Effective Thermal Conductivity of Polymer Composites Using Local Fractal Techniques

Rajpal Singh Bhoopal, Pradeep Kumar Sharma, Ramvir Singh, Sajjan Kumar

Abstract- ***The model developed by Springer and Tsai is extended using non-linear volume fraction in place of physical porosity for the effective thermal conductivity of composite materials with the help of local fractal techniques. The expression for non-linear volume fraction is obtained using data available in the literature. Present model is constructed in terms of fiber volume fraction, the fiber-matrix thermal conductivity ratio and the local fractal dimensions. The effective thermal conductivity ratio is evaluated using the model with the approximation of the fractal dimensions. These fractal dimensions [d_P and d_T] are considered to be equal in the absence of information about the arrangement of fibers in the composites. The technique of local fractal dimensions is used to reduce the geometric complexity of the fiber arrangements. Better agreement of predicted effective thermal conductivity values with experimental results is obtained. A comparison with other models is also done and found that our model predict the values of effective thermal conductivity quite well.***

Keywords- ***Effective thermal conductivity, local fractal dimension, correction term, composite materials***

I. INTRODUCTION

Polymer composites filled with metal and non-metal particles are of interest for many fields of engineering applications and important in the technological developments. The composites made by incorporation of powdery metal fillers into thermoplastic polymers combine the advantageous properties of the metal and plastics. These composite materials arise from the fact that the thermal characteristics of such composites are close to the properties of metals, whereas the mechanical properties and the processing methods are typical of plastics. However, polymer composite materials have been found to be extremely useful for heat dissipation applications in electronic packaging. Recent applications of polymers as heat sinks in electronic packaging require new composites with relatively high thermal conductivity. Polymer composites are good electrical and thermal insulators. Commonly used plastics, are electrical insulators with a low thermal conductivity. Improved thermal conductivity in polymers may be achieved either by changing molecular orientation or by the addition of conductive fillers. Application include encapsulations, die (chip) attach, thermal grease, thermal interface materials and electrical insulation [1, 2].

Manuscript published on 28 February 2013.
***Correspondence Author(s)**
Rajpal Singh Bhoopal, Thermal Physics Laboratory, Department of Physics, University of Rajasthan, Jaipur, India.
P. K. Sharma, Thermal Physics Laboratory, Department of Physics, University of Rajasthan, Jaipur, India.
Ramvir Singh, Thermal Physics Laboratory, Department of Physics, University of Rajasthan, Jaipur, India
Sajjan Kumar, Thermal Physics Laboratory, Department of Physics, University of Rajasthan, Jaipur , India

A number of experimental studies have been carried out, and various numerical and analytical models have been developed to predict the effective thermal conductivity of particle filled polymers [3-27]. In this paper, we extend their ideas and present a more detailed analysis of the problem of heat conduction in composite materials using the tool of local fractal techniques. Fractal is a new approach of the geometry science to study the irregular objects. An important characteristic in fractal structure is its self-similarity. The greatest difference between fractal geometry and Euclidean geometry is in the range of dimension. Euclidean geometry describes regular objects like points, curves, surfaces and cubes using integer dimensions 0, 1, 2 and 3 respectively. However, many of the objects in nature, such as the surfaces of mountains, coastlines, microstructure of metal etc. are not Euclidean objects. Such objects are called fractals and are described by a non-integral dimension called the fractal dimension. In all these applications, the fractal dimensions have been an effective means of rendering complex geometry tractable. It is this capability of the technique that will be made use of in present work, even though the composite cross section may not be a fractal by nature. We will adopt the term local fractal dimension in this present work. The concept of local, statistical self-similarity has been used in many applications ranging from characterization of microstructure of materials to analysis of speech waveforms and signals. More details about fractal geometry appear in publications [28-32]. The fractal dimensions used to estimate contact resistance between surfaces in the field of heat transfer. The roughness of the contacting surfaces was modeled as a Koch curve, which is an exact fractal [33]. A fractal method proposed to determine thermal conductivity of random porous media for unidirectional fiber-reinforced composites [34-36]. The fractal technique used to determine the effective thermal conductivity for an isotropic granular media. However, in these models the determination of local fractal dimension is still very hard and complex for practical use [37]. A unified model proposed for describing the fractal characteristics of porous media and developed a self-similarly model to calculate the effective thermal conductivity of porous media based on the thermal electrical analogy technique [38-40]. Fractal theory opens a new way to determine the thermal parameters of composites media, and study on heat and mass transfer in porous media can get more achievements and showed that the soil structure was a fractal. [41]. The fractal characteristics of real microstructure of polyurethane foam and obtained a new expression to calculate the effective thermal conductivity of foam materials [42]. In the present work, we used the simplified heat conduction model given by Springer and Tsai to predict the effective thermal conductivity (ETC) of polymers filled with metallic and non-metallic composites using local fractal techniques [43].

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

The effective thermal conductivity (ETC) is defined as the conductivity of an equivalent homogeneous medium, which exhibits the same steady-state thermal characteristics as the composite materials. Although, strictly speaking, a composites cross section may not be an exact fractal by nature, the technique of local fractal dimensions can be used to reduce the geometric complexity. We extend the model by incorporating correction in volume fraction for composite materials and are analyzed in relation to the ratio of thermal conductivities K_e/K_m where K_e is the effective thermal conductivity of composite and K_m is the thermal conductivity of matrix.

Expression for the correction term has been derived using data fitting technique and found non-linear behaviour, which provides wider applicability to the model given by Springer and Tsai and also enhances its ability to predict correctly the effective thermal conductivity of composite materials.

II. MATHEMATICAL FORMULATION

A. HEAT CONDUCTION MODEL :

In the Springer and Tsai [43] model, the filament and the matrix are arranged in series. The effective thermal conductivity (ETC) of composite is calculated by this expression

$$\frac{K_e}{K_m} = \frac{1}{\left(\frac{\upsilon_f K_m}{K_f}\right) + \upsilon_m} \qquad (1)$$

The above expression is independent of both the filament shape and its geometrical arrangement. These factors may be included in the analysis by considering the thermal model shown in Figure1.

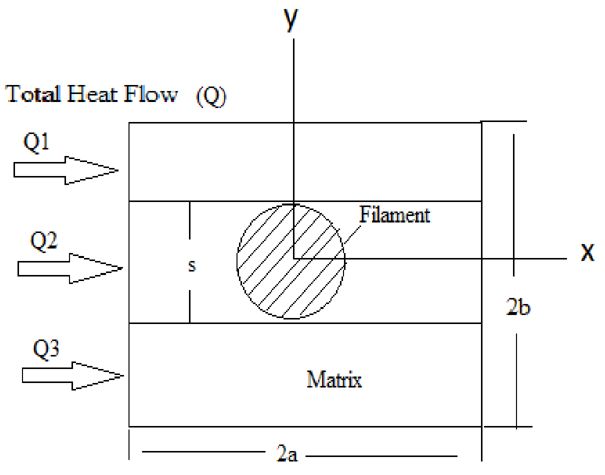

Figure1: Fundamental of heat conduction model

In this model it is assumed that the temperature difference is constant between $x = \pm a$ and that the total heat flow per unit length along the filament, Q, through the surface $x = -a$ may be divided into three independent parts, i.e. $Q = Q_1 + Q_2 + Q_3$. For this condition, and using the expression given for K_e

$$\frac{K_e}{K_m} = \left(1 - \frac{s}{2b}\right) + \frac{a}{b}\int_0^s \frac{dy}{(2a-h) + \left(\frac{hK_m}{K_f}\right)} \qquad (2)$$

The parameter *s* is the maximum dimension of the filament in the *y* direction and *h* is the width of the filament at any given *y* (Figure1). While Equation (2) is for a rectangular packing array, similar expressions could be obtained for other symmetrical packing arrays. In order to solve Equation (2) the shape of the filament must be specified. For a square filament (s = x = constant) and square packing array (a = b) Equation (2) yields

$$\frac{K_e}{K_m} = \left(1 - \sqrt{\upsilon_f}\right) + \frac{1}{\frac{B}{2} + \sqrt{1/\upsilon_f}} \qquad (3)$$

For a cylindrical filament (s = d) and square packing array Equation (2) gives

$$\frac{K_e}{K_m} = \left(1 - 2\sqrt{\frac{\upsilon_f}{\pi}}\right) + \frac{1}{B}\left[\pi - \frac{4}{\sqrt{1 - \left(\frac{B^2\upsilon_f}{\pi}\right)}}\right]\tan^{-1}\frac{\sqrt{1 - \left(\frac{B^2\upsilon_f}{\pi}\right)}}{1 + \sqrt{\frac{B^2\upsilon_f}{\pi}}} \qquad (4)$$

Where $B = 2\left(\frac{K_m}{K_f} - 1\right)$

The used model [35] is constructed in terms of the fiber volume fraction and local fractal dimensions. The final expressions for K_e/K_m is given as:

$$\frac{K_e}{K_m} = \left[1 - \left(1 + \frac{\pi}{2c}\right)\vartheta\right] + \frac{2\vartheta}{c\sqrt{1-c^2}}\tan^{-1}\sqrt{\frac{1+c}{1+c}} \quad c \geq -1 \qquad (5)$$

$$\frac{K_e}{K_m} = \left[1 - \left(1 + \frac{\pi}{2c}\right)\vartheta\right] + \frac{2\vartheta}{c\sqrt{c^2-1}}\ln\left(-c + \sqrt{c^2-1}\right) \quad c \leq -1 \qquad (6)$$

Where

$$c = \left(\frac{\beta - 1}{\beta}\right)\left(\frac{4\vartheta}{\pi}\right)^{\frac{(1-\delta)}{2}}, \quad \vartheta = \left(\frac{4\vartheta}{\pi}\right)^{\frac{(1+\delta)}{2}} \text{ and}$$

$$\delta = \frac{d_P - d_T}{d_P - 2d_P d_T + d_T} \qquad (7)$$

where ϑ is the fiber volume fraction, δ and c are the parameter defined in equation (7), β is the ratio of fiber conductivity to matrix conductivity the generalized unit cell, d_P is the local fractal dimension of a composite cross section in the direction of heat flow and d_T is the local fractal dimension of a composite cross section in the direction normal to heat flow.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Simplified model with $[d_P \, and \, d_T]$; the evaluation of the local fractal dimensions that as a simplification, or in the absence of information about the arrangement of fibers in the composite, the two fractal dimensions $[d_P \, and \, d_T]$ may be assumed to be equal. It is possible for two different fiber arrangements to have same values of local fractal dimensions. Physically, this means that in both the arrangements on the average, each fiber has nearly the same effect on the neighboring fibers with its range of influence. Therefore, the two arrangements are likely to have the same value of the effective thermal conductivity.

We have modified the model given by Springer and Tsai by incorporating a non-linear correction term F_P for effective thermal conductivity ratio as:

$$\left(\frac{K_e}{K_m}\right)_{d_P=d_T} = F_P\left[1-\left(1+\frac{\pi}{2c}\right)\vartheta\right]+\frac{2\vartheta}{c\sqrt{1-c^2}}\tan^{-1}\sqrt{\frac{1+c}{1+c}} \quad c \geq -1$$

where

$$F_P = C_1\vartheta^2 + C_2\vartheta + C_3 \qquad (8)$$

Where C_1, C_2 and C_3 are constants which have been determined using data fitting technique. The values of these constants are given in Table 1.

III. RESULTS AND DISCUSSION

In the present work, we have used two fractal dimensions $[d_P \, and \, d_T]$. These fractal dimensions $[d_P \, and \, d_T]$ are assumed to be equal in the absence of information about the arrangement of fibers in the composites. The effective thermal conductivity ratio has been evaluated using the model with the above approximation of the fractal dimensions. In the case of $d_P = d_T$, from equation (7), δ becomes zero.

The Springer and Tsai model predictions of ETC are analyzed in relation to the ratio of experimental thermal conductivities given for the same sample. It is observed that the correction term F_P has non-linear behavior to predict correctly the effective thermal conductivity of polymers filled with metallic and non-metallic composites. The evaluation of correction term F_P; the variation of effective thermal conductivity ratio with volume fraction of filler are plotted. We have used the data fitting technique and found that the correction term F_P best fits the curves obtained in figures (2-6) for different composite materials. Here F_P is equivalent to 'y' and ϑ (volume fraction of filler) is equivalent to x. The correction term as given by equation (8) in which C_1, C_2 and C_3 are constants and have different values of different types of composite materials. These constants are given in table 1 with the values of R^2.

Figures (7-12) show the comparison of experimental and predicted values of effective thermal conductivity of different metal filled polymer composites. Highly conductive metals like Al-oxide, Sn, Zn, Br, Fe and Cu are used as fillers into HDPE matrix in this study. In figures (7-12), it is noticed that the effective thermal conductivity of different metal filled polymer composites increases with the increase in volume contents of metal (filler) in HDPE. The enhancement in the effective thermal conductivity of HDPE/metal composite with increase in volume content of metal is mainly due to more interaction between metal particles as they come in contact with each other, resulting in the ease in transfer of heat and consequent enhancement of effective thermal conductivity.

In figures 13-16, we considered four representative combinations of highly porous metal foams in our results, i.e., Al/air, Al/water, RVC (reticulated vitreous carbon)/air, and RVC/water. It has been observed that the effective thermal conductivity of systems increases considerably with the increase of volume fractions of metal phase. All the calculations have been carried out with the thermal conductivities 218 W/m K of aluminium and 8.5 W/m K of RVC which are used as the solid phase in both cases, the thermal conductivity 0.0226 W/m K of air and the thermal conductivity 0.615 W/m K of water, are used as the fluid phase.

Finally, we present a comparison of the modified model predictions and predictions by other models [44-45] with the experimental results as given in the literature and found that our model predicts well the effective thermal conductivity values of composite materials as shown in figures (7-16). It is observed that as the volume fraction of inclusions increases, effective thermal conductivity of composite materials increase tremendously.

IV. CONCLUSION

In the present study, the model developed by Springer and Tsai is extended using non-linear volume fraction in place of physical porosity for the effective thermal conductivity of polymers filled with metallic and non-metallic composites with the help of local fractal techniques. Present model is constructed in terms of fiber volume fraction, the fiber-matrix thermal conductivity ratio and the local fractal dimensions. The correlation presented here showed that the ETC strongly depends on the volume fractions and the ratio of thermal conductivity of the constituents. Other factors have small effect on the ETC. The technique of local fractal dimensions is used to reduce the geometric complexity of the fiber arrangements. Better agreement of predicted effective thermal conductivity values with experimental results is obtained.

REFERENCES

1. G. Kalaprasad, P. Pradeep,G. Mathew, C. Pavithran, and S. Thomas, Thermal conductivity and thermal diffusivity analysis of low - density polyethylene composites reinforced with sisal glass and intimately mixed sisal/glass fibers, Composites Science and Technology, vol. 60, pp. 2967-2977, 2000.
2. Y. Xu, D.D.L. Chung, and C. Morz, Thermally conducting aluminum nitride polymer- matrix composites, Composites Part A, vol. 32, pp. 1749-1757, 2001.
3. Y. Agari, and A. Nagai Ueda, Estimation on thermal conductivities of filled polymers, Journal of Applied Polymer Science, vol. 32, pp. 5705-5712, 1993.
4. I. H. Tavman, Thermal and mechanical properties of aluminum powder filled high density polyethylene composites, Journal of Applied Polymer Science, vol. 62(12), pp. 2161-2167, 1996.
5. D. Kumlutas, I.H. Tavman, and M.T. Coban, Thermal conductivity of particle filled polyethylene composite materials, Composites Science and Technology, vol. 63, pp. 113-117, 2003.
6. A. Boudenne, L. Ibos, M. Fois, and E. Gehin, Thermophysical properties of polypropylene/aluminum composites, Journal of Applied Polymer Science,

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

vol. 42, pp. 722- 732, 2004.

7. R. Singh, and H. S. Kasana, Computational aspects of effective thermal conductivity of highly porous metal foams, Applied Thermal Engineering, vol. 24, pp. 1841-1849, 2004.
8. H. Serkan, D. Kumlutas, and I. H. Tavman, Effect of particle shape on thermal conductivity of copper reinforced polymer composites, Journal of Reinforced Plastics and Composites, vol. 26, pp. 113-121, 2007.
9. Rajinder Pal, New model for thermal conductivity of particulate composites, Journal of Reinforced Plastics and Composites, vol. 26, pp. 643-651, 2007.
10. Rajinder Pal, On the electrical conductivity of particulate composites, Journal of Composite Materials vol. 41, pp. 2499-2511, 2007.
11. M. Wang, J. H. He, J. Y. Yu, and N. Pan, Lattice Boltzmann modelling of the effective thermal conductivity for fibrous materials, International Journal of Thermal Sciences, vol. 46, pp. 848–855, 2007.
12. M. Wang, J. K. Wang, N. Pan, S. Chen, J. He, Three-dimensional effect on the effective thermal conductivity of porous media, Journal of Physics D: Applied Physics, vol. 40, pp. 260– 265, 2007.
13. M. Wang, J. K. Wang, N. Pan, and S. Chen, Mesoscopic predictions of the effective thermal conductivity of microscale random porous media, Physics Review E, vol. 75, 036702, 2007.
14. M. Wang, N. Pan, J. Wang, and S. Chen, Mesoscopic simulations of phase distribution effects on the effective thermal conductivity of microgranular porous media, Journal of Colloid and Interface Science, vol. 311, pp. 562–570, 2007.
15. M. Wang, J. K. Wang, N. Pan, S. Chen, and J. He, Three-dimensional effect on the effective thermal conductivity of porous media, Journal of Physics D: Applied Physics. vol. 40, pp. 260-265, 2007.
16. Rajinder Pal, On the Lewis-Nielson model for thermal/electrical conductivity of composites, Composites Part A, vol. 39, pp. 718-726, 2008.
17. S. Mahjoob, and K. Vafai, A Synthesis of fluid and thermal transport models for metal foam heat exchangers, International Journal Heat Mass Transfer, vol. 51, pp. 3701–3711, 2008.
18. M. Wang, and N. Pan, Modeling and prediction of the effective thermal conductivity of random open-cell porous foams, International Journal of Heat and Mass Transfer, vol. 51, pp. 1325-1331, 2008.
19. M. Wang, and N. Pan, Predictions of effective physical properties of complex multiphase, Materials Science and Engineering: R, vol. 63, pp. 1–30, 2008.
20. R. Singh, and P. Sharma, Effective thermal conductivity of polymer composites, Advanced Engineering Materials, vol. 10, pp.366-370, 2008.
21. Ramvir Singh, P. K. Sharma, R. S. Bhoopal, L. S. Verma, Prediction of effective thermal conductivity of cellular and polymer composites, Indian Journal Pure and Applied Physics, vol. 49, pp. 344-349, 2011.
22. Sajjan Kumar, Rajpal Singh Bhoopal, Pradeep Kumar Sharma, Radhey Shyam Beniwal, Ramvir Singh, Non-linear effect of volume fraction of inclusions on the effective thermal conductivity of composite materials: A modified maxwell model, Open Journal of Composite Materials, vol. 1, pp. 10-18, 2011.
23. Rajpal S. Bhoopal, P. K. Sharma, Sajjan Kumar, Alok Pandey, R.S. Beniwal and Ramvir Singh, Prediction of effective thermal conductivity of polymer composites using artificial neural network approach, Special Topics & Reviews in Porous Media – An International Journal, vol. 3(2), pp. 115-123, 2012.
24. Rajpal S. Bhoopal, Dharmendra Tripathi, Madhusree Kole, T. K. Dey, Ramvir Singh, Experimental and numerical investigations of effective thermal conductivity of low-density polyethylene filled with Ni and NiO particles, Composites: Mechanics, Computations, Applications, An International Journal, vol. 3, pp. 79-93, 2012.
25. T. K. Dey and M. Tripathi, "Thermal properties of silicon powder filled high-density polyethylene composites," Thermochimica Acta, vol. 502, pp.35-42, 2010.
26. Rajpal Singh Bhoopal, Ramvir Singh, Pradeep Kumar Sharma, Adaptive neuro-fuzzy inference system for prediction of effective thermal conductivity of polymer-matrix composites, Modeling and Numerical Simulation of Material Science, vol. 2, pp. 43-50, 2012.
27. N Ferguen, C Cogné, E Bellenger, M Guessasma and C Pélegris, A numerical model for predicting effective thermal conductivities of alumina/Al composites, Journal of Composite Materials, DOI: 10.1177/0021998312464081, 2012.
28. B. B. Mandelbrot, "The Fractal Geometry of Nature," W. H. Freeman, New York, 1983.
29. H. E. Stanley, NATO ASI Series B, Plenum, New York, vol. 133, pp. 85-97, 1985.
30. H. E. Stanley, N. Ostrowsky, "On growth and form. Fractal and Non-fractal Patterns in Physics,"NATO ASI Series E: Applied Science, Martinus Nijhoff, Dordrecht, The Netherlands. No.100, 1986.
31. Feder, "Fractals," Plenum, New York, 1988.
32. Dehong Xia, Shanshan Guo, Ling Ren, Study of the reconstruction of fractal structure of closed-cell aluminum foam and its thermal conductivity, Journal of Thermal Science, vol. 21, pp. 77-81, 2012
33. A. Majumdar, C. L. Tein, "Fractal network model for contact conductance," presented at the Joint ASME/AIChE National Heat Transfer Conference, Philadelphia, P A, 1989.
34. J. F. Thovert, F. Wary, M. P. Adler, "Thermal conductivity of random media and regular fractals," Journal Applied Physics, vol. 68, pp. 3872-3883, 1990.
35. R. Pitchumani, S.C. Yao, "Correlation of thermal conductivities of unidirectional fibrous composites using local fractal techniques," Journal of Heat Transfer, vol. 113, pp. 788-796, 1991.
36. S.C. Yao, R. Pitchumani, "Fractal based correlation for the evaluation of thermal conductivities of Fibrous composites," Transport Phenomena in Materials Processing, ASME HTD, vol.146, pp. 55-60, 1990.
37. S. Adrian Sabau, Y. X. Tao, G. Liu, "Effective conductivity for anisotropic granular porous media using fractal concepts," Proceeding of National Heat Transfer Conference, vol. 11, pp. 121-128, 1997.
38. B. M. Yu, J.H. Li, "Some fractal characters of porous media," Fractal, vol. 9, pp. 365-372, 2001.
39. Y. T. Ma, B. M. Yu, D. M. Zhang, "A Self-similarity model for effective thermal conductivity of porous media," Journal of Physics D: Applied Physics, vol. 36, pp. 2157-2164, 2003.
40. Y. J. Feng, B. M. Yu, M. Q. Zou, "A Generalized model for the effective thermal conductivity of porous media on self-similarity," Journal of Physics D: Applied Physics, vol. 37, pp. 3030- 3040, 2004.
41. S. Y. Liu, J. W.Zhang, "Fractal approach to measuring soil porosity," Journal of Southeast University, 27 (1997) 127-130.
42. S. Mingheng, LI Xiaochuan & Y. Chen, "Determination of effective thermal conductivity for polyurethane foam by use of fractal method," Science in China Series E: Technological Sciences, vol. 49, pp. 468-475, 2006.
43. G.S. Springer and S.W. Tsai, "Thermal conduct ivies of unidirectional materials," Journal of Composite Materials, vol. 1, pp. 166-173, 1967.
44. T. Lewis and L. Nielsen, "Dynamic mechanical proper-ties of particulate-filled composite," Journal of Applied Polymer Science, vol. 14, pp. 1449-1471,1970.
45. A. Bhattacharya, V. V. Calmidi and R. L. Mahajan, "Thermoplastic properties of high porosity metal foam," International Journal of Heat and Mass Transfer, vol. 45, pp. 1017-1031, 2002.

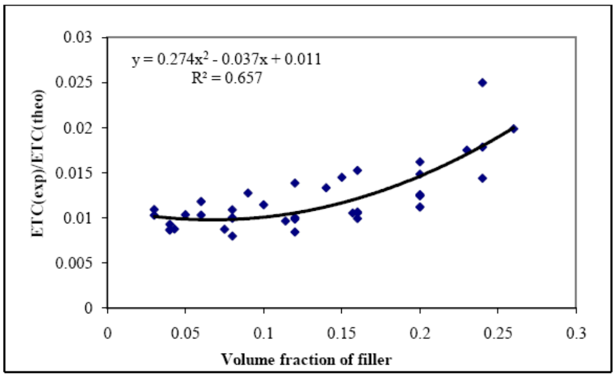

Figure 2: Variation of volume fraction of filler with ETC ratio for HDPE/metal*.

(*Metal - Al oxide, Tin, Zinc, Copper, Iron, Bronze)

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

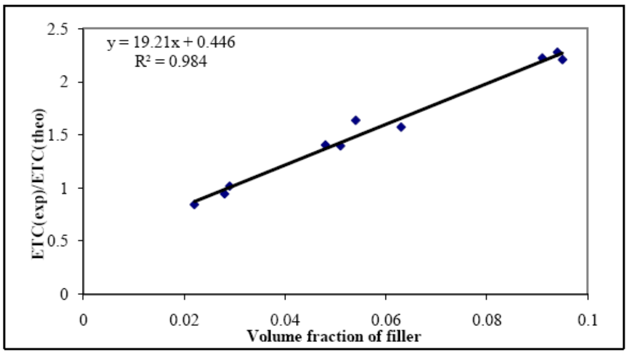

Figure 3: Variation of volume fraction of filler with ETC ratio for Al/air.

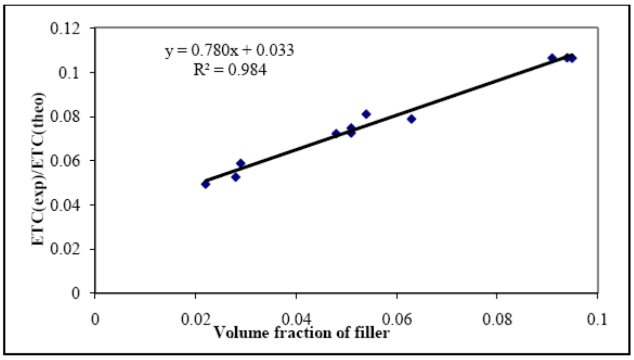

Figure 4: Variation of volume fraction of filler with ETC ratio for Al/water.

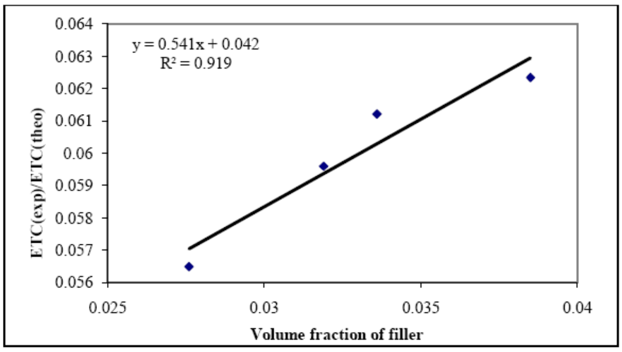

Figure 5: Variation of volume fraction of filler with ETC ratio for RVC/air.

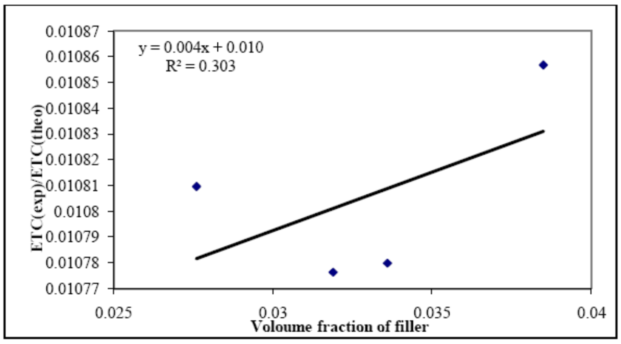

Figure 6: Variation of volume fraction of filler with ETC ratio for RVC/water.

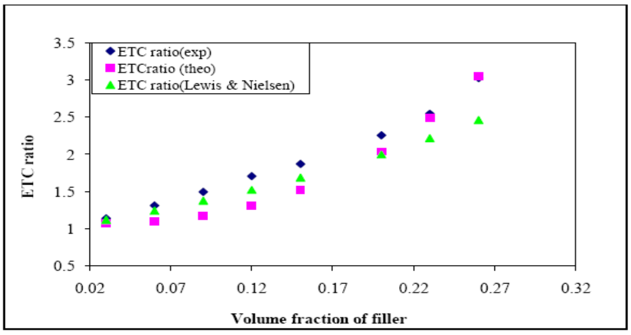

Figure 7: Comparisons of experimental and theoretical results for HDPE/Al Oxide.

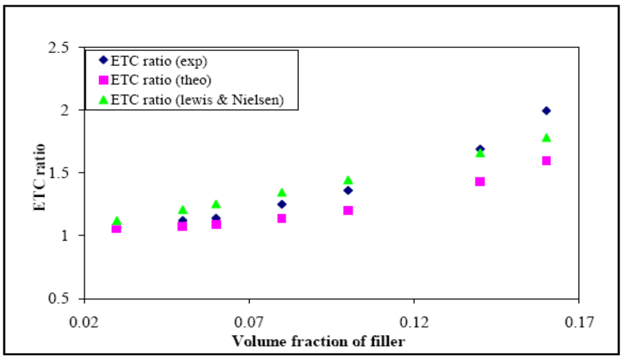

Figure 8: Comparisons of experimental and theoretical results for HDPE/Sn.

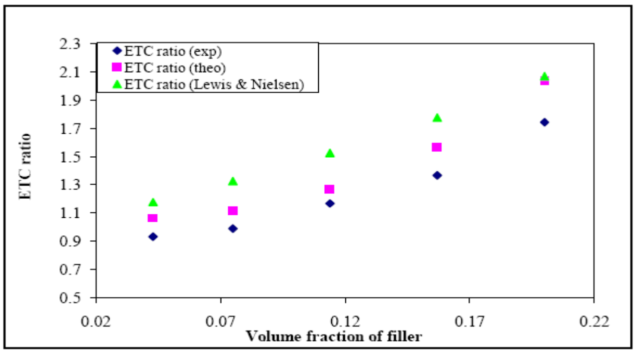

Figure 9: Comparisons of experimental and theoretical results for HDPE/Zinc.

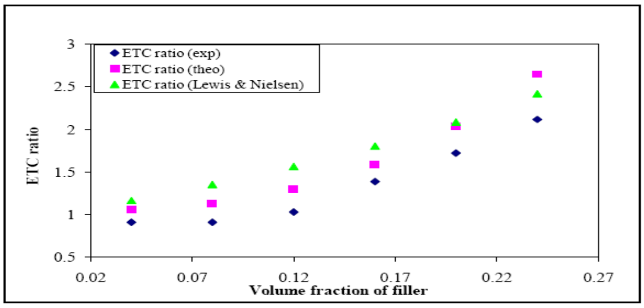

Figure 10: Comparisons of experimental and theoretical results for HDPE/Copper.

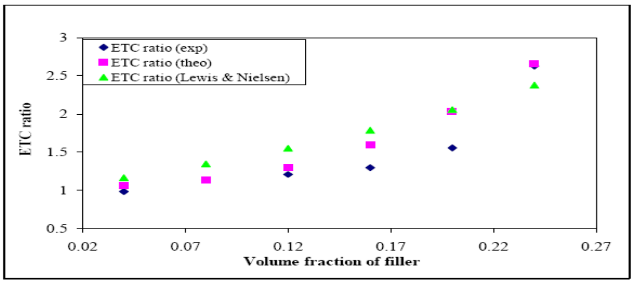

Figure 11: Comparisons of experimental and theoretical results for HDPE/Iron.

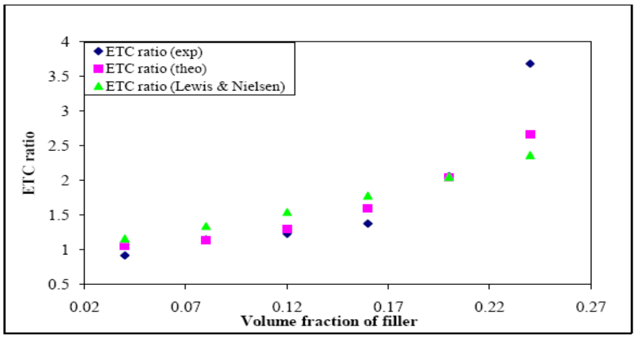

Figure 12: Comparisons of experimental and theoretical results for HDPE/Bronze.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

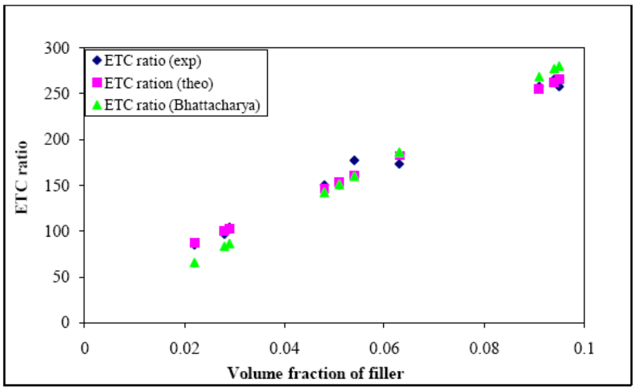

Figure 13: Comparisons of experimental and theoretical results for Al/Air.

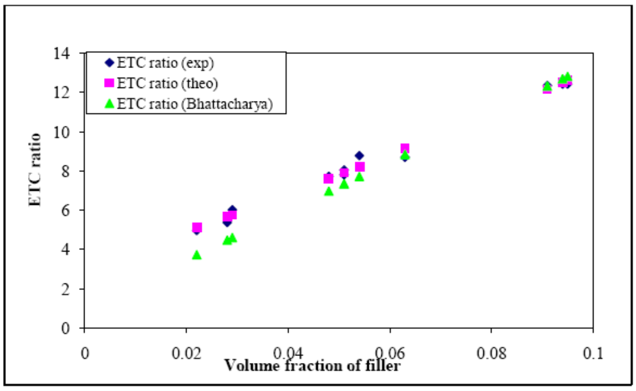

Figure 14: Comparisons of experimental and theoretical results for Al/Water.

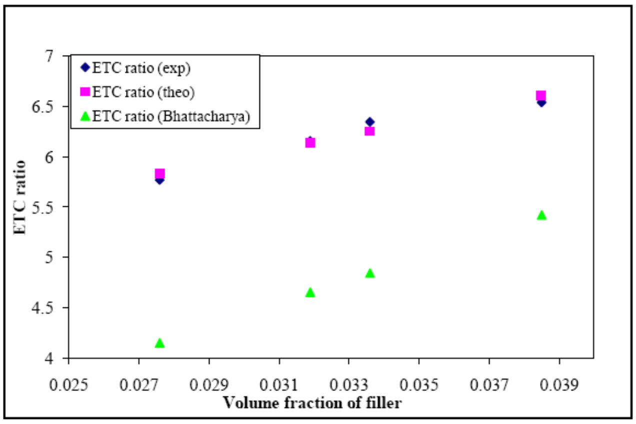

Figure 15: Comparisons of experimental and theoretical results for RVC/Air.

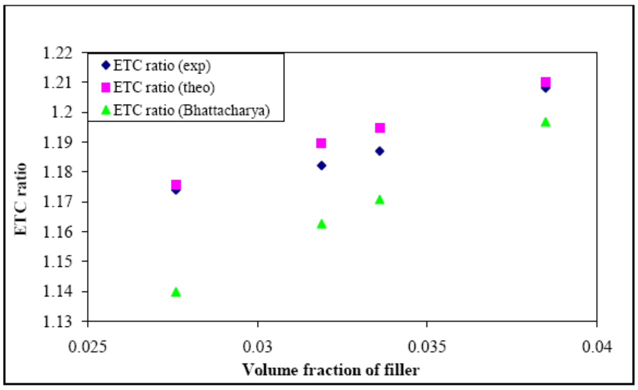

Figure 16: Comparisons of experimental and theoretical results for RVC/Water.

Table: 1

Values of the different constants (C_1, C_2, C_3 and R^2) in using equation (8):

S. No.	Sample	C_1	C_2	C_3	R^2
1.	HDPE/Metal*	0.2743	- 0.0370	0.0111	0.6571
2	Al/air	19.210	0.4456		0.9845
3.	Al/water	0 .7809	0.0336		0.9841
4.	RVC/air	0.5411	0.0421		0.9192
5.	RVC/water	0 .0045	0.0107		0.3032

Metal* – Al oxide, Sn, Zinc, Copper, Iron, Bronze.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)