

## WOVEN HYBRID COMPOSITES: WATER ABSORPTION AND THICKNESS SWELLING BEHAVIOURS

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Oil palm empty fruit bunches (EFB)/woven jute fibres ( $J_w$ ) reinforced epoxy hybrid composites were prepared by hand lay-up technique by keeping the EFB/ woven jute fibre weight ratios constant, i.e. 4:1. By combining oil palm EFB and woven jute fibre, it is possible to take advantage of both fibres while at the same time suppressing their less desirable qualities. These hybrids provide a new type of sandwich structure with a good skin-core adhesion and the potential for their applications as cost-effective sandwich construction. The effect of the layering pattern on the water absorption and thickness swelling of the hybrid composites was studied. It was observed that water diffusion occurred in the composites, depending on the fibre type as well as the layering pattern. EFB fibre composites exhibited maximum water absorption during the whole duration of immersion. The hybridization of oil palm EFB composites with woven jute fibre showed beneficial effects on both the water absorption and thickness swelling by improving fibre/matrix bonding.

*Keywords:* Hybrid composites; Woven jute fibre; Water absorption; Thickness swelling

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## INTRODUCTION

Natural fibers offer various potential advantages over synthetic fibres, such as low density, low cost, biodegradability, acceptable specific properties, less wear during processing, and low energy consumption. The abundance of natural fibers combined with the ease of their processability is an attractive feature, which makes them a covetable substitute for synthetic fibers that are potentially toxic (Jannah et al. 2009). Among the natural fibers, jute fibre constitutes a major area of investigation because of its highest content of cellulose when compared with other natural fibers. Jute is 100% biodegradable and recyclable and thus an environmentally friendly natural fibre procured from the bast or skin of the plant's stem. It is the second most important natural fibre after cotton, in terms of usage, global consumption, production, and availability. It has high tensile strength, low extensibility, and ensures better breathability of fabrics. Jute fibre reinforced composites can be used in everyday applications such as electrical appliances, pipes, roof tiles, partition panels, false ceiling, helmets, bath tub, water tank, etc.

Composite materials comprising of two or more fibres in a single matrix, which are called hybrid composites, are attracting the attention of many researchers. Hybridization with more than one fibre type in the same matrix provides another dimension to the potential versatility of fibre reinforced composite materials. Properties of the hybrid composite may not follow from a direct consideration of the independent properties of the individual components. Recently, water absorption and thickness swelling characteristics of hybrid composites were studied, such as pulp fibre/wood flour (Kiani et al. 2010), waste newspaper fibre/wood flour (Ashori 2010), recycled newspaper fibre/poplar flour (Ashori and Sheshmani 2010), jute/betel nut fibre (Hassan et al. 2010). Few researchers have worked on water absorption of natural fibre reinforced polymer composites made of woven jute fibre (Ahmed and Vijayarangan 2007; Ahmed et al. 2006). Khalil et al. (2007a) reported that the water absorption and the thickness swelling of oil palm fiber/glass hybrid reinforced with polyester composites is improved by the incorporation of glass fibers, while a reverse trend is observed when the oil palm fiber content is increased in the composites. Researchers reported that moisture absorption depended upon void content in the composites and any increase in the void content can lead to increasing water absorption (Roy et al. 2001). Mechanical and physical properties of natural fibre reinforced polymer composites were affected by water absorption and the thickness swelling behaviours.

Existing literature reveals that a lot of work has been carried out on natural fibre hybrid composites, but none has dealt with the use of woven jute fabric with oil palm EFB fibre as reinforcement in epoxy matrix. In the present study, epoxy based woven tri-layer EFB/J<sub>w</sub>/EFB and J<sub>w</sub>/EFB/J<sub>w</sub> hybrid composites were prepared, and their water absorption and thickness swelling behaviours were studied. Fibre weight ratios were taken as 4:1 (EFB and woven jute weight ratio). Pure EFB and jute fibre reinforced composites were also prepared for comparison purposes with hybrid composites properties. Hot pressure moulding was used for preparing the EFB/jute fibre reinforced hybrid composites.

## **EXPERIMENTAL**

### **Materials**

Oil palm empty fruit bunch fibre mats were supplied by Ecofibre Technology Sdn. Bhd., Malaysia. Woven jute fibre mat was procured from Indarsen Shamlal Pvt. Ltd. (Jute House since 1948), Kolkata, India. The physical and mechanical properties of oil palm EFB and jute fibre are given in Table 1. The epoxy resin (A331) and epoxy hardener (A 062) was supplied by Zarm Scientific & Supplies Sdn. Bhd, Malaysia. The epoxy resin used in this research was clear epoxy resin based on diglycidyl ether of Bisphenol A. A non-reactive benzyl alcohol was used, which was supplied by Aldrich Company. It was added in the epoxy-polyamide mixture in order to reduce viscosity and to ease the impregnation process of the composite.

### Preparation of Composites

The woven fibre mat of jute ( $J_w$ ) and oil palm empty fruit bunches (EFB) fibre were used in preparation of hybrid composites. It was then impregnated with epoxy resin in a mould of dimensions 304 mm x 203 mm. Composites with different sequence of fibre mat arrangement were prepared by keeping the oil palm EFB/woven jute fibre weight ratios constant at 4:1. Oil palm EFB fibre mat and woven jute fibre mat were stacked together with the layer of woven jute fibre mat sandwiched in between the layer of oil palm EFB fibre mat and vice versa in the mould. A neat epoxy matrix (unfilled) sample was prepared, and epoxy resin with pure EFB, and pure jute fibre composites were also prepared. The test specimens for water absorption and thickness swelling were cut from the composites according to ASTM standards.

### Water Absorption Test

The composite samples were immersed in distilled water at room temperature. The water absorption was determined from Equation (1) for various periods of times. Samples were weighed, and the weight of the samples was determined before and after removing from water at various time intervals. After the samples were removed, they were gently blotted with filter paper to remove excess water on the surface, and the weight of the samples was recorded. The water absorption test was continued for several days until a constant weight of the samples was obtained. The percentage equilibrium water absorption was calculated as an average value of several measurements. The percentage of water absorption was calculated from Equation (1) using ASTM D570,

$$\text{Water absorption}(\%) = \frac{W_n - W_d}{W_d} \quad (1)$$

where  $W_n$  is the weight of composites samples after immersion and  $W_d$  is the weight of the composite samples before immersion.

### Thickness Swelling Test

Five samples of each different type of composite were prepared for the testing of thickness swelling. Thickness swelling was calculated according to ASTM D 570 by using Equation (2). The thickness swelling test was used to measure the swelling of the samples. Before the samples were soaked into the distilled water, the thickness of every sample was measured, and each sample was labeled. After 24 hours, the sample was taken out and dried before it was measured. The thickness value of the samples was taken. The thickness swelling test was continued for several days until constant thickness values of the samples were obtained. The calculation of the thickness swelling is shown below,

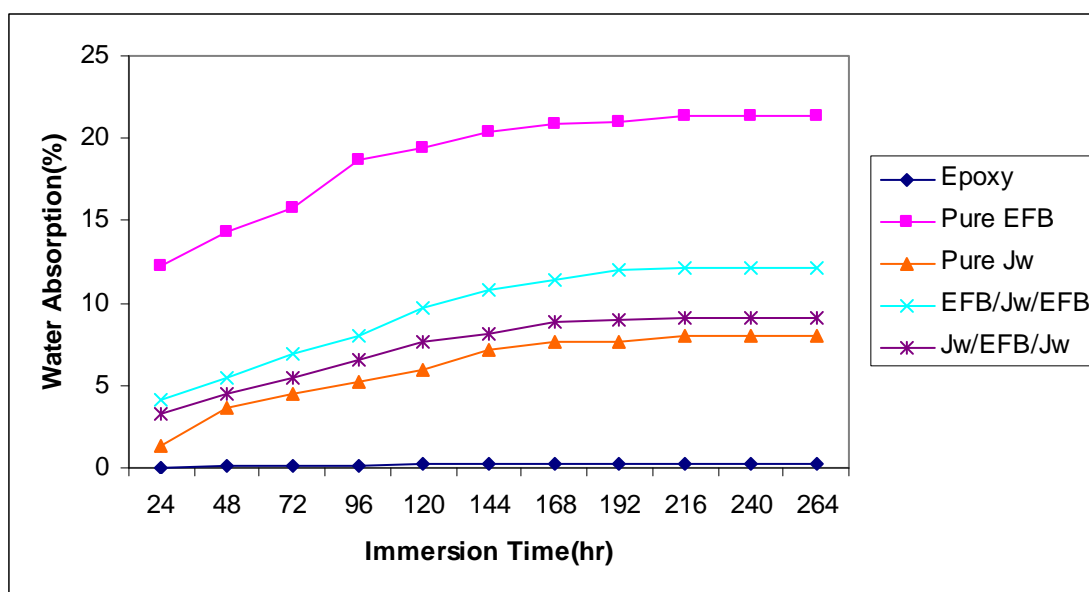
$$\text{Thickness Swelling}(\%) = \frac{T_1 - T_0}{T_0} \quad (2)$$

where  $T_1$  is the thickness after soaking and  $T_0$  is the thickness before soaking.

## RESULTS AND DISCUSSION

### Water Absorption

Figure 1 shows the trend of water absorption of composites made up of pure epoxy and oil palm EFB/jute fibres (pure epoxy, pure EFB, pure jute, and hybrid composites). It is clear from Fig. 1 that water absorption increased with immersion time. Hybrid composites showed rapid uptake of water over the first several hours due to the hydrophilic nature of the cellulosic materials, enabling the composites to take up a high amount of water. These water molecules remain in the inter-fibrillar space of the cellulosic structure and cause cracks and micro voids at the surface of composites (Ashori and Sheshmani 2010). When the composites have been immersed in water for a long time, the capillary action conducts the water molecules to the material and fills the voids and cracks in the composites (Ahmed and Vijayarangan 2007). Such water-filled voids at the interface result in interfacial de-bonding. A similar study was done on pulp fibre/wood flour reinforced polyvinyl chloride hybrid composites, and it was found that water absorption in hybrid composites is significantly higher than the neat polyvinyl chloride due to a large number of porous tubular structures present in fibre, accelerating the penetration of water by capillary action (Kiani et al. 2010).



**Fig. 1.** Water absorption (%) of oil palm EFB/woven jute (Jw) fibre reinforced hybrid composites

Hybrid composites (EFB/J<sub>w</sub>/EFB and J<sub>w</sub>/EFB/J<sub>w</sub>) exhibited better water absorption properties compared to pure EFB composite. For the EFB/J<sub>w</sub>/EFB hybrid composite, in which a woven jute layer was sandwiched between oil palm EFB layers, the water absorption was more than in the case of J<sub>w</sub>/EFB/J<sub>w</sub>. Incorporation of woven jute fibre with EFB fibre in an epoxy composite decreased the water absorption of the hybrid composites. This showed that the packing and hybrid arrangement of fibre will limit the absorption of moisture into the composite, because the voids have been filled up during

the formation of composite. Previous study done on void content of pure EFB composites indicated that oil palm EFB fibre composites exhibited a higher amount of voids (8.6%) compared to the jute fibre composite (2.6%) (Jawaid et al. 2011). The density of pure EFB composite is 1.042 g/cm<sup>3</sup>, which is lower than pure jute composites, 1.2 g/cm<sup>3</sup> (Jawaid et al. 2010). The percentage of water absorption in the composite will directly affect its density. This can be demonstrated by the low density of pure EFB composite with the presence of voids inside the composite, leading to higher water absorption. This may be due to formation of micro-channels, which contribute to the higher water absorption and also provide a way for water to pass through pores on the surface of the fibres as well (Pothan et al. 2007). Water will enter easily into the composites through such pores, and this water is absorbed by the polar OH groups of oil palm EFB fibres, causing a rise of water absorption. Water absorption behaviour of natural fibres also depends on free hydroxyl groups present in cellulose and hemicelluloses, which are accessible by water. Besides that, other factors such as porosity, void content, lumen size, and fibre-matrix adhesion also effect water absorption behaviour of the composites (Mariatti et al. 2008). It is reported that natural fibre polymer composites show remarkable water absorption due to the presence of voids (Yang et al. 2006, 2007). In contrast, the water absorption for the epoxy composite was the lowest, with a value of 0.22 %. This is due to the ability of epoxy resin to limit the absorption of water into the fibre-mat composite, since the epoxy resin matrix has a water-resistant nature.

**Table 1.** Physical and Mechanical Properties of Oil Palm EFB and Jute Fibre (Sreekala et al. 2002; Fu et al. 2001; Shinoj et al. 2011; Bledzki and Gassan 1999; Ahmed et al. 2003; Munikenche Gowda et al.1999)

Properties	Oil Palm EFB fibre	Jute fibre
Density(g/cm <sup>3</sup> )	0.7-1.55	1.3
Tensile Strength(MPa)	50-400	393-773
Young's modulus(GPa)	1-9	26.5
Elongation at break (%)	8-18	1.5-1.8
Cellulose content (%)	49.6	58-63
Hemicellulose content (%)	18%	12%
Lignin content (%)	21.2	12-14

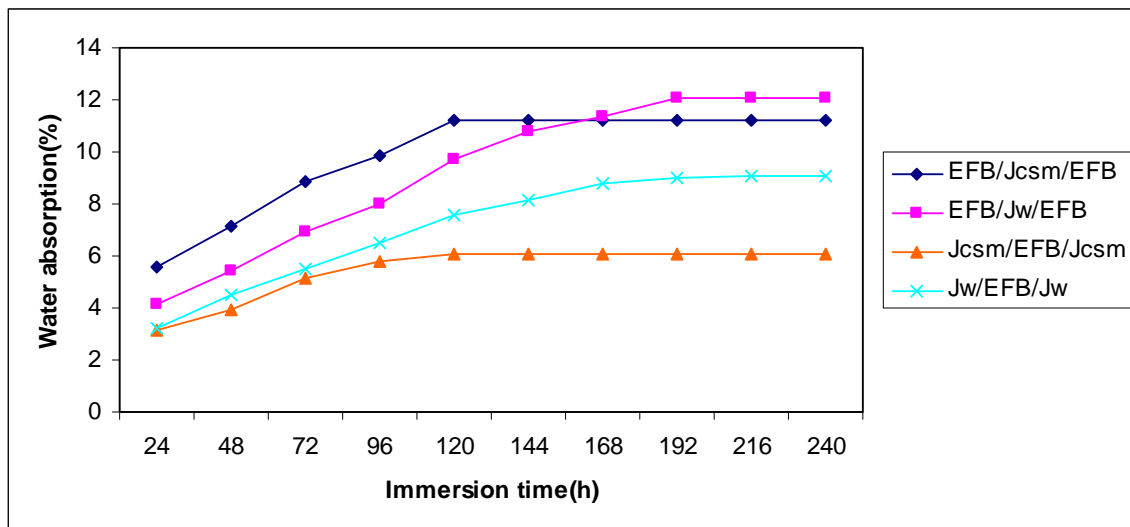
Oil palm EFB reinforced epoxy composite (pure EFB composite) showed higher water absorption compared to pure woven jute composite. This indicated the high porosity or the presence of voids on the surface of pure EFB composite. With the presence of voids on the surface of composite, the weight of composite will increase by trapping the water inside the voids. Oil palm EFB fibres contain a higher proportion of hemicelluloses, which are hydrophilic in nature and responsible for higher water absorption in the pure EFB composite (Table 1). This is also due to the highly hydrophilic nature of the EFB fiber, owing to the free hydroxyl group present in the cellulose and lignin structures (Khalil et al. 2010). The presence of hydroxyl and other polar groups in natural fibres result in poor compatibility between fibre and matrix, which increases the water absorption (Shakeri and Raghimi 2010). An optical microscopy study of jute-epoxy composite confirmed water damage and showed a gap between fibre and

matrix (Gassan and Bledzki 1999). Cell-from-cell debonding causing cracks within fibre was also detected by microscopy (Newman et al. 2007).

Figure 2 shows that woven hybrid composite exhibited higher water absorption compared to chopped hybrid composites (Jawaid et al. 2010). This is mainly attributable to the high void content of the woven fabric composites compared to chopped mat composites. Bao and Yee (2002) also reported that warp and weft fibres in woven fabrics restrict the matrix shrinkage during curing, hence increasing the residual stress in the composite. As a result of residual stress, micro-cracks were formed in hybrid composites. More void content and residual stress in the composites help to diffuse water easily into woven hybrid composite and ultimately increase water absorption behaviour of woven hybrid composites.

### Thickness Swelling

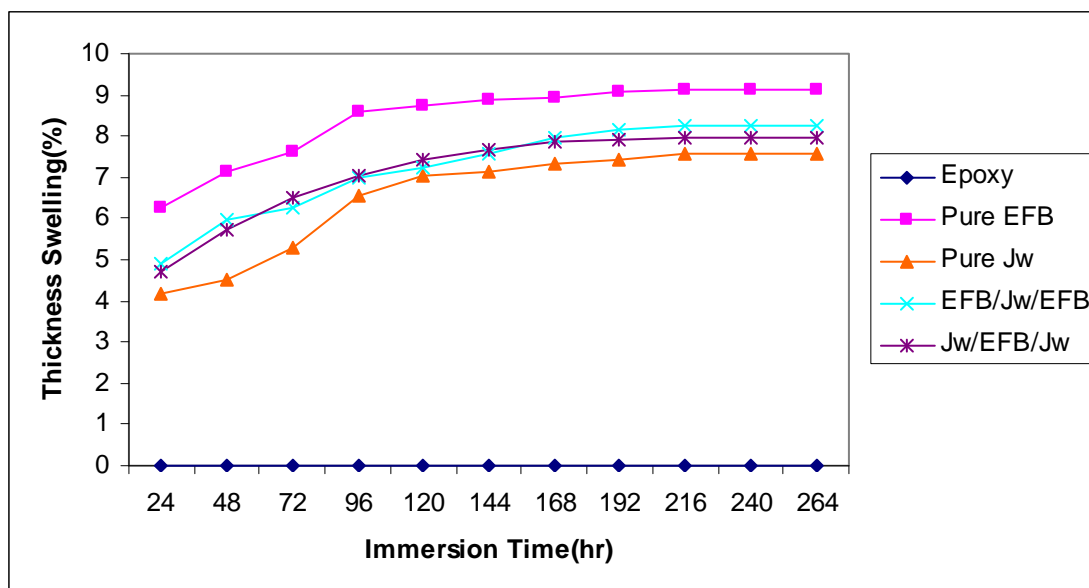
Natural fibre-based polymer composites are poorly water resistant due to the presence of polar groups, which attract water molecules through hydrogen bonding (Ashori and Sheshmani, 2010). These phenomena cause moisture buildup in cell walls (fibre swelling) and at the fibre/matrix interface. This is responsible for dimensional changes of natural fibre reinforced polymer composites, especially thickness and linear expansion due to reversible and irreversible swelling of the composites (Khalil et al. 2007b, Nourbakhsh and Ashori 2010).



**Fig. 2.** Comparison of water absorption (%) of woven jute (Jw) and chopped strand mat (csm) jute fibre hybrid composites having a ratio of oil palm EFB and jute fibre of 4: 1 at 40% fibre by weight

Figure 3 shows the thickness swelling behaviours of hybrid and pure composites. Pure EFB composite showed the highest rate of thickness swelling (9.12%) among all the composites. The pure woven jute composite showed a moderate thickness swelling (7.55%). In contrast, thickness swelling for the epoxy composite was the lowest, with the value 0 %. In other words, there was no thickness swelling in the epoxy composite. This is due to epoxy resin limiting the absorption of water into the fibre-mat composite

because epoxy resin provides a water resistant matrix. It is clear from Fig. 3 that the thickness swelling for hybrid composites followed a similar trend to the water absorption behaviour, increasing with immersion time until an equilibrium condition was obtained. As time goes on, water molecules penetration in the fibre cell walls results in swelling of the hybrid composite due to affected hydrophilic cellulose and hemicelluloses (Khalil et al. 2007a). Hybridization of pure EFB composite with woven jute fibre caused a remarkable reduction in thickness swelling rate. The thickness swelling of composite can be expected to depend on the exposure of the lignocellulosic fibre on the surface of composite.

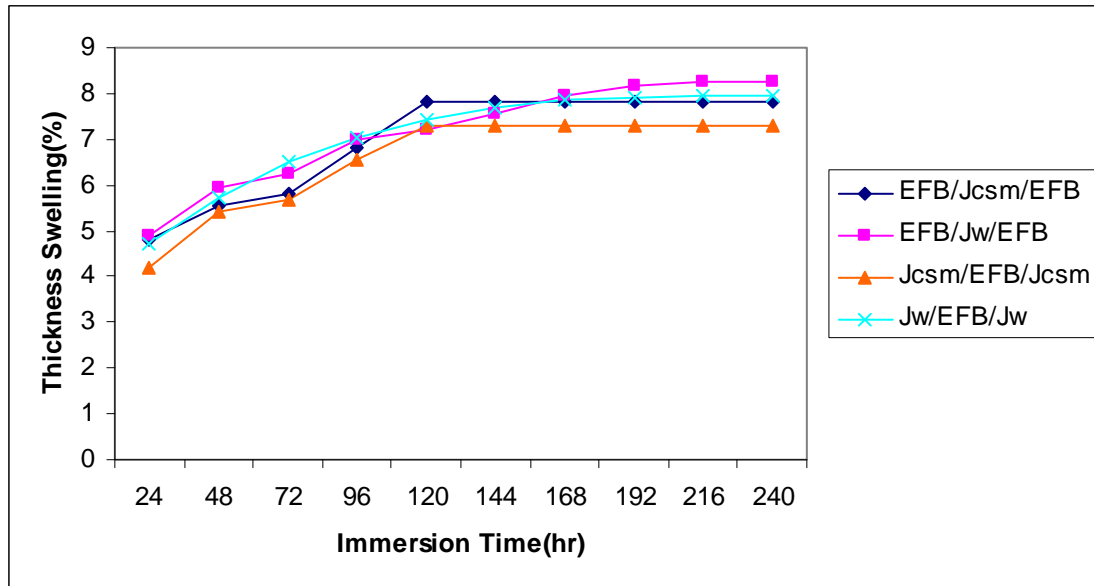


**Fig. 3.** Thickness swelling (%) of oil palm EFB/woven jute (Jw) fibre reinforced hybrid composites

The hybrid composites of EFB/J<sub>w</sub>/EFB and J<sub>w</sub>/EFB/J<sub>w</sub> showed moderate thickness swelling, i.e. 8.25 and 7.94 %, respectively. J<sub>w</sub>/EFB/J<sub>w</sub> hybrid composite showed less thickness swelling compared to EFB/J<sub>w</sub>/EFB, due to the presence of an outer layer of woven jute fibre. This indicated that the packing and hybrid arrangement of fibre will limit the absorption of moisture into the composite, thus limit the swelling of fibre and the percentage of thickness swelling. It also showed that the thickness swelling values of composites increased with an increased of water absorption time. By increasing the exposure time of composites to water, a significant amount of water absorbed, resulting in the swelling of the fiber. The swelling of the fibre places stress on the surrounding matrix and leads to micro-cracking, which would eventually cause the composite to fail catastrophically. Moreover, the hygroscopic properties in the natural fibers increased the water swelling ability, where water crept under the capillary of the composite (Khalil et al. 2001).

Figure 4 compares the thickness swelling of woven jute fibre reinforced hybrid composites versus the thickness swelling of chopped strand jute fibre reinforced hybrid composites. Woven jute fibre based hybrid composites show more thickness swelling

compared to chopped hybrid composites (Jawaid et al. 2010). Woven jute fibre-based hybrid composite showed higher values, which indirectly indicates higher void content in the system, allowing water to more easily diffuse into the composite through void spaces. Water is easily absorbed into the composite systems through the voids (Yang et al. 2006).



**Fig. 4.** Comparison of thickness swelling (%) of woven jute (Jw) and chopped strand mat (csm) jute fibre hybrid composites having a ratio of oil palm EFB and jute fibre of 4:1 at 40% fibre by weight

## CONCLUSIONS

Pure woven jute composites showed the lowest percentage of both water absorption and thickness swelling among all of the composite samples. A hybrid composites of EFB/J<sub>w</sub>/EFB and J<sub>w</sub>/EFB/J<sub>w</sub> showed improvement in water absorption and thickness swelling properties compared to pure EFB composites. A composite with oil palm EFB fibres showed the highest percentage in both water absorption and thickness swelling. This can be attributed to their high hemicellulose and high lignin content compared to jute fibre. With the water immersion tests, the water absorption and thickness swelling increased with immersion time for all types of composites.

## ACKNOWLEDGMENTS

The researchers would like to thank the Universiti Sains Malaysia, Penang for providing the USM fellowship and research grant (1001/PTEKIND/841020) that has made this work possible.



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Article submitted: December 14, 2010; Peer review completed: February 13, 2011;  
Revised article received and accepted: February 14, 2010; Published: February 17, 2011.