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Studying the Electrical Conductivity of Different Carbon Fillers Reinforced Polyvinyl Chloride Composite Materials

Nirvana A. Abed Al ameer — Chemical Engineering, Technical College Baghdad

Walla W. Jameel — Physical science, Technical College Baghdad

Nagham S.Hassan — Chemical Engineering, Technical College Baghdad

Abstract:

The aim of this study is development the electrical conductivity of composite materials which used three fillers of carbon reinforced PVC at different weight fractions. The experimental results showed that carbon black was more effective than carbon fiber and synthetic graphite at low weight fractions, it reached (0.229 S/cm) whereas it was (0.109 S/cm) and (0.104 S/cm) of each carbon fiber and synthetic graphite respectively. At (40%) weight fraction the electrical conductivity was increased to (0.216 S/cm) and (0.226 S/cm) of each carbon fiber and synthetic graphite while it was inattentive with carbon black. Hybrid composites were investigated also; the result appears that maximum value of the electrical conductivity at combination of (20%) weight fraction of fillers, it was (0.592 S/cm).

Keywords: electrical conductivity, polyvinyl chloride, carbon fillers.

Introduction

Most polymer resins are intrinsically insulating, and their conductivity values are approximately $10^{-14} \sim 10^{-17}$ S/cm. The electrical conductivity of polymeric materials can be increased by the addition of conductive carbon fillers, such as carbon fibers, carbon black, and synthetic graphite. Polymer carbon composites, or electrically conductive polymer composites (CPC), are obtained by blending an insulating polymer matrix with conductive fillers like carbon black, carbon fiber or metal particles. Whatever the nature of particles, current circulation is obtained through ‘percolation’ of the filler through the polymer resin, forming conductive pathways throughout the material. Compared to metals (conductivity 10^6 S\cm), polymers and carbon based polymer composites have much lower conductivity. when conductive carbon fillers (conductivity $10^2 \sim 10^5$ S/cm) are mixed with polymers, the corresponding composite might have higher conductivity than that of pure, electrically insulating polymer matrix, but the conductivity of composites will depend on the shape, particle size, and properties of conductive fillers applied. The dispersion of the particles and the formation of a continuous network of the conductive fill are also critical to conductivity. Carbon black filled thermoplastic composites are widely used as antistatic, electrostatic dissipative, and semi conductive materials. Carbon black with high surface area can lead to electrical current percolation at lower concentrations and to form a conductive carbon network; however, the porous structure of carbon black can decrease mechanical properties of composites, hence, carbon black filler loading within a polymer matrix is limited, Graphite based composite bipolar plates are made from a combination of graphite and a polymer resin with conventional polymer processing methods like compression moulding or injection moulding. As one of the commonly used conductive carbon fillers, graphite not only has good conductivity but is also helpful for improving process ability due to its lubricating effect in the melt. Usually, carbon fibres are used for mixing with polymer for reinforcement to improve mechanical properties. Recently, extensive studies have focused on the effect of carbon fibres for developing conductive thermoplastic composites [1].

There are two types of plastics. One is called thermosetting resin which does not soften again and hardened, and the other is called thermoplastic resin which becomes soft or hard when its temperature rises or falls. Although thermosetting resin has an older history[2].Polyvinyl chloride is commonly referred to as PVC or vinyl and is second only to polyethylene in volume use. Normally, PVC has a low degree of crystalline and good transparency. The high chlorine content of the polymer produces advantages in flame resistance, fair heat deflection temperature, good electrical properties, and good chemical resistance. However, the chlorine also makes PVC difficult to process. The chlorine atoms have a tendency to split out under the influence of heat during processing and heat and light during end use in finished products, producing discoloration and embrittlement. Therefore, special stabilizer systems are often used with PVC to retard degradation [3]. There are several methods for producing polymer shape, including moulding extrusion [4].

The techniques used to form the polymers depends to a large extent on the nature of the polymer in particular, whether it is thermoplastic or thermosetting such as extrusion, compression moulding and hardness. Extrusion may be considered as one of the most widely used technique for processing thermoplastics. Extrusion can serve two purposes; first, it provides a way to form certain simple shapes continuously. Second, extrusion provides an excellent mixture for additives (e.g. fillers and others) when processing polymers that ultimately may be processed using some other process. A screw mechanical consisting of one or a pair of screw (twin screw forces heated) [5].

“Product component applications for conductive PVC are predicted to grow 6.6 percent yearly to 22 million pounds in 2010 based on cost advantages over other materials. Uses include electromagnetic and radio frequency protected housings for business machines, computers and other electronic products. Good growth is also expected for smaller applications such as work surface and flooring protection products such as floor and table mats. PVC will expand at a faster pace based on its lower cost, performance enhancements, and design and processing ease [6].

Zou studied the influences of conductive graphite, resin, pressure and temperature on the properties of graphite/polymer composite bipolar plate for PEM fuel cell, the results showed those components of conductive fillers and the type and content of resin have a large effect on the composite properties. The composite bipolar plate obtained has a conductivity of 300 S/cm [7].

Matthew studied the synergistic effects of multiple-fillers conductive resin, the three fillers were (10%) weight fraction thermocarb, (5%) weight fraction carbon black and (10%) weight fraction PAN-Based carbon fibre reinforced Nylon 6,6 and polycarbonate. The results indicator that carbon black reinforced nylon 6,6 has maximum electrical conductivity at low weight fraction [8].

Zhang studied the effect of particle size and shape on the bipolar plate performance. With increasing of graphite particle size, bulk electrical conductivity and thermometric conductivity decreased, but flexural strength of bipolar plate was enhancing [9].

Barton studied multiple carbon fillers in liquid crystal polymer composites (synthetic graphite and carbon fibre), the results showed that the carbon fibre has an electrical conductivity of 4.8 S/cm at (50wt %), the synthetic graphite composite exhibits an electrical conductivity of 12.4 S/cm at (80 wt %) [10].

Experimental work

1- Material

- Polyvinyl chloride, PVC:
- carbon black (C.B)
- carbon fiber (C.F)
- synthetic graphite (S.G)

2-Equipments

- Extruder

LCR- meter

Experimental setup

1. Weight amount of fillers were mixed with PVC resin, various composition were prepared (10, 20, 30, 40 &50) % weight fraction. All weight fraction were based on (250 g) of total mixture.
2. This mixture feed into the extruder.
3. Composite sheet was cooled in water.
4. The samples were cutting with (2 & 0.5) cm dimensions.
5. The sample was dried for two hrs to remove humidity and then tested.
6. The simplest capacitor structure planer form, consisting of a layer of dielectric material sandwiched between two metal layers.
7. The device precision LCR meter was accurately adjusted then used to measure the resistivity (R) values on the electronic screen. From these value can be fined an electrical conductivity by equation 1. These measurements test for (50Hz-10^6 Hz.) at room temperature.

$$\sigma = \frac{d}{R.A} \text{ ------- } (1)$$

Where: σ: electrical conductivity (S/cm), d: diameter of specimen(cm), R: electrical resistivity,(Ω/cm), A: cross- section area, (cm^2).

Result and discussion

Electrical conductivity is the measure of the ease with which electrons move among atoms. It is the ease of movement of electrical charge from one position to another in a material. The charge is carried either by ions or electrons. The mobility of ions or electrons varies from material to material. Where mobility is high, the material is called conductor such as metal and carbon and where mobility is low the material is called insulator such as polymer and ceramic. An electron offers resistance to motion, if it is tied up by ions or covalent bond. In such cases there will be no conduction of electricity. Such materials which are ionically or covalently bonded are extremely poor conductors, because electrons are not free to conduct electricity.

Effect of frequency

If a material is placed in an electric field the charged particles interact with field. If the material is a conductor, the free electrons simply move to the nearest positive electrode. No field is, thus, left within the material. The displacement of charged particles occurs almost instantaneously bringing about the equilibrium. If the material is non-conducting or an insulator or a dielectric the electrons are only locally displaced, because they are bond to individual atoms.

Dielectric properties as function to frequency, figures (3-6) show the variation of the electrical conductivity with different frequency at room temperature; the results exhibit that electrical conductivity increased with increasing of frequency and then decreased. The permittivity depends on the dipoles and charges movement in the dielectric material, due to change in the field direction, because of an electric field alternation. The intensity of alternating electrical field was represented by the frequency of applying voltage, that effected by a dipoles of dielectric material into frequency range, this means the electrical polarization changed with an electric field changed.

Effect of weight fraction

The effect of weight fraction of different types of carbon reinforced polyvinyl chloride was investigated in this work, there were (10, 20, 30, 40&50) % weight fraction. The results showed that weight fraction of fillers were affected on electrical conductivity of composite materials due to conductivity of carbon, it was ranged from (10^2 to 10^5 S\ cm). The electrical conductivity for the carbon black, carbon fibre and synthetic graphite reinforced polyvinyl chloride resin show in table 5 which was exhibit that electrical conductivity of composite materials for fillers reinforced PVC higher than matrix material.

Effect of carbon types

The Experimental results observed that the electrical conductivity values were different according to type of fillers and its percentage (weight fraction). Carbon black was effective more than other fillers at low weight fraction due to its particles have high surface area is (0.229 S/cm) at (20%) weight fraction whereas the electrical conductivity of each carbon fibre and synthetic graphite was (0.109 S/cm) and (0.104S/cm) respectively.

Addition carbon fibre and synthetic graphite fillers on matrix material were apparent good electrical conductivity at high weight fraction comparing to their low percentage account of the fillers created conductive path in the matrix material, it reached to (0.216S/cm) and

(0.226S/cm) for carbon fiber and synthetic graphite; respectively at (%40) weight fraction as shows in figure 1.
In addition to that, a hybrid composite material which consists of 20% carbon black, 20% carbon fiber and 20% synthetic graphite is also investigated. The results indicate that combinations of fillers increased the electrical conductivity of the composite materials. Figure 3 shows how the electrical conductivity changes with increases in the various fillers which were (0.592S/cm).
In order to analysis above, the conductive fillers, such as carbon fiber as act channels for the electrons to flow through. The electrons are free to flow through the carbon fibers. However, once they reach the end of the fiber, they encounter the polymer matrix, which acts as dam, blocking the flow of the electrons.

Conclusion

1. Electrical conductivity increases with increasing in weight fraction of fillers.
2. The Experimental results exhibited that the electrical conductivity values were different according to type of fillers.
3. Carbon black was effective more than other fillers at low weight fraction due to its particles have high surface area.The results indicate that combinations of fillers increased the electrical conductivity of the composite materials.

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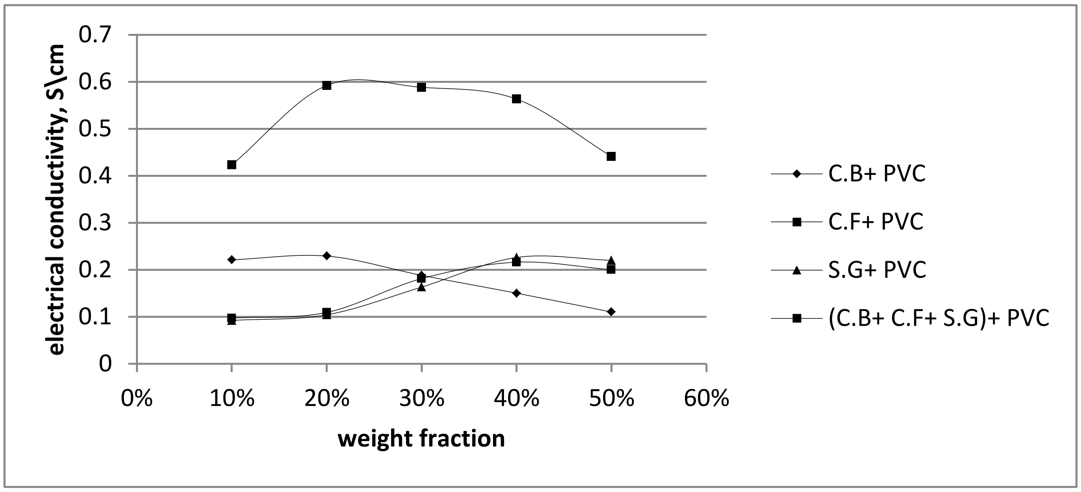

Figure 1: Electrical conductivity of different fillers reinforced PVC

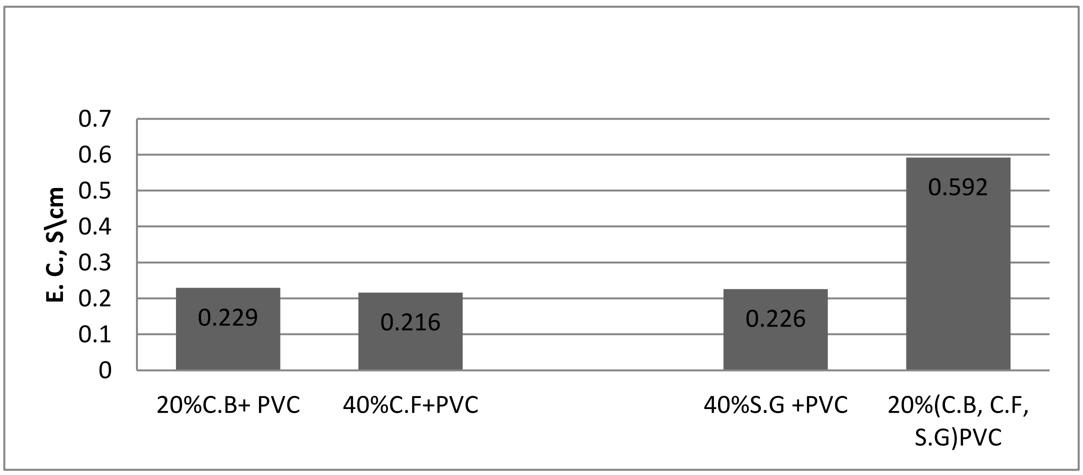

Figure2: Typical electrical conductivity of different fillers reinforced PVC

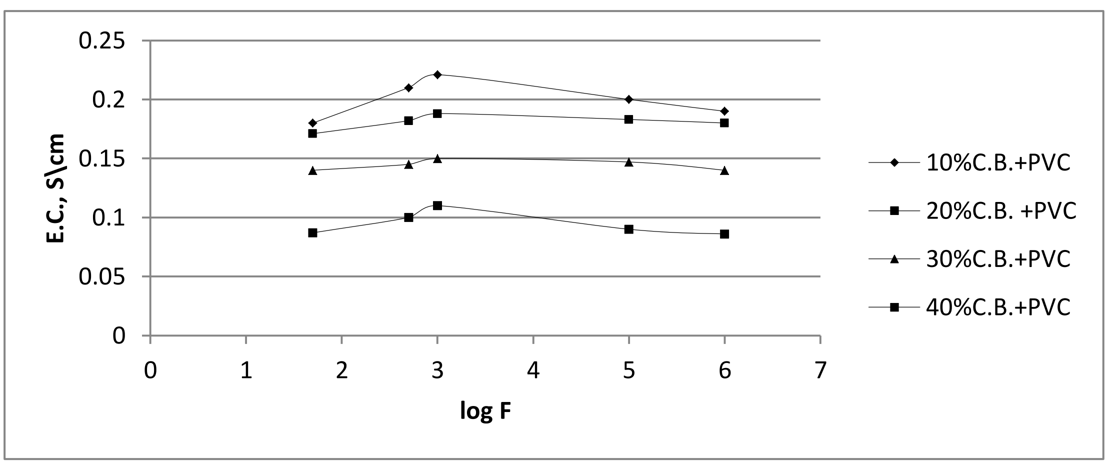

Figure 3: electrical conductivity of carbon black at different frequency

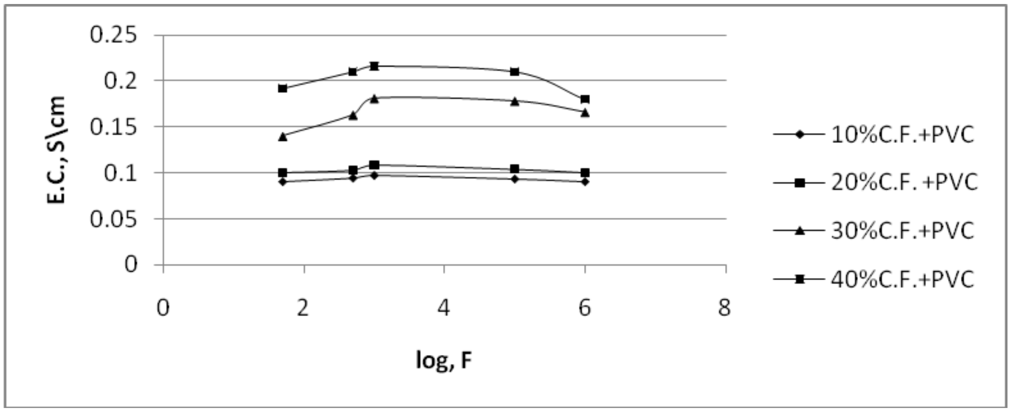

Figure 4: electrical conductivity of carbon fiber at different frequency

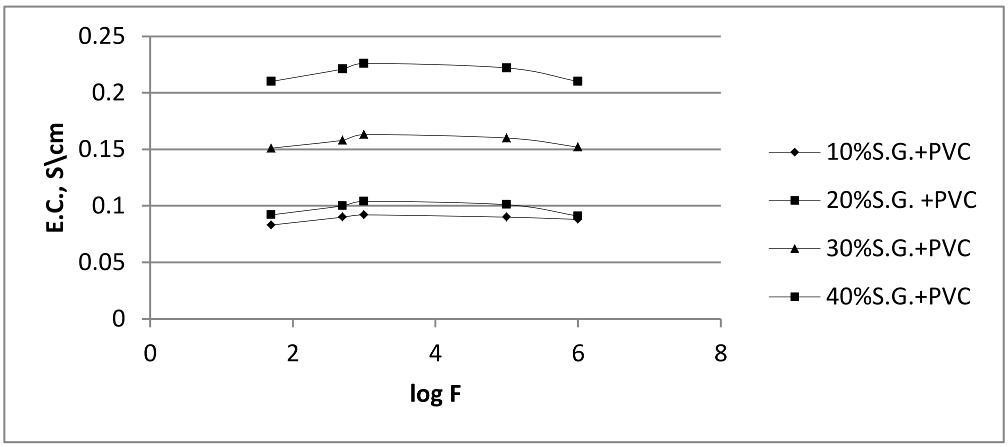

Figure 5: electrical conductivity of synthetic graphite at different frequency

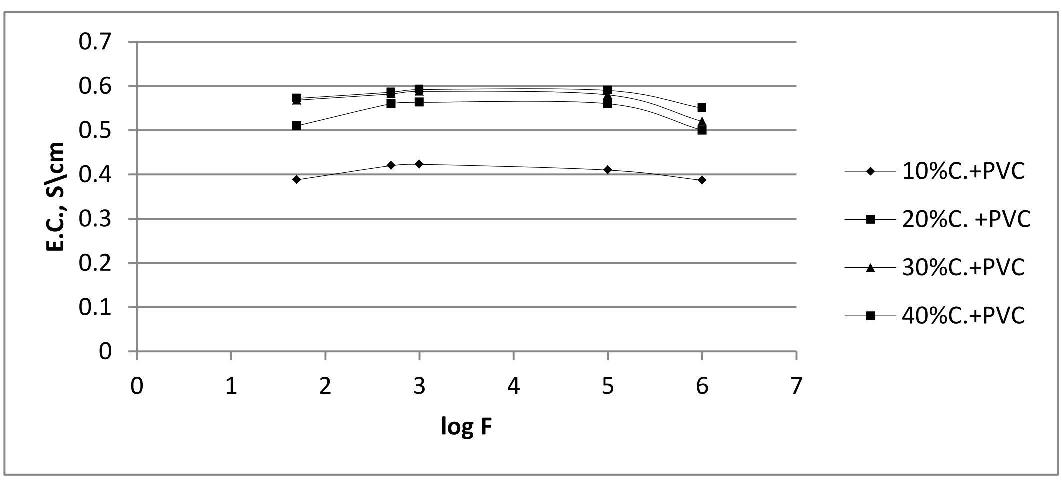

Figure 6: electrical conductivity of composite at different frequency

Table 1: electrical conductivity of carbon black at different frequency

Samples	E.C., S\cm				
F(Hz)	**50**	**500**	**1000**	**10^5**	**10^6**
10%C.B.+PVC	0.18	0.21	0.221	0.2	0.19
20%C.B. +PVC	0.171	0.182	0.188	0.183	0.18
30%C.B.+PVC	0.14	0.145	0.15	0.147	0.14
40%C.B.+PVC	0.087	0.1	0.11	0.09	0.086

Table 2: electrical conductivity of carbon fiber at different frequency

Samples	E.C., S\cm				
F(Hz)	**50**	**500**	**1000**	**10^5**	**10^6**
10%C.F.+PVC	0.09	0.094	0.097	0.093	0.09
20%C.F. +PVC	0.1	0.103	0.109	0.104	0.1
30%C.F.+PVC	0.14	0.163	0.181	0.178	0.166
40%C.F.+PVC	0.192	0.21	0.216	0.21	0.18

Table 3: electrical conductivity of synthetic graphite at different frequency

Samples	E.C., S\cm				
F(Hz)	**50**	**500**	**1000**	**10^5**	**10^6**
10%S.G.+PVC	0.083	0.09	0.092	0.09	0.88
20%S.G. +PVC	0.92	0.1	0.104	0.101	0.91
30%S.G.+PVC	0.151	0.158	0.163	0.16	0.152
40%S.G.+PVC	0.21	0.221	0.226	0.222	0.21

Table 4: electrical conductivity of composite at different frequency

Samples	E.C., S\cm				
F(Hz)	**50**	**500**	**1000**	**10^5**	**10^6**
10%C.+PVC	0.388	0.42	0.423	0.41	0.387

20%C. +PVC	0.572	0.586	0.592	0.59	0.55
30%C.+PVC	0.568	0.582	0.588	0.58	0.52
40%C.+PVC	0.51	0.56	0.563	0.56	0.5

Table 5: electrical conductivity for different fillers at 1 KHz

PVC	**E.C, *S/cm***				
	10%	**20%**	**30%**	**40%**	**50%**
C.B+ PVC	0.221	0.229	0.188	0.15	0.11
C.F+ PVC	0.097	0.109	0.181	0.216	0.2
S.G+ PVC	0.092	0.104	0.163	0.226	0.22
(C.B+ C.F+ S.G)+ PVC	0.423	0.592	0.588	0.563	0.441

دراسة التوصيلية الكهربائية للمواد المتراكبة البولي فينايل كلورايد المدعم بانواع مختلفة من حشوات الكاربون الموصلة

ولاء وديع جميل — **علوم فيزياء** — **الكلية التقنية بغداد**

نغم سلمان حسن — **هندسة كيمياوية** — **الكلية التقنية بغداد**

نيرفانا عباس عبد الامير — **هندسة كيمياوية** — **الكلية التقنية بغداد**

الخلاصة:

الهدف من الدراسة هو تطوير التوصيلية الكهربائية للمواد المتراكبة البولي فينايل كلورايد المدعم بحشوات مختلفة من الكاربون. النتائج المختبرية اظهرت ان الكاربون الاسود كان اكثر فعالية من الانواع الاخرى عند النسب الوزنيةالواطئة حيث وصلت الى (0.229S/cm) في حين كانت (0.109 S/cm) و(0.104S/cm) لكل من الياف الكاربون والكرافيت على التوالي. اما عند الكسور الوزنية العالية (40%) فان التوصيلية الكهربائية ازدادت الى (0.216S/cm) و (0.226S/cm) لكل من الياف الكاربون والكرافيت بينما كانت ضئيلة للكاربون الاسود. كذلك تم دراسة المواد المتراكبة الهجينة حيث اظهرت النتائج اعلى قيم لها عند دمج الحشوات بنفس الكسور الوزنية (20%) لكل حشوة , كانت (0.592S/cm).