Effect of Glass - Fiber on Electrical Properties of Polyamide Composite Material

تأثير ألياف الزجاج على الخواص الكهربائية لمواد البولي امايد المركبة

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Abstract

Temperature and Frequency dependence of dielectric constant (έ) and dielectric loss factor (ε'') in pure polyamide resin and polymer composites with various types of glass fibre(E, S &C) are studied in the frequency range (50, 500, 1000, 10^5 &10^6) Hz and temperature range (30, 60, 90, 110& 120) ºC. The results show that (έ) and (ε'') increased with the addition of glass fibre in polyamide resin. The value of (έ) decreased with increasing frequency while it increased with increasing temperature due to freedom of movement of the molecular chains within the polyamide at high temperature. The dielectric loss factor (ε'') increases with glass fibre addition as a result of increasing electrical conductivity to decrease resistivity of composite material.

الخلاصة

يعتمد ثابت العزل (έ) وعامل الفقدان ألعزلي (ε'') على درجة الحرارة والتردد للمعدلات (30, 60, 90, 110& 120) °C و (50, 500, 1000, 10^5 &10^6) Hz على التوالي لكل من راتنج البولي امايد النقي والمضاف إليه ألياف الزجاج بكل أنواعه (E, S &C) . أظهرت النتائج أن ثابت العزل (έ) وعامل الفقدان ألعزلي (ε'') يزداد بإضافة ألياف الزجاج إلى راتنج البولي امايد حيث أن قيمة (έ) تقل مع زيادة التردد وتزداد مع زيادة درجة الحرارة ويعود ذلك إلى حرية حركة السلاسل الجزيئية داخل الراتنج عند درجات الحرارة العالية أما عامل الفقدان ألعزلي (ε'') يزداد بإضافة ألياف الزجاج نتيجة لزيادة التوصيلية الكهربائية يعني نقصان في الممانعة الكهربائية للمواد المركبة.

Key word: polyamide, glass fibers(S, E& C), dielectric, temperature& frequency

1. Introduction

Many polymers can from neat fibers , as long as certain intermolecular forces can occur between chains , holding them together in crystal-like fashion .Thus polymer fibers are strong materials with excellent tensile strength , which makes them very useful as textiles[1] . Polymeric materials have been utilized extensively in the electronics packaging market, due to their low cost, ease of processing, chemical inertness, and attractive electrical properties [2]. Thermoplastic polyamides are linear polymers derived by condensation polymerization of a polemics acid and an alcohol. Depending on the types of the polemic acid and alcohol, various thermoplastic polyamides can be produced. Glass fibres are the most common of all reinforcing fibres for polymeric matrix composites (PMC). The principal advantages of glass fibres are low cost, high tensile strength, high chemical resistance, and excellent insulating properties. The two types of glass fibres commonly used in the fibres-reinforced plastics (FRP) industry are E-glass and S-glass. Another type, known as C-glass, is used in chemical applications requiring greater corrosion resistance to acids than is provided by E-glass. Several fibers incorporation techniques in thermoplastic resins have been developed and many of them are now commercially used to produce thermoplastic prepregs. These prepregs can be stored for unlimited time without any special storage facility and, whenever required. [3]. Polyamide resin characteristics are excellent stability at high temperatures, high pressure resistance, highly resistant to climate extremes, excellent chemical resistance, good stress cracking resistance, very low specific gravity , high impact resistance at sub-zero temperatures, low moisture absorption (0.9%) , low coefficient of friction, high abrasion resistance, good creep resistance, high dimensional stability [4].

The miniaturization in the microelectronics industry has increasing demands on the low dielectric constant ε, interlayer's to greatly reduce the resistance-capacitance (RC) time delays, cross-talks, and power dissipation in the high-density and high-speed integrated circuits. In addition to exhibiting low ε, the materials used as interlayer must also satisfy a variety of requirements, such as good thermal stability, low moisture absorption, and chemical inertness. Polyamides (PI) have been widely used as dielectric and packaging materials in the microelectronics industry because of their good mechanical, thermal, and dielectric properties [5]. The dielectric strength of an insulating material can be defined as the voltage gradient or dielectric stress through the material at which electrical failure or breakdown occurs. The total breakdown voltage is determined by placing electrodes on opposite surfaces of a specimen disc or plaque, and increasing the potential difference between the electrodes until the material can no longer resist the flow of current. Dielectric constant is significant because it affects the amount of energy stored in the circuit itself. Although a small added capacitance may not cause a problem, it is usually preferable to minimize dielectric constant rather than compensate for it throughout the circuit. Thus, low dielectric constant is particularly desirable for communications and electronic circuits that rely on crisp transmission of low-intensity signals. In particular, those circuits often employ a wide range of frequency, so that dielectric constant should remain stable throughout the range. Dissipation factor (tan δ) is closely related to dielectric constant. As mentioned earlier, dielectric constant reflects the instantaneous polarization expressed as energy stored in the system. Lost energy is dissipated as heat in the insulating material. In that sense, dissipation factor is the ratio of energy dissipated as heat compared to the energy stored in the system, both factors averaged over a cycle [6]. The fundamental building components for all electronic packaging systems consist of active and passive components on an interconnecting substrate. Resistors, inductors, and capacitors are examples of passive components, which represent a class of electronic components that result in no power gain to an electronic application. For example, in current cellular phone applications, the ratio of passive components to active components is nearly 20:1, and nearly 80% of circuit board area is occupied by discrete passive components. Conventional discrete components have to be mounted onto a printed wiring board (PWB) or interconnected substrate thereby resulting in higher parasitic, lower reliability, and large attachment area requirements. Integral passives are defined as functional elements either embedded in or incorporated on the surface of an interconnecting substrate. With increased production emphasis towards efficient electronic packaging, integral embedded passive technology may satisfy such demands. The main advantages of embedded passive components include: (1) no separate interconnects to the substrate, (2) improved electrical performance, (3) lower cost and (4) ease of processing. Due to increased product demands of increased silicon efficiency, package miniaturization, and higher reliability integral embedded technology will be replacing discrete electrical components [7].

2. Experimental work

2.1 Materials

- Polyamide resin, Germany
- Glass fibre (E, S& C), U.S.A
- Aluminium metal.

2. 2 Equipments

- Single screw extruder
- Coating unit
- LCR-meter, B&K precision crop. 889A

2.3 Samples Preparation

The materials studied are polyamides resin reinforced by 50 wt% of 10 mm long glass fibres. The mixture was then fed into single screw extruder. Shaped samples have dimensions of (200,100& 2) mm was prepared by cutting. Four samples Sample A (pure polyamide), sample B (polyamide + 50% E-glass fibre), Sample C (polyamide + 50% C-glass) and sample D (polyamide + 50% S-glass) were prepared under the same conditions.

The electrodes were prepared at higher vacuum (10^{-6} mbar) by using coating unit, which precipitates aluminium (Al) electrodes by using the tungsten wire which was put inside it, and by passing through high electrical current through tungsten wire, the aluminium (Al) material is fused gradually then evaporates, and precipitated on the samples. The substrate material chosen for this study was high purity alumina manufactured by Coors Porcelain, which is 99.5% Al_2O_3. These substrates are 2 centimetres square by 0.064 centimetres thick and have one side which is highly polished, ensuring good planarity and adhesion. Alumina is a common substrate material for high power circuits, due to its low cost, relatively high thermal conductivity, low coefficient of thermal expansion, and insulating properties.

The simplest capacitor structure planar form, consisting of a layer of dielectric material sandwiched between two metal layers.

2.4 Determination of Samples General Properties

Dielectric constants ($\acute{\varepsilon}$) and loss factors ($\varepsilon^{''}$) were measured in the frequency range (50, 500, 1000, 10^5 &10^6) Hz and temperature range (30, 60, 90, 110& 120) ºC for the all four samples.

The device precision LCR meter was accurately adjusted then was used to measure the capacitivity (C_P) and resistivity (R_P) values on the electronic screen. From these values dielectric constant ($\acute{\varepsilon}$), dielectric loss factor ($\varepsilon^{''}$), and dissipation factor (tan δ) could de calculated by using equations 1, 2& 3 respectively. These measurements were tested for (50Hz -10^6Hz) at room temperature and for (30 – 120) ºC at 1 KHz.

$\acute{\varepsilon} = c_p\, d / \varepsilon^{\circ}\, a$ ----------------------- (1)
Where:
$\acute{\varepsilon}$: dielectric constant
d :thickness of dielectric, 0.2 cm
a : cross section area, 2 cm^2
ε° : vacuum permittivity ($8.854 * 10^{-14}$ F/cm)

$\varepsilon^{''} = d / \omega\, \varepsilon^{\circ}\, R\, a$ ------------------(2)
Where
$\varepsilon^{''}$: is the dielectric loss factor.
ω: angular frequency which ($\omega = 2\pi f$)
R : is the resistance (Ω)
$\tan\delta = \varepsilon^{''} / \acute{\varepsilon}$ ------------------ (3)
$\sigma = \omega\, \varepsilon^{\circ}\, \varepsilon^{''}$ ------------------ (4)
$\tan\delta = \sigma / \omega\, \varepsilon^{\circ}\, \acute{\varepsilon}$ ---------------- (5)
$\sigma = 1/B$ ------------------ (6)
B = electrical resistivity, Ω. cm
σ = conductivity, S/cm

3. Results and Discussion

Dielectric constant , dielectric loss factor , dissipation factor (tan δ) and the electrical resistivity was depended as a measure of the effect of glass fiber on polyamide composites .

3.1 Dielectric constant (έ)

From table (1) which shows the effect of variation of frequency on dielectric constant (έ) at room temperature for all four Samples, we observe that marked differences were found in dielectric constant (έ) between polyamide resin and composite materials with different types of glass fibre. An important observation is that (έ) decreases considerably from 7.21 to 5.66 for sample A and from 12.23 to 6.21 for sample B and from 17.89 to 6.33 for sample C and from 11.78 to 5.12 for sample D as frequency increases from 50 to 10^6 Hz for all four samples. The addition of glass fibre to polyamide resin, which is most likely explained by the glass having a higher dielectric (έ) than the base polyamide resin, thus resulting in the higher dielectric constant of the composite.This effect may be observed from fig. (1)

Table 1: The effect of variation of frequency on dielectric constant (έ) at room temp.

F(Hz)	Dielectric constant (έ)			
	A	B	C	D
50	7.21	12.23	17.98	11.78
500	6.82	11.56	17.21	10.53
1000	6.22	9.47	13.55	9.38
10^5	5.89	6.61	9.34	6.67
10^6	5.66	6.21	6.33	5.12

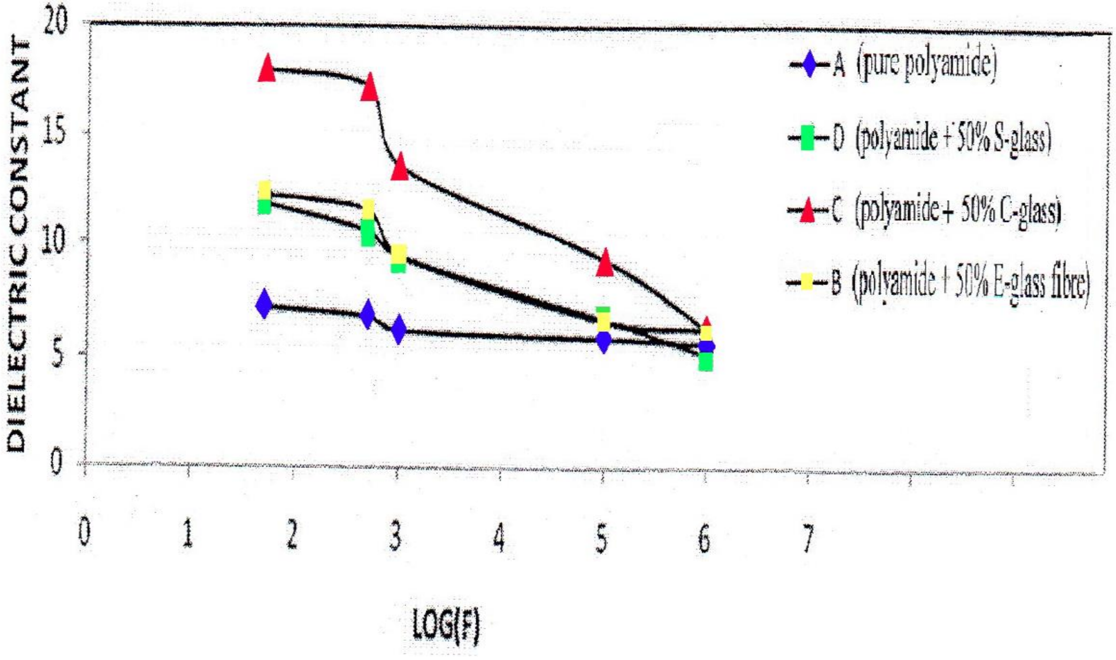

Figure 1: The effect of variation of frequency on dielectric constant (έ) at room temp.

Table (2) shows the effect of variation of temperature on dielectric constant (έ) at (1KHz) for the samples A, B, C and D, respectively. The value of dielectric constant (έ) increases with increasing temperature from 6.53 to 10.5 for sample A and from 9.87 to 16.87 for sample B and from 15.35 to 36.98 for sample C and from 10.11 to 16.81 for sample D as temperature increases from 30 °C to 120°C . The increase in dielectric constant (έ) with temperature is due to greater freedom of movement of dipole molecular of polyamide at high temperature. At lower temperature, as the dipoles are rigidly fixed in the dielectric, the field cannot change the condition of dipoles. As the temperature increases, the dipoles comparatively become free and they respond to the applied electric field. Thus polarization increased and hence dielectric constant is also increased with the increase of temperature.Fig (2) shows this effect .

Table 2: The effect of variation of temperature on dielectric constant (έ) at (1 KHz)

Temp. (°C)	Dielectric constant (έ)			
	A	B	C	D
30	6.53	9.87	15.35	10.11
60	8.76	11.58	20.44	10.65
90	9.45	13.66	26.56	12.38
110	9.92	15.12	32.87	14.23
120	10.5	16.87	36.98	16.81

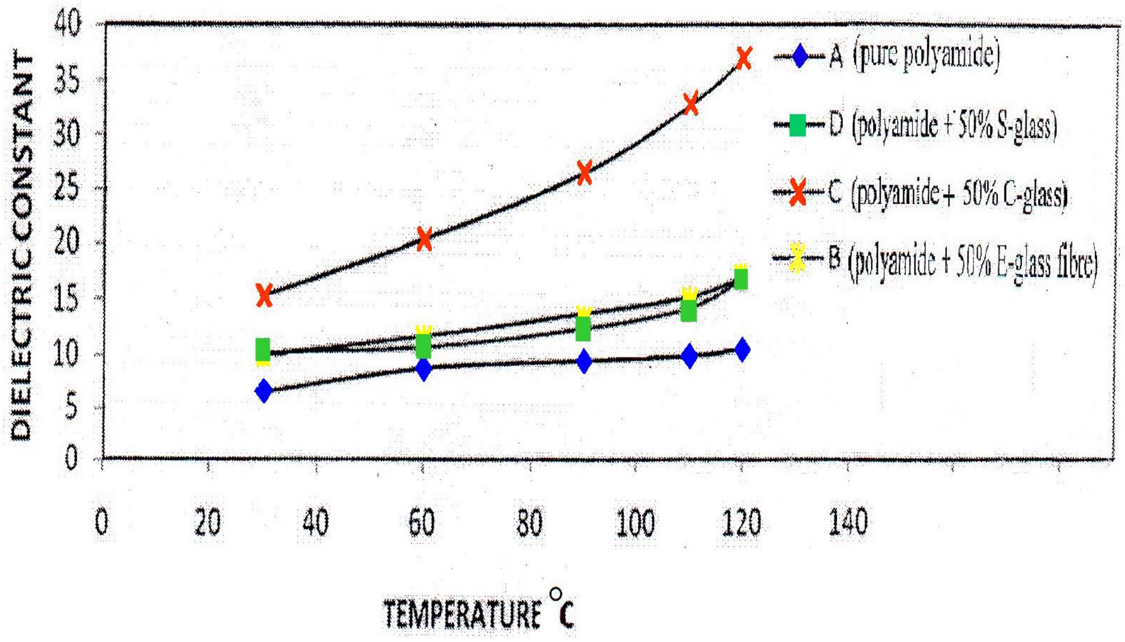

Figure 2: The effect of variation of temperature on dielectric constant (έ) at (1 KHz)

3.2 Dielectric loss factor (ε'')

Table (3) shows the effect of variation of frequency on dielectric loss factor (ε'') at room temperature for all four samples .

The value of dielectric loss factor (ε'') decreases with increases frequency at fixed temperature . As in table (3) it decreases from 1.34 to 0.15 for sample A and from 5.12 to 0.17 for sample B and from 6.67 to 1.4 for sample C and from 4.31 to 0.42 for sample D as frequency increases from 50 to 10^6 for all four samples . The value of dielectric loss factor (ε'') is calculated by using (LCR-meter) as in equation (2).

Figure (3) shows this effect for the all four samples , that means it is satisfying of the inverse proportion between the frequencies in the equation ($\omega=2\pi f$) with dielectric loss factor (ε'') in equation (2).

The dielectric loss factor (ε'') increases with increasing glass fiber as aresult of increasing conductivity to decrease resistivity as given in equation (4) .

Table 3: The effect of variation of frequency on dielectric loss factor (ε'') at room temp.

F(Hz)	Dielectric loss factor (ε'')			
	A	B	C	D
50	1.34	5.12	6.67	4.31
500	1.1	3.75	6.21	3.88
1000	0.5	2.5	3.58	2.45
10^5	0.22	0.5	2.26	1.43
10^6	0.15	0.17	1.4	0.42

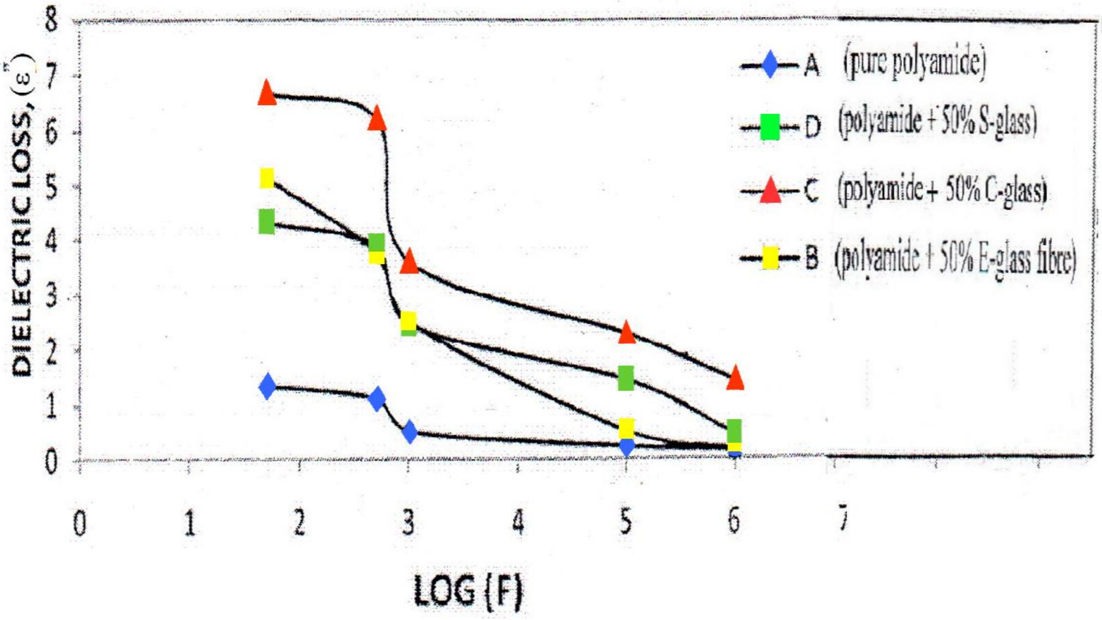

Figure 3:The effect of variation of frequency on dielectric loss factor (ε'') at room temp.

The dielectric loss factor increases with increasing temperature , particularly at fixed frequencies due to chain motion of polyamide is more effective due to the glass transition temperature of the polymer . This effect expressed in table (4) which shows the variation of temperature on dielectric loss factor (ε'') at (1 KHz) for all four samples where it increases from 0.2 to 3.2 for sample A and 2.3 to 9.9 for sample B and from 3.5 to 12.22 for samples C and from 2.5 to 9.8 for sample D as temperature increases from 30 to 120 ºC for the samples , fig. (4) shows this effect .

Table 4: The effect of variation of temperature on dielectric loss factor (ε'') at (1 KHz)

Temp. (ºC)	Dielectric loss factor (ε'')			
	A	B	C	D
30	0.2	2.3	3.5	2.5
60	0.5	4.22	6.34	4.2
90	0.8	6.57	9.23	7.41
110	2	9.11	11.1	8.87
120	3.2	9.9	12.22	9.8

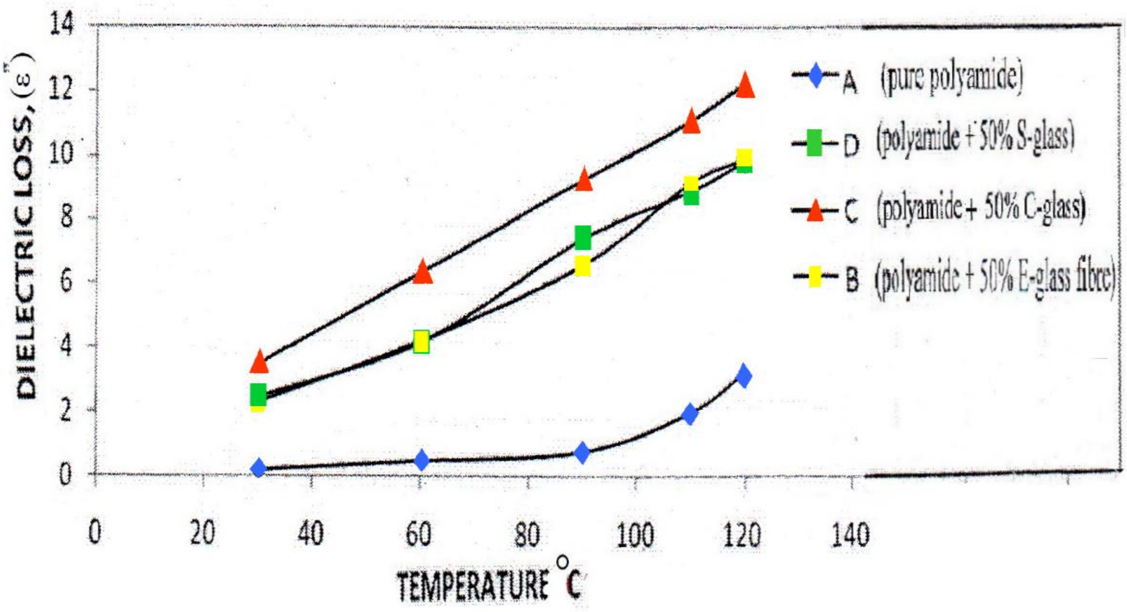

Figure 4: The effect of variation of temperature on dielectric loss factor (ε'') at (1 KHz)

3.3 Dissipation Factor (tan δ)

Table (5) shows the effect of variation of frequency on dissipation factor (tan δ) at room temperature . It appears that the dissipation factor (tan δ) decreases with increasing frequency according to equation (5).It decreases from 0.185 to 0.026 for sample A and from 0.418 to 0.027 for sample B and from 0.37 to 0.221 for sample C and from 0.365 to 0.082 for sample D as frequency increases from 50 to 10^6 Hz for all four samples, this effect is plotted in fig. (5) .

Table 5: The effect of variation of frequency on dissipation factor (tan δ) at room temp.

F(Hz)	dissipation factor (tan δ)			
	A	B	C	D
50	0.185	0.418	0.370	0.365
500	0.161	0.323	0.303	0.368
1000	0.08	0.263	0.264	0.261
10^5	0.037	0.075	0.241	0.214
10^6	0.026	0.027	0.221	0.082

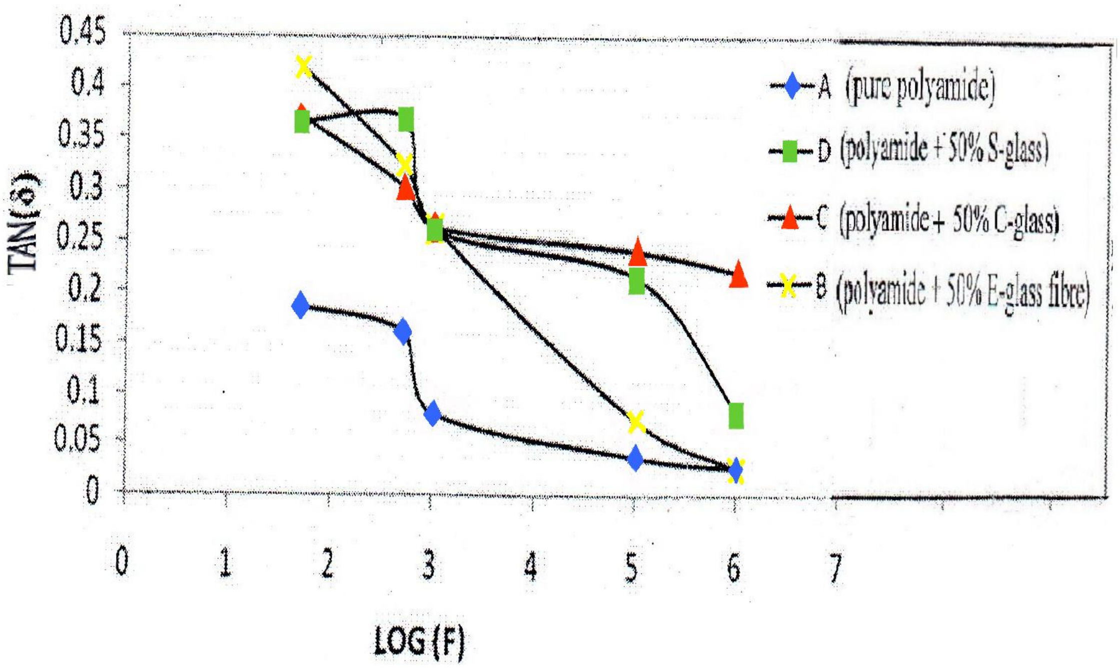

Figure 5:The effect of variation of frequency on dissipation factor (tan δ) at room temp.

The dissipation factor (tan δ) increases as temperature increases at fixed frequency (1 KHz) due to the glass transition temperature of the polymer (Tg)(where above Tg the amorphous domains of a polymer are said to be in a rubbery state and below it in a glassy state). Table (6) shows that (tan δ) increases from 0.03 to 0.304 for sample A and form 0.233 to 0.586 for sample B and from 0.228 to 0.33 for sample C and from 0.247 to 0.582 for sample D as the temperature increases from 30ºC to 120ºC for the all four samples . this effect is well shown in fig. (6).

Table 6: The effect of variation of temperature on dissipation factor (tan δ) at (1 KHz)

Temp. (ºC)	dissipation factor (tan δ)			
	A	B	C	D
30	0.03	0.233	0.228	0.247
60	0.057	0.364	0.31	0.394
90	0.084	0.48	0.347	0.598
110	0.201	0.602	0.337	0.623
120	0.304	0.586	0.33	0.582

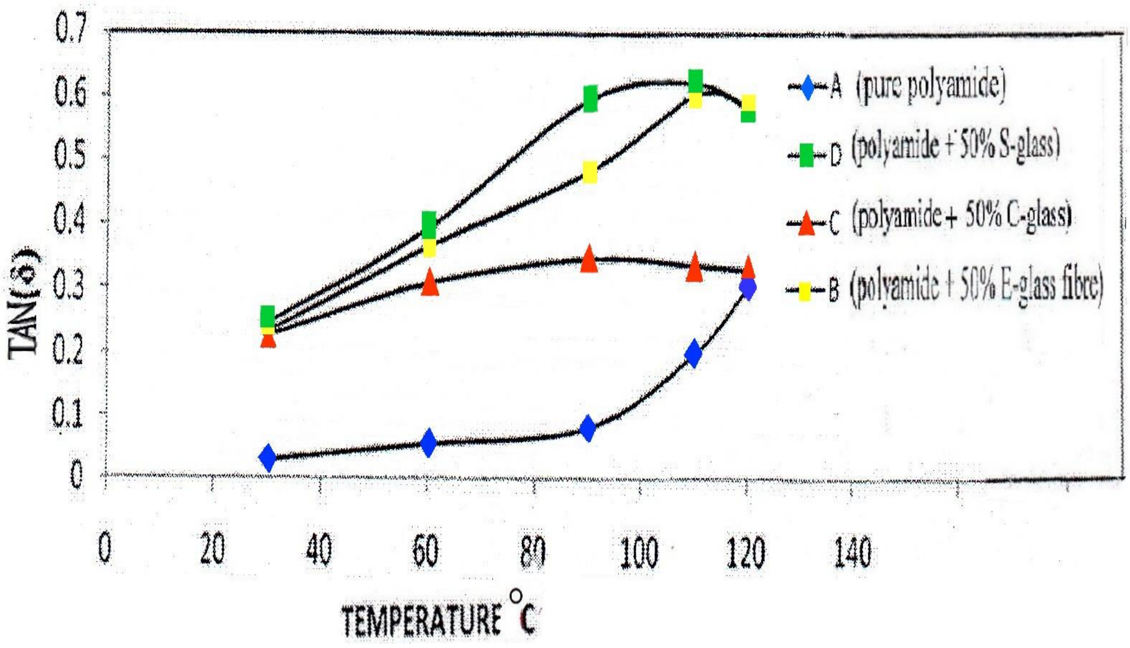

Figure 6:The effect of variation of temperature on dissipation factor (tan δ) at (1 KHz)

3.4 The electrical resistivity

Table (7) shows that the value of the electrical resistivity (B) decreases with increasing temperature, (increasing the conductivity) and is due to greater freedom of movement of the dipole molecular chains within the polyamide at high temperature. It was found that ($B\times10^{10}$) decreases from 90 to 5 for sample A and from 7 to 1.8 for sample B and from 5 to 1.4 for sample C and from 7 to 1.8 for sample D as the temperature increases from 30ºC to 120ºC for all four samples . fig. (7) shows this effect .

Table 7: The effect of variation of temperature on the electrical resistivity at (1 KHz)

Temp. (°C)	Electrical Resistivity (* $10^{10}\Omega$ .cm)			
	A	B	C	D
30	90	7	5	7
60	30	4.7	2.8	4.2
90	20	2.7	1.9	2.4
110	8	1.9	1.6	2
120	5	1.8	1.4	1.8

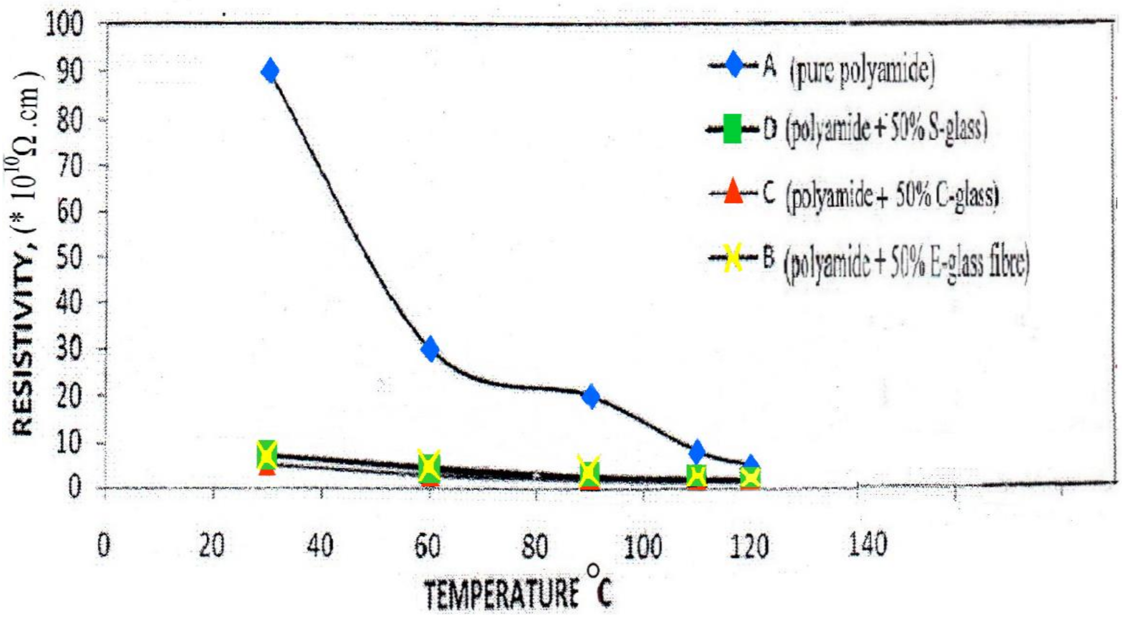

Figure 7:The effect of variation of temperature on the electrical resistivity at (1KHz)

Conclusion

1. Dielectric constant (ἐ) increases considerably with the addition of glass fibre in polyamide resin, also it) increases with temperature at lower frequencies.
2. The value of dielectric loss (ε'') decreases with the increase of frequency at fixed temperature in all the four samples and it increase with increase in temperature.
3. The variation of dissipation factor (tan δ) with frequency appears that decreasing with increasing in frequency according to eq. 5.in contras, it increases with increase in the temperatures at fixed frequency (1 KHz) .
4. Polyamides resin reinforced by 50 wt% of glass fibres are low electrical resistivity.

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