Fibre loading effects on dynamic mechanical properties of compression moulded luffa fibre polyester composites

G. Kalusuraman*, I. Siva and J.T. Winowlin Jappes

Centre for Composite Materials, Department of Mechanical Engineering, Kalasalingam University, Anand Nagar/TN, India
Email: kalusunrk@gmail.com
Email: isiva@klu.ac.in
Email: winowlin@yahoo.com
*Corresponding author

Xiao-Zhi Gao

Department of Electrical Engineering and Automation, Aalto University School of Electrical Engineering, Otaniemientie/Aalto, Finland
Email: xiao.z.gao@gmail.com

Sandro Campos Amico

Laboratory of Polymeric Materials, School of Engineering, Federal University of Rio Grande do Sul, Porto Aleger/RS, Brazil
Email: amico@ufrgs.br

Abstract: In this work, dynamic mechanical analysis (DMA) of untreated luffa fibre composites has been carried out. Composites are produced using luffa fibre mat and polyester resin. Compression moulding is done at 5MPa pressure from 30 to 50% for varying fibre loading. Temperature ramped dynamic mechanical analysis is done to understand the fibre loading effects on dynamic properties. Results show, that increase in fibre loading significantly increase the storage modulus of the composites without any change in mechanical characteristics. Cole-Cole plot is drawn to understand the elastic-plastic behaviours and results reveal that, the more fibre is mixed content the more the elastic behaviour is found.

Keywords: luffa fibre; polyester composite; fibre loading; DMA.

Biographical notes: G. Kalusuraman is a graduate in Mechanical Engineering from Periyar University in 2002. He received his Master’s in Manufacturing Engineering from Anna University Chennai in 2009. He is pursuing his PhD in Kalasalingam University, Tamilnadu, India. He is also working as an Assistant Professor in the Department of Mechanical Engineering, Kalasalingam University. His research interests include natural fibre reinforced polymer composite and material characterisations.

I. Siva is a graduate in Mechanical Engineering from Manonmania Sundaranar University in 2002. He received his Master’s in Manufacturing Engineering from Anna University, Madurai in 2005. He received his PhD from Kalasalingam University in 201, Tamilnadu, India. He is also working as an Associate Professor in the Department of Mechanical Engineering, Kalasalingam University. His research interests include natural fibre reinforced polymer composite and material characterisations.

J.T. Winowlin Jappes received his degree in Mechanical Engineering from Manonmaniam Sundaranar University, Thirunelveli in 1997 and his Master’s in Production Engineering from Annamalai University, Chithambaran in 2000. He received his PhD from IIT Madras, Chennai with specialisation in Mechanical Engineering. His research interests include surface modification and composites. Currently, he is working as a Professor in the Department of Mechanical Engineering, Kalasalingam University (Kalasalingam Academy of Research and Education), Krishnankoil, Tamilnadu, India.

Xiao-Zhi Gao received his BSc and MSc degrees from the Harbin Institute of Technology, China in 1993 and 1996, respectively. He earned his DSc (Tech.) degree from the Helsinki University of Technology, Finland in 1999. Since January 2004, he has been working as a Docent at the same university. He is also a Guest Professor of the Beijing Normal University, Harbin Institute of Technology and Beijing City University, China. Currently, he is working as an Adjunct Professor in the Department of Electrical and Automation, Aalto University of Electrical Engineering, Otaniemiete, Aalto, Finland. He was the General Chair of the 2005 IEEE Mid-Summer Workshop on Soft Computing in Industrial Applications. His current research interests are neural networks, fuzzy logic, evolutionary computing, swarm intelligence, and artificial immune systems with their applications in industrial electronics.

Sandro Campos Amico received his degree in Chemical Engineering in 1994 from UFRN/Brazil, Master’s in Materials Engineering in 1996 from UNICAMP/Brazil, and PhD in Materials Engineering University of Surrey (2000) – England. Currently, he is working as a Professor at UFRGS – Brazil since 2005.

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1 Introduction

Natural fibre reinforced composite materials have much attention in the research industry because of their easy availability, low cost and renewability (Rossa et al., 2013; Borsoi et al., 2013; Pigatto et al., 2012). They have limited application because of the low wettability and poor mechanical properties compared to the synthetic fibre (Romanzini et al., 2012). The natural fibres obtained from seed, leaves which include coir, sisal, jute, ramie, hemp pine apple, banana, etc., are put with resin to produce the resinous material to meet low load application of engineering needs (Chand et al., 1984). Polymer-based fibre reinforced composite material is on good attention in the various applications. In recent years, the growing interests are developed in the natural fibre as reinforcement materials. Now days, 14.5 million tons natural fibres are produced in India which is compared to world natural production 45.5 million tons (Sathishkumar et al., 2013). Natural fibres are adopted for the various applications like roof, home appliance, hard hat, etc. Özturk (2010) reported that effect of fibre loading is made great impact on the mechanical properties of kenaf fibre reinforced composites. It shows that at 52% higher mechanical properties is obtained (Özturk, 2010).

Dynamic properties of the materials are mostly analysed via dynamic mechanical analysis (DMA), which is perhaps the most efficient tool to study their viscoelastic characteristics. Understanding the dynamic properties helps in new materials development as well as for determining service conditions. Hence, many researchers investigated the dynamic behaviour of materials in a range of temperatures or frequency ramping.

Understanding the dynamic properties help in new materials development as well as service condition determinations. Hence, many researchers reported that the dynamic behaviour of materials usually in temperature had ramping and sometimes with frequency had ramping. Pothen and Thomas (2003) reported the effect of fibre weight percentage on dynamic mechanical properties of banana fibre reinforced composites by for temperature and frequency ramping. Authors concluded that, incorporation of banana fibre in to matrix reduces the loss modulus and damping peaks of the polymer matrix composite. Geethamma et al. (2005) studied the dynamic mechanical properties of short-coir fibre reinforced composites through temperature ramping and they have reported that mechanical loss factor reduces by raise in frequency while the storage modulus value increases as frequency increases.

Tajvidi et al. (2006) produced bamboo and kenaf fibres/polypropylene composite and also investigated that the DMA which resulted in temperature ramping. They have concluded when the fibre loading is more composite, it results lowering the loss modulus considerably. Luffa is one the regional fibres of Southern India which is used for simple domestic applications. The hard wearability nature of luffa fibre attracts many low load engineering applications. The authors (Kalusuraman et al., 2016) earlier reported that effects of fibre surface modification on the friction coefficient of luffa fibre/polyester composites under dry sliding condition. In the past, few works were reported on the mechanical properties of luffa fibre polymer composite, nevertheless, DMA on the luffa fibre composite is found vacuum. Hence, this work is performed to investigate the effect of luffa fibre addition and loading on the polyester composite with temperature ramping. Along with the regular DMA, the Cole-Cole plot is also used to understand the elastic-plastic behaviour of the produced composite.
2 Experimental details

2.1 Materials

Luffa fibre mat obtained from the nearest firms, Rajapalayam Tamil Nadu, was used as reinforcement to the unsaturated isophthalic polyester resin with commercial grade VBR4503 supplied by the Vasavibala Resins Pvt. Ltd., Chennai/TN India. Methyl ethyl ketone peroxide (MEKP) and cobalt naphthenate were used as catalyst and accelerator respectively. Figure 1 shows the result of luffa fibre mat used in the composite production. Fibres appeared in light brown colour are dry fibres, in common, this fibre mat yield from luffa plant fruit in green state. Fruits were then dried in direct sunlight for a while to turn them into dried fibres (Figure 1).

Figure 1  Luffa fibre (see online version for colours)

2.2 Composites fabrication

Table 1 shows the notations that were used in composite production. Initially dried luffa fibres are conditioned in the hot-air oven for residue moisture removal. Prior to moulding, wax is deposited on the mould cavity for the easy ejection. Catalysed polyester resin (each 1.5 wt% of catalyst and accelerator to resin) was layered initially on the mould cavity. Luffa fibre mat layers were stacked over until to reach estimated layer numbers with subsequent application of catalysed resin among the layers. For study, 30, 40 and 50 wt% of fibres were chosen and produced separately. Mould was closed for room temperature curing with 5 MPa until 24 h.

Table 1  Notations used in composite production

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Notation used</th>
<th>Expansion</th>
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<tbody>
<tr>
<td>1</td>
<td>U3</td>
<td>30 wt% untreated luffa fibre reinforced composites</td>
</tr>
<tr>
<td>2</td>
<td>U4</td>
<td>40 wt% untreated luffa fibre reinforced composites</td>
</tr>
<tr>
<td>3</td>
<td>U5</td>
<td>50 wt% untreated luffa fibre reinforced composites</td>
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2.3 Dynamic mechanical analysis

A dynamic mechanical analyser DMA 242 (NETZSCH/Germany) is used to study the produced composites of various fibre loading conditions. Dual-cantilever method is followed to investigate with the sample dimension of $60 \times 10 \times 3 \text{ mm}^3$. Test temperature range is chosen as RT to $250^\circ \text{C}$ with $2^\circ \text{C/min}$ ramping. All the experiments were conducted with the constant applied frequency of $1 \text{ Hz}$. Before the analysis, all the specimens are oven dried to ensure moisture free conditions and covered with air-tight bags.

3 Results and discussion

3.1 Storage modulus

Storage modulus characterises energy stored in stable state of material. Figure 2 shows the storage modulus ($E'$) variation with respect to the applied head as a function of varying fibre loading. During onset, the energy stored in material was significantly increased after the incorporation of excessive fibres into polyester matrix. U3 composite has initial $E'$ as 1,150 MPa, incorporation of additional fibres (U4 composite) imparts 30% increase in storage modulus. Higher the fibres content increases the higher fibre-matrix contact areas (effective), is enhanced in storage modulus. Similarly, further incorporation of luffa fibres (U5 composite) imparts 48% raise in storage modulus and this reveals the significance of fibre loading on dynamic properties of composites. Storage modulus is always released, due to the heat addition into the material system, a falling curve noted in $E'$ in all the fibre loading conditions. With the increase in applied temperature, a sudden slash in storage modulus occurred and reaches the least at end. Mobility of polymer structure in the fibre-matrix system would be responsible for this significant loss in storage modulus. Due to the heat addition, the fibre-matrix interaction (binding) gets broken. Hence the structure becomes weak and starts losing the storage modulus. Invariably, all fibre loading conditions respond typically in this analysis. The point on which the curve turns from plastic region to rubbery region is known as glass transience temperature ($T_g$). For U3 composites, the $T_g$ is noted on $92^\circ \text{C}$. For U4 and U5, the $T_g$ is $96^\circ \text{C}$ and $99^\circ \text{C}$ respectively. The polymer mobility is drastic in $T_g$ region.

3.2 Loss modulus

Figure 3 shows the loss modulus ($E''$) variation as a function of applied temperature with respect to the selected fibre loading conditions. Loss modulus increases considerably with respect to the fibre loading in an increasing order. Due to the polymer chain’s free movement, the composites dissipate higher mechanical energy at onset and less during the running period (for higher temperatures). For a composite within the effective free volume, addition of further fibres creates more number of chain segments which result more relaxation process inside the composite system. Due to this fact, peaks of $E''$ were increased for increasing fibre loading composites. U3 composites have $T_g$ of $92^\circ \text{C}$, which is increased to 96 and $99^\circ \text{C}$ for U4 and U5 composites.
3.3 Cole-Cole analysis

The Cole-Cole plot is embodied with storage modulus ($E'$) vs. loss modulus ($E''$) which can be a semi-circle. The semicircular plot attributes the homogeneity nature of the produced composite. It is mainly representing the structural changes of polymer/composite. Changes in semi-circularity of Cole-Cole plot represent the good adhesion between matrix and fibre of a composite system (Zhang and Chen, 2006). Flatten of the curve will report with the raise in fibre loading which attributes the formation of thick fibre-matrix interface and meantime the heterogeneity depends only the matrix system (Almeida et al., 2012; Ornaghi et al., 2012). Figure 4 shows the Cole-Cole plot for the produced composites. Flatten of semi-circularity of plot was increasing as increasing the fibre loading. This evident that enhance in fibre-matrix interfacial strength as a function of fibre loading.
Fibre loading effects on dynamic mechanical properties

Figure 4  Cole-Cole plot for luffa fibre reinforced composites (see online version for colours)

3.4 Damping factor

Mechanical loss factor is a ratio of loss to storage modules otherwise known as tan δ. Figure 4 shows the effect of fibre loading on the mechanical loss factor as a function of ramping temperature. Peak heights are significantly lowered with the increment of fibre contents. On the other hand, Tg of the composites shifted towards higher values in U4 and U5 composites. Initially U3 composite possess Tg as 92°C with the damping of 0.212. For an individual curve, the mechanical damping peak increases with the increase in temperature (Figure 5) and reaches the high point at the Tg region. During onset, the molecular elastic deformations cause the low viscous flow. The presence of molecular segments in the system possesses high stored energy. Due to this fact the energy dissipation is high at low temperatures. Attenuation of fibres inside the surrounded matrix volume causes the damping in multi-component material system. This internal vibration is influenced by the fibre loading and strength of fibre-matrix interface. In common the vegetable fibres have poor compatibility with the hydrophobic polyester matrix. Hence such attenuations are high in natural fibre composite materials. Nevertheless, increase in fibre members per unit volume of the matrix is significantly reduced the internal vibration which in turn less damping experienced. For U4 and U5 composites, the damping was 0.192 and 0.173 respectively. Lower the peak heights attributing the quality of fibre-matrix interface. Once the fibre-matrix interface becomes closed and thick then there would be an effective stress transfer and hence energy absorption is good. The elastic to the viscous phase balancing is studied from the tan δ curves. At the Tg region, the micro-Brownian motion resulted the high damping. After the Tg, molecular segments become free to move inside the volume which in turn decreases damping. After Tg, energy stored in every segment is released for each stage of temperature ramping; in addition, in rubbery region, molecules are free to move. Hence the damping at higher temperature is felt down.
4 Conclusions

In this work, dynamic properties of luffa fibre reinforced composites for different fibre loading (30, 40 and 50%) are described. Effect of fibre loading on modulus and damping are studied in detail and explained. Storage modulus for luffa fibre composites is increased with the increase in fibre content. High peaks are found for U5 composites. Similarly, for loss modulus, high peaks are observed in high fibre loaded composite. Increased internal friction among fibres causes the high loss modulus in fibre rich composites. In addition, increase in fibre content per unit volume increases the matrix segments which in turn more restrictions for polymer mobility.

Tg of the produced composites are shifted towards higher number with the incorporation of more reinforcing fibres. Closely packed fibre sets have increased the fibre-matrix interface due to the internal fibre-fibre friction and hence the glass transition temperature of the polymer increased.

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