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Superabsorbent

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Abstract

Superabsorbent hydrogel (SAH) is a cross-linked polyelectrolyte polymer that has the capability to absorb a lot of water by keeping it in a three-dimensional (3D) structure. The network's structure of SAH has the high elasticity that gives the ability of pores to expand in an aqueous media into up to 150–1500 times their own size in a dry state. The size of pores is the major factor that controls the swelling degree of the hydrogel. In contrast, the swelling degree is related to cross-linked density and the number of polarizable functional groups that immobilize on the polymer backbone. The hydrogels could be made by radical-initiated polymerization of hydrophilic monomers, and/or linear polymers dissolve in an aqueous solution. Free radical polymerization of the hydrogel can be done physically or chemically. Advantages and disadvantages of each method will be elaborated in this chapter. The advances in radiation cross-linking methods for the hydrogel preparation are particularly addressed besides other different techniques, e.g., (freezing/thawing and chemical initiation). This chapter will review the preparation methods of superabsorbent hydrogels from synthetic and natural hydrophilic polymers with other new phases such as wax, gum, and rubber. Methods to characterize these hydrogels and their proposed applications (internal curing agent for cement, agricultural proposal, biomedical proposal, and environmental proposal) are also reviewed.

Keywords: SAH, swelling, cross-linking, polyelectrolyte, hydrogel

1. Introduction

A cross-linked polyelectrolyte polymer that has the capability to absorb water up to 150–1500 times of their own size in a dry state and keep water in a three-dimensional (3D) structure is called superabsorbent hydrogel (SAH) (**Figure 1**). Several descriptions are used to express superabsorbent hydrogel (SAH): (I) SAH has synthetic three-dimensional swollen networked structures. The product from covalently cross-linked to certain synthetic

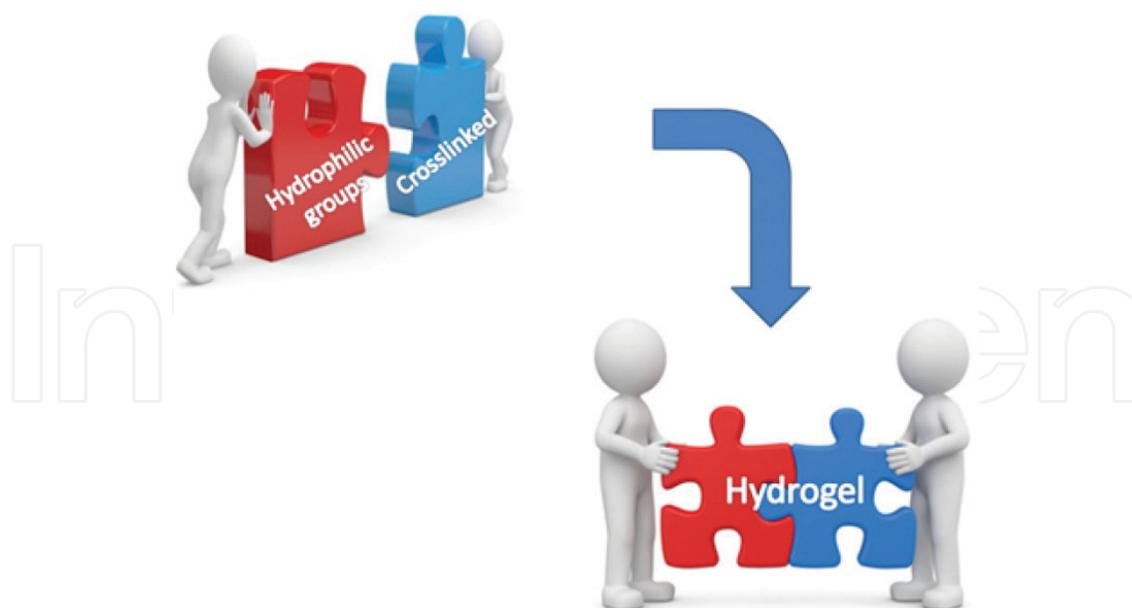


Figure 1. Hydrogel is a hydrophilic monomer that would be cross-linked.

monomer or nature polymer [1–3]. (II) SAH is a fine white powder-like sand or tiny granule-like sugar and has a high ability of water absorption. (III) SAH is the diffusion of the solvent (typically water) into the hydrogel network when the hydrogel is placed in contact with water; the water molecules begin to diffuse inside the solid hydrogel network. (IV) By another way, at equilibrium swelling hydrogel contains small fractions of solid and large fractions of water so it can be described as a hydrogel that begins to diffuse into the water. The diffuser of the water outlet of the hydrogel is a deswelling process. Over time, when the maximum swelling of hydrogel soaked in water is achieved, the bonds of the network will relax by evolving apportion of the water molecules (deswelling) and absorb of water molecules again (swelling) with the time interval. This deswelling/swelling process affecting by the pressure of water molecules on the bonds of hydrogel networks that given the swelling curve line saw shape (zigzag), this phenomenon so-called hydrogel breath. **Figure 2** is a representation of the 3D structure of a swollen and dried hydrogel.

From **Figure 2** it can be said that the hydrogel chains are in close and function groups tightly interacting with each other due to H bonds. As water diffuses inside the hydrogel network, the function groups begin to hydrate, and the interactions such as H bonds will terminate. With further water molecules absorbed, the chains will gain pressure with a gain swell. At appropriate conditions, the hydrogel will reach a state where the pores are fully filled with water and chains reach the maximum expanded. Responding to many external stimulus conditions, expansion and shrinkage of hydrogel are controlled [4].

2. Kinetics of water absorbed (swelling) in hydrogel

The swelling process of a hydrogel is a transition from solid state to fluid state without dissolution or dissociation. The two interfaces become one interface called “gel.” Eq. (1) was used to determinate the nature of diffusion of water molecules into the hydrogels:

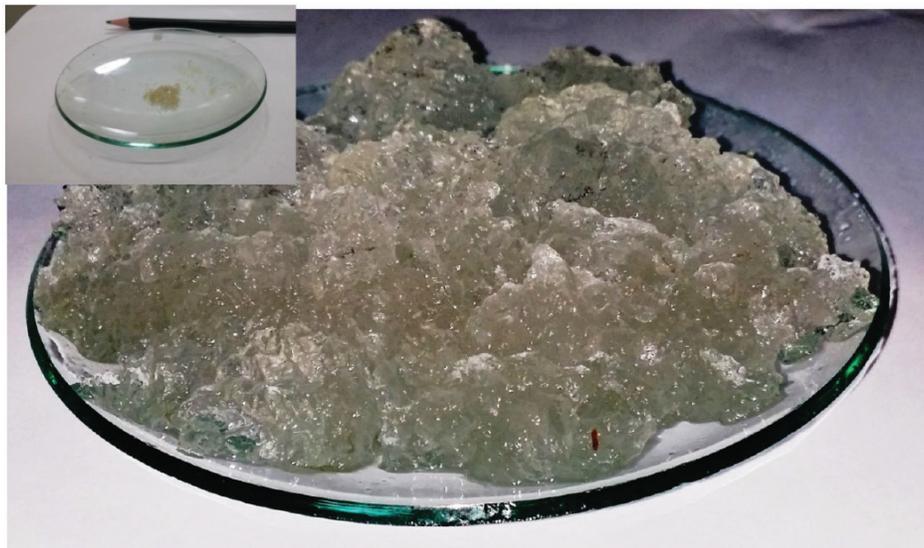
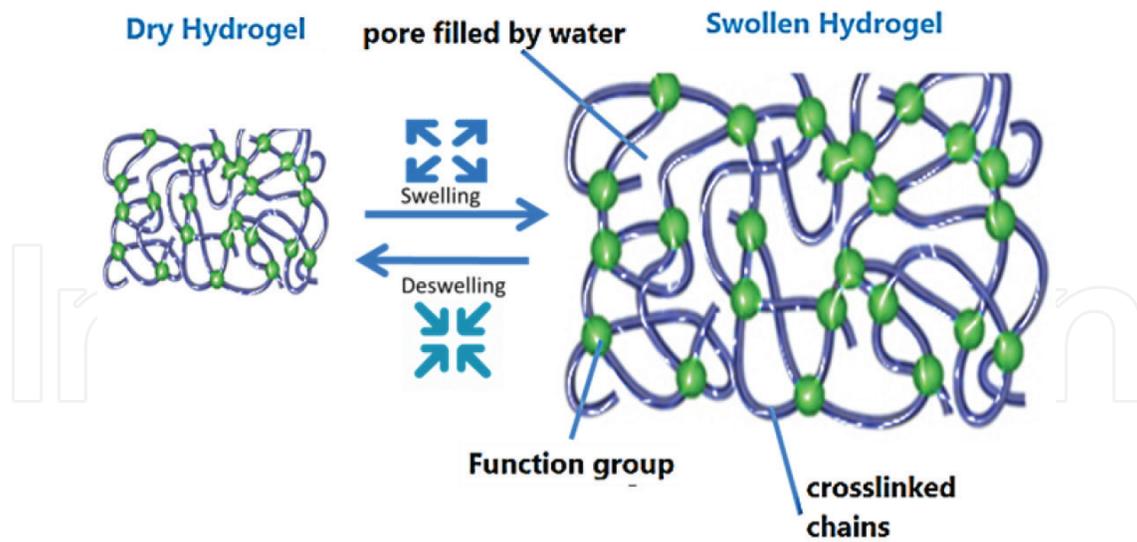


Figure 2. Illustration in the left hydrogel in a dry state or deswelling state (shrinking).

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$$\frac{M_t}{M_\infty} = K t^n \quad (1)$$

where M_t and M_∞ are the amount of water diffusion into the hydrogel at the time (t); at the infinite time, respectively, K is a constant related to the structure of the network; and n is a characteristic exponent of the transport mode of the water solvent [5]. Depending on the relative rates of water diffusion and hydrogel network relaxation, three cases of diffusion mechanisms are distinguished. The Fickian diffusion may be described by Case I which appears when the T_g of hydrogel is below the water medium temperature. In this case, the hydrogel chains have a high mobility and relaxation, and the water penetrates more easily into the relaxed network. Therefore, the water diffusion rate, R_{diff} is much less than the hydrogel chain relaxation rate R_{relax} ($n = 0.50$) ($R_{diff} \ll R_{relax}$). Case II is the non-Fickian diffusion, in which diffusion is very rapid compared to the relaxation processes ($0.50 < n < 1$), which appears when the T_g of hydrogel is well above the experimental temperature. In this situation, the hydrogel chains are not adequately

mobile to permit urgent penetration of water into the hydrogel ($R_{\text{diff}} \gg R_{\text{relax}}$). Case III is the anomalous diffusion. It is observed when the diffusion and relaxation rates are comparable ($R_{\text{diff}} \approx R_{\text{relax}}$) [6]. To detect the diffusion mechanisms, the swelling curves are fitted to Eq. (1) which becomes:

$$\log\left(\frac{M_t}{M_\infty}\right) = \log K + n \log t \quad (2)$$

The diffusional exponent n is calculated from the slopes and K (kinetic rate of swelling) from the intercept.

3. Swelling properties of superabsorbent hydrogels

3.1. Natural polymer

The natural polymers copolymerized with synthetic polymers provided these natural polymers to have a suitable functional group and gain mechanical strength more than individual [7]. A variety of natural polymers such as chitosan, heparin, pectin, chitin, hyaluronic acid, agarose, dextran, and alginate are excellent to covalently cross-link and polymerize to form hydrogel. They have been explored as biocompatible, biodegradable hydrogels for biomedical applications [8–13]. Polysaccharide hydrogel is a biopolymer with high permeability for nutrients, oxygen, and other water-soluble metabolites, making it attractive scaffolds for use in cell encapsulation [14–16]. In addition, polysaccharides have been copolymerized with proteins such as laminin, gelatin, collagen, and fibrin to form an interpenetrating network polymer (IPN) or composite hydrogels [17–21]. This insoluble cross-linked biopolymer hydrogel allows immobilization of biomolecules and active agents. Owing to their high water retender, hydrogels resemble natural soft tissue more than any other type of polymeric biomaterials [22]. The water retention in SAH-based natural polymer promotes cell migration, growth, proliferation, differentiation, and adhesion, leading to tissue regeneration scaffolds [23].

3.2. Gum and wax

Hydrocolloid materials such as wax and gum and a few others such as surfactant or acidic oils have been copolymerized with hydrogel and novel systems of hydrocolloid hydrogel matrices with attractive properties. Emulsion polymerization is an efficient method for the production of new wax-hydrogel such as cetyl alcohol: stearic acid-based acrylamide hydrogel by using triethylamine (TEA) as an emulsifier [24]. A cross-linking reaction is performed at a dose of 20 kGy. This wax-hydrogel matrix bearing of acid and amide groups shows high swelling value behavior at different pH values.

Figure 3 shows the SEM images of wax-hydrogel matrices of CtOH-StA/PAAm. It was observed that the perfect miscibility was between wax and hydrogel networks as one phase with the absence of a separation zone. **Figure 3a** shows the equilibrium swelling at pH 6

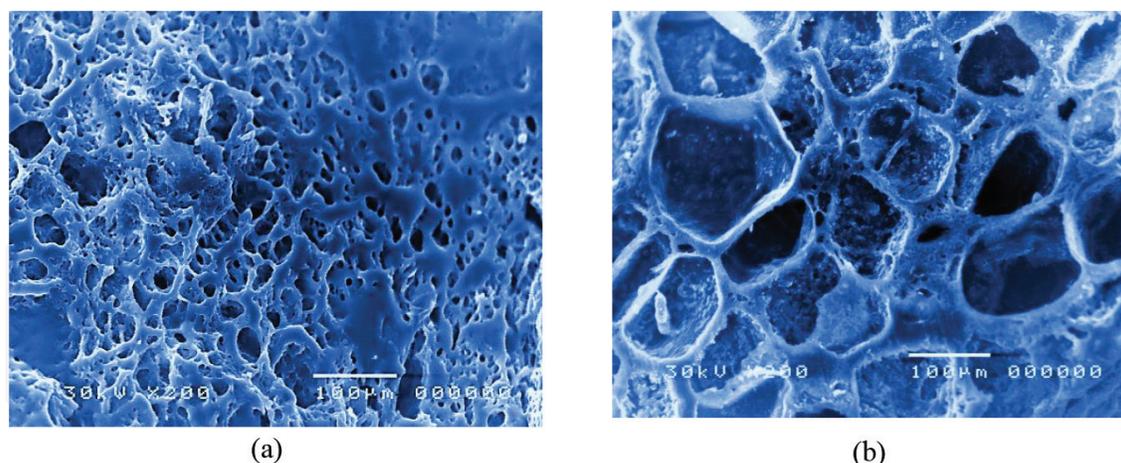


Figure 3. Scanning electron microscopy (SEM) images show the porous structure of CtOH-StA/PAAm (a) swelled at pH 6 and (b) swelled at pH 10.

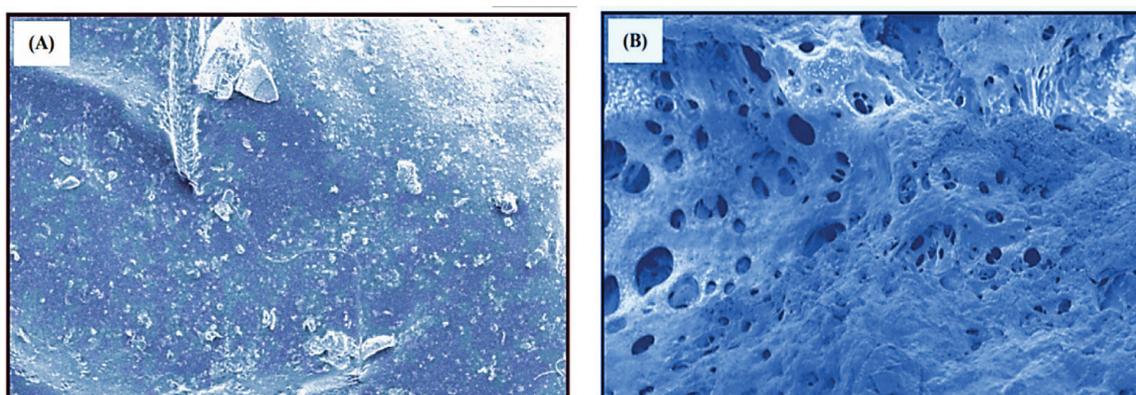


Figure 4. Scanning electron microscopy (SEM) images of (PAAm-g-XG) (A) swelled at pH 1.2 and (B) swelled at pH 7.4.

and the interconnected porous structure. At pH 10 (**Figure 6b**), an alveolate morphology and highly uniform pores are observed.

Another example of pH-sensitive gum (xanthan) based on acrylamide hydrogel is given (PAAm-g-XG) by radical polymerization [25]. **Figure 4** shows SEM images of the pH-sensitive swelling behavior reflecting the surface morphology of (PAAm-g-XG) exposed to acidic and alkaline pH. **Figure 4A** at pH 1.2 surface of (PAAm-g-XG) shows no pores as there was minimum swelling. In **Figure 4B**, at pH 7.4, the surface morphology of PAAm-g-XG reveals highly porous structure compared with the surface of PAAm-g-XG incubated in pH 1.2. As shown above, the swelling in alkaline medium is higher than in the acidic one due to the CONH_2 in acrylamide groups and hydrolysis to COO^- affected by NaOH. The electrostatic repulsion of the ionized groups COO^- leads to increase the pore size.

3.3. Rubber

Rubber could be used for improving the elasticity of many materials due to their flexibility and softness that has glassy transition temperatures bringing down the ambient temperature

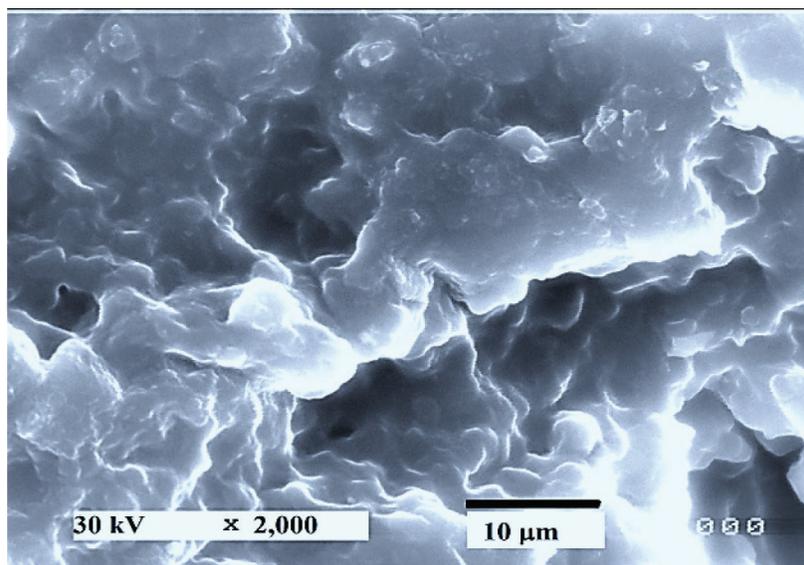


Figure 5. SEM image of SBR/PVP/MAA. The porous structure affected by elasticity of SBR chains.

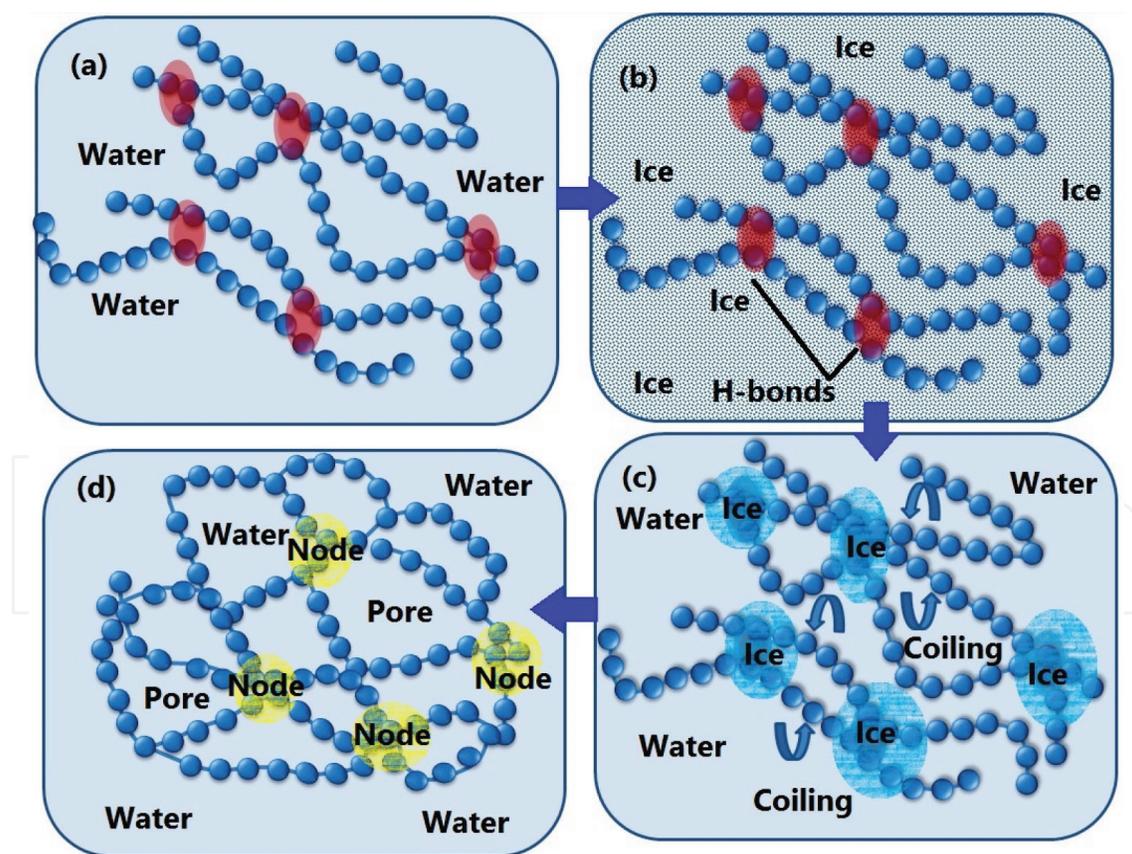


Figure 6. The mechanisms for PVA hydrogel formation from PVA solution by a freezing–thawing method: (a) PVA-water system. (b) PVA-ice system and frozen of chains. (c) PVA-ice-water system obtained by the gradual thawing of the PVA solution causing coiling of PVA chains together to form node (helix hydrogel). (d) Cross-linked network of PVA hydrogel was obtained.

[26, 27]. Water-swollen composite rubber-hydrogel materials are highly permeable to various applications. For example, rubber-hydrogel of SBR/PVP/MAA composite was prepared by mixing styrene-butadiene rubber (SBR) and copolymer hydrogel (polyvinylpyrrolidone-co-methacrylic acid) cross-linked by gamma irradiation. A high miscibility was observed between the MAA/PVP hydrogel and the matrix of SBR with swelling degree of 25 (g/g) after 4 h. **Figure 5** shows a SEM image of SBR/PVP/MAA revealed to a uniform of surface morphology indicating a high compatibility between the hydrogel and rubber matrices [28].

4. Preparation methods of SAH (freezing/thawing, ionizing radiation, and chemical initiation)

Superabsorbent hydrogels are prepared from either natural or synthetic polymers. The synthetic polymers are mechanically robust and stiffer compared to natural polymers. Their mechanical strength results in a slow degradation rate providing the durability as well, but mechanical strength of natural polymers is highly poor. These two inverse properties should be adjusted through ideal design [29]. The following section describes the physical and chemical methods reflecting the synthesis of hydrogels.

4.1. Freezing: thawing process

Freezing–thawing process is a physical method for creating a strong and highly elastic hydrogel [30]. The general advantage of physically forming hydrogel is the need for the addition of cross-linking and initiator entities. PVA is a common polymer that suitable cross-links by freezing–thawing techniques. Cross-linked PVA hydrogel is obtained when an aqueous solution of PVA highly crosslinked by the “repeated freezing-and-thawing cycles.” The steps in this method were as follows. First, an aqueous solution of PVA was frozen at a low temperature 0°C, and then the frozen PVA solution stands to thaw at room temperature or at a temperature of 60°C. These cycles were repeated, with increasing the cycle of freezing the resultant PVA hydrogel with much cross-linked density, and the water resistance has also been increased [31]. **Figure 6** reveals why the “freezing–thawing” process is well involved in the preparation of hydrogel for the PVA aqueous solution [32]. **Figure 6a** shows the H bond formation of PVA chains dissolved in water. Once the PVA solution was frozen (**Figure 6b**), ice crystals were formed within all PVA molecules, and the chains were freezing (low motion). During the “thawing” process, the ice will melt gradually from free chains before bonding chains (H bonds). A free space with water allowing free chains to cling together (tangle) and form node is seen on the left of **Figure 6c**. The “repeated freezing-and-thawing” method cross-linked PVA hydrogel with superporous structure that is formed (**Figure 6d**).

4.2. Chemical cross-linkage

Moreover, physically cross-linked hydrogels have limitations in which a few kinds of polymeric materials could be cross-linked by this method. Chemically, cross-linkage could be carried out in the wide kinds of polymeric materials in the presence of initiators and

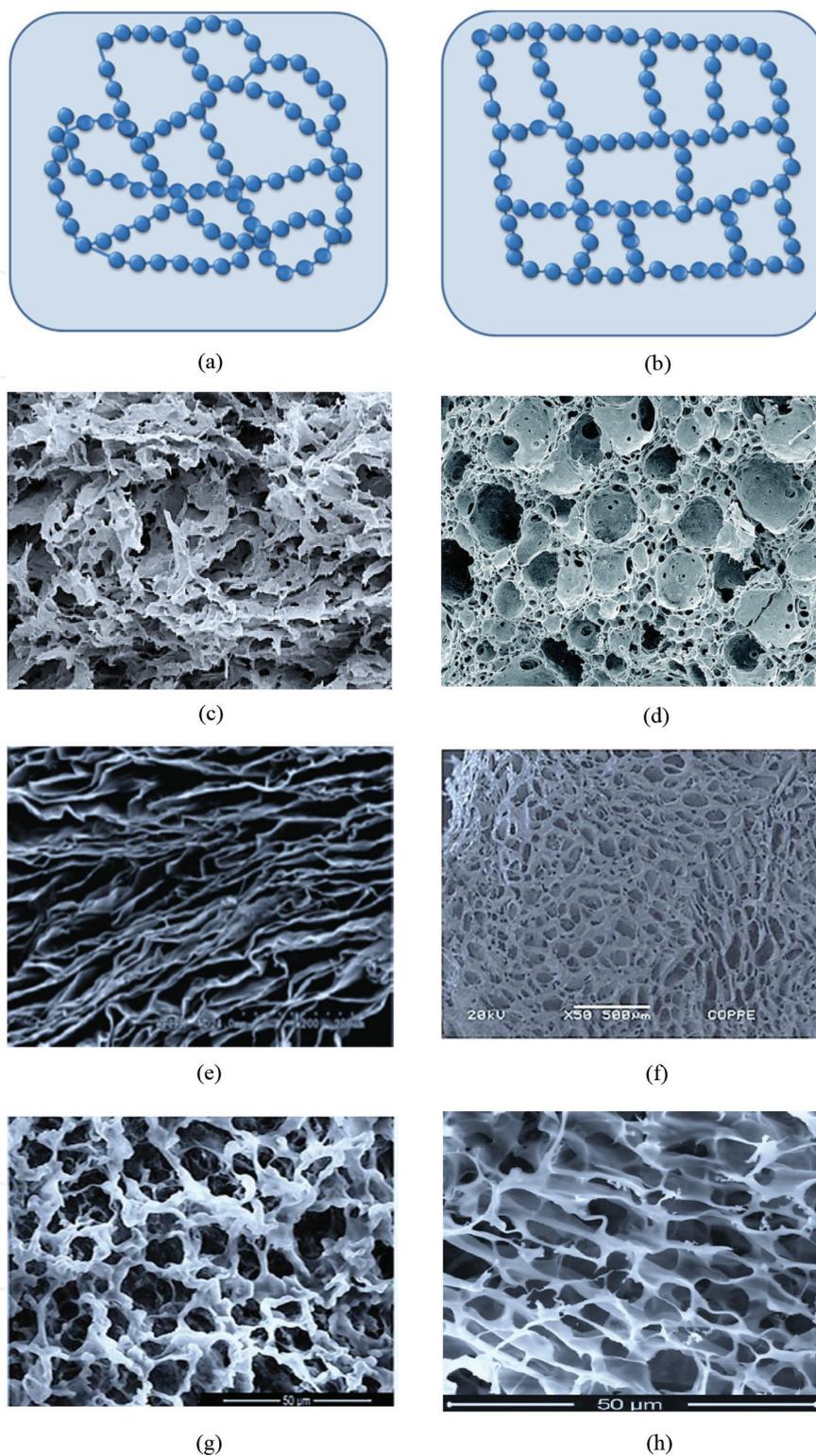


Figure 7. SEM images of morphologies of synthetic hydrogels. The changes in cross-linking method lead to the spontaneous formation of various porous structures. Physical hydrogels are not homogeneous, since clusters of molecular entanglements, or hydrophobically or ionically associated domains, can create homogeneities. Free chain ends or chain loops also represent transient network defects in physical gels. Physical hydrogel (a) chemical hydrogel (b) PVA hydrogel crosslinked (c) physically and (d) chemically (e) and (f) shows the chitosan hydrogel crosslinked physically as tubular porous structure and chitosan hydrogel crosslinked chemically using (g) succinic acid and (h) glutaric acid.

cross-linking agents. In another known difference, the physically cross-linked hydrogels are not homogeneous networks, the chain entanglements forming irregular porous structure, while chemically cross-linked hydrogels are covalently cross-linked networks forming regular porous structure [33]. **Figure 7** shows the morphologies of synthetic PVA hydrogels by two different processes (physically and chemically). The change in the parameters during cross-linking leads to the spontaneous formation of various porous structures. **Figure 7c** shows SEM image of PVA hydrogel prepared which underwent eight freezing–thawing cycles [34] given irregular porous structure. While **Figure 7d** shows a SEM image and PVA cross-linked chemically by adding H_3BO_3 [35], as seen in **Figure 7d**, the porous structure is more regular compared with the one in **Figure 7c**. **Figure 7e** and **f** shows an image of tubular chitosan prepared using the freezing–thawing method [36, 37]. **Figure 7g** and **h** shows SEM images of the chitosan cross-linked chemically by adding succinic acid [38] and by adding glutaric acid [39], respectively. Open-pore structure with a high degree of interconnectivity can be observed. It is indicated that the mechanism of cross-linking accompanied by reaction-induced phase separation leads to diverse morphologies of the resulting porous structure of cross-linked hydrogel.

4.3. Ionizing radiation

Cross-linking by irradiation occurs using a high-ionizing energy, such as gamma rays (Co-60), x-ray, or electron beam (*e*-beam). Gamma irradiation is more economically rather than the rest of the other irradiation techniques [40, 41]. Gamma irradiation is a promising technique to fabricate a wide scale of different materials especially polymeric materials [42–44]. Particularly, at the first step, a polymer radical is formed with regard to water radiolysis by ionizing radiation follow-up polymerization reactions. Water radiolysis generates six reactive species ($\cdot H$, $\cdot OH$, e_{hy} , $H_2\cdot$, $H_2O_2\cdot$ and $O\cdot$). All $\cdot H$ and $\cdot OH$ radicals beside e_{hy} produced upon radiolysis of water are transferred by the polymeric solute to form carbon chain macroradicals. The average number of macroradical centers formed in a pulse would then be determined simply from the radiation chemical yield of hydroxyl radicals and the dose per pulse. For example, radiation cross-linkage of acrylic acid (AAc) monomer and polymer radicals preferably undergoes intra-cross-linking and inter-cross-linking reactions producing a porous structure. Macroporous structures are produced when inter-cross-linking predominates and intra-cross-linking would cause nano-porous structures [45]. Radicals are generated from the radiolysis of AAc aqueous solutions; the predominance of the inter-cross-linking reactions is achieved due to the large number of carbon–carbon double bonds. The beginning of intra-cross-linking under these conditions is confirmed by the macroporous formation. Also, higher yield of C-centered free radicals along the PAAc chain enhances the intra-cross-linking reactions. Dimers are formed by combination of two macroradical molecules. In the same manner, a 3D cross-linked hydrogel will be obtained of PAAc polymer. **Figure 8** shows covalently cross-linked hydrogels. First, macroradicals are combined together, and then cellular structure consisted of small compartments or pores as rooms are filled with water. The network expansion probably takes place by means of an own pores are filled with water. At a certain water pressure bonds of the networks, walls contract and relax.

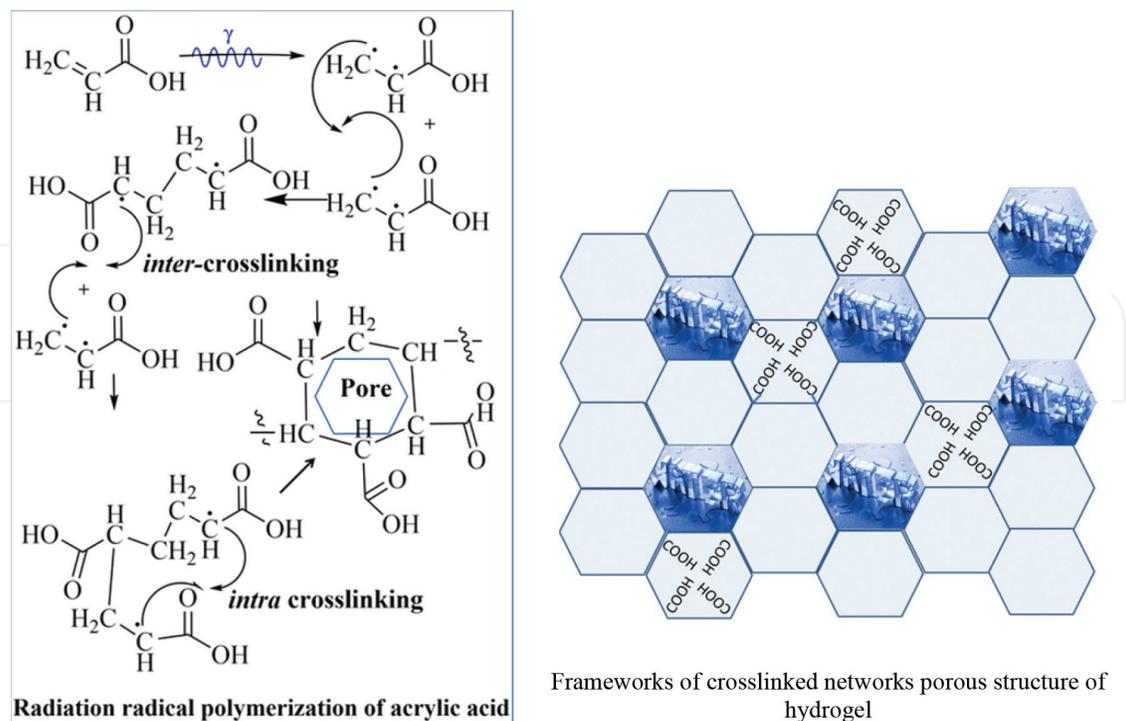


Figure 8. (Left) The proposed radical polymerization mechanism induced by gamma irradiation on the preparation of polyacrylic acid. (Right) The framework of SAH network structure has a preferential spatial orientation.

5. Design of the polymerization reaction according to appropriate monomer

A construction of 3D frameworks of superabsorbent hydrogel is random and amorphous of nature. But this does not prevent inspiration for the molecular architecture of hydrogels. The fabrication of various architectures for SAH is demonstrated in **Figure 9a** and **b**. According to the IUPAC definitions [46], semi-IPN networks are composed of one linear polymer entrapped within the network of another polymer, while IPN networks comprise more than one polymer network structures interlaced on a molecular scale. **Figure 9c** is an image of a multilayer hydrogel (MLH) [47] in which single networks are stacked one onto the other, interpenetrating network films with the mixture of two networks in the same layer. **Figure 9f** is an image of hydrogel fibers [48–50]. The synthesis of hydrogel depends on the concentration of monomer, initiator, and cross-linked agents.

The polymerization reaction may occur by two growth polymerizations such as step and chain growth polymerizations individually or of both [51]. In case of chain growth, the polymerization reaction is very fast, whereas in step growth, the reaction is gradual and monomer concentration decreases gradually. In case of chain growth, the polymerized hydrogel conversion is high, while pore size and swelling are low. Whereas in step growth the hydrogel conversion is poor, pore size and swelling are high [52]. **Figure 10** shows the framework

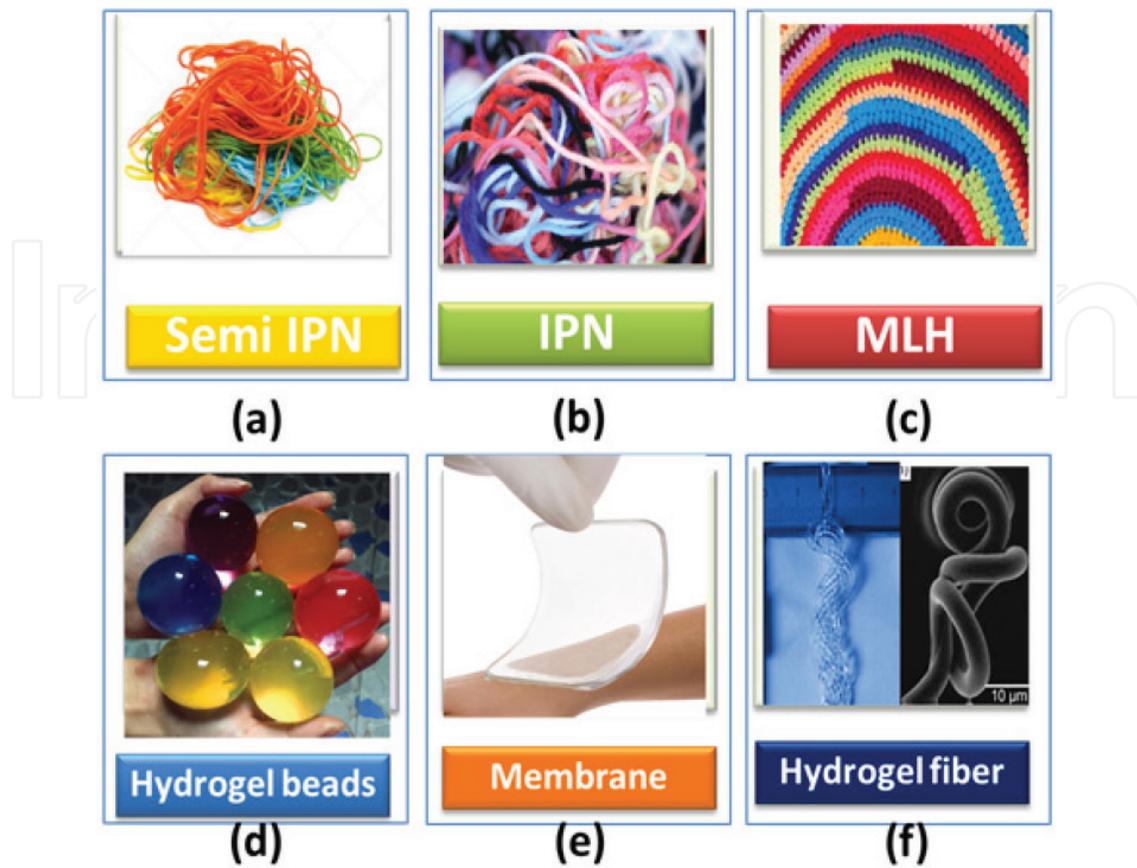


Figure 9. Predominated shape design of hydrogels.

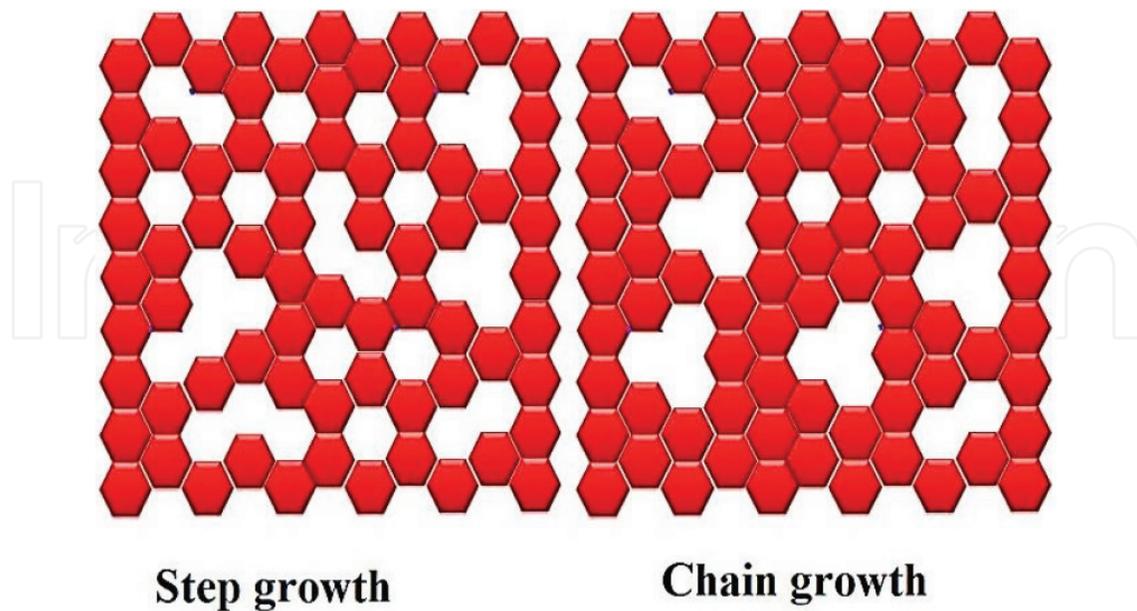


Figure 10. The two routes of polymerization reactions.

of both growths of polymerization reaction. As shown, the polymerization occurs which by chain growth would proceed by random dimerization of the neighboring monomers and then oligomerization formation until the cross-linked network is obtained. Step growth polymerization reaction has formed dimers, trimers, tetramers, etc., until short chains are formed within the combination of them to form cross-linked hydrogel.

6. Types of porous structure obtained

Another attractive feature is the development of new complex hydrogel films with targeted architecture. Porous materials are materials having different pore size structures (from nanometer to millimeter). Hydrogel has a porous structure in size of the micrometer called superporous structure. **Figure 11** shows the pores with different shapes with different accessibility. Almost, the surfaces of pores are hydrophilic, and the void begins to open due to group's repletion of the same charge. The swelling process shows variability of pore structure obtained as (a) closed pores, (b) one side opened pores like cylinder, (c) two sides opened pores like tunnel, (d) one side opened pores like ink bottle shaped, (e) two side opened pores like funnel shaped, (f) pores with rough surface, (g) separated closed pores, (h) interconnected pores, (k) collected pores or density pores, and (p) pores like internal tunnel. In maximum swelling we reach to superporous hydrogel when the pores predominate than the solid network.

Further compression properties of the superporous hydrogel are α -elastin fabricated under 60 bar CO_2 pressure which was comparable with 1 bar. SEM image in **Figure 12** shows the pore size of the hydrogels which was enhanced 20-fold when the pressure was increased from 1 to 60 bar.

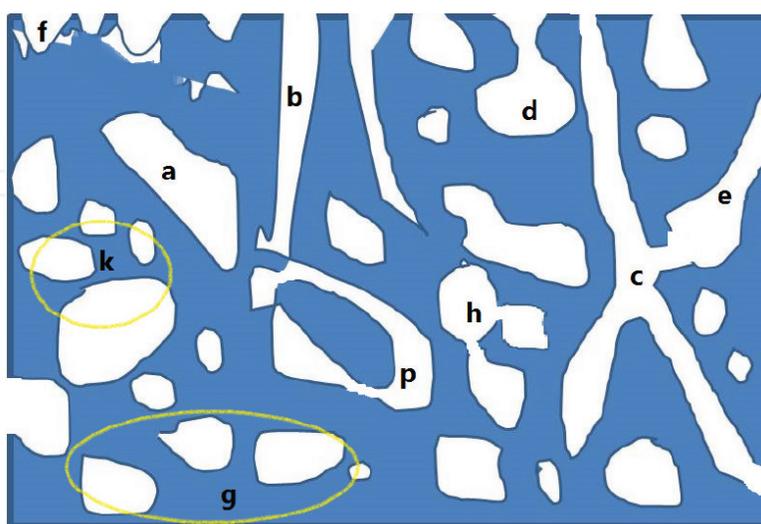


Figure 11. Given the different type of pores where white region is hydrophilic region filled with water and blue region is hydrophobic region or covalent bond of cross-linkage. **Shape:** a, k, g, and h (closed pores); (b) cylindrical open shaped, (c and p) tunnel shaped, (d) ink bottle shaped, (e) funnel shaped, and (f) roughness). **Accessibility:** a, p, h, g, and k (closed pores); c, e, d, f, and p).

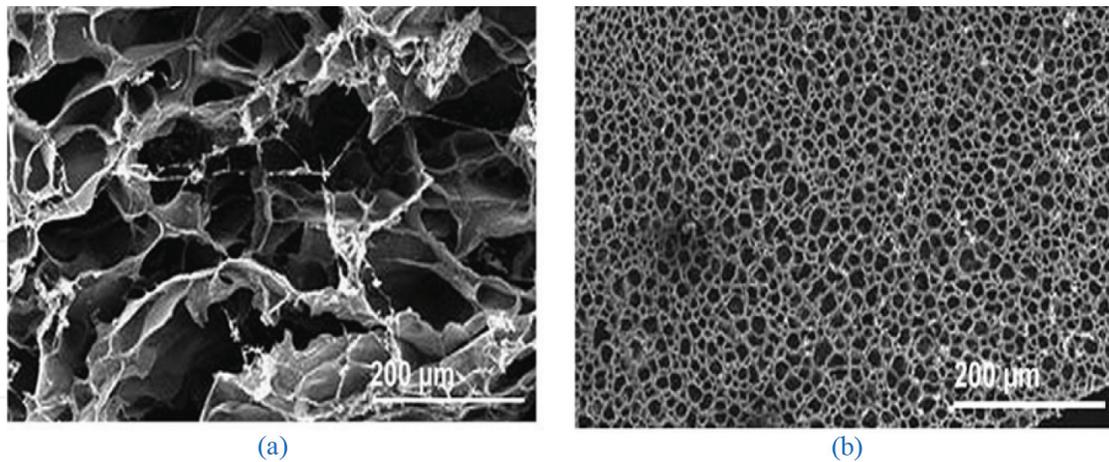


Figure 12. SEM images of (a) the α -elastin hydrogel fabricated at 60 bar CO_2 pressure which was highly porous structure. Comparison of SEM images (b) of α -elastin hydrogel produced under atmospheric CO_2 conditions (1 bar) indicated that a high-pressure CO_2 increased the pore size of the fabricated hydrogels [53].

7. Factors affecting superabsorbent hydrogel

7.1. Density of cross-linking

Increasing the ratio of cross-linked portion leads to slow down the movement of chains, resulting in the decrease in free volume, the pore sizes, and the swelling degree which are also decreasing. This can be observed by SEM analysis or DSC where increased cross-linking causes increase of glassy temperature (T_g) of the polymer [54, 55]. However, in some cases, a decreased cross-linking leads to a decrease of T_g , where nonfreezing (bounded) water molecules are attached to function groups causing a decrease of T_g [56].

7.2. The ratio of hydrophobic/hydrophilic surface area of the hydrogels

The ionization power and number of hydrophilic functional groups along the hydrogel chains and its counterion type play an important role in the degree of swelling. A high proportion of superabsorbent hydrogels are present as acrylates with carboxylic acid functional groups, which in the salt form undergo dissociation upon contact with water. In the dissociated state, the hydrogel network will have a series of functional groups that have the same electric charge and thus repel each other. This leads to expansion of the hydrogel network structure with the further absorption of water molecules. Furthermore, the number of hydrophilic moieties when increasing the swelling could be increased and vice versa.

7.3. Applications of superabsorbent hydrogel

According to the required application, the hydrogels have been tailored and designed to achieve the purpose of applications. The presented section demonstrates the research concerning the characterization of hydrogels on various bases, physical and concoction qualities of these items, and specialized practicality of their usage.

7.4. Internal curing agent for cement

Cross-linking of superabsorbent hydrogels based on poly(acrylamide-co-sodium alginate) by γ -radiation shows higher swelling capacities in basic than in acidic media [57]. This property proposes the use of (PAM-co-NaAlg) hydrogel as an internal curing agent for cement. The cement with (PAM-co-NaAlg) hydrogel mixture improves the compressive strength of cement at 0.1 and 0.2 wt%. Intermediate values are found when using 0.1, 0.3, 0.4, and 0.5 wt% of hydrogel. Thus, the maximal improvement percentage on the compressive strength is 0.2% with respect to the hydrogel. This would indicate that using 0.2 wt% of hydrogel is a critical value. Under this value, the hydrogel shows less ability for water retention than what is needed for cement curing. Above this value, the higher amount of hydrogel is contributing to increase voids that cause decreased compressive strength. **Figure 13** demonstrates the procedure for mixing of cement-hydrogel samples in the laboratory for compressive strength test. Mixing of cement and hydrogel samples was carried out with a known w/c ratio at 0.4. The setup of preparation steps is as follows: (1) The known weight of dried PAM-co-NaAlg is added to 100 ml water, and (2) during a specified time period, the hydrogel is allowed to swell, and water uptake is liberated slowly during the hydration of the cement. Then, 40 g of cement (3) is added to the swollen hydrogel, and the slurry of cement is obtained (4). The slurry is stirred well for 3 min and then poured in the aluminum mold ($4 \times 4 \times 4$) cm³ (5). After a period of time (24 hr) which corresponds to the time required obtaining dried cement samples, the mold is removed.

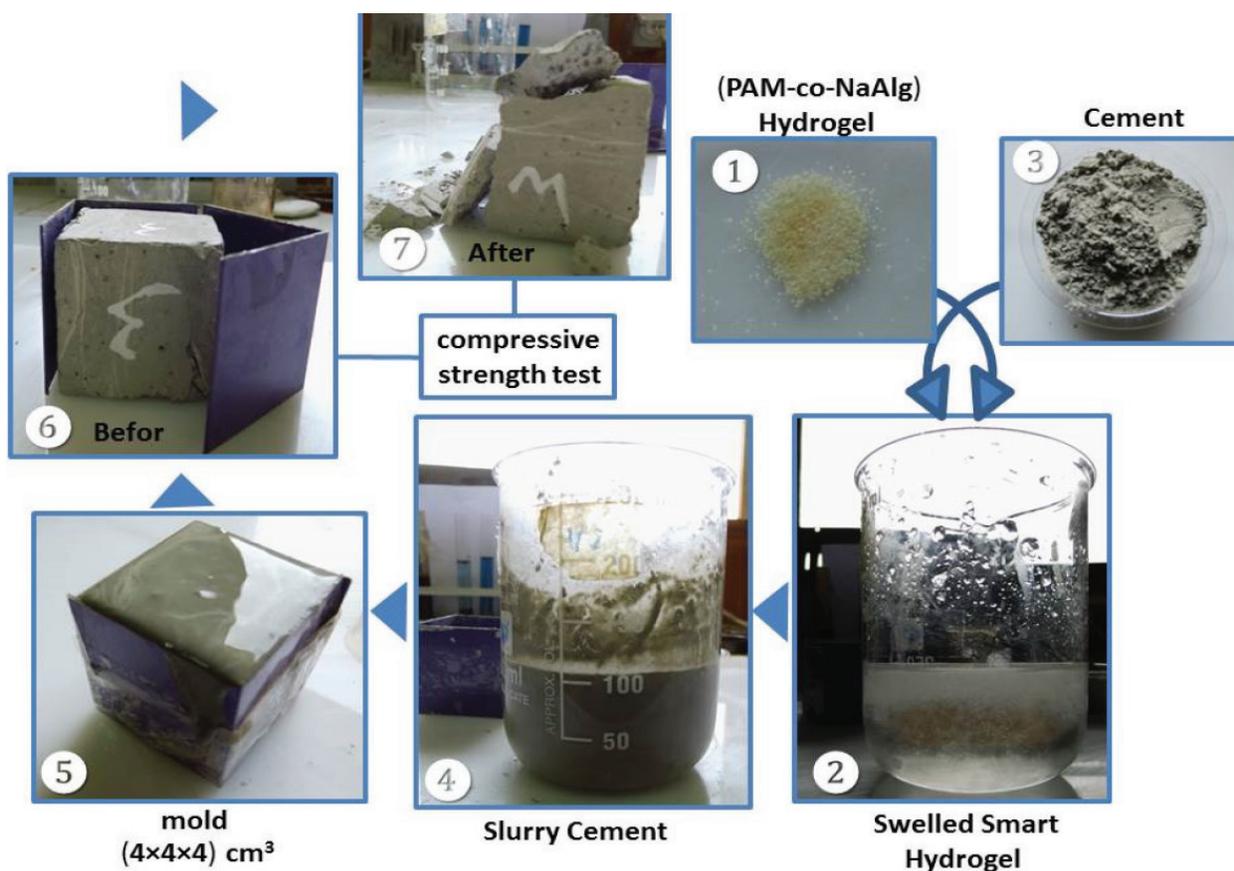


Figure 13. The procedures of preparing cement hydrogel mixture for compressive strength test.

Figure 14a and **b** shows the SEM images of the cement-hydrated (cured) product particles. It is clear that the particles in **Figure 14b** for 0.3 wt% hydrogel are smaller than the particles in **Figure 14a** (without hydrogel). This indicates that the slow absorption of water during cement curing helps the formation of small particles and leads to decreased permeability. Moreover, without hydrogels, the poorly hydrated system is reflecting the compressive strength results.

7.5. Agricultural proposal

Many studies report the use of superabsorbent hydrogel (SAH) in agricultural field (**Figure 15**). Using superabsorbent hydrogel increases soil ability to hold water, so plant growth increases and it can resist drought for a long time [58–60]. Also, adding superabsorbent hydrogel (SAH) to soil improves plants through supplying the plant roots with water, providing soil with potassium ion which is important to retain a K^+/Na^+ homeostasis, and components of polymers held the ions of salt in the drying soil [61]. Superabsorbent hydrogels (PVP/CMC) based on polyvinylpyrrolidone (PVP)/carboxymethyl cellulose (CMC) were prepared by using gamma radiation as an initiator of polymerization reaction [62]. Water and fertilizers are vital factors for producing high-yield agricultural crops. Fertilizers are composed of phosphate (P), potassium (K), and nitrogen (N) nutrients for plants in the form of water-soluble salts which are loaded into (PVP/CMC) hydrogel. The hydrogels show adsorption desorption of the three fertilizers; also, the results revealed that the presence of CMC in the hydrogel improves their water retention capability with high swelling ratio. This indicates that the addition of PVP/CMC hydrogels to soil could improve the water-holding capacity of the soil which has the excellent water absorbing capacity. So, the soil could hold much more water during the irrigation period or raining time than the soil without it and could efficiently reduce irrigation water consumption. It can be concluded that PVP/CMC hydrogel had good water retention capability suggesting their possible use of the prepared superabsorbent hydrogel as a soil conditioner in agriculture applications.

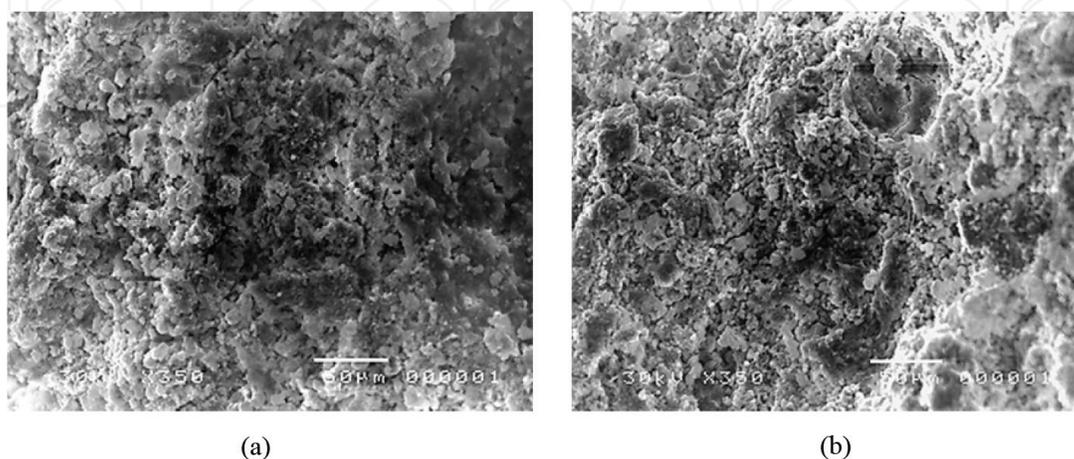


Figure 14. SEM image of a fracture surface of cement: (a) blank sample without hydrogel and (b) 0.3 wt% of hydrogel.

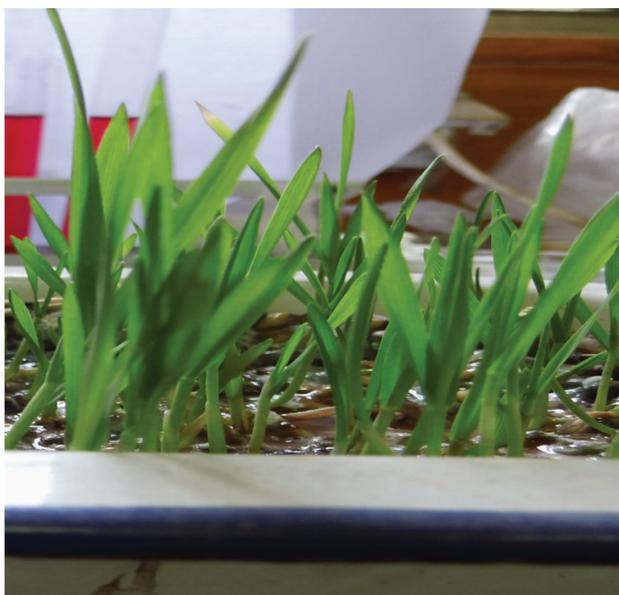


Figure 15. Used SAH as soil conditioner to support plant growth safely.

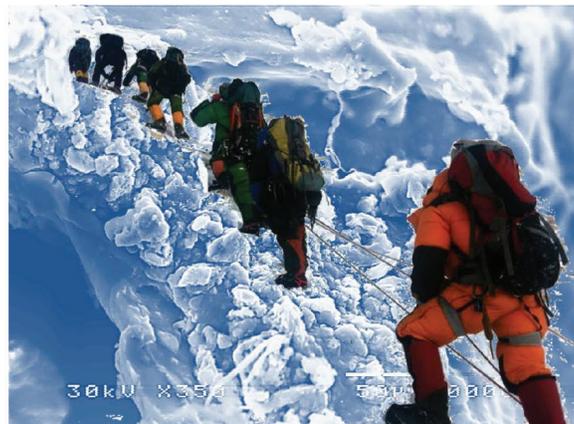
7.6. Biomedical proposal

Hydrogels have become very popular due to their unique properties such as high water content, biocompatibility, flexibility, and softness. Natural and synthetic polymers can be a resemblance to the living tissue that opens up several opportunities for applications in biomedical and medicine fields. Currently, hydrogels are used for manufacturing hygiene products, contact lenses, scaffolds, tissue engineering, wound dressings, and drug delivery systems. More developments are expected in drug delivery and tissue engineering. A hydrogel based on poly-2-hydroxyethylmethacrylate (PHEMA) as a synthetic biocompatible material is used as contact lens applications [63, 64]. Wound dressing is an effective hydrogel dressing that relies on an understanding of the healing process. Healing can be hindered by many factors such as infection, abnormal bacterial presence or desiccation, maceration, necrosis, pressure, edema, and trauma [65]. The “ideal” wound management product should absorb excess toxins and exudate, keep a good moisture between the wound and the dressing with increasing collagen production, preserve the wound from external sources of infection, prevent excess heat at the wound, have good permeability to gases, be supplied completely sterile, and be easy to remove without further trauma to the wound [66]. Their high water content allows vapor and oxygen transmission to the wounds such as pressure sores, leg ulcers, surgical and necrotic wounds, lacerations, and burns. They seem to play an important role as emergency burn treatment alone or in combination with other products, thanks to their cooling and hydrating effect [67]. Hydrogels have attracted noticeable interest for their use in drug delivery due to their unique physical properties [68]. The high porosity that characterizes SAH can easily absorb and desorb drugs easily by adjusting the density of cross-links in their matrix and the affinity to water.

Tissue engineering is the application of the principles and methods of engineering and life sciences toward fundamental understanding of the structure–function relationship in normal and pathological mammalian tissues and the development of biological substitutes for



(a)



(b)



(c)

Figure 16. SEM image of hydrogel in funny situation.

the repair or regeneration of tissue or organ function [69]. Tissue engineering is a more recent application of hydrogels, in which they can be applied as space-filling agents, as delivery vehicles for bioactive substances or as three-dimensional structures that organize cells and present stimuli to ensure the development of a required tissue. Space-filling agents are the most commonly used group of scaffolds, and they are employed for bulking, to prevent

adhesion, and as biological “glue.” Drugs can be delivered from hydrogel scaffolds in numerous applications including promotion of angiogenesis and encapsulation of secretory cells. Additionally, hydrogel scaffolds have also been applied to transplant cells and to engineer many tissues in the body, including the cartilage, bone, and smooth muscle [11].

7.6.1. Environmental proposal

Hydrogel is an eco-friendly material that has many uses as water purification and air purification. Hydrogel as a new type of adsorbent for water purification is a composite with graphene oxide [70]. These materials usually exhibit high-capacity adsorption toward water pollutants and air pollutants [71]. Due to their highly developed porous structure, hydrogel fabricated with other materials such as graphene oxide and zeolite exhibits a high capacity for gas adsorption and selectivity for gas separation. Researches are still on developing the efficiency of hydrogel gas adsorbents with a good stability, recyclability, and substantial capacity. Because of their porous structure, and their environment stability, hydrogel is a good candidate for gas adsorption.

7.6.2. Gallery of hydrogel

Figure 16 shows funny imaginary SEM pictures of swollen hydrogel (a) PVP/PAAc, (b) PVP/PAAc after swelled in 1 M KCl, and (c) CMC/PVP loaded with three kinds of salts.

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