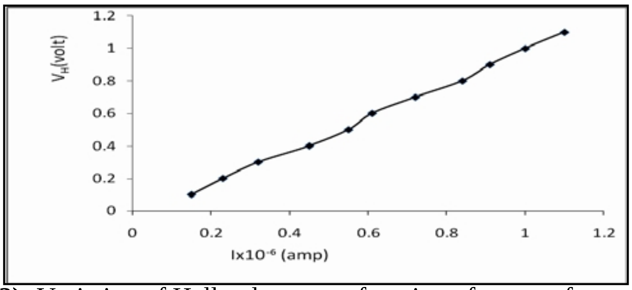


Fig.(3): Variation of Hall voltage as a function of current for pure epoxy

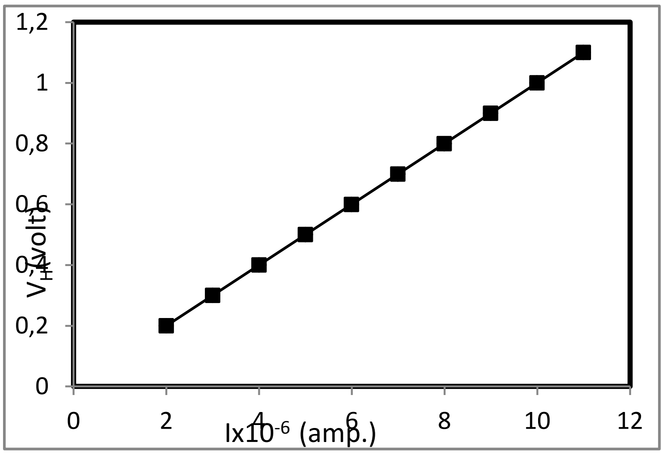


Fig.(4) Variation of Hall voltage as a function of current for composite of 2.5% carbon weight percentage

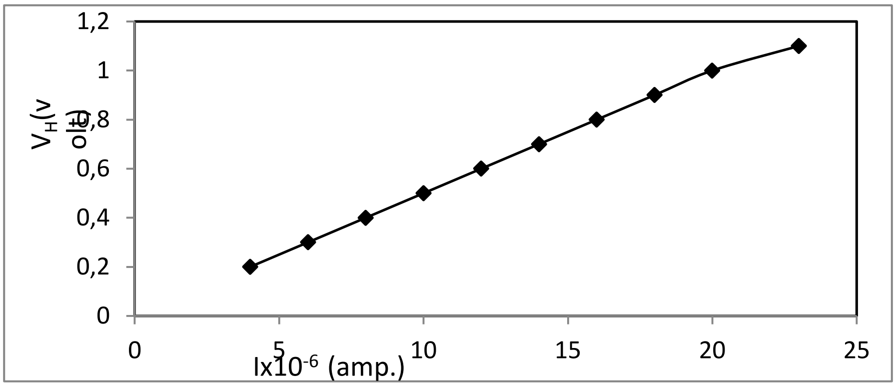


Fig.(5) Variation of Hall voltage as a function of current for composite of 5% carbonweight percentage

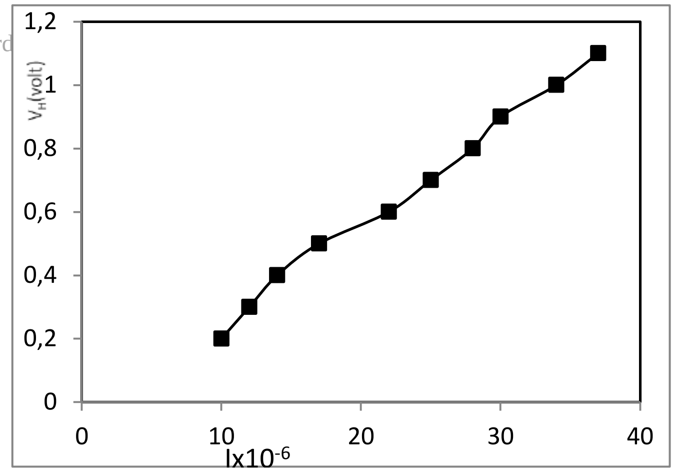


Fig.(6) Variation of Hall voltage as a function of current for composite of 7.5% carbonweight percentage

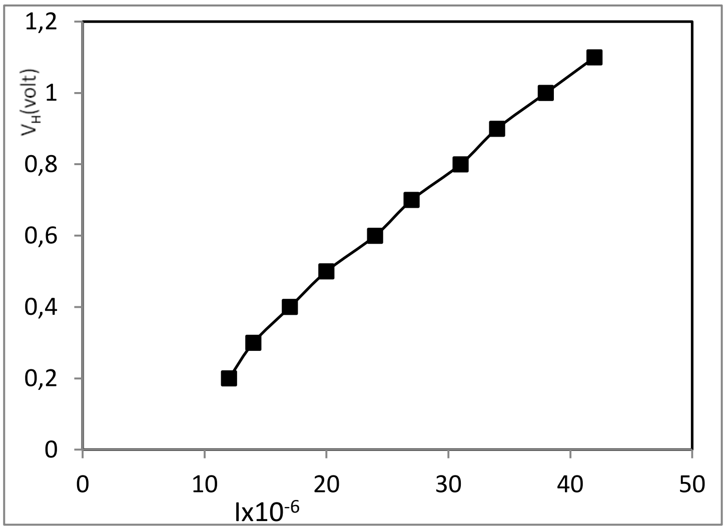


Fig.(7) Variation of Hall voltage as a function of current for composite of 10% carbonweight percentage

Table (3): Varation of Hall coefficients R_H and carriers concentration n_H and mobility μ_H with carbon content

1) Carbon(W_t%)	**R_H(cm^3/C)**	2) n_H (cm^{-3})	**μ_H (cm^2/V.sec)x10^{-8}**
0	**84**	3) 4.2 x10^4	**0.018**
2.5	**33.7**	4) 2.1 x10^6	**5.20**
5	**30.2**	5) 3.7 x10^6	**8.17**
7.5	**27.6**	6) 5.2 x10^6	**14.5**
10	**7.51**	7) 6.4 x10^6	**19**

Also the carrier's concentration and mobility were determined and listed in Table (3). It is found that the carrier's concentration of the composites much higher than that of pure epoxy due to the presence of excess carbon .It is found also that the mobility increases exponentially with increasing carbon concentration.

Conclusions

The conductivity at room temperatures increases with increasing C concentration .also the charge carrier concentration and Hall mobility increases with increasing C concentration.

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