

Poly(ethyleneterephthalate) Glycolysates as Effective Toughening Agents for Epoxy Resin

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ABSTRACT: The potential of poly(ethyleneterephthalate) glycolysates toward improving the energy absorption characteristics of cycloaliphatic epoxy resins has been explored. Microwave-assisted glycolytic depolymerization of PET was performed in the presence of polyether diols of different molecular weights. The obtained glycolysates were blended with epoxy, and their mechanical properties were studied under both quasi-static and dynamic conditions. Significant improvements were observed, which were found to depend both on the amount as well as nature of glycolysate. Amine functionalities were introduced at the terminal positions of glycolysates to improve the compatibility between the two phases. The amine derivatives exhibited superior performance and the Mode I fracture toughness (K_{IC}) of epoxy increased by $\sim 18\%$ in optimized compositions, which is indicative of its improved notch sensitivity. Neat epoxy specimens fractured in a brittle fashion, but all the blends exhibited ductile failure, as evidenced by surface morphological investigations. The mechanical properties of epoxy blends prepared with analogous aliphatic polyols, both before and after amine functionalization, were also studied which clearly reveal the beneficial role of aromatic groups toward improving the toughness of the base cycloaliphatic epoxy resin without compromising on the material stiffness. © 2013 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* **2014**, *131*, 39941.

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INTRODUCTION

Poly(ethyleneterephthalate) (PET) is one of the most important commodity thermoplastic, which has been extensively used in the last few decades for packaging beverages; particularly, mineral water and carbonated soft drinks. In addition, PET finds extensive usage in the textile industry, which consumes more than 60% of worldwide PET production.¹ The primary reasons behind its widespread use include its excellent barrier properties against oxygen and carbon dioxide,² mechanical properties, chemical and biological inertness, low cost, and high energy effectiveness. However, this widespread usage of PET, in combination with irresponsible methods of handling and disposal has led to its littering, which in turn has resulted in its undesired ubiquitous presence.^{3,4}

Several strategies have evolved for managing PET wastes, the most common being primary and secondary recycling techniques.⁵ Although, the fruition of “bottle to fiber and bottle to bottle” recycling⁶ has gained popularity in the last few years, but practically, only a small fraction of PET is recycled, the reason being the higher cost of the recycled product.⁷ It is thus

highly desirable to adopt technically and economically feasible routes toward recycling of PET into industrially important products. In this context, tertiary recycling of PET offers interesting possibilities.^{8–10} This process basically refers to the chemical depolymerization of PET, leading to the production of fuels or basic chemicals. In fact, products of tertiary recycling have found interesting applications including their usage as plasticizers,^{11,12} raw materials for preparation of metal organic frameworks,¹³ polyurethanes,^{14,15} unsaturated polyesters,^{16,17} and UV curable films.¹⁷

An interesting area where the potential of glycolysed PET remains unexplored concerns its prospect toward impact modification of epoxy resins. The considerably lower viscosity of the PET glycolysates is expected to improve the resin wetting action which can permit higher filler loadings, without compromising the rate of curing and thermal stability. In fact, polyether polyol-based reactive diluents have been employed for improving the resistance of epoxy toward brittle fracture^{18–20}; however, PET glycolysates have not been employed for this purpose. Blending of epoxy with aliphatic polyols is generally associated with a reduction in the material stiffness,¹⁸ a feature that can be

overcome by the alternate use of PET glycolysates. Interestingly, ample literature is available on toughening of epoxy resins derived from DGEBA (diglycidyl ether of bisphenol A), but their cycloaliphatic analogues have received less attention.^{21,22} Since cycloaliphatic resins possess their share of advantages including excellent chemical resistance, superior thermal, mechanical and electrical properties, it was considered of interest to improve their mechanical properties by blending with PET glycolysates, and quantify the extent of improvement. The presence of aromatic groups in the main chain of the PET glycolysate based diluent is expected to result in improvement in the mechanical properties of the base resin.

Previous studies have clearly demonstrated the potential of microwaves toward reducing the energy requirements of the glycolytic depolymerization process.^{13,23,24} In the present article, we aim to explore the potential of PET glycolysates as impact modifiers for epoxy resins. To further improve the compatibility between the two phases, the glycolysates were functionalized and the effect of amine termination toward its effectiveness as an impact modifier has also been explored. We observed substantial increase in the impact strength and fracture toughness of the base epoxy resin, without any loss in the material stiffness.

EXPERIMENTAL

Materials

Disposed off PET bottles were collected, washed, dried and used after removal of the polyethylene caps and the polypropylene label. The bottles were shredded into small pieces (6 mm × 6 mm) and glycolytic experiments were performed with diethylene glycol (DEG) and polyethylene glycol of varying molecular weights for which PEG 200, PEG 600, PEG 1000, and PEG 1500 (E. Merck) were used. Zinc acetate dihydrate [Zn (CH₃COO)₂·2H₂O, Merck] with a purity of 99% was employed as the trans-esterification catalyst. 4-Amino benzoic acid, xylene, and *p*-toluene sulfonic acid (PTSA) was obtained from E. Merck were used without any further purification. Cycloaliphatic epoxy resin (Ciba Geigy, Araldite CY 230; epoxy equivalent 200 eq/g) and hardener (HY 951; amine content 32 eq/kg) was used as received.

Microwave-Assisted Glycolysis

Microwave-assisted glycolysis of PET was performed in the presence of glycols of varying molecular weight as per the procedure reported previously.²³ A domestic microwave oven (LG) with a magnetron source for microwave generation (2.45 GHz, maximum power: 900 W) was used for this purpose. Transesterification of PET in the presence of higher molecular weight glycols including DEG, led to the formation of a viscous liquid, which did not solidify on cooling. The oligomers formed postglycolysis of PET with PEG will be referred to as PY-x, where x refers to the molecular weight of glycol used for its preparation. For example, PY-600 refers to the oligomer formed after glycolysis of PET with PEG 600.

Synthesis of Amine-Functionalized-Glycolysed Polyol

Glycolysed PET (PY 600) was esterified with 4-amino benzoic acid in the presence of *p*-toluene sulfonic acid (PTSA) to introduce amine functionalities as end groups.²⁵ The amine derivative will be referred to as AFPY 600 in the subsequent text. For this

purpose, PY 600 (100 g, 0.16 moles) was refluxed with 4-amino benzoic acid (45.6 g, 0.33 moles) in the presence of xylene (100 mL). A three-necked reaction flask fitted with a stirrer, a thermometer pocket, and Dean-Stark apparatus was used for this purpose. The reaction was continued till no more condensable liquid could be collected (~8 h). Excess xylene was subsequently removed by distillation and the reaction mixture was dissolved in chloroform, washed with sodium bicarbonate solution (10% w/v) to remove residual reactants and catalyst. The final product was dried over anhydrous sodium sulfate, subsequent to which the chloroform was removed by distillation.

Preparation of Epoxy Blends

Glycolysed polyols of different molecular weights were mixed with epoxy resin in the requisite ratio (5% w/w) to prepare toughened compositions. For this purpose, requisite amount of polyol was added to the mixture and stirred at room temperature for 10 min (80 rpm) to ensure homogeneity. TETA hardener was then added and the mixture was degassed to remove entrapped air bubbles and poured into silicone moulds for specimen preparation. For comparison purposes, neat epoxy samples were also prepared in the absence of any diluent, which will be referred to as EP. All blend compositions containing PET glycolysates will be referred to as EyPYx, where x refers to the molecular weight of glycol used for its preparation and y refers to the amount of polyol in the formulation (% w/w). For example, E10PY600 refers to a blend of epoxy with PY 600 (10% w/w). Additionally, epoxy blends were also prepared with the amine-terminated derivative of PET glycolysate (PY 600). These blends will be referred to as EyAPY600, where y refers to the amount of amine-terminated glycolysate, which varies from 5 to 15% (w/w). Analogous blends of epoxy prepared using PEG 1000 and its amine derivative will be referred to as EyPE1000 and EyAPE1000, respectively, where y refers to the amount of the additive.

Characterization Techniques

The intrinsic viscosity of the glycolysed polyols postchloroform extraction was determined by solution viscometry. For this purpose, the samples were dissolved in methanol, and the intrinsic viscosity [η] was measured using Ubbelohde suspension level viscometer at 25°C. The primary amine content (mol/g) was determined by potentiometric titrimetry according to reported procedure.²⁶ For this purpose, accurately weighed sample (500 mg) was dissolved in 1 : 1 ethylene glycol-isopropanol mixture (25 mL), and titrated against 1N HCl, and the reaction was followed by monitoring the variation in pH as a function of neutralizing acid.

The surface morphology of samples was studied using a Scanning Electron Microscope (Zeiss EVO MA15) under an acceleration voltage of 20 kV. Samples were mounted on metal stubs and sputter-coated with gold and palladium (10 nm) using a sputter coater (Quorum-SC7620) operating at 10–12 mA for 60 s.

The gel content of cured samples was determined by soxhlet extraction in chloroform. For this purpose, samples were ground, weighed and subjected to extraction for a period of 24 h, followed by drying to a constant weight under vacuum at

30°C. The percent gel content (gel %) was calculated gravimetrically using the following formula.²⁷

$$\text{Gel content} = \frac{W_g}{W} \times 100 \quad (1)$$

where W_o and W_g refer to the mass of dry sample before and after extraction.

FTIR spectra of samples were recorded in the wavelength range 4000–600 cm^{-1} using Fourier-transform infrared (FTIR) spectroscopy on a Thermo Fisher FTIR (NICOLET 8700) with an attenuated total reflectance (ATR) crystal accessory. The thermal properties of the samples were investigated using differential scanning calorimetry (TA instruments, Q 20 module) under nitrogen atmosphere. Five milligrams of the sample was placed in a 40 μL aluminum cap without pin and sealed with a lid. Samples were heated under a nitrogen gas flow of 50 mL min^{-1} from room temperature to 250°C at a rate of 10°C min^{-1} . Duplicate samples were analyzed for each set. The T_g s were estimated from the midpoint of the glass transition phenomenon. The thermal degradation behavior of samples was investigated using Perkin Elmer Diamond STG-DTA-DSC under air and N₂ atmosphere in the temperature range of 50–800°C. A heating rate of 10°C/min and a sample mass of 5.0 \pm 0.5 mg were used for each experiment. Quasi-static mechanical properties, were determined according to ASTM method D638 using a Universal Testing System (International equipments) at ambient temperature. Dog-bone shaped specimens used for tensile testing were 165-mm long, 3-mm thick, and 13-mm wide along the centre of the casting for epoxy resin. The samples were subjected to a cross head speed of 50 mm min^{-1} . The notched Izod impact strength of the specimens was determined according to ASTM D 256 using an impact strength testing machine (International Equipments, India) at a striking velocity of 3.5 m/s. Six identical specimens were tested for each composition and the average results along with the standard deviation values have been reported.

Notched flexural testing of the samples was performed under three point single edge notch bending mode according to ASTM D 5045. For this purpose, specimens of requisite dimensions (127-mm length \times 12.5-mm width \times 3.5-mm thickness and 3-mm notch) were prepared and subjected to a deformation rate of 2 mm/min while maintaining 60-mm span length. The data obtained were analyzed to determine the mode I fracture toughness (K_{IC}) of the samples as per the following equation²⁸:

$$K_{IC} = \frac{3 \times P \times L \times a^{1/2}}{2 \times B \times w^2} Y\left(\frac{a}{w}\right) \quad (2)$$

where P , L , and B refer to the load at break, span length, and sample thickness, respectively. The geometry factor, $Y\left(\frac{a}{w}\right)$, is calculated as per the formula below, where a is the notch length and w is the sample width.

$$Y\left(\frac{a}{w}\right) = 1.93 - 3.07 \times \left(\frac{a}{w}\right) + 14.53 \times \left(\frac{a}{w}\right)^2 - 25.11 \times \left(\frac{a}{w}\right)^3 + 25.8 \times \left(\frac{a}{w}\right)^4 \quad (3)$$

Unnotched samples were also prepared and evaluated for their flexural properties.

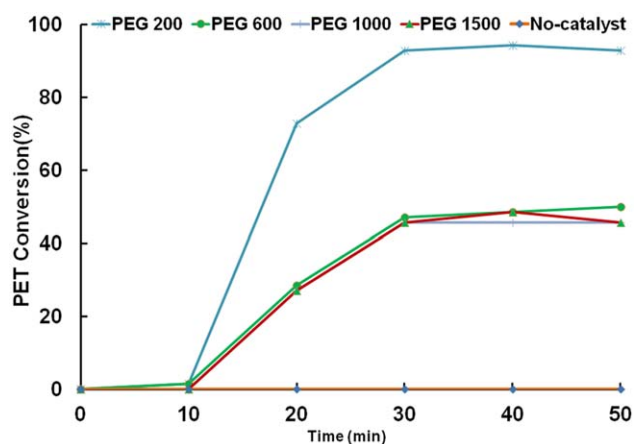


Figure 1. Effect of molecular weight of glycol on the extent of PET conversion. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

The K_{IC} was used to estimate the fracture energy (G_{IC}), which was calculated using the following equation

$$G_{IC} = \frac{K_{IC}(1 - \nu^2)}{E} \quad (4)$$

where E is the elastic modulus of the polymer, and ν is the Poisson's ratio of epoxy (0.35).²⁹

RESULTS AND DISCUSSION

Microwave-Assisted Glycolysis

Microwave-assisted glycolysis takes place at a substantially faster rate as compared to the conventional heating process,²³ which can be attributed to the high loss factor of glycols used for the glycolytic depolymerization process. Under the reaction conditions employed for transesterification of PET in the study, liquid oligomers were obtained, which could be separated from its water soluble reactants and catalyst by water extraction. The entire process was followed by monitoring the extent of PET conversion, the variation of which has been plotted as a function of irradiation time in Figure 1, where a PET: Glycol molar ratio of 1 : 6 was used for the glycolytic experiments. Our previous studies have revealed that complete PET conversion is achievable with lower molecular weight glycols ($M_w \leq 200$) within 30 min, after which even traces of PET could not be detected in the medium. In the case of higher glycols, the extent of PET conversion was much lower ($\sim 48\%$, PET : PEG 1000 = 1 : 6), which indicate that the reactivity of glycols decrease with the increasing of molecular weight of glycol. In the absence of catalyst, the glycolytic depolymerization did not take place even under extended time periods (Figure 1).

Detailed characterization of the PET glycolysates is presented elsewhere.²³ Preliminary investigations were carried out to evaluate the potential of these glycolysates as impact modifiers for cycloaliphatic epoxy resins. For this purpose, the glycolysates were blended with epoxy matrix (5% w/w), cured and subsequently subjected to quasi-static (tensile mode) and impact testing, the results of which are presented in Figure 2(a,b). It can be seen that the improvement in the impact resistance of

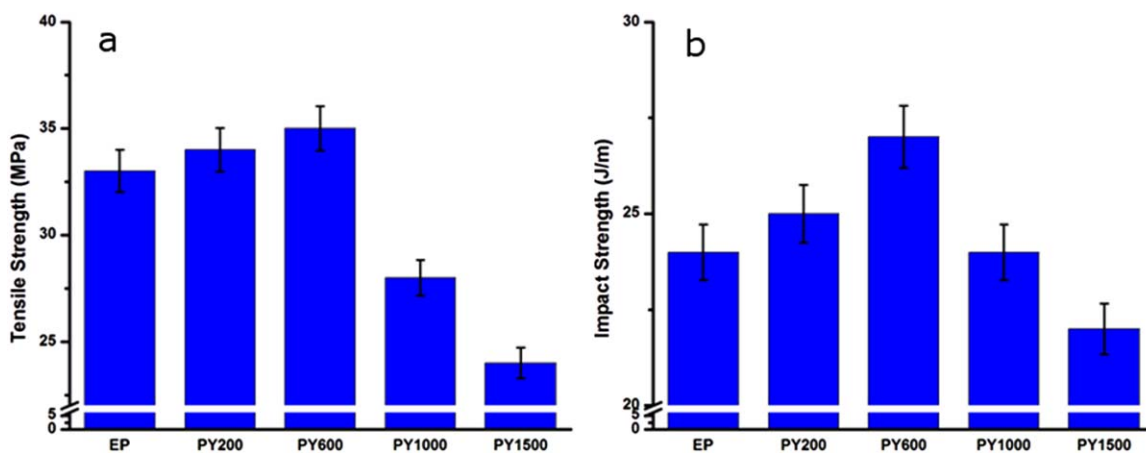


Figure 2. Effect of introduction of PET glycolysates on the mechanical properties of epoxy resin. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

composite was more pronounced in comparison to the tensile properties.

The improvement in the properties is a result of a separate rubbery phase within the epoxy matrix. The diluent glycolysate which is initially miscible with the epoxy in all proportions tend to separate out during the curing process. The presence of this phase allows plastic deformation and considerable shear yielding, thereby resulting in a ductile behavior.³⁰ The improvement in the mechanical properties can additionally be attributed to the hydrogen bonding interactions of the hydroxyl groups available in the cured resin with those present in the polyols,²⁰ which in turn depends on the chain length and the extent of branching, thereby providing an explanation to our observations.

To further improve the compatibility between the two separate phases, we considered functionalization of the glycol (PY 600) with amine groups, with the resulting product possessing the capability to react with epoxide rings present in the resin during the curing process. The reaction of the glycolysate with p-amino benzoic acid was carried out for extended periods, and the water formed as a result of condensation reaction was collected over a period of 8 h. Gravimetric methods were adopted to estimate the yield of APFY-600, which was found to be ~90–92%. The amine content of the APFY 600 and AFPE 1000 was determined to be 1.32 mmol/g and 1.47 mmol/g, respectively.

FTIR spectroscopy was used for structural characterization of the glycolysates, however no perceptible differences could be observed between the polyol and its amine derivative, because of the overlapping frequency region of hydroxyl and amine groups. The FTIR spectra of PET, PEG 600, PY 600, and its amine-terminated derivative (APFY 600) are presented in Figure 3. The spectrum of poly(ethylene glycol) exhibits a characteristic absorption band due to ether stretching (C—O) at ~1050–1150 cm^{-1} . Characteristic alkyl (R—CH₂—) stretching at ~2850–3000 cm^{-1} was also observed, along with hydroxyl group absorption ranging from ~3200–3600 cm^{-1} . All the glycolysed polyols exhibit an absorption at 1715 cm^{-1} due to —C=O stretching, a feature that is also present in the spectrum of neat PET. The presence of absorption band at ~3200–3600 cm^{-1}

can be attributed to the presence of free hydroxyl groups in glycolysed PET oligoesters (PY 600). The amino derivative (APY 600) exhibited absorption at 3358 cm^{-1} due to the N—H stretching and an additional absorption at 1631 cm^{-1} and 1352 cm^{-1} due to N—H bend and C—N aromatic stretching, respectively.

Blends of epoxy with the APFY 600 were prepared and the mechanical response against both tensile and impact mode was evaluated (Figure 4). As expected, the blends with amine derivatives exhibit improved mechanical properties in comparison to the glycolysed polyols, which can be attributed to the chemical reaction of the amine group with the epoxy functionalities of the resin. This allows the formation of blends with more uniform distribution of the second phase.

To establish the role of aromatic groups present in the glycolysed product toward improving the mechanical properties,

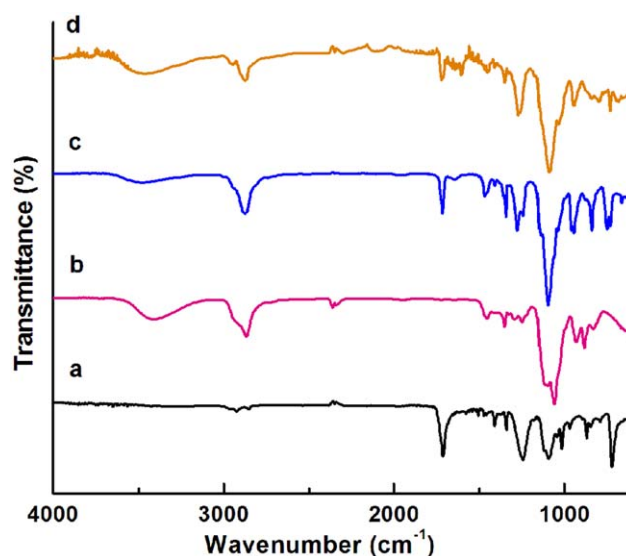


Figure 3. FTIR spectra (a) PET, (b) PEG 600, (c) PY 600, and (d) APY 600. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

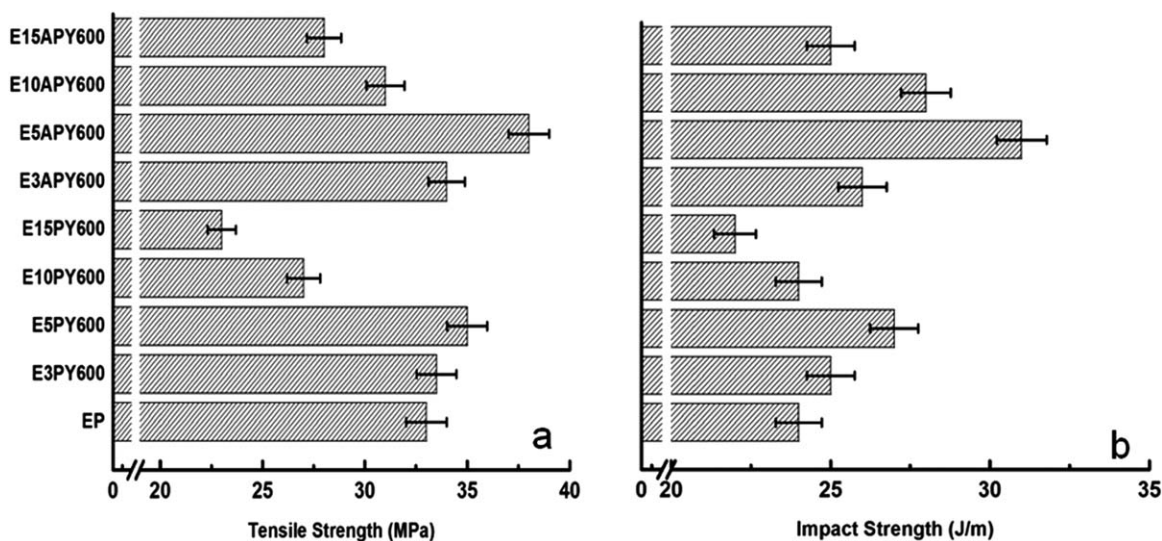


Figure 4. Tensile and impact properties of epoxy blends with glycolysed polyols and its amine-terminated derivatives.

epoxy composites were also prepared with neat polyether polyol (PEG 1000) and their amine derivatives. It is to be noted that the selection of polyether glycol ($M_n = 1000$) was based on the proximity of its molecular weight to that of the PET glycolysate ($M_n = 1114$). The results of the mechanical properties are presented in Figure 5. Although slight improvement in the properties was observed even with aliphatic diols, our studies clearly reveal that PET glycolysates are more effective in improving the toughness of the base cycloaliphatic epoxy resin.

Flexural three point bending tests were also performed on selected specimens, and the effect of notch on the mechanical response of the blend is presented in Figure 6. As expected, the introduction of polyols within the epoxy matrix led to an increased flexural strain, which can be attributed to the high extensibility of the rubbery polyol domain. More importantly, the amino derivative of the glycolysate could be flexed to a higher extent, which in turn reflected in larger values of fracture toughness (K_{IC}). The introduction of notch led to a lowering in

the flexural strength of specimens, which can be attributed to the stress concentration around the notch, which in turn leads to local yielding and initiation of cracks. A comparison of the fracture toughness (K_{IC}) and fracture energy (G_{IC}) as a function of composition type is presented in Figure 7. The Mode I fracture toughness of epoxy increased by $\sim 18\%$ in blends containing amine functionalized glycolysates (E5APY600), which is indicative of its potential toward improving the notch sensitivity of epoxy. Improvements of this order ($\sim 20\%$) have been reported earlier, but these are also associated with a decrease in the flexure stiffness.¹⁸ Interestingly, the introduction of PET glycolysates had a positive impact on the material stiffness which was quantified in terms of the notched flexural modulus [Figure 7(b)]. This can be attributed to the presence of phenyl rings in the main chain of PET glycolysates, which lead to the increasing of rigidity of the samples.

Gel content, which is an indicator of the insolubility of the crosslinked polymer, was determined in order to quantify the

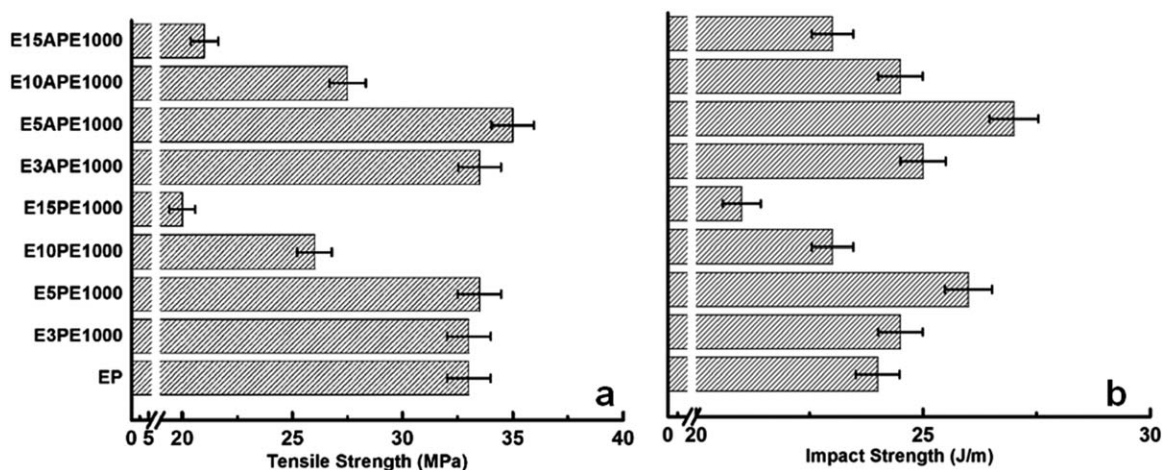


Figure 5. Tensile and impact properties of epoxy blends with polyether polyol and its amine-terminated derivatives.

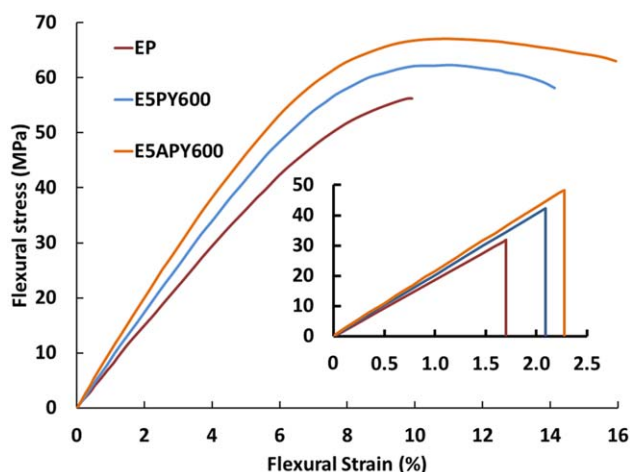


Figure 6. Representative stress–strain curves (flexural mode). Inset shows the effect of notch on the flexural response of specimens. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

extent of curing in epoxy and its blends. The results of the studies are presented in Figure 8. The gel content of cured epoxy is $\sim 99\%$, which is indicative of complete crosslinking. It is interesting to note that the entire amount of PET glycolysate or PEG could be removed by chloroform extraction but the gel content is much higher when the glycolysate is amino functionalized, which is indicative of its reaction with the epoxy groups.

Morphological Studies

The morphology of the fracture surface was studied to gain an insight into the mechanism involved during fracture. For this purpose, the fracture surface of both pristine and its blends with PET glycolysates and amine derivatives were examined by SEM and the images are presented in Figure 9(a–d). As can be seen, the fracture surface of neat epoxy is almost featureless, indicative of uninterrupted crack propagation postinitiation. These features are characteristic of brittle failure, which in turn accounts for its low fracture toughness.³¹ Figure 9(b–d) shows the micrographs of fracture surfaces of epoxy blends, which are comparatively rough, with the roughness indicative of the

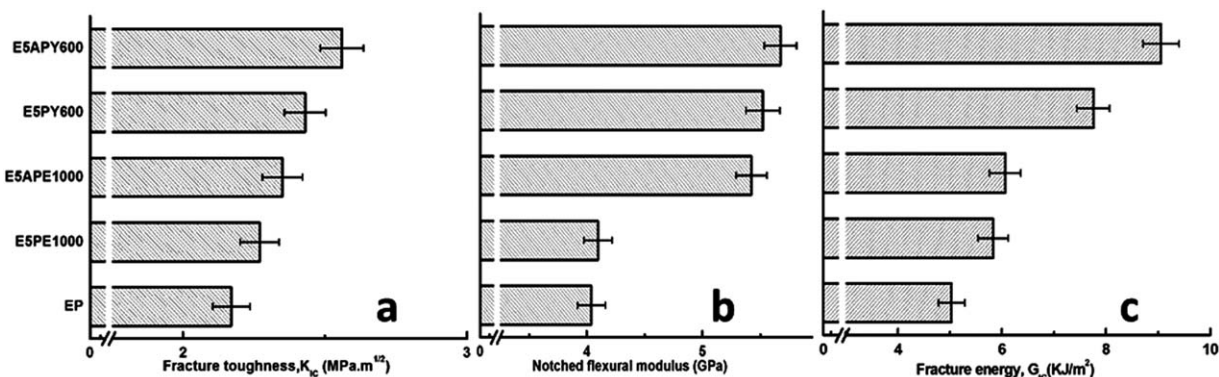


Figure 7. Flexural properties of epoxy blends with PET glycolysates and amino derivatives. (a) Critical stress intensity factor, (b) notched flexural modulus, and (c) fracture energy.

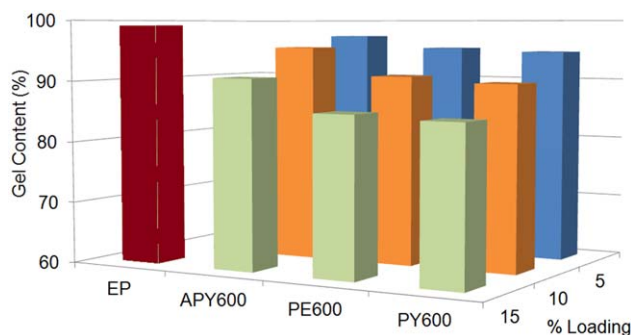


Figure 8. Percentage gel content of epoxy and its blends. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

significant amount of plastic deformation which occurs in the material prior to ductile failure.

The surface of epoxy appeared featureless even at higher magnification, however interesting features could be observed on the surface of blends, and the images are presented in Figure 10. From the SEM images, it is evident that the glycolysates and its derivatives, which were completely miscible initially, formed an immiscible rubbery phase within the epoxy matrix during the curing process.

Structural Characterization

FTIR spectra of epoxy resin, cured epoxy and its blends with PET glycolysates are presented in Figure 11. It can be seen that the uncured epoxy resin exhibits absorption due to oxirane moieties at 917 cm^{-1} , which decreases in intensity as a result of reaction with the curing agent.³² Complete curing of epoxy was confirmed by the absence of this peak in the cured resin. No appreciable differences are perceivable in the spectra of cured epoxy and its blends, except for an increased absorption at $\sim 1100\text{ cm}^{-1}$ in the blends. Comparison with the spectrum presented in Figure 3, it is clear that these absorptions result from ether stretching ($\text{C}-\text{O}$, $\sim 1050\text{--}1150\text{ cm}^{-1}$) arising from the presence of polyether polyols in the blends.

Thermal Analysis

The DSC traces of the cured epoxy and representative blends are presented in Figure 12. The curing studies of epoxy with

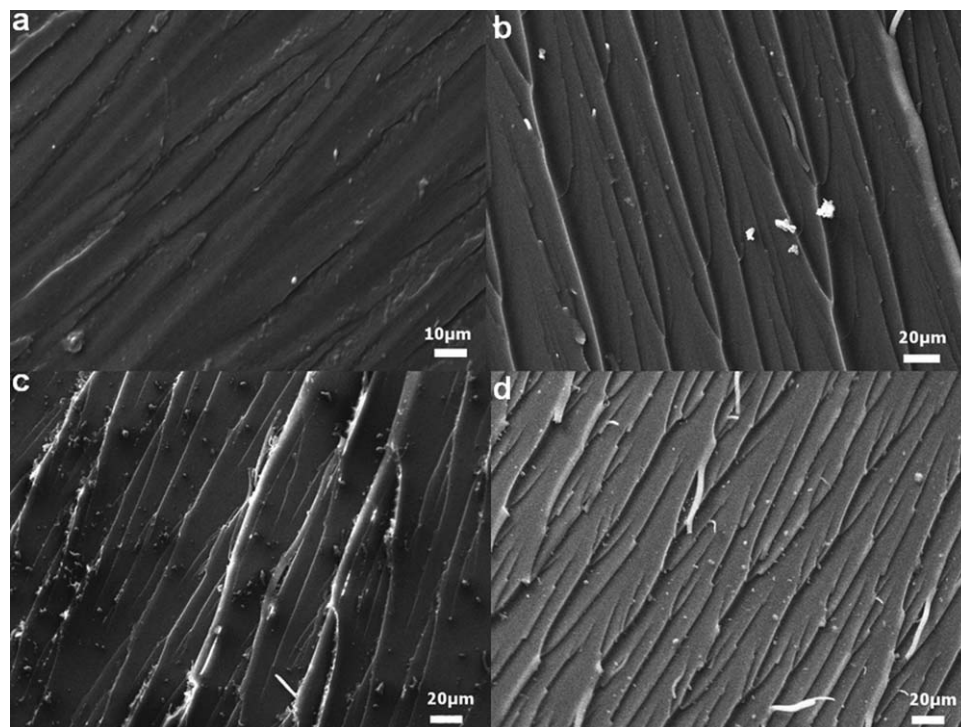


Figure 9. Morphology of fracture surface (a) neat epoxy, (b) epoxy blend with PET glycolysate (E5PY600), (c) epoxy blend with amine-terminated glycolysate (E5APY600), and (d) epoxy blend with amine-terminated polyether polyol (E5APE600).

TETA hardener have also been performed under dynamic conditions, the results of which are also included in the inset. It can be seen that TETA cured epoxy exhibit a glass transition temperature of $\sim 66^{\circ}\text{C}$ (Figure 12, curve a), which remains unaltered on blending with PET glycolysate (curve b). Interestingly, the blends of epoxy with amino derivatives of glycolysates exhibit two distinct glass transition temperatures (curve c), the first T_g is associated with the TETA cured epoxy, while the second T_g ($\sim 120^{\circ}\text{C}$) is due to the chains associated with the cured epoxy with amino derivative of PET glycolysate.

Detailed thermal characterization of PET and its glycolysates have been discussed in our previous article.²³ The representative TG traces of epoxy and its blends with PET glycolysates and its derivatives are presented in Figure 13. The degradation behavior of epoxy resins have been extensively studied by several researchers,³³ and a two-step degradation process is generally

reported. The first step is associated with evolution of water, which is followed by the pyrolytic decomposition of the main chain at $\sim 350^{\circ}\text{C}$, leading to the formation of condensables like acetone, carbon dioxide, hydrogen cyanide, aliphatic hydrocarbons, etc.³³ The presence of aromatic groups in the PET glycolysates leads to increased char content of the blends. It can however be concluded that the presence of the rubbery phase does not significantly affect the thermal properties of the base resin and the compositions can safely be employed in service till 250°C , without any appreciable thermal degradation.

CONCLUSION

Aromatic polyester polyol-based diluents obtained by glycolysis of PET were studied for their ability to enhance the energy absorption characteristic of cycloaliphatic epoxy resin. PET was catalytically glycolyzed with aliphatic polyether diols of different molecular weight (200–1500) under microwave irradiation.

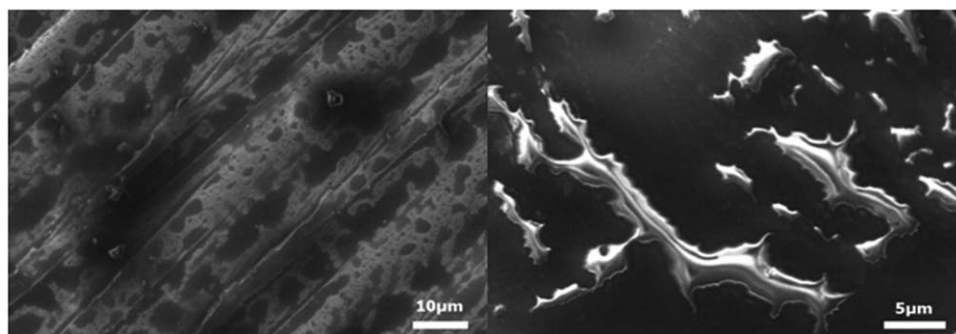


Figure 10. Secondary electron images epoxy blend with amine-terminated glycolysate (E5APY600) at different magnifications.

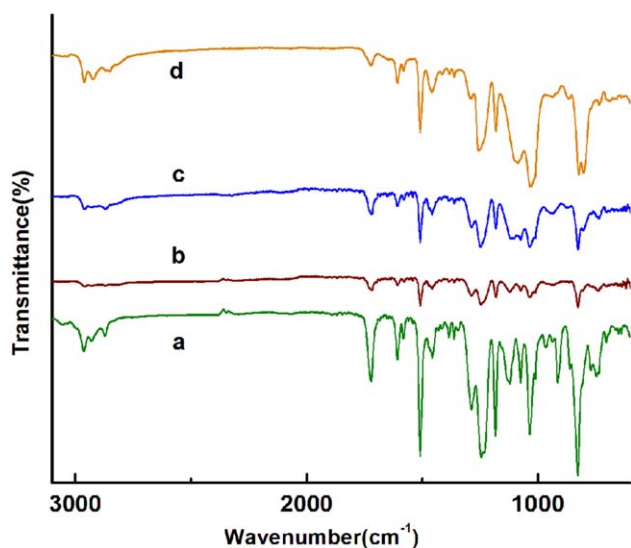


Figure 11. FTIR spectra: (a) epoxy resin, (b) cured epoxy, (c) epoxy blend with PET glycolysate (E5PY600), and (d) epoxy blend with amine-terminated glycolysate (E5APY600). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Blends of epoxy were prepared and subjected to both quasi-static and impact tests. Significant improvements in mechanical properties were observed, with the increase in impact properties being more pronounced, which was attributed to the presence of a separate immiscible rubbery phase within the matrix. Amine end groups were introduced in selected PET glycolysates, with an aim to improve the compatibility between the two phases. Epoxy composites were prepared with the amine derivatives of both aliphatic and aromatic polyether polyols, and detailed characterization in terms of their mechanical, structural, thermal properties

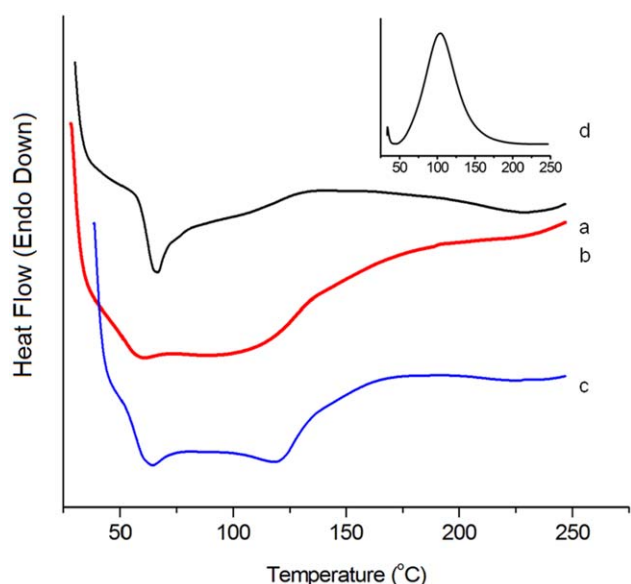


Figure 12. DSC traces of cured compositions: (a) EP, (b) EP5PY600, and (c) EP5APY600. Inset (d) depicts the curing behavior of epoxy resin with hardener under dynamic conditions. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

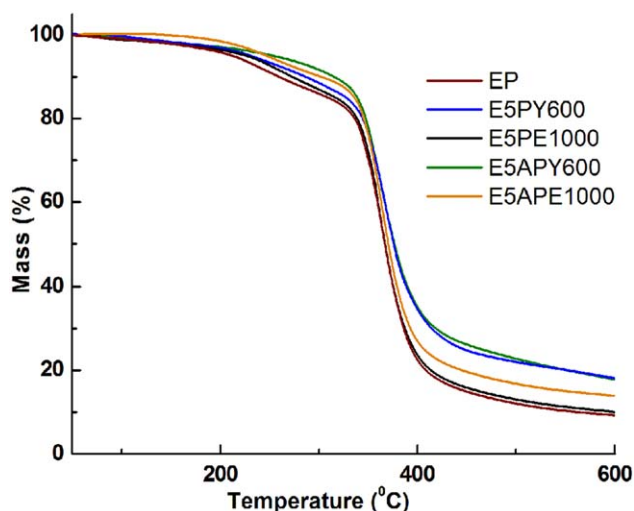


Figure 13. TG traces of epoxy and its blends with PET glycolates and its derivatives. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

and fracture surface morphology was performed. Because of the presence of aromatic groups in the main chain, the composites exhibited improvement both in flexural stiffness as well as fracture toughness. The fracture surfaces of neat epoxy are featureless revealing brittle failure, and that of blends was indicative of ductile failure revealing energy absorption during microcracking. Introduction of PET glycolysates and their derivatives did not adversely affect the thermal decomposition behavior.

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