ISSN: 2277-5528
Impact Factor: 5.085

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & MANAGEMENT

AN ASSESSMENT OF EFFECTIVE THERMAL CONDUCTIVITY OF EPOXY-TiO2 COMPOSITES

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ABSTRACT

The improvement of microelectronic gadgets like PCB, electronic bundling and so forth requires high warm conductivity materials for manufacture. This incite the necessities of improvement of particulate filled polymer network composites (PMCs) that have high warm conductivity. This examination gives a potential material framework to address this issue. A logical model is proposed to appraise the viable warm conductivity of polymer composites loaded up with cubical particulate fillers. By utilizing the scientific relationship created by this model, viable warm conductivity is determined and contrasted and values acquired from models by past creators in such manner for various volume portions (13.4 and 26.8 vol %) of cubical molded TiO_2 particulates. Unitherm TM 2022 analyser is utilized to gauge the successful warm conductivity (keff) of epoxy-TiO_2 composite for these volume part according to ASTM E-1530. These estimations of successful warm conductivity (keff) acquired from the test are contrasted and these model created in past writing and the proposed model. It is discovered that the estimations of viable warm conductivity determined by proposed model are close to the trial estimations of successful warm conductivity.

Keywords- PMCs, particulates, effective thermal conductivity, volume fraction.

Introduction

Power thickness of the electronic gadget is very high which causes the age of warmth inside the electronic part. Consequently it is required to divert the warmth from the electronic segments and keep the gadget by keeping up the temperature lower than the basic qualities [1]. Generally heat sink which were metal based and having staggering expense were utilized to disperse the warmth produced inside the part which are not adequate these days in light of warm cracking[2]. Additionally the heaviness of these gadgets is likewise the fundamental thought. Low weight electronic gadgets are the principle prerequisite in this day and age in order to convey them from one spot to other spot. These necessity prompted increment in the interest of superior miniaturized scale electronic gadgets implementing for the prerequisite of the headway in the advancements in regards to electronic bundling. The wide utilization of electronic and electrical innovations and their gadget requires the better small scale electronic bundling. Miniaturized scale electronic bundling is the multi-discipline subject in the field of electronic designing. It considers such a significant number of issues like cost, mechanical properties, heat exchange attributes, unwavering quality and so forth [3]

Polymers and earthenware production are commonly sought after for bundling materials in light of their better mechanical, electrical and warm properties [4]. For the most part accessible polymer for bundling material are polypropylene (PP), polyethylene (PE), polyamide (PA), epoxy, polyimide, However, normal polymers for bundling, for example, polyester, polyethylene (PE), acrylonitrile-butadiene-styrene (ABS)etc. They have less warm conductivities and high coefficient of warm development (CTE) in this manner they can't give viable warmth stream which prompted warm disappointment.

It is constantly requested in the realm of progression to supplant existing materials by cutting edge material having better properties to accomplish the new necessities. The utilization of bigger molecule and surface treated filler brought about composite materials with improved warm conductivity. Carbon based filler material additionally utilized as filler material [5, 6], however they couldn't give attractive outcomes on account of warm conductivity. Fired filler materials like SiC, Al_2O_3, Si_3N_4 and so on additionally builds the warm conductivity. Joining of metallic powder likewise builds the warm conductivity of composite [7-9] yet it is discovered that load of the composite material may likewise expands more than required. Additionally with the utilization of metallic powder electrical conductivity likewise builds which isn't required at times. Generally utilized metal based metal amalgams like copper, aluminum and all other metal combination are not ready to have capacity to be utilized in electronic bundling [10], along these lines polymer composite material appeared to deal with such issues. For creation of such particulate filled polymer composite the attributes like low material thickness, low coefficient of warm extension, low electrical conductivity, higher warm conductivity and so on are mulled over [11].

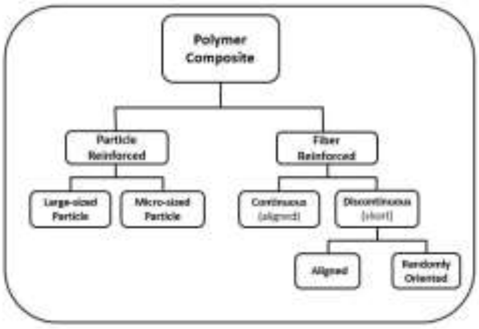

Figure 1 Classification of Polymer composites based on reinforcement

MATERIALS

By and large utilized framework material are metals, earthenware, carbon and polymer. The most regularly utilized grid material is Polymer because of its beneficial over other material like viable cost, effortlessness in manufacture of complex structure parts with minimal effort instrument, stable at lifted temperature and so on. Polymer network are available in either be in thermoplastic nature or in thermoset nature. In thermoset nature, cross-connected polymer lattice are framed by irreversible synthetic change of tar. It has huge atomic structure as a result of which it gives both warm and electrical protection. It has less consistency, high warm dependability and high killjoy obstruction [131]. Polyester, phenolic sap, vinyl ester and epoxy are the for the most part utilized thermoset.

In thermoplastic polymer intermolecular powers grants it to be remolded. All things considered the communication between the particles increments with cooling and therefore again reestablish its mass properties. The generation of these thermoplastic polymer are in one stage. They can be reused and reused. Due to their, such properties they are for the most part utilized in the modern application. Teflon, polyethylene, polypropylene, polyvinyl chloride, nylon and acrylic arte the most normally thermoplastic polymer found in market.

Epoxy are most broadly utilized polymer network because of its effectively accessibility, better mechanical and warm properties over other polymer, great attachment properties to various strands, synthetic opposition and better execution at higher temperature. Epoxy LY 556 gum is utilized as a grid material which by and large artificially has a place with epoxide family. The regular name of this material is Bisphenol-A-Diglycidyl-Ether. Epoxy is picked in light of the fact that it has low thickness (1.1gm/cm3) and it is most normal utilized thermoset polymer and substance safe. It is utilized with its comparing hardener HY 951. It has low warm conductivity (0.363W/mK)

Table 1 Properties of Epoxy

Properties	Values
Density (gm/cc)	1.1
Thermal conductivity (W/mK)	0.363

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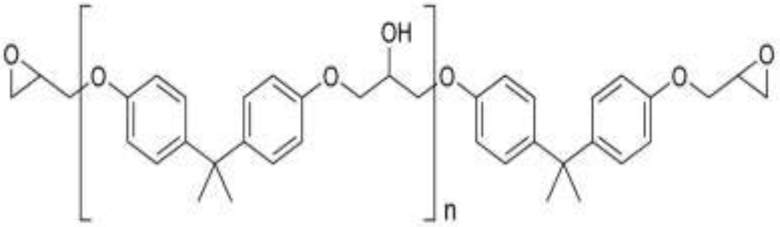

Figure 2 Epoxy resin chain

Figure 3 Epoxy resin and its corresponding hardener

FILLER MATERIAL (TIO2)

Miniaturized scale measured TiO2 is utilized as a particulate filler material for the manufacture of warm conductive PMCs in this work. It is found in the nature as anatase, brookite, and rutile as oxide of titanium. Ilmenite is the fundamental wellspring of TiO2. Ilmenite metal is copious type of TiO2 and next is Rutile. The anatase and brookite are the metastable stages and by them, they can be changed over into rutile. Miniaturized scale measured titanium dioxide (TiO2) is utilized as the filler material. It is favored over other material because of Moderate warm conductivity (12 W/m-K), Low electrical conductivity, and Low coefficient of warm extension

Table 2 Properties of TiO2 (filler material)

Properties	Values
Density (gm/cc)	1.6
Thermal conductivity (W/mK)	0.363

Figure 4 TiO2 Filler material

EXPERIMENTAL DETAILS

Composite Fabrication

TiO2 filled Epoxy composites (Hand lay-up technique):-

Polymer matrix (epoxy) Composite filled with TiO2 sample is fabricated by hand lay-up technique which is the quite old but very simple technique.

The fabrication of epoxy-TiO2 composites is done in following manner

Polymer matrix (epoxy) Composite filled with TiO2 sample is fabricated by hand lay-up technique. Epoxy LY 556 resin cured at Low temperature taken as matrix material along with the hardener (HY951). These both are mixed in the ratio of 10:1 by weight as mentioned. Epoxy having low density (1.1 gm/cc) and low magnitude thermal conductivity (0.363 W/m-K). Micro-sized particulates of TiO2 are mixed in this epoxy resin to make the composites. This

dough (epoxy filled with titanium oxide) is then slowly pour off into the cylindrical glass to get the composite specimen having disc shape The castings are kept at room temperature for around 26 hours to sustain complete polymerization, then from the glass moulds samples are taken for further testing of thermal conductivity of this fabricated sample.

Table 3 Set of Epoxy-TiO2 composites

Composition
Epoxy + 0 vol.% TiO2
Epoxy + 6.7 vol.% TiO2
Epoxy + 13.4 vol.% TiO2
Epoxy + 26.8 vol.% TiO2
Epoxy + 40.2 vol.% TiO2

Process illustrate the fabrication of Epoxy-TiO2 composites by hand lay-up technique is shown in figure 3.5 and figure 3.6 shows the samples of fabricated composites.

EXPERIMENTAL MEASUREMENT

Unitherm^{TM} 2022 tester is used to measure the effective thermal conductivity (keff) of epoxy-TiO2 composite for these volume fraction as per ASTM E-1530. In this tester the sample is held in between the upper and lower plate held at some temperature gradient under a uniform compressive load. The lower plate contains the transducer. The heat flows from the upper plate to lower plate. The temperature gradient is recorded by sensors accompanied with the output heat flow from the heat transducer. These results or output from the tester are used to calculate the thermal conductivity of samples by Fourier's law of heat conduction.

Figure 5 Unitherm^{TM} Model 2022 Tester

RESULTS AND DISCUSSION

Effective thermal conductivity of Epoxy- TiO2 composites

Effective thermal conductivity of Epoxy-TiO2 composites is calculated by the equation provided above for different loading of volume fraction of particulate. These value are calculated for distinct volume fraction of 0%, 6.7%, 13.4%, 26.8% and 40.2%. The values obtained are 0.363W/m-K, 0.6185W/m-K, 0.8269W/m-K, 1.406 W/m-K and 2.72 respectively for these volume fraction For volume fraction of 13.4% and 26.8%, these value of *k*eff of obtained from this proposed model, are shown in figure 4.1 and figure 4.2 along with the magnitude of *k*eff for previous models and correlation. Each of these figures fig. 4.1 and fig. 4.2 gives the comparison of theoretical value of *k*eff among proposed model, all previous model and experimentally measured values.Also the percentage error between the theoretical models and experimental value is provide in the table. These comparative results provided in the table are illustrated graphically for their comparison with experimental values. The observation are carried out with the help of these graphs and discussion is done based on these results for the validation of this model.

Table 4 Comparison of keff for distinct model for 13.4 % of filler volume fraction (kexp = 0.739W/m-K)

Co-existing Model	*keff* (W/m-K)	Percentage error (%)
Proposed Model	0.82609	11.89
Maxwell Model	0.5150	30.31
Rules of mixture Model	0.4172	43.54
Lewis & Nielson Model	0.5265	28.75
Rayleigh Model	0.40259	45.52

Table 5 Comparison of keff for distinct model for 26.8 % of filler volume fraction (kexp = 1.232W/m-K)

Co-existing Model	*keff* (W/m-K)	Percentage error (%)
Proposed Model	1.406	14.12
Maxwell Model	0.71469	41.89
Rules of mixture Model	0.4904	60.19
Lewis & Nielson Model	0.7806	36.63
Rayleigh Model	0.70422	42.83

The effect of filler content is seen through the figure 4.3 which discus about the variation of thermal conductivity of epoxy-TiO2 composites with the variation of volume fraction of TiO2 particulate

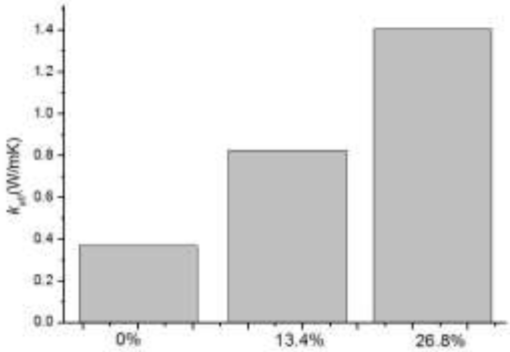

Figure 4.3 Comparision of effective thermal conductivity of Epoxy-TiO2 composite at different volume fraction

The Comparison among the theoretical and experimental value of effective thermal conductivity shown in the Table 4.3 and figure 4.4 for different volume fraction of TiO2 particulate. The gap between these theoretical and experimental values shows the percentage error in the theoretical value to the experimental value of effective thermal conductivity of epoxy- TiO2 composite.

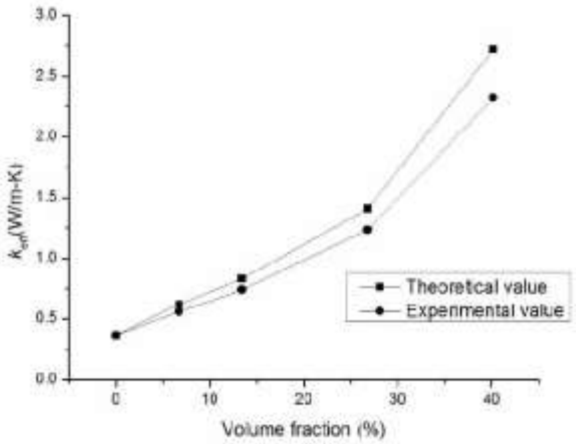

Figure 4.4 Comparision of theoretical and experimental *keff* of Epoxy-TiO2 composite

OBSERVATIONS

These results gives the following observation:

1) With increase in the TiO2 content in the composite the effective thermal conductivity improves quite notably. This indicates that the incorporation of micro sized TiO2 helps in the enhancing the heat conduction capability.
2) The mathematical correlation proposed by previous investigators are found to be underrating the value of effective thermal conductivity and the deviation from the measured value are large.
3) The correlation proposed in this work provide value of effective thermal conductivity for different volume fraction of particulates are found to be in good consensus with the measured value as illustrated.
4) There is increase in the gap in-between the theoretical and experimental lines of magnitude of effective thermal conductivity.

CONCLUSIONS

The present analytical and experimental work has led to the following conclusion:

1) Successful fabrication of epoxy composites steel-clad with micro-sized TiO2 particulates is possible by hand lay-up technique.
2) With addition of these TiO2 particulates, heat conduction capability of epoxy is notably increased.
3) A mathematical correlation has been developed by taking the one-dimension heat conduction across the cube-in-cube three-dimensional physical model to estimate the effective thermal conductivity.
4) It is seen that the effective thermal conductivity of such particulates filled composites is a function of filler content and of the intrinsic properties of filler and matrix materials.
5) The correlation is validated by conducting laboratory scale measurement of effective thermal conductivity of these composites and then by comparing the test result.
6) It is found that the results obtained with the addition of 6.7%, 13.4%, 26.8% and 40.2% the thermal conductivity increases by 53%, 103%, 238% and 552% respectively.
7) It is also found that the results obtained from the proposed correlation are in very good agreement with the measured value.
8) With the increase in the filler content, the percentage error increases in the measurement of effective thermal conductivity. This increase in the error is due to the domination of increase in the thermal contact resistance over decrease in the thermal resistance of composites.

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