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# A Review of Polymers and Plastic High Index Optical Materials

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***Author's contribution***

*The sole author designed, analysed, interpreted and prepared the manuscript.*

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## ABSTRACT

The industry of plastics has grown rapidly since its inception in the 1940s, the use of plastics as an optical material only really started to pick up in the 1970s and has had a much slower underlying growth than for the commodity industry e.g. packaging, closures, etc. After that, in this industry the advantage of material consistency and uniformity, full three dimensional machining capability and mass production are exploited to the full.

However, plastics in general are weaker and more costly than traditional materials and people still retain a 'bad image' of them because of their previous misuse. In the past, and to a certain extent today, plastic engineering components have been designed to directly replace components in traditional engineering materials, leading to poor performance and costly reproduction. For effective material substitution, the designer using plastics has to appreciate their benefits as well as their limitations. Today, designs are being produced that are not only unique to plastics but are also out-performing designs in traditional materials.

In a comparable way, prejudices prevent consumers trusting plastic lenses. Although they realize benefits such as thinner and lighter design, they worry about clarity and transparency, and the most common question is if plastic lenses harm their eyes or obstruct their vision.

Furthermore, in recent years the industry has confused consumers rather than informing them. Optical properties, like refractive index and Abbe value are not clearly defined by manufacturers

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(i.e. a given “n” is nd or ne?). Many people ask themselves why high index plastic lenses must be always multicoated? Another similar question is why high index plastic lenses mainly are designed as aspheric? Is chromatic dispersion more or less affected by the refractive index? What is the relation between Abbe value and chromatic performance of these materials?
Consequently, this review has to investigate mainly the above questions in order to search and estimate the performance of new plastic high index materials and to compare with traditional lens materials.

*Keywords: Plastics; high index; optical materials; spectacle lenses; safety.*

## 1. INTRODUCTION

Since plastics are lightweight, fragmentation-resistant and easy to be dyed in comparison with glasses, they have been developed rapidly in recent years for the application as optical elements such as lenses of spectacles and cameras [1]. However, since the refractive index of the normally used resins was less than 1.53, so there was a need to develop new type of optical resins, which possess high refractive index and low dispersion (with less chromatic aberration). The best way to raise the refractive index of the optical resins is to introduce sulphur element into polymer structure, as the sulphur-containing resins have properties of high refractive index, low dispersion, lightweightness and good heat stability [2,3].

Epoxy resins possess the advantage of chemical resistance, small shrinkage, good heat resistance and excellent mechanical properties. So, in recent years, they have been used as optical materials for such applications as optical disk matrix, lenses and prisms [4,5]. However, as the refractive index of the conventional epoxy resins is lower, the applications of these resins as optical materials such as lenses where high refractive index is required are limited. So it is necessary to synthesize new optical epoxy resins, which possess high refractive index, good mechanical and good heat properties [6].

### 1.1 Research Background - Patent Review

Diethylene glycol bisallyl carbonate resin, polymethylmethacrylate and polycarbonate have been generally known as resins to be used for the optical material such as plastic lenses. However, since the diethylene glycol bisallyl carbonate resin and the polymethylmethacrylate have low refractive indices of 1.49 to 1.50, when these resins are moulded into plastic lenses, they bring about a drawback that the centre thickness, edge thickness and curvature of the lens become greater as compared with those of inorganic optical glass lenses. Further, although the polycarbonate resin has a high refractive index of 1.58 to 1.59, it is liable to cause birefringence in moulding and thus is defective in optical homogeneity. Moreover, because polymethylmethacrylate and polycarbonate are thermoplastic resins of non-cross linked structure, the resins are fused during cutting or grinding and they cannot be considered satisfactory as materials for use in precision optical machinery, optical elements or ophthalmic lenses [7]. To remedy the above drawbacks of the thermoplastic resins, a method has been so far known which produces resins having a cross linked structure using ethylene glycol dimethacrylate as a cross linking agent, but the resin of such a cross-linked structure has low impact resistance [8,9].

Various characteristics are required for transparent synthetic resins as optical materials in addition to the above, and the refractive index is extremely important among them [10]. For example, transparent synthetic resins having a high refractive index, when used as lenses, can be rendered thinner than materials having low refractive indexes to give the same focal distance. Accordingly, it can reduce the volume of space occupied by lenses in optical assemblies thereby reducing the weight and minimizing the size of optical apparatuses. Furthermore, since transparent synthetic resins have excellent impact resistance as compared with inorganic optical materials such as glass, they can be considered also excellent in durability [11].

Further, there is also a method of manufacturing a resin of a cross-linked structure by using trimethylol propane tri(meth)acrylate, but the resin material cannot be put to practical use as the optical material since it has a poor transparency being prepared by curing with dispersed metal oxide hydrates [12].

In order to overcome the foregoing drawbacks, optical materials and optical moulding products using a resin of high refractive index have been developed, for example, for ophthalmic plastic lenses. For producing an optical moulding product such as plastic lenses by using a resin of high refractive index, a process has been adopted of using a cast polymerisation process [13] This involves casting, into a moulding die, a polymerizable ingredient having halogen atoms such as chlorine or bromine; a nitrogen atom-containing ingredient such as urethane; a sulphur atom-containing ingredient such as thiol; or an aromatic ring or the like in the molecule, for example, vinyl monomer, prepolymer or (poly) condensation type monomer [13,14].

Various materials for optical lenses, like resins of high transparency such as acrylic resin, diethylene glycol bis-allylcarbonate resin (e.g. CR-39), polystyrene and polycarbonate have been used [15,16]. Of these resins diethylene glycol bis-allylcarbonate, which is a thermosetting resin, is most extensively used as a material for spectacle lenses, due to the high transparency, low dispersabillity (quite high Abbe number) and very good heat and impact resistance. Even though, a lens made of this resin has the disadvantage in that the refractive index is as low as 1.50 and its thickness is unavoidably greater than ordinary glass (refractive index 1.523). Further, this type of lens is inferior in abrasion resistance, although a method of coating the surface with an organosilane hard coat film is often used [17].

Optical lenses have been produced from the polymer of diethylene glycol bis(allyl)-carbonate (DEG-BAC) by thermal curing techniques. These techniques for polymerizing DEG-BAC to produce an optical lens, however, have several disadvantages and drawbacks [18,19]. One of the most significant drawbacks is that it takes approximately 12 hours to produce a lens according to this technique and therefore a lens-forming mould can produce at most two lenses per day [7,20].

Moreover, the thermal curing process employs a thermal catalyst so that the polymerizable mixture of DEG-BAC and catalyst will slowly polymerise even while refrigerated. The polymerizable mixture therefore has a very short shelf life and must be used within a short time or it will harden in its container [18,21]. Furthermore, the thermal catalysts utilized in these procedures are quite volatile and dangerous to work with requiring extreme care in handling.

Despite the above-mentioned drawbacks, DEG-BAC polymer exhibits desirable optical and mechanical properties. These properties include high light transmission, high clarity, and a high index of refraction, together with high abrasion and impact resistance. These properties in the past made DEG-BAC one of the leading monomers in the manufacture of high quality lenses, face shields, sun and safety glasses [22].

Neef (1978) described the formation of a plastic lens by disposing a lens forming material comprising a liquid monomer and a photosensitive initiator into a mould cavity defined in part between a pair of spaced apart moulds each having a lens forming surface facing the cavity and an outer opposed surface, and then directing rays of ultraviolet light against the outer surface of at least one of the moulds to act on the lens forming material in the cavity to produce a lens [23,24].

Further, due to increasing demand to reduce the weight of spectacle lenses, materials of low specific gravity were actively being studied. For example, the Japanese Patent JP-A-2-238006 proposed acrylic resins of high specific gravity (1.31 to 1.35).On the other hand, JP-A-5-215903 proposed a copolymer compound with a low specific gravity [15], but readily deformable in process of dyeing and hard coating, because of being low in heat resistance [25,26].

In 1983, Tarumi et al. working for Hoya Lens Corp., invented a polyfunctional allyl monomer with excellent physical properties [27,28], hardness about H (in pencil test), transmittance about 89%, refractive index 1.568 and reasonable Abbe number of about 34. Makino et al. [29] introduced an organic glass having a high refractive index and excellent physical properties. This material has as polymerisation initiator, di-isopropyl peroxydicarbonate, giving a refractive index of at least 1.55, according to the patent claim. Sakagami et al. [30] suggested an acrylic copolymer with refractive index 1.58 and 28 Abbe value [29,30].

Subsequently, Fujio et al. [31] presented a novel organic copolymer, a glycol allylcarbonate, that achieves a high refractive index. Furthermore, Suzuki et al. [32] described polystyrenes (refractive Index 1.58, Abbe number 31) and polycarbonates (refractive Index 1.58, Abbe number 30) as thermoplastic resins having high refractive index, but these resins have a large chromatic aberration due to low Abbe number, undesirable low heat resistance and polycarbonate has also very low surface hardness [31,32].

As an alternative polycarbonate-based and polysulfone-based plastics have been proposed. These plastic materials have a high refractive index of about 1.60 but they have problems in a low light transmittance, deficient optical uniformity and colouring. Unlike CR-39 and other plastic lens materials, polycarbonate (LEXAN® resin) is injection moulded. Heated polycarbonate resin is forced into the lens mould under high pressure. The lens solidifies almost immediately and all stresses introduced during moulding, become locked permanently into the lens [7,33].

A range of organic plastic materials have been proposed which are formed of cross-linked polymers, improved the above properties. For example, in 1992 two Japanese patents JP-A-4-202208 and JP-A-4-202209 [34] disclosed a polymerizable composition having improved light transmittance, very good optical uniformity and adequate colouring ability. In order to overcome the above disadvantages, metha-crylate/styrene resins were suggested in patent JP-A-62-246001 [35]. But these are high in the haze rate, low in transparency and heat resistance, and since these resins are thermoplastic resins, there is also a problem in edging ability [36,37].

In 2001, Evans et al., described a variety of ophthalmic lenses [38]. Such lenses may comprise a number of different types of materials ranging from inorganic to thermoset plastics, such as allyl-diglycol carbonate sold under the (CR-39®), (trademark of PPG Industries, Inc.), to more recent formulations using thermoplastic materials, such as polycarbonate ("PC").

## 2. PLASTIC MATERIALS USED FOR LENSES

Ophthalmic lenses of plastic material have become very popular because they are commonly inexpensive, lighter in weight and more resistant to shattering than glass. However, plastic lenses generally have less surface hardness and wear resistance [7]. Therefore, they are usually coated with abrasion resistant coatings [39]. Generally, plastic lenses have been made from a variety of conventional plastic materials, such as polycarbonate, polyethylmethacrylate, and polyallyl diglycol carbonate. For many decades, the principal optical plastic used for making eyeglasses has been CR-39®, a polycarbonate product of PPG industry [40].

CR-39® combines the optical properties of glass with the excellent mechanical, thermal, and chemical resistance properties of a thermoset material. It has a refractive Index of 1.498 and an Abbe value of 57.8. It has met to an adequate degree all of the significant requirements as to optical properties, strength, index of refraction, cure time, and compatibility with coating and tinting materials. Although improved over the years, its cost is relatively high, its processing properties require relatively long cure times and the index of refraction is only in a medium range [41].

Acrylic and polyesters have been given consideration over the years, because they are inherently lower cost materials than the polycarbonate. But their properties, although suitable for spectacle lenses, still do not meet current standards. Lately, some commercial efforts have been reported pertaining to polyester casting materials for spectacle lenses, but these have had little success in the market. Instead, polyester based optical compounds have been offered on a commercial basis [42].

## 3. HIGH INDEX MATERIALS

High index lens materials are lighter in weight and thinner than their regular glass or plastic counterparts [7,43]. This is of particular benefit in high prescriptions. High index lenses are made of materials that are denser, so the same amount of visual correction is taking place using less lens material than traditional plastic or glass requires. "*High index*" means that the lenses are constructed of a plastic or glass material that has a higher index of refraction.

### 3.1 High and Medium Index Plastics Offer Very Light Lenses

For a given prescription, the weight of a lens is primarily determined by its size, thickness, and the weight of the material used. Frame selection determines the size of the lens while the refractive index of the material and the thinness of the surfacing determine the thickness of the lens. Its density gives the weight of the material. Since spectacle frames play a significant role, lens weight comparisons should only be made on edged lenses and density comparisons cannot provide an accurate representation of lens weights [44].

Though high and medium index materials produce light lenses, the choice of the frame also plays an important role in determining the actual weight experienced by a wearer. Frame weights may vary from 10 grams for a rimless frame to 25 grams for a thick metal frame. Therefore, gain in frame weight could be as important as gain in lens weight. Frame selection is also a key to lighter spectacles for the patient [7]. Considering an average frame weighing 15 grams, high and medium-index lenses offer about 10 to 15 percent reduction in total spectacle weight.

### 3.2 High Index Material Provides Thin Lenses

The refractive index of a lens material - its ability to bend light - plays a critical role in the creation of the power and thickness of a lens. For any lens design, the higher the index, the flatter the front and back curvature of the lens surfaces needed for a given optical power (Fig. 3). As a result of these flatter curves, the thickness of the

**Table 1. Significant commercial plastic eyeglass lenses and the refractive index and Abbe value of the used plastic materials (*after PPG Ind.*)**

| Commercial material | Refraction index | Abbe value | Further process |
|---|---|---|---|
| PPG CR-39® monomer | 1.498 | 57.8 | .............. |
| HIRI® resin | 1.56 | ? | .............. |
| PPG CR-307™ Transitions® | 1.586 | 30 | hardcoat |
| Optima Hyper Index 166 | 1.66 | 32 | aspheric, hardcoat |
| Pentax Ultra Thin | 1.66 | 32 | hardcoat, AR coat |
| Seiko Super 16 | 1.6 | 33 | hardcoat |
| Pentax 1.6 | 1.6 | 36 | hardcoat |
| Zeiss Claret 1.6 | 1.6 | 36 | hardcoat |
| Signet/Armorlite | 1.56 | 36 | hardcoat |
| Optima 160 | 1.6 | 37 | aspheric, hardcoat |
| Essilor Thin&Lite | 1.6 | 37 | aspheric, hardcoat |
| Rodenstock Cosmolite 1.6 | 1.6 | 37 | hardcoat |
| Sola Spectralite | 1.537 | 47 | hardcoat |
| Rodenstock Cosmolite | 1.5 | 47 | hardcoat |
| Essilor Thin | 1.498 | 58 | hardcoat |

**Table 2. Comparison chart of Refractive Index, Specific gravity and Abbe number for different Materials (After Blackstock and Associates Optometrists)**

| Lens type | Refractive index | Specific gravity | Abbe number |
|---|---|---|---|
| Air | 1.0003 | - | - |
| Water | 1.333 | 1.00 | - |
| Crown Glass | 1.52 | 2.54 | 58 |
| CR-39® | 1.498 | 1.32 | 58 |
| Polycarbonate | 1.59 | 1.20 | 31 |
| High Index | 1.54 -1.66 | 1.21 -1.35 | 47-32 |
| Diamond | 2.417 | 3.52 | - |

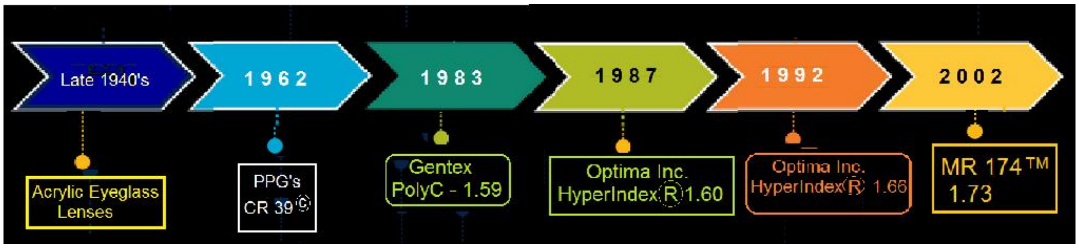

Fig. 1. Timeline of the major plastic materials for lenses

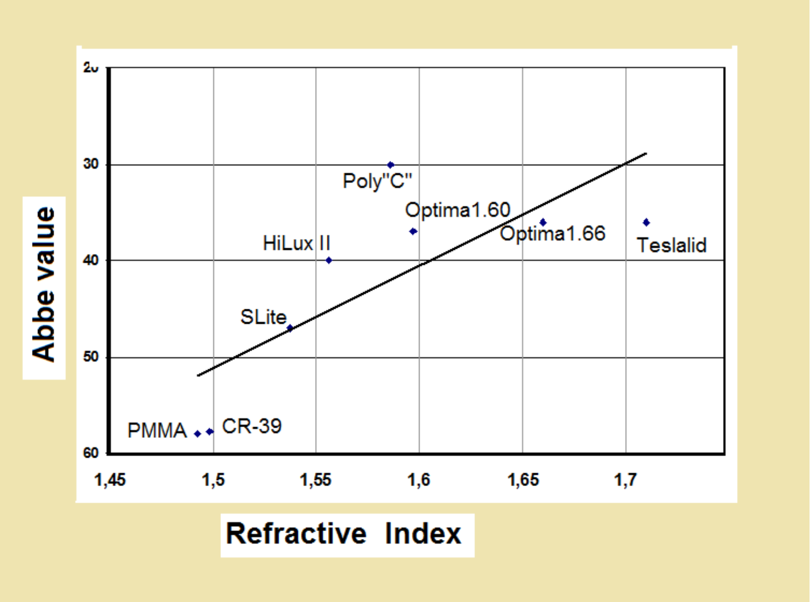

**Fig. 2. Relationship between index of refraction and Abbe numbers for commonly used optical materials [7]**

lens is automatically reduced. Furthermore, the nature of high-index plastic makes it possible to grind minus-power lenses to a thinner centre thickness than CR-39 while keeping the lens' impact-resistant properties [43,44].

High-index plastic materials may be surfaced to a 1.5 mm centre thickness in the minus range and still satisfy impact-resistance standards, while CR-39 is generally surfaced to 2.0 mm in the minus range to respect these standards.

### 3.3 Chromatism and High Index Material

In general, the higher the refractive index of a material, the greater its tendency to disperse light and create rainbow contours of objects seen through a lens periphery. This chromatic dispersion exists in any lens, but is slightly more pronounced in high-index materials [7]. However, it never occurs in the central part of a lens and can only be noticed in the periphery of very high-powered lenses made in very dispersive materials, because a strong prismatic effect must be present for it to be noticeable [45,46].

The dispersive power of a lens material is characterized by its Abbe value, a number that is directly proportional to its chromatic quality [7,47]. Abbe numbers for ophthalmic lens materials range between 60 and 30. For example, CR-39, which is considered a low chromatic material, has an Abbe value of about 58. Polycarbonate, which is considered highly chromatic, has an Abbe value of 30. Normally, Abbe values for high and medium-index plastic materials fall in the 35 to 45 range.

**Fig. 3. Comparison of central thickness of +3.00 lens (up) and edge thickness of –3.00 lens (down) made of 1.74 index plastic and classical 1.49 plastic (*After Seico Optical)***

## 3.4 Introduction to Plastic Lens Manufacture

By and large, plastic lenses made from conventional plastic materials such as polycarbonate, poly (methyl methacrylate) and poly (allyl diglycol carbonate) are lighter in weight, higher in impact resistance and lower in cost, and can be produced more rapidly, than conventional glass lenses; and because of this superiority have found extensive use in eyeglasses, cameras, telescopes, etc. Nevertheless, they generally have much lower surface hardness than glass lenses, and this causes the defect that by contact or collision with another object or by scratching, their surfaces are susceptible to damages, which will result in impaired aesthetic appearances and markedly, degraded optical properties [7,48].

Various attempts have been made heretofore at removing such a defect of plastic lenses. For example, there is known a method, which comprises coating of the surface of a plastic lens with a silica-type glass material for vacuum deposition, a silicone compound or a melamine compound and then curing the coating to form a film having improved surface hardness. The plastic lens so produced, however, still has various defects [49].

For example, the extent of improvement achieved of its surface hardness is not entirely satisfactory. The adhesion between the coated film and the plastic lens substrate is poor, and cracking is liable to occur in the interface, especially at high temperature and humidity. Furthermore, because the refractive indexes of the coated film and the plastic lens substrate differ from each other at the interface between them, the transmittance of high frequencies decreases and an optical strain tends to occur [50]. Another disadvantage is that it is difficult to adjust the viscosity of the coating agent or control the coating conditions for the formation of a uniform coated film, and consequently, the cost rises or the efficiency of production is reduced [51,52].

### 3.4.1 Manufacturing methods and techniques

One of the most critical points in the fabrication of polymer optical components is the mould insert required for injection moulding or injection compression moulding, respectively [7,48]. There is a broad range of technologies, which can be used to produce optical mould inserts and/or micro-structuring techniques. Which methods should be employed depends mainly on the application.

Technological advantages in the fabrication process of polymer optics enable fast replication of optical elements with a wide range of geometries as well as microstructures. This is a major advantage compared to glass optics, allowing for more freedom in optical design. Free-form optics is just one example of optical element that can be produced at a significantly lower price than traditional glass lenses. Therefore a wide range of applications emerges with increasing opportunities for the optical design [48,53].

Upcoming trends in polymer optics are micro-structured components. The combination of lenses with micro-structured features can be used to reduce the weight of optical systems, increase their performance, correct aberrations or shape beams [51,52].

## 3.5 Polymers

A variety of polymer materials can be used as optical materials. These materials are known as polymer optics or plastic optics. Common polymer materials for optical applications include, Poly Metha Metacrylate (PMMA), Polystyrene, Polyurethane, Polycarbonate (PC) and numerous liquid silicones (resins) [54,55]. On the other hand polymer optics have been used in various industries, like defence, aerospace or illumination. Most polymer optics have a refractive index of somewhere between 1.4 and 1.6.

One drawback of polymer optics is a lower optical quality in comparison to glass materials. Optical glass materials can achieve higher optical transparency and chromatic quality. This is also one of the main reasons glass materials are still used as optical elements, despite the higher costs. Another danger, in some situations, is the high-temperature sensitivity of plastic optics. In some cases this might be a problem. Plastic optics are softer than glass optics, meaning they are prone to scratches. As such, an optical coating may be required [51,56].

However, polymer optics also have advantages over glass optics. These materials demonstrate low density. Polymers allow fabrication of lightweight components, which is a significant advantage over glass optics. Optical properties of polymer optics are dependent upon the specific polymer (or copolymer) material that is being used. The formulation (fillers, plasticizers, colouring agents and other additives) as well as the crystallinity of the materials will also impact the optical properties [52,56].

### 3.5.1 Polyesters

The use of polyester as a material for ophthalmic lenses has been disclosed in various U.S. Patents. Sherr and Bristol in 1968, proposed a composition in which polyester is combined with methylmethacrylate and styrene in order to produce an ophthalmic lens [54]. In 1970, Sherr disclosed a composition in which specific unsaturated polyester is combined with styrene and ethylene glycol dimethylacrylate [55,53]. Styrene raises the index of refraction up to 1.52 and ethylene glycol dimethylacrylate reduces the brittleness of the polymer.

Engardio et al. [56] described a number of commercially available polyester resins [56], which are clear when cast and have a refractive index of approximately 1.56. The density of these various polyester systems are also quite low (on the order of 1.25 g/cc). These properties are superior to CR-39 (index 1.498 and density 1.32 g/cc).

Polyester resins can be manufactured using different composition to achieve a wide variety of physical properties (hard, soft, rigid, flexible and the like). Typical commercial polyesters include those made from a variety of glycols and acids. Resins made using phthalic anhydride are commonly called “ortho” resins. Those made using isophthalic acid referred to as “iso” resins. Typical iso resins have good scratch resistance but generally are slow to tint. Ortho resins, on the other hand, are generally more scratch-prone, but tint more readily [57]. All of the unsaturated polymers have a propensity to polymerize somewhat non-uniformly causing internal optical distortion or visible “waves”. As previously mentioned, as the portion of styrene is increased, the index of refraction also increases, but also tends to cause formation of optical distortion within the lens.

### 3.5.2 Polycarbonate or “Poly C” lenses

Polycarbonates are transparent thermoplastics, formed by the condensation of polyphenols with phosgene. They are noteworthy for high-strength and temperature resistance, as well as good electrical resistance and stability. They are stable to water, dilute mineral and organic acids, and are insoluble in aliphatic hydrocarbons, petroleum ether, and most alcohols [58].

Polycarbonate is a material, which has been called a thermoplastic “metal” because of its extremely high impact strength, even greater than that of aluminium. As strong as CR-39 is, polycarbonate can withstand over 5 times the impact energy [59]. Among polycarbonate’s other advantageous properties over glass and CR-39 are its low specific gravity of 1.20, compared to that of crown glass (2.53) and CR-39 (1.31), and higher refractive index (1.586) compared to crown glass (1.523) and CR-39 (1.498).

Polycarbonate is a material that is considered highly chromatic, and has an Abbe value of 30, whereas Abbe values for high- and medium-index plastic materials fall in the 35 to 45 ranges. Polycarbonate lenses are more impact resistant than glass, conventional, or high index plastic lenses, and this extra margin of safety makes polycarbonate lenses ideal for children [60] or for safety purposes (sports or safety goggles).

**Table 3. Properties of Polycarbonates**

| Specific gravity | 1.2 | Volume resistivity ohm-cm | 2,1 x 1014 |
|---|---|---|---|
| Tensile strength (lb/in2) | 8-10.000 | Specific heat cal/oC.g | 0.30 |
| Impact strength (lb/in2) - Izod | 2 – 3 | Dielectric strength v/mil | 400 |
| Hardness R | 118 | Dielectric constant 6oc | 3.2 |

**Table 4. Edge thickness comparison (mm) the front base curve, centre thickness and lens diameter are held constant**

| Refractive power of lens | CR-39 Resin | Crown glass | Polycarbonate | HY-per index (1.595) |
|---|---|---|---|---|
| -2.00 D | 4.0 | 3.9 | 3.7 | 3.4 |
| -4.00 D | 6.1 | 5.9 | 5.4 | 5.0 |
| -6.00 D | 8.1 | 7.8 | 7.1 | 6.6 |
| -8.00 D | 10.3 | 9.8 | 8.8 | 8.3 |

Although new high index materials of glass, like germanosilicate glass, invented by a research group at Pennsylvania State University [61], to the author's knowledge at the time of this publication, no plastic novel material with higher refractive index, was yet developed. Samples of the germanosilicate glass demonstrated a high refractive index, about 1.60, which also showed high transparency, good UV-shielding properties, and good glass-forming ability, making them suitable for lens applications. Nowadays many efforts target the green plastics for environment or special novel optical materials but not applicable for spectacle lenses. A modern concept is also the high index hybrid inorganic/resin optical materials for various purposes, like transparent thin films.

## 4. DISCUSSION

The most outstanding advantage of high index plastic lenses leads to their name. The higher the index rating, the less material required to make a lens in a particular prescription. And in ophthalmic lenses, less material means a significant advantage. Because high index lenses can form prescriptions using less physical material, they provide lenses that are both lighter and thinner than identical standard lenses. On the reverse, reduced edge size relates to the thinness of the high index material.

Possibly the most noticeable disadvantage of high index lenses is the higher cost, which can be considerable for specific prescriptions. This happens due to the added cost of the manufacturing process and the material waste. It is also related to the more accurate process of forming and grinding of high index lenses.

In general, spectacle lenses used to correct eye imperfections are made of various optical materials and especially recently from a variety of high refractive index plastic materials. The imaging properties of the spectacle lens depend on the refractive index of the lens material. On one hand, new materials offer a high refractive index. At the same time, quite the opposite a high Abbe value, which makes the provided image quality by the lens to decrease and the user to recognize lower optical acuity.

In a similar study, Miks et al. [62] showed that a higher refractive index of the lens material does not significantly reduce the image quality [62]. Quite the opposite, a low value of the Abbe number increases the chromatic aberration of the lens. The higher refractive index has a positive effect only on the shape of the lens, as it allows the use of lenses with a smaller center or edge thickness in the case of positive or negative lenses.

High refractive index lens materials tend to have high chromatic dispersion (low Abbe number), which may add to the optical blurring with oblique observation. Transverse chromatic aberration (TCA) in spectacle lenses results from the prismatic effects of light beams passing through the lenses away from their optical centers, causing white light to scatter in its spectral elements

When a patient complains of unexplained or else blurred vision with a new pair of lenses, it is important to consider also the off-axis aberrations, especially after the increasing promotion of high refractive materials with high chromatic dispersion. On the other hand, the emphasis on the use of polycarbonate glasses for children, due to their practicality in protection, can be mitigated by the reduced off-axis visual acuity caused by their increased transverse colour deflection, especially with higher power recipes.

Furthermore, high index lenses can be more brittle and are definitely more reflective than standard materials. But a second very important advantage of new high index materials is the impact resistance, exclusively of polycarbonate. Every day around the world, thousands workers experience a work-related eye injury. The severity of these injuries ranges from mild irritation that requires no or minimal treatment, to potential accidents that lead to blindness and require urgent treatment, and force workers into a significant recovery period and a considerable lost production time. Employers are responsible to provide the appropriate level of eye and face protection for their employees, whose needs may differ depending on the exposure to various risks.

Attention is given to the high-impact safety goggles that incorporate the patient's prescription into the lenses. It is noteworthy that if new prescription lenses are then placed in the original frame, the safety features may be compromised. Today's safety goggles market has given way to newer, improved materials and designs that are available as options for the goggle provider as well as the consumer.

Of course, the cost of the material may cause the main safety glasses to be made of 3.0 mm thick plastic, but this is no longer an option for high impact glasses. Polycarbonate lenses are made using a process that significantly compresses the material, while allowing it to maintain flexibility and "give" slightly upon impact. Recent studies have confirmed the superiority of polycarbonate high index material in impact resistance and identified the expected variability in polycarbonate lens retention based on differences in curvature, strength and eye-size.

## 5. CONCLUSION

High index plastic lenses, by their very nature and chemical makeup, have distinct advantages over standard plastic or glass. Because high index lenses can form prescriptions using less physical material, they provide lenses that are both lighter and thinner. The lighter and thinner materials are more comfortable and cosmetically look better for higher power prescriptions, but that does come with an optical clarity trade-off.

High index lenses also reflect a higher percentage of light than standard lenses. Because of this, an anti-glare coating is strongly recommended with the dispensing high index lenses. Polycarbonate although of high refractive index and low Abbe value is very popular among the youngsters.

The older versions of the material had a lot of aberrations and chromatic distortions. Over the past 20 years the manufacturing of this material has improved dramatically. It can be a good choice as long as the prescription isn't too strong. While it does not have the best abbe value, it does have impact resistance. Protective eyewear is highly recommended but underutilized, in the sporting population as well, with specific products recommended for various activities.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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