HARD COATING AND THE DURABILITY Of ANTI-REFLECTION COATINGS

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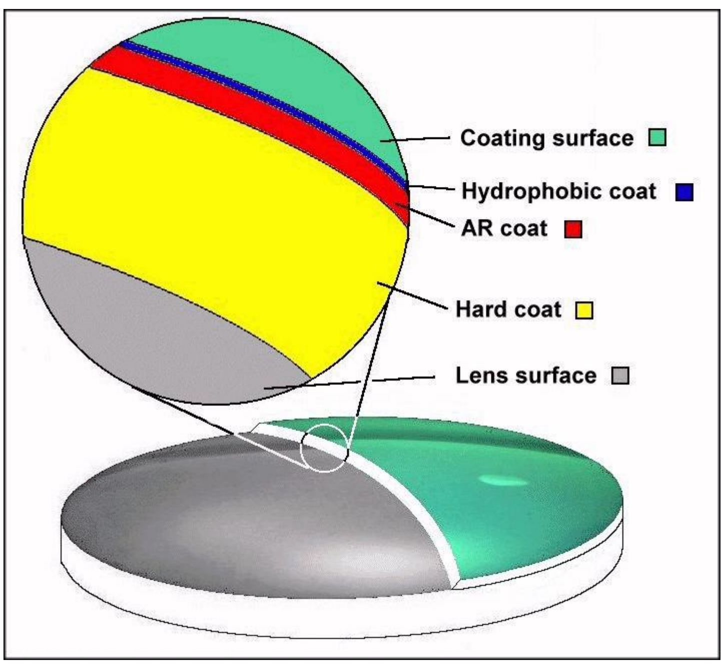
published in Optical World, April 2000

Durability is the key issue for laboratories considering in-house Anti-reflection coating. What is not always appreciated, is that the hard coat has a greater influence on performance than the AR coating itself. In this article, Dr Michael Walls and Dr Rick Spencer of Applied Vision show that the hard coat and AR coating must be considered together and not as separate treatments. Only in this way can outstanding durability be guaranteed.

1. Introduction

Anti-reflection "AR" coatings are popular with spectacle wearers because they reduce reflection and glare. Most optical markets internationally are witnessing a growth in AR coatings. As a result, coatings are becoming increasingly important to optical laboratories in the Industry.

Durability is the most important issue facing the laboratory since delamination or poor scratch resistance leads to customer dissatisfaction and lens returns. Durability is rarely a problem on 1.5 index mineral lenses since glass provides an ideal scratch resistant foundation for AR coatings. However, it is now well accepted that a plastic lens must be hard coated prior to AR coating otherwise its durability is likely to be problematic.



A finished AR coated, plastic lens typically has had many surface treatments. These treatments include hard coating, tinting, AR coating, and hydrophobic application as illustrated in Figure 1. The performance of the finished lens depends on all of these treatments and on the way they interact. The most important interaction is between the hard coat, and the AR coating. To ensure the best quality the hard coat and AR coating must be considered together rather than simply viewed as separate and independent treatments.

Figure 1. A schematic diagram showing the structure of a typical AR coated lens. Note that the hard coat is much thicker (varies between 1 and 8 microns depending on type and manufacturer) than the AR coating (typically 0.2 - 0.3 microns). The hydrophobic coating is extremely thin (less than 0.005 microns).

A number of hard coating systems are available. Some are based on dipping so that both sides of the lens are coated simultaneously. Others are spin systems for re-applying a hard coat to the concave face after surfacing. The most common compositions for hard coatings are based on acrylic (UV cured) or polysiloxane (thermally cured) chemistries. In most cases, these hard coats have not been developed specifically to meet the requirements of AR coating and great care is needed to ensure their compatibility. This article is aimed at reviewing the technical performance of hard coats and providing some guidelines to select those hard coats which ensure the best possible performance of an AR coating.

2. Requirements for AR Coating

The optical laboratory needs to produce a good quality AR coating with excellent durability. This means that the coating must not peel, scratch excessively, change colour or crack. It should also be easy to clean.

Colour changes are governed by the AR coating itself and can be avoided simply by using a vacuum coater which produces a dense, high quality AR coating. This can be achieved using systems based on reactive magnetron sputtering or ion-assisted electron beam evaporation technologies. Ease of lens cleaning is determined by the chemistry and smoothness of the outer surface and an ultra-thin hydrophobic coating is often applied to ensure that the lens has a slippery surface.

The most important requirements of a good quality AR coating, such as adhesion and scratch resistance, depend on the relationship of the AR coating with the hard coat. For the hard coat to provide a good base for the AR coating it must :-

· adhere well to the lens surface

· provide a good stable surface for the AR coat to adhere to

· be chemically compatible with the AR coating

· be flexible enough to prevent cracking

· be hard enough and thick enough to resist scratching

The optical laboratory may also wish to tint or hard coat the lens before AR coating. In general the harder the coating, the less tintable and the less flexible it is.

3. UV-cured hard coating

UV-cured hard coating systems have been developed predominantly in the United States. This has been driven by the impact resistance requirements of the FDA and the associated popularity of polycarbonate lenses. Polycarbonate accounts for about 20% of the lenses sold in the US market. However, although polycarbonate is tough it is also extremely easy to scratch and must be hard coated. Also, polycarbonate is difficult to tint. Hence UV hard coats have been designed not only to improve scratch resistance, but also to accept a dye. The original UV-cured hard coat formulations were not intended to be used on CR39 and the requirements of AR coatings were probably never considered. Only recently have these issues been addressed and great care must be taken when choosing a UV cured hard coat as a foundation for an AR coating.

With few exceptions, lens manufacturers have not adopted UV cured hard coatings for coating 'stock' lenses. In the optical laboratory, they are almost exclusively spun onto the concave, surfaced face. Automated machines will fixture the lens onto a rotating vacuum chuck, the lens surface is washed using a high pressure jet of alcohol and water and the hard coating lacquer is then applied from a nozzle. The thickness of the coating is determined by the rotation speed and the viscosity of the lacquer and is typically in the 5um to 10um range.

The UV curing stage takes in the order of 1 minute to complete and for this reason they are very convenient to use. This cure time depends on the flux of UV light at a specific wavelength and the condition of the UV lamp is critical to efficient curing.

All UV lacquers for hard coating are currently acrylic based. A basic UV cured lacquer contains many materials including:-

- monomer/oligomer
- UV absorber
- Photoinitiator
- light stabiliser

Many of these materials are not included in the polymerisation reaction of the monomer and remain trapped in the cured hard coat. These can migrate to the surface (before or after AR coating) causing adhesion problems.

There is generally a compromise in performance between tintability and hardness. As the UV hard coats are less hard than the thermal hard coats, a highly tintable UV hard coat is likely to be soft. The tintable UV lacquers also tend to contain more uncured material.

Finally, the curing of UV lacquers is inhibited by the presence of oxygen. This means that due to the curing stage taking place in air the hard coat surface can be less cured than the bulk of the hard coat. This also can lead to adhesion problems as the subsequent AR does not have a hard stable surface to bond to.

4. Thermally cured hard coating

Thermally-cured hard coats are the usual choice of lens manufacturers for stock CR39 and high index plastic lenses. At the laboratory level, systems are available for both dipping and spinning the lacquer. In dip systems, the lenses are typically pre-treated in a potassium hydroxide solution to activate the surface. The lenses are then dipped in the lacquer and the thickness of the hard coat is determined by the viscosity of the lacquer and the pull speed. A thermal hard coat thickness is usually in the range 1.5 to 3 microns. Spin systems using thermal lacquers for coating the back of the lens work using same principles as those developed for UV cured coatings.

Even room temperature will initiate curing of the lacquer so that its effective lifetime is reduced. The lacquer must be managed to control this curing. Lacquer management means monitoring the age of the lacquer and replacing it when required, and also cooling the lacquer to a specified temperature when not in use.

In modern hard coating units such as that shown in Figure 2, this lacquer management is automated. When the unit is in standby the lacquer is cooled to extend the operating life. To start hard coating, after the "start" button is pushed, the lacquer is brought to operating temperature (16^{o}Cto18^{o}C) in about 15 minutes and the unit is ready to use. At the end of the working period, the operator simply pushes 'standby' and the unit will cool the lacquer again.

Thermal hard coats are Polysiloxane based, often with a silica content. As their name implies, these hard coats are thermally cured by placing the coated lenses in an oven at about 100^{o}C for a period of two hours or longer. This siloxane/silica based coating produces the best performance of all the types of hard coat currently available (1). The final hard coat is much more stable than the UV cured hard coats (2). Thermal lacquers are available in tintable and non-tintable forms. The non-tintable thermal hard coats are very hard and as a consequence they are brittle. In addition, they are more inert than the tintable forms which makes good adhesion of a subsequent AR coating harder to achieve. Excessive temperatures can cause crazing of the non-tintable hard coat and concomitant problems with the AR coating. In general, a good quality tintable thermal hard coat will be the best choice for a foundation for AR coating.

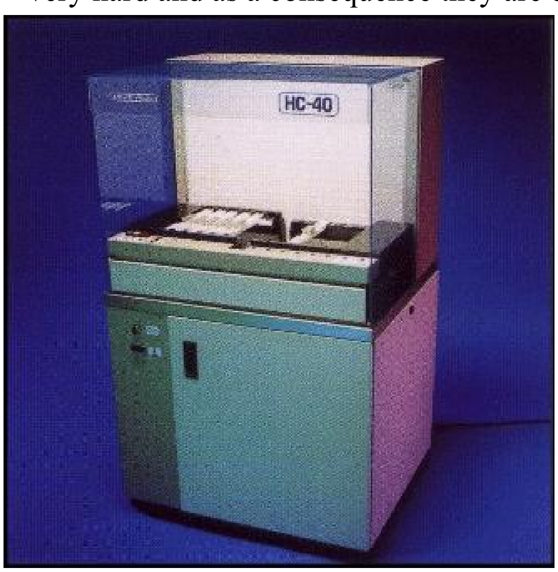


Figure 2. A lens dipping system for the automatic application of a thermally cured hard coat simultaneously on both sides of a lens (HC40 model from Applied Vision).

5. Adhesion tests

The adhesion between the AR coating and the hard coat must remain throughout the lifetime of the prescription which is typically 1 to 3 years. The lens to hard coat interface and the hard coat to AR coat interface are both subject to ageing. A good adhesion test must therefore include some ageing (real or artificial). It is simply not sufficient to test the 'as made' adhesion at the point of manufacture. There are many adhesion tests and it is beyond the scope of this article to discuss them all in detail. The only true test is a real wearer trial but these are relatively slow. Laboratory tests attempt to speed up the process. Such is the level of experience with these tests that reliable predictions of performance can be made. Briefly the laboratory tests are a combination of some or all of the following :-

- increased temperature
- increased humidity
- chemical exposure (salt, caustic soda, etc.)
- UV exposure
- abrasion
- tape or pull test
- regular inspection

The results presented here are from a laboratory test based on a US military test (3). The test used is a cyclic humidity test with cycles of 16 hours at 65°C, 100% relative humidity, followed by 8 hours at ambient temperature, terminating in a tape test on a cross hatched area of coating and then repeating the cycle. The tape test results are scored daily and the results from each day added together to give a total score. This is a particularly severe test that in practice has correlated well with actual lens trials.

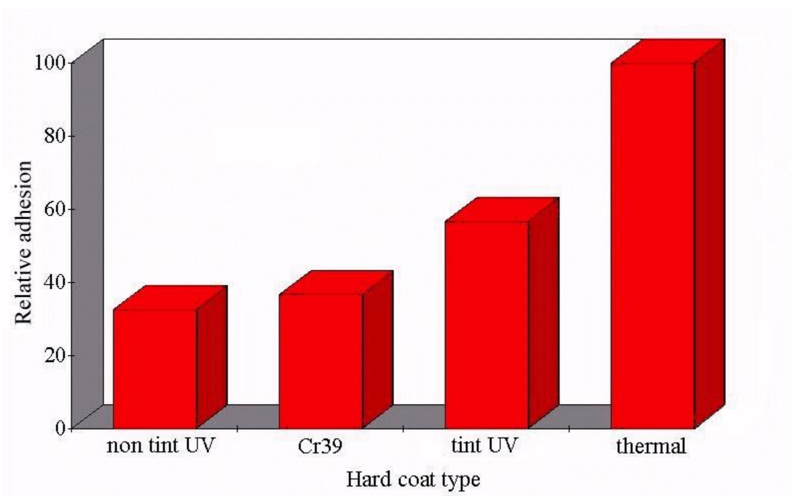


Figure 3. The relative adhesion of an AR coating on CR39 and on various types of available hard coat as measured using accelerated lifetime (cyclic humidity) tests . Note that the AR coatings on the tintable thermal coating did not actually fail in the tests.

Typical results from AR coatings on CR39 and a range of hard coat types are shown graphically in Figure (3). This shows that the aged adhesion of an AR coating varies significantly between hard coat types. These results indicate that some UV hard coats actually perform worse than bare CR39. Their performance actually varies over a range and the best of the UV hard coats can be marginally better than CR39. Neither type of UV cured coating can match the performance of the tintable thermal hard coat. It should be noted that no adhesion failure was actually recorded on the tintable thermal hard coat. These AR/thermal hard coat samples were removed from the test after 80 days with no sign of failure. The thermal hard coat results here are from the tintable thermal hard coat supplied with the HC40 hard coating system.

6. Scratch resistance

Scratch resistance is evaluated using a range of tests (2). The test used here is a steel wool abrasion test using 'OOO' steel wool, 500g load, and 50 strokes, at a stroke length of 37 mm and a frequency of 0.5 Hz. This is typical of an ophthalmic industry test. Between laboratories there will be variations in load and the number of strokes (there is, as yet, no agreed test in detail), however the resulting ranking of different hard coat types should be similar.

The performance of the various hard coats can be judged from the sequence of optical micrographs shown in Figure (4). The images are each of an area 2mm x 1.5mm. In each case the lens surface was cleaned following hard coating and AR coated using identical conditions in a PlasmaCoat Plus II from Applied Vision.

Figure 4[a] shows the effect of 50 strokes on an AR coated sample of bare CR39 without any hard coat. The AR coating is green in the images. Most of the AR coating (green) remains intact, but there are extensive areas of lost AR coating.

For comparison, Figure 4[b] shows the effect of 50 strokes on a tintable UV cured hard coating on a CR39 lens. This micrograph reveals complete loss of hard coat in the central black lines of abrasion, and only a few areas of remaining AR coating (green). The performance of this hard coat is poor and is actually worse than bare CR39.

Figure 4[c] shows the effect of the same test on a non-tintable UV-cured hard coat on CR39. This hard coat gives better performance and most of the AR coating (green) remains intact, with only a few areas of lost coating.

Finally, Figure 4[d] shows the result of the same test on a tintable thermal hard coat on a CR39 lens. The durability of the AR coating on the thermal hard coat is outstanding and all of the AR coat (green) remains intact. The damage is limited to a few shallow linear scratches.

Figure 4a - bare CR39

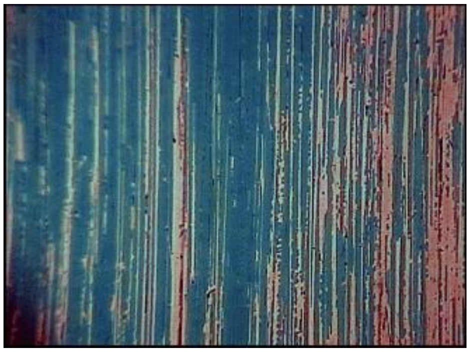


Figure 4b - Tintable UV hard coat

Figure 4c - Non-tintable UV hard coat

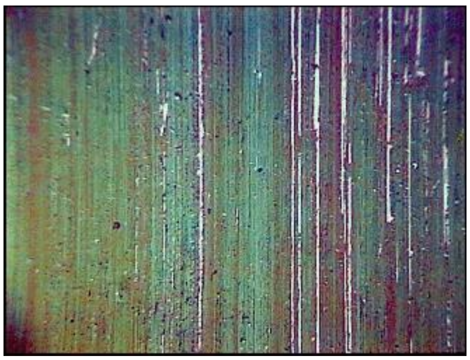


Figure 4d - Tintable thermal hard coat

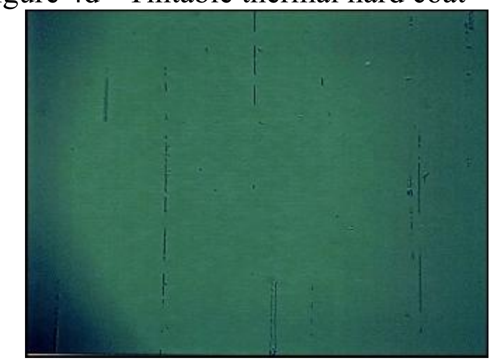


Figure 4. Optical Micrographs of surfaces following steel wool abrasion tests.

These abrasion test results show that the choice of hard coat has a major influence on the abrasion resistance of the final AR coated lens.

7. Discussion

The adhesion and scratch resistance results presented here illustrate graphically that the choice of hard coat can result in a wide range of durability performance of AR coatings. Some "hard coatings" can actually impair the scratch resistance when compared with a bare CR39 lens.

The treatments applied to an AR coated lens cannot be considered in isolation. In particular the choice of hard coat has the most important influence on the performance of the finished lens. The best performance in terms of adhesion and scratch resistance is obtained by using a thermally cured hard coat. UV cured hard coats, although more convenient to use, do not at this time offer the same level of performance. There is a growing awareness of the characteristics required of a hard coat to provide good support for AR coatings and it is likely that better UV-cured formulations will be developed.

Non-tintable thermal hard coats are the hardest available, but the adhesion of AR coatings can be compromised as the hard coat becomes too inert for chemical compatibility with the AR coating. Non-tintable hard coats are very hard but they are also brittle and can craze at high temperature or can crack when under the high mechanical strain exerted on a lens in glazing or fitting. In general terms, the results presented here show overall that a tintable thermally cured hard coat provides the best foundation for durable AR Coatings.

References

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3) US Mil-Std-810C, method 507, procedure 1