A Study on Thermal Characteristics of Polypropylene Composites with Addition of Fillers

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Abstract- The report regards the heat transfer in the polymer composites of solid glass micro-spheres (SGM) or hollow glass micro-spheres (HGM) filled with polypropylene (PP). The net effective thermal conductivities (Keff) of the polymer composites of PP and SGM or PP and HGM are estimated by analytical integral approach and its result was compared with ANSYS model and existed theoretical models. It was observed that the effect of thermal insulation in hollow glass spheres filled polypropylene composites is more than the solid glass spheres filled polypropylene composites and the net effective thermal conductivity (Keff) is linearly decreases with increases of volume fraction (φf) of filler and then decreased somewhat with increasing filler diameter. It was found that the analytical model is very close to ANSYS model and existing analytical models. Furthermore, the net effective thermal conductivity (Keff) of the three dimensional (3D) ANSYS model is lesser than two dimensional (2D) ANSYS model i.e. 3D ANSYS model is fairly closer with the experimental data than 2D ANSYS model. With improved insulation capability and light weight of composites, the solid glass micro spheres (SGM) and hollow glass micro-spheres (HGM) inserted polypropylene composites can be utilized in areas such as building materials, aviation industry and space flight, insulation boards, thermo flasks, food containers etc. Some other properties changed like enhanced wear resistance, increased reflective index, decreased coefficient of thermal expansion and increased the glass transition temperature. Out of the five arrangements, the best thermal performance was given by hollow glass microsphere whose thermal insulating property is better than solid glass microsphere.
Keywords: Polymer composites, PP, SGM, HGM, volume fraction, Thermal characteristic.

I. INTRODUCTION

Now a day, polymer composites are the most replacing materials in different structural and engineering utilizations. They have been widely utilized industrial applications, space craft uses due to their low density, good specific strength, good modulus and good wear resistance (Hutchings, 1992). Due to they have less weight, those are most preferable material in sensitive weight utilizations. Sometimes their use restricted in general applications due to their high cost. By using easily available and low cost fillers having improve properties, they can decrease the overall cost of components (Unal et al., 2003; Kranthi and Satapathy, 2010;). Metal particulates or ceramic like hard particulates are used now a day, due to their thermal resistance and good wear resistance of the polymer (Gregory et al., 2003). Addition of such reinforced fillers in polymer materials for the use of domestic applications is mainly focused at the cost decrease and the stiffness betterment (Rothon, 1999). Many researchers (Nayak et al., 2010; Suresha et al., 2010; Bahadur & Schwartz, 2001 and Mohan et al., 2011) have presented that the thermal resistance and wear resistance is improved of polymers due to addition of filler particulates.

In last two decades, it has been emerged as subject of most research by ceramic mixed polymer composites. In this current work, my objective is to explore the potential of Solid glass micro spheres (SGM) and Hollow glass micro- spheres (HGM) as are filling materials in polypropylene polymer composites and investigate its thermal characteristics of result composites. In this work an attempt has been taken to find a useful use of SGM and HGM as particulates filler in polymer composites for the development of thermal resistant composites.

Solid glass micro spheres (SGM) and hollow glass micro spheres (HGM) contain outer stiff glass, by which we got some useful properties as light weight, low thermal conductivity, high strength, wear prevention and resistance to salt or organic solvent . Due to having these properties , SGM and HGM have been used for different applications in polymer composites (Khamis and Kim, 2001; Liang, 2002; Zhao, 2007; Liang, 2005). They have other properties like low moisture absorption, high specific compressive strength and high thermal stability, due to these properties they more suitable for marine and aeronautical applications (Wouterson et al., 2004; Khamis &Kim, 2001; Nagorny & Gupta, 2006, Plubrai & Kim 2004).

II. BACKGROUND

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Plubrai & Kim[2018] Solid glass micro spheres (SGM) and hollow glass micro spheres (HGM) have require able thermal properties with high softening point (glass transition temperature), low coefficient of thermal expansion, high resistance to water attack, acids attack, halogens, salt and organic solvents.

Kranthi, G. & Satapathy, A. [2017] Inspired by the biological nervous system, an artificial neural network (ANN) approach is a fascinating computational tool, which can be used to simulate a wide variety of complex engineering problems such as tribo-performance of polymer composites. This paper, in this context, reports the implementation of ANN in analyzing the wear performance of a new class of epoxy based composites filled with pine wood dust. Composites of three different compositions (with 0, 5 and 10 wt.% of pine wood dust reinforced in epoxy resin) are prepared. Dry sliding wear trials are conducted following a well-planned experimental schedule based on design of experiments (DOE).

Gregory, S.W., Freudenberg[2016] A solid lubricant composite material was made by compression molding PTFE and 40 nm alumina particles. Prior to compression molding the constituent powders was blended using a jet milling apparatus? Composites from 0 to 20 wt. % were prepared. These composites were tested against a polished stainless steel counter face on a reciprocating tribometer. The experimental conditions were a contact pressure of 6.4 MPa, a stroke length of 50 mm, and a sliding speed of 50 mm/s.

III. PROBLEM IDENTIFICATION

(i) Most of the investigations are aimed at enhancing the heat conductivity of the polymer by adding conducting filler rather than attempting to improve its insulation capability.
(ii) Most of the works reported on thermal conductivity of particulate filled polymers are experimental in nature and reports available on numerical and analytical models are few.
(iii) Most of works have done on solid glass micro spheres (SGM) but very less work have done on hollow glass micro spheres (HGM).

IV. RESEARCH OBJECTIVE

(i) Explore the potential of Solid glass micro spheres (SGM) or Hollow glass micro spheres (HGM) as are filler materials in polypropylene polymer composites.
(ii) A theoretical model is developed for the estimation of Effective thermal conductivity of particular filled reinforced composites.
(iii) Estimation of effective thermal conductivity of such particulate filled polymer composites using Finite element method (FEM).Fabrication of different sets of PP composites filled with SGM or HGM.
(iv) Validation of the proposed theoretical analytical model by comparing with ANSYS result of FEM model and existing theoretical models. Comparing 1-D heat transfer with 3-D heat transfer.

V. METHODOLOGY

The calculation of actual properties of the composites is of main important for better design and utilization of the Composite materials. Micro structural properties of composites are essential thing which affect the effective properties of composites. Micro structural means size, shape, orientation and spatial distribution of embedment of matrix. arrangement is shown in below fig. The boundary conditions and the heatflow direction for conduction is shown in the below fig. Here the temperature at top face is 100^0c, convection heat transfer occurs at the bottom face having convection heat transfer coefficient is $25W/m^2$-K and other four faces are insulated. The temperatures on other boundaries and at inside domain are not arrested.

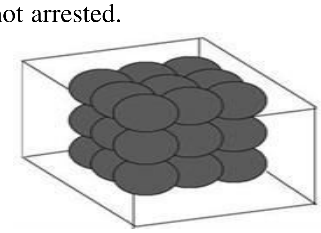


Figure 1: Schematic Presentation of Solid Micro Glass Spheres

GOVERNING EQUATIONS

Analytical model for determination of the net effective thermal conductivity (Keff)

Values of the net effective thermal conductivity of the above PP composites of different filler percentage have been estimated analytically by using the Eqn. given below. It is derived on one dimensional (1D) conduction model by integral approach. The assumptions that have taken to solve this Eqn. are
(i) Heat flows only one direction i.e. other four faces are insulated.
(ii) Both the boundary surfaces are at uniform temperatures throughout the surfaces.
(iii) Heat flows perpendicular to the surfaces.
(iv) Composites are homogeneous in macroscopically.
(v) Both filler and matrix isotropic in locally.
(vi) Contact resistance between matrix and filler material neglected.
(vii) No void inside the composites is assumed.
(viii) Uniformity in distribution of filler inside the matrix in a periodic manner.

VI. RESULTS AND ANALYSIS

Net Effective thermal conductivities (Keff) of polypropylene and Solis glass micro spheres composites are estimated numerically by help of spheres in cube model. Different temperature profiles have been obtained from analysis of FEM of composites of polypropylene and SGM of 100 µm size having different volume fractions .05%, .42%, 1.41%, 3.35% and 5.23% as shown below.

Table 1: Thermal Conductivity(K_{eff}) of SGM

SGM (vol %)	K_{eff} (W/m-K)
0	.2
.05	.1998
.42	.199
1.41	.196
3.35	.192
5.23	.188

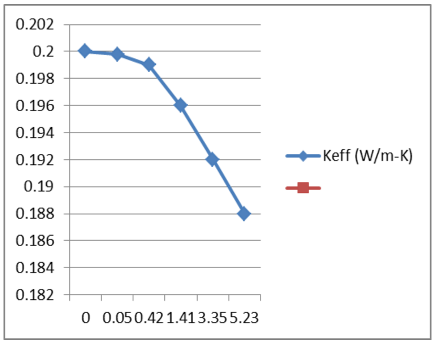
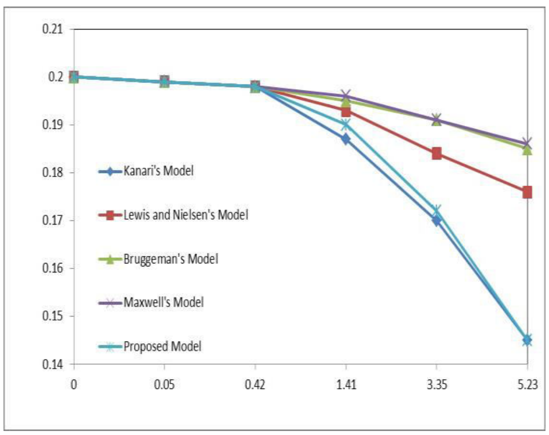


Figure 2: Proposed Model.

From the above fig. it is observed that the



temperature variation between the top and bottom surface areas of the cubes increases with volume fraction percentage of the SGM. It is because of opposition of heat flow by the micro glass spheres along the conduction way. The above table and above fig. represent the variation of Keff with SGM content in composites obtained from finite element method. It is noticed that, with increase in filler percentage in the composites, the value of Keff decreases gradually. By addition of 5.23% of solid glass micro sphere, the net effective thermal conductivity of polypropylene composites decreased by 6% and by addition of 3.35% of SGM, thermal conductivity decreased by 4%.

THEORETICAL MODEL FOR DETERMINATION OF EFFECTIVE THERMAL CONDUCTIVITY (KEFF)

Below table represents the values of the net effective thermal conductivities (Keff) of composites of PP- SGM obtained through proposed theoretical model with different volume percentage of SGM and results obtained through ANSYS by finite element model models.

By the help some existing theoretical models, I have calculated the effective thermal conductivity of polypropylene composites with SGM concentration varying from 0 to 5.23 vol.

From the above comparison, I found that the effective thermal conductivity of proposed model is fairly closed to Kanari's Model, which is revised of Bruggmen's model. Thus it is noticed that proposed mathematical model is an acceptable theoretical model for 1-D analysis of composite materials.

Below fig. represents the comparison of the net effective thermal conductivities (Keff) results obtained through proposed theoretical model and results from FEM simulation of composites having different volume concentration. From the graph it is found out that the values of effective thermal conductivity of proposed theoretical model is fairly closed with the FEM model. But with higher percentage of SGM the FEM model deviates from proposed analytical model, because it is difficult to find the effective node in ANSYS due to course meshing.

VII. CONCLUSIONS

For finding out the effective thermal conductivity (Keff), there are two theoretical correlations of solid glass microspheres (SGM) and hollow glass microspheres (HGM) filled polymer composites are presented based on 1-D heat conduction models development. It is found out that, theoretical mathematical models represents as very good acceptable empirical models for the spherical (solid and hollow) inclusions and the derived relations from proposed mathematical models can be used very well to calculate Keff for composites. The output of numerical simulations drew the following conclusions

(i) It is propitious that with addition of SGM and HGM in PP matrix material, thermal insulating ability of polypropylene composite increases significantly. It is noticed that with increase in reinforced filler SGM and HGM contents, the value of net effective thermal conductivities decreases.

(ii) With the addition of hollow glass microspheres (HGM) in polypropylene composites, the net effective thermal conductivities (Keff) of composites decreases more than the incorporation of solid glass microspheres(SGM).
(iii) The results revealed that the hollow glass microsphere have better heat insulating performance than the solid glass microsphere. Similar results were also observed by khamis and kim in their experimental work.

Since, it was observed that hollow glass microsphere has better thermal insulating property than solid glass microsphere, hence it would be interesting to conduct research work on metal and ceramic based composites like silicon carbide, alumina and mullite. The present work is expected to be very helpful for carrying out the new future project.

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