LENS TREATMENTS

PART 1: ANTI-SCRATCH AND HARD COATS

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In this paper, the various types of hard and anti-scratch coatings for spectacle materials are examined and reviewed, their relative merits explained, and practical advice given on the provision of hardcoats in practice

Basic choice of optical materials?

There are three main groups of optical materials.

1. Glass is generally considered to be the most abrasion resistant optical material. Strictly speaking it is not actually a solid, but in chemical terms is classed as a super-cooled liquid. High index glasses can be much less abrasion resistant, (and are also prone to chemical staining,) but these are normally AR coated to reduce the higher reflection due to the high index, so both the chemical staining and abrasion resistance are related to the quality of the AR coating.

2. Thermosetting plastics (usually called resins) are created by a chemical reaction, during which a monomer reacts with a catalyst to form a fairly rigid cross-linked structure. This lattice-like structure produces a fairly rigid and moderately abrasion resistant material. CR39 is the best-known version of an optical resin. Mid and high index plastics are usually much softer than standard index resin. Once a thermoset has been created it cannot be softened with heat. (When heated the cross-linked lattice structure prevents softening and ultimately a thermoset will blacken and char as the chemical bonds are broken.) Abrasion resistance can be enhanced by the addition of a thin scratch resistant coating. The coating is typically a polysiloxane (by which we mean a polymer with some Silicon molecules to increase hardness).

3. Thermoplastic plastics (usually just called plastics) are also formed by a chemical reaction, but unlike resins, the molecules link together into long chain molecules (without a cross-linked lattice structure). They can be repeatedly softened and their shape changed by reheating (as the long chains slip over each other). All plastics are less abrasion resistant and less chemical resistant than resins, and to produce a viable spectacle lens must be abrasion resistant coated. The flexibility of the long chain molecules does however make plastics less brittle than resins (as illustrated by polycarbonate, which is the commonest thermoplastic material, used for spectacle lenses.)

Which materials need anti-scratch coatings?

While it is preferable to coat all materials, (and this is becoming more common) some materials still provide an acceptable level of abrasion resistance without coating. Taking the three materials listed above the general advice is:

1. Glass - for all higher indices, the provision of an AR coat is generally considered essential (for reasons of chemical resistance as well as reflection)

2. Thermosetting plastics - For (non-AR coated) CR39 a hardcoat is generally considered optional. However, if CR39 is to be AR coated, most of the major optical companies, and the author of this article, believe it is essential in order to provide a long-lasting durable product. For all other thermosetting plastics (i.e. most of the mid and high index plastics) a hardcoat is generally considered essential.

3. Thermoplastic plastics - All must be hardcoated to produce acceptable life. The only thermoplastic in general use (polycarbonate) is so soft that a really good hardcoat is needed.

Within each group of material types, there is obviously considerable variation in abrasion resistance, and this also varies depending on the type of coating used. The list on the right **(Table 1)** gives approximate relative abrasion resistance of common ophthalmic materials.

Should both back and front surfaces be hardcoated?

Many lenses are produced in semi-finished form (by the large mass manufacturers) ready for back surfacing in the Rx laboratory. Some of these lens blanks already have their front surfaces hardcoated. Because not all Rx labs have a back-surface hardcoating facility, and because of the cost involved, these lenses are sometimes passed to the wearer with only a front surface hardcoat. The normal assumption is that most abrasion occurs on the front side of the lens. Some years ago an inspection of a large number of pre-worn lenses showed that this is not really true. The pattern was of one or two deep scratches on the front surface (usually on plus power lenses) but very large number of finer scratches (caused by cleaning) on the back surface. The front surface scratches were so deep that a hardcoat would not prevent them, but the back surface fine scratches can be prevented by hardcoating. The resulting logic is that it is actually more important to hardcoat the back surface than the front. The author of this article therefore believes that it is un-ethical to make any claim for abrasion resistance or to state that a lens has a hardcoat unless the back surface is also hardcoated.

Level of Abrasion Resistance	Materials
Extremely good	Crown 1.5 index glass AR coated crown glass
Very good	High Index glass (AR coated) CR39 with SiO2 coating CR39 with thermally cured hardcoat
Quite good	CR39 with UV cured hardcoat 1.6 index with hardcoat 1.56 index with hardcoat
Acceptable	Polycarbonate with hardcoat CR39 with chemical 'tinted' hardcoat Standard CR39
Limit of acceptability (as defined in latest draft ISO Standard)	
Poor	High Index plastic without hardcoat
Very poor	Mid-index 1.56 without hardcoat
Extremely poor	Polycarbonate without hardcoat

(This table was created by the author and is based on his work within the International Standards Organisation who are currently developing an ISO standard for the durability of lens coatings, as described later in this article.)

TABLE 1: Relative abrasion resistance of common materials

Slippy or hard?

Whether a lens can be easily scratched is as much a function of its 'slippyness' as its 'hardness'. By 'slippyness' we mean a lack of friction, which means that any abrasive particle glides over the surface easily without scratching it. By 'hardness' we mean that the surface material is strong enough to resist damage when abraded. Some coatings include what may be called a 'slippy' ingredient and this can be as beneficial as a hardcoat. However, it should be remembered that 'slippy' coats are extremely thin and do not last for very long. Although not sold with the words 'slippy' coat, hardcoats that are created by dipping in a tinting bath for a short period are generally of the 'slippy' type. They should therefore be considered as considerably inferior to hardcoats produced by coating with a lacquer.

Does a hydrophobic coating help to prevent scratches?

Hydrophobic coatings (because they electrostatically repel water molecules) prevent water, grease and sweat droplets from spreading over the lens surface. Instead, the water settles as more spherical shaped droplets that will more easily run-off the surface. Hence there is less water left to dry on the surface. Therefore the lenses stay cleaner and as a consequence the lens wearer will not need to clean the lens so frequently. This obviously means that 'cleaning scratches' are much less likely to be created.

Can hardcoats reduce reflection?

Because reflection is related to refractive index, it is possible to reduce surface reflection by applying a hardcoat of lower refractive index to the lens. The effect is not large. For instance, if a 1.586 index polycarbonate lens is hardcoated with a 1.5 index hardcoat, then the reflection would reduce from about 10% to about 8%. For higher index plastics this effect is even greater. The difference between the refractive indices can however create a detrimental effect due to wave interference effects as explained below. (Because of this detrimental effect hardcoat lacquers are normally chosen to match as closely as possible the refractive index of the lens).

Can hardcoats create unusual optical effects?

A hardcoat is very thin, (but not as thin as an AR coating,) however it is thin enough to create the same type of optical wave interference effects as an anti reflection coating. Unfortunately it is not possible to manufacture a dipped or spun hardcoat that has exactly the same thickness over the whole lens surface (to an accuracy of 1/4 wavelength). The wave interference effects (that create the typical green colour of an MAR) therefore create different colours at different points over the lens surface. This variation of reflection colour over the lens surface may be unacceptable where there is a significant difference in refractive index between the lens and the hardcoat. (It can look like the pattern that is created when there is a thin layer of oil on top of water.) This interference effect is more visible in monochromatic light and can therefore often be seen under fluorescent lighting.

The effect is not large when there is only a hardcoat, but will appear much worse if the lens is also AR coated. This effect can be prevented by using an index-matching hardcoat (where the hardcoat has a similar index to the lens).

What different types of hardcoats are available?

There are four basic types of hardcoat, - vacuum deposited, thermally cured lacquer, UV cured lacquer, and absorbed (or tinted) hardcoats.

1. Vacuum deposited hardcoats are manufactured by depositing a 'thick' layer of SiO_2 within a vacuum coating machine in much the same way as an AR is created. Normally this is done at the same time as the AR coating. SiO_2 is extremely hard (being essentially glass) so the result is a very scratch resistant coating. There are some negatives including the following. Tinting must be done before hardcoating, there may be optical interference index matching problems as mentioned above, and there may be difficulties with coating adhesion due to stress between the softer plastic and the very hard glassy hardcoat.
2. Thermally cured lacquer hardcoats are the commonest type; being used in large volume production by most of the worlds major lens manufacturers. These are available in a range of indices hence avoiding the index-matching problem and have the advantage that they can normally be tinted after hardcoating. Because the lacquer deteriorates (with time and heat) before application it must be carefully controlled and used quickly. This is no problem in large manufacture, but can limit its use for small capacity prescription laboratories.
3. UV cured lacquer hardcoats are very similar to thermally cured hardcoats, although they are generally less abrasion resistant and it can be more difficult to achieve good adhesion of an AR coating. They are however extremely convenient for use in small volume in Rx laboratories using a back-side spin coating machine. They are not normally used in large volume lens manufacture, where a dip (two-sided) thermal cure is more convenient. (There are some exceptions such as the production of in-mould semi-finished lenses where UV curing is used.)
4. Absorbed or tinted hardcoats are applied by a process similar to tinting and are therefore convenient for retail use. However, these generally fall into the

category of 'slippy' coats and usually have a short life and are not very abrasion resistant.

Does the method of application matter?

Obviously vacuum deposited and absorbed (tinted) hardcoats can only be applied in one way, but the lacquer coatings can be applied by a number of different methods. Some techniques (such as spray or curtain coating) are only used for non-ophthalmic coatings (eg car headlamps and windows) where small defects are not important. The common three techniques are:

1. In-mould coating can obviously only be used by the lens casting companies. It is usually only used for semi-finished lens manufacture. Adhesion and hardness are normally excellent but there can be AR coating problems and tinting is not normally possible.

2. Dip coating is very common and used by large manufacturers. The use of index-matched lacquers are necessary if the lens is to be AR coated otherwise small variations in thickness down the direction of dip can create interference colours. The edges of the lens (as well as the front and back surfaces) need to be clean otherwise they will introduce dirt into the dip tank. Careful monitoring of the lacquer is essential but if this is done excellent results are achieved.

3. Spin coating is simpler and less prone to the cleanliness and monitoring problems associated with dip coatings. Hence it is more suitable for prescription use, although the cost per lens (because of lacquer waste and machinery complexity) can be significantly higher.

What standards exist for hardcoatings?

At the time of writing no International Standards exist for the durability or abrasion resistance of hardcoatings. However, there are currently two ISO standards being prepared. The major ophthalmic companies are already aware of these draft ISO standards. The only situation in which the supplier should seek further assurance is where different aspects of production are carried out separately (eg where an AR coating is applied by a different organisation to that which applied the hardcoat).

One draft standard sets a minimum acceptable level of abrasion resistance for ophthalmic lenses (regardless of whether they are hardcoated or not). This level is shown in **Table 1** on page 7. Essentially the draft ISO standard states that a minimum acceptable level of abrasion resistance for an ophthalmic lens is equivalent to that of a fully cured non-hardcoated CR39 material. (Note: If CR39 is not properly cured its abrasion resistance is inferior.) On the question of one or two sided hardcoats, the draft standard states that 'both surfaces shall meet the requirements of the standard'.

The other draft standard relates to the durability of coatings (in particular AR coatings). This standard describes a way of testing the durability of coatings, by repeated cycles of humidity, heat and exposure to UV light, following some initial abrasion. Methods such as the Taber abrader did not provide sufficiently consistent results and the ISO committee is currently combining and adapting different methods. Lenses satisfy the durability criteria if they show no signs of coating delamination after a specified number of test cycles. Tests have shown that many factors can affect coating durability, including glazing stress, tinting etc so it is important that all these factors are taken into consideration by the supplier.

How can you detect whether the hardcoating is of acceptable quality?

There are no non-destructive tests for hardcoats. Hence you must rely on your supplier to produce an acceptable and durable product. This article should provide you with the key questions to ask.

For example – Are all back surfaces hardcoated? What index lacquers are used on which index lenses? If the AR coating and hard coating is done by different organisations, is the communication between them good enough to ensure that the processes are compatible with each other? If the lens was originally hardcoated as a semi-finished, how will the AR company deal with the different front and back hardcoats when preparing the lenses for AR coating? If samples can be obtained then some testing can be done. However most tests require special equipment, such as a QUV weathering machine to apply heat, humidity and ultra-violet on a controlled cyclic timed basis and coating companies should also have equipment to monitor lacquer solids content and other quality control equipment. A simple way of doing a crude test of the adhesion of a hardcoat is to make cuts (with a sharp knife) on the coated surface, then tint the lens and then see if sticky tape can pull off the hardcoat. However, this test is not sufficient to quantify long-term durability.

Hardcoating should be seen as part of an integrated process in producing a complete product. Further articles in this series will cover other aspects including anti-reflection, tinting, impact resistance and ultra-violet protection, all of which may potentially interact with each other.

A list of references and further reading will be published at the end of the final article in the series. ■