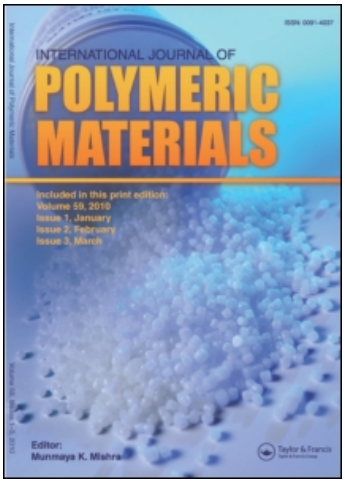


International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

Hydrophilic Sponges Based on 2-Hydroxyethyl Methacrylate. VI. Effect of Phase Sequence Inversion on the Characteristics of IPN between Sponges and Homogeneous Gels

Traian V. Chirila[a]; Xia Lou[a]; Sarojini Vijayasekaran[a]; Brian W. Ziegelaar[a]; Ye Hong[a]; Anthony B. Clayton[a]
[a] Department of Biomaterials and Polymer Research, and Centre for Ophthalmology and Visual Science, Lions Eye Institute, University of Western Australia, Nedlands, Western Australia, Australia

To cite this Article Chirila, Traian V. , Lou, Xia , Vijayasekaran, Sarojini , Ziegelaar, Brian W. , Hong, Ye and Clayton, Anthony B.(1998) 'Hydrophilic Sponges Based on 2-Hydroxyethyl Methacrylate. VI. Effect of Phase Sequence Inversion on the Characteristics of IPN between Sponges and Homogeneous Gels', International Journal of Polymeric Materials, 40: 1, 97 — 104
To link to this Article: DOI: 10.1080/00914039808050146
URL: http://dx.doi.org/10.1080/00914039808050146

Intern. J. Polymeric Mater., 1998, Vol. 40, pp. 97–104
Reprints available directly from the publisher
Photocopying permitted by license only

Hydrophilic Sponges Based on 2-Hydroxyethyl Methacrylate. VI. Effect of Phase Sequence Inversion on the Characteristics of IPN between Sponges and Homogeneous Gels†

TRAIAN V. CHIRILA‡, XIA LOU, SAROJINI VIJAYASEKARAN, BRIAN W. ZIEGELAAR, YE HONG and ANTHONY B. CLAYTON

Lions Eye Institute, Department of Biomaterials and Polymer Research, and Centre for Ophthalmology and Visual Science, University of Western Australia, 2 Verdun Street, Nedlands, Western Australia 6009, Australia

(Received 4 July 1997)

Poly (2-hydroxyethyl methacrylate) (PHEMA) is currently used as a prosthetic polymer in an artificial cornea consisting of a skirt made of a PHEMA sponge attached to a transparent circular core of homogeneous PHEMA hydrogel. Along the interface between components, a gradient IPN was achieved by using PHEMA sponge as polymer I into which the precursor liquid monomer mixture for the central hydrogel diffused significantly prior to polymerization. In this study, the phase sequence was reversed in order to find whether the inversion affects the manufacture of prosthesis. By using the homogeneous hydrogel as polymer I, the diffusion of liquid monomer mixture for the sponge is negligible. As a result, the IPN region along the interface is very narrow and leads to a weak union between prosthetic polymers. The direct phase sequence (in which PHEMA sponge is polymer I) should be exclusively used for the manufacture of such prostheses.

Keywords: Poly(2-hydroxyethyl methacrylate); homogeneous hydrogels; sponges; gradient IPN; phase sequence inversion; diffusion; penetration

† For Parts I to III see references 9 to 11, respectively.
Part IV : *Intern. J. Polymeric Mater.*, 1997, **37**,1.
Part V: *Polym. Intern.*, 1997, in press.

‡ To whom correspondence should be addressed.

1. INTRODUCTION

This research was prompted by our developmental work on a novel type of core-and-skirt artificial cornea (keratoprosthesis) consisting of two components, both polymers of 2-hydroxyethyl methacrylate (HEMA), which are joined along the boundary through an interpenetrating polymer network (IPN) [1–6] (Fig. 1). An IPN is defined [7] as a combination of two or more polymers in network form that are synthesized in juxtaposition. There are many ways to make IPNs. When a crosslinked polymer I is swollen by a liquid monomer II (containing initiator and crosslinking agent), and then polymerization takes place *in situ*, a sequential IPN is generated.

In our artificial cornea (dubbed "Chirila keratoprosthesis"), an annular skirt made from a PHEMA sponge is attached to a PHEMA hydrogel core. While the PHEMA sponges are produced by the phase separation polymerization in excessive amounts of water [4, 8–11], the transparent core of the device is made by the polymerization of HEMA in lower water concentrations, in the presence of the existing peripheral sponge. Polymer I (sponge) is swollen by the guest monomer mixture which not only fills the pores but also diffuses into the material, therefore the resulting system is a sequential IPN. More specifically, since the polymerization of monomer II was initiated before the swelling reached an equilibrium, the system should be also regarded as a gradient IPN.

The synthetic phase sequence includes the formation of sponge in the first stage, followed by the diffusion and polymerization within sponge of the core precursors in the second stage. By using staining

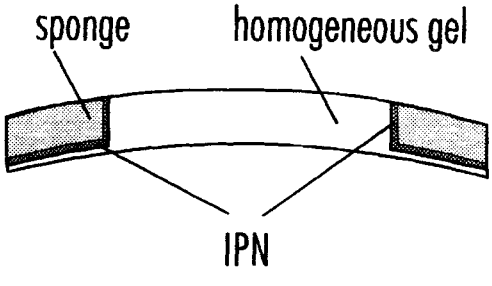


FIGURE 1 Chirila keratoprosthesis.

and microscopic techniques, it was estimated [4] that the distance of penetration of polymer II (transparent core) into polymer I (spongy skirt), along the boundary between them, was 540 μm (average).

We report now the study of IPNs produced by employing the inverse synthetic phase sequence, i.e., when polymer I is the homogeneous gel and polymer II is the sponge. As the most significant feature of the sequence inversion, the change in penetration distance of polymer II into polymer I was investigated by microscopy. For staining purposes, 1,3-pentadiene was incorporated by copolymerization in polymer II.

2. EXPERIMENTAL

Materials

HEMA was supplied as Rocryl® 400 by Rohm and Haas and subjected to vacuum distillation prior to use. Ethylene dimethacrylate (EDMA), supplied by Tokyo Kasei Kogyo Co. (Japan), was used as a crosslinking agent without additional purification. Aqueous solutions (10%) of ammonium persulfate (APS, supplied by BDH, UK) and sodium metabisulphite (SMBS, supplied by Merck, Germany) were used together as redox initiators. 1,3-Pentadiene was supplied by Aldrich Chem. Co. (USA) as a mixture of isomers, with a purity of 90%, and used as such. Durcupan® ACM epoxy resin (for embedding) was supplied by Fluka AG (Switzerland). Osmium tetroxide (for staining) was supplied by Sigma Chemicals Co. (USA). Toluidine blue was supplied by Ajax Chemicals (Australia).

Synthesis of Polymer Bicomponent Systems

The synthesis of PHEMA sponges has been described in great detail in our previous papers [1–5, 8, 9]. For the present study, the sponges were produced by polymerization of HEMA (20% wt) in water, in the presence of 0.5% wt EDMA, 0.12% wt APS/SMBS initiator (as 10% solutions), and 1% wt 1,3-pentadiene (comonomer for staining). All percentages are reported to the amount of HEMA. The homogeneous transparent PHEMA hydrogels were produced by using the same

formulation, with the difference that concentration of HEMA in water was 70% wt, and no staining comonomer was included. These formulations are amongst those currently used in the manufacture of Chirila keratoprosthesis.

In order to simplify the procedure, we produced two-layer polymer buttons, rather than keratoprostheses. The two polymerizations were carried out sequentially in polypropylene molds (17.5 mm in diameter, 15 mm in depth). First, the liquid monomer mixture corresponding to the gel component was placed in a mold and polymerized under nitrogen. The polymerization was achieved in a temperature-controlled water bath at 30°C, 40°C and 50°C, for 10 hours at each temperature. The monomer mixture corresponding to the sponge component was then placed in the same mold covering the gel and polymerized in the same conditions, after allowing various durations for diffusion into gel at room temperature. Four specimens of bicomponent systems were produced by varying the standing period; one specimen was placed in the water bath immediately after adding the liquid sponge precursors; the other 3 specimens were allowed standing periods of 2, 4 and 8 hours, respectively. However, we have to emphasize that diffusion of monomer II into polymer I probably stops only when its conversion to polymer II is complete. We consider the standing periods as pure diffusion times.

Microscopic Analysis

Two processing methods of specimens for light microscopic analysis were used.

Method A. Rectangular pieces (5×3×2 mm) were cut from the region encompassing the boundary between the transparent and spongy polymers. The pieces were treated with an aqueous solution (1% wt) of osmium tetroxide for 1 hour, which induced the selective staining of the sponge component (since it contained double bonds resulting from the diene comonomer). The stained specimens were then dehydrated in graded aqueous solutions of ethanol. For sectioning, the specimens were embedded in epoxy resin (Durcupan®). Semithin 2-μm sections were cut from the embedded specimens using an LKB 2088 Ultrotome V (LKB-Prokdukter, Sweden) ultramicro-

tome equipped with a diamond knife. After additional staining with toluidine blue, the sections were examined and photographed in an Olympus BX 40F-3 microscope.

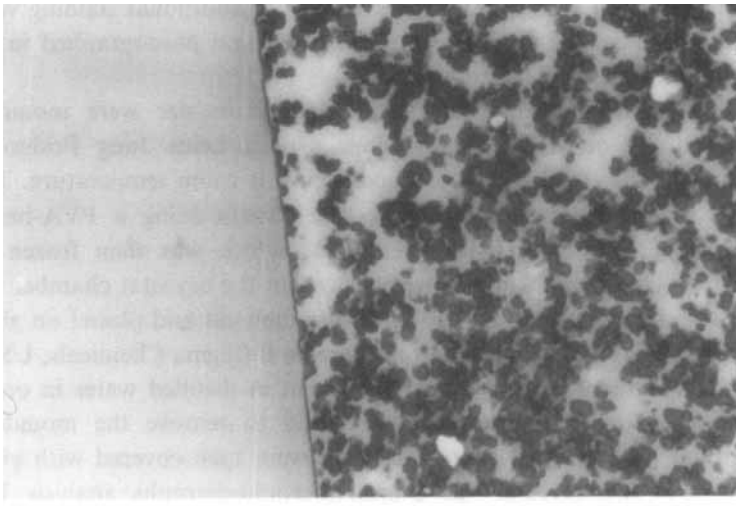
Method B. Polymer blocks of appropriate size were mounted horizontally on the mounting chucks of a Leica Jung Fridgocut cryostat. The chucks were preconditioned at room temperature. The polymer blocks were attached to the chucks using a PVA-based mounting medium (Tissue Tek, USA) which was then frozen to −70°C. The frozen samples were placed in the cryostat chamber for about 5 minutes. Sections (40 μm) were then cut and placed on glass slides. Their staining with Sulforhodamine B (Sigma Chemicals, USA) for 5 minutes was followed by treatment in distilled water in order to reduce the background staining and to remove the mounting medium. The isolated stained samples were then covered with glass coverslips and stored at −20°C until microphotographic analysis. The sections were examined and photographed in an Olympus IX 70 microscope.

3. RESULTS AND DISCUSSION

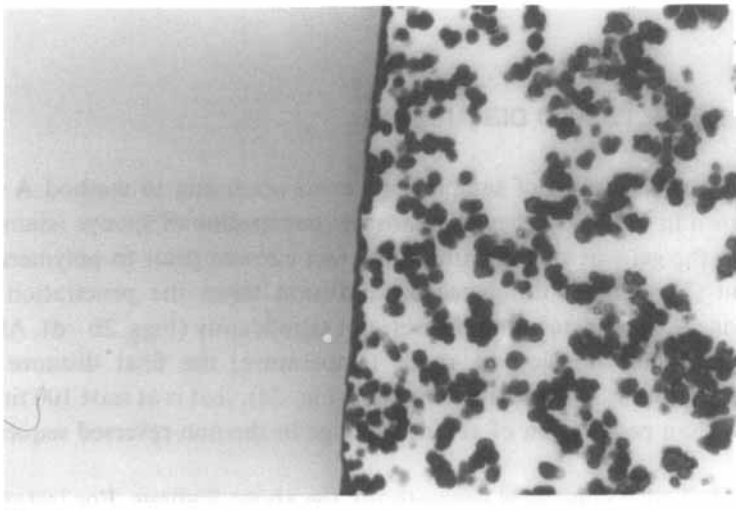
Light micrographs of samples processed according to method A are shown in Figure 2. There is almost no penetration of sponge (stained) into the gel when no diffusion time was allowed prior to polymerization (Fig. 2a). With increasing diffusion times the penetration of sponge phase increased, however, not significantly (Figs. 2b–d). After 8 hours of diffusion at room temperature, the final distance of penetration was approximately 5 μm (Fig. 2d), that is at least 100 times less than penetration of gel into sponge in the non-reversed sequence [4].

Method B confirmed dramatically the above findings. For instance, Figure 3 shows a sample that was allowed 8 hours for diffusion prior to polymerization. It is difficult to ascertain any penetration in this sample.

Clearly, the inversion of phase sequence is of no benefit in creating an IPN junction. The diffusion of liquid monomer mixture into the compact homogeneous hydrogel is negligible, and the resulting union

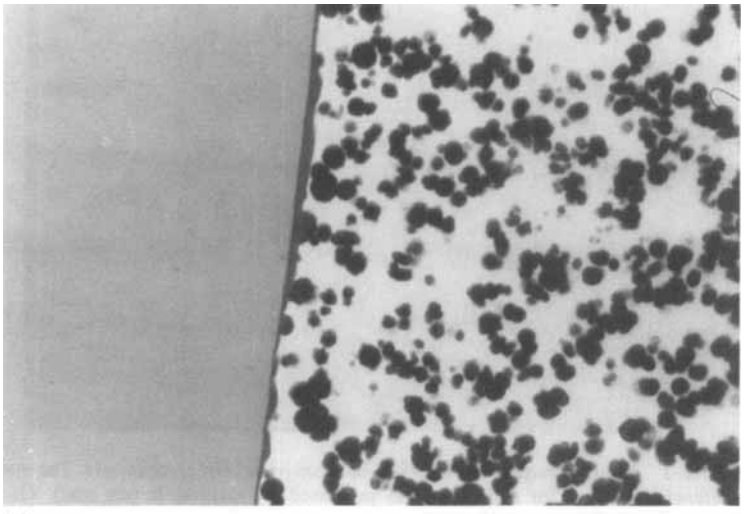


(a)

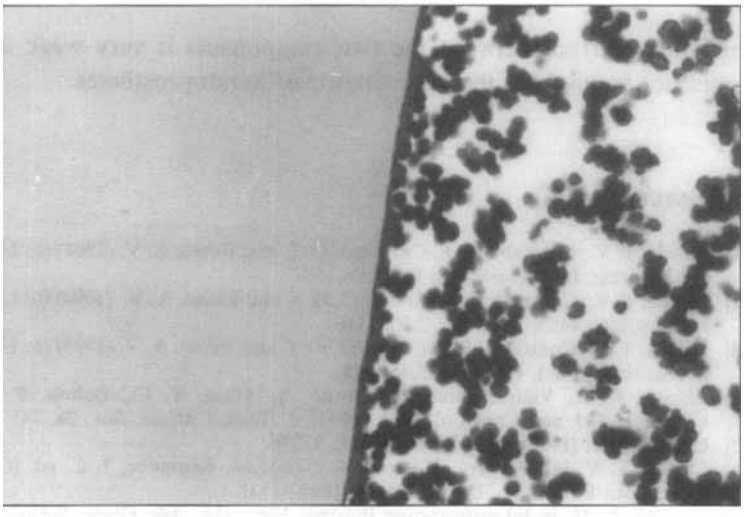


(b)

FIGURE 2 Photomicrographs of interface between prosthetic components. The sponge component (polymer II) was stained with osmium tetroxide and toluidine blue. (a) no diffusion time allowed prior to polymerization; (b) 2-hour diffusion time; (c) 4-hour diffusion time; (d) 8-hour diffusion time. Magnification: 650 X.



(c)



(d)

FIGURE 2 (Continued).

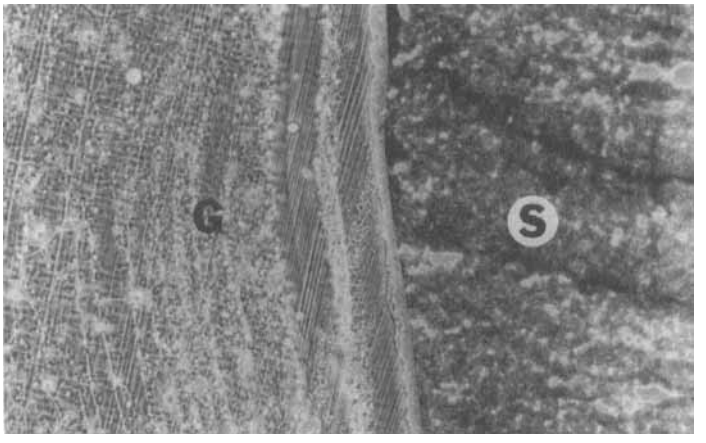


FIGURE 3 Photomicrograph of interface between prosthetic components. The sample was allowed 8 hours for diffusion, and processed by method B (see text). G: gel; S: sponge. Magnification: 40 X.

along the interface between the two components is very weak and should not be used for the manufacture of keratoprostheses.

References

[1] Chirila, T. V., Constable, I. J., Crawford, G. J. and Russo, A. V. (1994) (to Lions Eye Institute, Inc.), Australian Pat., 650,156.
[2] Chirila, T. V., Constable, I. J., Crawford, G. J. and Russo, A. V. (1994) (to Lions Eye Institute, Inc.), U. S. Pat. 5,300, 116.
[3] Chirila, T. V., Constable, I. J., Crawford, G. J. and Russo, A. V. (1995) (to Lions Eye Institute, Inc.), U. S. Pat. 5,458,819.
[4] Chirila, T. V., Vijayasekaran, S., Horne, R., Chen, Y. C., Dalton, P. D., Constable, I. J. and Crawford, G. J. (1994). *J. Biomed. Mater. Res.*, **28**, 745.
[5] Chirila, T. V. (1994). *Trends Polym. Sci.*, **2**, 296.
[6] Chirila, T. V. in *Polymeric Materials Encyclopedia*, Salamone, J. C. ed. (CRC Press, Boca Raton, FL, USA, 1996), **2**, 1525–1531.
[7] Sperling, L. H. in Interpenetrating Polymer Networks, *Adv. Chem. Series*, **239**, Klempner D., Sperling, L. H. and Utracki, L. A. eds. (ACS, Washington, DC, USA, 1994), pp. 3–38.
[8] Chirila, T. V., Constable, I. J., Crawford, G. J., Vijayasekaran, S., Thompson, D. E., Chen, Y. C., Fletcher, W. A. and Griffin, B. J. (1993). *Biomaterials*, **14**, 26.
[9] Chirila, T. V., Chen, Y. C., Griffin, B. J. and Constable, I. J. (1993). *Polym. Intern.*, **32**, 221.
[10] Chen, Y. C., Chirila, T. V. and Russo, A. V. (1993). *Mater. Forum*, **17**, 57.
[11] Clayton, A. B., Chirila, T. V. and Dalton, P. D. (1997). *Polym. Intern.*, **42**, 45.