J. Mater. Environ. Sci. 3 (6) (2012) 1109-1116
ISSN : 2028-2508
CODEN: JMESCN

Thermal Conductivity Characterization of Bamboo Fiber Reinforced Polyester Composite

M. Mounika[1,*], K. Ramaniah[2], A.V. Ratna Prasad[2], K. Mohana Rao[2], K. Hema Chandra Reddy[3]

[1]*M.Tech Student, Department of Mechanical Engineering, V R Siddhartha Engineering College, Vijayawada-520 007, India*
[2]*Department of Mechanical Engineering, V R Siddhartha Engineering College, Vijayawada-520 007, India*
[3] *JNT University Anantapur, Anantapur-521501, India*

Received 04 July 2012, Revised 15 July 2012, Accepted 15 July 2012
* Corresponding Author details: movva.mounika@gmail.com Tel: 09030067779.

Abstract
The main focus of this study is on thermal conductivity characterization of bamboo fiber reinforced composite by varying volume fraction, temperature and fiber angles (0^0, 45^0 and 90^0). Bamboo fibers are extracted from its stem using retting and mechanical extraction procedure. These extracted fibers are used as reinforcement in polyester resin matrix for making partially green biodegradable material composite via hand lay-up technique. The thermal conductivity characterization of composites is investigated experimentally by a guarded heat flow meter method. The results show that the thermal conductivity of composite decreases with increase in fiber content and quite opposite trend was observed with respect to temperature. Moreover, the experimental results of composites at different volume fractions were compared with two different theoretical models (E-S Model and Rule of Mixture Model). Good agreement between theoretical and experimental results has been observed. On the other hand, the variation in thermal conductivity with respect to fiber orientation also showed significant effect on thermal conductivity. Thermal conductivities of bamboo fiber reinforced composite at maximum volume fractions are 0.185W/mk,0.189W/mK and 0.196W/mK for fiber angles of 0^0, 45^0 and 90^0 respectively. The results of this study indicate that the developed composite is an insulating material. Therefore, this composite can be used in building and automotive industry to save energy by reducing rate of heat transfer.

Keywords: bamboo, thermal conductivity, fiber orientation, guarded heat flow meter.

1. Introduction:
Natural fiber as a replacement to synthetic fiber in polymer matrix is the focus of many scientists and engineers. The reason for focus on natural fiber reinforced polymer matrix is because of its low cost, low effect on environment and also it shows good mechanical properties compared to polymer resins. Natural fiber reinforced composites are advantageous over the metals when excellent corrosion resistance is required. Apart from mechanical properties, thermal properties are also required for specific applications [1-3].

Tests on mechanical properties of natural fiber reinforced composites were extensively done by many investigators. The tensile properties of sisal, hemp, coir, kenaf and jute reinforced composites have been studied, and reported that among all the composites, hemp reinforced composite exhibited the highest mechanical properties whereas the coir showed the lowest [4]. Symington et al. studied the effect of moisture content on tensile properties of natural fibers: jute, kenaf, flax, abaca, sisal, hemp and coir and concluded that jute fiber exhibited better mechanical properties than other fibers [5].Work is also done on the investigation of mechanical properties of bamboo fiber reinforced polymer composite. The experimental results of ultimate tensile strength and tensile modulus are 126.2Mpa and 2.48Gpa, while the ultimate flexural strength and flexural strength are 128.5Mpa and 3.7Gpa respectively [6].
Sherely Annie Paul et al. worked on the periodical method, to estimate the thermal conductivity, thermal diffusivity of polypropylene (PP)/banana fiber commingled composites at room temperature. It was found that the thermal conductivity and thermal diffusivity of the composites decrease with fiber loading [7]. The thermal conductivity, thermal diffusivity, and specific heat of flax fiber–high density polyethylene (HDPE) bio composites were determined in the temperature range of 170^0–200^0C using the line-source technique. Thermal conductivity and thermal diffusivity did not change significantly with temperature in the range studied whereas specific heat and density of the bio composites increased gradually with temperature [8]. G. Kalaprasad worked on the thermal conductivity and thermal diffusivity of sisal-reinforced polyethylene (SRP), glass-reinforced polyethylene (GRP) and sisal/glass hybrid fibre-reinforced polyethylene (GSRP) from at cryogenic to high temperature (120±350 K). They concluded that the thermal conductivity increased with temperature and leveled off afterwards [12]. Thermal conductivity of composite is anisotropic property similar to elastic modulus [9]. Some theoretical and empirical models have been developed to predict the thermal conductivity of composites [10-14]. Heat flow meter [15] or the transient plane source method [15] was used to measure the thermal conductivity of polymer composites. Extensive research has been carried out on synthetic fiber reinforced polymer composites. But little information is available on thermo physical properties of natural fiber reinforced composites over and above room temperature [16-20]. Thermal conductivity characterization of Fiber Reinforced Polymer (FRP) composites is also done in three directions (longitudinal, transverse and through-the-thickness). Results showed that E-glass/Vinyl ester samples have a thermal conductivity of 0.350.05 W/ m K, while the conductivity of carbon composites is higher in the fiber direction and lower in through-the-thickness direction. Addition of 10 wt% and 12.5 wt% of graphite additive in neat vinyl ester resin increased the conductivity by 88% and 170% respectively. The overall trend shows that conductivity of E-glass/Vinyl ester composite is in the range. Carbon/Vinyl ester composite has a thermal conductivity in longitudinal direction being almost twice the conductivity in transverse and four times greater than through-the-thickness direction [21].
Bamboo is a type of grass (Scientific name: Bambuseae) and is among the fastest growing plants on the planet. One Japanese species rockets skywards at a rate of a meter a day. Some bamboos can reach a lofty 35metres in height while others are only half a meter tall. It is economically important to humans as a building material. There are 1,500 different species of bamboo.
Extensive work has been carried out on natural fiber reinforced composites and when compared to the research on mechanical properties of natural fiber composites, the analysis and evaluation of thermal properties is also left a step behind. Therefore the focus of the work is to investigate the thermal properties of composite by considering some natural fibers which are not explored so far. In that aspect the thermal conductivity characterization of bamboo fiber reinforced polyester composite is investigated. Thermal conductivity is investigated as a function of fiber volume fraction, temperature and fiber orientation.

2. Materials and Methods

2.1 Materials

Unsaturated polyester resin of grade ECMALON 4411, methyl ethyl ketone peroxide and cobalt naphthanate were purchased from Ecmass resin (Pvt) Ltd., Hyderabad, India.

2.2 Fiber extraction

A process called retting is employed to extract fiber from plant strips.This process involves the action of bacteria and moisture on dried bamboo strips to dissolve and rot away cellular tissues and gummy substances that surround the fiber bundles in the strips. And this soaking process loosens the fibers and can be extracted out easily. Finally, the fibers were washed again with water and dried at room temperature for about 5 days.

2.3 Preparation of composite

Composites are prepared as per the ASTM E-1530 standards. The foremost required resin mixture is prepared by adding accelerator and catalyst to resin at room temperature for curing which was 1.5% by volume of resin. The samples were prepared using Hand lay-up technique. Hand lay-up technique was adopted to fill up the prepared mold with an appropriate amount of polyester resin mixture and unidirectional fibers, starting and ending with layers of resin. Fiber deformation and movement should be minimized to yield good quality, unidirectional fiber composites. Therefore at the time of curing, a compressive pressure of 0.05MPa was applied on the mold and the composite specimens were cured for 24 h. The specimens were also post cured at 70^0C for 2 h after removing from the mold.

2.4 Thermal conductivity measurement

Thermal conductivity of the composites as a function of volume fraction, temperature and fiber orientation (Fig. 1) was measured using guarded heat flow meter (Unitherm model 2022, ANTER Corp., Pittsburgh, PA).

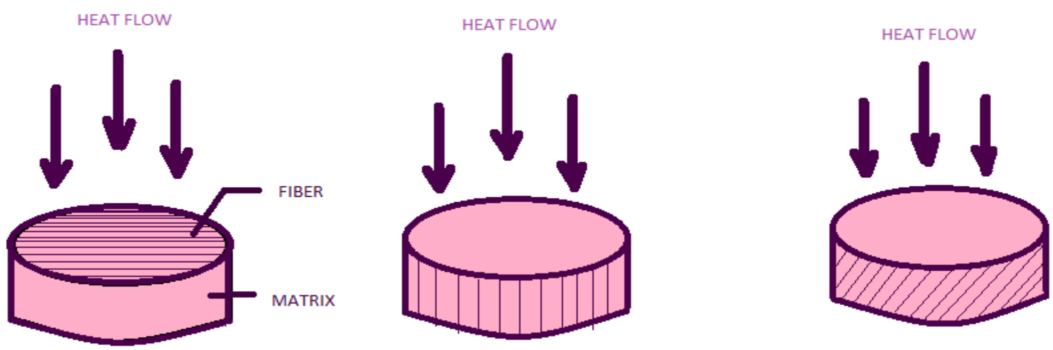

Fig. 1: Representation of heat flow while changing the fiber orientation.

In accordance with ASTME1530–99 [22], the test sample of size 50 mm in diameter and 10 mm in thickness were prepared. Following equations (1-3) correspond to the calculation of thermal conductivity [23, 24]:

$$q = \frac{k(T1 - T2)}{L} \quad (1)$$

$$R = \frac{(T1 - T2)}{q} \quad (2)$$

$$k = \frac{L}{R} \quad (3)$$

Where q is the heat flux (Wm^{-2}), k is the thermal conductivity (Wm^{-1} K^{-1}), T1-T2 is the difference in temperature (K), L is the thickness of the sample (m), and R is the thermal resistance of sample (m^2KW^{-1}).

ISSN : 2028-2508
CODEN: JMESCN

3. Results and discussion

3.1 Measurement of Thermalconductivity

Thermal conductivity of bamboo fiber reinforced composites with different fiber loadings are presented in Table 1.The results show that thermal conductivity of composites decreases as fiber content increases. The thermal conductivity of fiber and matrix have been evaluated by extrapolating the linear regression of thermal conductivity values of the composite to 100% fiber and 0% fiber and are found be 0.07W/mK and 0.2386W/mK respectively. The behavior of the thermal conductivity of different composites can now be explained using thermal conductivity values of the fiber. Further, the measured thermal conductivity of composites was compared with series model (Rule of mixture) and E-S model.The expressions for these two models are:

Series model:

$$\frac{1}{k_c} = \frac{v_f}{k_f} + \frac{(1-v_f)}{k_m} \tag{4}$$

E-S model:

$$K_e = \frac{k_c}{k_m} = 1 - \frac{1}{c} + \frac{\pi}{2d} - \frac{c}{d\sqrt{(d^2-c^2)}} \ln\left|\frac{d+\sqrt{(d^2-c^2)}}{c}\right| \tag{5}$$

Where $c = \sqrt{\pi\rho / v_f} / 2$, $d = \rho(1/\beta - 1)$, $\beta = k_f / k_m$, and v_f is volume fraction of fiber. k_c, k_f and k_m are the thermal conductivity of composite,fiber and matrix respectively. The calculated and measured thermal conductivity of bamboo fiber-polyester composites as a function of fiber content are presented in (Fig. 2). It is observed that the two theoretical models overestimate the value of thermal conductivity with respect to the experimental ones. This may be attributed to the fact that some of the assumptions taken for model are not practical. In E-S model, the cross section of the fibers was assumed to be elliptical, while in the present it is not perfectly elliptical. Further, in theoretical models, orientation of the fibers was assumed to be perfect, but in actual practice when liquid matrix is poured over the fibers some of the fibers may be misaligned. However, at higher volume fractions of fiber, the experimental values of thermal conductivity are in agreement with the predicted values (Fig. 3). The thermal conductivity of all the samples increases with the increase of temperature because in this case the vibration of the phonons is the thermal carrier and the moisture in the fiber begins to evaporate and escape from the sample (Fig. 5). The thermal conductivity also increased with an increase in fiber angle (Fig. 4). Bamboo fiber reinforced composite showed least thermal conductivity when compared to polyester resin, glass composite and bamboo fiber reinforced composite (Fig. 6). These results indicate that the bamboo fiber reinforced composites considered in this study have good thermal insulation properties. The core of the fibers is porous and air is entrapped. This may be the reason for higher thermal insulation properties of the composites. Hence; these materials may be considered as building components to reduce heat transfer in air conditioned buildings in order to decrease energy consumption.

Table 1: Variation of thermal conductivities for varying volume fraction

Volume fraction of fiber	Thermal conductivity W/mK		
	Experimental	Rule of mixture model	E-S Model
0.151	0.211	0.175	0.195
0.209	0.205	0.155	0.18
0.263	0.194	0.146	0.168
0.304	0.185	0.137	0.16

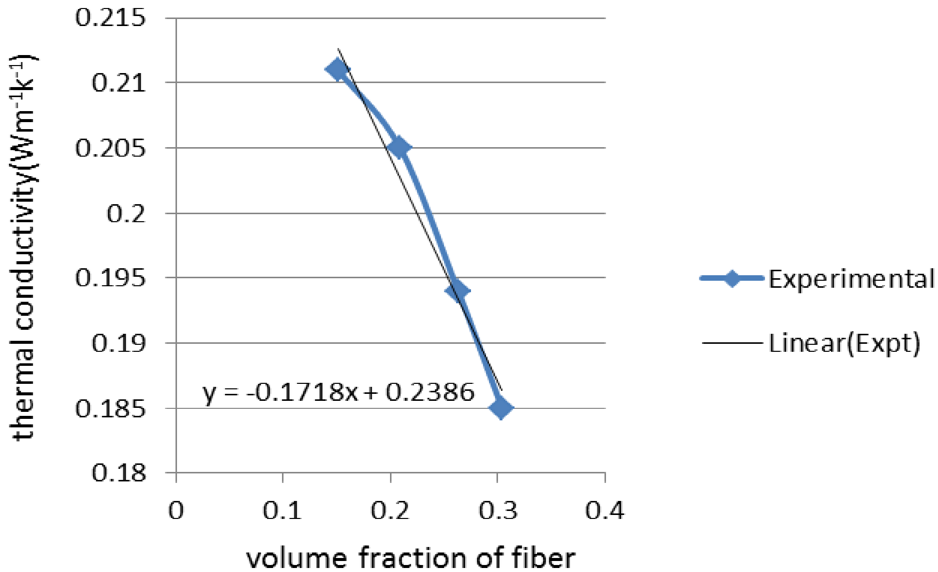

Fig. 2: Effect of volume fraction on thermal conductivity of composites.

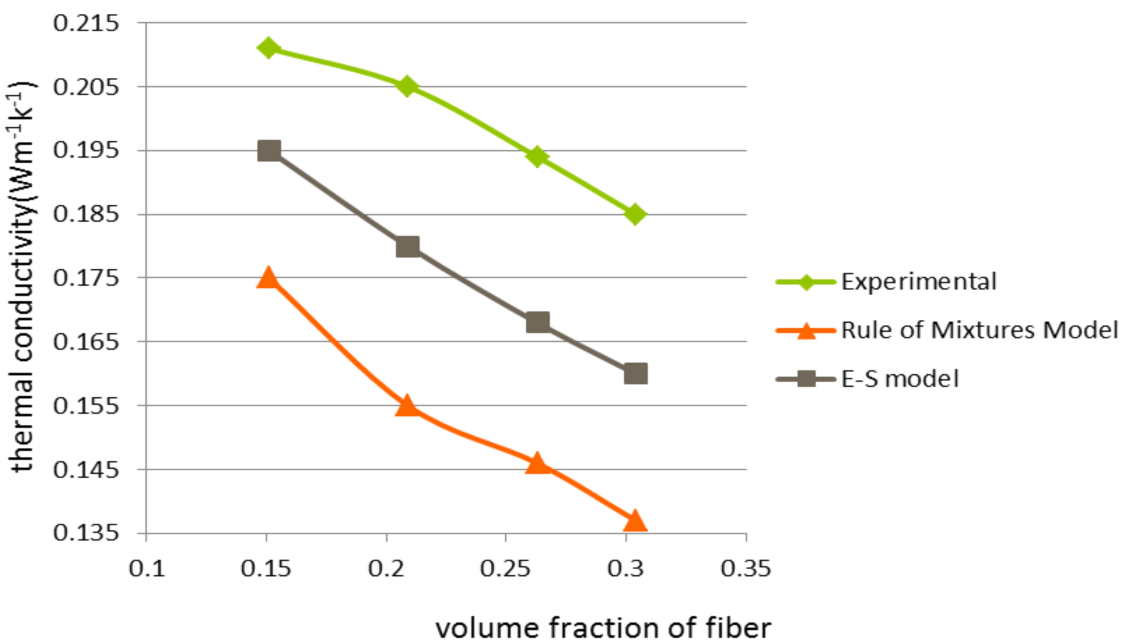

Fig 3: Variation of thermal conductivity of fiber reinforced composite with volume fraction of fiber

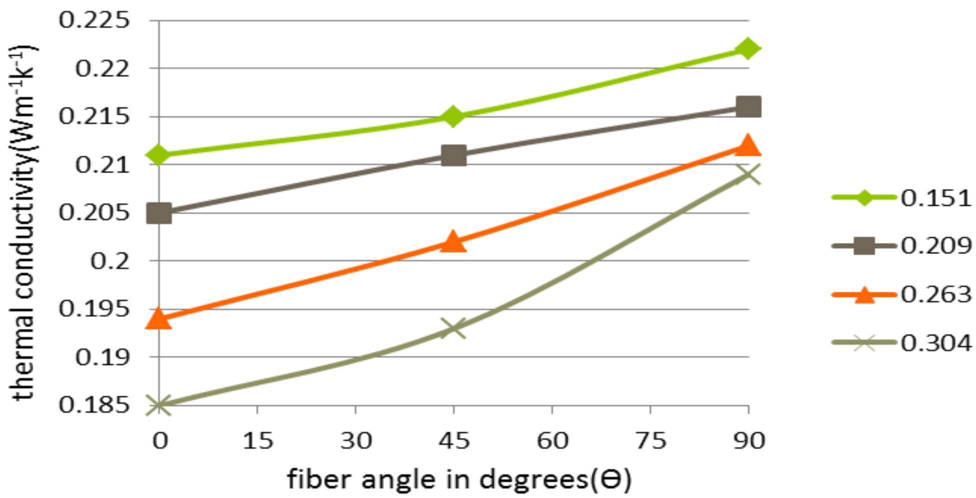

Fig 4: Variation of thermal conductivity of fiber reinforced composite with fiber angle at specified volume fraction

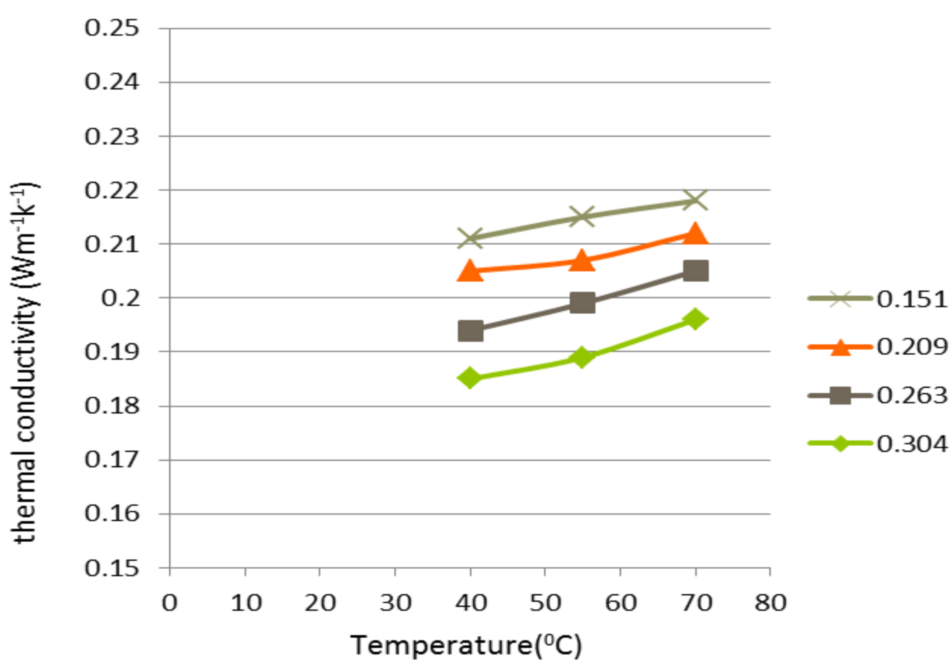

Fig 5: Variation of thermal conductivity of fiber reinforced composite with temperature at specified volume fraction.

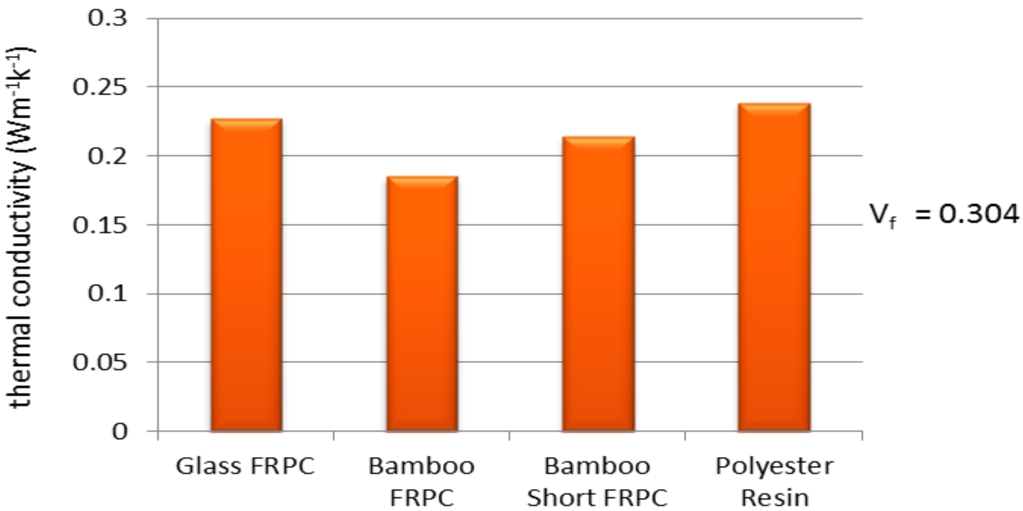

Fig 6: Comparison of thermal conductivities of various composites with polyester resin.

4. Conclusion

In this work, partially biodegradable green composites with various volume fractions of bamboo fibers were successfully developed and their thermal conductivities were investigated as a function of volume fraction, temperature and fiber angles. From the results obtained, the following conclusions are drawn:

- The thermal conductivity of the composites has decreased withincrease in volume fraction of fibers.
- At maximum volume fraction of fiber, the thermal conductivityof the composites has varied from 0.185W/mKto0.196W/mK in the temperature range of 40-70^{0}C
- The thermal conductivity of composite increases with increase in fiber angles
- Bamboo fiber reinforced composite showed the lowest value of thermal conductivity then glass fiber reinforced composite, bamboo short fiber reinforced composite and polyester resin.

The results of this study indicate that the waste grass broom fiber reinforced composites are light in weight, economical and possess good thermal insulating and mechanical properties. Hence, the newly developed composite material can be used for applications such as automobile interior parts, electronic packages, building construction, and sport goods.

References

1. Jonathan D. Mar, Efim Litovsky and Jacob Kleiman, *Journal of Building Physics*, 32(2008) 9.
2. RavindraMangal, N.S. Saxena, M.S. Sreekala, S. Thomas, Kedar Singh, *Materials Science and Engineering*, A339 (2003) 281.
3. Maries Idicula, AbderrahimBoudenne, L. Umadevi, Laurent Ibos,Yves Candau, Sabu Thomas, *Composites Science and Technology*, 66 (2006) 2719–2725
4. Sreenivasan VS, Soma Sundram S, Ravindran D, Manikandan V, Naryanaswamy R, *Materials and Design*, 32 (2011) 453.
5. Symington MC, Banks WM, West Opukuro David, Pethrick RA., *Journal of Composite Materials*, 43 (2009) 1083.

6. Murali Mohan Rao K, Ratna Prasad AV, Mohan Rao K., *Materials & Design*, 31 (2010) 508.
7. Sherely Annie Paul, Abderrahim Boudenn, Laurent Ibos, Yves Candau, Kuruvilla Joseph, Sabu Thomas, *Composites: Part A*, 39 (2008) 1582.
8. Xue Li, Lope G. Tabil, Ikechukwuka N. Oguocha, Satyanarayan Panigrahi, *Composites Science and Technology*, 68 (2008) 1753.
9. Hashim Rokiah, Wan Noor Aidawati Wan Nadhari, Sulaiman Othman,kawamura Fumio, Hiziroglu Salim, Sato Masatoshi, et al., *Materials & Design*, 32 (2011) 246.
10. Kalaprasad G, Pradeep P, Mathew G, Pavithran C, Thomas S, *Composites Science & Technology*, 60 (2000) 2967.
11. Tavman IH., *International Communication in Heat Mass Transfer*, 25 (1998)723.
12. Zou Mingqing, Boming Yu, Zhang Duanming, Ma Yongting., *Journal of heat transfer*, 125 (2003) 981.
13. Zhou Hu, Zhang Shimin, Yang Mingshu, *Composites Science and Technology*, 67(2007) 1035–40.
14. Samual Graham, David L, Mc Dowell, *Journal of Heat Transfer*, 125 (2003)389.
15. Kim SW, Lee SH, Kang JS, Kang KH, *International Journal of Thermo physics*, 27 (2006) 1873.
16. Laosiriphong K. Theoretical and experimental response of FRP bridge deckunder thermal loads. Ph.D. Dissertation. West Virginia University; 2004.
17. Pattanayak S, Raju Raman VS, Kanagaraj S.,*Int Plast Engg Technol*, 4 (2000)47.
18. Kanagaraj S, Pattanayak S., *Cryogenics* 43 (2003)451.
19. Khedari Joseph, Watsanasathaporn Pornnapa, Hirunlabh Jongjit., *Cement and Concrete Composites,* 27 (2005)111.
20. Binici Hanifi, Aksogan Orhan, Bodur Mehmet Nuri, Akca Erhan, Kapur Selim., *Construction and building materials*, 21 (2007) 901.
21. Bhyrav Mutnuri, Ruifeng (Ray) Liang and Hota Ganga Rao ANTEC 2006, May 7-11, Charlotte, NC
22. ASTM E1530–99, Standard test method for evaluating the resistance to thermal transmission of materials by the guarded heat flow meter technique, ASTM International; 1999–3-10.
23. Necati Ozisik M. Heat transfer – a basic approach. International. Singapore: McGraw-Hill Book Co; 1985.
24. ANTER corporation technical notes <http://www.anter.com/TN50.htm>[accessed 03.02.10].