

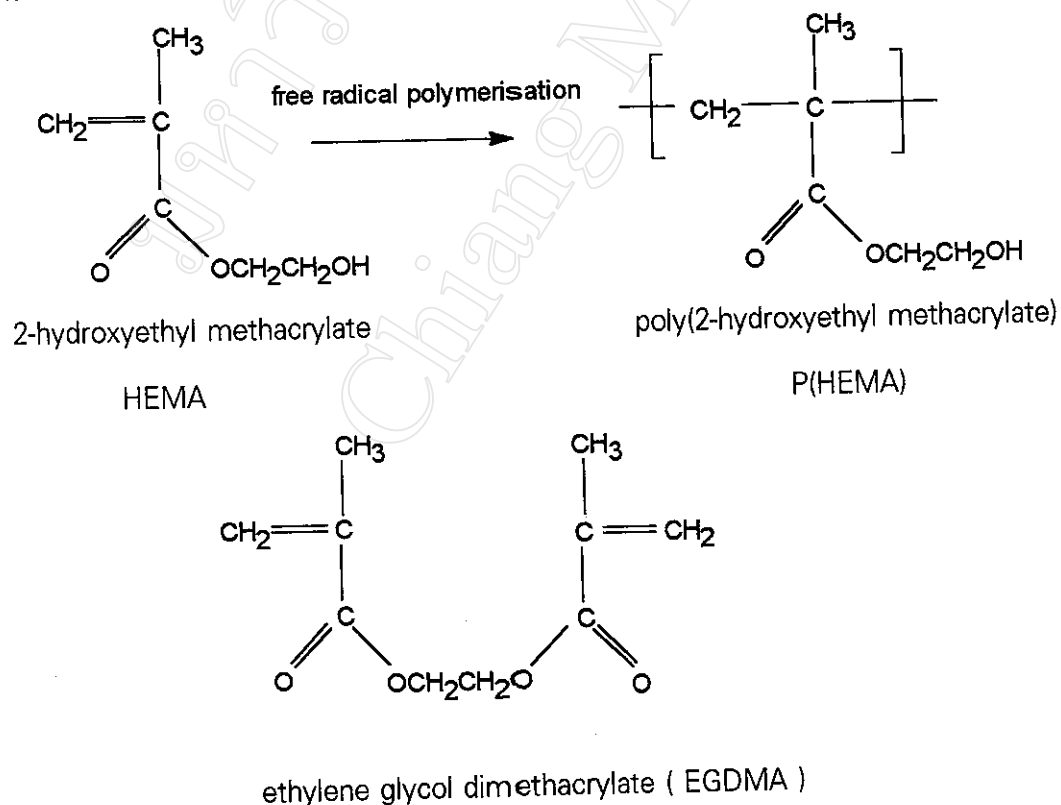
# CHAPTER 4

## DISCUSSION AND CONCLUSIONS

In this Chapter 4, the following conclusions can be drawn from the experimental results described in Chapter 3. As the results have shown, the main aims of this research project, as stated at the end of Chapter 1, have been achieved in this study of synthetic hydrogels as temporary skin substitutes.

### 4.1 Hydrogel Synthesis

The main objective of this research project has been to synthesize hydrogels based on poly(2-hydroxyethyl methacrylate), P(HEMA), by free radical bulk polymerisation. Ethylene glycol dimethacrylate, EGDMA, was used as the crosslinking agent.



The 3-dimensional network structure of crosslinked P(HEMA) is represented below in Figure 4.1 showing how the difunctional EGDMA units serve to join the P(HEMA) chains together at random points throughout the matrix. The structural similarity between EGDMA and HEMA ensures that the crosslinking does not seriously affect the chemical nature of the polymer.

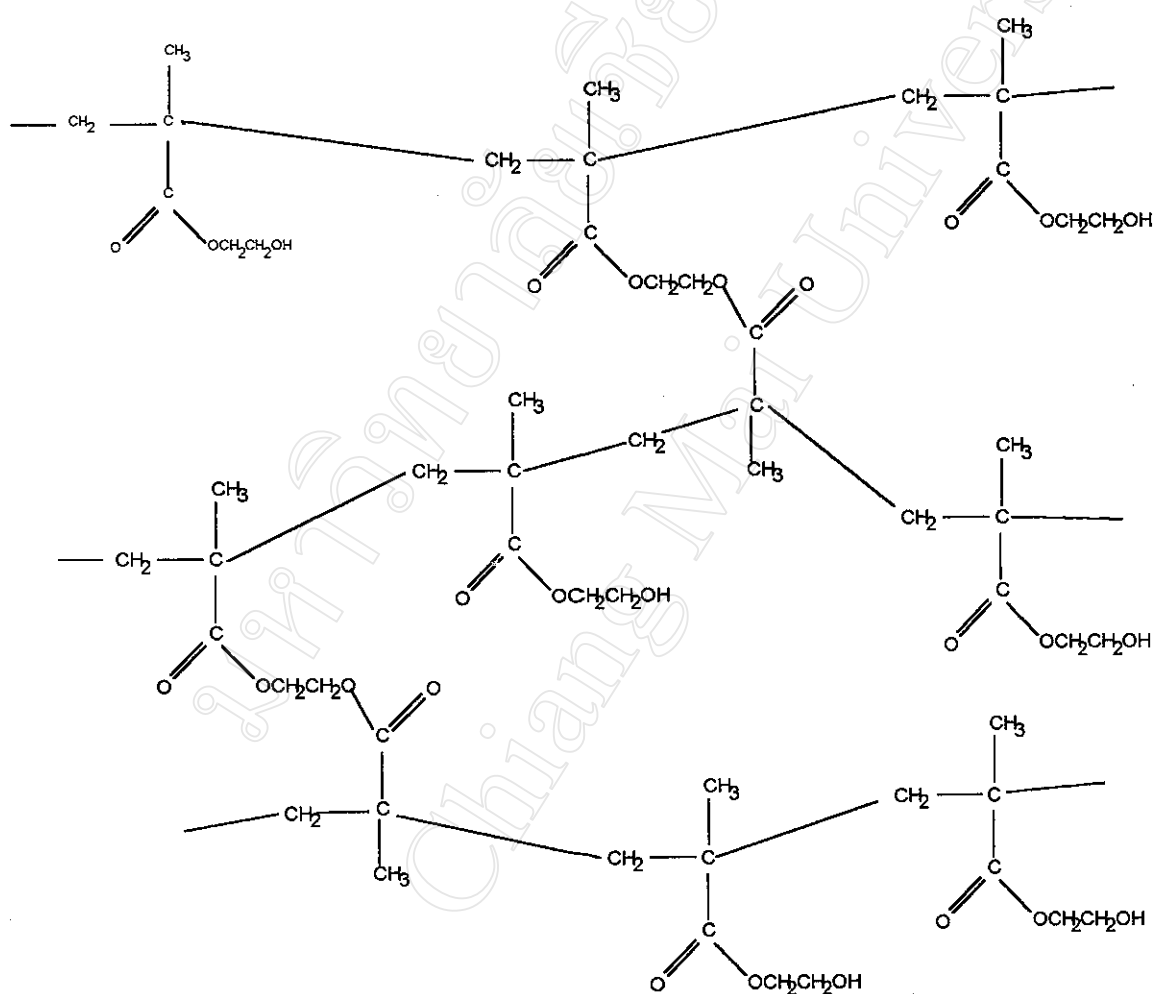
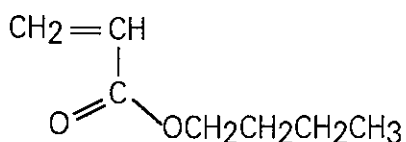
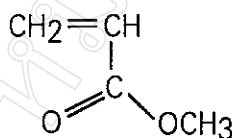


Figure 4.1 : Structural representation of P(HEMA) crosslinked by EGDMA.

The two comonomers chosen to improve the mechanical properties of crosslinked P(HEMA) were butyl acrylate (BA) and methyl acrylate (MA).



butyl acrylate (BA)



methyl acrylate (MA)

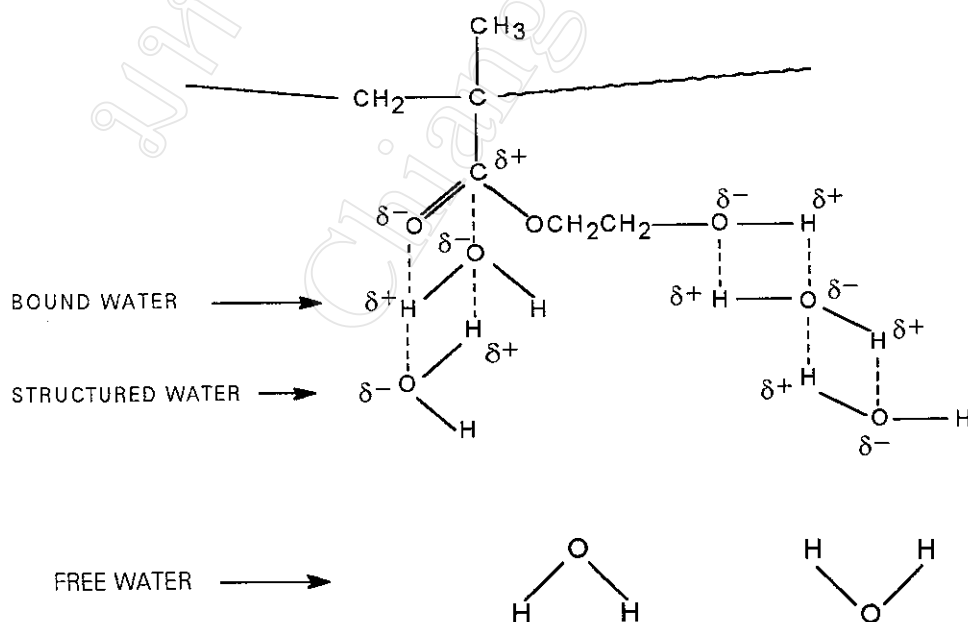
These two comonomers were chosen on the grounds that their chemical structures are similar to HEMA but do not possess the same hydrogen-bonding capability due to the absence of the hydroxyl group. Their inclusions will therefore decrease hydrophilicity but increase mechanical strength.

Thus, a range of homopolymers and copolymers were prepared, containing varying proportions of HEMA and BA on the one hand and HEMA and MA on the other. The copolymers prepared were essentially random copolymers. Since there was almost complete 100% conversion in the synthesis reaction, with only trace amounts of monomers being eluted when the polymers were hydrated, the copolymer compositions corresponded to the initial comonomer feeds. This was confirmed by elemental analysis.

All of the copolymers investigated therefore contained both a hydrophilic and a hydrophobic component. In their dry state, copolymers containing BA or MA were more flexible than P(HEMA), flexibility increasing with increasing BA or MA content. However, when hydrated, the flexibilities of the homopolymers and copolymers were more directly dependent on the amount of water absorbed which, in turn, depended upon their chemical structures.

## 4.2 The Nature of Hydrogel-Water Interactions

Hydrogels may be conveniently described as hydrophilic polymers that are swollen by, but do not dissolve in, water. The underlying role of water in acting as a plasticizer, a transport medium in the polymer matrix for dissolved species (such as oxygen), and a “bridge” between the very different surface energies of synthetic polymers and body fluids, is responsible for the unique position that hydrogels occupy in the field of biomaterials [40]. The nature of the interaction between water and P(HEMA), which gives the polymer its so-called “hydrogel” properties, has been discussed in the literature [59]. The general consensus of opinion seems to be that there are different “levels” of interaction depending upon the proximity of the water molecule to the polymer chain. Since this interaction is clearly “hydrogen-bonding” in nature, the strength of interaction (or force of attraction) will obviously increase as this proximity increases. These different levels of interaction are represented in a simplified fashion in Figure 4.2 below.



where :

- Bound (or non-freezing) water = water strongly associated directly with the polymer chain through hydrogen bonding
- Structured (or semi-bound) water = less tightly bound water interacting only indirectly with the polymer chain
- Free (or freezing) water = water with a much greater degree of mobility, unaffected by the polymeric environment

**Figure 4.2** : Different levels of polymer-water interaction in P(HEMA).

The rather simplistic view in Figure 4.2 of the water-bonding process suggests that, in **bound water**, the water molecules are hydrogen-bonded to hydrophilic groups on the polymer chain, while **structured water** molecules are hydrogen-bonded to both **free** and **bound** water molecules. Using the concept of **hydration shells**, it is possible to envisage the bound water hydrogen-bonded in the innermost shell to hydrophilic sites (in this case, hydroxyl and carbonyl groups) on the polymer chain with other hydration shells of structured and free water molecules surrounding them. Furthermore, as the number of monomer units between crosslinks decreases, the network becomes more tightly bound. Hence, there is a marked decrease in free water content with increasing crosslink density, together with a small decrease in the number of moles of bound water per mole of hydrophilic repeat unit.

An indication of the strength of these polymer-water interactions in hydrogels can be provided by thermal analysis, in particular, differential scanning calorimetry (DSC) [60]. To illustrate this point, a hydrated P(HEMA) sample was heated in a DSC volatile sample pan until the water inside boiled off. Water alone was also heated under the same conditions for comparison. When the two DSC curves are compared in Figures 4.3 and 4.4, the different shapes of the water volatilisation curves demonstrate clearly the effect of the polymer. Whereas the water curve in Figure 4.4 shows an almost instantaneous decrease following the peak maximum, the P(HEMA) sample curve in Figure 4.3 shows a much more gradual decrease. This is a result of the higher energy (i.e., higher temperature) which is required in the hydrogel to overcome the polymer-water interactions in the innermost hydration shell so that the “bound” water can volatilise. Usually, in the literature [60], the freezing point transition is used to illustrate this effect rather than the boiling point transition. However, in this work, sub-ambient ( $<20^{\circ}\text{C}$ ) DSC analysis was not possible and so the boiling point transition was studied instead.

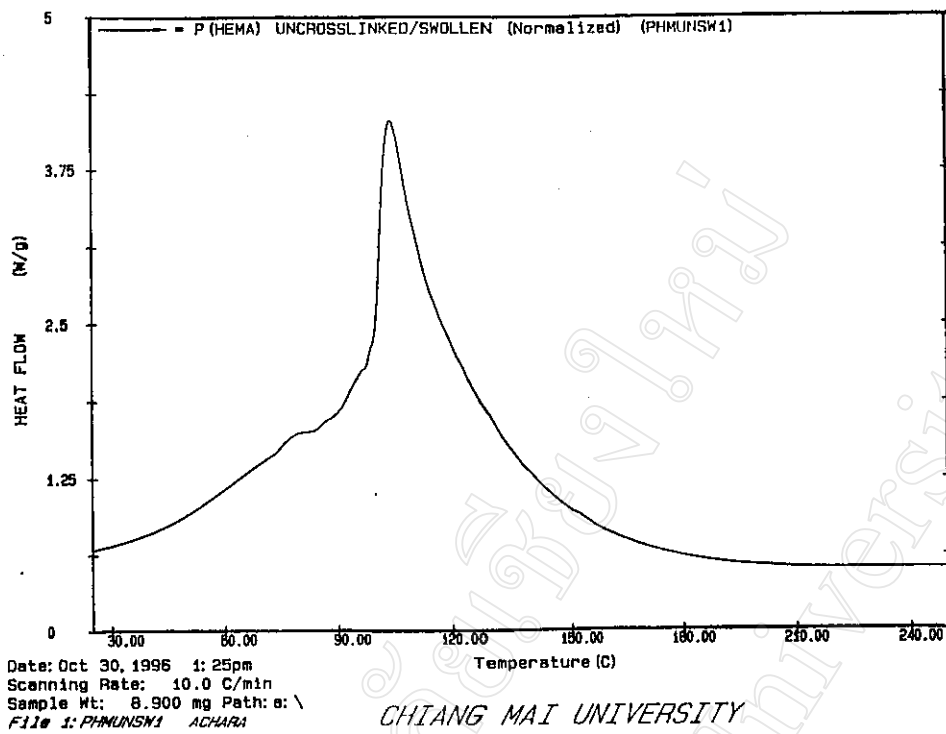


Figure 4.3 : DSC thermogram of hydrated P(HEMA) hydrogel showing the water volatilisation endotherm.

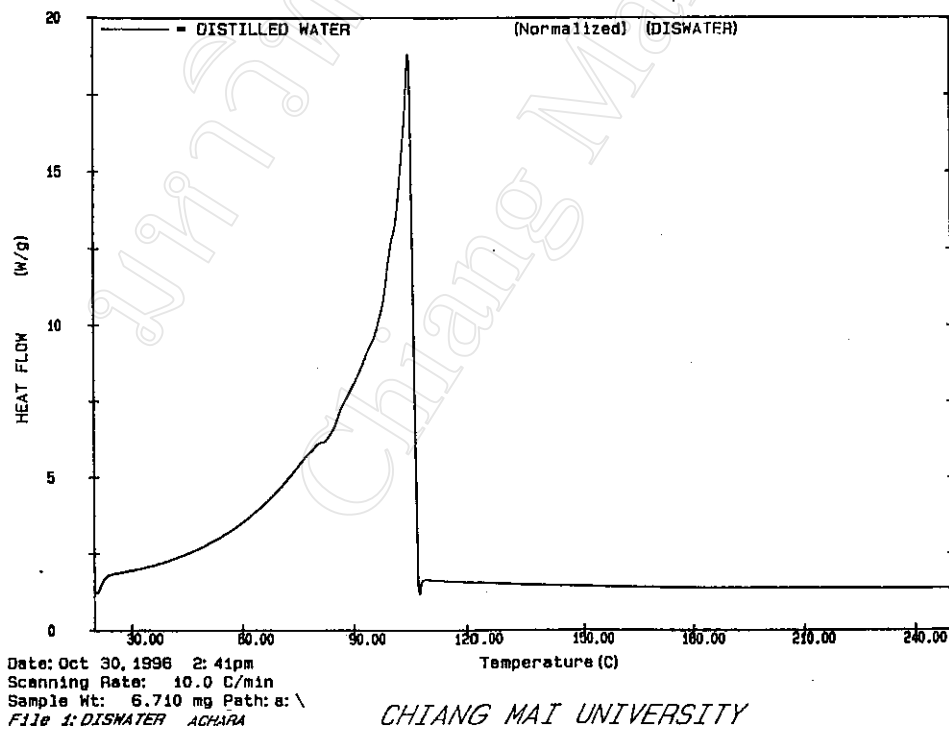


Figure 4.4 : DSC thermogram of distilled water alone showing the volatilisation endotherm.

### 4.3 Glass Transition Temperature

The effects of chemical structure and copolymer composition on the glass transition temperatures ( $T_g$ ) of the homopolymers and copolymers were shown previously in Table 3.18 on page 84. The  $T_g$  values of PBA, PMA, and some of the copolymers could not be observed from their DSC curves either because they were sub-ambient ( $<20^\circ\text{C}$ ) or indistinct. From the results in Table 3.18, the main conclusions to be drawn are:

- (1) The observed  $T_g$  of P(HEMA) ( $103^\circ\text{C}$ ) is in close agreement with its literature value ( $104^\circ\text{C}$ ).
- (2) The literature  $T_g$ s of PMA ( $10^\circ\text{C}$ ) and PBA ( $-54^\circ\text{C}$ ) are much lower than that of P(HEMA) due to the absence of intermolecular hydrogen-bonding. This lowers the energy barriers to chain rotation and therefore lowers the  $T_g$ . The lower  $T_g$  of PBA relative to PMA can be explained in terms of the "internal plasticizing" effect of the butyl group in PBA. Since it is a straight-chain *n*-butyl group, it is flexible in nature. It can therefore facilitate chain rotation by sliding in between the main chains, thereby increasing the "free volume" between the chains without imparting any steric hindrance effect.
- (3) Comparing the observed  $T_g$ s of the uncrosslinked P(HEMA) ( $103^\circ\text{C}$ ) and the crosslinked P(HEMA) ( $106^\circ\text{C}$ ), the small amount (about 1%) of crosslinking does not appear to have much effect on the actual  $T_g$  value. What it does do, though, is to suppress the  $T_g$  transition, due to the constraints imposed on molecular motion, and therefore make the  $T_g$  less distinct. This is apparent from comparing the DSC curves in Figures 3.27 and 3.28 on page 76 - 77.



(4) As would be expected, the  $T_g$  values of both copolymers, P(HEMA-co-BA) and P(HEMA-co-MA), decrease with increasing BA and MA contents. However, only the P(HEMA-co-MA) series gave observable  $T_g$ s in their DSC curves. It is also interesting to note in Table 3.18 that the observed  $T_g$ s of the P(HEMA-co-MA) copolymers agree closely with the theoretical values calculated from the Fox Equation. This supports the earlier assertion that the copolymers are, indeed, **random** copolymers, as is usually the case from free radical bulk copolymerisation.

#### 4.4 Thermal Stability

Since hydrogel polymers for use as temporary skin substitutes are unlikely to be subjected to high temperatures, thermal stability is not a critical property. However, it is quite possible, during the synthesis reaction, that temperatures in excess of  $100^\circ\text{C}$  could be reached, so it is necessary to study thermal stability up to this temperature at least.

Thermal stability in this work was studied by means of dynamic (non-isothermal) thermogravimetry (TG). The results obtained were shown previously in Figures 3.41-3.48 / pages 86 - 89 and compared in Table 3.19 / page 90. The main conclusions to be drawn from these results are:

- (1) Since all of the homopolymers/copolymers studied were stable up to temperatures in excess of  $200^\circ\text{C}$ , thermal decomposition during the synthesis reaction should not be a problem.
- (2) In the case of P(HEMA), crosslinking increases thermal stability. This crosslinking effect is not so noticeable in PBA and PMA because, in their uncrosslinked states, their thermal stabilities are already much higher ( $T_i > 300^\circ\text{C}$ ) than P(HEMA). Crosslinking generally increases thermal stability in polymers by restricting

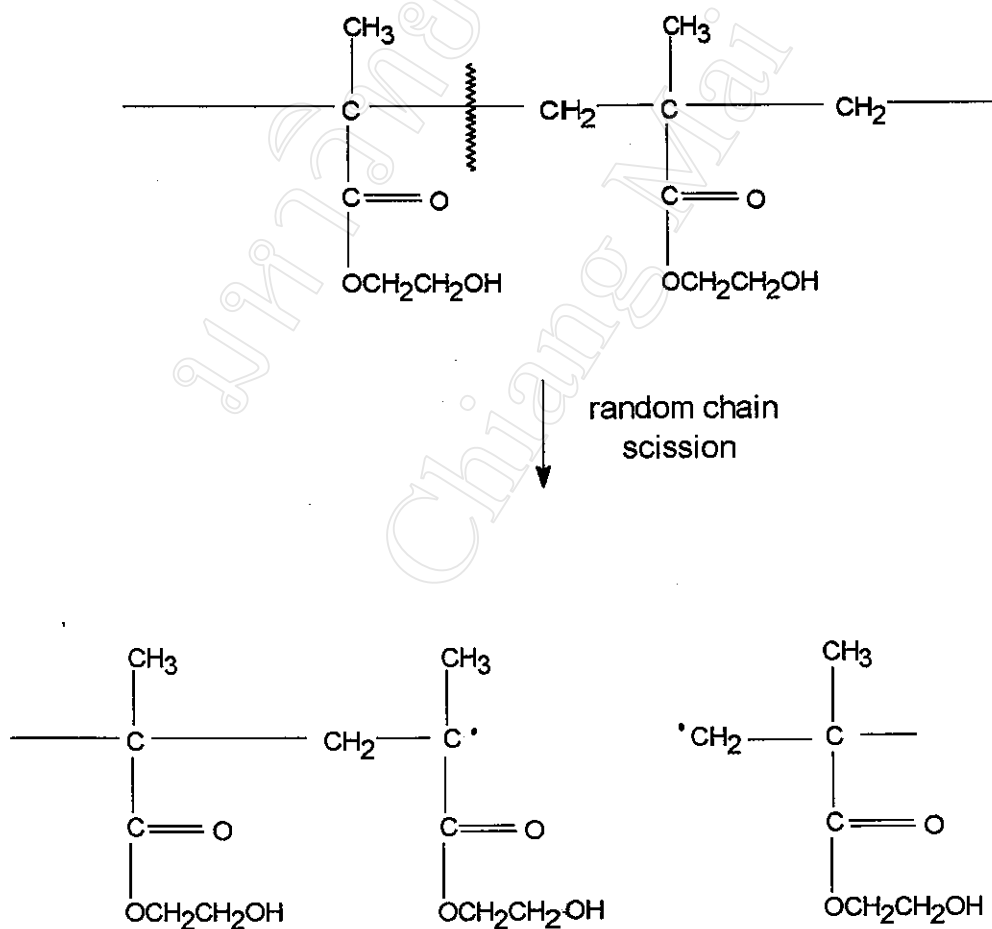
molecular motion and delaying the onset of volatile product formation.

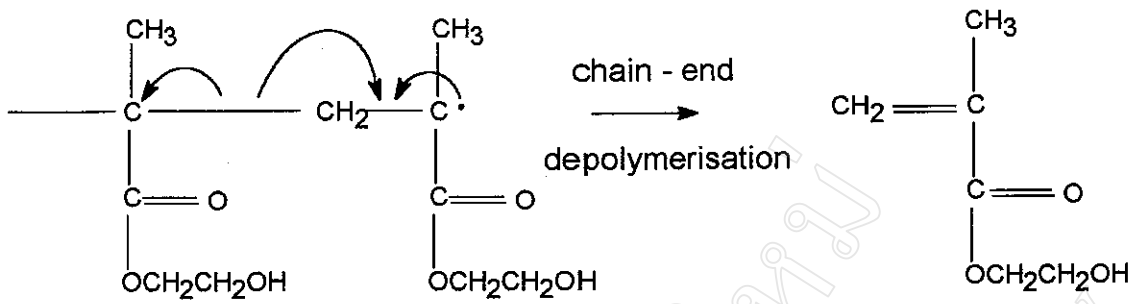
(3) The uncrosslinked homopolymers showed thermal stabilities in the order of :



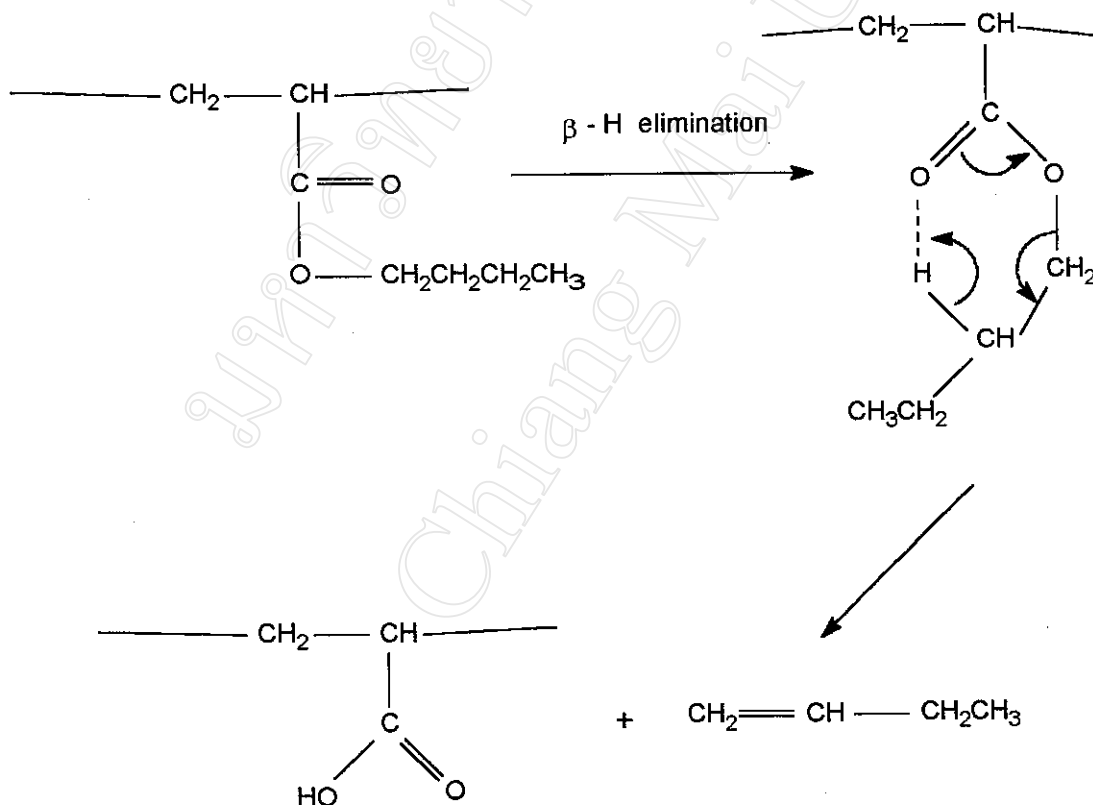
Obviously, this order is determined by the temperatures at which the respective mechanisms of thermal degradation occur which, in turn, depend on chemical structure. Details of the types of degradation mechanisms which are believed to occur in these polymers are given below.

In the case of P(HEMA), the main mechanisms of thermal degradation are random chain scission followed by chain-end depolymerisation. This is similar to the well-known case of poly(methyl methacrylate), PMMA.





However, in the case of PBA, a  $\beta$ -hydrogen elimination mechanism is also possible. Butene-1 is eliminated from within the butyl ester group but the main chain of the polymer remains intact. This is an example of what is often termed “non-chain scission”.



This  $\beta$ -hydrogen elimination mechanism cannot occur in PMA because the pendant methyl ester group only contains  $\alpha$ -hydrogens, not  $\beta$ -hydrogens.

When comparing the 3 homopolymers together, the lower thermal stability of P(HEMA) relative to PBA and PMA is probably due to the presence of the  $\alpha$ -CH<sub>3</sub> group. This has the effect, in P(HEMA), of stabilising the tertiary radical formed from chain scission. Once formed, the driving force for subsequent chain-end depolymerisation is provided by the thermodynamic stability of the HEMA monomer which is produced.

#### 4.5 Water Absorption and Retention Properties

In this study, the effects of ethylene glycol dimethacrylate, EGDMA, crosslinker (1% w/w) on the equilibrium water content, EWC, of P(HEMA), PBA and PMA were studied. The results indicated that, with or without crosslinking, the EWC was reached after about 2 hours immersion in deionized water at 35.0°C. However, the EWC of the uncrosslinked P(HEMA) (37.3%) was higher than that of the crosslinked P(HEMA) (33.7%). Similar effects were found in the cases of PBA and PMA. This effect of crosslinking on the EWC is as would be expected since the crosslinks have the effect of tying the polymer chains together in a 3-dimensional network, thereby stiffening the matrix and decreasing its capacity to expand or swell. This, in turn, decreases its porosity towards the absorption of water molecules. An increase in the crosslink density causes a slight decrease in the bound water content but a large decrease in the free water content. These decreases in water content are a result of the decreased availability of hydrophilic binding sites due to decreased chain mobility and, hence, increased steric occlusion. Thus, the crosslink density, which simply depends on the amount of crosslinking agent used in the synthesis reaction,

provides an easy and convenient means of controlling the EWC of the hydrogel polymer.

Significant changes in P(HEMA) water binding behaviour also arise from the introduction of hydrophobic comonomers. In this project, butyl acrylate, BA, and methyl acrylate, MA, were chosen as the modifying comonomers over the 5-20 wt % range. The effects of copolymer composition on the EWC values of the crosslinked P(HEMA-co-BA) and P(HEMA-co-MA) hydrogels are summarized in Figure 4.5. As the two plots show, the EWC decreases approximately linearly with increasing BA/MA content in the copolymer. The decrease is more pronounced in the case of the P(HEMA-co-BA) copolymer series because BA is a more hydrophobic comonomer than MA. These results show that P(HEMA) modification, even at a relatively low level of comonomer inclusion, provides an effective and predictable means of controlling water absorption properties.

Similar to the EWC in water, the EWC in air is also found to be approximately linearly dependent on copolymer composition. As Figure 4.6 shows, the EWC in air decreases with increasing BA/MA content in the copolymer. Again, the more hydrophobic BA comonomer shows the greater effect, as would be expected, since the less hydrophilic the hydrogel, the less able it is to retain absorbed water. Refojo [61] has postulated that, in addition to hydrophilic bonding, hydrophobic bonding is also important in hydrogels and that the formation of these hydrophobic bonds is an endothermic process. Hydrophobic bonds are van der Waals interactions between non-polar groups. These result from the driving force that the solubility of non-polar groups in water (hydrophobic hydration) is entropically unfavourable because the water is not capable of structuring itself in the vicinity of a non-polar compound. These hydrophobic bonds therefore act as "physical crosslinks" to reduce the EWC of the hydrogel.

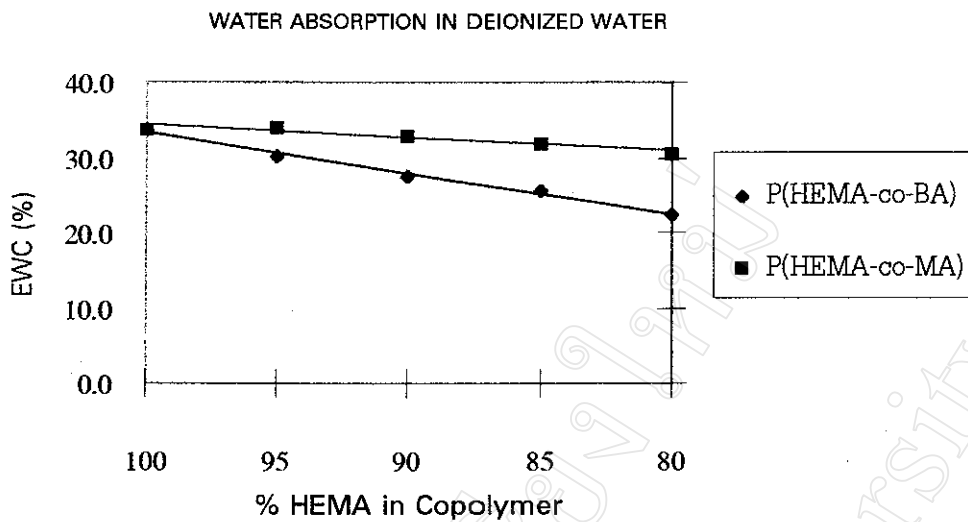


Figure 4.5 : Effect of copolymer composition on the EWC of the P(HEMA-co-BA) and P(HEMA-co-MA) hydrogels when immersed in deionized water at 35.0°C.

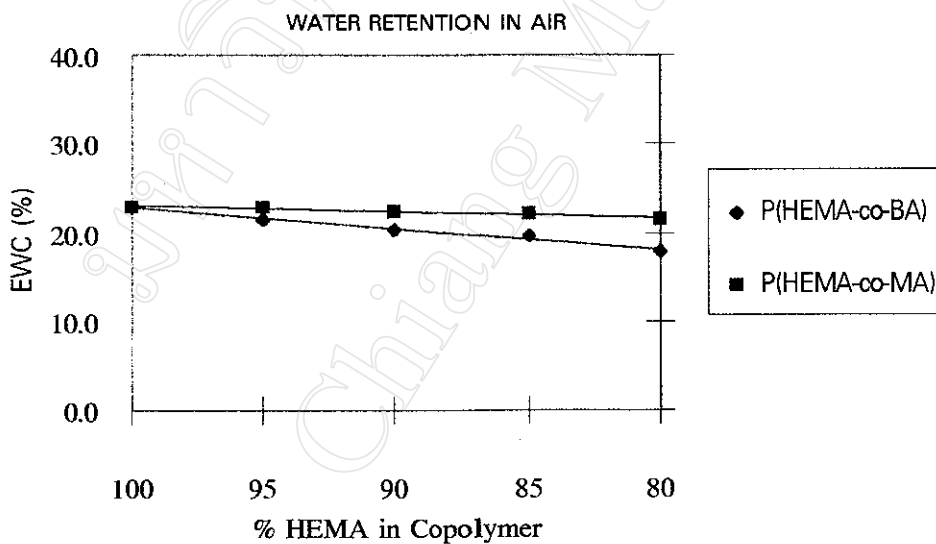
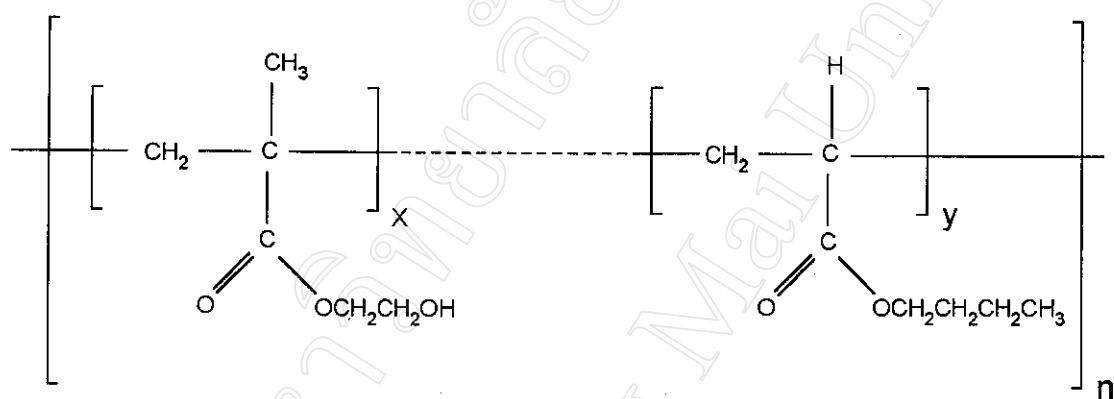
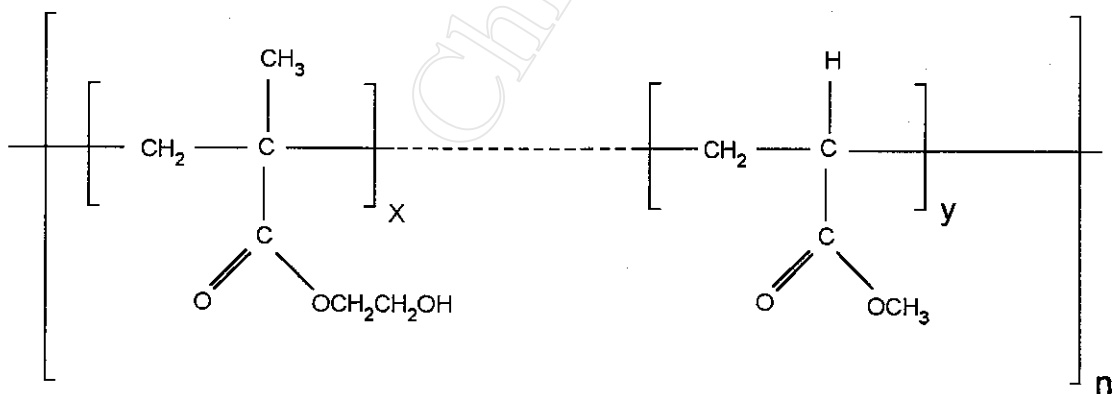


Figure 4.6 : Effect of copolymer composition on the EWC retained by the P(HEMA-co-BA) and P(HEMA-co-MA) hydrogels when left in air at 35.0°C.

When all of these ideas and findings about water absorption/retention are brought together, the following picture emerges about the hydrogels studied in this work. Initially, the water absorbed is strongly hydrogen-bonded to the polymer. At higher proportions of the hydrophilic HEMA monomer, and therefore high EWCs, strongly bound water is present together with water in a more mobile form, referred to as free water. Free water can also be regarded as “plasticizing” water in view of its greater relative effect on chain mobility. It is for this reason that the transition from rigid to flexible behaviour takes place at a point corresponding to the first appearance of free water in the hydrogel network.



poly(2-hydroxyethyl methacrylate - co - butyl acrylate) P(HEMA-co-BA)



poly(2-hydroxyethyl methacrylate - co - methyl acrylate) P(HEMA-co-MA)

Therefore, the EWC of the P(HEMA-co-BA) and P(HEMA-co-MA) copolymers at a given composition can be considered to depend upon the balance of polar and non-polar effects. The polar contribution arises predominantly from the hydroxyl groups in the HEMA units and, to a lesser extent, from the carbonyl groups. However, as the proportions of the BA and MA units increase, the non-polar contribution increases leading to a decrease in EWC. It is through the understanding of these structure-property relationships that new hydrogel structures with predictable water absorption properties can be designed.

#### 4.6 Water Vapour Transmission Properties

An effective burn cover should allow water vapour transmission, WVT, sufficient to keep the wound surface just moist enough to obtain the benefits of accelerated healing but without pooling of fluid between the wound and the covering because of the risk of infection. Such conditions can be best obtained by using a material with both exudate absorption and water vapour transmission properties.

Lamke et al [47] investigated water vapour transmission using an Evaporimeter technique. They also reported the evaporative water loss for burns, granulating wounds and donor sites along with the average wound surface temperature (Table 4.1). Their WVT rates, shown in Table 4.1, are useful for a study of temporary skin substitutes such as this by laying down guidelines as to the required WVT rate of a dressing for a particular injury.



**Table 4.1** : Water vapour transmission (WVT) rates and surface temperatures reported by Lamke et al [47].

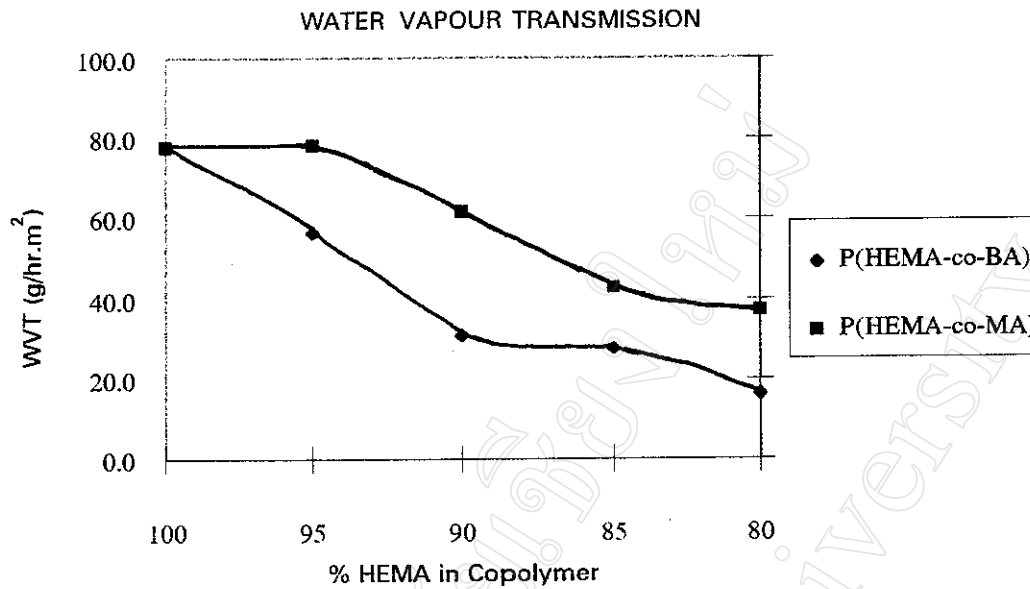
Area Studied	Number Studied	Surface Temperature (°C)	WVT (g/hr.m <sup>2</sup> )
Normal skin	0	35.8 ± 0.2	8.5
First degree burn	12	35.3 ± 0.1	11.6
Second degree burn	30	35.3 ± 0.4	178.1
Third degree burn	20	34.5 ± 0.4	143.2
Granulating wound	31	34.7 ± 0.2	214.1
Donor site	35	35.3 ± 0.2	149.6

From Table 4.1, granulating wounds have WVT rates (214.1 g/hr.m<sup>2</sup>) of around 25 times that of normal skin (8.5 g/hr.m<sup>2</sup>). Based on these results, various investigators [50], irrespective of the technique employed, have advocated WVT rates in the range of 83.3 - 104.2 g/hr.m<sup>2</sup> for an ideal temporary skin substitute. The reasoning behind this recommendation is that WVT rates of 83.3 - 104.2 g/hr.m<sup>2</sup> are approximately half that of the granulating wound and would provide an adequate moisture balance at the wound surface, thus preventing wound desiccation. However, other investigators have claimed that a wound covering should have a WVT rate similar to that of normal skin [62] or in the range of 20.8 - 70.8 g/hr.m<sup>2</sup> [63]. Consequently, the ideal WVT rate of a temporary skin substitute is not yet universally agreed upon. Since different skin substitutes with different properties are desired for different degrees of burn injury, it is not possible to assign any fixed value to a skin substitute in general. In medical practice, a balance needs to be struck between fluid evaporation and fluid

retention so that the wound surface is kept moist enough to promote the healing process.

In this project, the "Inverted Cup" method was used for WVT rate determinations because, in this method, the water is in direct contact with the sample, the same as the wound fluid (exudate) would be with a temporary skin substitute. From the results in Table 3.45 (page 131) previously, the WVT rates decrease with increasing BA and MA content in the P(HEMA-co-BA) and P(HEMA-co-MA) copolymers, as would be expected. These results are summarized graphically in Figure 4.7 which shows how the WVT rate varies with copolymer composition. The main conclusions which can be drawn from Table 3.45 / Figure 4.7 are:

- (1) P(HEMA) has a high water vapour permeability whereas PBA and PMA have much lower permeabilities. As with their water absorption properties previously, this is linked to their hydrophilicities.
- (2) Crosslinking decreases WVT as a result of stiffening the polymer matrix and, thereby, decreasing its porosity towards the passage of water molecules.
- (3) WVT decreases with increasing BA or MA content in the copolymer, this effect being more pronounced for the more hydrophobic BA. However, unlike the EWC previously, the relationship between WVT and copolymer composition appears to be non-linear.
- (4) The crosslinked P(HEMA), P(HEMA-co-BA) and P(HEMA-co-MA) copolymers have WVT rates varying from 16.2 - 78.0 g/hr.m<sup>2</sup>. This range of values corresponds closely to the 20.8 - 70.8 g/hr.m<sup>2</sup> range previously mentioned as having been recommended by earlier workers [63]. It also falls conveniently in between the first- and second-degree burn WVT values in Table 4.1.



**Figure 4.7** : Effect of copolymer composition on the water vapour transmission (WVT) rates of the P(HEMA-co-BA) and P(HEMA-co-MA) hydrogels. (As determined by the “Inverted Cup” method)

On the basis of these results, it would therefore appear that the hydrogel materials studied in this work have potential for use as temporary skin substitutes. Not only can they absorb appreciable amounts of water, they can also allow it to evaporate at a rate which matches the intended application. Furthermore, the EWC and WVT values can be pre-determined by controlling the degree of crosslinking and the copolymer composition. Having thus established the suitability of their **water-related** properties, the hydrogels' equally important **mechanical** properties will now be discussed.

## 4.7 Mechanical Properties

In designing a polymer for use as a temporary skin substitute, many property requirements need to be taken into consideration. These requirements were listed in the **Introduction** chapter of this thesis. In addition to the water transport properties previously discussed, an effective temporary skin substitute should have adequate toughness to withstand handling and be elastic and flexible to allow conformation to uneven body surfaces. To obtain a satisfactory balance of hydrophilicity and mechanical properties has long been one of the main objectives in hydrogel research.

The mechanical properties of the hydrogel samples prepared in this work are summarized in Table 4.2. Since the samples were all tested in their fully hydrated states, their corresponding EWC values are also given. It was necessary to test the samples when hydrated because this is the physical state in which they would be used as temporary skin substitutes. The test results in Table 4.2 are therefore functions of both chemical structure and water content. As explained previously, water content has an important bearing on mechanical properties since the free water between the polymer chains has a plasticising effect on bulk deformation. Thus, the main conclusions to be drawn from the results in Table 4.2 are:

**Table 4.2** : Summary of the mechanical properties of the hydrogel samples prepared in this work, each tested in its equilibrium hydrated state.

Samples	EWC* (%)	Tensile Strength (kPa)	Elongation at Break (%)	Young's Modulus (kPa)
uncrosslinked P(HEMA)	37.3	19.9	286	13.2
crosslinked P(HEMA)	33.7	17.8	92	32.6
uncrosslinked PBA	1.36	9.5	597	6.3
crosslinked PBA	0.87	8.1	144	12.4
uncrosslinked PMA	3.13	73.3	1,436	12.0
crosslinked PMA	2.11	33.6	431	15.5
crosslinked P(HEMA-co-BA) 5%	30.2	21.5	159	29.5
crosslinked P(HEMA-co-BA) 10%	27.4	38.7	211	26.8
crosslinked P(HEMA-co-BA) 15%	25.7	32.8	226	28.8
crosslinked P(HEMA-co-BA) 20%	22.3	42.1	295	20.3
crosslinked P(HEMA-co-MA) 5%	34.0	20.8	158	25.6
crosslinked P(HEMA-co-MA) 10%	32.8	30.4	197	21.9
crosslinked P(HEMA-co-MA) 15%	31.8	33.7	169	26.7
crosslinked P(HEMA-co-MA) 20%	30.5	42.7	199	28.2

\* EWC in deionized water at 35.0°C (taken from Table 3.30 on page 110)

(1) Effects of Crosslinking:

On comparing the uncrosslinked and crosslinked homopolymer samples, it is clear that the main effects of crosslinking are (a) to decrease the tensile strength, (b) to decrease the elongation at break, and (c) to increase Young's modulus. Since the purpose of crosslinking is to tie the polymer chains together in a 3-dimensional network structure, thereby increasing the energy required to make them deform, the effects on elongation and modulus can be easily understood in terms of the network's constraints on chain mobility. However, the observed decreases in tensile strength are quite unexpected since, usually, crosslinking increases tensile strength.

In this work, what the "tensile strength" really means is the "maximum stress at break" or, alternatively, the "maximum force at break per unit initial cross-sectional area". Therefore, for the tensile strength to decrease, it means that less force is required to break the sample. However, since crosslinking ties the chains together, more force should be required not less. In order to try to explain this apparent anomaly, it should be remembered that the uncrosslinked and crosslinked homopolymers differ not only in crosslinking but also in their water contents. This is important because the samples were mechanically tested in their equilibrium hydrated form. As discussed in the previous section, crosslinking decreases the EWC and, in particular, the amount of free water present between the chains. This reduces the "plasticising" effect normally ascribed to the free water which, in turn, partially accounts for the decreases in elongation at break and increases in modulus. Similarly, this same argument can be extended to explain the decreases in tensile strength. If crosslinking drastically decreases elongation at break (in Table 4.2, by a factor of between 3-5), the value of the ultimate force required for bond rupture may also decrease. What this is, in effect, saying is that the decrease in water absorption

brought about by crosslinking is more influential than the relatively low concentration (approx. 1%) of the crosslinks themselves. If this interpretation is true, then it serves to emphasize the fact that the introduction of crosslinks into the polymer does not exert an independent effect on mechanical properties. Instead, crosslinking exerts a composite effect which also includes a contribution from the decrease in water content.

## (2) Effects of Copolymer Composition

As stated at the end of Chapter 1, the main objective of this project has been to improve the overall properties of P(HEMA) by copolymerisation. In particular, improvements have been sought in mechanical properties, often perceived to be the weak point in P(HEMA) hydrogels. The results of this work, as summarized in Table 4.2, lead to the following conclusions:

- (1) For both copolymer series, as the percentage of the modifying comonomer increases from 0→20% by weight :
  - (a) the tensile strength increases
  - (b) the elongation at break increases
  - (c) the modulus does not show a consistent trend with composition but is generally lower for the copolymers than for crosslinked P(HEMA) alone
- (2) The tensile strength and elongation at break changes are more pronounced for the P(HEMA-co-BA) series, presumably because:
  - (a) BA is more hydrophobic than MA
  - (b) BA lowers the  $T_g$  of the copolymer more than MA

When translated into simple terms, what these results mean is that copolymerisation with either BA or MA increases the toughness (tensile strength), stretchability (elongation), and flexibility (inversely proportional to modulus) of crosslinked hydrated P(HEMA). This is despite the fact that copolymerisation lowers the EWC. Therefore, it can be concluded that the effect of introducing hydrophobic BA/MA units into the polymer chain outweighs the effect of decreasing the amount of plasticising free water on mechanical properties. Thus, chemical modification through copolymerisation provides an effective means of improving mechanical properties. Given an appropriate choice of comonomer, the required balance of mechanical and water-related properties becomes an attainable objective.

#### 4.8 Overall Conclusion

In this work, the general physical, mechanical and water-binding characteristics of a range of copolymers of 2-hydroxyethyl methacrylate with hydrophobic monomers have been examined. The combination of these properties in the hydrogels obtained is clearly related to the balance of hydrophilicity and hydrophobicity in the copolymer and, in particular, to the steric and polar contributions of backbone substituents. Consequently, the tailoring of hydrogel properties to meet the specific requirements of a particular application is an exercise in microstructural design and process control in all stages of the hydrogel's synthesis and fabrication.

As for the hydrogels prepared in this work, the P(HEMA-co-BA) and P(HEMA-co-MA) copolymers have shown potential for improving the mechanical properties of P(HEMA) without detracting too much from its hydrophilicity. From this



point of view, this project has succeeded in achieving its immediate objective. However, much more work needs to be done before the ultimate objective is reached of developing a material which can gain acceptance for clinical use as a temporary skin substitute.

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## SUGGESTIONS FOR FURTHER WORK

In continuation of the research work carried out in this research project, the following suggestions for further work are now made :

1. In this work, hydrogel sheets of uniform thickness  $0.750 \pm 0.100$  mm were studied. Since sample thickness can be expected to have an effect on both water absorption / vapour transmission and mechanical properties, sheets of different thicknesses should be produced and their properties compared.
2. It would be useful at this stage of the research to compare the properties of the samples prepared with those of commercial hydrogel-type wound dressings. This would indicate the level of performance that needs to be achieved.
3. It has been suggested [64] that a small amount of a volatile solvent (e.g., dichloromethane) added to the polymerisation mixture can increase the macroporosity of the hydrogel membrane as it forms which, likewise, increases its capacity for subsequent water absorption. This is an interesting possibility which is worth investigating.
4. An alternative method to elemental analysis for the determination of copolymer composition is the rapidly developing technique of FT-Raman spectroscopy. Since FT-Raman spectra, amenable to quantitative analysis, can be conveniently obtained from solid samples, homopolymer mixtures of known compositions could be used as calibrants. Copolymer compositions could then be determined by the type of "absorbance ratio" method commonly used in IR spectroscopy.

5. Since the water absorption / vapour transmission and mechanical properties of the P(HEMA-co-BA) and P(HEMA-co-MA) copolymers seem to be of the order required, biocompatibility testing should be considered. Biocompatibility testing is the necessary precursor to *in vivo* / clinical trials and would take the work an important stage nearer towards possible biomedical application.