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INTRODUCTION

Polycarbonate lenses are commonly used in many optical applications. Their high impact resistance, low weight, and cheap cost of high-volume production makes them more practical than traditional glass in various applications [1]. Some of these applications require safety (e.g. safety eyewear), complexity (e.g. Fresnel lens) or durability (e.g. traffic light lens) criteria that are difficult to meet without the use of plastics. Its ability to cheaply meet many requirements while maintaining sufficient optical qualities makes plastic lenses stand out in its field. Polycarbonate lenses also have limitations. The main concern for consumers is the ease at which they can be scratched. To compensate for this, extra processes can be carried out to apply an anti-scratch coating.

Nanovea takes a look into some important properties of polycarbonate lenses by utilizing our three metrology instruments: Profilometer, Tribometer, and Mechanical Tester.

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IMPORTANCE OF TESTING POLYCARBONATE LENSES

Surface data of a lens is ideal for obtaining the surface roughness and radius of curvature. These properties influence the optical quality of the lens. Radius of curvature affects the lens' optical power while surface roughness will influence the scattering of light. In addition, the thickness of the lens will be measured. Lens thickness of the lens will affect its effective focal length.

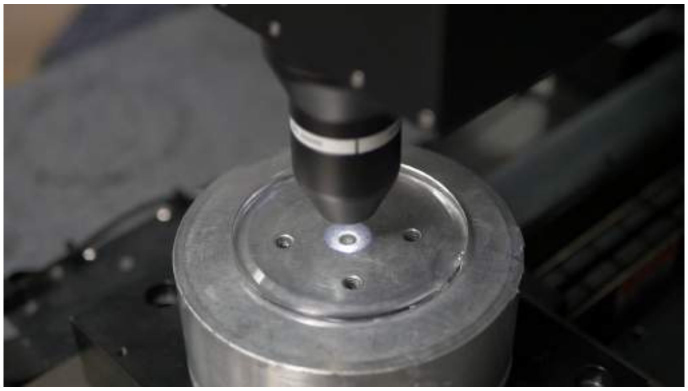
The quality of the lens will decrease as more defects are on the surface of the lens. Material with high scratch resistance tends to wear less over time and are less prone to defects caused by external sources. Scratch hardness will define the resistance of the sample to scratch defects. This can be used to determine the scratch hardness of the bulk material or effectiveness of a scratch resistant coatings. Additionally, adhesive scratch testing can be conducted to determine the quality of adhesion between the coating and the lens.

Coefficient of friction (COF) can be obtained from tribology testing against various materials. Since polycarbonate lenses are used in many different applications, it would be practical to understand how other materials will behave when interacting with the lens. Thus, friction can be minimized (or maximized) when selecting complementary materials. Wear testing demonstrates the durability of the sample in different conditions.

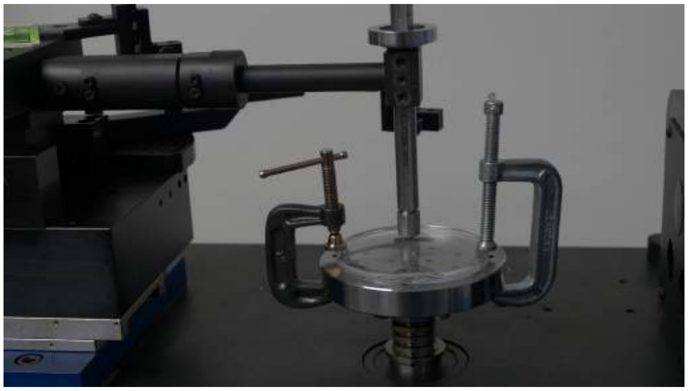
The testing and results found during this study is representative of how the sample will perform in real life applications. The results can be used to determine which type of material, process, or design is ideal for the user's application. Quality control testing can also be repeatedly conducted with our highly accurate instruments.

MEASUREMENT OBJECTIVE

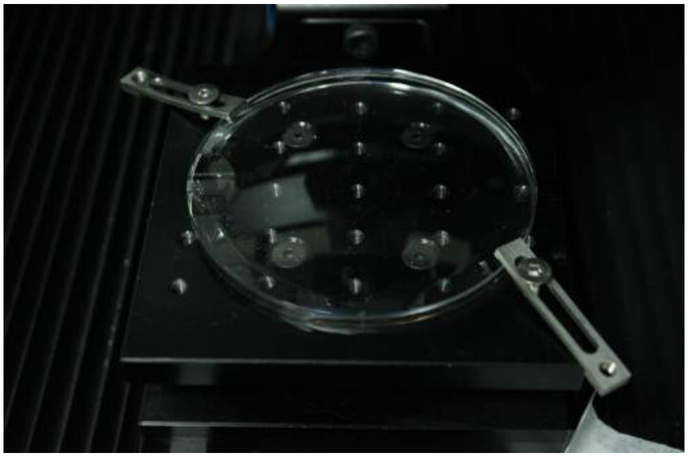
In this case study, a general investigation on several important properties of a polycarbonate lens is conducted. The following properties will be obtained from our profilometer, tribometer, and mechanical tester: surface roughness, radius of curvature, thickness, scratch hardness, COF against various materials, and wear rate.



Example of polycarbonate lens about to be tested on Nanovea Profilometer



Example of polycarbonate lens about to be tested on Nanovea Tribometer

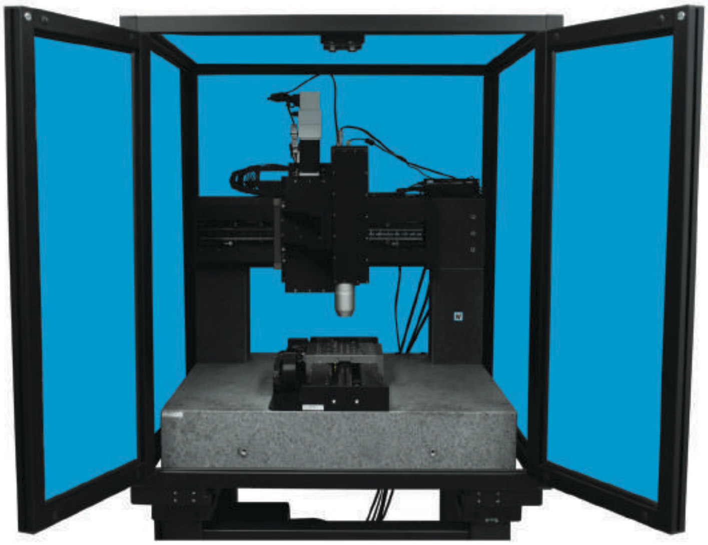


Example of polycarbonate lens about to be tested on Nanovea Mechanical Tester

PROFILOMETRY

EQUIPMENT FEATURED

NANOVEA HS2000



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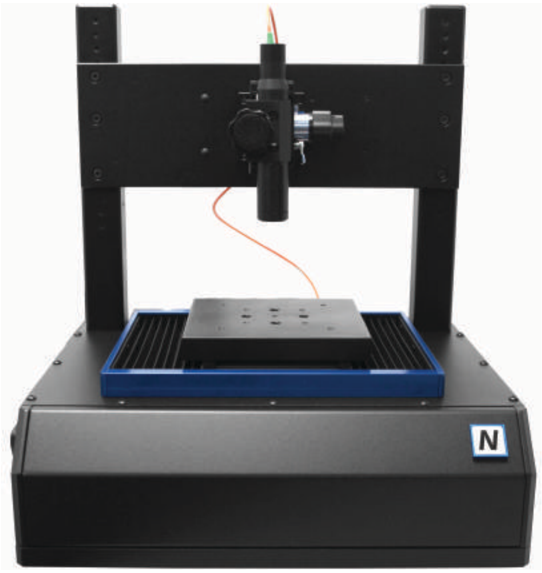

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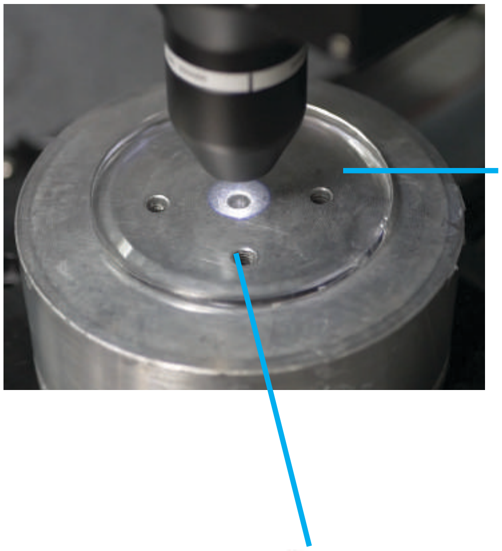
RADIUS OF CURVATURE AND ROUGHNESS

MEASUREMENT PARAMETERS

Table 1: Test parameters for roughness and radius measurements on the lens

Test Parameter	Value
Instrument	Nanovea HS2000
Optical Sensor	L1 Lens (200µm Z-range)
Scan size (mm)	10mm x 10mm
Step size (µm)	5µm x 5µm
Scan time (h:m:s)	00:01:02

The results from the profilometry measurements can be seen in Figure 1 and 2. The Figures below are 2D and 3D images of the lens's true form.



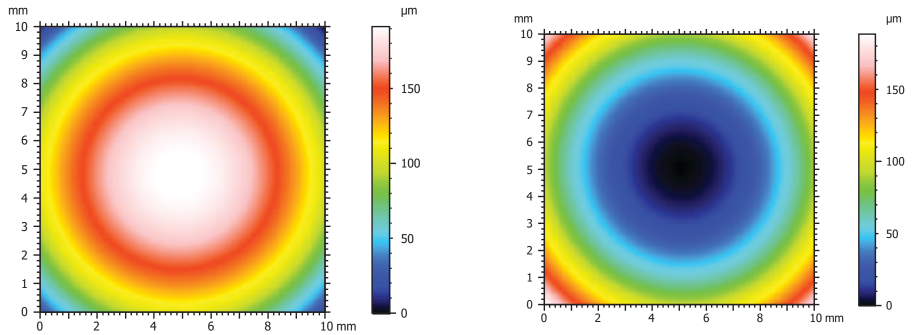


Figure 1: False-color view of front side (left) and back side (right) of polycarbonate lens

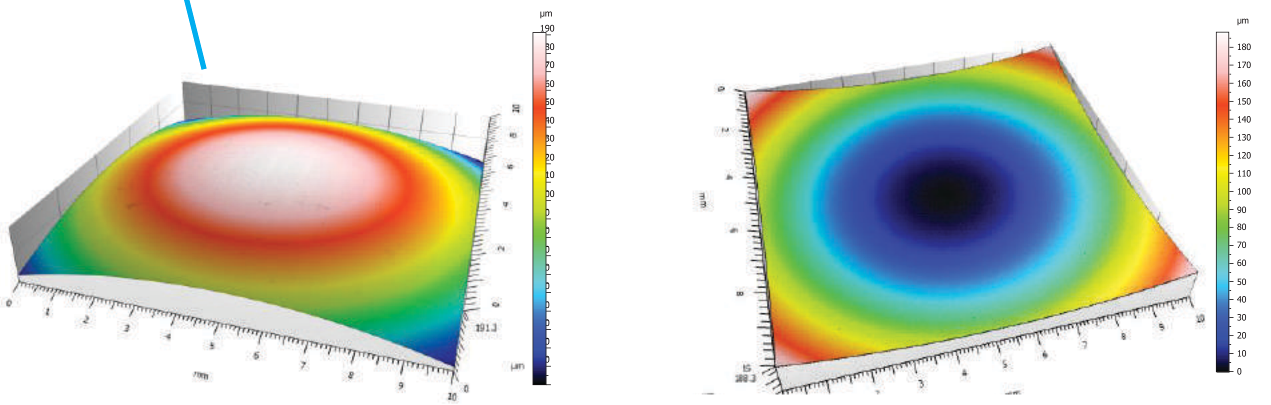
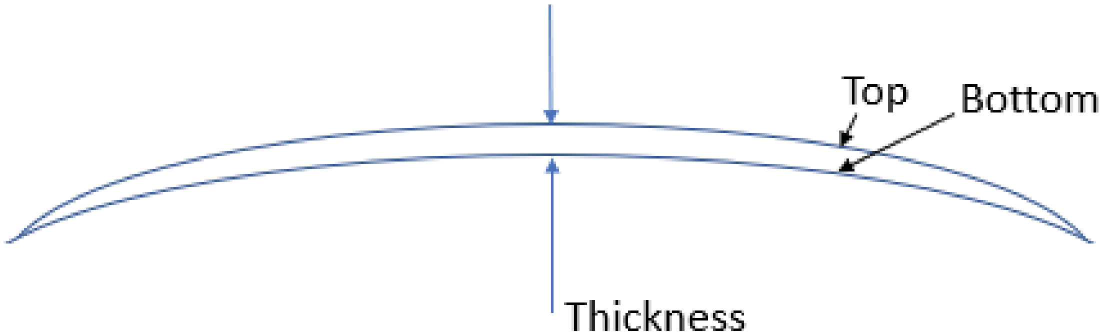


Figure 2: 3-D view of front side (left) and back side (right) of polycarbonate lens; amplified 10%

PROFILOMETRY

RADIUS

Conducting an area scan on the lens ensures the radius of curvature is captured at the apex of the curve. To observe the symmetry of the lens, radius of curvature was calculated from both the X- and Y-axis. Values of 142.1 and 135.5mm were obtained for the front side and 137.0mm and 139.2mm were obtained for the back side.



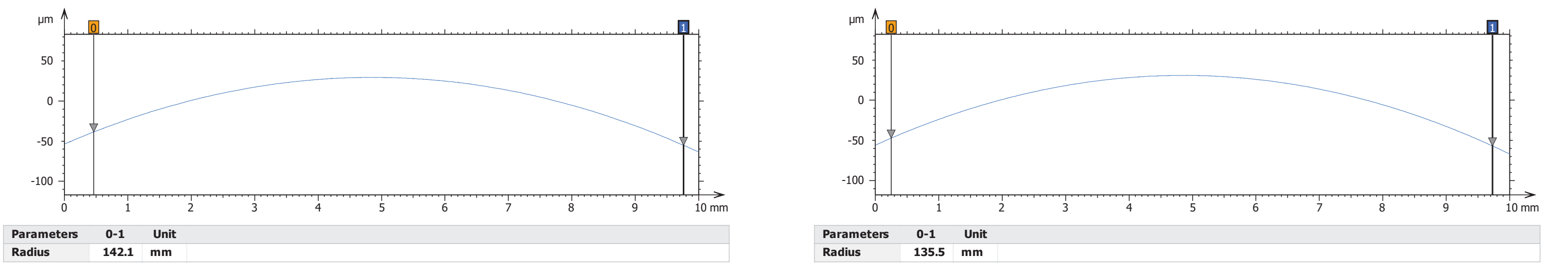


Figure 5: Profile extraction in the X-axis (left) and Y-axis (right) of front side of polycarbonate lens

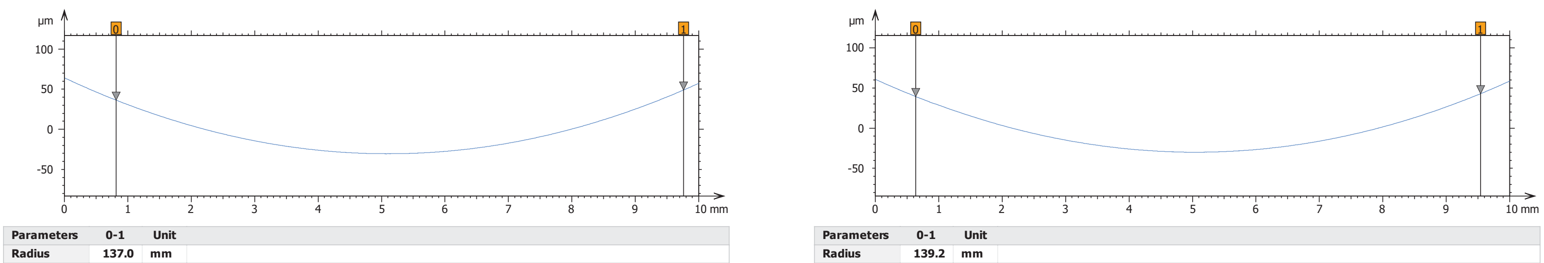
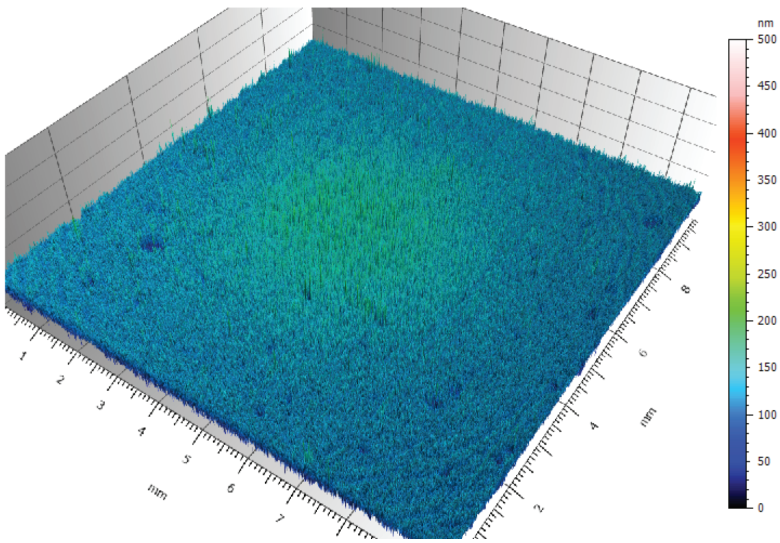


Figure 6: Profile extraction in the X-axis (left) and Y-axis (right) of back side of polycarbonate lens

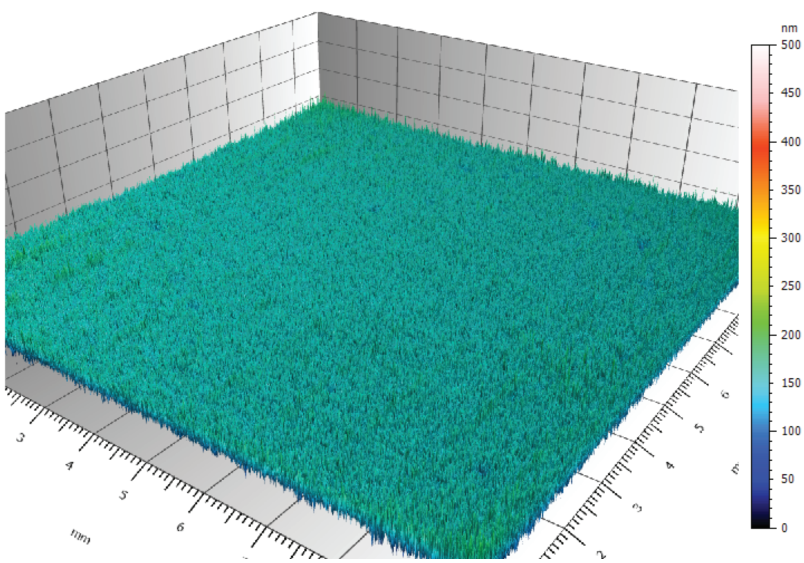
ROUGHNESS

To obtain roughness data, the form of the sample must be removed. A Gaussian filter with a nesting index of 0.25mm was applied to obtain roughness height parameters. An Sa value of 26.76nm was obtained for the front side of the polycarbonate lens, and 18.16nm for the back side of the plastic lens. Their respective Sq values were 37.77nm and 36.02. These values are very low and are ideal to minimize scattering of light when light interacts with the lens's surface.



ISO 25178		
Height Parameters		
Sa	0.02676	µm
Sq	0.03777	µm
Ssk	1.105	
Sku	19.22	
Sz	1.325	µm
Sp	0.8653	µm
Sv	0.4596	µm
Other 3D Paramet...		
Miscellaneous		
Sdar	96.05	mm²
Spar	96.04	mm²

Figure 3: 3D-view and height parameters of front side of polycarbonate lens after a Gaussian filter of 0.25mm



ISO 25178		
Height Parameters		
Sa	0.01816	µm
Sq	0.03602	µm
Ssk	37.09	
Sku	2554	
Sz	3.913	µm
Sp	3.381	µm
Sv	0.5324	µm
Other 3D Paramet...		
Miscellaneous		
Sdar	96.04	mm²
Spar	96.04	mm²

Figure 4: 3D-view and height parameters of back side of polycarbonate lens after a Gaussian filter of 0.25mm

THICKNESS

MEASUREMENT PARAMETERS

Table 2: Test parameters for roughness and radius measurements on the lens

Test Parameter	Value
Instrument	Nanovea PS50
Optical Sensor	PS5 (10000µm Z-range)
Scan size (mm)	5mm x 5mm
Step size (µm)	10µm x 10µm
Scan time (h:m:s)	00:36:32

Utilizing our point sensor system, the thickness of the polycarbonate lens was obtained. This measurement works by having a focal point at each surface. Having multiple focal points are possible due to our axial chromatism technique. The difference in refraction between air and the sample is corrected using the sample's index of refraction. The two surfaces, top and bottom, can be seen in figure 7. Since the coposition of our sample is unknown, this was set to a value of common plastic: polycarbonate – 1.58. By subtracting the two surfaces scanned, the thickness can be obtained. The mean thickness of the sample, scanned near the apex of the curvature, was found to be approximately 2.611mm.

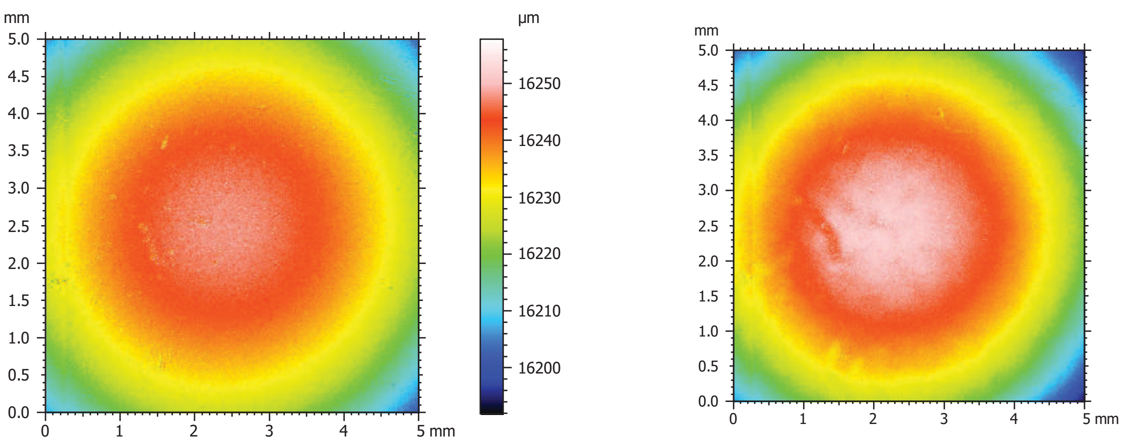
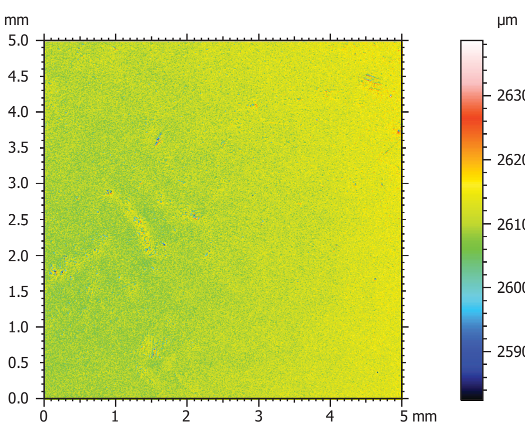


Figure 7: False-color view of top surface (left) and bottom surface (right)



ISO 25178		
Height Parameters		
Sa	2.134	µm
Sq	2.721	µm
Ssk	-0.1878	
Sku	4.576	
Sz	56.15	µm
Sp	27.79	µm
Sv	28.37	µm
Other 3D Paramet...		
Miscellaneous		
Sdar	27.11	mm²
Spar	25.00	mm²
Smean	2611	µm

Figure 8: False-color view (left) and height parameters (right) for thickness of polycarbonate

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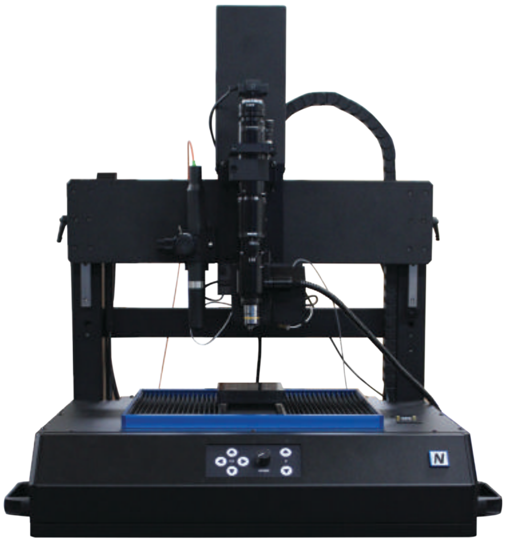


SCRATCH HARDNESS

MEASUREMENT PARAMETERS

Table 3: Parameters used for scratch hardness testing on polycarbonate lens

Test Parameter	Value
Load type	Constant
Final Load (N)	15
Scratch Length (mm)	5
Scratching speed (mm/min)	18
Indenter geometry	120° cone
Indenter material (tip)	Diamond
Indenter tip radius (µm)	200

SCRATCH HARDNESS

The scratch test was conducted in accordance to ASTM-G171. Scratches were made at the apex of the lens to minimize error caused by the curvature of the lens.

A scratch hardness of 420.59 ± 8.69MPa was obtained. As expected, the scratch hardness value is quite low due to the nature of plastics. For reference, the scratch hardness testing we previously conducted on aluminum, copper, and steel in the past were 0.84, 0.52, and 3.20GPa respectively [2]. Even though testing conditions were different, the scratch resistance of the polycarbonate lens appears to be in the same magnitude as a soft, scratch-prone metal like copper.

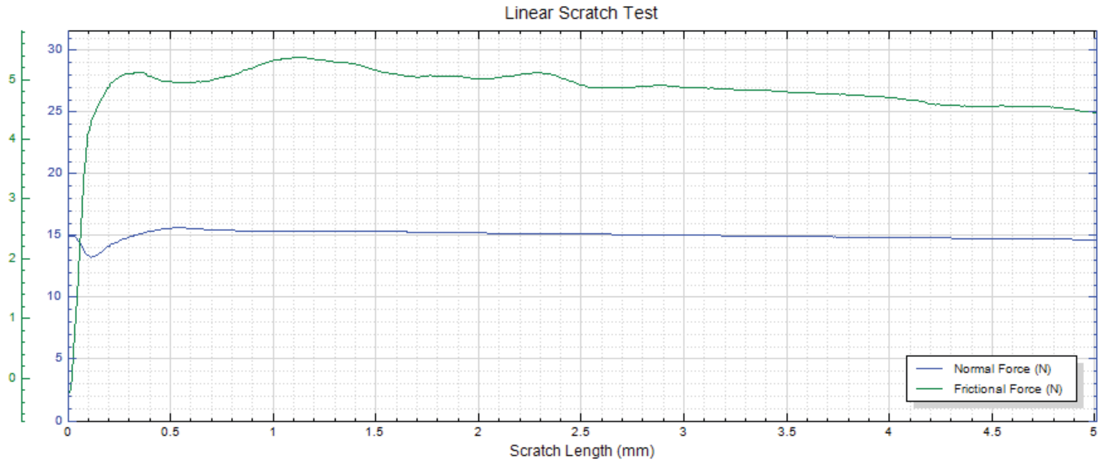


Figure 9: Friction graph obtained from the scratch test

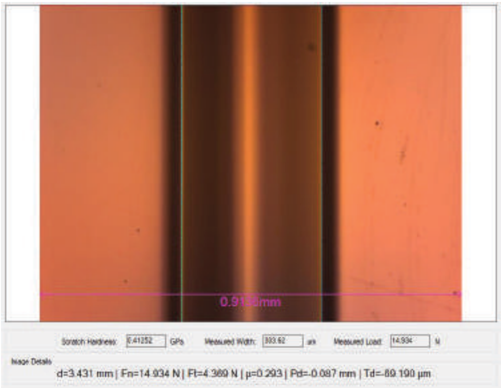


Figure 10: Scratch hardness measurement conducted under an optical microscope.
The blue dotted lines are positioned at the edge of the scratch to obtain scratch width.

Table 4: Results from scratch hardness test

	Measurement 1 (MPa)	Measurement 2 (MPa)	Measurement 3 (MPa)
Scratch 1	432.19	418.89	412.52
Scratch 2	431.51	416.25	413.4
Scratch 3	431.71	421.55	409.8

SCRATCH IMAGING WITH OPTICAL PROFILOMETRY

The polycarbonate lens was profiled with our profilometry instrument to closely inspect the outcome of the scratch test. A great deal of material was found to be surrounding the area where the scratch took place (Figure 13). The volume of material around the scratch (Peak) and the volume lost (Hole) are about the same. From this study, it is observed that the soft plastic seems to have been easily displaced during the scratch. This allows us to make the conclusion that the material has a low scratch resistance.

The mean depth of the scratch ended up being 7.864 ± 0.2652µm into the surface. This was obtained by extracting a series of profile across the scratched area and averaging the maximum valley depth (Pv) of each profile (Figure 14).

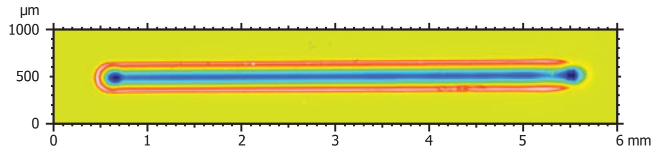


Figure 11: False-color view of a scratch made on the lens

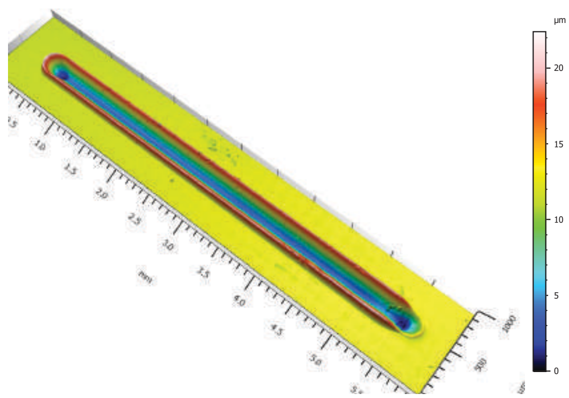
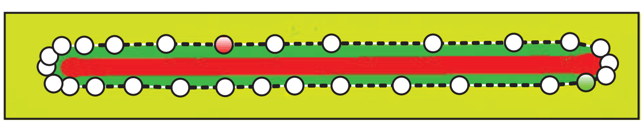
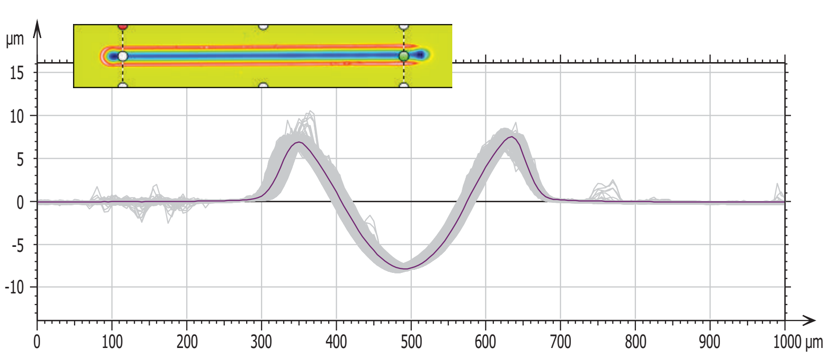


Figure 12: 3-D view of scratch made on the lens



Parameters	Unit	Hole	Peak
Surface	µm²	842375	1147975
Volume	µm³	4360728	4307441
Max. depth/height	µm	11.79	10.65
Mean depth/height	µm	5.177	3.752

Figure 13: Volume of a hole/peak analysis on the scratch created



		Mean	Std dev
ISO 4287			
Amplitude parameters - Primary profile			
Pa	µm	1.785	0.05234
Pq	µm	3.200	0.06309
Pz	µm	15.78	0.3143
Pp	µm	7.864	0.2652
Pv	µm	7.914	0.1409
Pc	µm	15.06	1.288

Figure 14: Extracted series of profiles (left) and their primary profile parameters (right). Red line indicates the mean profile.

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COEFFICIENT OF FRICTION

MEASUREMENT PARAMETERS

Table 5: Parameters used for coefficient of friction testing on polycarbonate lens

Test Parameter	
Load (N)	0.5
Test Duration (min)	5
Speed (rpm)	10
Radius (mm)	0.0-5.0
Total Distance (m)	0.78
Pin Geometry	Ball
Pin Material	Rubber, PTFE, ZrO_2, Al_3O_2, SS440C
Pin Diameter (mm)	6

Table 6: Pin-On-Disk material combinations

Combination	Disk Material	Pin Material
1	Polycarbonate	Rubber
2	Polycarbonate	PTFE
3	Polycarbonate	ZrO_2
4	Polycarbonate	Al_3O_2
5	Polycarbonate	SS440C

COEFFICIENT OF FRICTION

A Pin-On-Disk Spiral Test was performed to ensure that the pins would pass over an unworn region throughout all tests. The first five revolutions were cropped from the graphs. This was done to remove data when the radius was near 0 (minimal tangential movement). The curvature of the lens must be kept in consideration when analyzing the COF data.

The test results rank the following material from highest COF to lowest COF: Rubber, Al2O3, ZrO2, PTFE, SS440C. The tests conducted were performed with a small normal force to minimize the effects of wear on the sample.

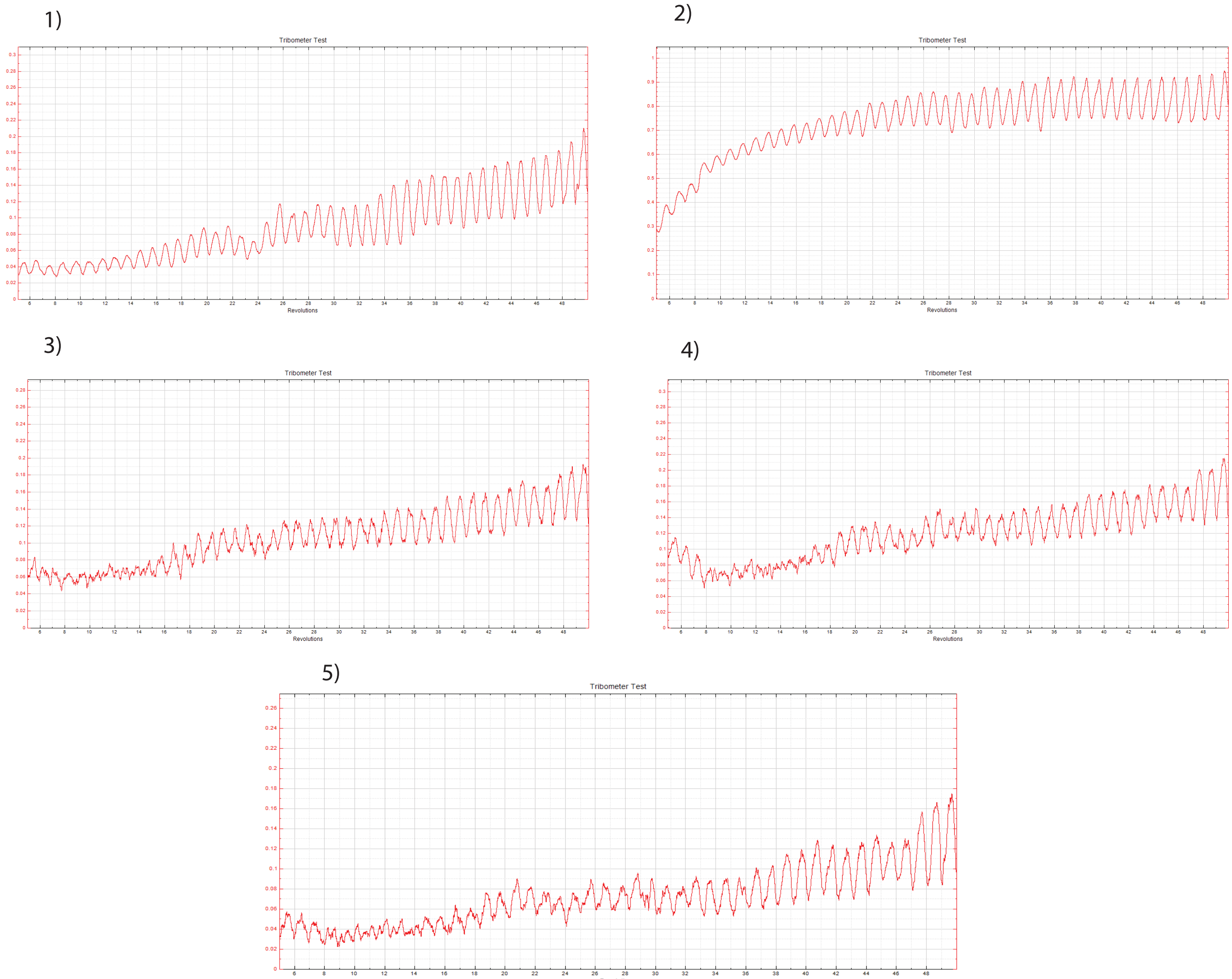


Figure 15: COF graphs of 1) Rubber, 2) PTFE, 3) ZrO2, 4) Al2O3, 5) SS440C

Table 6: Results of COF testing on Plastic Lens

Pin Material	Max COF	Min COF	Average COF
Rubber	**0.947**	**0.277**	**0.734**
PTFE	**0.210**	**0.027**	**0.089**
ZrO_2	**0.193**	**0.043**	**0.106**
Al_3O_2	**0.215**	**0.051**	**0.120**
SS440C	**0.175**	**0.022**	**0.072**

LINEAR WEAR

MEASUREMENT PARAMETERS

Table 8: Parameters used for linear wear testing on polycarbonate lens

Test Parameter	Value
Load (N)	20
Test Duration (min)	20
Speed (rpm)	100
Amplitude (mm)	10
Total Distance (m)	40
Ball Material	ZrO_2
Ball Diameter (mm)	6

The linear test was conducted near the apex of the lens to minimize effects from curvature. From the COF graph, two stages of wear can be observed. At 0-200 revolutions, the two surfaces are adapting to surface of the sample. After 200 revolutions, significant wear begins to occur. Loose particles created from the wear test are now rampant along the surface of the worn area, creating three-body abrasion wear. To accurately calculate wear rate, the volume loss was calculated by profiling the wear track, analytically removing the curvature from the lens, and conducting a volume of a hole study (Figure 18). A total volume of 577,479,379µm3 was lost. The zirconium oxide wore an average of 61.69 ± 6.830µm into the plastic lens.

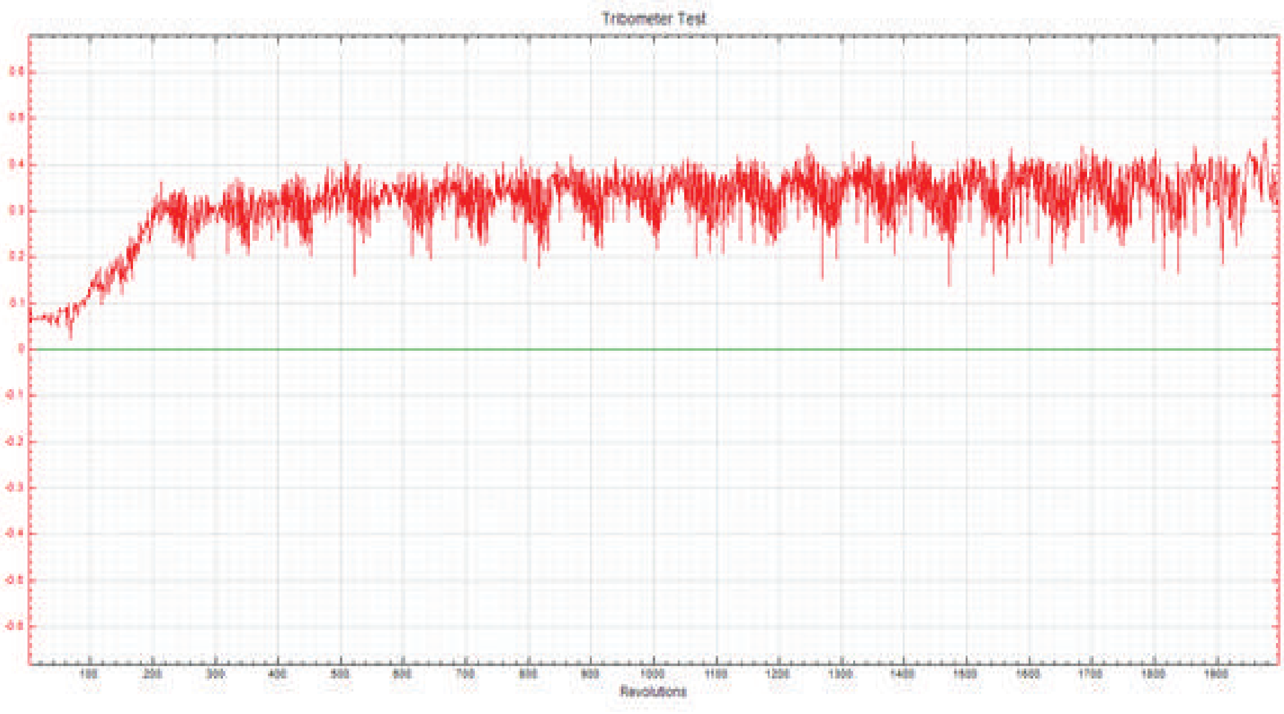
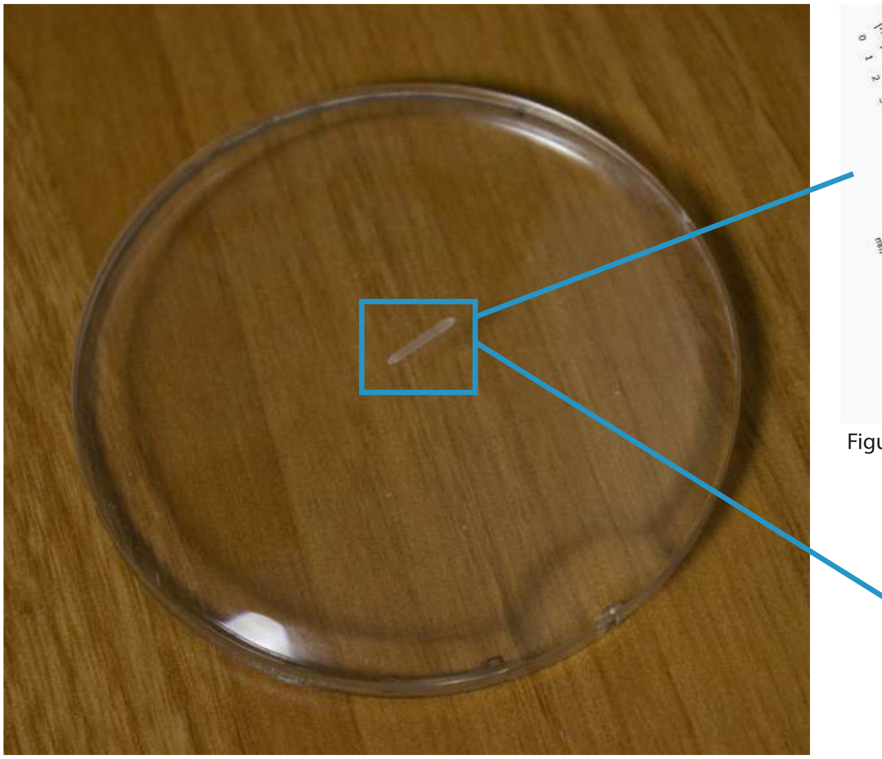


Figure 16: Friction graph from linear wear testing

LINEAR WEAR



Sample of polycarbonate lens with wear track

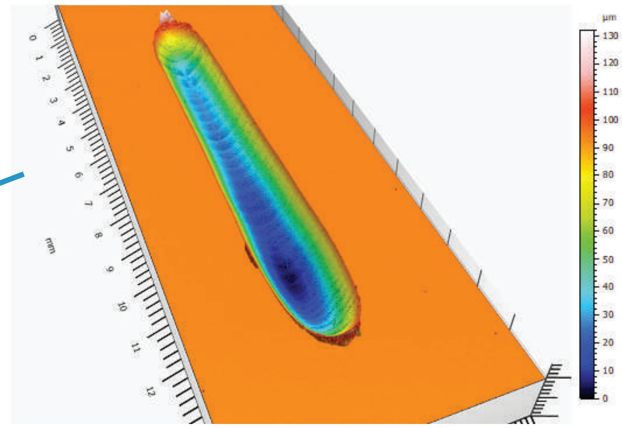
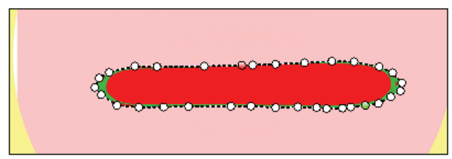
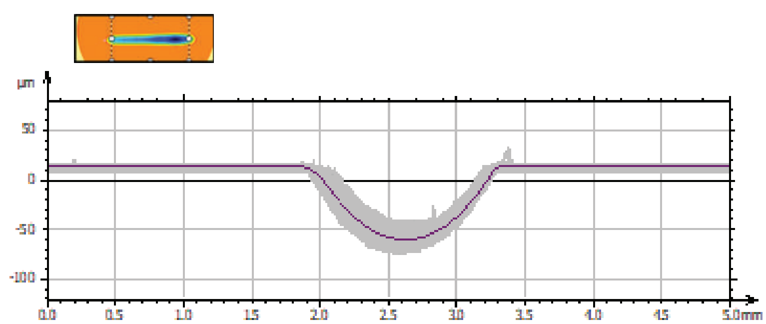


Figure 17: 3-D View of wear track created by linear wear test



Parameters	Unit	Hole
Surface	mm^2	12.33
Volume	μm^3	577479379
Max. depth/height	μm	94.02
Mean depth/height	μm	46.82

Figure 18: Volume of a hole analysis conducted on worn area



		Mean	Std dev
ISO 4287			
Amplitude parameters - Primary profile			
Pa	μm	19.59	3.305
Pq	μm	24.59	3.668
Pz	μm	77.59	10.71
Pp	μm	15.90	4.438
Pv	μm	61.69	6.830
Pc	μm	*****	*****

Figure 19: Extracted series of profiles (left) and their primary profile parameters (right). Red line indicated the mean profile.

Table 9: Linear wear testing results

Max COF	Min COF	Average COF	Volume Loss (μm^3)	Wear Rate x 10^{-5} (mm^3/Nm)
0.459	0.037	0.336	577479379	72.185

CONCLUSION

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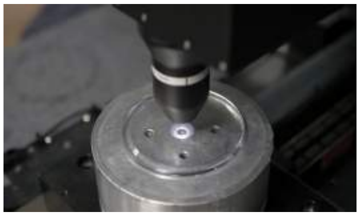
Important properties of polycarbonate lens were investigated using Nanovea's metrology instruments. The ability to accurately measure and quantify properties of materials is important for material selection and quality control processes.

The different types of testing show Nanovea is able to target a wide variety of specific applications with our instruments. Environmental conditions can also be easily applied with our temperature, humidity, lubrication, and corrosion modules.

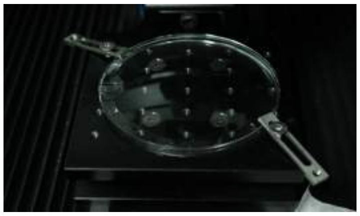
Profilometry testing included roughness, radius, and thickness measurements.

Download our Profilometer Brochure!



Scratch resistance or scratch hardness testing was conducted on our mechanical tester

Download our Mech. Tester Brochure!



The COF and wear rate of the plastic lens was obtained by using the tribometer.

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Thank you for reading our application note!

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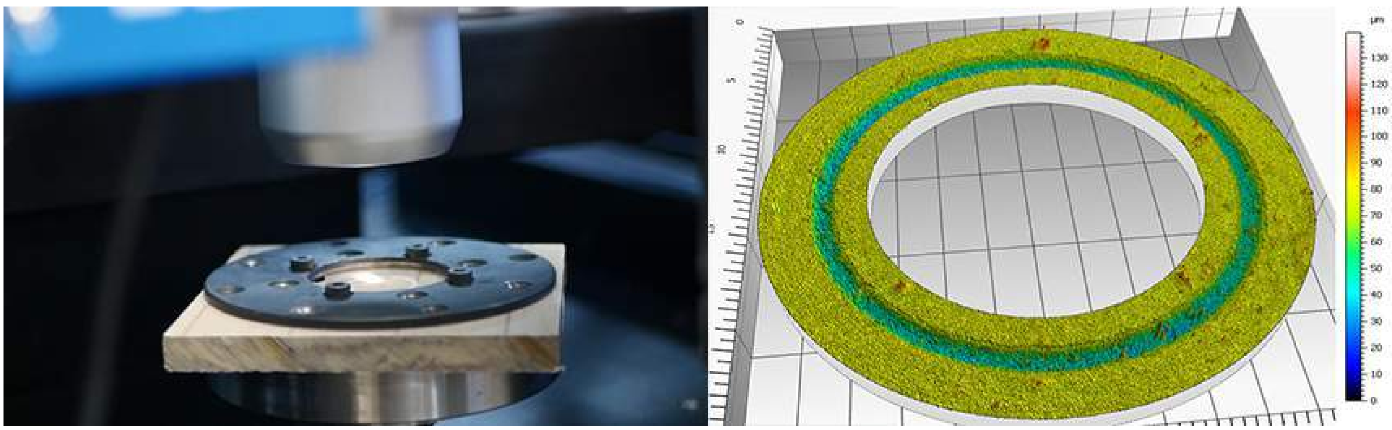

If you have any other questions please call or email us at anytime and we will get back to you as soon as we can!

www.nanovea.com/contact

REFFERENCES

[1] Kogler, Kent. "Selection of plastics for optical applications." Advanced materials and processes technology (1999).

[2] Li, Duanjie. "SCRATCH HARDNESS MEASUREMENT USING MECHANICAL TESTER." (2014).