



Synthesis and characterization of epoxy methacrylate of (E)-1,3-bis(4-hydroxyphenyl)prop-2-en-1-one and its jute/glass composites

J. D. Thanki, P. H. Parsania*

Polymer Chemistry Division, Department of Chemistry, Saurashtra University,
Rajkot 360 005, Gujarat, India

Tel.: +91-281-2583984, Fax: +91-281-2577633

*E-mail address: phparsania22@gmail.com & phparsania@aol.com

ABSTRACT

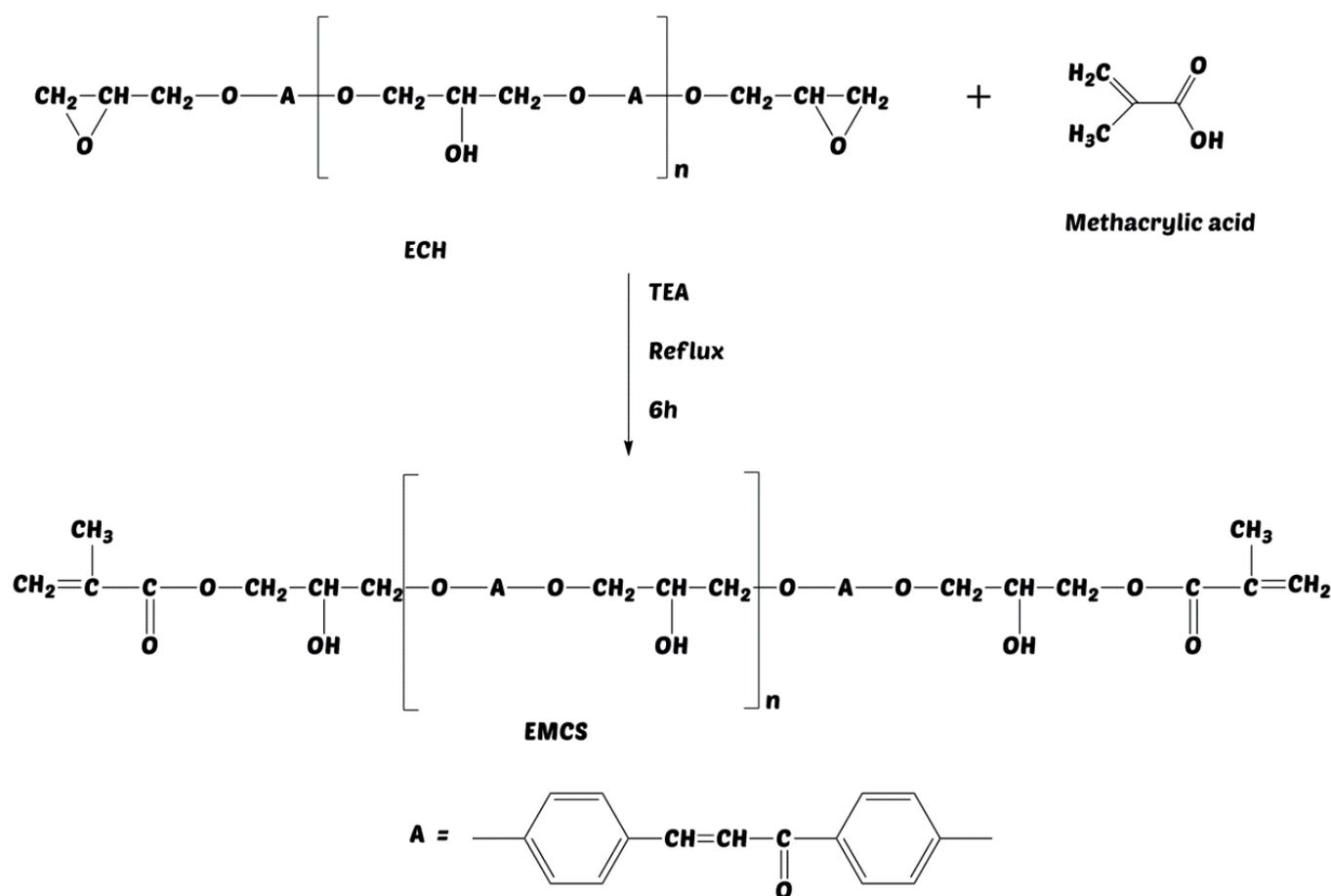
Epoxy methacrylate of (E)-1,3-bis(4-hydroxyphenyl)prop-2-en-1-one (EMC) has been synthesized by condensing 1 equivi. (318g) epoxy resin of (E)-1,3-bis(4-hydroxyphenyl)prop-2-en-1-one and 2.1 equivi. (181g) methacrylic acid using 10 ml triethyl amine as a catalyst, 2.5 g hydroquinone as an inhibitor and 350 ml tetrahydrofuran as a solvent at reflux temperature for 1-7 h. Styrene was used as a reactive diluent. The structure of EMC was supported by FTIR and ¹H NMR techniques. EMC showed endothermic transition at 118 °C and 307 °C, respectively due to melting and crosslinking followed by decomposition reaction and EMCS showed endothermic transitions at 81 °C and 255 °C due to branched and uncrosslinked EMCS and some physical change. EMC and EMCS are thermally stable up to about 265 and 332, respectively. EMC followed two steps degradation kinetics, while EMCS followed single step degradation kinetics. Jute and glass composites of EMCS were fabricated by hand lay-up technique followed by compression molding under 20 bar pressure and at 120 °C for 4 h. J-EMCS and G-EMCS showed 22.7 and 182 MPa tensile strength; 10.9 and 156.5 MPa flexural strength; 3.1 and 1.6 kV mm⁻¹ electric strength; and 2.2 x 10¹² and 2.8 x 10¹¹ Ohm cm volume resistivity. Both J-EMCS and G-EMCS showed excellent hydrolytic stability even in harsh acidic and saline environments and also in boiling water. Observed equilibrium water content at 35 °C for J-EMCS and G-EMCS in water, 10% of aq. NaCl, and 10% of aq. HCl are 8.8, 10.8, and 8.7% ; 5.8, 4.6, and 4.7%, respectively. The composites may be useful for low load bearing housing units, and in electrical, electronic and marine fields.

Keywords: epoxy methacrylate; thermal stability; composites; hydrolytic stability

1. INTRODUCTION

Vinyl ester resins possess comparable physico-chemical properties to those of epoxy resins [1-3]. The aromatic rings contribute good mechanical properties and heat resistance, while ether linkage contributes to good chemical resistance [4-9]. Epoxy methacrylate resins have terminal reactive double bonds [10], which can be cross-linked with or without the addition of comonomer. They possess good toughness, improved elongation, good chemical resistance, and better wetting and bonding to glass reinforcements [11-13]. This class of resins are mainly used to fabricate a variety of reinforced products such as pipes, tanks, scrubbers, ducts [14,15] airplanes, automobile control rods [16] and wind turbine blades [17].

Recently we have reported physico-chemical properties of epoxy resin of (E)-1,3-bis(4-hydroxyphenyl)prop-2-en-1-one [7] but no work has been reported on synthesis and properties of epoxy methacrylate of (E)-1,3-bis(4-hydroxyphenyl)prop-2-en-1-one (Scheme 1). In the present work we have reported synthesis and characterization of epoxy methacrylate, its jute and glass composites.



Scheme 1. Synthesis of epoxy methacrylate of (E)-1,3-bis(4-hydroxyphenyl)prop-2-en-1-one

2. EXPERIMENTAL

2. 1. Reagents and materials

Solvents and chemicals used were of laboratory grade and purified prior to their use [18] or used as received. Epoxy resin of (E)-1,3-bis(4-hydroxyphenyl)prop-2-en-1-one (EEW 318) was synthesized and purified according to our recent publication [7]. Styrene (Siscochem, Mumbai), triethylamine (Spectrochem, Mumbai), hydroquinone (Siscochem, Mumbai) methylethylketoneperoxide and 6% cobalt naphthenate (free samples from EPP Composites, Rajkot) were used as received. Woven jute fabric (Brown jute, Corchorus capsularis) used in the present study was collected from a local market and silane treated E-glass fabric was collected from Unnati Chemicals, Ahmedabad.

2. 2. Synthesis of epoxy methacrylate

To a 100 ml three-neck round bottomed flask equipped with a condenser, mechanical stirrer, and thermometer was placed in an oil bath. To this flask 8.0 g epoxy resin, 4.5 g methacrylic acid, 10 ml tetrahydrofuran, 0.1 g hydroquinone and 0.2 ml triethylamine were charged and the temperature was raised to reflux with stirring. The reaction was carried out at the interval of 1h. The reaction mixture was cooled to room temperature and the solid resin was isolated from cold water, filtered, washed well with saturated hot bicarbonate solution, and finally washed well with distilled water and dried in an oven at 50 °C. The yield of the resin was 10-11 g. The resin is soluble in common solvents like tetrahydrofuran, N, N-dimethylformamide, dimethylsulfoxide, etc. The resin was purified three times dissolving in DMF and precipitating out using a large excess of water. Hereafter resin is designated as EMC. The acid and hydroxyl values were determined according to reported methods [19] and are reported in Table 1 from which it is observed that acid value decreased and hydroxyl value increased with extent of reaction confirming practically completion of esterification reaction.

Table 1. Hydroxyl and acid values of epoxy methacrylate EMC.

Time (h)	1	2	3	4	5	6	7
Hydroxyl value (mg KOH/g)	193	223	284	324	329	332	343
Acid value (mg KOH/g)	51.83	46.75	36.19	33.17	24.36	18.09	13.04

2. 3. Preparation of epoxy methacrylate film

Into a 100 ml beaker, 10 g EMC and 10 g styrene were dissolved in 20 ml THF at room temperature. To this solution 0.5 ml MEKP and 0.5 ml cobalt naphthenate were added with continuous stirring. The resultant solution was stirred manually for 15 min and initiated at 60

°C for 5 min and then poured into a leveled 15 cm X 15 cm glass mold. The solvent was allowed to evaporate at a controlled rate. After 24 h, the film was peeled from the mold. Hereafter film is designated as EMCSF.

2. 4. Fabrication of jute/glass composite

Hand lay-up followed by compression molding technique was used for the fabrication of the jute and glass composites. Required quantity (Table 2) of EMC and styrene were transferred into a 1000 ml beaker containing 250 ml of tetrahydrofuran and was stirred well at room temperature. To this solution, 2% (of matrix) methylethylketoneperoxide and 1% (of matrix) of 6%-cobalt naphthenate were added as an initiator and an accelerator, respectively. The solution was stirred well and was applied to jute/glass fabrics (24 cm × 24 cm) with a smooth brush and solvent was allowed to evaporate at room temperature. Eight such jute/glass impregnated fabrics were stacked one over the other between two teflon sheets and kept between two preheated stainless steel plates and pressed under 1.5 bar pressure at 120 °C for 4 h and 2 h at room temperature. Silicone spray was used as a mold releasing agent. Hereafter, jute composite is designated as J-EMCS and glass composite as G-EMCS. Samples with required dimensions were machined for tensile and flexural tests. For chemical resistance study, 2 cm × 2 cm samples were machined and edges were sealed with a matrix material.

Table 2. Mechanical and electrical properties of jute/glass EMCS composites.

Composite	Jute / Glass g	EMCS g	Tensile strength, MPa	Flexural strength, MPa	Electric strength, kV mm ⁻¹	Volume resistivity, Ohm cm
J-EMCS	180	180	22.7	10.9	3.1	2.2 x 10 ¹²
G-EMCS	120	120	182	156.5	1.6	2.8 x 10 ¹¹
EMCSF	-	-	12.3	-	-	-

2. 5. Measurements

IR (KBr pellet) spectrum of EMC was scanned on a Shimadzu FTIR-8400 spectrometer over the frequency range from 4000 to 400 cm⁻¹. ¹H NMR spectrum of EMC was scanned on a Bruker AVANCE II (500 MHz) spectrometer using DMSO-d₆ as a solvent and TMS as an internal standard. The tensile strength (ISO/R 527- 1996 Type-I), flexural strength (ASTM-D-790-2003), electric strength (IEC-60243-Pt-1-1998), and volume resistivity (ASTM-D-257-2007) measurements were made on a Shimadzu Autograph Universal Tensile Testing Machine, Model No. AG-X Series at a speed of 10 mm min⁻¹, a high voltage tester (Automatic Electric-Mumbai) in air at 27 °C using 25/75 mm brass electrodes and a Hewlett Packard high resistance meter in air at 25 °C after charging for 60 s at 500 V DC applied voltage, respectively. Replicate measurements were carried out and the mean values were considered. Differential scanning calorimetric (DSC) measurements were carried out on a Shimadzu DSC60 at a heating rate of 10 °C min⁻¹ under a nitrogen atmosphere (flow rate 20 mLmin⁻¹) using standard aluminium pans. Known amounts of the samples were sealed with

the help of a crimper. The DSC thermograms were scanned over the temperature range from 50-400 °C. Thermo gravimetric analysis (TGA) was carried out on a Shimadzu DTG-60H at 10 °C min⁻¹ heating rate in nitrogen atmosphere. Chemical resistance study was carried out at 35 °C in water, 10% of aq. HCl, and 10% of aq. NaCl solutions and also in boiling water according to our recent publication [9].

3. RESULTS AND DISCUSSION

3. 1. Spectral analysis

FTIR (KBr) spectrum of EMC is presented in Figure 1. The characteristic IR absorption frequencies (cm⁻¹) are 3439.19 cm⁻¹ (O-H str.), 3061.13 cm⁻¹ (=C-H str.), 2939.61 cm⁻¹ (C-H asym. str.), 2877.89 cm⁻¹ (C-H sym. str.), 1712.8 cm⁻¹ (C=O str.), 1647.26 cm⁻¹ (C=C str. alkene), 1599.04 and 1510.31 cm⁻¹ (C=C str. aromatic), 1452.45 and 1423.51 cm⁻¹ (C-H def.), 1336.71 cm⁻¹ (C-OH def.), 1026.16 cm⁻¹ (C-O str.), 1257.63 cm⁻¹ (C-O-C str.), 1293.17 and 1170.83 cm⁻¹ (C-H ipd.), 1116.82 cm⁻¹ (C-H def., alkene), 981.8 and 914.29 cm⁻¹ (C-H def., alkene), 821.7 cm⁻¹ (C-H oopd.).

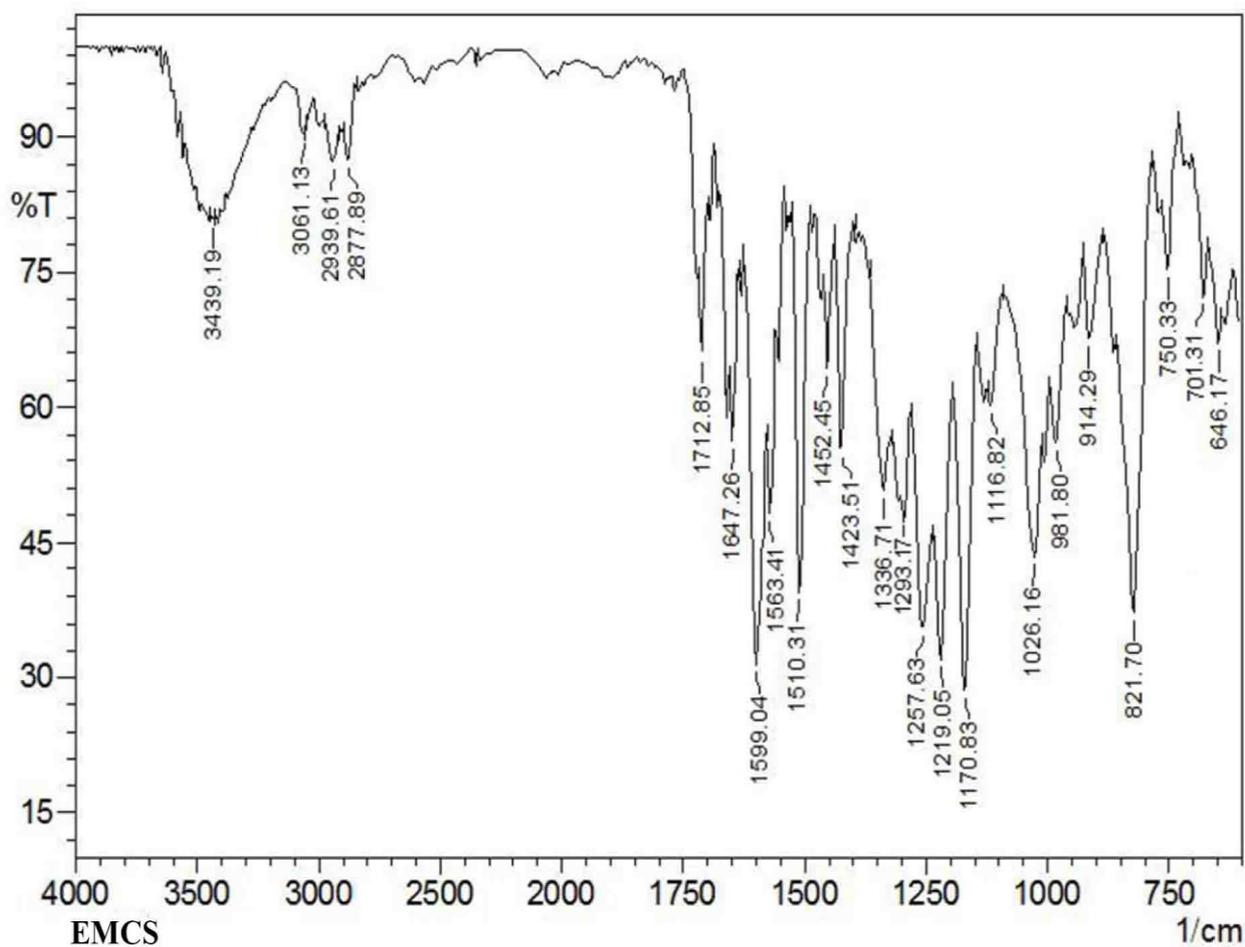


Figure 1. FTIR (KBr pellet) spectrum of EMC.

^1H NMR (DMSO- d_6) spectrum of EMC is presented in Figure 2 from which it is observed that the spectrum is highly complex. Different types of protons, their chemical shifts (ppm), and multiplicities are assigned as follows: 1.89 [s, $-\text{CH}_3$ (k)], 3.68 [s, $-\text{OH}$ (i)], 3.83-4.09 [m, $-\text{OCH}_2$ (g)], 4.10-4.18 [m, $-\text{CH}(\text{OH})$ (h)], 4.19-4.21 [m, $-\text{CH}_2\text{O}$ (j)], 5.66 [s, $=\text{CH}_2$ (m)], 6.06 [s, $=\text{CH}_2$ (l)], 7.01-7.19 [m, ArH (a,b,f)], 7.67-7.71 [d, $\text{CH}=\text{CH}$ (c)], 7.82-7.95 [m, ArH(e)], 8.15-8.17 [d, $\text{CH}=\text{CH}$ (d)]. Residual DMSO and moisture appeared at about 2.50 and 3.40, respectively. Side spinning bands are also observed around intense peaks. Thus, IR and NMR spectral data supported the structure of EMC.

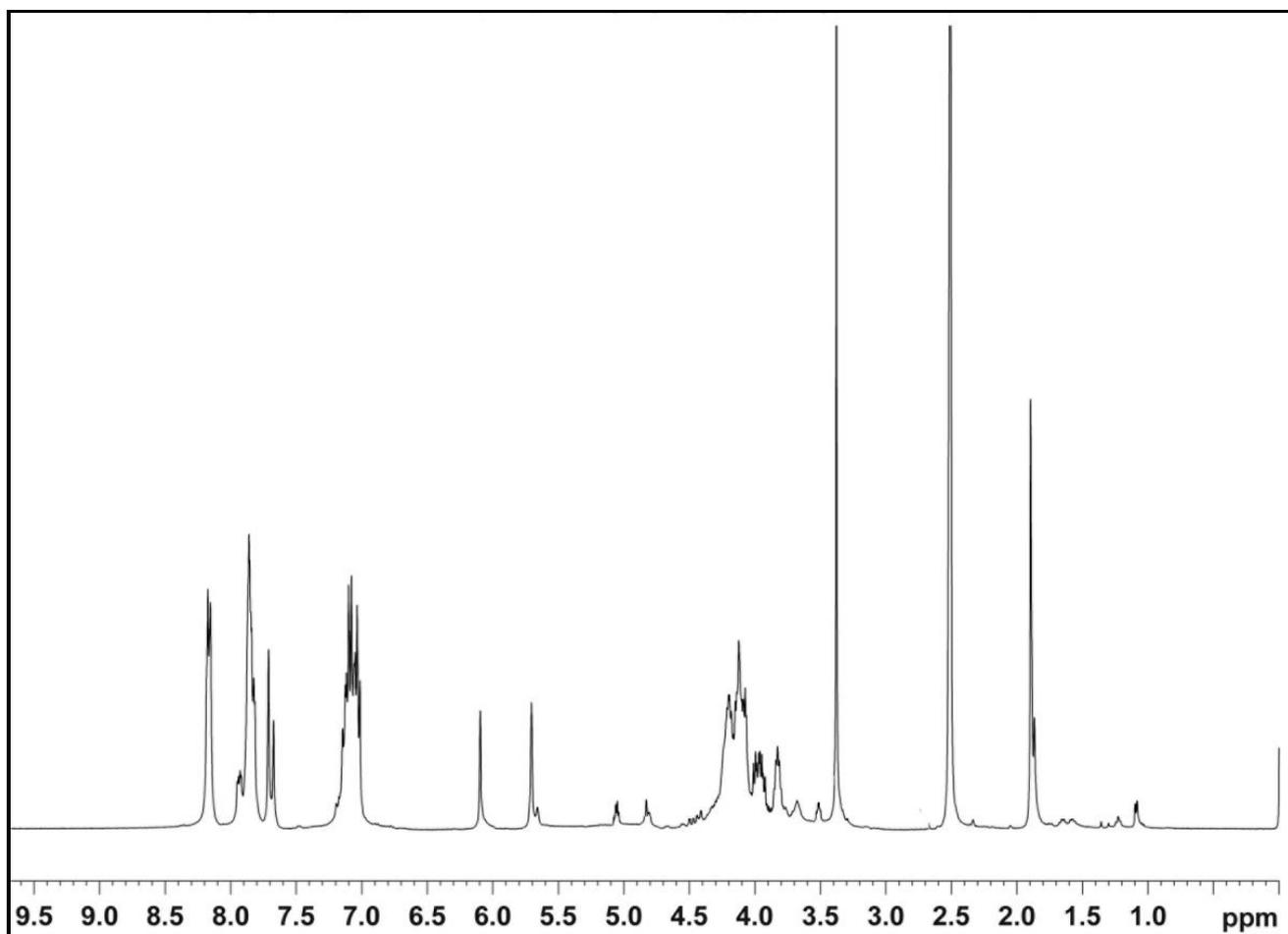


Figure 2. ^1H NMR (DMSO- d_6) spectrum of EMC.

3. 2. Thermal analysis

DSC thermograms of EMC and EMCS are presented in Figure 3. EMC showed endothermic transition at 118 °C and 307 °C, respectively due to melting and crosslinking followed by decomposition reaction and further confirmed by no weight loss over that temperature in its TG thermogram (Figure 4). EMCS showed endothermic transitions at 81 °C

and 255 °C due to branched and uncrosslinked EMCS and some physical change and further supported by no weight loss over that temperature in its TG thermogram (Figure 4).

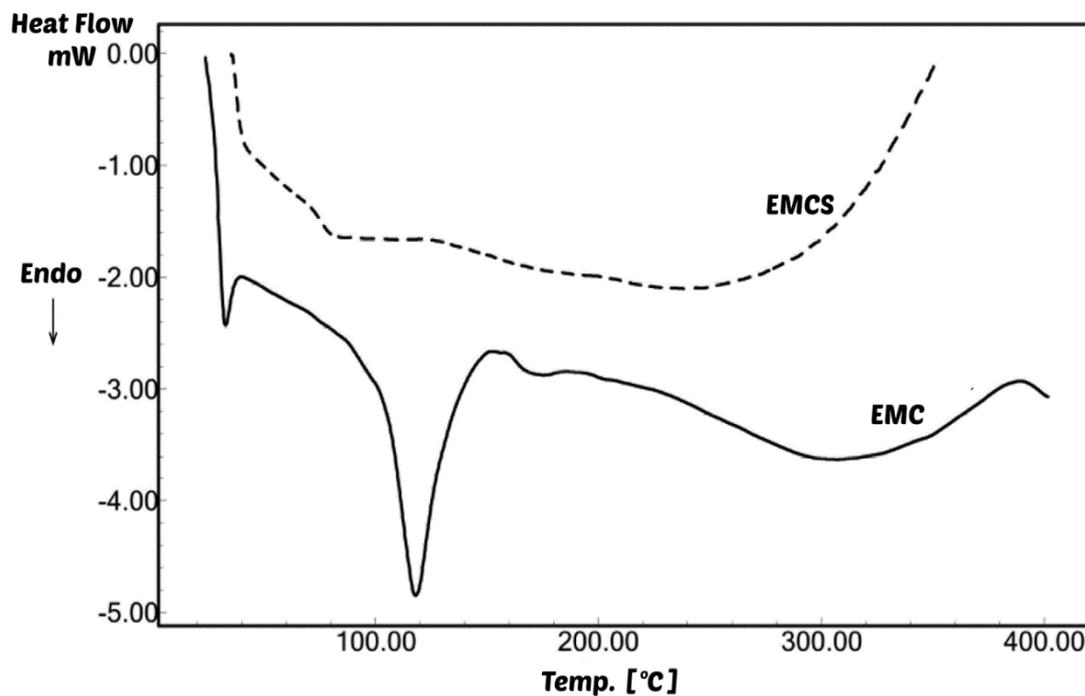


Figure 3. DSC curves of EMCS at 10 °C min⁻¹ heating rate in nitrogen atmosphere.

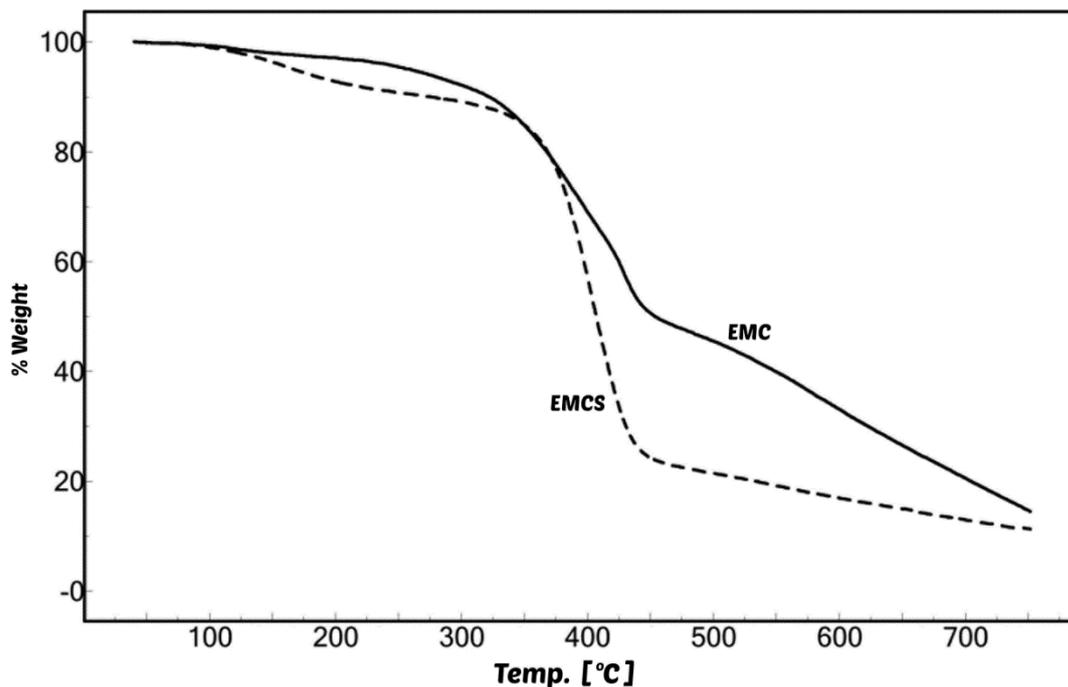


Figure 4. TG thermograms of and EMCS at 10 °C min⁻¹ heating rate in nitrogen atmosphere.

From Figure 4, it is clear that EMC is thermally stable up to about 265 °C and followed two-step degradation reactions, while EMCS is thermally stable up to about 332 °C and followed single step degradation reaction. EMCS showed excellent thermal stability than EMC due to high degree of cross linking density. EMCS showed small weight loss over temperature range from 118 °C to 208 °C due to traces of entrapped solvent. Initial decomposition temperature (T_o), decomposition range, temperature of maximum weight loss (T_{max}), % weight loss, and % residue remained at 750 °C for EMC and EMCS are presented in Table 3. T_{max} values were derived from dw/dt against Temperature plots. Associated kinetic parameters such as energy of activation (E_a), frequency factor (A) and order of the reaction (n) for all compounds were derived according to Anderson-Freeman method [20]:

$$\Delta \ln \frac{dw}{dt} = n \Delta \ln W - \left(\frac{E_a}{R} \right) \Delta \left(\frac{1}{T} \right) \quad (1)$$

$$A = \frac{E_a \beta}{RT^2} e^{E_a/RT} \quad (2)$$

$$\Delta S^* = R \ln \frac{Ah}{kT} \quad (3)$$

where dw/dt is the rate of decomposition, W is the active mass, β is the heating rate, R is the gas constant, h is the Planck's constant, T is temperature and k is the Boltzmann constant.

The least square values of above mentioned parameters along with regression coefficients (R^2) are reported in Table 3. The entropy change ΔS^* was determined at corresponding T_{max} . From Table 3, it is observed that both EMC and EMCS followed apparently zero order degradation kinetics. For EMC E_a and A values of second step degradation reaction are almost doubled than first step degradation reaction indicating rigid nature of the degradation product formed in the first step reaction. A large and negative magnitudes of ΔS^* suggested that transition states are more in orderly states [8].

Ether, ester, methyl, hydroxyl and phenyl side substituent groups are weak linkages in EMC and EMCS.

Table 3. TG and kinetic parameters of EMC and EMCS according to Anderson- Freeman method.

Parameter	EMC	EMCS
$T_o, ^\circ C$	265	332
Decomposition Range, $^\circ C$	265-394	332-462
	402-467	

T_{\max} , °C	393.5	402.5
	411.8	
% Wt. loss	11	59.7
	14.1	
% Residue at 750 °C	14.6	18.6
E_a , kJ/mol	151.4	127.1
	309.3	
A , s ⁻¹	9.11×10^9	3.70×10^7
	0.25	
ΔS^* , J/K mol	-60.8	-106.8
	-263.6	
n	0.18	0.08
	0.03	
R^2	0.973	0.98
	0.984	

Selective rupture occurs from such weak points and free radicals form, which further undergo a variety of reactions namely cross-linking, branching, rearrangement, etc. and formation of new product(s) take(s) place, which further degrade at elevated temperatures. It is likely that ester linkage is more susceptible to rupture than ether and side chain C–C linkages with evolution of carbon dioxide. Considerable residue for EMC (14.6%) and for EMCS (18.6%) at 750 °C indicated formation of highly thermally stable products.

3. 3. Mechanical and electrical properties

Tensile strength, flexural strength, electric strength, and volume resistivity of J-EMCS and G-EMCS are presented in Table 2. EMCSF showed low tensile strength due to rigid and brittle nature of the film. J-EMCS and G-EMCS showed moderately good tensile and flexural strengths. Both the composites showed comparatively low flexural strength than tensile strength due to rigid and brittle nature of the crosslinked EMCS and good interfacial adhesion. Jute composite of epoxy methacrylate of 1,1'-bis(4-hydroxy phenyl)cyclohexane (J-EBCMAS)^[21] showed better tensile strength (34.5 MPa), flexural strength (32.3 MPa), volume resistivity (1.2×10^{11} ohm cm) and comparable electric strength (3 kVmm^{-1}) confirmed more rigid and brittle nature of J-ECHS. Among several factors, the nature of matrix and fibers, degree of cure and interfacial adhesion have played an important role in

determining overall physical properties. Both the composites showed poor electric strength and moderately good volume resistivity due to polar nature of nature of the matrix. Among several factors, the nature of matrix and fibers, degree of cure and interfacial adhesion have played an important role in determining overall physical properties. Both the composites may be useful for low load bearing housing units and also in electrical and electronic industries as insulating materials.

3. 4. Chemical resistance

The water content in the sample can be determined according to Equation (4):

$$M = \frac{W_m - W_d}{W_d} \times 100 \quad (4)$$

where M = % water absorbed, W_m = weight of moist sample and W_d = weight of dry sample.

The percentage weight gained by J-EMCS in water, 10% of aq. HCl and 10% of aq. NaCl solutions with the passage of time at 35 °C is shown in Figures 5 and 6. The % weight gained (M_t) by each composite in a given environment increased, reached to maximum, and then practically remained constant, when equilibrium was established. The equilibrium water content and the equilibrium time for each of the composites in water, 10% of aq. HCl, and 10% of aq. NaCl environments are recorded in Table 4.

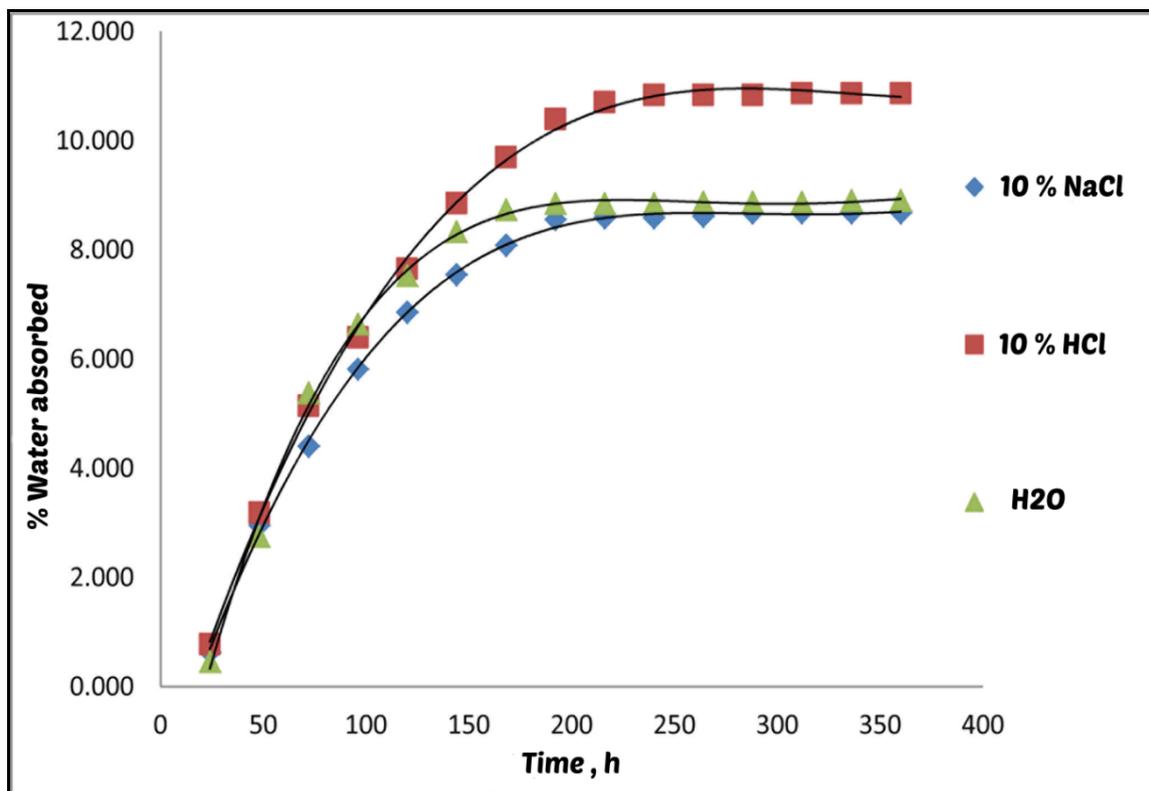


Figure 5. The plots of % wt gain against time for J-EMCS in H₂O, 10% of aq. NaCl, 10% of aq. HCl at 35 °C.

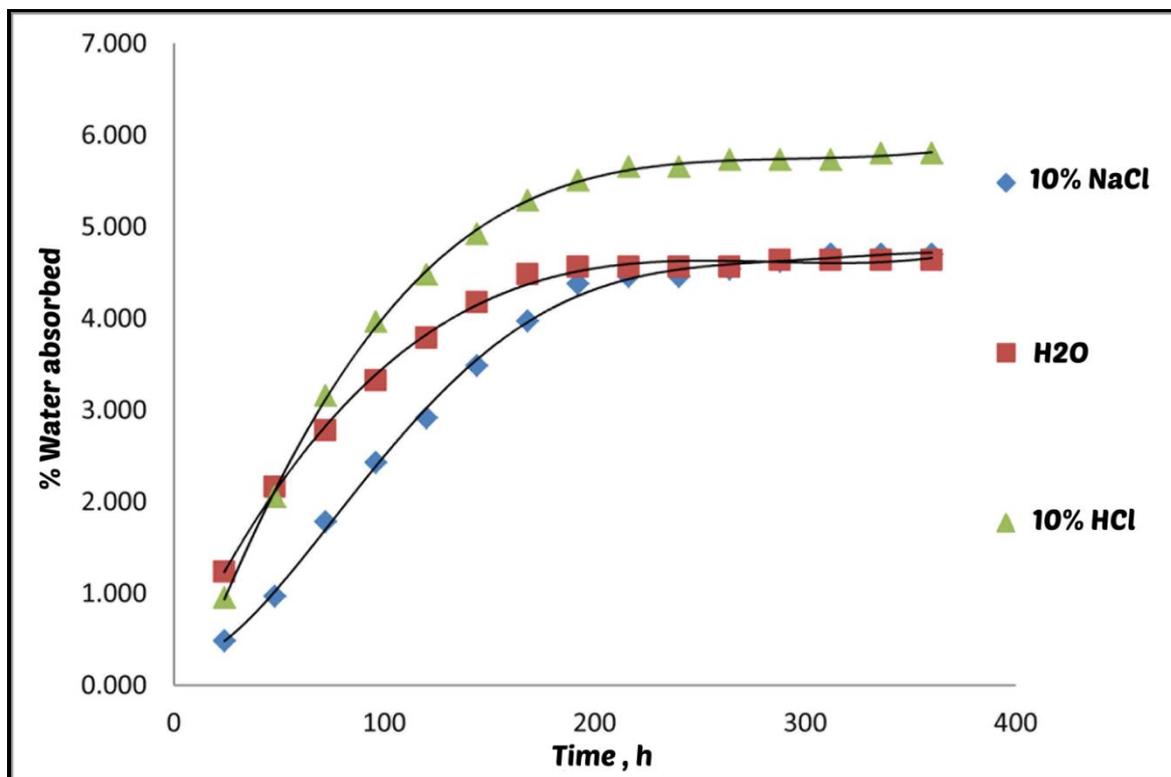


Figure 6. The plots of % wt gain against time for G-EMCS in H₂O, 10% of aq. NaCl, 10% of aq. HCl at 35 °C.

Table 4. Water uptake and diffusivity data of J-EMCS and G-EMCS at 35 °C and in boiling water.

Parameter	J-EMCS			G-EMCS		
	H ₂ O	NaCl	HCl	H ₂ O	NaCl	HCl
Equilibrium time (h)	192	240	288	264	264	192
% Equilibrium water content at 35 °C	8.8	10.8	8.7	5.8	4.6	4.7
Diffusivity (D_x) $10^{-11} \text{ m}^2\text{s}^{-1}$	47.9	33.9	35.4	6.9	3.8	5.6
% Equilibrium water content in boiling water	15.5	-	-	4.6	-	-

Both J-EMCS and G-EMCS showed identical water absorption trend. Relatively high water uptake in J-EMCS and G-EMCS is mainly due to large number of free hydrophilic hydroxyl groups in EMC. This may also be due to formation of micro cracks in jute fiber. Water absorption in composites is affected to some extent in acid environment probably due to surface solvolysis.

3. 5. Diffusivity (D_x)

The solution of diffusion equation in terms of % water absorption is given by Equation (5):

$$M = \frac{4M_m}{h} \sqrt{\frac{t}{\pi}} \sqrt{D_x} \quad (5)$$

where M_m = equilibrium water content.

Diffusivity in a given environment can be determined from the initial slope of the plot of %M against \sqrt{t} according to Equation (6):

$$D_x = \pi \left(\frac{h}{4M_m} \right)^2 (slope)^2 \quad (6)$$

Absorbed water in the composites influences mechanical behavior, and long-term durability of the polymer matrix composites. Water absorption in composites is proved to be Fickian as well as non-Fickian in character [22].

Assuming one-dimensional diffusion, water absorption in semi-infinite plate exposed to same environment was determined according to equation. Diffusivity in different environments was determined by determining the initial slope of the plot of M_t vs. $t^{1/2}$. Diffusivity in J-EMCS and G-EMCS in H_2O , HCl and NaCl environments is reported in Table 4.

Observed diffusivity order in J-EMCS and G-EMCS is $H_2O > HCl > NaCl$. Decrease in diffusivity is due to surface solvolysis in acidic and saline environments. Absorption of water in composites causes swelling of fibers till the cell walls are saturated with water and beyond that water exists as free water in the void structure [23] leading to composites delamination or void formation.

Absorbed water causes weakening of the interfacial adhesion and hydrolytic degradation of both matrix and fibers and hence deterioration of tensile property. Cracking and blistering of fibers cause high water absorption, while degradation causes leaching of small molecules [24,25].

3. 6. Water absorption in boiling water

The percentage weight gain with the passage of time in boiling water for J-EMCS and G-EMCS is presented in Figure 7. In J-EMCS showed almost double water uptake in boiling water probably due to increase in microcrack formation in the composite. As compared to 35 °C equilibrium times in boiling water is decreased 19 and 33 times, respectively for J-EMCS and G-EMCS. Thus, temperature affected to equilibrium to greater extent.

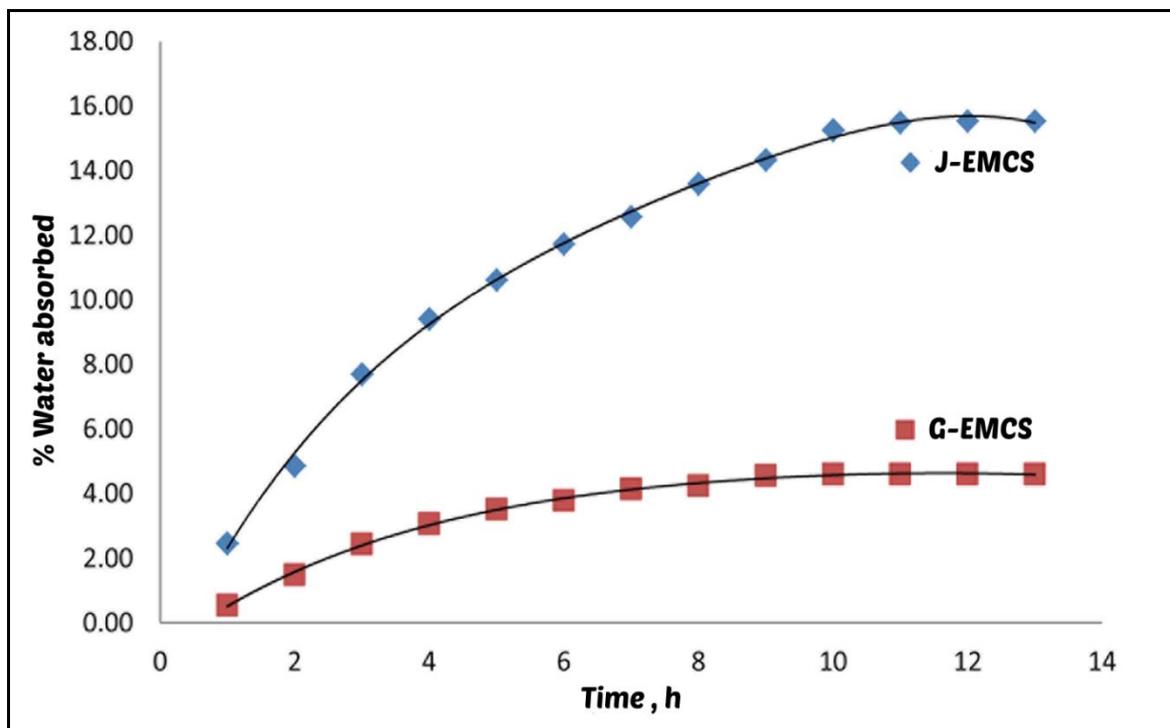


Figure 7. The plots of % wt gain against time for J-EMCS and G-EMCS in boiling water.

4. CONCLUSIONS

Both EMC and EMCS showed good thermal stability and considerable residue at 750 °C. Both J-EMCS and G-EMCS showed moderate mechanical and electrical properties and excellent hydrolytic stability even in harsh acidic and saline environments and also in boiling water. The composites may be useful for low load bearing housing units and also in electrical, electronic and marine industries.

ACKNOWLEDGEMENTS

The authors are thankful to FIST-DST and SAP-UGC for their generous financial support. Jabal is also thankful to Department of Science & Technology-New Delhi for Major Research Project grants (SERC SI. No. 1272, 15-06-2010).

References

- [1] Herzog B, Gardner DJ, Lopez-Anido R, Goodell B. "Glass-transition temperature based on dynamic mechanical thermal analysis techniques as an indicator of the adhesive performance of vinyl ester resin." *J. Appl. Polym. Sci.* 97 (2005) 2221-2229.

- [2] Ratna D, Khan S, Barman S, Chakraborty BC. "Synthesis of vinyl ester-clay nanocomposites: Influence of the nature of clay on mechanical, thermal and barrier properties." *The open Macromol. J.*, 6 (2012) 59-67.
- [3] Kumar MN, Siddaramaiah. "Studies on acrylonitrile-butadiene (NBR) latex reinforced jute nonwoven fabric composites: Chemical resistance, mechanical properties, and water absorption." *Polym. Plast. Technol. Eng.* 45 (2006) 409-414.
- [4] Ollier R, Stocchi A, Rodriguez E, Alvarez V. "Effect of thermoplastic incorporation on the performance of thermosetting matrix." *Mater. Sci. Appl.* 3 (2012) 442-447.
- [5] Gryshchuk O, Karger-Kocsis J, Thomann R, Konya Z, Kiricsi I. "Multiwall carbon nanotube modified vinyl ester and vinyl ester – based hybrid resins." *Compos. Part A: Appl. Sci. Manuf.* 37 (2006) 1252-1259.
- [6] Lu S, Hamerton I. "Recent developments in the chemistry of halogen-free flame retardant polymers." *Prog. Polym. Sci.* 27 (2002) 1661-1712.
- [7] Adroja PP, Ghumara RY, Parsania PH. "Physico-chemical study of chalcone moiety containing epoxy resin and its fiber reinforced composites." *Desig. Monom. Polym.* 16 (2012) 503-508.
- [8] Adroja PP, Koradiya SB, Parsania PH. "Synthesis, curing behavior and characterization of epoxy acrylate and triethylamine cured epoxy resin of 1,1'-bis(3-methyl-4-hydroxyphenyl)cyclohexane." *Polym. Plast. Technol. Eng.* 50 (2011) 52-58.
- [9] Koradiya SB, Patel JP, Parsania PH. "The preparation and physicochemical study of glass, jute and hybrid glass-jute bisphenol-C-based epoxy resin composites." *Polym. Plast. Technol. Eng.* 49 (2010) 1445-1449.
- [10] Jaswal S, Gaur B. "Curing and decomposition behaviour of cresol novolac based vinyl ester resin." *J. Chem. Eng. Trans.* 32 (2013) 1591-1596.
- [11] Patel RD, Thakkar JR, Patel RG, Patel VS, "Glass-reinforced vinyl ester resin composites." *High Perform. Polym.* 2 (1990) 261-265.
- [12] Li L, Sun X, and Lee LJ. "Low temperature cure of vinyl ester resins." *Polym. Eng. Sci.* 39 (1999) 646-661.
- [13] Stocchi A, Rodriguez E, Vazquez A, Bernal C. "Deformation and fracture behaviours of vinyl ester/fly ash composites." *J. Appl. Polym. Sci.* 128 (2013) 1547-1556.
- [14] Rodriguez-Mellaa Y, López-Moránb T, López-Quintelac MA, Lazzari M. "Durability of an industrial epoxy vinyl ester resin used for the fabrication of a contemporary art sculpture." *Polym. Degrad. Stab.* 107 (2014) 277-284.
- [15] Gupta N, Ye R, Porfiri M. "Comparison of tensile and compressive characteristics of vinyl ester/glass microballoon syntactic foams." *Compos. Part B: Eng.* 41 (2010) 236-245.
- [16] Chauhan SR, Gaur B, Dass K. "Effect of fiber loading on mechanical properties, friction and wear behaviour of vinyl ester composites under dry and water lubricated conditions." *Int. J. Mater. Sci.* (2011) 1-8.

- [17] Chawla TS, Cavalli MN. "Mechanical evaluation of repair resins for fiber-glass wind turbine blades". *J. Compos. Mater.* 0 (2014) 1-11.
- [18] Panforn AB, Giardello MA, Grubbs RH, Rosen RK, and Timmers FJ. "Safe and convenient procedure for solvent purification." *Organometallics.* 15 (1996) 1518-1520.
- [19] ASTM D 1980-87. (1998), Standard method for acid value of fatty acids and polymerized fatty acid.
- [20] Freeman ES, Anderson DA. "Kinetics of the thermal degradation of polystyrene and polyethylene." *J. Polym. Sci.* 54 (1961) 253-260.
- [21] J. V. Patel, J. P. Patel, R. D. Bhatt and P. H. Parsania "Mechanical and electrical properties of jute-biomass-styrenated methacrylate epoxy resin sandwich composites". *J. Sci. Indus. Res.* 74 (2015) 577-581.
- [22] Collings TA. "Moisture absorption- Fickian diffusion kinetics and moisture profiles. In: Jones FR, editor. Handbook of polymer-fiber composites." *Horlow: Longman Scientific and Technical;* (1994). p. 366-371.
- [23] Koradiya SB, Patel JP, Parsania PH, "The preparation and physico chemical study of glass, jute and hybrid glass-jute bisphenol-C-based epoxy resin composites." *Polym. Plast Tech. Eng.* 49 (2010) 1445-1449.
- [24] Pavlidou S, Papaspyrides CD, "The effect of hygrothermal history on water sorption and interlaminar shear strength of glass/polyester composites with different interfacial strength." *Compos. Part. A: Appl. Sci Manuf.* 34 (2003) 1117-1124.
- [25] Lin-Gibson S, Baranauskas V, Riffle JS, Sorathia U. "Cresol novolac-epoxy networks: properties and processability." *Polym.* 43 (2002) 7389-7398.

(Received 12 February 2016; accepted 24 February 2016)