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Ophthalmic Application of Hydrogel Polymer Containing Carbon Nanomaterials

Jae-Wuk Seok[1], Yong-Pil Geum[2], Dong-Seok Shin[3], and A-Young Sung[1†]

Abstract

This experiment is to evaluate the physical properties of the hydrogel lens with the addition of carbon-based nanomaterials, Graphene oxide and Carbon nanotube, and to confirm the improvement of strength. Hyaluronic acid, a hydrophilic substance, was used as an additive by using HEMA (2-hydroxyethyl methacrylate) and ethylene glycol dimethacrylate (EGDMA) as a base monomers. Graphene oxide and two types of Carbon nanotubes(Amide functionalized and Carboxilic acid functionalized) were added 0.1%, 0.3%, 0.5%, respectively, and the physical properties were analyzed by measuring water content, refractive index, breaking strength and SEM image. In the case of the sample added with each carbon nano material, the water content tended to increase for all three materials. The breaking strength tended to increase in Graphene oxide and Carbon nanotube; Carboxilic acid functionalized, but in the case of Carbon nanotube; amide fuctionalized, the breaking strength tended to decrease. However, Carbon nanotube; amide fuctionalized had the highest breaking strength among the three nano materials. Thus, the addition of certain carbon nanomaterials seems to be appropriate for improving the strength of hydrogel lenses.

Keywords : Graphene Oxide, Carbon nanotube, Breaking Strength

1. Introduction

Carbon nanotubes (CNTs) were first discovered in the analysis process of carbon on graphite cathodes through transmission electron microscopy.[1] Later, the single-walled CNT, the most basic structure when using transition metals like Fe and Ni during electrical discharge, was formed. In 1994, the first nanocomposite material using CNT as an additive was developed by Ajayan et al.[2] The interest in CNT as a new material is rapidly increasing, along with the interest in graphene. CNTs are basically classified into single-walled CNTs (SWCNTs),[3] double-walled CNTs (DWCNTs),[4] and multi-walled CNTs (MWCNTs).[5] DWCNTs have higher stiffness than SWCNTs but are smaller than MWCNTs. In the case of SWCNTs, the CNT classification criterion is basically a monolayer of graphene composed of carbon covalent bonds rolled into nano-sized diameters. Depending on the number of covalent bonds, it is divided into SWCNTs, DWCNTs, MWCNTs, etc.[6] The most important features of CNTs are their ability to bend and recover well,[7] their low mass density,[8] and their high tensile modulus[9] (maximum 1 TPa) and tensile strength[10] (150-180 GPa). In the case of metallic CNTs, the electricity is not scattered, and the electrical conductivity is high. Graphene was first published in 2004 by the research team of Geim and Novoselov in the UK as they succeeded in tearing off a layer of graphite with tape.[11] Graphene has high strength, high elasticity[12], high electrical conductivity (up to 100 times that of copper),[13] and high thermal conductivity.[14] On account of these, graphene is used in various fields, such as semiconductors, solar cells, and computers, and is attracting attention as a next-generation material.[15-17] The most common features of both carbon-based materials are their high strength, high elasticity, and high thermal and electrical conductivity. Therefore, this study measured the effect of the strength improvement when CNT, a carbon-based nanomaterial, was used as an additive in the fabrication of hydrogel lenses, and compared its physical

[1]Department of Optometry & Vision Science, Catholic University of Daegu, Gyeongsan
[2]Department of Innovative Start-Up & Growth, Catholic University of Daegu, Gyeongsan
[3]R&D Center, Youngwon Tech,. Daegu

[†]Corresponding author : say123sg@hanmail.net
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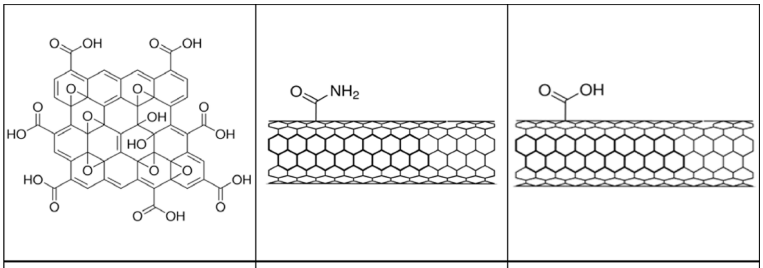


(a) Graphene oxide (b) Amide (c) Carboxilic acid

Fig. 1. Structures of the additives.

properties with those of graphene oxide (GO).

2. Experimental

2.1. Fabrication of Hydrogel Lenses

For the reagent used for fabricating hydrogel lenses, HEMA (2-hydroxy ethyl methacrylate) and EGDMA (ethylene glycol dimethacrylate) were used as a basic combination, AIBN (azobisisobutyronitrile) was used as an initiator, and HA (hyaluronic acid) was used as a basic additive. The nanomaterials that were used were GO nanocolloids, SWCNT, amide-functionalized (CA), and SWCNT, carboxylic-acid-functionalized (CC). The reagents that were used in the experiment were all products of Sigma-Aldrich. For the GO nanocolloids, only GO in powder state after evaporating water at 80°C for 30 hours was used. Each nanomaterial was added to the mixed solution containing HA and monomer at 0.1, 0.3, and 0.5%, respectively, and was used after being dispersed in an ultrasonic disperser for about 2 hours. The contact lenses were fabricated through the mold casting method at 100°C for 1 hour, and the prepared samples were separated from the mold and hydrated in a 99% normal saline solution for 24 hours to measure their physical properties. The graphene samples were named HGO-1, HGO-2, and HGO-3, respectively; the CA samples, HCA-1, HCA-2, and HCA-3; and the CC samples, HCC-1, HCC-2, and HCC-3. The mixing ratios of the samples are shown in Table 1.

2.2. Evaluation of the Physical Properties

2.2.1. Evaluation of Refractive Index and Water Content

The refractive index was measured using an ABBE refractometer (NAR-1T, Atago, Japan), and the water content was obtained by calculating the ratio of the weight of the wet sample to the weight of the completely dried sample. The refractive index and the water content were each measured five times, and the average values were calculated.

Table 1. Compositions of the samples (unit: wt%)

	HEMA	EGDMA	AIBN	HA	GO	CA	CC	Total
Ref	99.40	0.50	0.10	-	-	-	-	100.00
HA-1	94.70	0.47	0.09	4.73	-	-	-	100.00
HGO-1	94.61	0.47	0.09	4.73	0.09	-	-	100.00
HGO-2	94.43	0.47	0.09	4.72	0.28	-	-	100.00
HGO-3	94.25	0.47	0.09	4.71	0.47	-	-	100.00
HCA-1	94.61	0.47	0.09	4.73	-	0.09	-	100.00
HCA-2	94.43	0.47	0.09	4.72	-	0.28	-	100.00
HCA-3	94.25	0.47	0.09	4.71	-	0.47	-	100.00
HCC-1	94.61	0.47	0.09	4.73	-	-	0.09	100.00
HCC-2	94.43	0.47	0.09	4.72	-	-	0.28	100.00
HCC-3	94.25	0.47	0.09	4.71	-	-	0.47	100.00

2.2.2. Measurement of Breaking Strength

The breaking strength was measured at a speed of 10 mm/min and a maximum load of 20 N, using AGX-20N (SHIMADZU, Japan). The breaking strength was converted to the kgf unit.

2.2.3. Measurement of Protein Absorption

Albumin (Sigma-Aldrich) was used to evaluate the protein absorption. Albumin 10% was added to the distilled water for adsorption onto the lens at 120 rpm and 40°C for 7 days. A protein was separated from the protein-adsorbed contact lens using a sodium dodecyl sulfate (SDS) solution, which is a surfactant, and the absorbance of the separated SDS solution was measured using Cary 60 UV-VIS.

2.2.4. Analysis of SEM Image

The SEM (scanning electron microscopy) images were measured for the surface analysis of the lenses fabricated using the GO, CA, and CC samples. SEM image analysis was done to determine the correlation with various physical properties.

3. Results

3.1. Hydrogel Lens Fabrication

The carbon-based materials that were used in this experiment (GO nanocolloids single-walled CNT, amide-functionalized (CA) and single-walled CNT, carboxilic-acid-functionalized (CC)) are basically black-colored. Therefore, all the fabricated lenses were black, as shown in Fig. 2.

3.2. Measurement Results of Water Content and Refractive Index

The refractive indices and water contents of the lenses are shown in Table 2 and Fig. 3, 4, and 5. For the GO samples, the refractive index decreased from 1.4377 to 1.4268, and the water content tended to increase from 37.0 to 41.14%. For the samples to which carboxilic-acid-functionalized and single-walled CNT was added (the CC samples), the refractive index decreased from 1.4377 to 1.4259, and the water content tended to increase from 37.0 to 44.01%. In these two sample groups, the water content tended to increase as the refractive index decreased. On the other hand, for the samples to which amide-functionalized and single-walled CNT was added (the CA samples), the refractive index increased from 1.4377 to 1.4440, and the water

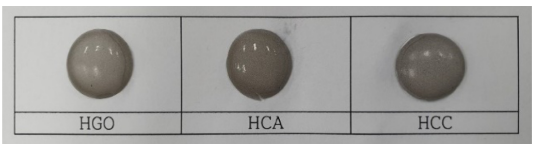


Fig. 2. Image of the manufactured hydrogel lens samples.

Table 2. Refractive indices and water contents of samples

	Refractive index	Water content(%)
Ref	1.4377	37.00
HA-1	1.4365	38.25
HGO-1	1.4369	39.41
HGO-2	1.4318	39.47
HGO-3	1.4268	41.14
HCA-1	1.4365	39.55
HCA-2	1.4403	40.37
HCA-3	1.4440	41.73
HCC-1	1.4369	39.20
HCC-2	1.4318	40.55
HCC-3	1.4268	44.01

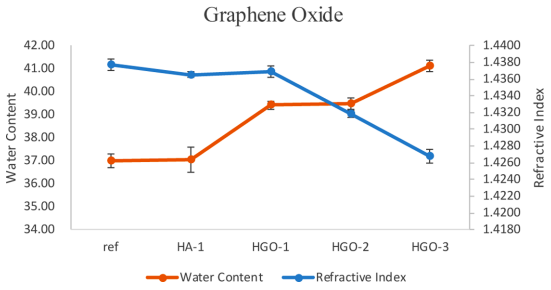


Fig. 3. Water content and refractive index of the GO samples.

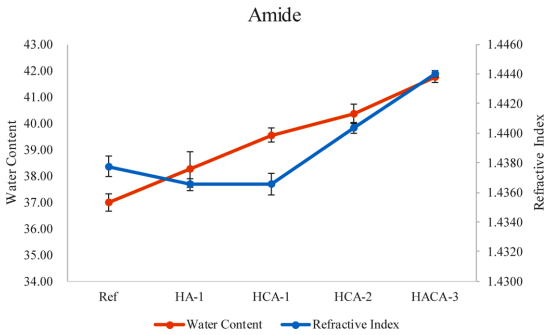


Fig. 4. Water content and refractive index of the CA samples.

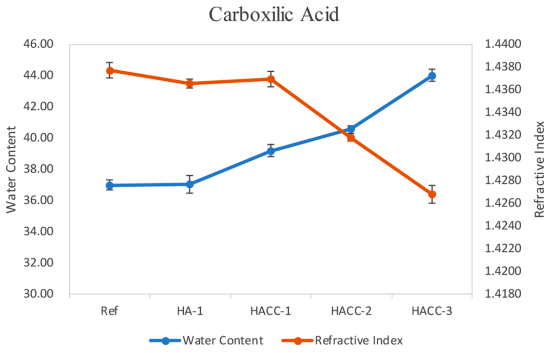


Fig. 5. Water content and refractive index of the CC samples.

content also increased from 37.0 to 41.73%.

3.3. Measurement of Breaking Strength

As a result of expressing the breaking strength of each sample in kgf, all the three sample groups showed increasing trends: the GO samples, from 0.081303 to 0.154514 kgf; the CA samples, from 0.081303 to 0.203558 kgf; and the CC samples, from 0.081303 to 0.198787 kgf. In particular, the CA samples showed the highest breaking strength among all the samples, and the GO samples showed the lowest breaking strength. In general, as the water content increased, the strength tended to decrease, but due to the inherent properties of the carbon-based material with high strength, the breaking strength increased without being affected by the water content as the amount added increased. The breaking strengths of the samples are shown in Table 3. and Fig. 6.

Table 3. Breaking strength of samples (unit: kgf)

	Breaking strength(kgf)
Ref	0.079515
HA-1	0.081303
HGO-1	0.102462
HGO-2	0.120707
HGO-3	0.154514
HCA-1	0.203558
HCA-2	0.188703
HCA-3	0.183480
HCC-1	0.103960
HCC-2	0.145557
HCC-3	0.198787

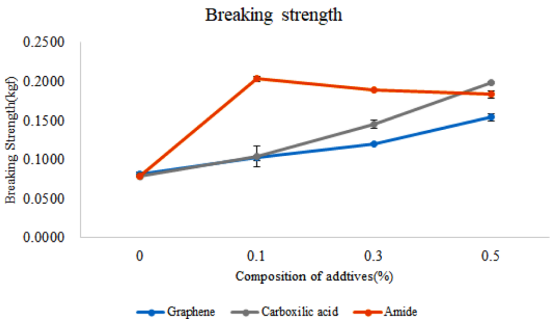


Fig. 6. Breaking strengths of samples.

3.4. Protein Absorption Results

The protein absorption results of the fabricated lenses are shown in Table 4 and Fig. 7. For the measurement results of the absorbance of the SDS solution, in which the protein was separated for each sample, the protein absorption was 2.646971-3.07278 for the GO samples, 2.958191-3.296632 for the CC samples, and 3.314235-435403 for the CA samples. The results showed that the

Table 4. Protein absorption of samples

	Protein absorption
Ref	2.78883
HA-1	3.51554
HGO-1	2.64697
HGO-2	3.02130
HGO-3	3.07278
HCA-1	2.95819
HCA-2	3.05827
HCA-3	3.29663
HCC-1	3.31424
HCC-2	3.42590
HCC-3	3.43540

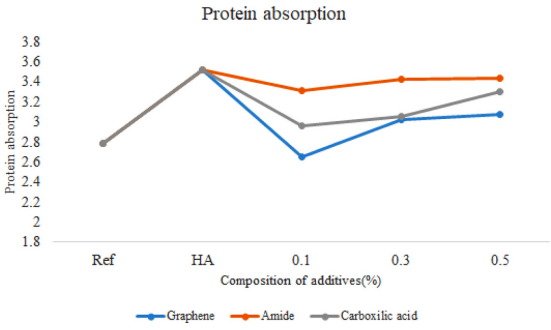
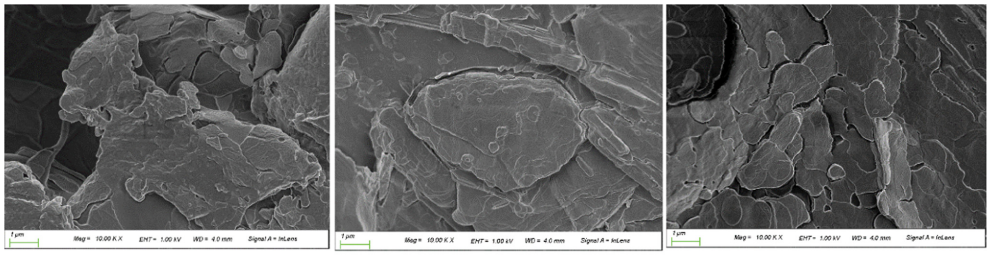


Fig. 7. Protein absorption of samples.



(A) (B) (C)

Fig. 8. SEM images of samples (A: GO; B: CA; C: CC).

protein absorption increases as the added amount increases.

3.5. Analysis of Surface Condition by SEM Image

For the observation results of the SEM images for lens surface analysis, the shape of the materials considered nanomaterials appeared on the surface, as shown in Fig. 8. It is believed that the change in shape affects the moisture content, refractive index, and breaking strength.

4. Conclusion

The carbon-based nanomaterials that were used in the experiment in this study were all hydrophilic when used as contact lens materials. In all the combination samples, the water content tended to increase, and the refractive index decreased except for the carbon nanotubes (CNTs) containing the amide group. In the case of protein deposition, the amount of albumin deposited appeared to have increased in all the combinations with carbon nanomaterials added. The breaking strength also increased in all the combinations. In the cases of the GO and CC samples, the breaking strength tended to increase in all the combinations, but in the case of the CA samples, the breaking strength tended to increase greatly when CA was first added, and then gradually decreased when the addition amount exceeded a certain level. The overall measurement results of breaking strength showed that the strength of the lens fabricated by adding carbon-based nanomaterials was significantly higher than that of the basic HEMA and HA-1 combinations without nanomaterials added. Therefore, carbon-based nanomaterials are considered suitable as a material capable of increasing the strength of the hydrogel lens when used as an additive. Long-term studies are needed, however, to improve the transmittance and transparency of black-colored lenses due to the nature of the existing carbon nanomaterials.

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