Synthesis of Magnetic Nanocomposite Gels for Ophthalmic Applications

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ABSTRACT

Retinal detachment is estimated to cause 150,000 (in the United States alone) to be blind every year. Many detached retinas occur in older people. It occurs when the vitreous gel that adheres to retina shrinks and separates from the retina. In this process retinal fissure could occur. We have produced magnetic nanoparticles with uniform dispersion that can be used for the application. These particles are used to produce a magnetic gel. The soft magnetic gel will be inserted in the region where the repair is required, a 5 millimeter wide magnetized scleral buckle a magnetic buckle will be use to hold the gel in place..

Keywords: Nanocomposite, magnetic, gel, retina reattachment, Ophthalmic

1 INTRODUCTION

Retinal detachment is estimated to cause 150,000 Americans to be blind every year. Many detached retinas occur in older people. It occurs when the vitreous gel that adheres to retina shrinks and separates from the retina. In this process retinal fissure could occur. When the retina detaches, it separates from the back wall of the eye and is removed from its blood supply and source of nutrition. The retina will degenerate and lose its ability to function if it remains detached. Central vision will be lost if the macula remains detached. The conventional methods to repair the retinal fissures is to inject silicon fluid or a gas bubble directly into the eye to push the retina back into place and seal the tear. Both of these conventional methods fail if they are lighter than the vitreous liquid in the eye as they will float away from the tear. The conventional methods rely on gravitational forces to keep the silicon and the bubbles at the tear location. If the tear occurs at the lower side of the eye, patients will be asked with the current treatment methods to keep their heads down to force the silicon and the bubbles to stay at that location. A scleral buckle can be used in these situations but does not always work to close the hole adequately.

Rutnakorpituk et al. [1] proposed the use of a magnetic fluid to seal off the holes of the retina. The fluid is held in place by a 5 millimeter wide magnetized scleral buckle. We have produced nanomagnetic particles with uniform dispersion that can be used for the application. However, because of toxicity, and particles stability in dispersion for a long time and possible oxidation we propose to synthesize a magnetic gel for the purpose of retinal detachment repair. A soft magnetic gel will be inserted in the region where the repair is required, a magnetic buckle will be use to hold the gel in place. We have synthesized magnetic responsive polymer gels using in house synthesized nanomagnetic particles. Both superparamagnetic nano particles (γ-Fe_2O_3) and ferromagnetic nano particles (Fe-Ni-B) are being used in the nanocomposite. Figure 1 shows the schematic of the proposed solution for the retina detachment.

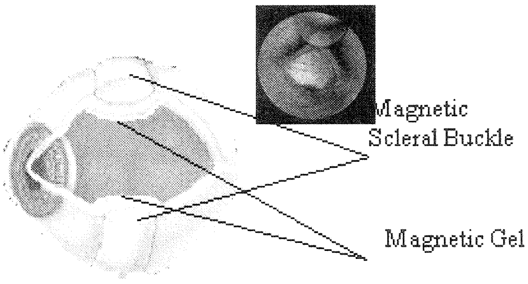

Figure 1 Schematic diagram of proposed solution

In order to form a magnetic responsive gel a ferrofluid is introduced in polymeric matrix and chemically crosslinked thereafter [2]. A ferrofluid is a colloidal dispersion of monodomain magnetic particles of superparamagnetic nature and with size of about 10nm. These colloidal solid particles are the elementary carrier for magnetic moment and they remain attached to the flexible net work structure. Here we report a method of synthesis of magnetic gel with a hydroxy propyl cellulose, a biopolymer widely used in pharmaceuticals [3] and related industries.

In most of the cases, ferrogels are made using water soluble polymer and ferrofluid. There are different ways to make that. One way is the precipitation of particles within polymeric matrix before or after crosslinking [4] and another method is preparation and characterization of magnetic particles separately and mix that with polymer and subsequent crosslinking [5].

Here we report a two step synthesis of magnetic gel. Each of the steps is important to influence the final gel structure. In fact, magnetic nanomaterial is being formed in each step. In the first step hydroxyl propyl cellulose particles are formed with surfactant modified maghemite by emulsion method as done by Hu et al [6] to synthesize crosslinked HPC particle. In the second step these particles are crosslinked by a commercial crosslinking agent Zirmel M to give a net work structure. By this mechanism of network formation, a homogeneous distribution of maghemite was possible into the polymer matrix. Atomic force microscopy is used to study the surface structure of the gel. The internal morphology of the particles and the network structure formed by them was determined by scanning transmission electron microscopy. The magnetic property of the gels is measured by using superconducting quantum interference device (SQUID).

2 MAGNETIC NANOPARTICLES

The detailed synthesis of maghemite was described earlier [7]. In brief ferrous chloride and ferric chloride were mixed in a molar ratio of 1:2 in deionized water at a concentration of 0.1 M iron ions. The solution was used immediately after preparation. A highly concentrated solution of sodium hydroxide (10M) was added to it for coprecipitation with continuous stirring. Then the solution with the precipitate was stirred in high speed for 1 hr. at 20°C and was then heated at 90°C for 1 hr with continuous stirring. The ultrafine magnetic particles obtained were peptized by Nitric acid (2 M). The iron oxide dispersion was then sonicated for 10 mins. at 90°C at 50% amplitude. The precipitate was then washed repeatedly with deionized water and filtered and dried in vacuum to get fine iron oxide particles. In order to modify the surface of the iron oxide, a cationic surfactant CTAB (30% by weight of iron oxide) was mixed with iron oxide suspension by vigorous stirring for 4 hours and then the water was dried up and the dried powder was used to mix with hydroxyl propyl cellulose.

3. GEL FORMATION

In the first step polymeric chain and maghemite is crosslinked in to an individual composite particle and in the second step the individual composite particles are crosslinked to form a network structure. CTAB modified iron oxide showed much better adhesion with the HPC nanoparticles and in fact ultrasonication in the first step before crosslinking reduced the particle size and helped in better mixing of meghemite with HPC. The second step is important as the actual gel structure has been formed in this step by the crosslinking action of Zirmel M in alkaline medium (pH = 8.5-9) Zirmel M was used here as a crosslinking agent and it is basically an ammonia free system mostly used in paper and coating industry for crosslinking with carboxyl or hydroxy groups in the binder, such as starch, proteins, CMC, carboxylated latex etc.

Surface and internal morphology.

Fig 1(a) and 1(b) show atomic force micrographs of the gel in height (3D view) and amplitude mode respectively. A mesh has been formed with the nanoparticles of HPC attached with maghemite as observed in these micrographs. The network structure shows a globular pattern on the surface which is also clearly observed in figure 1(b). In amplitude mode figure 1(b) the maghemite particles are observed clearly on the HPC particle. The section analysis (which is obtained by using the software in AFM) of the fig 1(a) shows that the average individual particle size is about 35nm.

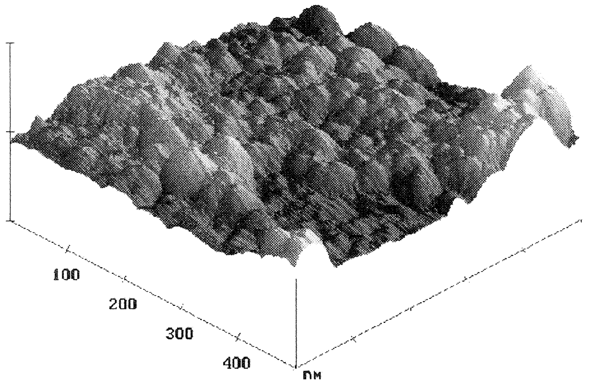

Figure 1(a) AFM monograph 3D

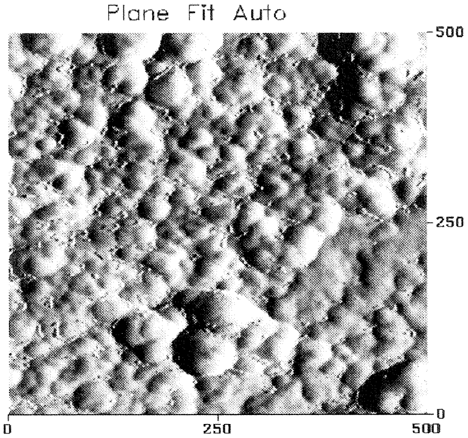

Figure 1 (b) AFM monograph amplitude mode

Transmission electron micrographs show the HPC particles with iron oxide in nanometer range and the network structure of the gels. Homogeneous distribution of iron oxide was observed in the gels. Figure 2 shows hydroxy propyl cellulose nanoparticles which formed the gel is in the range of 30-100nm.

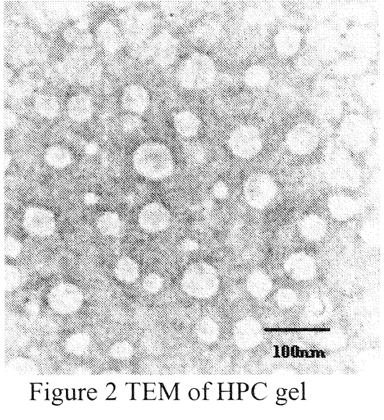

Figure 2 TEM of HPC gel

4. MAGNETIC PROPERTIES

Figure 3 shows temperature - susceptibility plot at 50G for the ZFC and FC case for gel. In zero-field cool (ZFC) the sample is brought to 5K while the applied field is maintained at zero. An applied field of 50G is imposed on the sample when the temperature stabilizes at 5K. Once the temperature reaches 300K the sample is cooled back to 5K at steps of 10K while the applied field remains at 50G (FC). Initially an increase of susceptibility with temperature was observed in ZFC curve, as there was no applied field and the magnetic particles in the gel had a random orientation of their magnetizations. When a small field is applied and thermal energy is added to the sample, the smaller particles will have an amount of energy comparable to their energy barrier thus their magnetization aligns in the direction of the applied field and so an increase in the sample magnetization is observed with temperature. As the sample has significant distribution of particle sizes, we did not observe a blocking temperature (temperature below which the particle moments are blocked and it is usually determined by measuring the peak position of the ZFC susceptibility vs. temperature, the χ– T curve [8] even at room temperature. As the sample was cooled in a constant applied magnetic field, thermal energy is being reduced, which allows the particle to fix their magnetic moment in the direction of the magnetic field. Almost no change in the susceptibility was observed. The inflexion at about 235K in the FC curve and 250K in the ZFC curve is must be due to the melting and freezing of the ice and water respectively. These temperatures are lower than the normal melting and freezing temperature of water. This lowering of melting and freezing temperature can be explained by the well known principles of colligative properties of a multicomponent system [9].

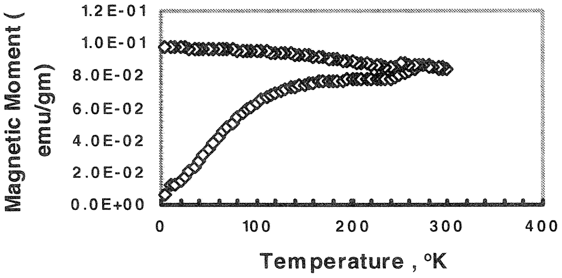

Figure 3 Magnetic moment of the gel at different temperatures

Fig 4 shows the magnetization at 5K and 300K as a function of applied magnetic field for the gel. A very small and almost negligible hysterisis loop was observed at room temperature. At 5K, the hysteresis is rather sizable with a coercive field. The hysteresis loop is also symmetric about the center for both temperatures. This symmetric nature of the loop is a characteristic of superparamagnetic behavior [8]. Magnetization curve at 300K showed no hysterisis and both plots obtained at two different temperatures fall under same universal curve demonstrating the superparamagnetic behavior of the composite particles [8].

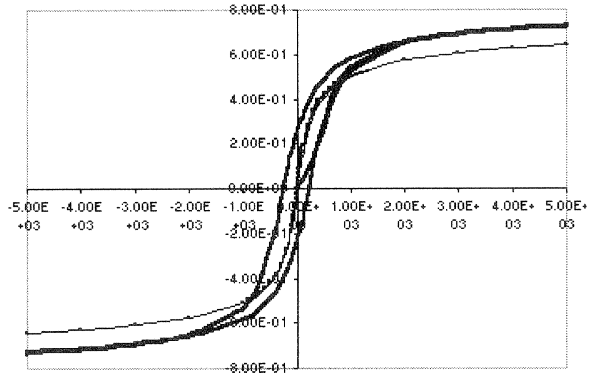

Figure 4 Magnetic moment

5. CONCLUSIONS

Synthesis of nanocomposite particles and formation of gels with them by crosslinking can be very useful method of preparation of magnetic gel for retina reattachment. The distribution of magnetic particles in the three dimensional polymer networks can be uniform when they are modified with a surfactant. The magnetic gel has magnetic moment in an applied field. Superparamagnetic behavior was observed for the gel. Studies on the effect of external stimuli specifically effect of magnetic field and ultrasound on this magnetic gel are underway.

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