Synthesis and Characterization of New Dextran-Acrylamide Gels

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ABSTRACT: Dextran-acrylamide gels were synthesized in a single step reaction by using 4,4′-azobis(4-cynovaleric acid) as bi-functional initiator at 60°C. Corresponding acrylamide (AaM) gels in the absence of dextran were also prepared for comparison. Several parameters such as reaction period (6, 12, and 24 h), monomer and crosslinker concentrations were varied and their effects on the properties of gels were investigated. Gels were characterized by their mechanical and swelling behaviors and in terms of structural changes using SEM. It was observed that swelling degree decreased by increasing the monomer concentration due to formation of more crosslinking points that cause tighter network structure. Mechanical measurements showed that elastic modulus of AaM gels was higher than that of dextran-AaM gel which indicating the importance of dextran concentration on the flexibility of the network. © 2007 Wiley Periodicals, Inc. J Appl Polym Sci 106: 3565–3570, 2007

Key words: biodegradable; gels; networks; polysaccharides

INTRODUCTION

Polysaccharides, such as cellulose, starch, chitin, and dextran are attractive materials for biomedical and pharmacological research fields due to their biocompatibility and biodegradability.[1] These natural polymers consist of large amounts of hydroxyl groups; hence they can be formed into hydrogels easily and considered as potential drug delivery systems and wound dressings, among others.[2,3]

Dextran, an amorf and water soluble polysaccharide, consists mainly of α-1,6 linked anhydroglucose unit and partly of α-1,2-, α-1,3-, or α-1,4- linked side chains.[4] It has been used as plasma expander for several years. Recently there have been considerable efforts to synthesis hydrogels from dextran by many different methods.[5,6]

Dextran-based hydrogels have usually been prepared by using functionalized dextran with polymerizable double bonds (methacrylate etc.).[7,8] van Dijk-Wolthius et al. had synthesized glycidyl methacrylate derivatized dextran and polymerized this compound by ammonium persulfate (APS) and *N*,*N*,*N*′,*N*′-tetrametiletilendiamin (TEMED) to form a hydrogel.[9] The reported standard procedure has been used by many researchers dealing with dextran hydrogels.[10,11] In another study, dextran-maleic anhydride (dex-MA) precursor was synthesized by Chu and coworkers and dex-MA/poly(*N*-isopropylacrylamide) hybrid hydrogels were prepared by UV photocrosslinking.[12] There are also a few methods for preparing dextran based hydrogels in a single step reaction by using bi-functional crosslinkers such as isocyanate type monomers.[13]

The aim of this study was to synthesize dextran-acrylamide (AaM) in a single step reaction by using 4,4′-azobis(4-cynovaleric acid) (ACVA) and *N*,*N*′-methylenebisacrylamide (MBA) as initiator and crosslinking agent respectively, at 60°C. ACVA is a thermal initiator that has two carboxylic end groups and should be used in the range of 60–80°C. It has been rarely used in the reactions of polysaccharides.[14,15] The swelling and mechanical properties of these gels as well as the effects of AaM concentration and reaction period on their properties were investigated. Corresponding AaM gels in the absence of dextran were also prepared for comparison.

MATERIALS AND METHODS

Materials

Dextran was supplied by Sigma (Istanbul, Turkey). Average molecular weight of dextran used was 100,000–200,000. Acrylamide (AaM), MBA, ACVA were obtained from Fluka (Istanbul, Turkey). Acetone was in Merck (Istanbul, Turkey) degree.

Method

Aqueous solution of dextran (10 g/100 mL) was prepared and AaM (concentrations listed in Table I),

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TABLE I
Reaction Conditions[a]

Experiment no.	AaM conc. (mol/L)	MBA (g/100 mL)	Reaction time (h)
1-1	1.0	0.2	6, 12, 24
1-2	1.5	0.2	6, 12, 24
1-3	2.0	0.2	6, 12, 24
2-1	1.0	0.1	24
2-2	1.5	0.1	24
2-3	2.0	0.1	24
3-1	1.0	0.4	24
3-2	1.5	0.4	24
3-3	2.0	0.4	24

[a] $t = 60^{\circ}$C.

ACVA (0.02 g/100 mL), and MBA (at different dextran/MBA ratios) were added. Reaction mixture was then poured into tubes. Gelation synthesis was carried out in a thermostat at 60°C. The tubes were purged by nitrogen throughout the reaction period, which was varied between 6 and 24 h. Gels were removed by breaking the tubes and they were cut into small cylindrical pieces. Each of them was weighed and immersed in distilled water to remove all the unreacted substances and let the gel to swell. Swollen gels were put into acetone/water mixtures by varying acetone percentage up to 100% and then dried in a vacuum oven at 70°C to a constant weight. AaM gels were also prepared using the same method.

FTIR characterization

The FTIR spectra of dextran and its copolymers were recorded on a SHIMADZU FTIR 8300 Spectrophotometer. Translucent discs were prepared by grounding samples together with infrared grade KBr. The FTIR spectra were obtained by recording 128 scans between 4000 and 400 cm^{-1}.

Swelling experiments

Swelling properties of gels were determined as a function of time and monomer concentration. Dry samples were weighed and immersed into distilled water at room temperature. Gels were weighed three times a day and water was refreshed every day. After equilibrium was reached, gels were weighed and the weight swelling ratio (W_s) was defined as

$$W_s = g_s/g_d$$

where g_s and g_d are the weights of the swollen gel and the weight of the dry sample, respectively.

Elastic modulus measurements

Elastic modulus measurements were carried out according to the method described elsewhere.[16] Briefly, unaxially compression was employed on the gels after the synthesis and after the swelling reaches equilibrium at 20°C. The modulus of elasticity was calculated by using the following equation[17]

$$F/A = G(\alpha - \alpha^{-2})$$

where G (Pa) is the elastic modulus of gel, F/A is the compressive pressure (Pa), and $\alpha = l/l_0$ is the deformation ratio (l_0 is the initial and l is the deformed lengths (mm) of the gel).

SEM investigation

Scanning electron microscopy images were recorded by using JEOL JSM-S910LV instrument, at 20 kV. Air dried unswollen gel samples were fixed on aluminum discs with a carbon band and were coated with gold by plasma vapor deposition.

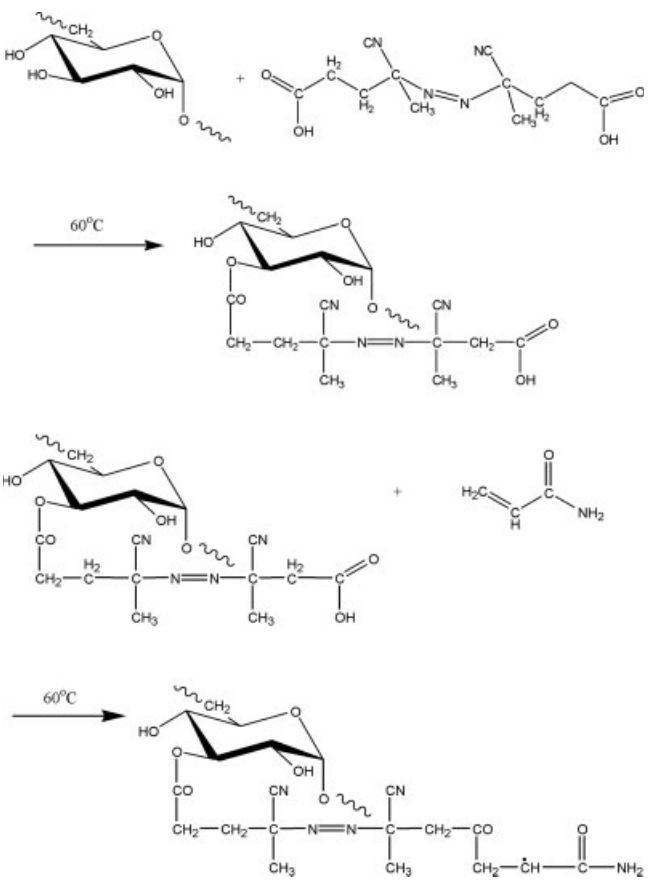

Figure 1 The schematic representation of the initiation step of gel synthesize.

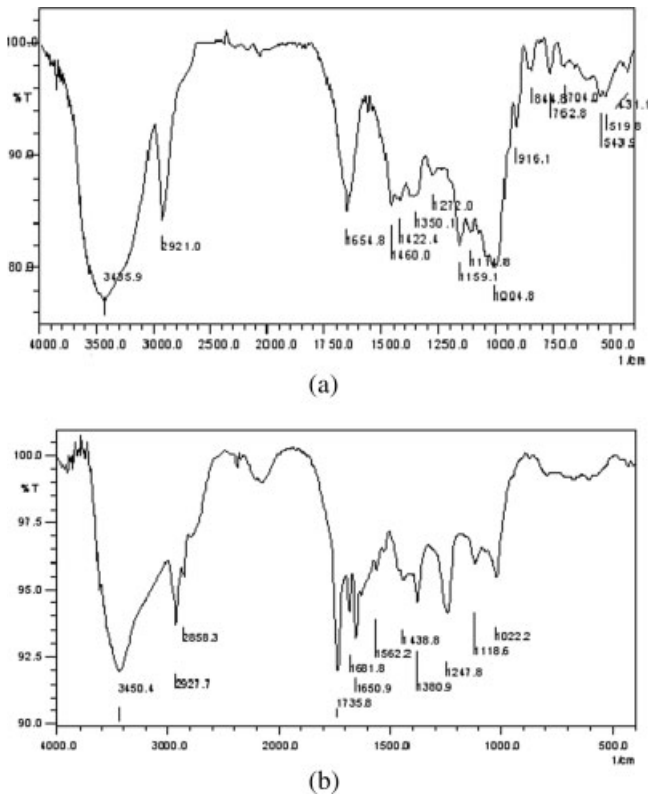

Figure 2 FTIR spectra of (a) dextran and (b) dextran-AaM gel.

RESULTS

The initiation step of synthesis was illustrated in Figure 1. We used carboxylic acid derivative of azo compound, (ACVA), as a radical initiator. While one carboxylic end group of ACVA was reacted with hydroxyl group at dextran backbone, the other one was reacted with the functional group of monomer (vinyl group of AaM).

FTIR spectra of dextran and dextran-AaM gel (2-3) are given in Figure 2(a,b), respectively. FTIR spectrum for dextran showed a broad band 3435.9 cm^{-1} due to O—H stretching vibrations, a band at 2921 cm^{-1} which refers to C—H stretching and partially overlapping bands in 1200–800 cm^{-1} and 1270–1000 cm^{-1} frequency ranges, associated with C—O—C and alcoholic C—O absorptions, respectively.

In the spectrum of gel, a broad band in the 3700–3200 cm^{-1} range was observed and was assigned to both O—H stretching (from dextran) and N—H stretching (from PAaM). There are additional peaks at 2858 cm^{-1} due to CH_2 stretching derived from PAaM and at 1681 cm^{-1} assigned to the C=O group of PAaM. In addition, corporation of ACVA moiety into the resulting gels was confirmed from the appearance of the peak around 2290 cm^{-1} (CN bonds).

The experimental conditions are given in Table I. Notably, experiments 1-1, 1-2, and 1-3 were carried out at different reaction periods (6, 12, and 24 h). In

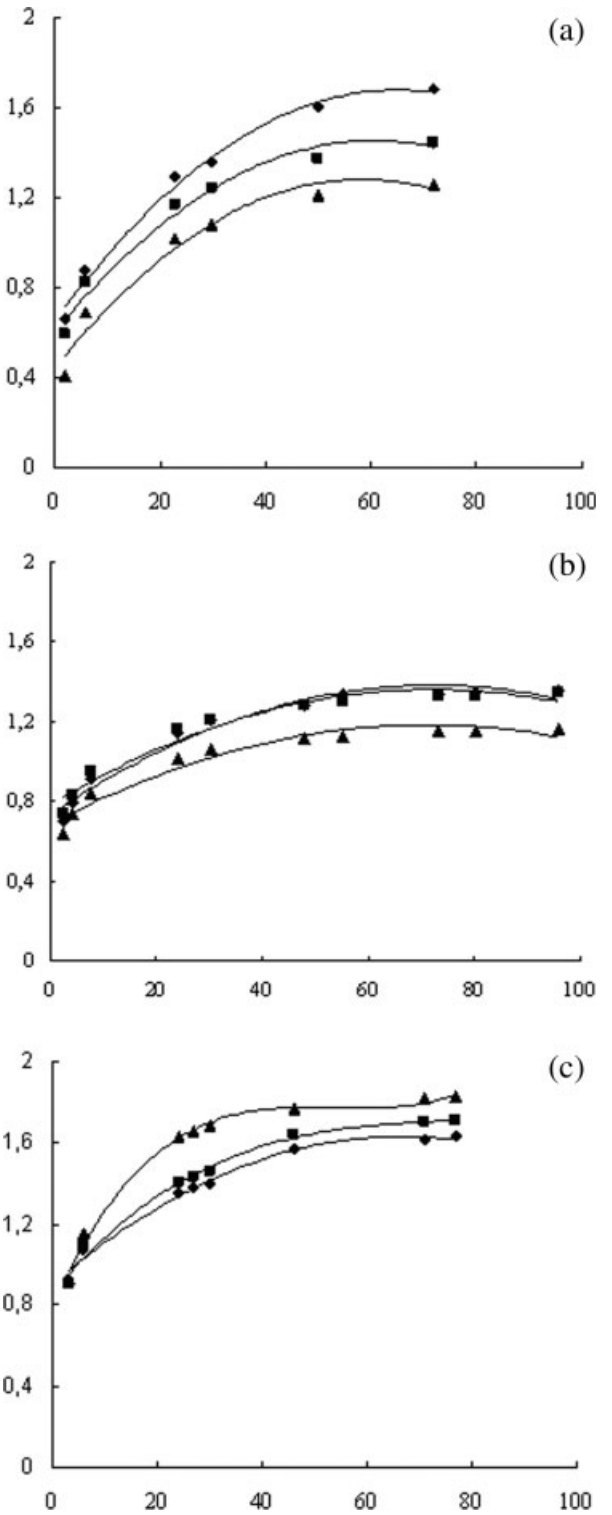

Figure 3 Effect of reaction time on swelling at different acrylamide concentrations. (a) 1*M*; (b) 1.5*M*; and (c) 2*M*. *x*-axis: time (h), *y*-axis: swelling (g); ◆ 6 h, ■ 12 h, ▲ 24 h.

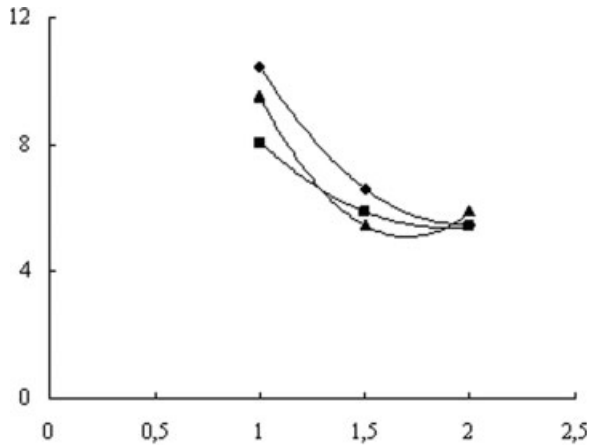

Figure 4 W_s values versus AaM concentration. *x*-axis: AaM concentration/mol/L, *y*-axis: W_s; ◆ 24 h, ■ 12 h, ▲ 6 h.

this group of experiments, while AaM concentration was varied, the amount of MBA was kept constant. Swelling behaviors of gel samples of (1-1), (1-2), and (1-3) are presented in Figure 3(a–c), respectively. These results showed that in lower AaM concentration, swelling degree of gels are affected by time [Fig. 3(a)]. On the other hand more concentrated AaM in the gel structure caused rapid consumption of MBA during the synthesis. Therefore swelling amount of these gels (1-2 and 1-3) did not change significantly with the increasing reaction period [Fig. 3(b,c)].

The W_s values of gels at various AaM concentrations (for samples of 1-1, 1-2, and 1-3) were measured in distilled water. It can be seen from Figure 4 that as the AaM concentration increased the W_s values of the gels decreased. At higher AaM concentrations, the spaces between polymer chains are smaller than those at lower AaM concentrations due to the high crosslink density. Elastic moduli values of the gels were measured before (G_0) and after the swollen state equilibrium was reached (G) (Table II). The graphical presentation of these data as illustrated in Figure 5 indicates that elastic moduli of gels were increased by the monomer concentration. These results are in agreement with the usual swelling behaviors of gels, that it is a well known the reverse relation between the elastic modulus and the swelling degree. Moreover elastic modulus increases by the crosslink density. As mentioned above, at higher AaM concentrations more cross-linked points occurred between the polymer chains; therefore the structure of the network is tighter which hinders access of water molecules.

Elastic modulus of AaM gel (1A) was found to be higher when compared with that of dextran-AaM gel (Table II) indicating the importance of dextran concentration on the flexibility of the polymer network. Dextran consists of large amounts of hydroxyl groups which react with carboxylic group of ACVA. These hydroxyl groups can also interact with their neighbors leading to the formation of intramolecular linking. The resultant hydrophilic and more elastic network structure accommodates water inside the hydrogel.

Gelation reactions were repeated at different MBA/dextran ratios with three different concentrations of MBA and constant concentration of dextran (Table I). Expectedly, elastic modulus of these gels, which are represented in Figure 6 (G_0 and G) decreased with decreasing crosslink ratio.

Morphologies of gels were also investigated by SEM instrument. Analyses were performed using dried gels. SEM image of dextran-AaM gel and AaM gel are presented in Figure 7(a,b), respectively. There are some clear distinctions between two different gels. The appearance of AaM gel was fragile and delicate when compared with dextran-acrylamide gel. In terms of pore structure, AaM gel has relatively big and irregularly shaped pores and pore

TABLE II
Elastic Modulus Values of Gels

Experiment no.	AaM conc. (mol/L)	MBA (g/100 mL)	G_0 (Pa)	G (Pa)
1-1	1.0	0.2	3280.5	2209.9
1-2	1.5	0.2	4587.2	4235.3
1-3	2.0	0.2	9916.1	6836.6
1A[a]	2.0	0.2	11,444.0	7530.1

[a] Acrylamide gel.

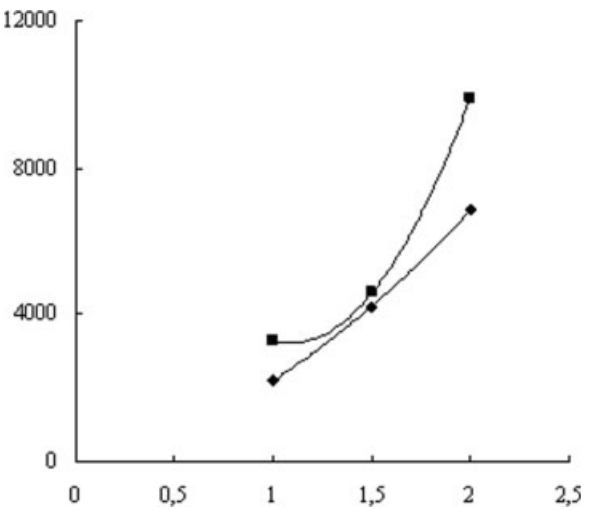

Figure 5 Elastic modulus values of gels at different monomer concentrations. *x*-axis: AaM concentration/mol/L, *y*-axis: elastic modulus/Pa; ◆ G, ■ G_0.

size distribution was wider than that of dextran-AaM gel.

CONCLUSION

In this study, we reported a new method for synthesis of dextran based gels in a single step reaction. ACVA was chosen as initiator due to possessing of two carboxylic end groups which can interact with hydroxyl groups at dextran backbone. The structure of obtained gel was characterized by FTIR. Besides the reaction period, effects of concentration of AaM and MBA on the gel properties were examined. It was found that the flexibility of resulted network structure was affected by both intra- and intermolecular interactions between dextran–dextran and dextran–AaM molecules. Therefore the swelling and mechanical properties of obtained gels are strongly dependent on the amount of dextran.

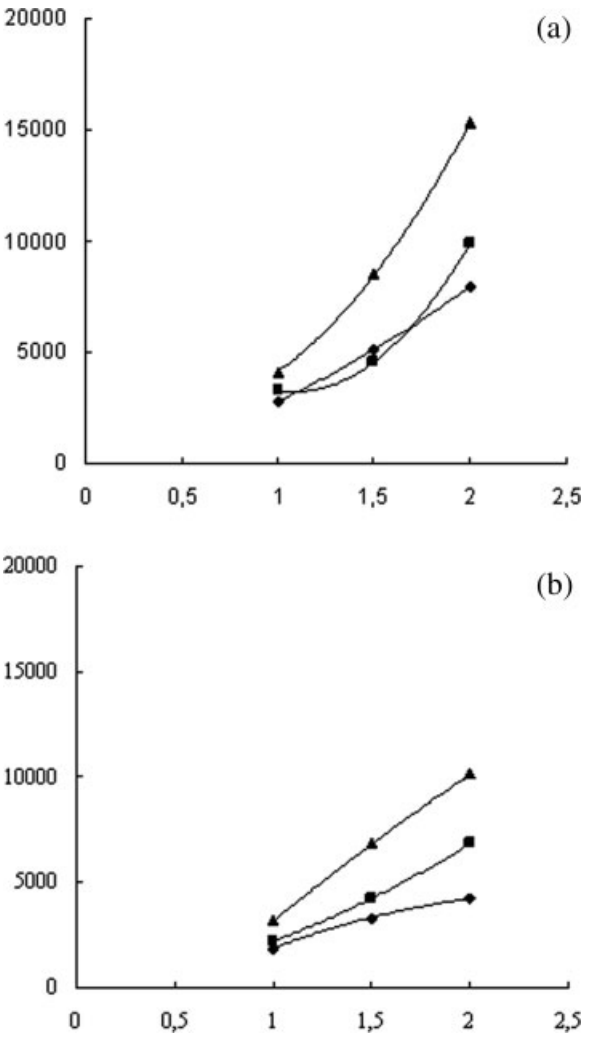

Figure 6 Elastic modulus values of gels at different cross-linking ratios (CR). (a) G_0; *x*-axis: AaM concentration/mol/L, *y*-axis: G_0 (Pa); ◆ CR: 1/100, ■ CR: 1/50, ▲ CR:1/25. (b) *G*; *x*-axis: AaM concentration/mol/L, *y*-axis: G (Pa); ◆ CR: 1/100, ■ CR: 1/50, ▲ CR:1/25.

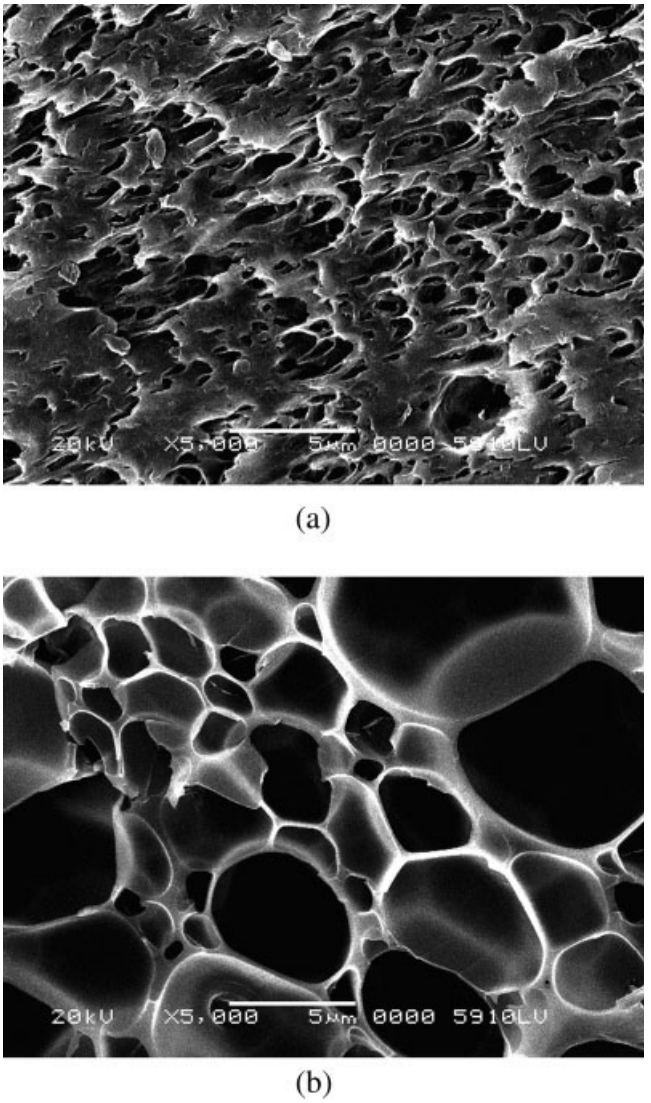

Figure 7 SEM images (a) dextran-AaM gel (b) AaM gel.

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