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Research Paper

Studying the mechanical and electrical properties of epoxy with PVC and calcium carbonate filler

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Abstract

In the present research composite material was prepared from epoxy and PVC reinforced with calcium carbonate as a filler material with different percent weight ratios (0.6,1.2,1.8 and 2.4) g.The effect of different weight ratios of calcium carbonate particles and PVC different content on electrical permittivity , dielectrical loss constant, hardness ,young modulus and compression strength were studied. Electrical properties of these composites were investigated by using Fourier transform infrared spectroscopy (FTIR) to study the bonds which enhanced the insulating properties of epoxy material compounded with filler and PVC. The inclusion of CaCO3 in epoxy and (PVC) polymer matrices greatly enhances the physical and mechanical properties of the composite.
The experimental results also show that sample (5) compounded with 2.4 g of Calcium Carbonate has the minimum dielectric loss therefore it had the best insulating properties. The compression strength, young modulus, hardness decrease with filler content increase and PVC compound decreased. The maximum electrical permittivity in sample (3) compounded with 1.2 g of calcium carbonate and 4.8 g of PVC. Cost also can be reduced by the addition of filler material. .

Keywords: *PVC, Epoxy, Filler, Calcium Carbonate, FTIR, Dielectric Properties.*

1. introduction

Polyvinyl Chloride (PVC) is widely used as cable insulation for low voltage application. In order to strengthen the electrical properties of the material, some additives have to be added. In this project, various fillers were compounded with PVC. The main parameters that have been studied were dielectric strength, and the dispersion of PVC molecules. The polymer structure of PVC was altered after undergo high voltage stress and it can be related to the breakdown voltage.[1] Electrical insulators are very important materials in the electrical power systems, such as substation, distribution and transmission lines [2].
Ground calcium carbonate are generally used as filler with an interesting ratio performance/price. Calcium carbonate is the active ingredient in agricultural lime, and is created when Ca ions in hard water react with carbonate ions creating lime scale. Figure (1) represent the chemical composition of calcium carbonate, PVC and epoxy. Table (1) represent the properties of $CaCO_3$
The specific structure allows this material to fulfill additional functions like Processing aid, impact modification and better weather ability. Its regular and controlled crystalline shape and ultra-fine particle size together This low-cost material has numerous advantages, such as a high modulus, excellent chemical resistance and easy conversion.[3].
Epoxies are the most widely used resin materials and are used in many applications, from aerospace to sporting goods [1], [2].
Epoxies are cured by chemical reaction with amines, anhydrides, phenols, carboxylic acids, and alcohols. Epoxy have carboxyl function group. Epoxy are an exception, in that they undergo chemical grafting onto PVC in their role as stabilizers, replacing labile chlorides so Epoxy with PVC provide good thermal properties because epoxy have oxirane oxygen groups in their molecules formed by the epoxidation of olefinic double bonds in their starting raw materials.[4]

The curing (crosslinking) reaction takes place by adding a hardener or curing agent (e.g., diethylene triamine). Toughened epoxies are made by adding thermoplastics to the epoxy resin by various patented processes. [3] PVC was added to enhance the toughness of epoxy because it is tough, brittle and has relatively good flexural strength. [4,5]. Filler material are widely used as a reinforcement material to increase the mechanical, electrical, and other properties such as stiffness, dielectric strength fire retardant and to prevent electrical discharge cause by void [6], [7].

Calcium carbonate is added Polyvinyl chloride, polyolefins, phenolics, Polyesters and epoxies to improve the insulation's electrical resistance [8], [9].The effect of fillers on properties of composites depends on their level of degree of dispersion, aggregate size, surface characteristics, loading, and shape, particle size. Low electrical strength could lead to failure of cable due to over voltage [9], [10], and [11]. The electrical and mechanical properties of composites are significantly dependent on the filler's aspect ratio, interaction between fillers, polymer matrix and also the surface area. [12], [13].

In general, insulation materials should have good mechanical characteristics as any serious degradation in the mechanical properties of an insulating material leads to dielectric failure [14], [15] .

The physico-mechanical and dielectric properties of NBR filled with increasing amounts of silica and mica were studied by D.E.El- Nashar . The mix of NBR/ silica/mica (100: 25:11) shows promising mechanical and dielectric properties than the other compositions. On the other hand, the lower value of dielectric loss given for such mix validates its use for insulating purpose

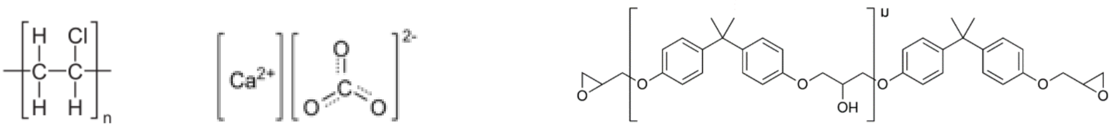


Fig. 1: The chemical composition of PVC, calcium carbonate and epoxy

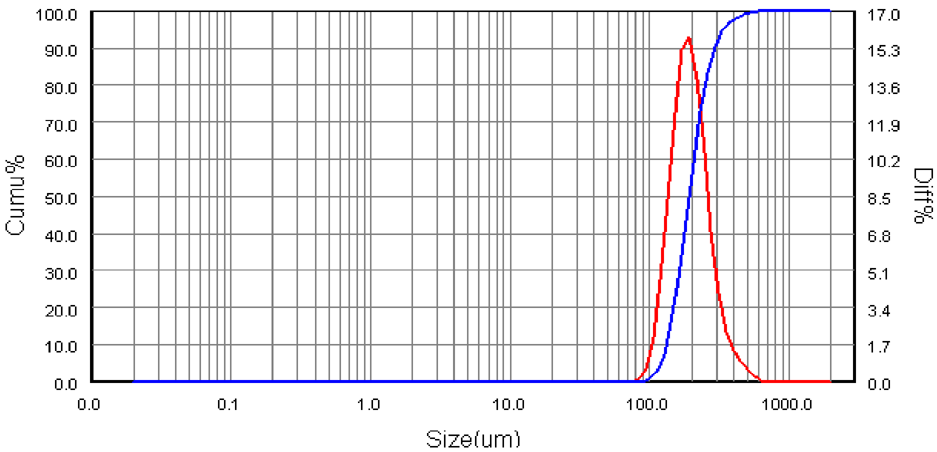
Table 1: the properties of $CaCO_3$

Properties	
Molecular formula	$CaCO_3$
Molar mass	100.0869 g/mol
Appearance	Fine white powder; chalky taste
Odor	odorless
Density	2.711 g/cm^3 (calcite) 2.83 g/cm^3 (aragonite)
Melting point	825 °C (aragonite) 1339 °C (calcite)
Boiling point	decomposes
Solubility in water	0.0013 g/100 mL (25°C)
Solubility product,K_{sp}	4.8×10^{-9}
Solubility in dilute acids	Soluble
Acidity (pK_a)	9.0
Refractive index(n_D)	1.59
Structure	
Crystal structure	Trigonal ,isometric
Space group	32/m
Thermochemistry	
Std molar entropy S^o_{298}	93 J·mol^{-1}·K^{-1}
Std enthalpy of formation $\Delta_f H^o_{298}$	−1207 kJ·mol^{-1}

2. Experimental work

The samples were prepared by using cylindrical plastic mold with dimensions (2 cm) height and (8 mm) diameter epoxy condensed with diethylene triamine .Calcium carbonate was added at (0 ,0.6, 1.2, 1.8, and 2.4) wt% , PVC powder was added to enhance the toughness. Table (2) represents the components of the samples molded according to:

1) Weight the components.
2) The average particles size range of calcium carbonate powder is (100-1000) µm determined by using LBZA device to determine the required size [D50:191.6 µm] as shown in figure (1).
3) Mixing the components well by using intensive mixer.
4) Mold the mixture; keep it in the mold for 24 hrs.
5) Put the molds in the oven for 24 hour in order to complete currying process.
6) For measuring hardness and compression resistance the samples had been prepared with dimensions (8) mm in diameters and (20) mm in height.
7) The shore hardness A test was used to measure the samples hardness
8) The compression device was used to measure the compression strength and young modulus
9) LC multi meter device was used to measure the electric permittivity dielectric loss constant
10) PH meter device was used to measure the PH of the samples
11) FTIR device was used to measure the Fourier transform infrared spectroscopy



Diam um	Percent
0.000-78.48	0.00
78.48-99.75	0.67
99.75-126.7	6.70
126.7-161.1	20.64
161.1-204.8	30.99
204.8-260.3	24.44
260.3-330.9	10.97
330.9-420.6	3.74
420.6-534.6	1.56
534.6-679.6	0.29

Fig.2: LBZA Chart of Particle Size Analysis of $Caco_3$.

Table 2: Represents Samples Properties.

Sample number	Epoxy [g]	Calcium carbonate [g]	PVC [g]
1	20	0	6
2	20	0.6	5.4
3	20	1.2	4.8
4	20	1.8	4.2
5	20	2.4	3.6

3. Result and discussions

The hardness of the samples decreases with the increase of filler ratio and PVC content decrease as shown in figure (3). The hardness decreases when the filler ratio increases due to filler ability to occupy space and reduce crosslink content through polymerization and act as a cheap diluent of the more plastic product also offer some functional benefit that contributes to the process ability or utility of the plastic product. The hardness in sample (4) increase may be due to good filler and epoxy polymer interactions when PVC content decrease.

The compression strength decrease when filler content increase and PVC content decrease because isometric Calcium carbonate particles have (100-1000) µm in average particle size and it has low surface area and low aspect ratio therefore its diluent material enhance the movement of polymer chains and reduce the compression resistance as shown in figure (4).similar trend has been done with **abeer adnan ,** the compression strength decrease of polyester with calcium carbonate increase[16]

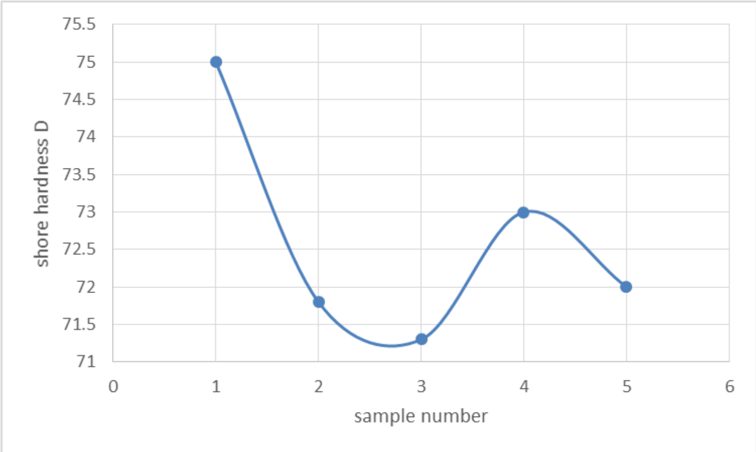


Fig. 3: Represent Shore Hardness Verses Sample Number.

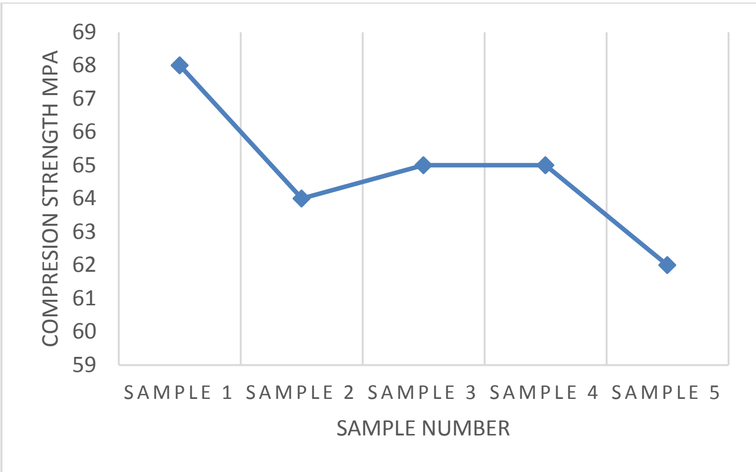


Fig.4: Represent Compression Strength Verses Sample Number.

Figure (5) represent the young modulus of the samples. The young modulus decrease with filler ratio increase .Filler with low aspect ratio and isometric particle shape will decrease resistance to compression because it has low contact area therefore the elasticity increase and the young modulus decrease.

The elongation increase with filler content increase due to the fact that epoxy matrix allows more rheological flow due to good filler- polymer interaction. After adding more filler the material is stiffer and harder due to that the filler particles hinder the chains movement so the elongation decreased and when the filler concentration increase the aggregation of filler particle increase as shown in figure (6).

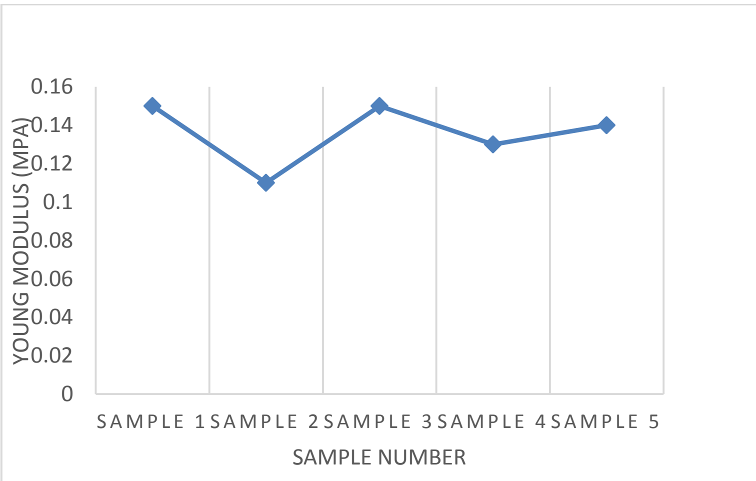


Fig. 5: Represent Young Modulus Verses Sample Number.

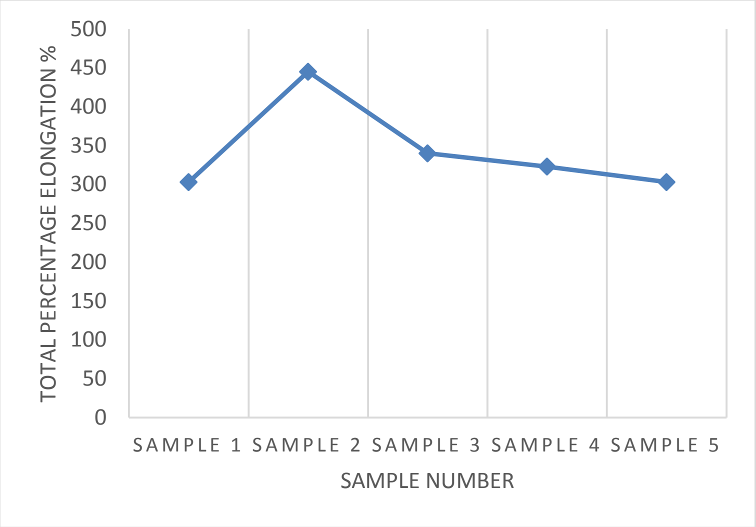


Fig. 6: Represent Total Percent Elongation Verses Sample Number

Figure (7) represent PH verses sample number .PH increase with $CaCO_3$ content increase because $CaCO_3$ have PH=11 so it's high base and there is reaction between filler and polymer. When filler content increase the basic filler reaction with acidic polymer increase

The permittivity decrease with frequency increase as shown in figure (8). In such range the permittivity has contribution from orientation polarization. Also it is clear that increased by increasing calcium carbonate content. It is evident that complex di- electric constant of $CaCO_3$ lower than that of epoxy and PVC Then the complex dielectric constant of the mixture should decrease with the addition of $CaCO_3$. Also it's relating to mechanisms related to the main chain and its related motions. One of the expected mechanisms related to Maxwell Wagner effect for heterogeneous systems. The origin of such process is in phase with the applied potential due to the difference in permittivities and resistivities of the blends. . The electrical insulation enhanced because the covalent bonds and there is no free electrons so the electrical domain decreased when filler concentration increased.

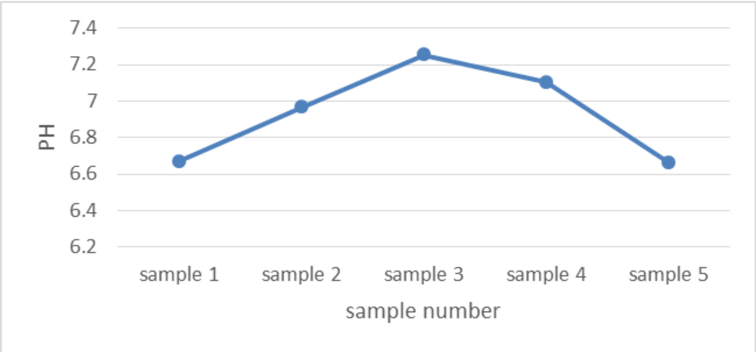


Fig. 7: Represent PH Verses Sample Number

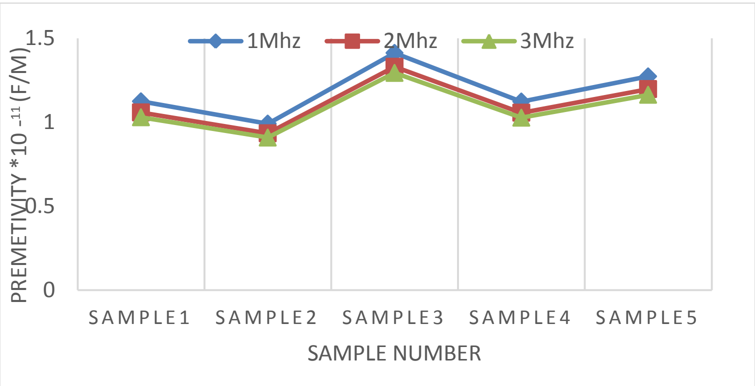


Fig. 8: Represent Permittivity Verses Sample Number

Figure (9) represent the dielectric loss constant of the samples in different frequency. The dielectric loss constant is showing an anomalous dispersion. The dielectric loss increase with frequency increase .the die electric loss constant increase with filler content increase and PVC content decrease because $CaCO_3$ has lower dielectric loss constant than PVC so the insulting properties increase

Figure (10) represent transparence versus wave number for the samples. FTIR showed that there is reaction between PVC and epoxy by the appearance of new bonds with wave number (2100, 2300) as shown in sample (1). When compared between the epoxy intensity without any additives and sample (1) intensity as shown in figure (11) which represent the transparences verses wave number of samples, the intensity decreased in sample (1) with the using of PVC therefore the bond forces increased. In sample (1) contain epoxy and PVC without filler the bonds with wave numbers (746.45, 1292.31, and 3670) disappeared when compared with epoxy alone.

The bonds that were appeared as shown in table (3), and selected in fig. (11) also there is new bonds appears between epoxy and calcium carbonate with wave number (3695.61, 3037.89, 2115.91) which was found in calcium carbonate FTIR as shown in sample (2) in figure (11) because CaCo3 with PH =11 has good ability to react with epoxy therefore there is good filler – matrix interaction and dispersion and the toughness enhanced.

The bonds with wave number (1125) disappeared in sample (3) and the bonds with wave number (3695, 3037, and 2115). The bonds with wave number (3037, 1560) which was responsible of crosslinks in epoxy chains still exist in all the samples therefore the filler may envelope by the polymer chain. Figure (12) represent FTIR analysis curve of PVC the bonds with wave numbers (2000-3200, 700-1000) appear in the samples therefore the interaction between the molecules increase.

The intensity of sample (2) decreased more than samples 2 therefore the bonds will be strong when $CaCO_3$ was added also the intensity decreased in the other samples therefore the bonds be more strong and the insulation properties enhanced.

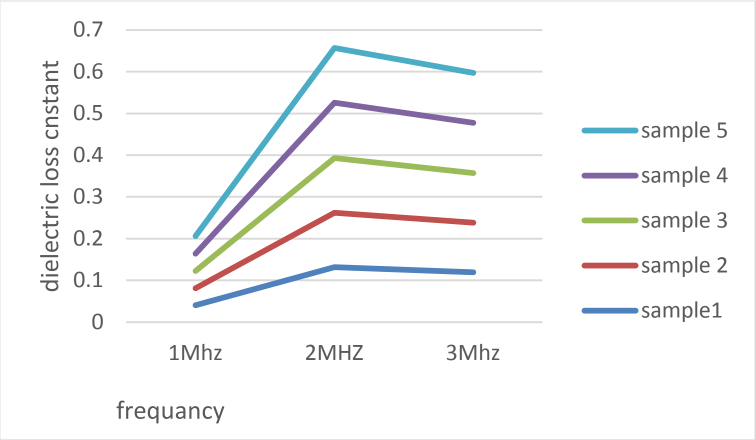
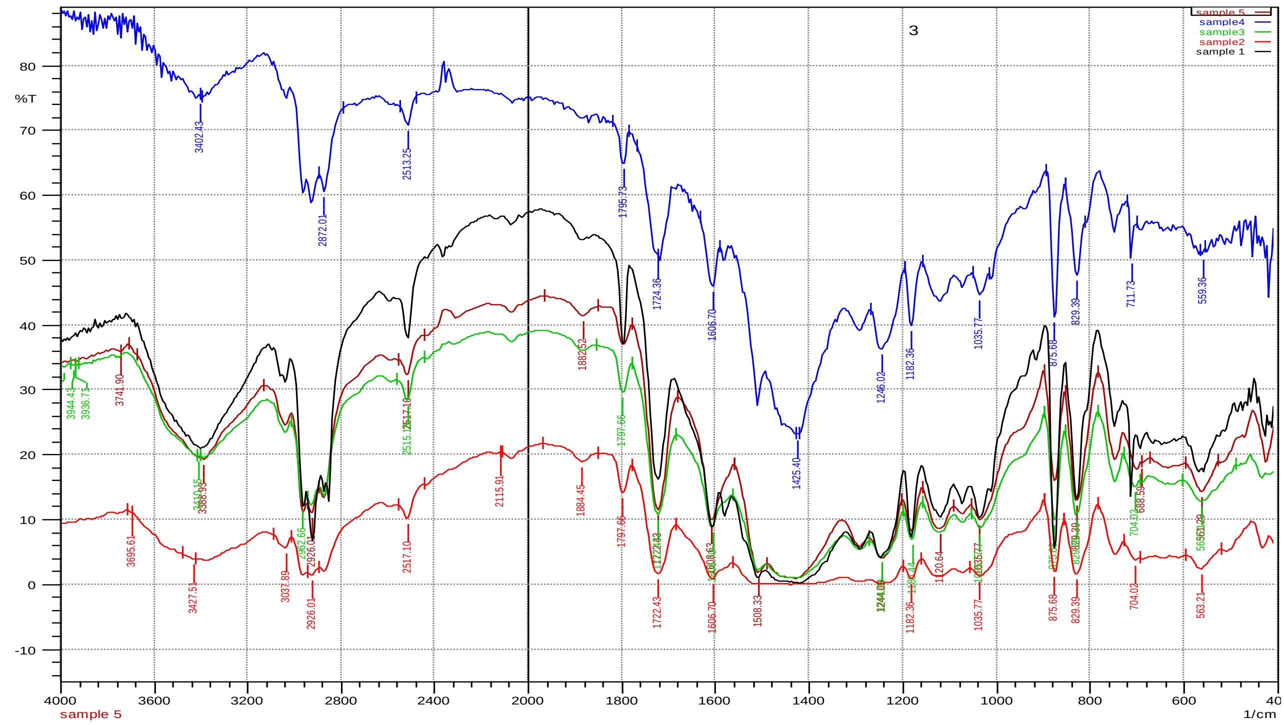


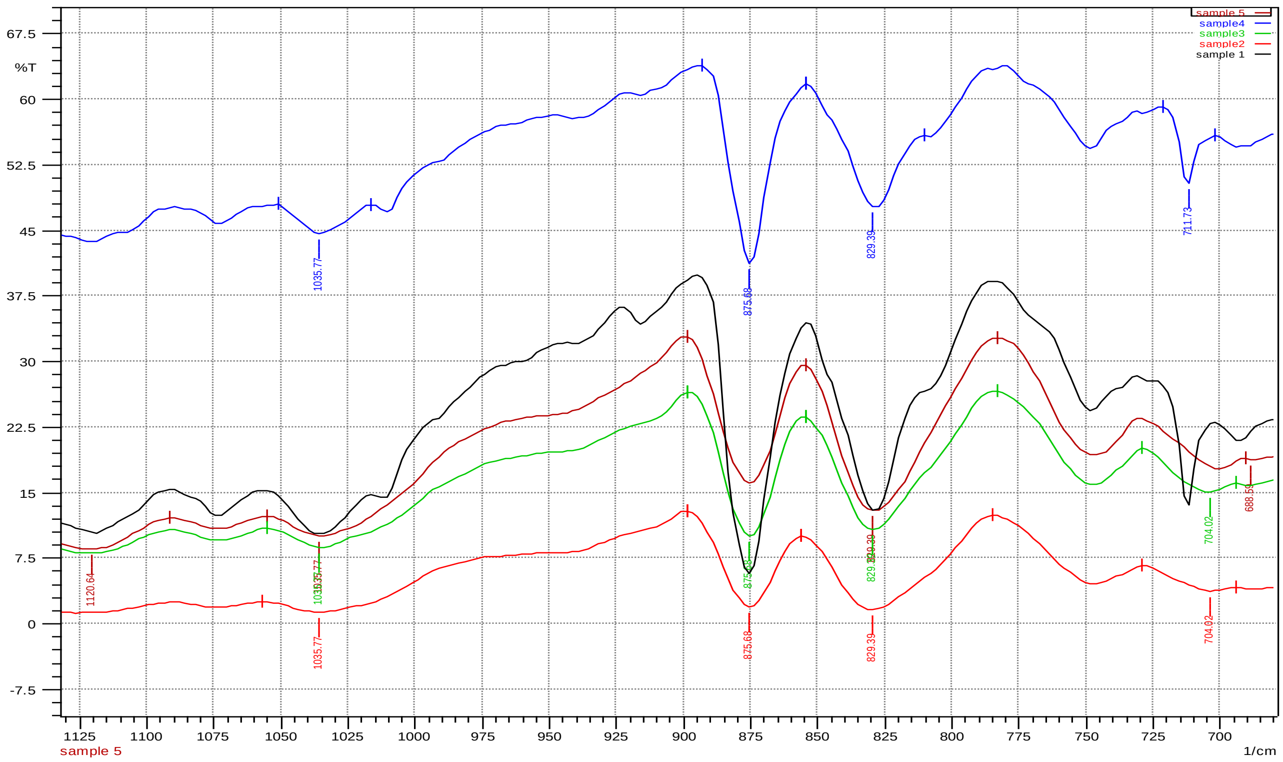
Fig.9: Represent Dielectric Loss Verses Sample Number

Table 3: Represents The Peak Number Of Some Bonds.

Bond	Peak number
C-H	569,640.37,1292.31,1246
C-C	1606.7
C-O	1118.71
C=C	1452.4
O-H	3035.96
N-H	3037,1560
N-C	1035.77,1118.71
C-Cl	540-760



(a)



(b)

Fig. 10: A) Represent Intensity Verses Wave Number for 1. Sample (1) 2.Sample (2) 3. Sample (3) 4. Sample (4) 5. SAMPLE (5) B) Enlarge Part of It.

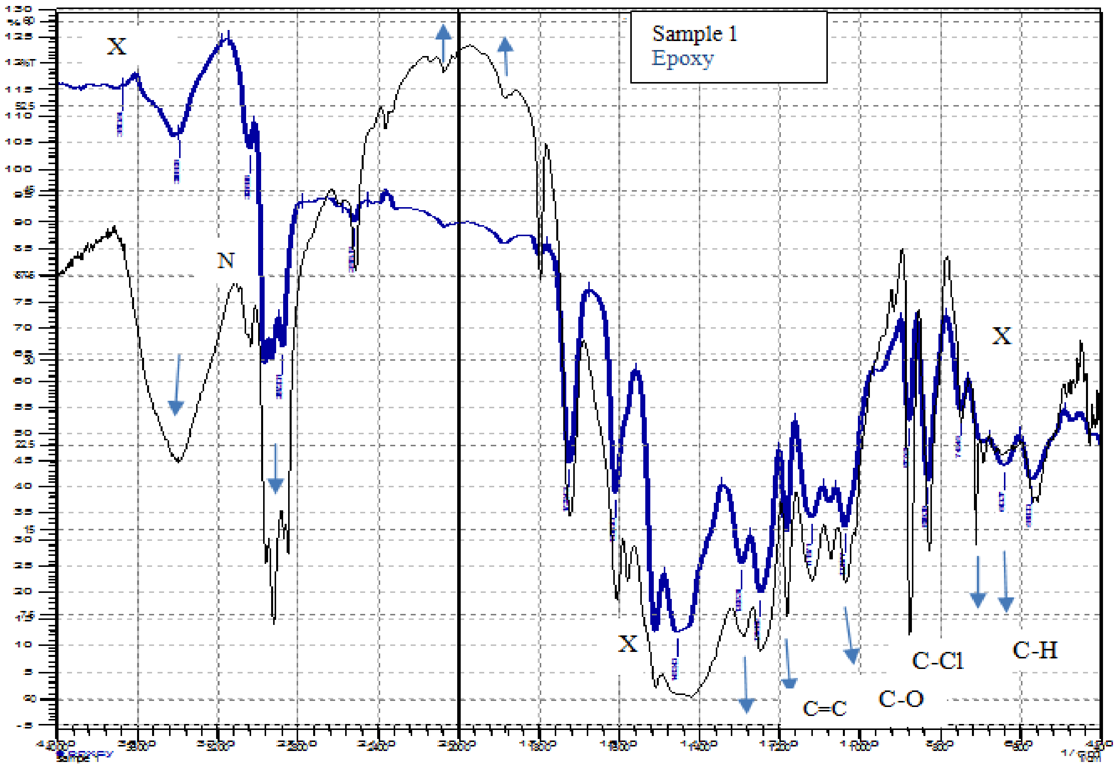


Fig. 11: FTIR for sample 1, epoxy.

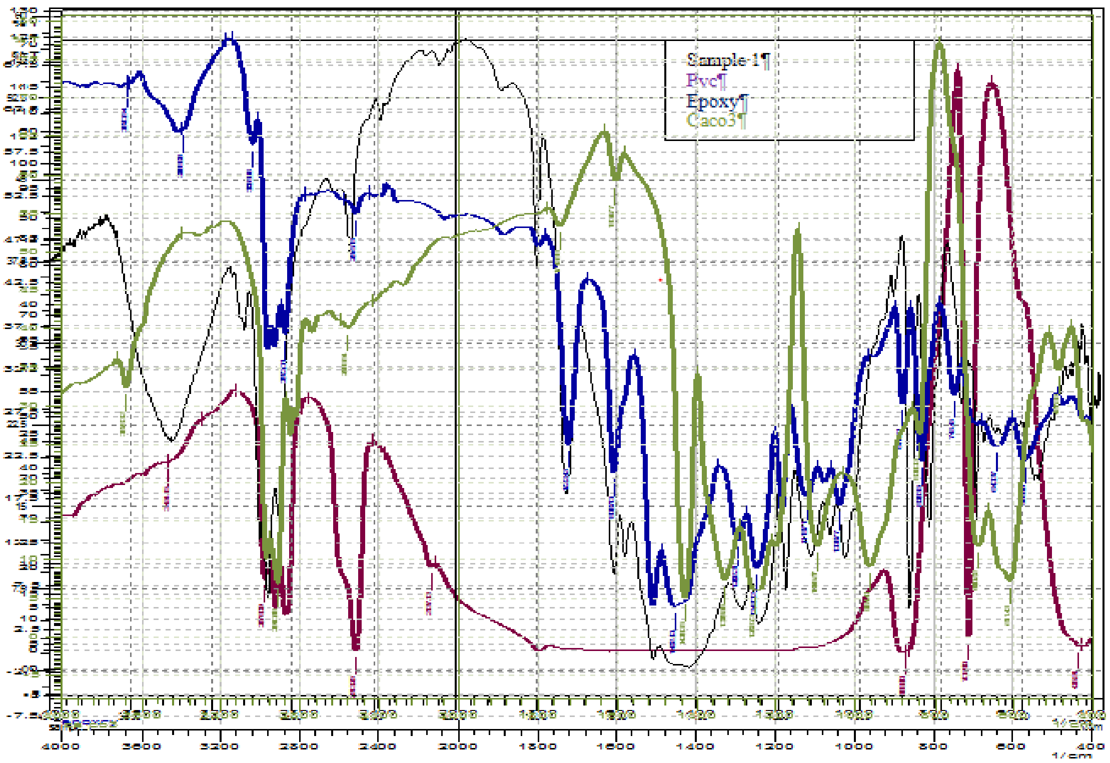


Fig.12 : FTIR for sample 1,pvc,epoxy,caco$_3$

4. Conclusion

From this study, it was found that the epoxy containing 2.4 g of CaCO3 give better mechanical as well as dielectric properties among the other CaCO3 loading because the interaction between molecules enhanced by the reaction between PVC molecules and epoxy with CaCO3 filler.

CaCO3 in some applications of epoxy, leading to a lower formulation cost. The addition of PVC and CaCO3 compound leads to improvement of mechanical properties (compression strength, hardness, and Young's modulus and crosslinking density) and dielectric properties.

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