EFFECT OF GRAPHENE ON MECHANICAL, ELECTRICAL AND THERMAL PROPERTIES OF POLYMETHYL METHACRYLIC NANOCOMPOSITES IN ELECTRICAL PACKAGING APPLICATION.

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ABSTRACT: *Polymethyl methacrylate (PMMA)/Graphene nanocomposites that fabricated by casting solution method at (0.1, 0.3, and 0.5 wt.%) Graphene fraction in a polymer and their mechanical, electrical properties were analyzed. Mechanical (Tensile Strength, elongation, Young Modulus, Tear Resistance, Hardness), electrical properties (D.C conductivity and Thermal conductivity were studied. Increased from 0 to 0.5 % of graphene in PMMA nanocomposites were improved in tensile strength, Young Modulus, and Hardness but decreased in Elongation and Tear Resistance. The results of electrical conductivity increases and when the temperature increases, the activation energy decreased when the additional Graphene increases. Thermal conductivity increased significantly with the increase of graphene content of PMMA nanocomposite.*

Key Words: PMMA, Graphene, Tear strength, D.C conductivity, Thermal conductivity.

INTRODUCTION

Polymethyl methacrylate (PMMA) is chemical compound artificial from the chemical change of methyl radical methacrylate to production chemical compound clear and rigid , PMMA is utilized in substitute application for shut-in product examples splinterproof of windows, skylights, light signs, and craft canopies [1].PMMA may be a sturdy chemical compound powerful conjointly light-weight, that incorporates a density of one.17–1.20 g/cm3, that is a smaller amount than [*fr1] that of glass. The impact strength is nice and better than each glass and chemical compound polystyrene; that impact strength continues to be considered not up to polycarbonate (PC) and a few designed polymers. PMMA ignited at 460 °C and once burnt, forming carbon dioxide and binary compound, CO and low-molecular-weight compounds, together with gas [2]. PMMA low price, thermal softening process, mouldability to any form, optical clarity and well purgative mechanical properties. PMMA may be a clear thermoplastic material. it's additional wide used than alternative plastics because of its high lightweight transmission, long service life, high actinic radiation resistance and weathering, and smart insulation properties. PMMA additionally has the best surface hardness of all thermoplastics. It is often invented by means that of bulk chemical change, answer chemical change, and radical chemical change since primarily it's with chemicals an artificial of methyl radical methacrylate. many PMMA properties of note embody breakdown potential properties of 16–30 kV/mm, insulator loss issue of 0.4-0.06%, the density of one.18 g/cm^3, the freezing point of 160°C, and the boiling purpose of 200°C [3]

Graphene, a two-dimensional layer of sp2-bonded carbon atoms densely packed in a very honeycomb lattice, has attracted important interests because of its exceptional mechanical, electrical, thermal and optical properties and victimization in physics, nanocomposites chemical change sensors, clear and versatile electrodes materials, star cells and supercapacitor application [4]. so the employment of graphene as a nanofillers incorporating in a very compound matrix has been extensively investigated to modification cost-efficient, superior graphene-polymer nanocomposites applications like sensors, batteries, supercapacitors and chemical element storage[5].

Graphene is a combination of superlative electrical, mechanical, and thermal which electronic mean the quantum hall result conjointly high carrier quality beneath close condition (~250,000 cm2V-1s-1) , exceptional thermal conduction (3000-5000 W m-1K-1) , well optical transparency (~97.7%) , high specific area (~2600 m2g-1) properties with Young's modulus of ~1 TPa and a breaking strength of ∼125 grade point average (∼42 N/m[6]. Graphene is taken into account to be the strongest material applicable in future versatile physics, wear-resistant coatings, and reinforcements in advanced composite materials. However, with its sturdy C−C sp2 valence bonds, graphene lacks plasticity. Atomic vacancies (point defects) and grain boundaries (GBs, plane defects) will simply amendment its mechanical strength [7].

Graphene sheets will give percolated pathways for negatron transfer, creating the composites electrically semiconductive. Similar edges are often achieved with alternative semiconductive carbon fillers like smut (CB), carbon nanofibers (CNF), and dilated carbon [8]. However, graphene permits the material to conductor transition at considerably lower loading. Particle orientation conjointly plays a crucial role: the percolation threshold becomes larger as particles square measure aligned parallel. Production of electrically semiconductive polyolefin, vinyl and acrylic polymers, polyester, polyamide, polyurethane, natural and artificial rubbers with graphene has been according. These materials are often used, as an example, for magnetism shielding, antistatic coating, and semiconductive paints. Fig (1) shows the wide selection of electrically semiconductive polymer/graphene

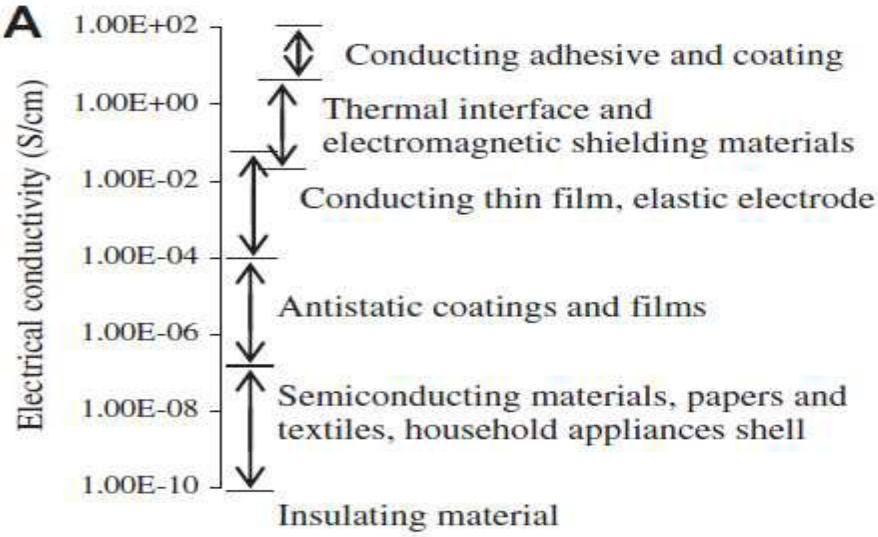

Fig (1): Applications of electrical conducting composites[9,10].

In this study, the enduringness, elongation, Young Modulus, Tear Strength and Hardness of the PMMA/graphene nanocomposites.Investigate the results of Graphene on electrical and thermal physical phenomenon properties of compound nanocomposite

EXPERIMENTAL WORK

Materials: Pure PMMA with density one.15 g/ cm3 provided by (Shenzhen Esun Industrial Co., Ltd. Chain).Chloroform resolution was purchased from Applied Chem (Germany).Graphene provided from Sigma-Aldrich that particle size is 50.22nm. PMMA/Graphene nanocomposites were made-up by resolution casting technique 1st PMMA weight at 3gm was dissolved in thirty ml of chloroform with continuous stirring for two h so as to utterly dissolve the PMMA. Graphene (0.1, 0.3, 0.5) wt.% was spread in chloroform (10 mL) single . after, {the resolution|the answer} containing spread was transferred into PMMA-chloroform mixture by employing a high-speed shear mixer to disperse the nanoparticles directly into PMMA solution with ten min shear mix and a thousand revolutions per minute speed. Finally, the PMMA–Graphene resolution was cast on Petri dish and any, dried underneath close conditions for twenty-four h. The dried composite films were raw off fastidiously from the petri dish; films were finally dried in a very vacuum at 50◦C for ten h. The obtained films were kept in airtight baggage at temperature for any characterizations

Characterizations: The surface morphology of graphene nanoparticles was observed with AFM micrographs as shown in Fig (2). It emerges that average diameter of 59.22 nm for graphene particles

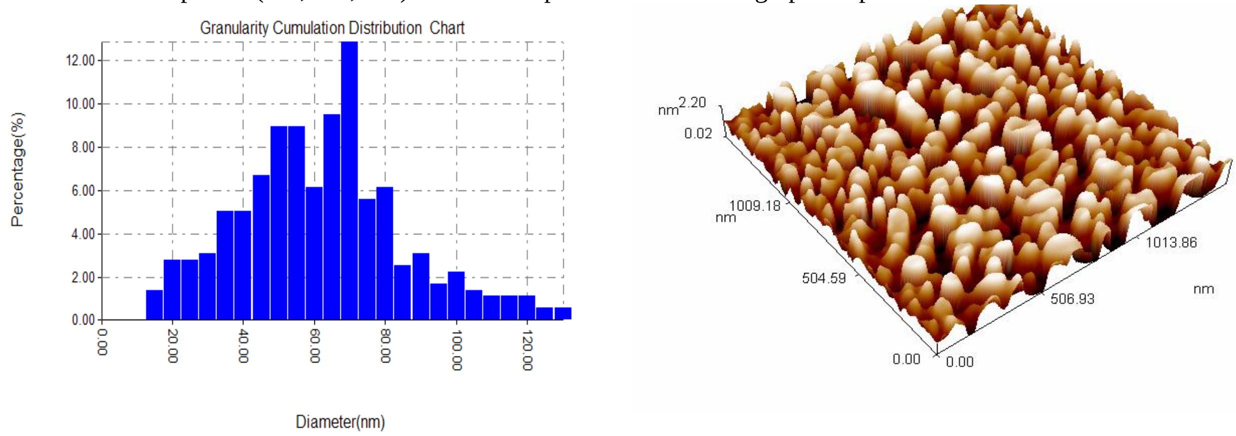

Fig (2): AFM analysis images of graphene nanoparticles used in the work

Thickness Calculated thickness of pure PMMA and PMMA/Graphene nanocomposites calculated by electronic digital micrometer sort (293-821, Mitutoyo) sensitivity was wont to live the thickness of composites films and notice that's 0.125 mm.

Tensile Strength in step with ASTM D-882[11] commonplace modulus of physical property, durability, and elongation equipped with a five metric weight unit load cell in tensile mode. Tested films turned over ten-millimeter dimension and one hundred fifty millimeters long and therefore the initial gauge length and therefore the speed was mounted at ten mm/min. durability (σs), Young's modulus (E) were determined in step with the subsequent equation:

$\sigma s = F / A$ ………..1

$E = F\, L0 / A\, \Delta L$ ………..2 Where: F: the force exerted on associate degree object underneath tension, L0: original length, A: cross section space, ΔL: length of the article changes**Tear Strength** decided on identical Universal Electronic measuring instrument in step with ASTM D-1922[12] by the garment tear methodology. The sample size was a hundred millimeter long and sixty-three millimeters wide having a cut of fifty millimeters at the middle of 1 finish. Tester used apparatus impact is employed to live the force needed to propagate slit a hard and fast distance to the sting of the take a look at the sample.

Hardness The experiment was conducted at temperature (25C) with50% humidness. The surface hardness of the samples was measured by employing a (Shore A durometer) in step with ASTM D 2240[13]. All the hardness values according to ar obtained from a minimum of four take a look at results.

Electrical properties. The resistivity has been measured as a operate of temperature within the vary (303-393K) by mistreatment the electric resistance (ρ) of the films is calculated by mistreatment the subsequent equation:

$\rho = R.AL$……….3

Where: R is the sample resistance, A is the cross section area of the film and L is the thickness of the samples. The conductivity of the films was determined from the relation:

$\sigma dc. = 1/$………… **4**

The activation energies could be calculated from the plot of Ln σ versus 1000/T from the Arrhenius equation to obtain the Activation Energy (Ea) by the following formula:

$\sigma = A \exp(-Ea / KB\ T)$……… 5

KB is the Boltzmann's constant which is 1.3806 ×10-23 J/K, *T* is the temperature in Kelvin. The Ea is in practice taken to be the slope of an Arrhenius plot of ln (*σ*) versus 1/*T* in Kelvin [14].

Thermal conductivity_ Thermal conductivity coefficient was calculated to the data that measurement by using the lee's disk {manufacture by Griffin and George / England}, thermal conductivity coefficient was calculated by using the following equation [15]

$K\ [T_B-T_A\ /d_s\ ]= e[\ T_A+\ 2/r[d_A\ +d_S/4]\ T_A+\ 1/2r\ (d_S\ T_B)$ …….(6)

$H=IV=\pi r^2 e\ (T_A+T_B)+2\pi re[d_AT_A+(1/2)d_S(T_A+T_B)+d_BT_B+d_CT_C]$……(7)

Where:

K: Thermal conductivity Coefficient, **e**: Represents the amount of thermal energy passing through unit area per second disk material , **H**: Represents the thermal energy passing through the heating coil unit of time , **d:** Thickness of the disk (mm) , **r**: The radius of the disk(mm), **d_S** : Thickness of the sample(mm) , **T:** The temperature of the disk(°c).

RESULTS AND DISCUSSION

Mechanical properties In Fig (3) shows the strain – strain curves at pure PMMA that enduringness is 15.43MPa and Elongation is 3.17% as a result of that PMMA is very brittle materials

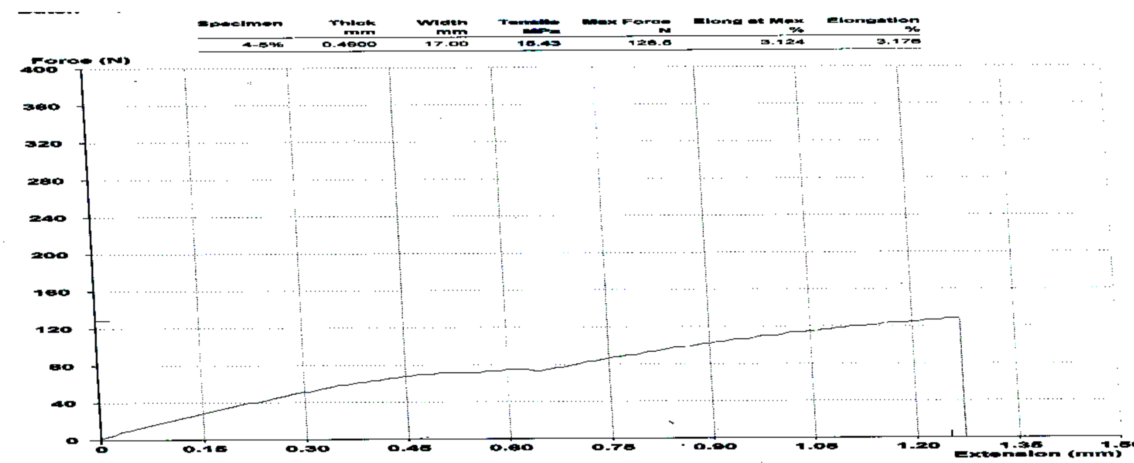

Fig (3) Stress-Strain curves at pure PMMA

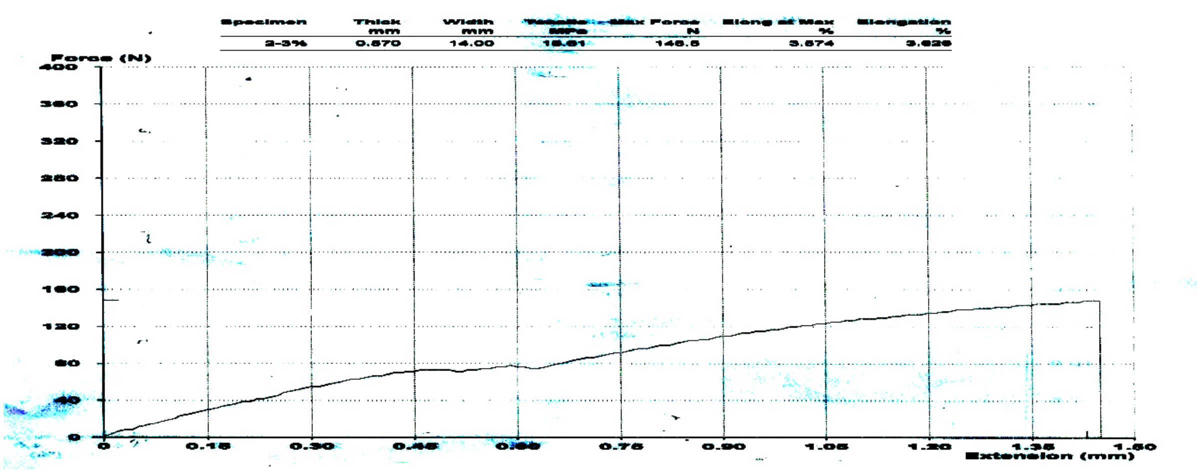

Fig (4): stress-strain curves at PMMA/Graphene at 0.1%

When adding 0.1% Graphene it is clear that lastingness and Young Modulus area unit magnified to sixteen.61MPa and 963MPa severally, magnified the Graphene content in composites at (0.3%, 0.5%) amendment from (19.58- 2290) MPa and (1032-1090)MPa that as a result of Graphene is the stiffest and strongest material ever reported in nature. These outstanding intrinsic properties of graphene or RGO sheets (compared to most compound materials), let alone their massive surface areas, enable them to be the first bearing element of compound composites. However, it additionally shows that the most reinforcement is proscribed by the most possible volume fraction wherever sensible dispersion is maintained. Graphene could be a comparatively high modulus, high lastingness, graphene contains Young's modulus of around 1TPa, associate degreed it additionally has an intrinsic lastingness of one hundred thirty standards that makes it the strongest material thus far [16].

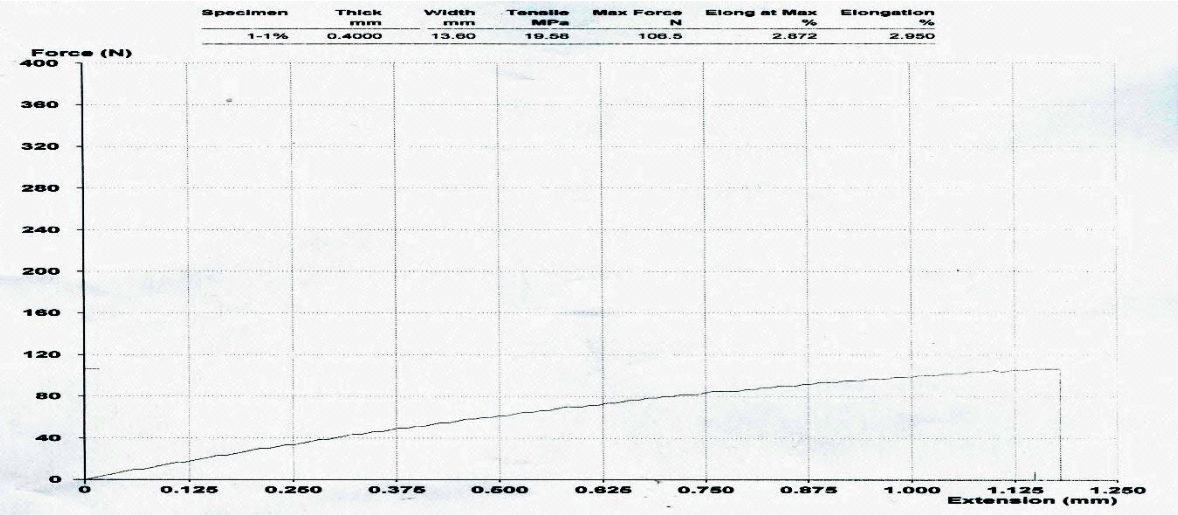

Fig (5): ***stress-strain curves at PMMA/Graphene at 0.3%***

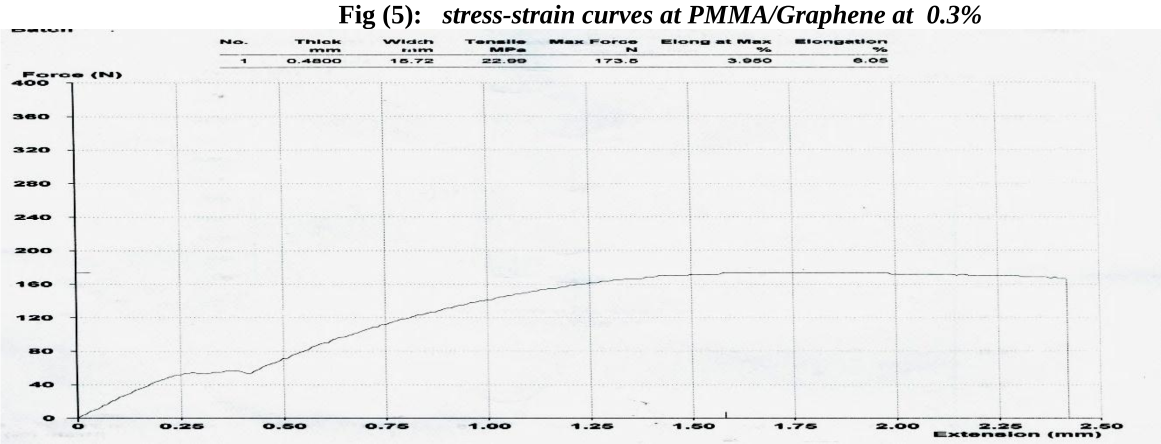

Fig (6): ***stress-strain curves at PMMA/Graphene at 0.5%***

Table (1): Mechanical properties of PMMA, PMMA/Graphene nanocomposites

Samples	Tensile Strength MPa	Elongation %	Young Modulus MPa
PMMA	**15.43**	**3.17**	**945**
PMMA/0.1%graphene	**16.61**	**3.02**	**963**
PMMA/0.3%graphene	**19.58**	**2.95**	**1032**
PMMA/0.5%graphene	**22.90**	**3.01**	**1080**

Fig (4, 5, 6) shows decreased in elongation at the break because of the localization of an almost of graphene in the droplets of PMMA, caused the stability of droplets and prevention of deformation of droplets and that increased the brittle of composites

In Table (2) shows the values of Tear Strength within the film and determines the quantity of energy that every material is ready to soak up before it fails (catastrophic tear growth). normally plastic sheet with a property of crispness can have terribly low tear resistance and accepted that brittle materials absorb lesser energy to fracture than the ductile materials, this is often clearly proved from the Table (2), pure PMMA may be a brittle material it shows tear Strength is eleven.3 mN. it's obvious that the addition of Graphene nanocomposites cut in Tear Strength for (10.6-8.5) as a result of that composites is becoming very brittle that seem in Table (1). The values of hardness calculated by Shore A may be alive of the resistance of cloth to the penetration of a spring-loaded needle-like indenter, pure PMMA is ninety.12 and exaggerated as a result of the massive expanse of Graphene in composites

Table (2): Tear Strength and Hardness of PMMA, PMMA/Graphene nanocomposites

Samples	Tear Strength mN	Hardness (Shore A)
PMMA	11.3	90.12
PMMA/0.1%graphene	10.6	91.40
PMMA/0.3%graphene	9.2	92.70
PMMA/0.5%graphene	8.5	94.67

Electrical properties (D.C Conductivity)

Fig (7) shows the link between the Napierian logarithm of the conduction and also the inverted temperature of the PMMA/Graphene composites, the variation of electrical conduction of pure PMMA at totally different loadings of Graphene. Neat PMMA like different acrylic chemical compound is incredibly insulating and show conduction of 10-11 S/cm. The electrical conduction of PMMA was found to extend, on the addition of Graphene, specified a pointy increase in conduction of the composite was determined between zero.1 and 0.5 nothing (w/w) of Graphene loading which might be attributed to the formation of electrically conducting percolation networks throughout the PMMA matrix.

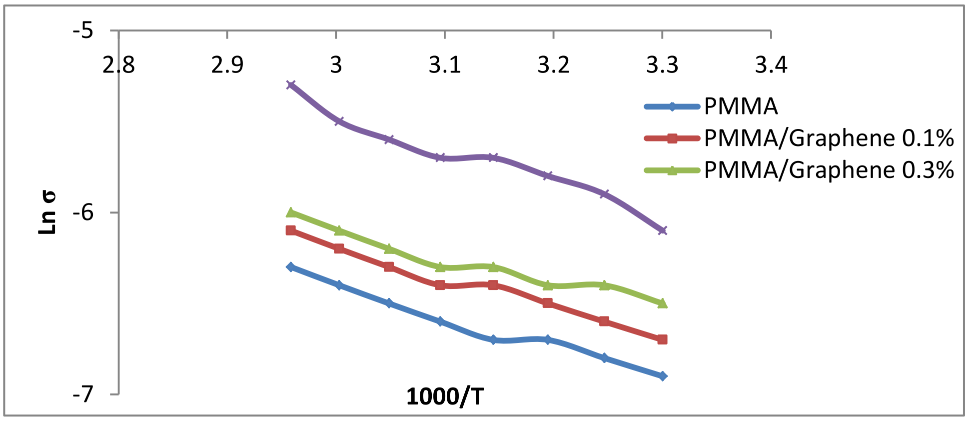

Fig (7) : Electrical conductivity of PMMA and MMA/Graphene nanocomposites

Most polymers behave almost like insulators; thus, the addition of conducting fillers might remodel these insulators into conductors. The conducting fillers like carbon derivatives (GNPs, CNTs, EG, etc.) may well be used for rising the electrical physical phenomenon of chemical compound composites. The percolation theory may well be wont to justify the conduction mechanism of the composites. At the start, the loading of the fillers is low; thus, the chemical compound matrixes dominate the electrical physical phenomenon of the composites, and also the composites behave like insulators. once the loading will increase to an explicit purpose, the electrical physical phenomenon of the composites steeply will increase by many orders of magnitude, and this loading is named because of the percolation threshold. the massive ratio and high electrical physical phenomenon of graphene and its derivatives build it promising semiconducting fillers to enhance the electrical properties of assorted polymers together with PMMATable (3) shows the energy of activation calculated inequivalent (5), the high energy of activation values for pure PMMA and faded at high Graphene concentration sample which will be attributed to the thermal movement of ions and molecules and maybe to the electronic physical phenomenon mechanism that is expounded to the decreasing of the space among the Graphene particles

Table (3): Electrical conductivity values of PMMA, PMMA/Graphene nanocomposites

Samples	Activation Energy (eV)
PMMA	0.68
PMMA/0.1% graphene	0.60
PMMA/0.3% graphene	0.56
PMMA/0.5% graphene	0.41

Thermal Conductivity

Table (4) shows values of thermal conductivity of pure PMMA and PMMA/Graphene composites are 0.2W/m.K and increased to (0.9-2.5)W/m.K because that Graphene is high thermal conductivity is around 5.1×103 W/mK and high specific surface area [16].

Table (4): Thermal conductivity values of PMMA, PMMA/Graphene nanocomposites

Sample	Thermal conductivity W/m.K
PMMA	0.2
PMMA/0.5% Graphene	0.9
PMMA/1% Graphene	1.2
PMMA/3 % Graphene	2.5

The smaller distinction in thermal conduction of compound between (0.1-1) W/m.K and graphitic carbons (MWCNT 3000 and graphene 5000 W/(m . K)) that increased the thermal conduction of composites as a result of thermal physical phenomenon is achieved by phonons and electrons. However, the PMMA compound is Associate in Nursing nonconductor which suggests the electrons won't play a vital role in the thermal physical phenomenon. The physics of phonons (the main heat carriers in graphene) has been shown to be considerably completely different in 2-D crystals, like graphene thanks to graphene sheets could give lower surface thermal resistance and therefore manufacture highly-improved conduction for compound composites even impart important property to the thermal conduction of the compound composite because of the measured in-plane thermal conduction the maximum amount as 10 times on top of the cross-plane conduction.

CONCLUSIONS

The properties of composite materials area unit determined by many alternative variables and study of the mechanical, electrical and thermal properties of the parts that determine properties of the ultimate composite, distributed PMMA/Graphene nanocomposite is ready by casting technique. The Mechanical properties electrical conduction and Thermal conduction of PMMA/Graphene increase and grow considerably with the rise of graphene content of PMMA/Graphene nanocomposite that could be utilized for EMI-shielding applications and electronic application packaging.

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