

BisGMA/Thermoplastic Polymer Blends: A Study of Mechanical and Corrosive Properties

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Abstract

The objective of this work is to synthesize various blends of Bisphenol-A-glycidyl dimethacrylate (BisGMA) resin with different proportions of thermoplastic polymers like poly-N-vinylpyrrolidone (PVP) and poly-ethyleneoxazoline (PEOZ) and to study their mechanical and corrosive properties. The experimental results showed that BisGMA/PVP and BisGMA/PEOZ blends displayed an improvement in the mechanical properties over unmodified BisGMA resin and the 50:50 blend system is the optimum blend composition in both BisGMA/PVP and BisGMA/PEOZ blends. Then further, a comparative study of mechanical and corrosive properties between pure BisGMA, BGP₅₀ and BGPO₅₀ has been made. All the mechanical properties such as ultimate tensile stress, Young's Modulus and elongation at break are determined using the universal testing machine (UTM) and impact strength has been determined using the IZOD test. Water absorption capacity of blends and corrosion test has also been carried out which suggests that the blends can be used in saline and corroded environment. This provides an advantage for the blends to be used in different types of structural composites with high mechanical strength.

Keywords: BisGMA, polymer blend, mechanical properties, water absorption capacity, corrosion tests.

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INTRODUCTION

Polymers have been the study of interest over the last four decades due to their relatively low cost and ease of processing. They exhibit poor damage tolerance, low mechanical strength and stiffness relative to other engineering materials such as metals [1]. Therefore, their utilization in industrial applications has been restricted to some extent. For that reason, various different methods including blending or mixing of different types of polymers have been conducted to tailor physical, mechanical and thermal properties of polymers. Polymer blends are physical mixtures of structurally different polymers, which adhere together through the action of secondary bond forces and no covalent bonding exists between them [2, 3]. Blending of polymers is a common industrial practice to offer various grades of polymers and to exhibit properties that are superior to any of the component polymers alone. As a result, these blends can also be used to prepare polymer composites. Vinyl ester resins (VERs) are addition products

formed by the esterification of an epoxy resin with an unsaturated monocarboxylic acid such as acrylic or methacrylic acid (Figure 1). Nowadays, commercially available vinyl ester resin materials utilize BisGMA as a major monomer in the resin. Polymer supports based on BisGMA are mainly used as excellent thermosetting adhesives. They have gained popularity owing to their superior performance in applications like binding of drugs and biomolecules. In electronic industries, they are used as negative electron beam resists [4–7]. In leather industry, they serve as primary material for the formulations of the base and topcoats [8, 9]. But the main problem in this viscous, bulky bifunctional monomer is its high reactivity, high molecular weight, low polymerization shrinkage, and cross-linked three-dimensional resin network. Due to the high viscosity of BisGMA, the resin phase of the material has to be diluted or blended to enhance the handling of monomer material [10, 11].

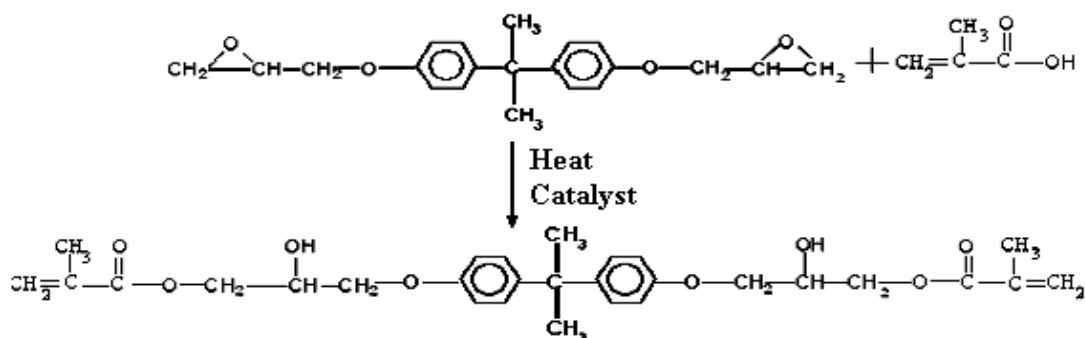


Fig. 1: Synthesis of BisGMA by the Reaction of Bisphenol-A Glycidylether with Methacrylic Acid.

As part of the overall objective and to develop methods for improving the performance of BisGMA, this paper identifies some thermoplastic polymers like PVP and PEOZ which are both miscible and compatible with BisGMA. These polymers are blended with BisGMA to form an entirely different polymeric material having the potential of global usage. In this work, BisGMA prepolymer is first synthesized by the reaction of bisphenol-A glycidylether with methacrylic acid and then its blends with different weight percents of thermoplastic polymers like PVP and PEOZ. Initially, the blends are characterized with the help of solubility parameter and then their mechanical properties, corrosion and water absorption tests are studied to determine the most optimum blend composition for their use in structural purposes specifically for low-cost housing projects. Further, a comparative study of mechanical and corrosive properties has been made between BisGMA and the optimum blend compositions. Here, specific blend compositions have been mentioned to emphasize only on the important experimental results.

MATERIALS AND METHODS

Raw Materials

Diglycidyl ether of bisphenol-A-type (DGEBA) epoxy resin and methacrylic acid were used for the synthesis of BisGMA [12]. Butylated hydroxytoluene (BHT) is used as a stabilizer, triphenylphosphine (TPP) as catalyst and benzoyl peroxide (BPO) and t-benzoyl peroxide (t-BPO) were used as initiators respectively. PVP and PEOZ were used as received to blend with BisGMA. Other chemicals and solvents were used without any modifications.

Synthesis of BisGMA

BisGMA was synthesized by the esterification of DGEBA with methacrylic acid (1:2) using butylated hydroxytoluene (0.03 wt %) as stabilizer and triphenylphosphine (1 wt %) as catalyst. The temperature was raised to 90–95 °C and the reaction took 6 h for completion.

Synthesis of BisGMA/PVP and BisGMA/PEOZ Polymer Blends

Different thermoplastic polymers like PVP and PEOZ (10–100 wt %) were dissolved in BisGMA resin with stirring until clear solutions were obtained. The initiators [benzoyl peroxide (1 wt %)] and [t-benzoyl peroxide (0.01 wt %)] were then added and stirring was maintained for 4 h to ensure the initiators were dissolved. Curing was carried out at 120 °C in a convention oven for 1 h. Nomenclatures of different blend systems are given in Tables 1 and 2. Miscibility of different blends was investigated with the help of solubility parameter.

Characterization of BisGMA/PVP and BisGMA/PEOZ Polymer Blends

Solubility Parameter Measurement

The solubility parameters of the blended polymers (BisGMA, PVP and PEOZ) were estimated by group contribution methods using the MG&PC software [13] according to Eq. (1):

$$\delta = \rho \sum F_i / M \quad (1)$$

where F_i is the molar attraction constant of the group being considered, ρ is the density of the polymer, and M is the molar mass of the polymer. The summation was carried out over all structural features in the molecules.

Table 1: Nomenclature of BisGMA/PVP Blend.

Material Designation	BisGMA (Wt %)	% PVP (Wt %)
BGP ₀	100	0
BGP ₃₀	70	30
BGP ₅₀	50	50
BGP ₆₀	40	60
BGP ₇₀	30	70

Table 2: Nomenclature of BisGMA/PEOZ Blend.

Material Designation	BisGMA (Wt %)	%PEOZ (Wt %)
BGPO ₀	100	0
BGPO ₃₀	70	30
BGPO ₅₀	50	50
BGPO ₆₀	40	60
BGPO ₇₀	30	70

Tensile Test

The specimen size used for all the mechanical testing was $12 \times 10 \times 3 \text{ mm}^3$. The tensile test was conducted according to ASTM D790-03 standard. Tensile testing was carried out using Instron universal testing machine model 3369. Five specimens of each formulation were tested and average values were reported.

Young's Modulus and Elongation at Break

Both the tests were carried out according to ASTM D790-03 standard using the Kalpak universal testing machine. Five specimens of each formulation were tested and average values were reported.

Impact Test

IZOD impact tests were conducted as per D256-05. Five specimens of each formulation were tested and average values were reported.

Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectra were collected using Thermo-Nicolate Model 400 instrument equipped with a controlled temperature cell (Model HT-32 heated demountable cell used with an Omega 9000-A temperature controller).

Scanning Electron Microscopy (SEM)

SEM was utilized to qualitatively examine the microstructure of pure BisGMA and its blends. The samples were gold coated and examined using a Philips 420T scanning transmission electron microscope with a secondary electron detector, operating at 60 KV in the SEM mode.

Corrosion Test

For corrosion tests, three specimens ($12 \times 10 \times 3 \text{ mm}^3$ and exposed area of

372 mm^2) were tested according to ASTM B117 [14] standard. The tests were conducted by dipping the specimens in circulating salt water with 10% NaCl concentration and pH value of 6.5. The initial weights of the specimens were taken in dry condition in a 4-digit electronic balance. After a gap of 24, 48, 72 and 120 h of testing at a temperature around $40 \text{ }^\circ\text{C}$, the specimens were rinsed and cleaned in deionized water; dried and final weights were taken.

Moisture Absorption Test

Moisture absorption tests were conducted as per ASTM D570. The test specimens ($25 \times 25 \text{ mm}$) were cut from the laminates with edges of the samples sealed with BisGMA. The samples were pre-conditioned by drying in an oven for 24 h at $60 \text{ }^\circ\text{C}$ and weighing before being dipped in distilled water. Five specimens of each formulation were tested and the average values were reported. The samples were removed from the water at regular intervals and wiped with tissue paper to remove the excess fluid on the surface. An electronic balance of accuracy 0.00001 mg and model AY220 was used to measure the weight of samples in the moisture absorption test.

RESULTS AND DISCUSSION

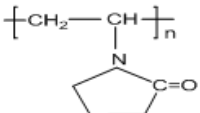
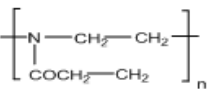
Solubility Parameter Measurement

Table 3 shows the solubility parameter values of the two chosen thermoplastic polymers (i.e., PVP and PEOZ) that were blended with BisGMA. From the data, it is clear that the solubility parameters of PVP ($= 20.78 \text{ MPa}^{0.5}$) and PEOZ ($= 20.04 \text{ MPa}^{0.5}$) are close to that of BisGMA ($= 19.97 \text{ MPa}^{0.5}$). Due to the small

difference in the solubility parameter values, it can be concluded that both PVP and PEOZ are

soluble in BisGMA resin and form a miscible blend system with BisGMA network.

Table 3: Solubility Parameter of Different Polymers.

Polymers	Repeat Unit	Solubility in vinyl ester resin	Solubility parameter MPa ^{0.5}
Poly(N-vinyl pyrrolidone)		yes	20.78
Poly(ethylene oxazoline)		yes	20.04

Ultimate Tensile Stress (UTS) and Young's Modulus

In the case of BisGMA/PVP blends, it was found that the values of UTS and Young's Modulus gradually increased with increasing proportion of PVP in the blend system which suggested a marked improvement as compared to pure BisGMA (Figures 2 and 3). The improved property of such blends may be attributed to specific interactions like H-bonding and dipole-dipole interactions between molecules of the constituent polymers [15]. It can also be suggested that the

α -hydrogen of PVP can interact with the BisGMA carboxylate group (H-bond acceptor of the acrylic polymer) to form a hydrogen bond and is also a key factor in achieving miscibility [15, 16] and thereby enhancing properties. Thus, till BGP₅₀, the blends can withstand maximum stress. But this increase was observed only up to the 50:50 blend system beyond which there was a marked decrease in the values of tensile stress as well as Young's Modulus. The values went on decreasing up to the BGP₁₀₀ system.

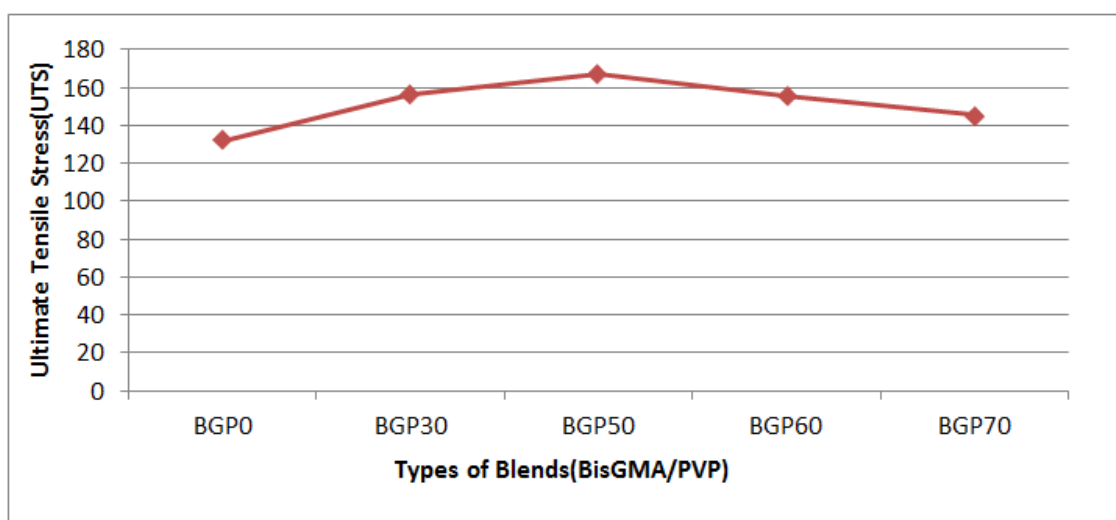


Fig. 2: UTS of Different BisGMA/PVP Blends.

This can be attributed to the fact that with increasing PVP content, the rubbery nature of blend increases making it more soft and flexible causing more deformations in it, and

thus making it mechanically weak. As a result, the blends cannot withstand stress and break easily. Thus, BGP₅₀ blend is the optimum one.

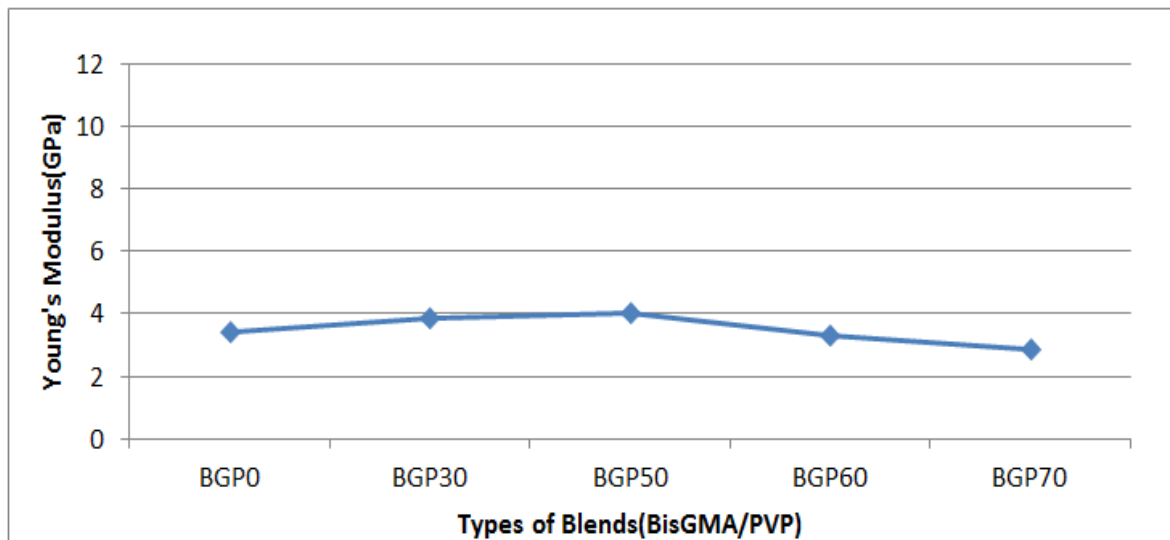


Fig 3: Young's Modulus of Different BisGMA/PVP Blends

As the trends observed in the properties of blends after the BGP₅₀ system were similar, the mechanical properties only up to the BGP₇₀ system have been described to avoid unnecessary description.

On the other hand, it was observed that there was a decrement in the values of UTS and Young's Modulus in case of BisGMA/PEOZ blends up to BGPO₅₀ (Figures 4 and 5) because with increasing PEOZ content, the hardness of the material increases and the number of deformations that can be caused decreases,

i.e., the blends cannot be easily stretched or pulled (suffer less stress) due to which the values decrease. But the decreasing values do not necessarily indicate deterioration in the mechanical properties. The values gradually increase beyond the BGPO₅₀. But interestingly from mechanical testing, it was concluded that the BGPO₅₀ blend is way stronger than BGP₆₀, BGP₇₀, BGP₈₀, BGP₉₀, etc. This is due to the fact that pure BisGMA is brittle in nature and as the proportion of PEOZ increases in the mixture, it makes the blend more and more brittle.

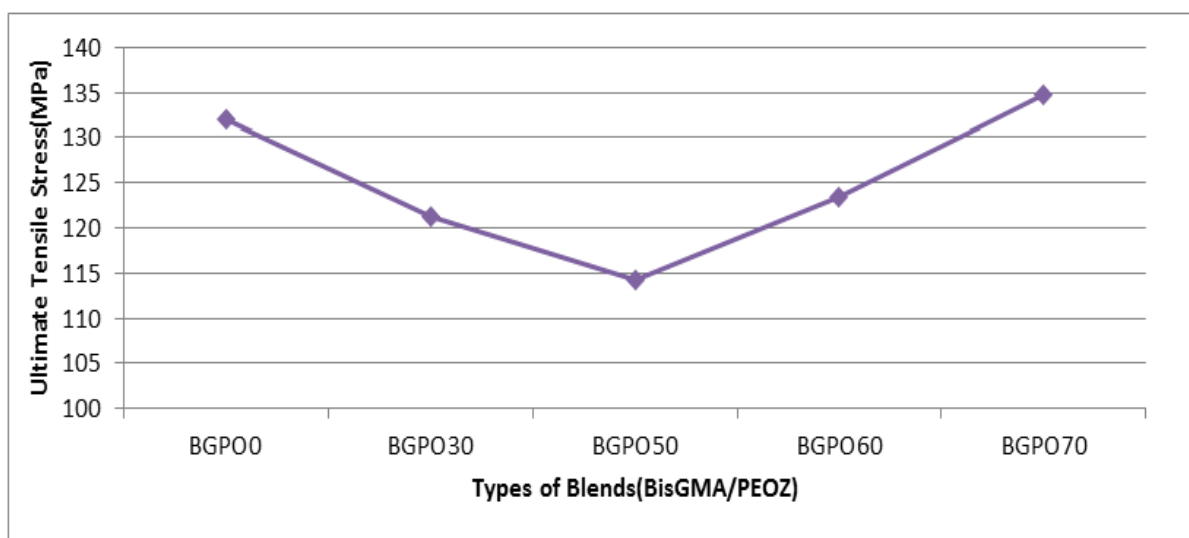


Fig. 4: UTS of Different BisGMA/PEOZ Blends.

Due to the increase in hardness, the blends can endure more stress which is obvious from the increasing values but the blend becomes more

susceptible to breakage. Thus, the BGPO₅₀ displays optimum properties.

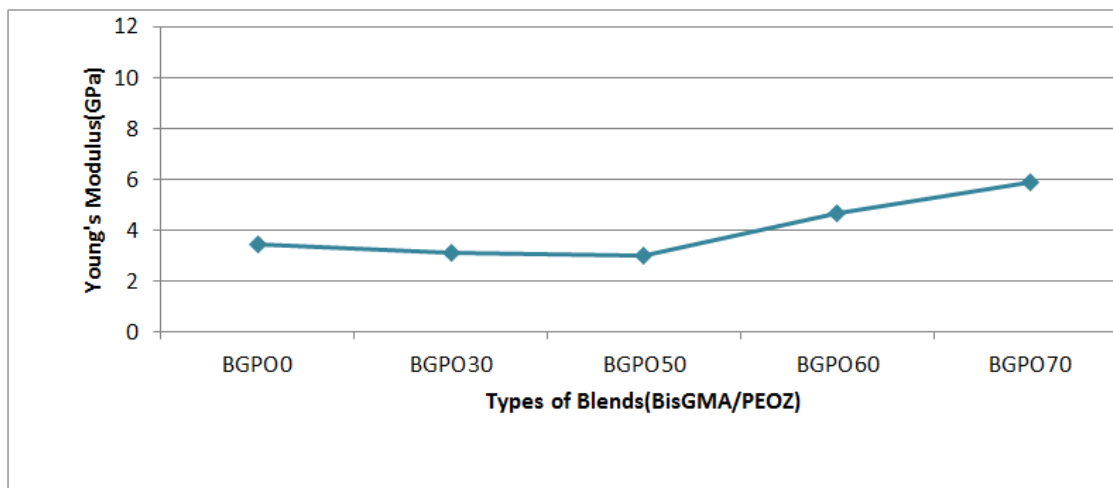


Fig. 5: Young's Modulus of Different BisGMA/PEOZ Blend.

Elongation at Break (EB) and Impact Strength

It is interesting to note that with increasing PVP content both the impact strength and elongation at break decreases which

conformed to the authors' expectation (Figures 6 and 7). However, both these mechanicals always lie much above the corresponding values of unmodified (no PVP) resin.

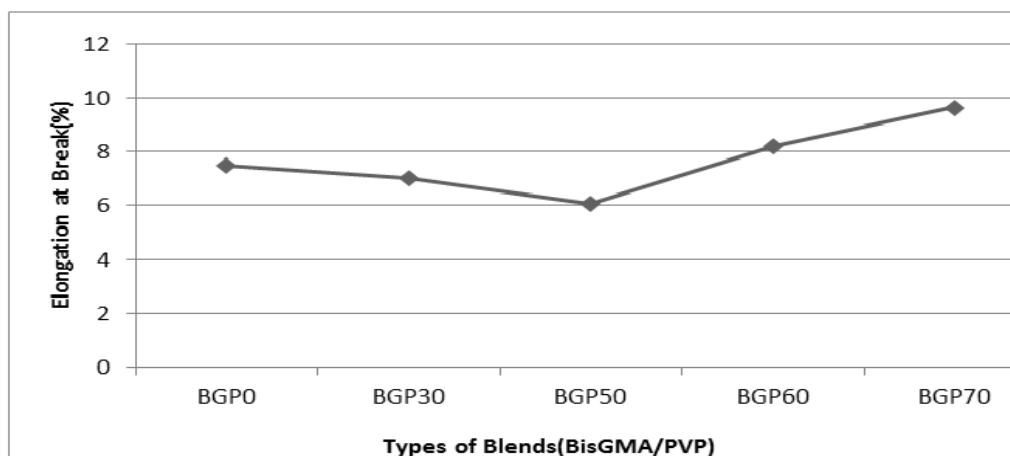


Fig. 6: EB of Different BisGMA/PVP Blends.

The reason is that both the number of dispersed PVP particles and their coalescing tendency increase with progressive increase in PVP content (Figures 16(a), (b), (c)). Thus the path length for propagation of cracks decreases and hence the reduction in toughness and EB%. The PVP particles can be expected to exert their influence as their content increases in the matrix. This decrease in the values is observed up to the BGP₅₀ system. With further increase in PVP content, the values go on increasing because along with gradual increase in rubbery nature of blends, their rigidity increases excessively which

prevents them from stretching. The impact strength also increases beyond BGP₅₀ due to excessive rubbery nature but the blends become too flexible to be used suitably. Thus, the BGP₅₀ blend shows maximum positive results.

But BisGMA/PEOZ blends show a different tendency here. Initially, the blends exhibit a marked increase in the values of both EB and Impact strength up to BGPO₅₀ which then gradually decreases further on increasing the composition of PEOZ in the blend mixture (Figures 8 and 9).

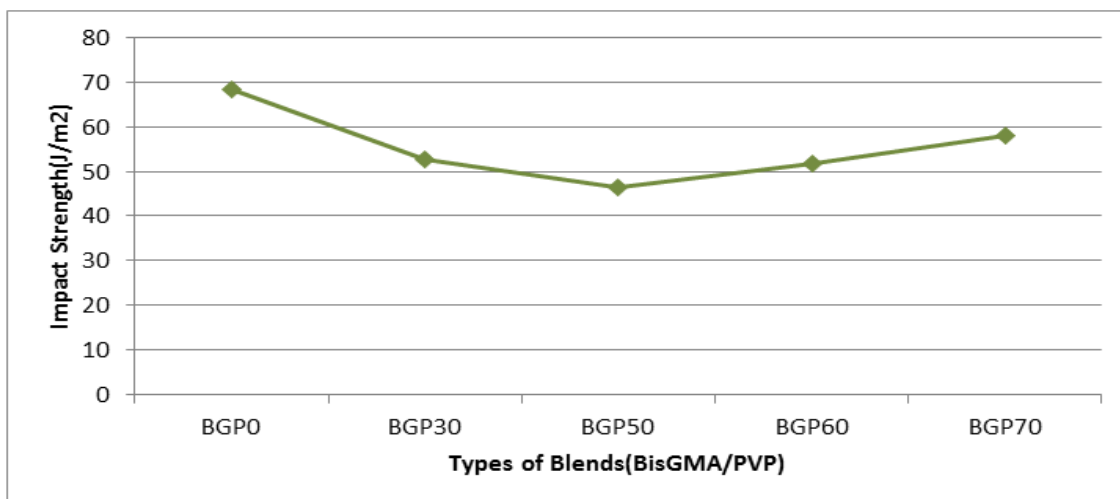


Fig. 7: Impact Strength of Different BisGMA/PVP Blends.

The intrinsic rigidity and stiffness of PEOZ can be accounted for such improved properties. The close value of the solubility parameters of PEOZ and BisGMA might also be expected to account for the compatibility and hence enhancing the properties. But beyond BGPO₅₀, due to increased brittleness

of the blends, their ability to resist shock decreases which is responsible for the decreasing values. It can be thus rightly concluded that not only does PVP show enhanced mechanical properties but PEOZ also exhibits improved properties.

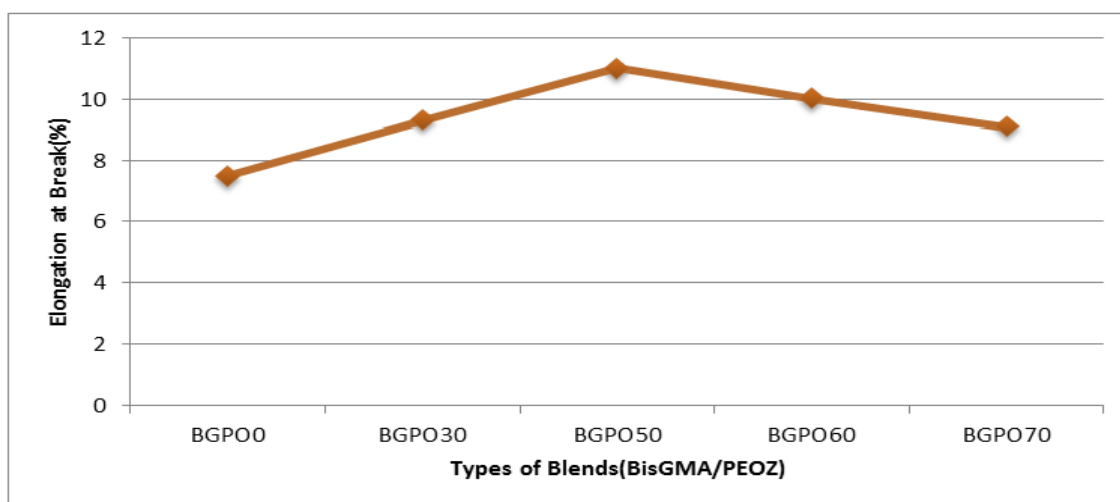


Fig. 8: EB of Different BisGMA/PEOZ Blends.

This is because while addition of PVP makes the blend more rubbery in nature, on the same hand, addition of PEOZ makes the blend more brittle in nature. Some of the properties are dominated by BisGMA/PVP blends while some are dominated by BisGMA/PEOZ blends.

It was a common observation that beyond the 50:50 compositions, the mechanical properties of the blends deteriorated. This can be

explained by the fact that with increasing composition of PVP/PEOZ in the mixture, the equilibrium of the blend composition is lost and the blend separates into two mixed-composition phases. This means that each phase (i.e., the dispersed and continuous phase) contains some of each polymer. This decreases the strength of H-bonding between the two polymer chains, thereby reducing the mechanical properties.

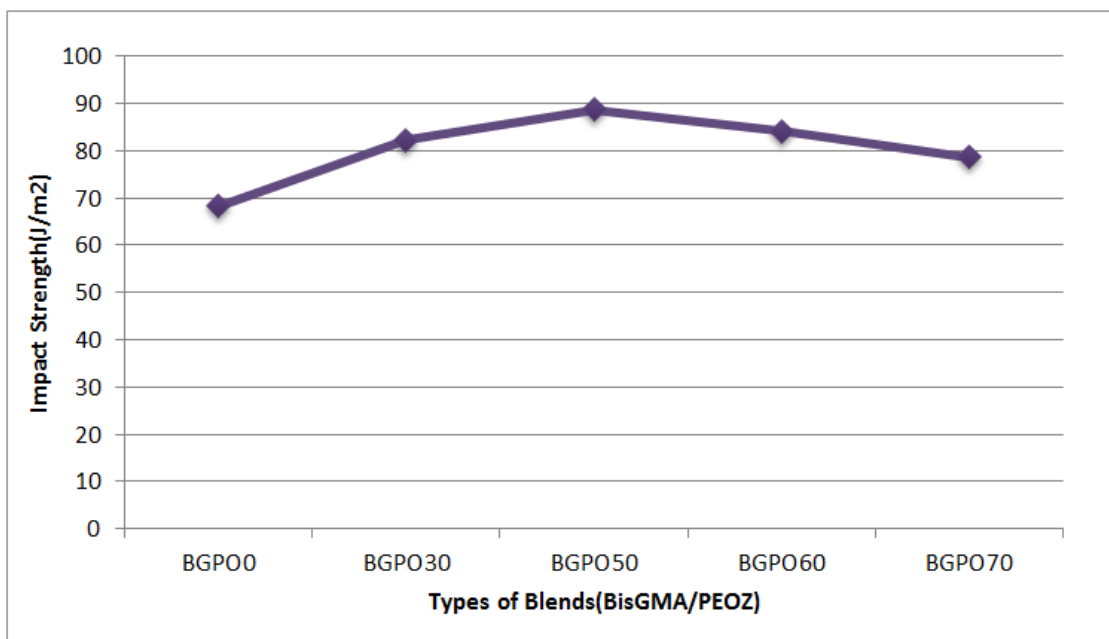


Fig. 9: Impact Strength of Different BisGMA/PEOZ Blends.

The existence of strong hydrogen bonding between BisGMA and sizing materials and the decrease in the mechanical properties of blends with increasing proportion of PVP/PEOZ can be further confirmed by FTIR.

Since PVP and PEOZ are water soluble polymers and can easily absorb moisture, their blends were dried in a vacuum oven at 60 °C overnight before doing FTIR.

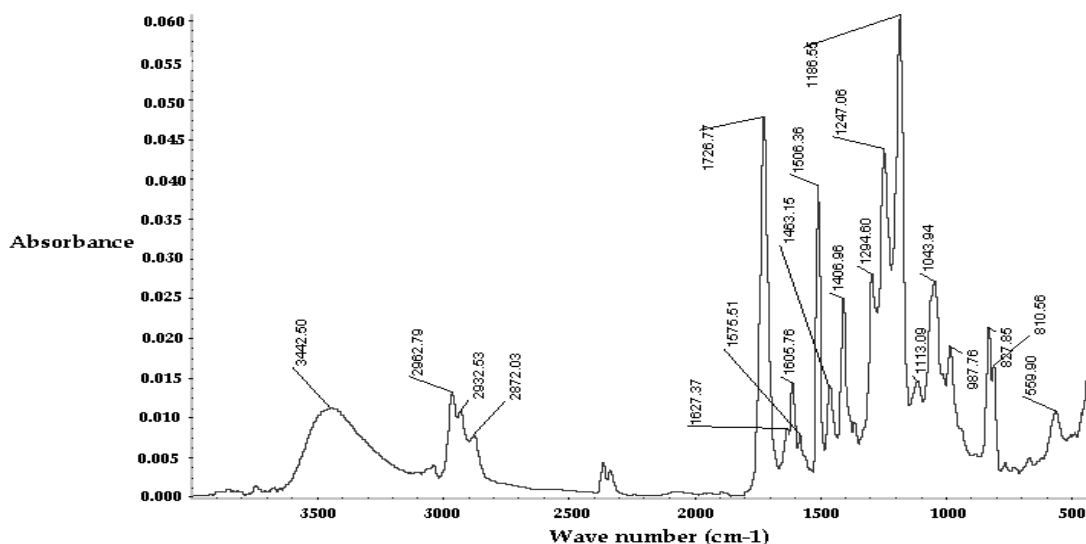


Fig. 10: FTIR Spectrum of BisGMA at Room Temperature by the Reaction of Bisphenol-A Glycidylether with Methacrylic Acid after 6 h.

Figure 11 shows scale-expanded infrared spectrum in the carbonyl stretching region (1740–1620 cm^{-1}) for pure PVP and 50:50 blend of BisGMA with PVP recorded at room temperature. Pure PVP is characterized in this region by a rather broad band at 1677 cm^{-1} .

The relatively low frequency for PVP compared to the usual carbonyl frequencies can be explained by the mixed contributions from the carbonyl stretching and N-C stretching vibrations [17].

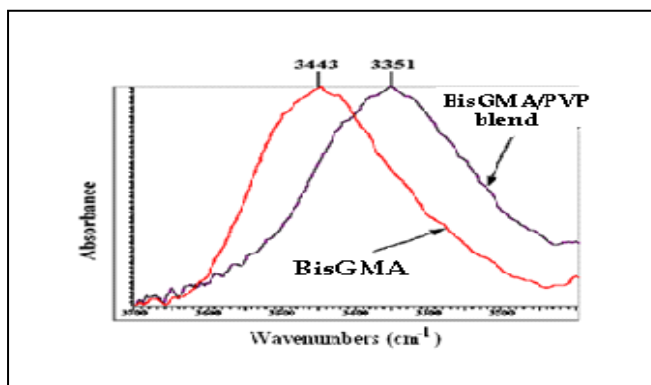


Fig. 11: FTIR Spectra of PVP and 50:50 Blend of BisGMA/PVP in C = O Stretching Region.

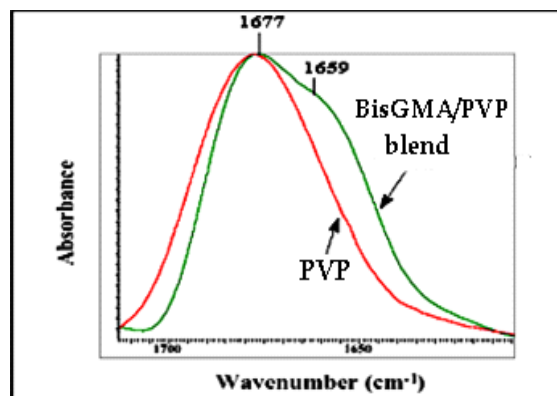


Fig. 12: FTIR Spectra of BisGMA Resin and 50:50 Blend of BisGMA Resin with PVP in OH Stretching Region.

Upon mixing with BisGMA, a second band is observed at 1659 cm^{-1} and can be assigned to hydrogen-bonded PVP carbonyl groups. The formation of hydrogen bonding weakened the strength of the carbonyl bond of PVP in the blend, shifting the carbonyl stretching vibration to a lower frequency [18–19]. Figure 12 shows the corresponding hydroxyl-stretching region ($3700\text{--}3100\text{ cm}^{-1}$) for pure

BisGMA and 50:50 blend of BisGMA with PVP recorded at room temperature. Upon blending with PVP the self-associated OH stretching frequency band at 3443 cm^{-1} is shifted to the lower frequency side, 3351 cm^{-1} . Similar results have also been observed for pure BisGMA and 50:50 blend of BisGMA with PEOZ recorded at room temperature as shown in Figures 13 and 14.

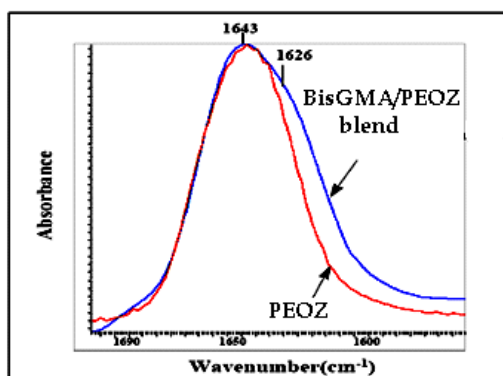


Fig. 13: FTIR Spectra of PEOZ and 50:50 Blend of BisGMA Resin with PEOZ in C = O Stretching Region

Beyond the 50:50 blend composition, as the PVP/PEOZ content increases, phase separation takes place with each phase containing some of each polymer. But the content of one polymer may be more than the other in some phase. Due to the increasing coalescing tendency of sizing particles, the continuous phase in the blend system contains maximum BisGMA and the dispersed phase contains more of PVP and PEOZ. Figure 15 shows the

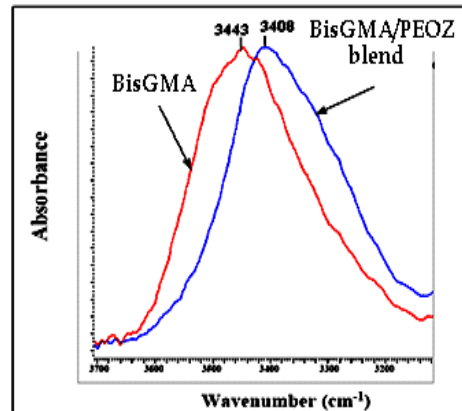


Fig 14: FTIR Spectra of BisGMA Resin and 50:50 Blend of BisGMA Resin with PEOZ in OH Stretching Region.

FTIR spectrum of the continuous phase of BGP₆₀ (higher composition) in which BisGMA is the dominant polymer. The spectrum shows the maximum characteristic absorption peaks of pure BisGMA. This proves that due to higher PVP content, phase separation has taken place and in this case the phase contains maximum BisGMA in it as the characteristic peaks coincide with that of pure BisGMA.

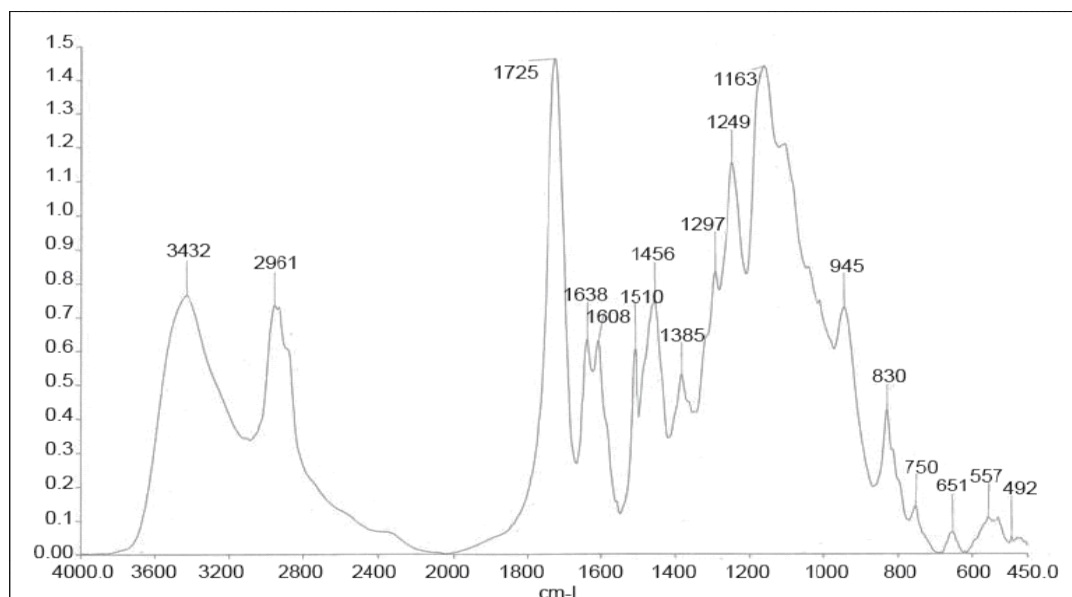


Fig. 15: FTIR Spectra of 40:60 Blend of BisGMA with PVP.

Due to lesser content of PVP, the hydrogen bond interaction between the two polymers reduces thereby decreasing the mechanical properties. Similar FTIR is also obtained in case of 40:60 blend of BisGMA/PEOZ as the continuous phase also contains more of BisGMA. This proves the phase separation tendency of both blends with increasing content of PVP and PEOZ.

SEM Study of Blends

In order to correlate the morphological parameters with the fracture properties of the toughened networks, the microstructures of the fracture surfaces of different BisGMA/PVP and BisGMA/PEOZ blends were analyzed by SEM. The micrographs are shown in Figure 16(a–d).

The fracture surface of the unmodified BisGMA is homogeneous without any dispersed particles. It further confirms the brittle nature of the fracture process in the unmodified BisGMA networks (Figure 16(a)). But the fracture surfaces of BisGMA/PVP and BisGMA/PEOZ blends consist of two distinct phases; globular PVP and PEOZ particles are uniformly distributed throughout the

continuous BisGMA matrix (Figure 16(b–(d)). In the micrographs, one can see the stress-whitened zone (Figure 16(b)). The stress-whitened zone is due to the scattering of visible light from the layer of the scattering center – in this case voids. The generation of these voids is due to the cavitation's of the PVP particles, and the matrix surrounding the voids exhibits notable plastic deformation as evidenced by the beveled edge of the voids. Also there is clear evidence of shear banding between PVP particles, which suggests appreciable matrix shear yielding and plastic deformation over a large volume. This is the primary cause for energy absorption mechanism.

The number of dispersed PVP particles increases with an increase in the concentration of PVP. The modified BisGMA networks having 50% of liquid PVP is uniformly distributed throughout the matrix. The aggregation starts at higher concentration (Figure 16(c)). This explains why the impact and adhesion properties attain a maximum value at about 50% and subsequently decreases.

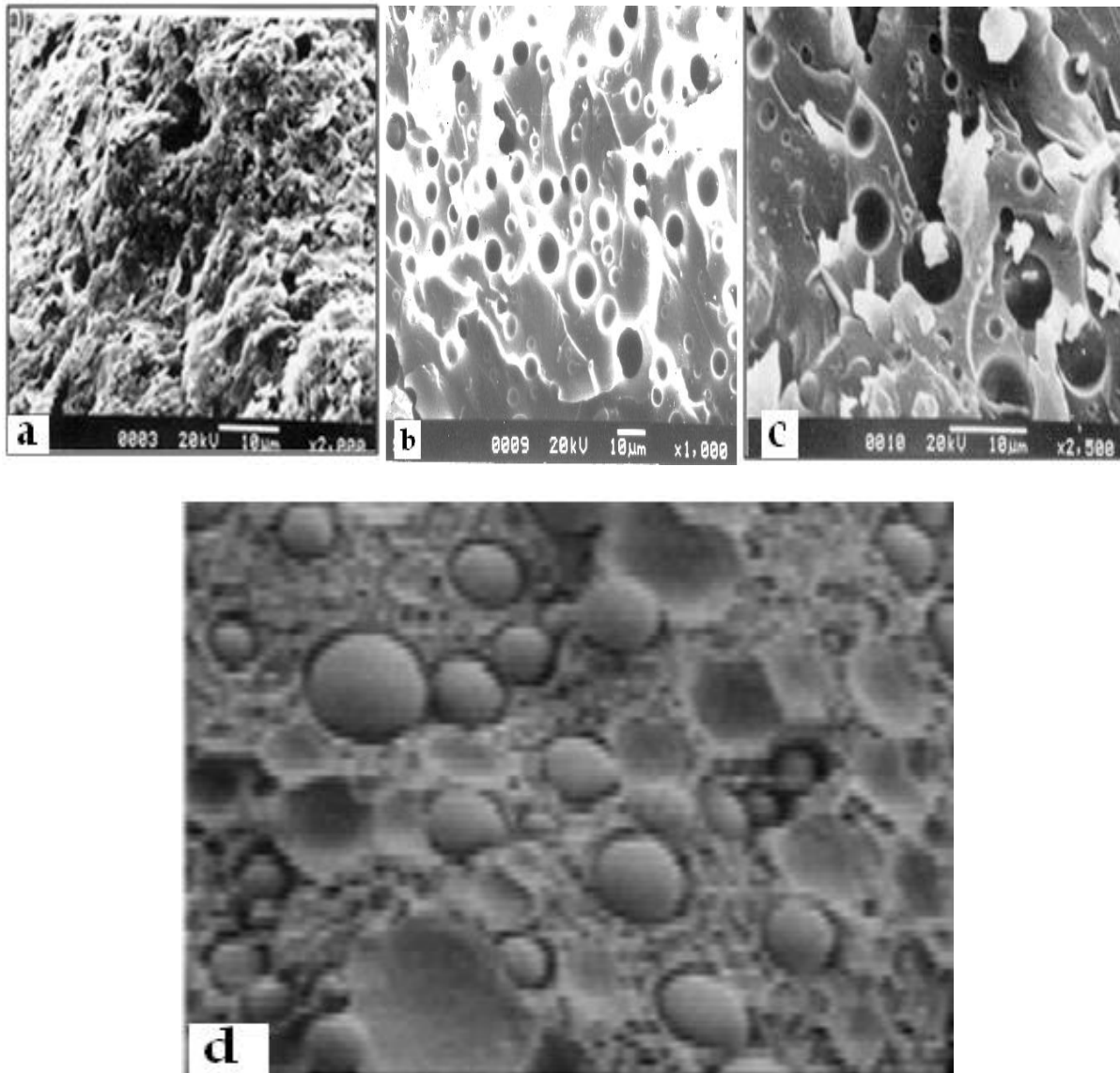


Fig. 16: SEM Photographs of the Fracture Surfaces of (a) BGP₀ (b) BGP₅₀ (c) BGP₆₀ (d) BGPO₆₀.

Similar result is also obtained in case of BisGMA/PEOZ blend system exhibiting coalescing tendency in higher compositions (Figure 16(d)). This coalescing tendency is responsible for phase separation at higher compositions which deteriorates the mechanical properties.

Overall, it can be concluded that only the BGP₅₀ and BGPO₅₀ blends have the potential of being used in different fields without any operational and functional difficulties. Therefore, the water absorption and corrosion tests are all studied using BGP₅₀ and BGPO₅₀.

Corrosion Test

The weight losses and the weight gains are noted for plotting a graph of weight change as a function of time as shown in Figure 17. It is observed that weight gains refer to oxidation and losses confirm reduction. In all the three specimens, oxidation occurs, i.e., they all absorb NaCl solution in which they are immersed but to different extents. BGP₅₀ and BGPO₅₀ blends show less weight change as compared to pure BisGMA resin because the blends do not absorb much of the saline water due to uniform surface and lesser number of voids as compared to BGP₀. Thus, from corrosion tests it is found that the blends are non-corroded in saline water.

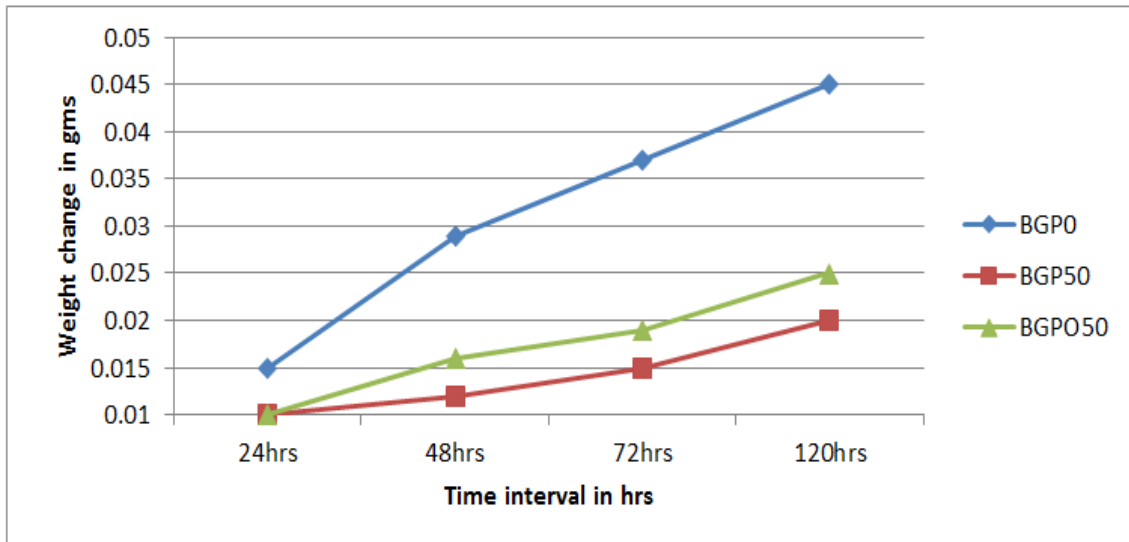


Fig. 17: Accelerated Test on Pure BisGMA and BGP₅₀ and BGPO₅₀ Blends at Temperature 42 °C with Concentration 10 wt % NaCl.

Moisture Absorption Test

Moisture absorption of the blends would lead to swelling and degradation which may result in poor mechanical properties and dimensional instability. Thus, the water absorption capacity of the blends was evaluated to find out whether the blends could be used to prepare composites of high mechanical strength. Figure 18 shows the moisture absorption as a function of time for pure BisGMA, BGP₅₀ and BGPO₅₀ recorded after every 2 h interval. The moisture absorption tests showed that the two blend systems, i.e., BGP₅₀ and BGPO₅₀ absorb

less water compared to that of pure BisGMA (BGP₀). The water uptake is more for BGP₀ because the pure resin is highly brittle and crystalline in nature. As a result, there are a large number of voids which absorb water to a great extent. But when PVP and PEOZ are added to BisGMA, the surface becomes more even thereby reducing the number of voids and so also the water uptake capacity. The moisture absorption of BGP₀, BGP₅₀ and BGPO₅₀ was found to be around 6, 3.2 and 2.8% respectively after 10 h of immersion in water.

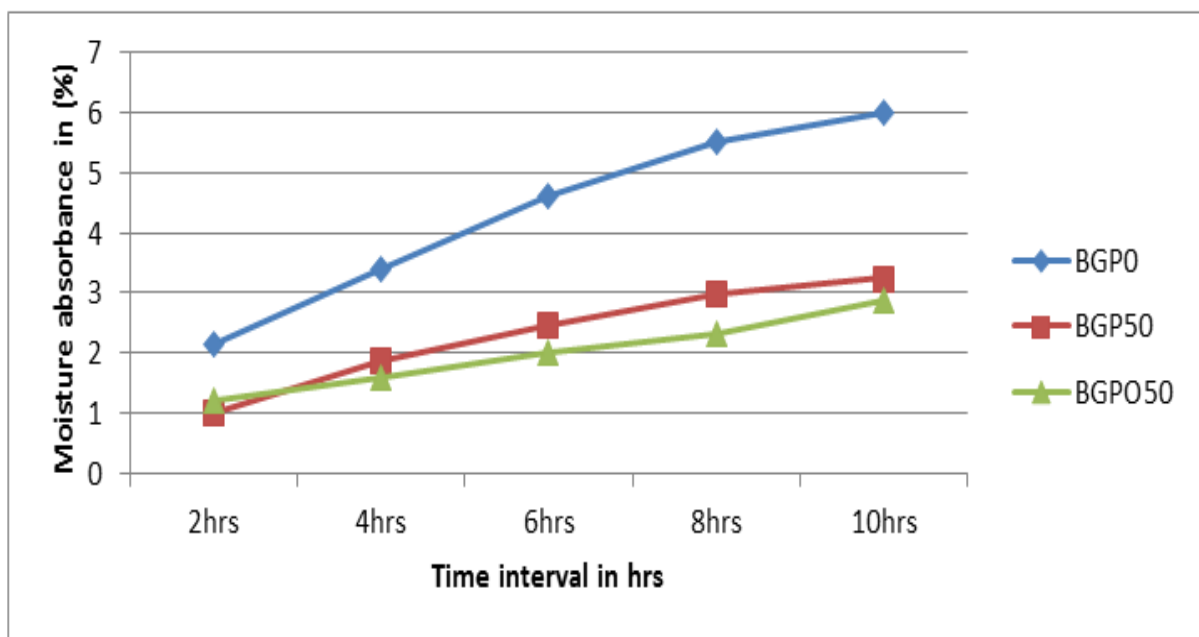


Fig. 18: Moisture Absorbance of BGP₀, BGP₅₀ and BGPO₅₀.

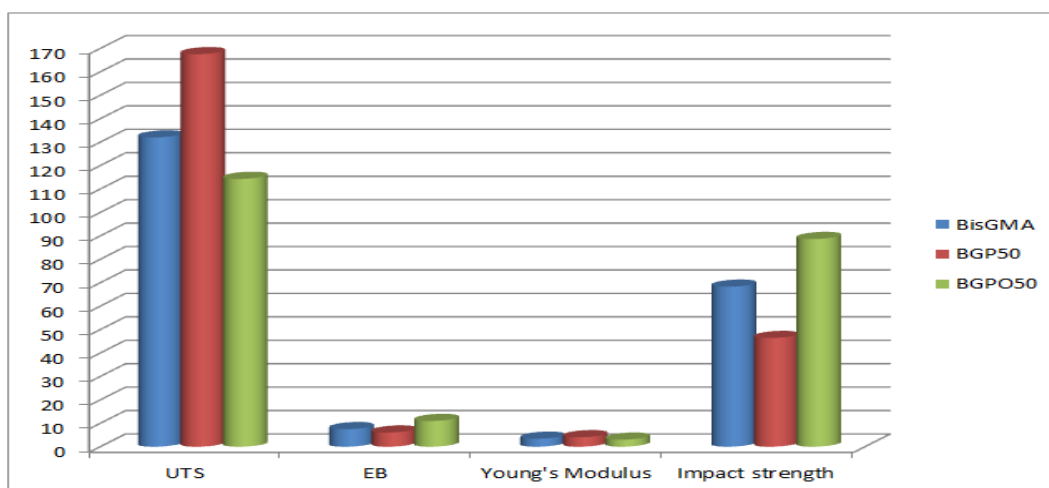


Fig. 19: Comparative Study of Mechanical Properties of BGP₀, BGP₅₀ and BGPO₅₀.

MECHANICAL AND CORROSIVE PROPERTIES OF BisGMA AND BisGMA/PVP AND BisGMA/PEOZ BLENDS: A COMPARATIVE STUDY

From Figure 19, it is clear that when pure BisGMA resin is blended with thermoplastic polymers like PVP and PEOZ, the overall mechanical properties of the blend get enhanced. The properties like UTS and Young's Modulus are dominated by BisGMA/PVP blends whereas EB and impact strength are dominated by BisGMA/PEOZ blends. Thus, it is difficult to predict a better blending system as far as the mechanical properties are concerned. Both the blends are effective and useful in their respective ways. However, in both cases, the 50:50 blend composition exhibits maximum improvement. It is because this is the only balancing mixture where both the polymers are present in equal

proportions. This mixture displays the enhanced qualities of both polymers which can be utilized in many sectors. But the other blends contain polymers in non-uniform compositions which can sometimes exhibit extreme properties. Thus, it can be rightly said that the BGP₅₀ and BGPO₅₀ blends are the most suitable ones from the mechanical point of view.

Moreover, BGP₅₀ and BGPO₅₀ show better resistance to corrosion and moisture as compared to pure BisGMA due to their better surface qualities (Figure 20). The shortcomings of the above blends are negligible but their advantages are many which have been proved experimentally. Both the BGP₅₀ and BGPO₅₀ can be preferably used than pure BisGMA resin.

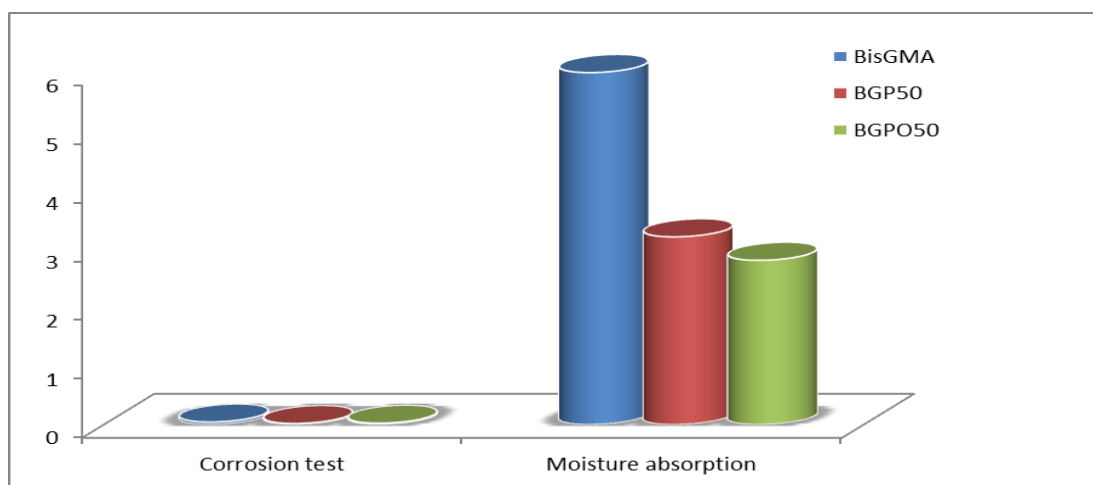


Fig.20: Comparative Study of Corrosive Properties of BGP₀, BGP₅₀ and BGPO₅₀.

Thus, it can be rightly said that both the polymers, i.e., PVP and PEOZ make BisGMA a better resin to work with by reducing its viscosity and reactivity and making it more flexible. The blends formed are relatively cheap and can act as potential structural materials for transportation and building purposes which can also be manipulated in many ways to be used universally. The biodegradable nature of these blends also conforms to the principles of “Green and Clean environment.”

CONCLUSIONS

The solubility parameter results confirmed that PVP and PEOZ were potentially miscible and soluble within the cured BisGMA network. The above blend system under study displayed an improvement in the mechanical properties over unmodified resin one. The 50:50 blend system is the optimum blend composition in both the systems due to maximum improvement in mechanical properties. Corrosion and water absorption studies suggested that the above blend system can be used in corroded and saline environment. Due to this resistant property, the above blends can be used in their optimum compositions (50:50) to prepare various polymeric composites that can be used in automobiles, transportation applications, low-cost housing and building projects.

ACKNOWLEDGEMENT

The authors of this paper are thankful to KIIT University for their support and help. The assistance provided by IIT, Kharagpur, during the completion of the experimental work is greatly acknowledged.

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