Borosilicate and Polyurethane as Materials for Lenses to Correct Human Presbyopia

Ali H. Alhamdani*, Hayder H. Al-aaraji, Maha. R. Abdul-Hussein and Rajaa A. Madlool
*Department of Laser and Optoelectronics Engineering/University of Technology, Iraq, Baghdad.
Department of Physics/College of Science/University of Kerbala Iraq, kerbala

*Correspondence: ali_alhamdani2003@yahoo.com

Abstract. Start your abstract here The novel of this paper is, using gradient refractive index and spherical surfaces to design a bifocal polyurethane lens with single power instead of the previous designs, which consist of two lens with different powers to correct the vision of near and medium distances at the same time. Presbyopia occurs naturally as eyes age and the structure of the lens responsible for focusing images changes. Presbyopia treatments include corrective lenses like eyeglasses known as progressive lenses. The aims of this work were to evaluate the performance of the human eye after the treatment by using different gradient refractive glass materials. Zemax was used to design an optical system for human eye based on Liu & Brennan model. Two types of optical materials, namely, borosilicate and polyurethane, were selected to design a multifocal lens. The effects of these materials on the performance of the human eye were compared to select the best material. Three different criteria were used; minimum root mean square error, the modulation transfer function and the diffraction image analysis. Modulation transfer function and root mean square Results show that the polyurethane lens is more suitable than the borosilicate lens for correcting presbyopia. Polyurethane material lens gave a better eye performance in three distances, namely, farther, intermediate, and near than the borosilicate lens. Polyurethane lens could be used as trifocal while borosilicate work only as Bifocal lens. The Results suggested that by using only one polyurethane lens power with gradient refractive index and a variable conic for lens curvature in Zemax corrected the vision of distance, near and medium distances at one time.

1. Introduction
Refractive errors are vision problems that occur when the shape of the eye prevents light from focusing, particularly on the retina. For example, the eyeball is either too long or too short), or the shape of the cornea is wrong. The aging of the lens can also cause refractive errors. The most widely recognized refractive errors can be remedied with eyeglasses, contact lenses, or refractive surgery [1]. Presbyopia, which is the aging of the eye and the loss of near vision as a person ages, is another type of hyperopia. This condition leads to the gradual deterioration of the capability of the eye to focus clearly on nearby objects; it is part of the natural aging process of the eye [2]. The hardening of the eye lens causes the eye to focus light behind rather than on the retina when looking at nearby objects;
the lens cannot change its shape sufficiently to enable the eye to focus on nearby objects because the accommodation strength of the eye decreases with aging [3].

Glasses are the simplest, safest, least expensive, and most common way to correct vision problems caused by refractive errors [4]. Most cases of presbyopia can be corrected by using simple reading glasses with convex lenses. Individuals suffering from myopia and hyperopia regularly need multifocal lenses [5]. Such lenses have more than one focal point and can be found in lined bifocals, lined trifocals, and progressive lenses. These lenses have either two (bifocals) or three (trifocals) focal points. They are designed for distance vision and reading (bifocals) or for distance vision, intermediate vision, and reading (trifocals).

In the past, eyeglasses were made exclusively of glass. At present, most eyeglasses are made of plastic. Plastic offers the best combination of strength, scratch resistance, and cost. Glass lenses are breakable and are approximately twice as heavy as plastic lenses. Although glass lenses are the most scratch resistant and the heaviest lens type, they are the least impact resistant [6]. The selection of material that will be used for the correction of refractive defects is important in visual design because the material plays a role in the visual aspects, such as efficiency and capacity, and in other areas, such as weight and density. In this regard, manufacturers of lenses have to consider the appropriate properties of plastic and glass materials in the design of lenses. In this study, two types of materials, namely, borosilicate and polyurethane plastic, were selected to model the correction of presbyopia.

2. Material properties

Borosilicate is a typical optical glass material and is commonly used to produce high-quality optical components. This type of material is characterized by the presence of substantial amounts of silica and boric oxide (>8%) [7]. Borosilicate exhibits excellent chemical durability, high permeability in the visible light spectrum, and low thermal expansion. It is also relatively easy to procure. Borosilicate glass is less subject to thermal stress as illustrated in Table 1 [8].

Table 1. Physical properties of Borosilicate [8]

| The Properties                      | The Symbol | The value       |
|-------------------------------------|------------|----------------|
| Refractive index                    | $n_d$      | 1.5168         |
| Abbe Number                         | $V_d$      | 65             |
| Density                             | $\rho$     | 2.51 g/cm$^3$  |
| Young Factor                        | $E$        | 82.10 G N/mm$^2$ |
| Thermal expansion coefficient       | $T_e$      | $8.3 \times 10^{-6}$ k$^{-1}$ |
| Glass transition temperature        | $T_{glass}$| 557 °C         |

Polyurethane is a versatile plastic material that exists in various forms. It is unique because it provides the flexibility of rubber and the durability of metal. Polyurethane exhibits excellent resistance to oils, solvents, fats, grease, and benzene; high corrosion resistance; and low temperature resistance [9]. It is lightweight, flexible, nonconductive, and has low fabrication cost (i.e., low tooling cost). Polyurethane was first produced by Dr. Otto Bayer in 1937 as illustrated in Table 2 [10].
### Table 2. Physical properties of polyurethane [10]

| The Properties | The Symbol | The value |
|----------------|------------|-----------|
| Refractive index | $n_d$ | 1.6585 |
| Abbe Number | $V_d$ | 36 |
| Density | $\rho$ | 1.4 g/cm$^3$ |

### 3. Optical System Design

To build the human eye model, Zemax optical design software is first placed in sequential mode, which is preferred when designing imaging systems or any system that requires optimization and detailed image analysis. Wavelengths are set within the range of visible light, and the dimensions are in millimeter. The design of the human eye model in Zemax requires eight surfaces, which starts from the surface of the object (Surface 0) and ends on the surface of the retina (image surface) in the following section:

Surface 0: The surface of the object, which is labeled “OBJ” in Zemax Lens Data Editor.
Surface 1: The first surface is a dummy plane, which represents the input beam.
Surface 2: The surface of the outer cornea.
Surface 3: This surface represents the area between the cornea and the glass liquid.
Surface 4: This surface is labeled “STO” in Zemax Lens Data Editor; it is the pupil plane of the eye model.
Surface 5: The front part of the crystalline lens of the model; a surface type (gradient 3) provided by the Zemax program is used.
Surface 6: The back part of the crystalline lens of the model.
Surface 7: The interface between the lens and the vitreous body of the eye.
Surface 8: The retina of the model, which is labeled “IMA” in Zemax Lens Data Editor.

The aforementioned model is the Liou and Brennan (1997) eye model, in which the Lens Data Editor should appear similar to Figure 1. The 3D layout of the system, in which Surface 1 was set as the input beam surface instead of Surface 0, is shown in Figure 2.
Figure 1. Optical data of Liou & Brennan eye model in Zemax optical design software.

Figure 2. 3D layout of Liou & Brennan human eye

After designing the eye model in Zemax, the model will be used to design an eyeglass lens for presbyopia patients by using the multi-configuration function in the Zemax optical design program.
The eyeglass lens is designed by placing the lens on the front of the eye model and then optimizing the lens to provide perfect vision for close (mm), midrange (mm), and far (mm) objects. To achieve this, three surfaces were inserted between the input beam and the cornea. These surfaces will represent the front and rear surfaces of the eyeglass lens, and a coordinate break to tilt the eye below the three new surfaces.

Surface 2: The front surface of the eyeglass lens. On this surface, the type of material polyurethane or borosilicate used in the design of the lens will be determined by inserting the refractive coefficient and the Abbe number of each material into the glass cell located in the lens data editor window (see figures 3-6).

Surface 3: The rear surface of the eyeglass lens.

Surface 4: The coordinate break placed at the centre of the eyeball.

![Figure 3. Optical data of the modified eye model with borosilicate lens in Zemax optical design.](image-url)
Figure 4. Optical data of the modified eye model with polyurethane lens in Zemax optical design software.

Figure 5. Shows the 3D side-view layout of the system from three configurations (near, intermediate, and far distances) with borosilicate Lens.
Figure 6. 3D side-view layout of the system from three configurations (near, intermediate, and far distances) with polyurethane Lens.

4. Result and Analysis

Figure 7 shows the Liou model root mean square spot diagrams at the far distance (1.00E-9 mm), intermediate (1000 mm), and near (500 mm) in the visual ranges (400-650 nm). Table 3, column 2 shows that as for far object, the root mean square is 8.202 µm and it increased for med and near distance (16.377 and 28.787 µm) respectively. Figures 8, 9 indicate the modified model by inserting borosilicate and polyurethane in Liou respectively. Figures 8, 9 and Table 3, Column 3 and show that the insertion of polyurethane or borosilicate lens in the modified model reduce the root mean square for the far, intermediate, and near distances. The reduction in root mean square means a reduction in wave front aberrations. The results indicate that the use of polyurethane improve the optical system more than borosilicate usage.

The modified transfer function is an important method for describing the contrast in an image within a certain spatial frequency presented in the scene being viewed. Modified transfer function plots for the three configurations are provided in Figures 10 and 11. The Sagittal modified transfer function before and after inserting borosilicate and polyurethane lens for the three distances are shown in figure 10. Sagittal modified transfer function after inserting the polyurethane lens is higher than that without lens at far and near distances. Furthermore, the borosilicate lens defocus error appears at near distance. Figure 11 shows the Tangential modified transfer function at far, intermediate, and near distances using the modified transfer function technique before and after the insertion of the polyurethane and borosilicate lenses. The modified transfer function value at far distance before inserting the lenses is less than the modified transfer function value after inserting the polyurethane lens, whereas at an intermediate distance, the modified transfer function value with the borosilicate lens is higher than the modified transfer function value with and without the polyurethane lens, thereby indicating that the polyurethane lens achieves higher contrast at far and near distances and can be used as bifocal lens.
Figure 7. Root mean square for Liou& Brennan model at far distance (a), intermediate (b) and near distance (c).
Figure 8. Root mean square for modified model with borosilicate lens at far distance (a), intermediate (b) and near distance (c).
Figure 9. Root mean square for modified model with polyurethane lens at far distance (a), intermediate (b) and near distance (c).
Figure 10. Sagittal modified transfer function for Liou& Brennan model, modified model with borosilicate lens and modified model with polyurethane lens at far distance (b) and near distance (c).
Figure 11. Sagittal modified transfer function for Liou & Brennan model, modified model with borosilicate lens and modified model with polyurethane lens at far distance (b) and near distance (c).

The image analyses of the three configurations with and without borosilicate lens are shown in Figures (12-15). A quick assessment of image quality is provided, such that the eye vision of objects is simulated and an idea of the shape and content of an image is obtained in terms of clarity, colors, and contrast without providing digital data on the characteristics of an image. The image of the letter “F” at far and intermediate distances are clearer after placing the lens than before placing the lens. the
image at far distance is clearer than the images at other distances, and the image with the polyurethane lens is better than the image with the borosilicate lens.

**Figure 12.** Tangential modified transfer function for Liou, model, modified model with borosilicate lens and modified model with polyurethane lens at far distance (a) intermediate distance (b) and near distance (c).
Figure 13. The diffraction image for Liou & Brennan model at far distance (a), intermediate (b) and near distance (c).
References

[1] Fedtke C, Ehrmann K, Holden BA. A Review of Peripheral Refraction Techniques. Optometry and vision science : official publication of the American Academy of Optometry 2009;86:429-46.

[2] Curtin BJ. Physiologic Vs Pathologic Myopia: Genetics Vs Environment. Ophthalmology 1979;86:681-91.

[3] Charman WN, Radhakrishnan H. Peripheral Refraction and the Development of Refractive Error: A Review. Ophthalmic & physiological optics : the journal of the British College of Ophthalmic Opticians (Optometrists) 2010;30:321-38.

[4] Verkicharla PK, Mathur A, Mallen EA, et al. Eye Shape and Retinal Shape, and Their Relation to Peripheral Refraction. Ophthalmic & physiological optics : the journal of the British College of Ophthalmic Opticians (Optometrists) 2012;32:184-99.

[5] Elliott DB. Clinical Procedures in Primary Eye Care, 4th ed. Philadelphia: Saunders/Elsevier Health Sciences; 2013.

[6] Curtin BJ. Physiologic Vs Pathologic Myopia: Genetics Vs Environment. Ophthalmology 1979;86:681-91.

[7] Miller AD, Kris MJ, Griffiths AC. Effect of Small Focal Errors on Vision. Optometry and vision science : official publication of the American Academy of Optometry 1997;74:521-6.

[8] Liu WD, Zhang LC, Mylvaganam K. Relaxation Oscillation of Borosilicate Glasses in Supercooled Liquid Region. Scientific reports 2017;7:15872.

[9] Bahl S, Peuget S, Pidchenko I, Pruessmann T. Pu Coexists in Three Oxidation States in a Borosilicate Glass: Implications for Pu Solubility. 2017;56:13982-90.

[10] Abed AS, Ziadankm ,Qbdulah AQ. Some properties of polyurethane. J. of polymers 2014; 17:18-28.