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Fracture characteristics of chem-tempered lenses

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Abstract
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Fracture Characteristics

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STRENGTHENED LENSES

The problem of eye protection from the shattering of spectacle lenses has recently been addressed by the Federal Food and Drug Administration and the American National Standards institute's Z80.1 drop ball test. It specifies a minimum fracture resistance for all spectacle and safety lenses.

It is now understood that surface flaws are the underlying cause of lens breakage. Any stress that lenses are subjected to is concentrated at these flaws rather than being distributed evenly across the surfaces. Therefore, ordinary annealed glass that isn't absolutely free of even minute scratches is relatively weak.

Acid Etching:

A technique developed to remove the surface flaws of glass and strengthen it in this way is called acid etching. There are problems inherent with this procedure, however, that make it impractical for ophthalmic lenses.

INTRODUCTION AND PURPOSE

Although chemical strengthening of glass is not a new technique, its use for ophthalmic glass is. Much of the early work, done in the mid 1960's, was carried out at Corning Glass Works, Pittsburgh Plate Glass Corporation and the American Optical Corporation. Corning had used the process earlier for the production of impact resistant aircraft and automotive windshields.

In 1971, developmental work was undertaken to adapt the process for ophthalmic lenses.(1) The need created for strengthened lenses by recent legislation has increased the importance of this work. Several laboratories in the Portland, Oregon, area are now using the chem tempering process developed by Corning. It is at present being done on a limited basis pending further availibility of information about the characteristics of lenses treated in this way.

The purpose of this study is to further investigate the fracture characteristics of chemically treated lenses and to make direct comparisons with lenses that have undergone the heat tempering process. The relevancy of making this comparison can be found in the fact that the heat tempering process is currently the most widely accepted method of increasing the fracture resistance level of glass lenses.

Another method of strengthening glass is to place the surfaces under compression. Any external force placed on the lens must first overcome this surface compression before breakage can occur. Although this type of procedure tends to minimize the effect of surface scratches, the impact performance of lenses strengthened this way will depend directly on the effective compression remaining at the top of the deepest flaw. The two methods used to put a surface compression on glass are air tempering - more commonly know as heat tempering, and chemically induced compression.

Air Tempering:

In air tempering, the lens is heated to just below the softening point of the glass. This causes the glass to expand slightly. The outer surfaces are then frozen in this expended state by hitting the lens with a blast of cool air. As the interior of the lens cools, it goes into tension. The interior wants to return to its original size, but is prevented from doing so by the already rigid outer surfaces. Studies have shown that this process makes lenses 2 to 3 times as strong as annealed glass.[2] There are several drawbacks of heat tempering which are discussed later in this paper.

Chem Tempering:

The chemical tempering process involves submerging the lenses in a bath of liquie nitrate salts which are kept at a temperature of 350^{o} to 500^{o} C, well below the melting point of glass. In the salt bath, a chemical ion exchange occurs. Sodium ions from the lens go into the solution and potassium ions from the salt bath diffuse into the lens.

How chemically strengthened lenses compare with those heat treated will determine the process's acceptance in the ophthalmic industry and in professional practices.

Parameters compared are fracture resistance as it varies with (1) powers and (2) thickness (2.2 mm and 3.0 mm). Our methods are designed to make our results comparable to studies on heat tempered lenses done to Wigglesworth,[1] Davis and Brandt,[2] and Chase, Krause and Kozlowski.[3]

The testing was extended to include lenses of varying cylindrical powers, fixed tints, multifocal lenses and drilled and notched lenses. There haven't been any comparable studies with heat tempered lenses that consider these factors, so they will be used as a comparison among the variables of the chem tempering process alone.

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(1) Wigglesworth, E.C., The Impact Resistance of Eye Protector Lens Materials. American Journal of Optometry and Archives of American Academy of Optometry, March 1971, pg. 245-260.

(2) Davis, John K. and Brandt, Neill M. "Variables Affecting the Impact Resistance of Glass Ophthalmic Lenses. American Optical Corp., Optical Products Division Southbridge, Massachusetts.

(3) Chase, George A., Reinhard P. Krause, and Theodore R. Kozlowski. Chemical Strengthening of Ophthalmic Lenses. Journal AOA, Vol. 43. No. 10, Sept. 1972, pg. 1-7.

TESTING METHOD AND APPARATUS

To test the chem tempered lenses, the mean fracture height using the drop ball test was selected as the way of assessing the fracture resistance. This method was chosen for several reasons. (1) Previous tests of heat treated lenses used the same method. This allows for direct comparison of results. (2) The mean fracture height will determine the full strength of a sample in comparison to a minimum standard level of performance under similar conditions of applying stress to a lens. (3)Limitations of both financial and materials resources precluded a study of fracture resistance to smaller higher velocity objects.

609 lenses were obtained from the College of Optometry, Pacific University. We chose a sample of new lenses (which we cut and edged), used lenses, multifocals, fixed tints, and drilled and notched lenses. We included a power range from -7.00 D to +4.00 D and two thicknesses; 2.2 ±.1 mm and 3.0 ±.1 mm. Each lens was checked for power and cylinder with a lensometer, overall condition and center thickness with a Vernier Caliper. Each was classified into an appropriate category according to its parameters.

Testing was done on a rigid 14 foot tower. It was aligned so that a partially guided 1" steel ball weighing 66.7 grams dropped from within the range of heights used, would fall within a 3/16" diameter circle in the center of the lens holder. The holder conformed to the ANSI Z80.1 specifications. The entire apparatus was secured to the floor and wall to elimate any movement or misalignment.

A 1" steel ball was used due to tower height limitations. Our comparison studies also used a 1" ball, so although the contact area of the impacts differ slightly from a 5/8" ball, the results are still comparable.

The initial height the ball was dropped from was 36". This was chosen because the force in foot/pounds of a 1" steel ball dropped from this height is comparable to the Z80.1 standard of 7/8" ball dropped from 50". The height the ball was dropped was increased until the lens fractured.[4]

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[4] This repeated impact method assumes that if the lens survives the initial impact, it could continue to resist breakage from that height indefinately. However, it has been shown that a single drop will cause microscopic flaws which weakens the lens. But, as the study makes comparisons with other studies that used the same methods, our results can be considered valid.

To prevent scratching of the lens by the dropped ball, each lens was covered by a 3" x 3" piece of Handi-Wrap.

The mean fracture height was also converted to foot/pounds of force.

Temperature and humidity were largely ignored. An ASSE report showed that the strength of glass lenses are about the same through a temperature range of 75° F. to 150° F. and slightly stronger at 0° F. It, therefore, seems unlikely that any temperatures we encountered would significantly influence the results.[5]

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[5] Plastic Eye Protectors, Chicago, National Safety Council, 1947.

RESULTS

When we initially started our study we felt there would be certain factors which could influence the fracture height of a lens. These factors are listed below along with a short statement of what we found in our study on chemically tempered lenses. They are:

1) Sphere Power - It appears to be a factor in our study. Plus lenses of the same center thickness as minus lenses were more resistant to fracture using the drop ball test. As the power of the lenses increased in minus the less resistant they were in most cases. This same trend was apparent in the heat tempered lenses and all the other studies we reviewed prior to doing our study.

2) Center Thickness - We chose to use only 2.2 $\pm$.1 mm and 3.0 $\pm$.1 mm thick lenses in all cases except for the drilled and notched lenses. The 3.0 lenses were much stronger than the 2.2 thick lenses in our study as well as for studies on heat tempered.

3) Cylinder Power - It doesn't appear to show any particular trend as far as increasing or decreasing the strength of the lens. In most cases, regardless of the power of the cylinder (up to -6.00 D in our study), it was within 6" of the mean value for that sample of lenses.

4) Single Vision Lenses vs Bifocals - When lenses of similar physical conidition and the same center thickness were compared, the bifocals in that sample were stronger than single vision lenses. We also kept track of the type of bifocal and the 4 types tested (Ft-22, Ft-25, Kryptok, and Panoptic). Their respective mean values for fracture all fell within a 6 inch range with the median value being 64.5 inches. So, the type of bifocals didn't appear to be particularly significant for the used chem tempered bifocals.

5) Tinted Lenses - These appear to be less resistant to fracture than the clear crown lenses that were chem tempered. We tested two types of tints and the data showed quite a difference in their mean fracture heights. The therminon tint had a mean fracture height 80 inches and the G-15 tints were 55.5 inches and we were unable to obtain information as to why this discrepency appeared.

6) Drilled and Notched Lenses - These lenses were the weakest of all the lenses we tested. Chem tempering does increase their strength approximately 3 times greater than the non tempered crown which can not be heat treated. We also varied the center thickness in these lenses in order to have a large enough sample of lenses. Though the small sample did cause some discrepencies, in general, we found a gradual increase in strength with increasing center thickness; this is also the case for all the literature on heat tempering.

7) <u>Shape</u> - We failed to find that shape was a significant factor in fracture height unless the lens was a small tear drop shaped lens which did not fit with all its edges over the rubber washer on the lens holder. These lenses fracture at a consistently lower height but it was due to the testing conditions rather than the lens strength.

8) <u>Base Curve</u> - We originally planned to keep data on the base curves of the lenses, but during the verification process we found that 95% of our lenses were within a range from +6.00 D to +7.00 D and since some previous investigators* had ruled out base curve as a major factor in lens strength, we decided not to use this part of the data.

Several trends are apparent as to the lenses we tested. They are:

1) New chem tempered lenses are from 1.5 to 2.0 times stronger than the used chem tempered samples we tested.

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*Wigglesworth, E. C., "The Impact Resistance of Eye Protector Lens Materials." (He quotes studies by Silberstein & Lueck). Archives of American Academy of Optometry, Vol. 48, 1971, pg. 246.

2) 3.0 mm lenses are more resistant to fracture than 2.2 mm thick lenses.

3) Bifocal lenses of the same center thickness and power appear to be more resistant to fracture than single vision lenses.

4) Tinted lenses appear to be less fracture resistant than clear lenses.

5) For used drilled and notched lenses chem tempering increased their strength 2.8 times over the used non tempered lenses (so actually the process should increase their strength 4 to 6 times in new lenses).

Comparison of Impact Test Results of Various Workers

3.0mm NEW Lenses with 6.00 Base Heat Treated

7/8" Ball Size

Source	Number of Lenses	Median	Mean	Range	FT. LBS. Force Range
Peters	25	125	114	85-130	0.70-1.07
Silberstein	44	126	121	65-175	0.54-1.44
Wigglesworth	20	X	123	91-177	0.75-1.46
Chem. Temp. using 1" steel ball					
Wright, Garton & Luehrs	28"	141"	128.9"	114- 168"	1.40-2.07

1" steel base weighing 66.7 grams or .147 lbs.

FT LBS.= Fr. Ht. (infeet) X .147 lbs.

Data Comparison for New Chem. Tempered lenses

	2.2 Chem. Temp.	3.0 Chem. Temp.
Range	72-168"	114- 168"
Median	120"	141"
Mode	108"	132" & 120"
Mean	112.3"	128.9"

Sph. Power		
-4.25 to -5.00	84	X
-3.25 to -4.00	94	X
-2.25 to -3.00	103*	120"
-1.25 to -2.00	119*	132"
-0.25 to -1.00	94.2	X
PLANO	104	X
+0.25 to +1.00	114	X
+1.25 to +2.00	105*	126"
+2.25 to +3.00	162	131"

*small sample of lenses for this group.

Data Comparison of 2.2 vs. 3.0mm center thickness lenses

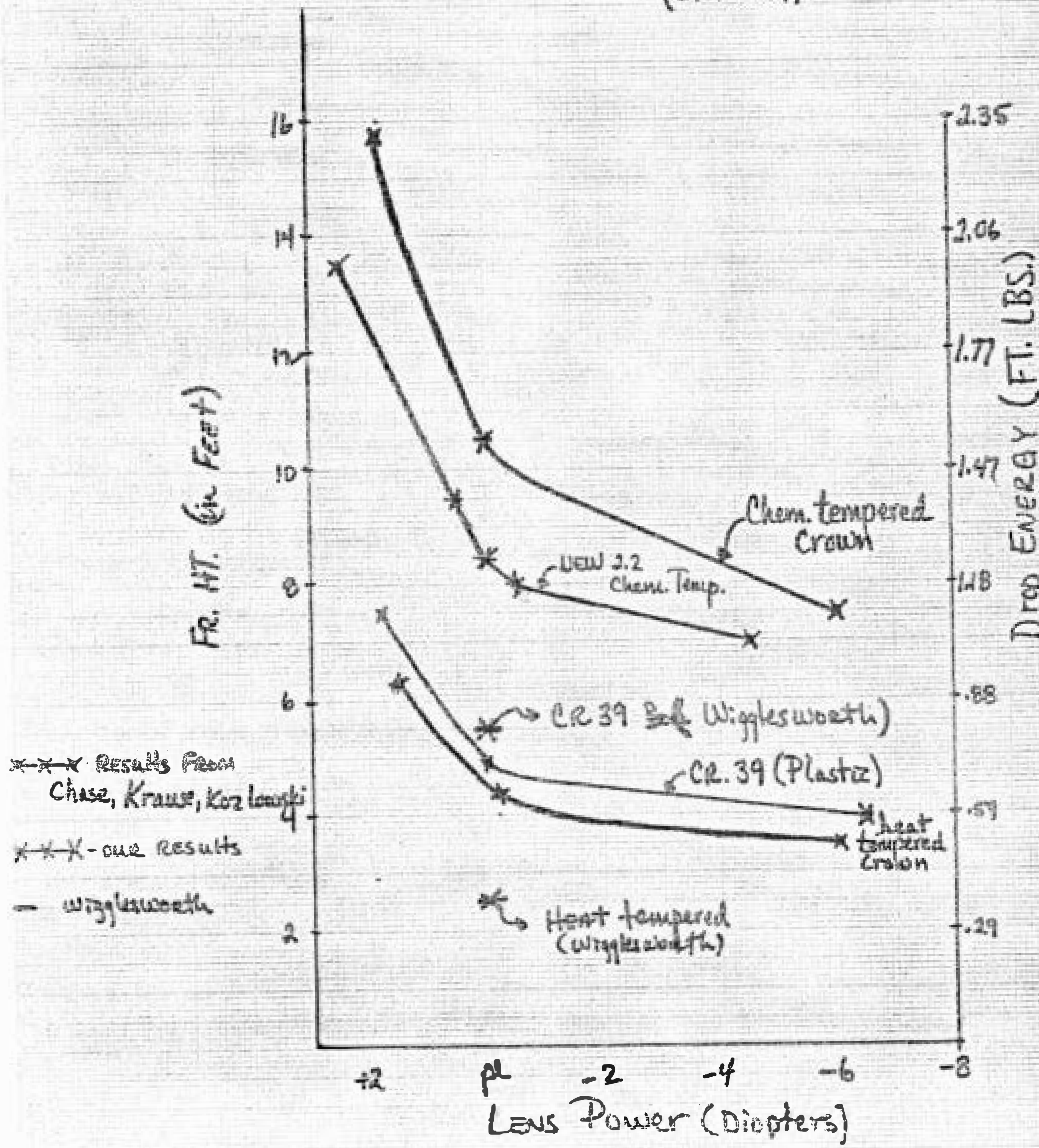
	2.2		3.0	
	New	Old	New	Old
Single Vision	112.3"	66.5"	129	114.5"
Tinted	58.5	X	118.7"	X
Bifocal	X	64.3"	X	112"

Data Comparison for Used Chem. Tempered Lenses

	Single Vision				Drilled & Notched	
	2.2 Chem. Temp.	Re-Temp 2.2	2.2 Tinted	3.0 Chem. Temp.	Non-Tempered	Chem. Temp.
Range	42-120"	66-108"	42-102"	90-134"	6-30"	38-78
Median	81"	87"	72"	112"	18"	54"
Mode	54"	78"	54"	134"	18"	42"
Mean	64.4"	84.4"	58.5"	114.6"	17.6"	49.3"
Bifocals						
Range	48-102"		60-102"	102-132	12-24"	36-72"
Median	75"		81"	117"	18"	54"
Mode	54"		84"	102"	24"	66"
Mean	64.3"		77.4"	112	21"	56.3"

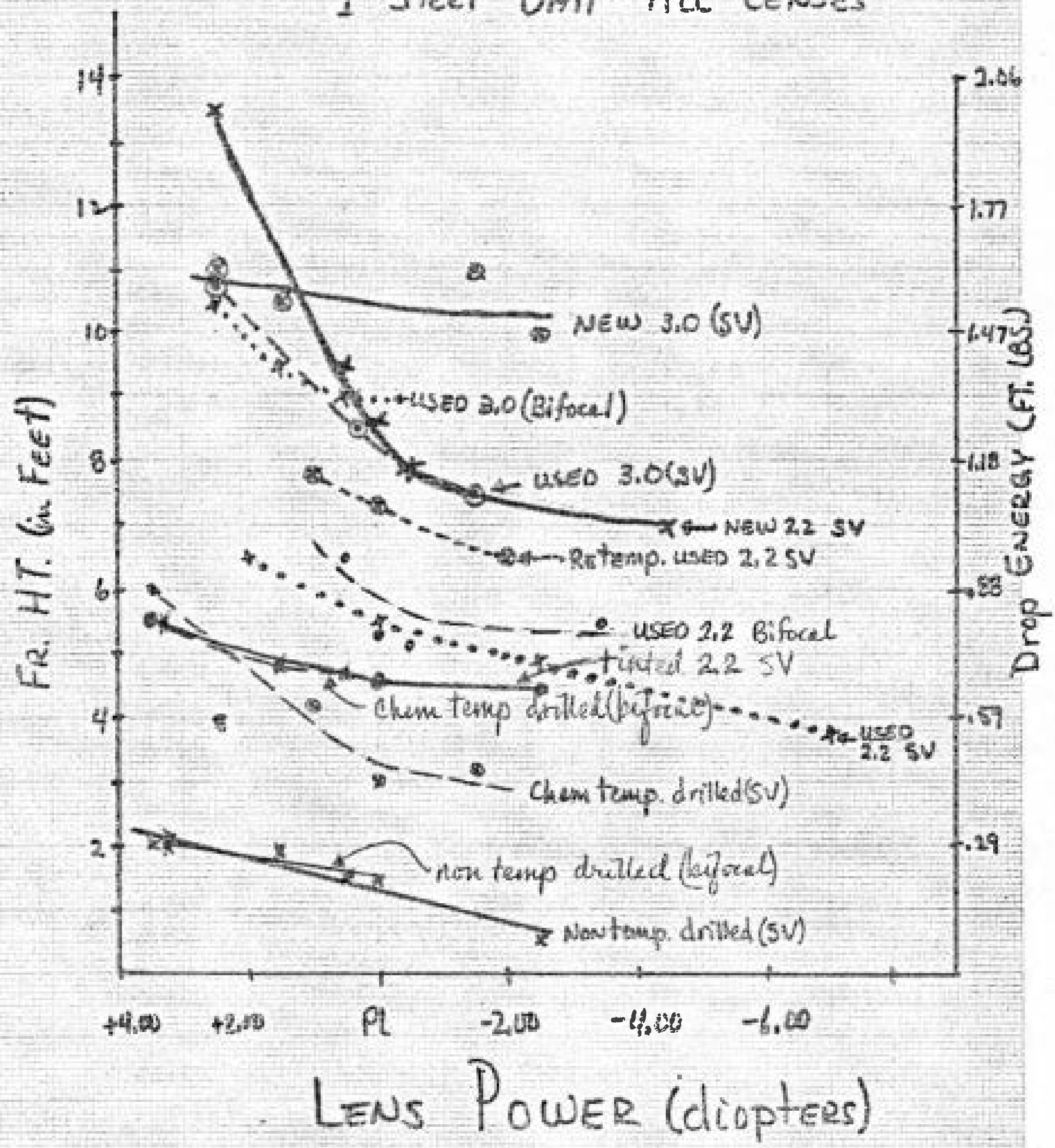
Graph #1

Impact Test Results
1" steel ball
(2.2 mm.)



Impact Test Results

1" steel ball - All Lenses



CHEM TEMPERED LENSES COMPARED TO HEAT TEMPERED

Advantages

(A) Increased Fracture Resistance:

From this study the most obvious advantages offered by chem tempered lenses is an increased fracture resistance to the conditions of the drop ball test. Of the 609 lenses tested not a single one failed at the Z80.1 standard. Refer to the results and summary sections of this report for specific value and comparisons with heat treated lenses.

(B) Drilled and Notched Lenses Can Be Chemically Strengthened:

They cannot be heat tempered. Our study shows them to be almost 3 times stronger than untreated drilled and notched lenses of comparable powers and thicknesses. This gives an option to plastic lenses for frames that require drilling or notching for mounting.

(C) All Types of Lenses Can Be Tempered Without Altering The Process:

With heat tempering, the thickness, and tint must be considered for each lens and the process adjusted accordingly.

The chem tempering process is not dependent of the shape or weight of the lens and is relatively independent of glass types and colors. Corning's laboratory work has shown that lenses of all curves, sizes, shapes, single vision or multifocal, tinted or clear can be strengthened together in the same bath using a single time and temperature cycle. Although photochromic lenses can also be included in the same batch and still pass the drop ball test, a different processing solution and temperature are normally used to give them their greatest impact resistance.

(D) No Loss of Optical Quality:

A far lower temperature is required for maximum strength with chem tempering than for heat tempering. Therefore, there is no warpage or disturbance of the original optical characteristics of the lens. In heat tempering of the lenses the labs have a +1.00 D diopter change in base curve as a tolerance limit.

(E) Chem Tempering is a More Economical Process:

Because chemically tempered lenses are considerably more resistant to breakage with the standard drop ball test, there will be less loss to labs and the practioners who temper the lenses, in the form of breakage. This means a savings in both money and time.

(F) Thinner Lenses are Possible:

Although our study did not investigate the minimum thickness at which a chem tempered lens could pass the Z80.1 requirement, thinner lenses are definately a reasonable possibility. The reason is that the required thermal gradient of heat tempered lenses which necessitates minimum center thickness of approximately 2.0 mm is not a requirement for chem tempered lenses. Thinner lenses allow for reduced weight and improved cosmetic appeal.

(G) Chem tempered lenses have less internal tension stored in them than heat tempered lenses. This allows for (1) less susceptibility to scratches and surface flaws caused by normal wear and abuse. This means they maintain their protection longer than heat treated lenses. (2) Less chance for spontaneous fracture. (See section under Spontaneous fracture).

Disadvantages

When making a comparison with heat tempered lenses, very few disadvantages that are entirely characteristics of chem tempered lenses can be stated.

(A) Identification of chem tempered lenses is considerably more difficult than for heat tempered lens. Because of the uniform stress over the surfaces of the lens, no characteristic Maltese Cross can be observed with the Colmascope. A rainbow pattern will be seen if the lenses are viewed through the edges. This is caused by the surface tension layers.

Some labs are putting a dot of special silver paint on the edge of the lenses before they are chem tempered. But to remove and verify all lenses from the labs would be a considerable inconvenience. The best assurance that a lens has been properly chemically strengthened is the chem tempered lens certificate provided by the laboratory.

(B) The processing of chem tempered lenses takes 16 hours. Heat treatment takes only about 3 to 4 minutes. This, however, is offset by the fact that all types of lenses can be processed in the same bath and the larger units can handle up to 2000 lenses at once. Also, the tempering can be done over night. The process is automatic and requires no immediate supervision.

(C) Our attention to the fracture characteristics of chemically tempered lenses that failed the drop ball test showed the lenses to break into (1) larger irregular pieces of glass with sharp edges (2) medium to small, sharp, jagged slivers of glass and (3) very fine particles of glass. While heat tempered lenses have been claimed to break into less dangerous squarish pieces, a study by Rose and Stewart[7] found that the vast majority of the heat toughened lenses broke, at least partially, into sharp pointed dagger like pieces, accompanied by a considerable number of fine sharp splinters quite similar to chem tempered lenses.

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[7] American Academy of O. & O., pg. 404-410.

SPONTANEOUS FRACTURE

Heat and chemically tempered lenses obtain greater strength via greater surface tension. But there is a limit to this relationship that requires the surface energy in the form of compression to be balanced by internal energy in the form of tensile stress. The nature of heat treatment requires a maximum of internal stress to obtain the increased surface strength. The thermal gradient require to bring about this relationship necessitates a minimum thickness for effective tempering. Spontaneous fracture can result if a surface flaw penetrated the compression and layer and extends into this internal tension zone.

Chem tempering doesn't require a thermal gradient and therefore avoids this violent disintegration of a lens by maintaining low levels of internal energy in comparison with heat treated lenses. Should the internal energy be released suddenly by a deep flaws, a slowly propagating fracture would develop which at worse may cause the lens to split into several pieces. These pieces would most likely remain in the frame.

The importance of this is shown in a recent article in the American Optometric Association News.[8] Of the eleven malpractice suits in 1972 that involved lens fracture 4 of them (37%) of these were results of spontaneous fracture and no physical contact whatever with the lenses were reported.

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[8] American Optometric Association News, pg. 6, April 1973.

RELATION OF STUDY TO THE APPLICATION OF CHEM TEMPERED LENSES

In a sense, chem tempered lenses are "super" heated treated lenses. They have all of the advantages of heat treated lenses plus several advantages of their own. Additionally, they are free of many of the heat processes advantages. There is no application of heat tempered lenses in which chemically tempered lenses would not be equal, and in most instances superior. In industry particularly, heat treated lenses have proven their practical value by the reduction which they have effected in industrial eye injuries. By virtue of their increased fracture resistance, we would expect chem tempered lenses put to the same type of use would further reduce eye injuries.

Chem tempering can be done on drilled and notched lenses. This offers the vision care practitioner and the patient a more scratch resistance and non-yellowing alternative to plastic lenses.

By the way of the reduced center thickness chem tempering allows, high minus lenses can be more cosmetically appealing and of less weight.

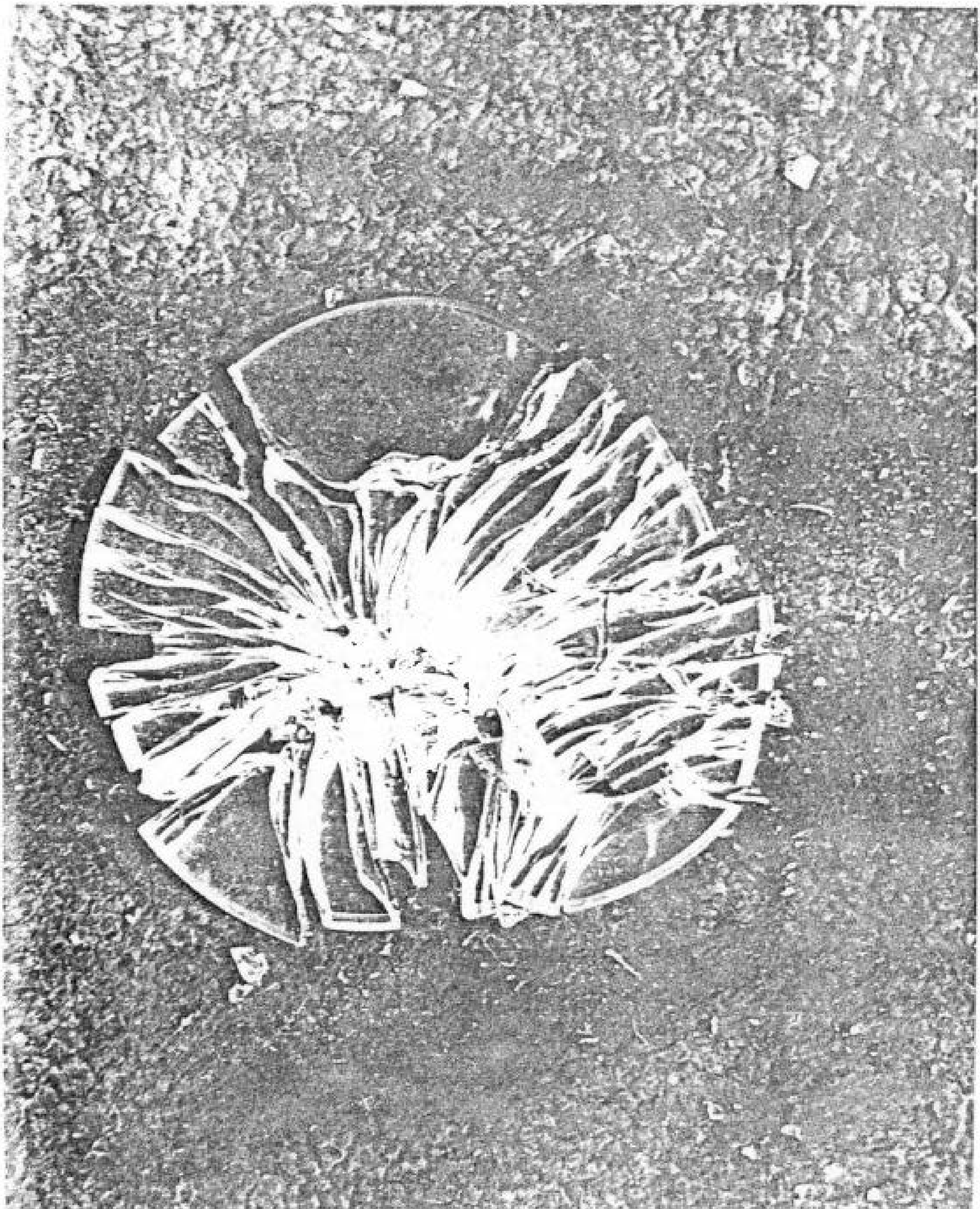
To summarize this section, we have found no reason why chemically tempered lenses will not soon replace heat tempered ones in all phases of application.

SUMMARY AND CONCLUSIONS

This study was done to investigate the fracture resistant characteristics of chemically tempered lenses. One of our primary interests was to make comparisons with heat tempered lenses because they are the accepted standard for strengthened lenses at present.

Our most obvious conclusion is that the chemically treated lenses have a higher level of impact resistance to the conditions of the drop ball test than do heat tempered lenses. In comparison, the chem tempering process offers increased strength, lighter weight, improved optics, better retention of strength as it is subjected to daily abuse, an almost zero potential for harmful spontaneous fracture, more convenience of processing and it allows for effective strengthening of drilled and notched lenses. Disadvantages that would cause a preference of heat treated lenses over chem tempered lenses are non-existant. The fact that 11 of the 28 malpractice suits filed against O.D.'s in 1972 involved fracture spectacle lenses,[5] would be a considerable arguement for providing stronger lenses by the chemical tempering process.

In conclusion, we feel that the chem tempering process developed by Corning should become the next standard of strengthened ophthalmic lenses. Also the minimum standards should be increased to reflect this advancement.



LIMITATIONS AND CRITICISMS OF THE DROP BALL TEST

Our testing and research has led us to several conclusions about the drop ball test. We recognize it as being a convenient test that ensure repeatable conditions of constant severity. It allows for establishing a minimum standard such as the Z80.1, and an easy means of comparing a lens to this minimum level of performance.

However, this type of testing is arbitrary in nature and has an extremely doubtful correlation with actual applications. It does not take into account various sizes and types of missles, various velocities, angles of impact or, possibly most important, the effects of the lenses being mounted in spectacle frames and the give of the frames while on the face[1] It does not discriminate between higher quality lenses and the ones just able to pass the drop ball test.

We feel that the drop ball test should be used only by ophthalmic manufacturers and laboratories as a standard of production control, not as a minimum acceptable standard. Much more comprehensive testing of the strengthening methods that become available in the future is desirable. As an example Wigglesworth [2 & 3] and Rose and Stewart[4] have found that heat toughened lenses are actually more susceptible to fracture whem impacted with small high velocity particles than ordinary annealed glass, yet the heat treated lenses successfully withstands the drop ball test.

FOOTNOTES

(1) Davis & Brandt have the opinion that the greatest amount of protection that spectacles offer is due to the fact that there are simply a flexible shield in front of the eyes - regardless of the type of strengthening process involved.

(2) Wigglesworth, (Investigative Ophthalmology, Dec. 1971, Vol. 10 #12) "The Effect of Thermal Roughening of the Impact Resistance of Simulated Safety Lenses."

(3) Wigglesworth, E. C., "The Impact Resistance of Eye Protector Lens Materials", Australian Defense Scientic Service, Melbome, Australia. AAAO, March 1971, pg. 245-260.

(4) Rose, Stewart, Eye Protections Against Small High Speed Missles, Science News Letter, Nov., 1956.

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Tinted - USED 2.2mm Chem. Temp.

Single Vision

G-15 = 55.5"
Thermidon = 80"

Range = 42-102"
Median = 72"
Mode = 54"
Mean = 58.5"

Sph. Power	Fr. HT. (in.)	Force in (FT. lbs.)
-3.25 - 4.00	62"	.76
-2.25 - 3.00	54	.66
-1.25 - 2.00	64.5	.79
-0.25 - 1.00	57	.70
plano	55.5	.67
+0.25 - +1.00	75	.92

Cyl. Power

-1.00 -1.75 = 64"
-2.00 -2.75 = 76"
-3.00 -3.75 = 48"

Shape factor

tear shaped = 61"
Rectangular = 59.2"
Round = 54.8"

Bifocal Tints - chem. Tempered

Range = 60-102
Median = 81
Mode = 84
Mean = 77.4

Sph. Power	Fr. HT.	Force (FT. lbs.)
-1.25 to -2.00	84"	1.03
-0.25 " -1.00	66	.81
plano	78	.96
+0.25 to +1.00	82.5	1.02
+1.25 to +2.00	72	.89

Cyl. Power

-1.00 to -1.50 = 66"

USED 3.0 MM Chem. Temp.

	Single Vision				Bifocals	
Range	90 - 134"				102 - 132"	
MEDIAN	112"				117"	
MODE	134"				102"	
MEAN	114.6"				112"	

Sph. Power	Fr. HT.	Force (ft lbs)	Fr. HT.	Force
-1.25 to -2.00	90	1.11	X	X
-0.25 " -1.00	X	X	X	X
plano	X	X	X	X
+0.25 to +1.00	102	1.26	105.6"	1.29
+1.25 " +2.00	117	1.44	118"	1.46
+2.25 " +3.00	130	1.60	126"	1.55

NO cyl > -0.75 D

All Flat Top's exept for 1 lenses

3.0mm NEW Chem. Temp.

Single Vision
Range 114-168" w/ 2 > 168"
MEDIAN 141
MODE 120 & 132
MEAN 128.9"

Sph Power	Fr. HT.	Force (ft.lbs)
-2.25 - 3.00	120"	1.48 ft.lbs.
-1.25 - 2.00	132"	1.62
-0.25 -1.00	X	x
plano	X	x
+0.25 - +1.00	X	x
+1.25 - +2.00	126"	1.55
+2.25 - +3.00	130.8"	1.60

Cyl. Power
-1.00 to -1.75 = 137.3"

Both those lenses that withstood 168" had -1.00 & -1.25 cyl.

2.2 mm USED Chem. Temp. Bifocals

Range	48-102"	FT-22	= 64.5"
MEDIAN	75"	FT-25	= 67.9"
MODE	54"	Kryptok	= 61.4"
MEAN	64.3"	Pantoptic	= 64.7"

Sph. Power	Fr. HT.	Force (ft. lbs.)
-3.25 to -4.00	66"(*)	.81
-1.25 " -2.00	61.2"	~~54~~ .75
-0.25 " -1.00	63.8"	~~75~~ .77
plano	64.2"	.78
+0.25 to +1.00	77.9"	.98
+1.25 " +2.00	60*	.74
+2.25 " +3.00	48*	.59

(*) small sample of lenses outside ±1.00 D ∴ so data strange ∴ not graphed

Cyl Power

-1.00 -1.75 =	81.3"
-2.00 -2.75 =	58.8"
-4.00 -4.75 =	84"
-6.00 =	57"

Shape

only shape significantly weaker was the small tear shaped lenses - which were too small for our base

DATA COMPARISON

DRILLED & NOTCHED LENSES

— St. vs. g force

SINGLE VISION LENSES (Drilled & Notched)

	NONTEMP.	CHEMTEMP.	STR. FACTOR
RANGE	6-30"	38-78"	x
MODE	18"	42"	2.3
MEDIAN	18	54	3.0
MEAN	17.6	49.3	2.8
DRILLED	19.8	49.2	2.5
NOTCHED	16.8	62.4	2.6
GOOD COND.	16.9	52.4	3.1
POOR COND.	20	38	1.9----Range 1.9 to 3.1

Mean 2.6 times stronger

SPH. POWER

-2.25-3.00	6" .08	x	x
-1.25-2.00	x	38 .47	x
-0.25-1.00	12 .15	42 .52	3.5
plano	18 .22	36 .44	2.0
+0.25+1.00	18 .22	51 .63	2.8
+1.25+2.00	x	78 .96	x
+3.25+4.00	24 .29	72 .89	3.0----Range 2.0 to 3.5

Mean 2.8 times stronger

CYL.POWER

RANGE	-0.75- -1.75	-0.75- -2.00	
FR.HT.	22.5"	53"	2.35 times stronger

BIFOCAL LENSES (Drilled & Notched)

	NONTEMP.	CHEMTEMP.	STR. FACTOR
RANGE	12-24"	36-72"	x
MODE	24"	66"	2.5
MEDIAN	18	54	3.0
MEAN	21	56.3	2.7
FL.TOP	21	58.5	2.8
KRYPTOK	21	49.5	2.3
GOOD COND.	23.3	57.7	2.5
POOR COND.	18	36	2.0----Range 2.0-3.0

Mean 2.5 times stronger

SPH. POWER

+0.25+1.00	18 .22	55.7 .68	3.1
+1.25+2.00	23 .28	56.4 .69	2.4
+2.25.....	18 .22	63 .77	3.5
+3.25.....	24 .29	66 .81	2.8
+4.25.....	24 .29	x	x-----Range 2.4-3.5

Mean 2.95 times stronger

(Next page [illegible])

CYL. POWER	NONTEMP.	CHEMTEMP.	STR.FACTOR
RANGE	-0.75- -2.00	NO CYL. -0.50D	xx

CENTER THICKNESS	NONTEMP.	CHEMTEMP.	STR.FACTOR
1.1-1.3mm.	6"	36"	6.0
1.4-1.7	18	39	2.2
1.8-2.0	20.7	43.2	2.1
2.1	18	48	2.7
2.2	22	54	2.4
2.3	24	42	1.7
2.4	18	48	2.7
2.6	24	54	2.3
2.7	24	66	2.8
2.8	24	60	2.5
2.9-3.1	x	62	x
3.6	24	72	3.0
4.0	24	78	3.2----Range 1.7 to 6.0 Mean 2.8 times stronger

To convert inches to FT. LBS. of force $= \frac{\text{FR. HT. in feet}}{.147 \text{ lbs.}}$

USED 2.2mm Chem. Tempered
(Single Vision)

Range	42-120"
Median	81"
Mode	54"
Mean	64.4"

Sph. Power	Fr. Ht.	Force (ft.lbs)	Redone Lenses (Retempered) Fr. Ht.	Redone Lenses (Retempered) Force (ft lbs.)
-7.00	45"	.55	x	x
-6.00	42"	.52	x	x
-3.25 – 4.00	54	.66	x	x
-2.25 – 3.00	58.5	.72	x	x
-1.25 – 2.00	59.3	.73	78"	.96
-0.25 – 1.00	61.4	.75	76"	.94
plano	65.8	.81	88"	1.09
+0.25 – +1.00	71.6	.88	93.3"	1.15
+1.25 – +2.00	78	.96		

Cyl. Power	
-1.00 & -1.50	62.1"
-1.75 & -2.00	64"
-2.25 & -2.50	75"
-3.50	42"
-4.00	66"

Cyl Power
-1.00 to -1.50 = 75"
x
x
x
x

Shape
tear drop = 55.4"
Round = 64.9"
Rect. = 71.4"

New Lenses 2.2mm C.T.
– Single Vision

#=62 lenses

Range = 168 – 72"
Median = 120"
Mode = 108"
Mean = 112.3"

Sph. Power	Fr. Ht	Force	
-4.25 to -5.00	84"	1.03	ft. lbs.
-3.25 " -4.00	94	1.16	"
-2.25 " -3.00	103*	1.27	"
-1.25 " -2.00	119*	1.47	"
-0.25 " -1.00	94.2	1.16	"
plano	104	1.28	"
+0.25 to +1.00	114.4	1.40	"
+1.25 " +2.00	105*	1.29	"
+2.25 " +3.00	162	1.99	"

* small sample of lenses for this power range

Cyl Power
-1.00 = 105.8"
-2.00 = 112.5"
-3.00 = 118 "

Shape factor not signif. for these – all were 46 Rd.

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