Thermo-Physical and Mechanical Properties of Unsaturated Polyester /Cobalt Ferrite Composites

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ABSTRACT

Unsaturated polyester was used as a matrix which was filled with different percentages of cobalt ferrite using hand lay-up method. Cobalt ferrite was synthesized using solid state ceramic method with reagent of CoO and Fe_2O_3. Mechanical properties such tensile strength, Young's modulus and shore D hardness of the composite have been studied. All these properties have increased by 10% with increasing cobalt ferrite contents. Also the thermal properties such thermal conductivity and specific heat capacity are highly increased as the ferrite content increased, while the thermal diffusivity increased by 22 %. On the other hand dielectric strength of composite has been measured which increased by 50% by increasing the cobalt ferrite content.

Keywords: cobalt ferrite, thermal conductivity, thermal diffusivity, specific heat capacity, tensile strength, dielectric strength.

الخواص الفيزو حرارية والميكانيكية لمتراكب بولي استر الغير مشبع/ كوبلت فرايت

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الخلاصة

استخدم البوليستر غير المشبع كمادة اساس وذلك بتدعيمها بنسب مختلفة من فرايت الكوبلت ، تم تحضير المتراكبات بالطريقة اليدوية. أستخدمت طريقة الحالة الصلبة السيراميكية وهي احدى الطرق التقليدية في تحضير فرايت الكوبلت .

درست الخواص الميكانيكية مثل متانة الشد ، معامل يونك وصلادة شور دي. كل هذه الخواص تأثرت باضافة فرايت الكوبلت حيث تزداد هذه الخواص مع زيادة نسبة الكوبلت فرايت.

اما الخواص الحرارية مثل التوصيلية الحرارية والنفاذية الحرارية والسعة الحرارية النوعية فقد تم دراستها وايضا تأثرت باضافة فرايت الكوبلت حيث ازدادت بصورة بسيطة. ايضا تم دراسة متانة العزل لهذا المتراكب وازدادت بزيادة محتوى فرايت الكوبلت.

الكلمات الرئيسية: كوبلت فرايت، التوصيلية الحرارية، الانتشارية الحرارية، السعة الحرارية النوعية، مقاومة الشد، مقاومة العزل الكهربائي.

1. INTRODUCTION

The importance of polymer is mainly still regarded as a cheap alternative material that is manufactured easily. The intensive use of polymer in broad use has led to the development of materials for specific applications namely composite. One of these polymers is unsaturated polyester which characterized by vinyl unsaturation in the polyester backbone which is thermosetting polymer unsaturated polyester resins are most widely used in systems, particularly in marine industry. By for the majority of dinghros, yachts and workboat built in composite make use of the resin system **Han and Soon, 2001**.

Ferrite with spinel structure represents the importance class of magnetic materials which are ferromagnetic oxides consisting of ferric oxide and metals oxides. The spinel ferrites having the chemical formula MFe_2O_4 (where M is a divalent metal ions such Co, Ni, Mn , etc.) **Mukta, et al., 2009**.

Among the different spaniel ferrites cobalt ferrites $CoFe_2O_4$ are promising magnetic materials because of their moderate saturation magnetization, high electrical properties, high magnetic-crystalline anisotropy, good mechanical properties and chemical stability **Mukta, et al., 2009**.

Magnetic polymer composites are a subclass of composite materials which have attracted the attention of the researchers and scientists due to their unique properties, which render their use to be important in various applications such as high capacity information storage device, integral circuits, micro sensors, cell separation, bioprocessing, medical diagnosis and controlling drug delivery **Gomez-Del et al., 2014, Gardea and Lagoudas 2014**.

Adding small amounts of ferrite particles into polymers is one of the major research challenges because they can substantially improve the quality of composite materials in the terms of mechanical, thermal and electrical properties **Andrei et al., 2006**.

Haifel et. al. have studied the thermal conductivity and dynamic mechanical analysis of ferrite particles filled thermoplastic natural rubber composite **Haifel et al., 2013**.

Many works have been done on polymer based composites filled with magnetic materials in micrometer- size such as barium ferrite **Li et al., 2007**. NiZn ferrite **Nakamuca et al., 1994** and Fe_3O_4- Yag **Yusof et al., 2007**. Faiq and Attiyah have studied the effect cadmium ferrite on the epoxy resin. The mechanical properties and thermos- physical properties have affected with incorporated the ferrite content **Faiq and Attiyah, 2016**.

The main objective of the research is to study the effect of cobalt ferrite on the mechanical and thermal properties and dielectric strength of polyester.

2. EXPERIMENTAL PART

2.1 Materials Used:

Cobalt ferrite was synthesized from reagent grade of CoO and Fe_2O_3 using solid state ceramic method.

The unsaturated polyester resin is used as the matrix in the preparation of ferrite- polymer composite. It is provided from the Saudi Arabia (SIR) Company in the form of transparent viscous liquid at room temperature which is a thermally hardened polymer (thermosets) with a density of (1.255 gm / cm^3). MEKP is stable organic peroxide that decomposes rapidly in the presence of certain metallic carboxylate salts. MEKP is used as hardener Table 1 shows the characteristics of unsaturated polyester used in the research.

2.2 Procedures:

The synthesis of cobalt ferrite starting from stoichiometric mixture of CoO and Fe_2O_3 subjected to a combination of mechanical mixing and ball milled grinding and then sintered at 1200^oC for 4 hrs.

The unsaturated polyester was in the form of viscous liquid, transparent pink color at room temperature.

The resin converts from a liquid to solid state by adding hardener which is manufactured by the company itself; a methylethylketon peroxide symbolized by (MEKP) in the form of a transparent liquid is added to resin by rate 2% room temperature and increasing the speed of hardened by stirring for 2 hrs. The most basic fabrication method for thermoset composite is hand lay-up which is typically consisted of laying polymer layer by hand on to a tool to form a laminate stack. A good mixing between polymer and its hardener is done to form a matrix. Cobalt ferrite powder with different percentages(2,5,8,10,15)% mixed with matrix and stirred for one hour to avoiding any bubbles occur.

The mixture was poured into a mould. Finely composite plates were cut into different shape and dimensions for each test according to international standard. The casting time occurred overnight at room temperature.

2.3 Characterization:

2.3.1 Tensile test

The tensile test was performed according to (ASTM D638) at room temperature with capacity (20KN) applied load and strain rate of (0.5 mm/min) by using the machine type WDW-200E. **Fig. 1** shows the tensile machine and **Fig. 2** shows standard and experimental specimens for tensile test.

2.3.2 Hardness test

The hardness test is performed by using hardness (Shore D) and according to (ASTM DI-2242) standard. Samples have been cut into a diameter of (40mm) and a thickness of (5mm). **Fig.3** shows the hardness machine.

2.3.3 Thermal and dielectric properties test

To study the thermal properties test, two samples with the same dimensions have been prepared according to the standard specifications of instrument (3x2)mm, one of the most precise and convenient techniques for studying thermal transport properties is the transient plane source (TPS) method. It is a modern technique, yielding information on thermal conductivity, thermal diffusivity as well as specific heat per unit volume of material under study. The dielectric strength is performed by the impedance analyzer device. The optimization of polymer/ ferrite filler interfacial interaction is significant for the enhancement of thermal transport of polymer/ ferrite composite. The most important thermos- physical properties of a material that are needed for heat transfer calculations are: thermal conductivity, thermal diffusivity and specific heat. **Fig.4** shows thermal properties machine and **Fig. 5** shows thermal properties specimens. The dielectric strength is performed by the impedance analyzer device.

3. RESULTS AND DISCUSSION:

X- ray diffraction (XRD) was carried out at room temperature to determine the crystallinity of cobalt ferrite. All the diffraction peaks in the XRD pattern were compared with JCPDS (standard values cards) with nearly no impurities respect to cobalt ferrite pattern. It shows that the cobalt ferrite formed well defined spinel phase as shown in **Fig. 6.** The tensile strength at break for ferrites composite with variation of ferrite contents are demonstrated in **Fig. 7.** It can be seen from the graph that at 10% ferrite content the tensile strength shows remarkable increasing with the highest value of 27 MPa. As the content of ferrite continually increased the tensile strength of composite slightly increased. The lowest value of 14 MPa is for pure polymer.

The incorporation of cobalt ferrite as filler loading actually is associated with the improvement of tensile strength. The effect of good interface between cobalt ferrite particles and polyester resin is very important to the composite to stand the strength. When load is applied the matrix will distribute the forces to cobalt ferrite, which carry most of the applied load. The same behavior was for the Young's modulus of the composite, the modulus increased slightly with the ferrite content having the highest value at 10% with 2.93 GPa Young's modulus after that it decreased as shown at **Fig.8**.

Fig.9 represents the effect of ferrite content on the shore D hardness of the composite which again is increased as the ferrite content increased having a high value at 10% with value of 85.3 and then decreased while the hardness of pure polyester is 74. Most mechanical properties may be due to the flaw acts as stress concentration and causes the bond between the filler content and the matrix to break. The filler will act as physical and chemical cross-linking points and restricts the movement of polymer chain. It is a sign of the materials flexibility, which shows that the addition of cobalt ferrite creates a stronger but yet brittle composite **Surata et al., 2014**.

Fig. 10 reveals the thermal conductivity measured at different content of cobalt ferrite. It can be observed that the thermal conductivity of the composite with 10% cobalt ferrite is larger than pure polyester or other present thermal transport in the ferrite composite includes phonon diffusion in the matrix and ballistic transportation in the filler. The improving of thermal conductivity in this composite may stem from the improved percolation because of better dispersion and formation of a network **Jin et al., 2007**. This indicates that the thermal properties of the composite are mainly dominated by the interface thermal transport between cobalt ferrite /matrix interface **Kumar et al., 2007**.

The thermal diffusivity is an important property in all problems involving a non-steady state heat transfer. **Fig. 11** represents the effect of ferrite content on thermal diffusivity of the composite having the highest value at 15% cobalt ferrite which increased slightly with the increasing content of ferrite. The thermal diffusivity of the composite cannot be explained solely by the differences in the properties of the ferrite content. This indicates that the real quality determined in this study was so-called apparent thermal diffusivity **Sivakumar et al., 2007**. The obtained values of thermal diffusivity are affected by some factors e.g heat losses as a temperature dependent thermo-physical property. It depends too much on density of the used materials while the specific heat capacity has much effect on thermal diffusivity.

Fig. 12 represents of the heat capacity of the composite which is affected by cobalt ferrite content, again the same behavior occurs having the specific heat capacity with high value at 10% cobalt ferrite which increased as the content of ferrite increased but it decreased slightly after 10% cobalt ferrite.

Fig.13 demonstrates the dielectric strength of the composite against the ferrite content. As shown in the figure the pure polymer has a good dielectric strength which is 8.29KV/mm, but when adding the ceramic material (cobalt ferrite) which has a high strength because it is good insulator. The dielectric strength increased with increasing ferrite content having the highest value at 15% **Hasselman and Donaldson, 1990**.

4. CONCLUSIONS

From the work done on the synthesis of cobalt ferrite and the polymer/ ferrite composite the following conclusions can be drawn

1- Solid state ceramic method is a good method for synthesis cobalt ferrite.

2- All the mechanical properties increased with cobalt ferrite content at 10% and then decreased.

3- The thermal properties are affected by the incorporation of cobalt ferrite powder which increased slightly with the ferrite content.

4- Dielectric strength of the composite was affected by the ferrite content.

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Table 1 Characteristics of unsaturated polyester used in the research

Density(gm/cm^3)	Tensile strength (MPa)	Percent elongation (EL%)	Thermal conductivity w/m.c^o
1.255	70.3 -103	<2.6	0.17

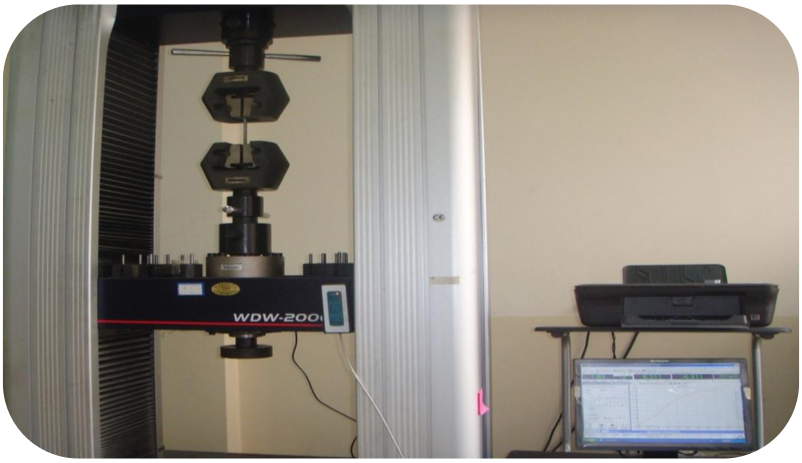

Figure1. Tensile strength machine.

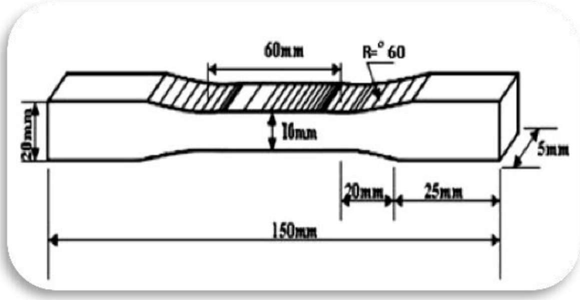

Figure2. Standard and experimental specimens for tensile test.

Figure 3. Hardness device.

Figure 4 .Thermal properties device.

Figure 5. shows thermal properties specimens.

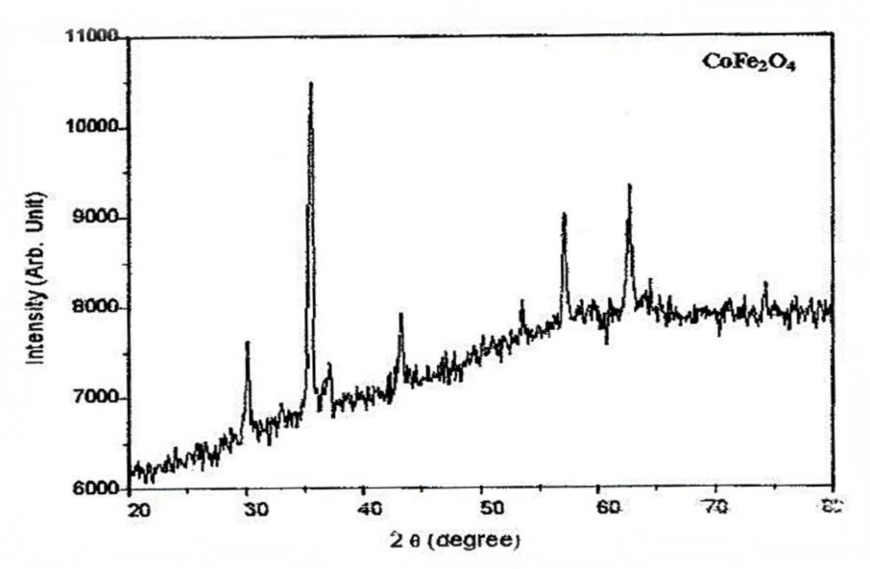

Figure 6. XRD pattern of cobalt ferrite.

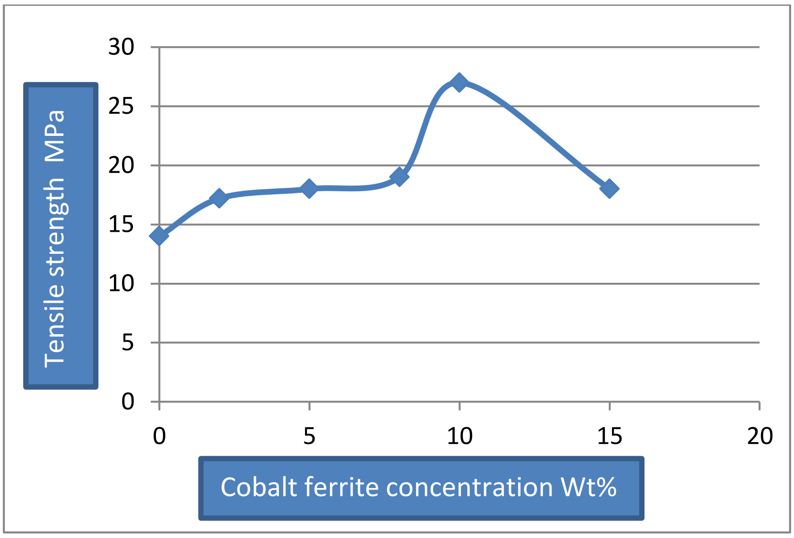

Figure 7**.** The effect of ferrite content on the tensile strength of composite.

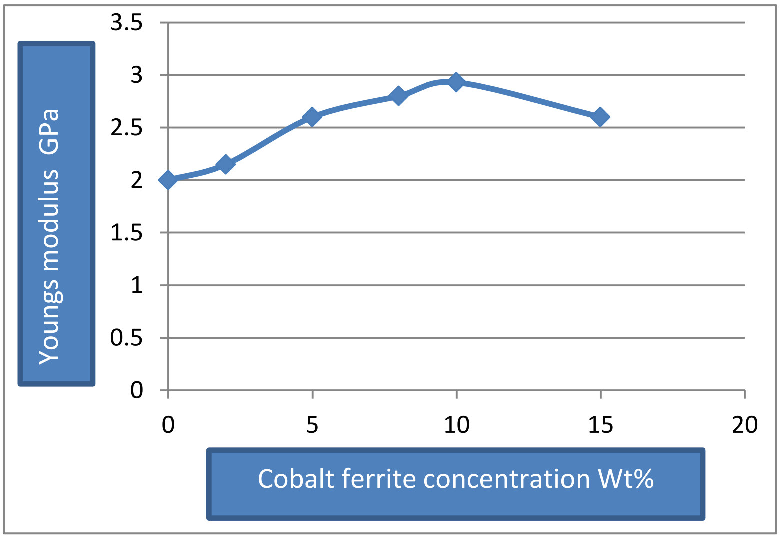

Figure 8. The effect of ferrite content on the youngs modulus of composite.

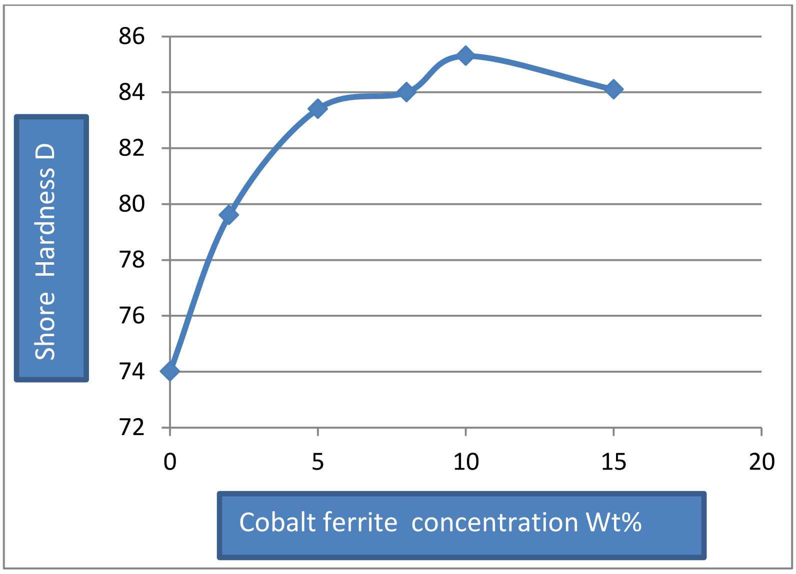

Figure 9. The effect of ferrite content on the shore hardness D of composite.

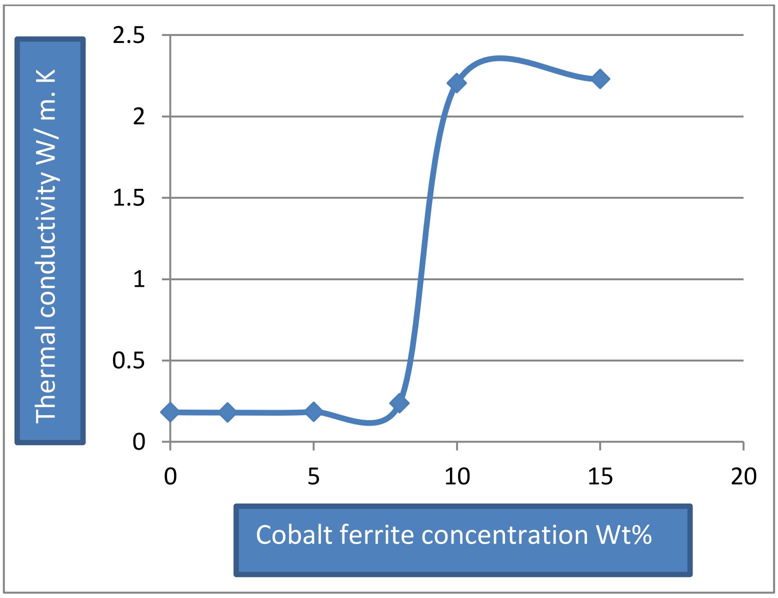

Figure 10 . The relation between cobalt ferrite content and thermal conductivity of composite.

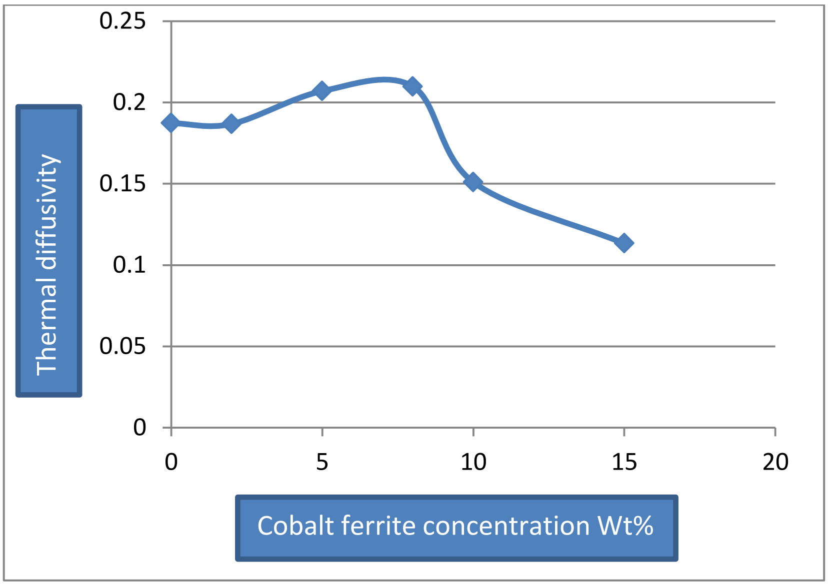

Figure 11. Thermal diffusivity vs cobalt ferrite content.

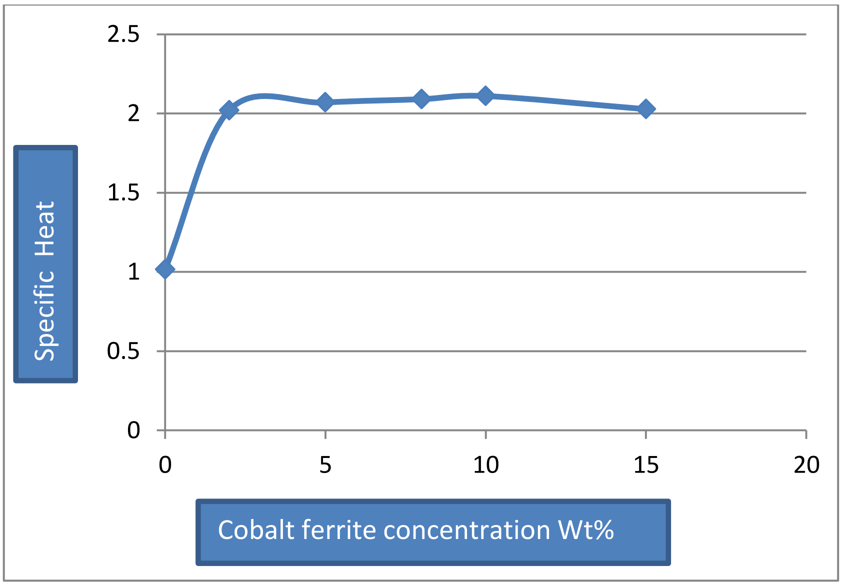

Figure 12. The relation of specific heat capacity with ferrite content of the composite.

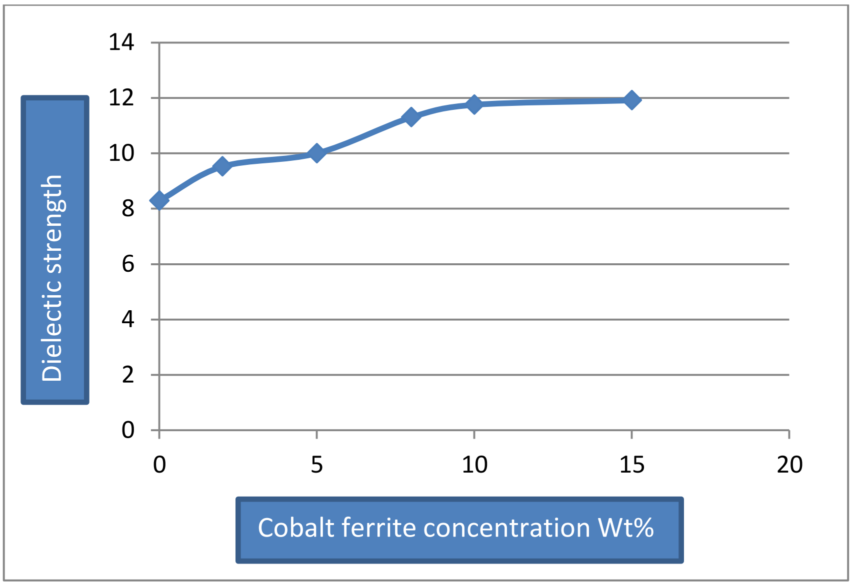

Figure 13. Dielectric strength of composite vs cobalt ferrite content.