Enhancement of Thermal Conductivity of Polymer Composites

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ABSTRACT

Thermal management is the important topic while considering performance, life and reliability of electronic devices. Now a day, Thermal dissipation becomes a most crucial and challenging problem. Also, in case of heat exchangers use of metallic component increases weight and manufacturing cost To deal with such challenges, it is necessary to develop polymer composite materials with enhanced thermal conductivity. In this review, different combinations of polymer composite and fillers are taken such as MWCNT/PP, MWCNT/HDPE, Cu/PP, Cu /HDPE. The key factors influencing the thermal conductivity of polymers, such as crystallinity, orientation of polymer chains, properties of thermally conductive fillers such as carbon nanotubes, metal particles, and ceramic particles in boron nitride, polypropylene and HDPE domain with length are discussed. The dependence of thermal conductivity of composites on the filler loading, filler morphology is also discussed. The review also summarizes some emerging applications of thermally conductive polymer composites. Finally, we look for the challenges and lookout for thermally conductive polymer composites

Keywords: Polymer Composite, Thermal Conductivity, Ball Milling

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1.1 INTRODUCTION

Recently, the interest for the usage of materials having low cost, low weight and high strength is increasing. In addition, environmental pollution is currently being discussed as one of the most demanding issues in materials development.

Thermal conductivity has become an important parameter for new technologies, especially in aerospace and aeronautics. The advanced materials used in some electronic applications tend to undergo an increase in temperature when they are used. Increasing the thermal conductivity of a material will help to dissipate heat faster to avoid substantial overheating which may damage the system or may cause fire. Also for transfer of heat energy in case of heat exchanger, it is necessary to find alternative for metallic material which increases weight and manufacturing cost [3]

In everyday life, heat and temperature are commonly used but these two concepts should be distinguished from a scientific perspective Heat, which is directly related to the thermal conductivity, which is defined as the thermal energy transfer from a particle to its adjacent particle and temperature tells us how much particles are vibrating and heat evaluates how much of this energy is transferred, how fast and in what direction.

Fig.1.1.1 Second law of thermodynamics [4]

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1.2 THERMAL CONDUCTIVITY

Heat transfer can occur through radiation, convection or conduction It has been established that thermal conduction corresponds to the transfer of a particle's vibrational energy to adjacent particles without any motion of the matter, mainly by collision

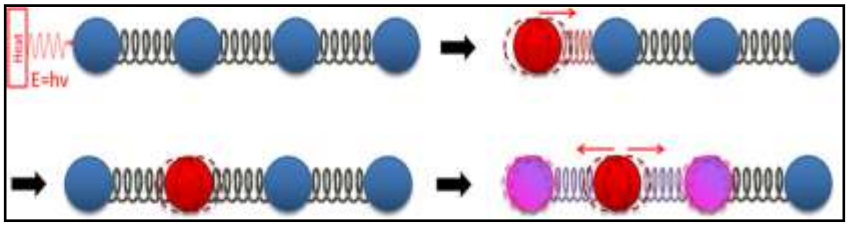


Fig.1.2.1 Thermal conductivity by collision of particle [4]

For one-dimensional, steady state heat flow, the heat conduction rate is expressed by Fourier's equations [5]

$q = kA\Delta T/L$ ….(1.1)

$J = q/A = -k\, dT/dx$ …(1.2)

Where q is rate of heat transfer (W); J is heat flux (W/m2), k is thermal conductivity W/(m K); A is cross sectional transfer area (m2); dT is temperature difference (◦C); L is conduction path length (m).

1.2.1 THERMAL CONDUCTIVITY OF POLYMER COMPOSITES

The thermal conductivity (TC) of polymers (usually rep-resented by Greek letter *k* or Latin lowercase k), can be obtained from the Debye equation, [4]

$k = Cp\mu l/3$ …..(1.3)

Where Cp is the specific heat capacity per unit volume, µ is the phonon velocity, and l is the phonon mean free path.

Most polymers have a low Thermal Conductivity in the range of 0.1–0.5 W/(m K), which is not sufficient for many applications that require high heat conduction However, polymers have the advantages of good processability, lightweight, low water absorption, high electrical resistivity, high voltage breakdown strength, corrosion resistance, and most importantly, low cost. Polymer-based thermally conductive materials are therefore often desired in many applications.

1.2.2 ROLE OF FILLER MATERIAL IN POLYMER COMPOSITES

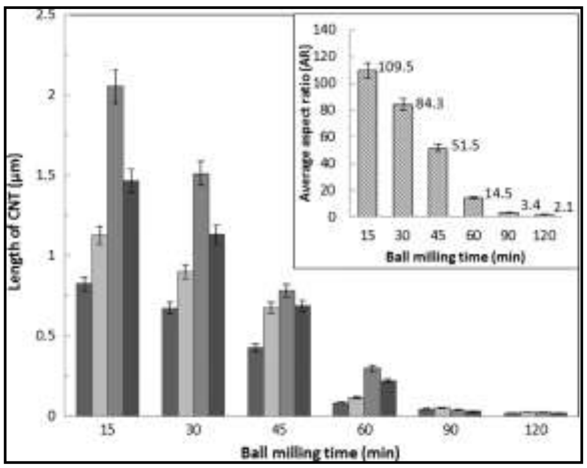
Typically, heat conductive fillers, such as aluminium oxide, boron nitride, aluminium nitride, silicon nitride, diamond, graphite, metal particles, carbon nanotube, graphene, etc., are introduced into polymers to increase thermal conductivity. For applications that require both high TC and electrically insulating properties, electrically insulating fillers, such as aluminium oxide, boron nitride, aluminium nitride, etc. can be used, while graphite, metal particles, carbon nanotube, and graphene are often utilized in applications where electrical insulation is not required. Also, length of MWCNT polymer filler have a great influence on thermal conductivity of polymer composites **Hyun Su Kim, Jung Hyun Na, Yong Chae Jung, Seong Yun Kim** introduced one new expanded graphite filler EG is considered as an effective filler for improving the thermal conductivity of composites owing to its unique structure of graphite sheets with interlayer spacings. It can efficiently fill polymer matrix and form thermal transfer pathways. [2]

1.2.3 COMBINATIONS USED FOR TESTING

1. **Polypropylene and MWCNT**
2. **HDPE and MWCNT**
3. **Polypropylene and Cu powder**
4. **HDPE and Cu powder**

1.3 Ball milling process:-

To find variation in thermal conductivity according to length and shape of particles, MWCNT &Cu powders were ball milled The volume of the ball mill jar is 1 L, and the impeller length is 75 mm. The milling balls are made of zirconia (ZrO_2) with a diameter of 5 mm, and the ball milling was done with powder-to-ball mass ratio of 1:20. To prevent excessive temperature rise during ball milling, cooling water was supplied into the jacket of the milling jar. Also, to prevent the samples from oxidizing, the sealed mixing jar was filled with Argon gas. Since MWCNTs are lighter and smaller than metallic particles, MWCNTs should be processed at lower speed than Cu powder as it gets easily oxidised



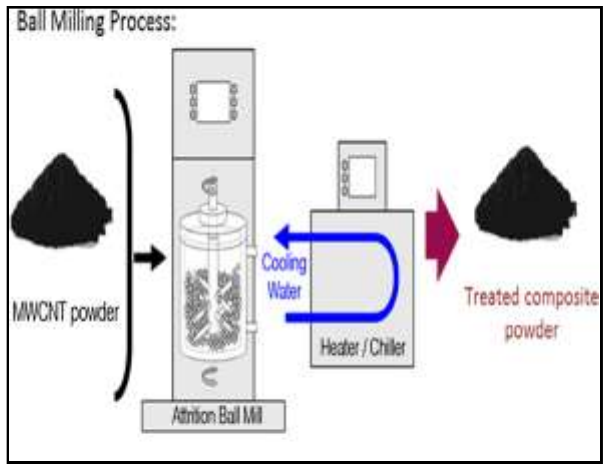


Fig.1.3.1 Length of CNT vs. Ball milling time [3]

Fig.1.3.2 Ball Milling Process [3]

1.4 COMPOSITE PREPARATION

Composite is fabricated by melt blending process Initially polymer is melted ,fillers added and mixture is prepared using internal mixture This process is performed at 300℃ Hot pressing is done to form specimen of desired shape

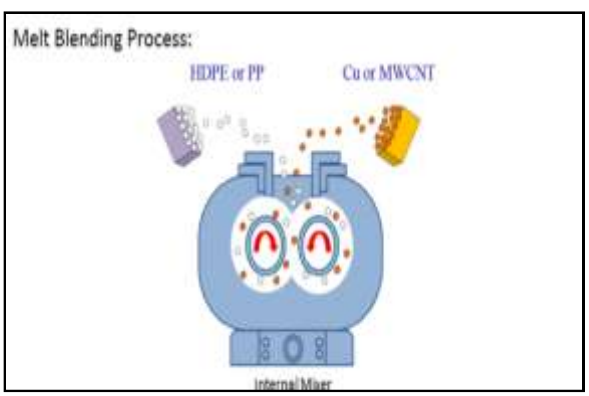


Fig.1.4.1.Melt Blending Process [3]

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1.5 THERMAL CONDUCTIVITY MEASUREMENT

Thermal conductivity is measured using laser flash method. It measures temperature rise at opposite side of sample with time using infrared detector

$\alpha(T)=0.1388.l^2/t$ .....(1.4)

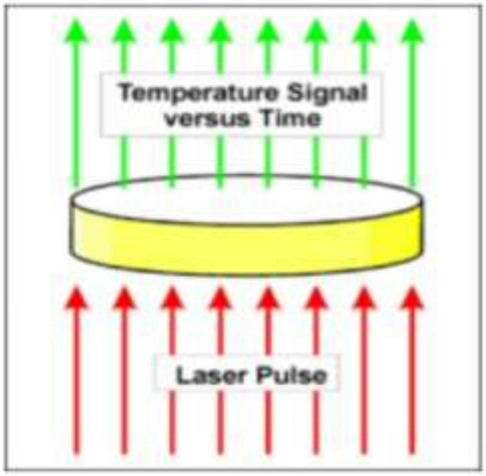

Fig1.5.1 Laser Flash Method [3]

1.6 BEHAVIOUR OF MWCNT COMPOSITE WITH BALL MILLING TIME

- As ball milling time increases, MWCNT length decreases
- It improves dispersion of CNTs in composite, which facilitate movement of energy carriers
- The structural transformation occurs, which changes the aspect ratio(length/weight).
- As a result ,thermal conductivity increases with ball milling time At particular instant ,it reaches to maximum value That value decreases further [3]

1.6.1 BEHAVIOUR OF MWCNT WITH PP

- At 45 minutes, maximum value of thermal conductivity is reached
- That value is in between 0.5 to 0.6 W/mK

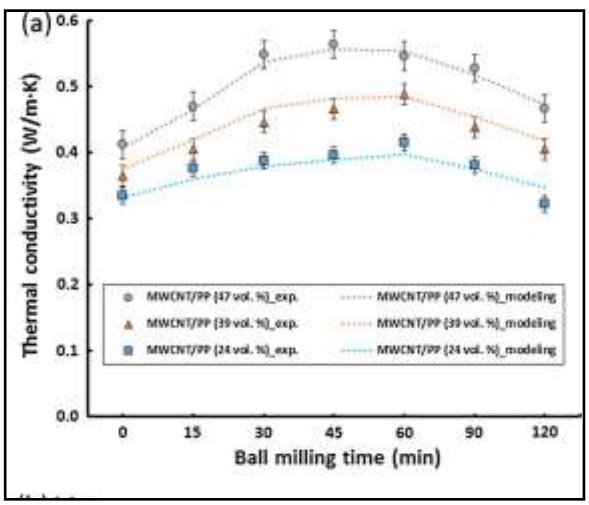

Fig.1.6.1 MWCNT/PP [3]

1.6.2 BEHAVIOUR OF MWCNT WITH HDPE

- At 60 minutes, maximum value of thermal conductivity is reached
- That value is in between 0.8 to 0.9 W/mK

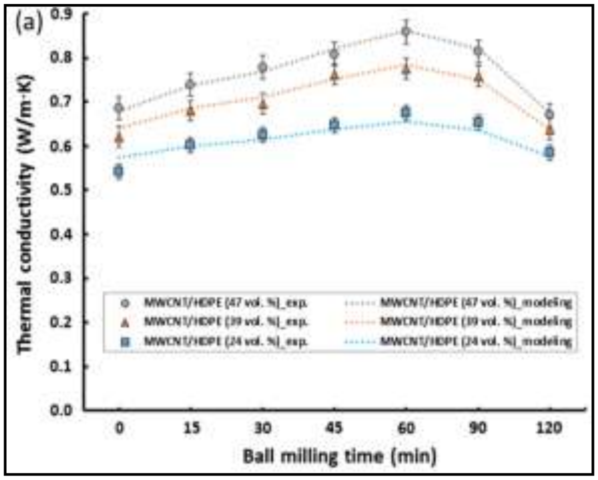

Fig.1.6.2 MWCNT/HDPE[3]

1.7 BEHAVIOUR CU/PP AND CU/HDPE

- In case Cu filler, particles become flat as the time proceed, surface area increases
- It promotes movement of heat carriers(phonons) Thus, thermal conductivity increases up to 60 minutes
- Further there is a decrease in value

1.8 APPLICATIONS OF THERMALLY CONDUCTIVE POLYMER COMPOSITES

Nowadays, with the increasing cooling demand in emerging industries, new thermally conductive materials are in high demand Polymer composites have following features [5]

(a) Electrical insulation and electrical conduction can be controlled via selecting appropriate fillers
(b) Light weight.
(c) Corrosion resistant
(d) Vibration damping due to resilience of polymer composites.

Some emerging application areas of thermally conductive polymer composites:

1. **LED devices**- 70% energy in LED devices is transformed into heat. Such large quantity of heat can significantly influence the LED's performance; therefore, a good thermal management system for dissipating the heat from inside of the LED package to the surroundings is very important.
2. **Heat Exchanger-**It is used as alternative material for metallic component, which reduces weight and manufacturing cost of system
3. **Electronic packaging**-There should be effective thermally conductive path for heat dissipation and eliminating hot spots in electronic parts which maintains temperature of component in specific range
4. **Solar-**Mostly in photovoltaic cell absorbed solar energy converts into thermal energy within the cell .It is well known that the solar conversion efficiency of the PV cells decreased with the rise of its operating temperature thus for fast cooling polymer composite are used

CONCLUSION

In this review, we discussed the research progress on thermally conductive polymer composites and their applications. Also we have discussed and propose the fabrication of thermally enhanced composites as influenced by the different manufacturing conditions, fillers, and matrix. From the experimental results, the following conclusions were obtained:

1. It was confirmed that the length of carbon nano tubes was decreased with the increase of ball milling time. The thermal conductivity of both MWCNT/PP and MWCNT/HDPE increases with the increase in ball milling time and was observed to have the highest value when they were ball milled for 60 min.

2. In case of Cu particles, surface area of particle increases with the increase of ball milling time up to 60 min. The morphology was similar to flake-like and/or hexagonal shape. However, if the powder is treated for over 60 min, the large and small particles will be mixed together, and then the number of small particles gradually increases.
3. The thermal conductivity of Cu/HDPE also was increased up to 60 min. This growth means that the increase of surface area as a function of ball milling promotes the movement of heat carriers (phonons) through the particle-matrix junctions.

Future Scope

1. For getting high thermal conductivity significant amount of fillers are added, in case high filler loading of composite may cause composite brittle and also create more challenges to processing of polymer composite
2. Filler materials are very costly than matrix of polymer so further research is required for composite with less filler loading
3. As working temperature of polymer composite is less, So there are limitations for its application

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