A Future FOR THE Sport

BALL HARDNESS RESEARCH REPORT 2022

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SUMMARY

Since 2019, the United States Bowling Congress (USBC) Equipment Specifications staff has conducted updated research looking at how bowling ball hardness changes after use over time. These research reports demonstrated urethane shell balls drop in hardness the most after use. Reactive shell balls have less significant changes, showing little to no drop in hardness after use.

The issue of ball hardness has become an issue of concern at the professional level and for ball manufacturers. This 2022 report summarizes additional research projects completed this year. The results provide clear data to allow bowling's stakeholders to share a common set of facts.

- Urethane bowling balls get naturally softer with use. USBC data shows friction and shear forces along with lane oil exposure are contributing causes. However, this natural softening of bowling balls through use minimally impacts performance, if at all.
- Lower ball hardness at manufacture clearly impacts performance. Testing two versions of the same model urethane ball with different hardness out of the box shows very different performance. The softer ball is stronger.
- Chemically altering bowling balls to make them softer significantly impacts performance. The softer altered balls are stronger.

These are important findings. USBC does not have data to justify removing used bowling balls from competition due to hardness changes from ordinary use. Field testing whether bowling balls are below a hardness number doesn't provide enough information to know if a given ball creates an advantage. You need to know what caused the ball to reach the hardness number. Ordinary use is minimally impactful while a ball manufactured below specification or altered has an advantage.

The fact that changes in ball hardness from ordinary use minimally impact performance should not lead to a conclusion that ball hardness doesn't matter. This study indicates hardness changes due to friction and oil (ordinary use) compared to hardness changes due to manufacture or chemical alteration are different.

USBC equipment specifications are designed to set boundaries on the manufacturing of bowling equipment to address that side of the issue. USBC rules then prohibit tampering with approved products. USBC believes proper governance is in place on this topic.

Manufactured hardness is a physical property of bowling balls that has clearly been demonstrated to have performance implications. Therefore, it is essential that manufacturing regulation in this area continues to ensure that the performance range allowed for bowling balls is maintained.

2022 TESTING OVERVIEW

USBC's historical field test data shows urethane balls drop in hardness with use. In 2022, USBC conducted testing to investigate this from a performance perspective. These tests were done using USBC's test robot simulating one bowler throwing shots to produce a controlled data set. This laboratory testing, while useful, has limitations and is not designed to reflect conditions such as pattern migration with multiple players. The tests do not simulate ball performance on the PBA Tour.

USBC conducted testing of the two most popular urethane balls in the market. An analysis measured how the balls changed in hardness with use and then correlated drop in hardness to:

- Overall ball path
- Total hook
- Entry angle

Results from the tests are described later in the report in detail.

Here are some key findings:

- The results showed that hardness changes through ordinary use minimally impact these performance characteristics. The urethane balls all dropped in hardness but maintained their relative ball path, total hook and entry angle. USBC's analysis indicates used urethane balls that drop in hardness through ordinary use perform minimally different than they did out of the box at a higher hardness. Losses of 3.8D and 7.1D respectfully for each urethane model resulted in no meaningful differences.

- USBC compared two samples of the same model urethane ball. One sample was 5.2D softer in hardness out of the box than the other. This test provided a clearer indication that manufactured hardness does, in fact, impact performance. The softer ball read the oil stronger and began hooking more than the harder ball, resulting in a difference of 3 boards at 59 feet when entering the pocket. In this test, we showed that 1 point of hardness equates to 0.6 boards more hook.

- USBC also conducted testing to analyze the impact of intentionally altering the hardness of bowling balls with a solvent. For these tests, USBC soaked balls in a solvent and then conducted performance tests. USBC analysis showed that altering balls with a solvent significantly impacted performance characteristics of urethane and polyester balls. Reactive shell balls did not show as much change.

THE DUROMETER

The durometer[1] is the tool for measuring hardness. It was originally invented in 1915 to study the hardness of elastomers and polymers (exactly what bowling ball covers are made of). Durometers have stood the test of time as an accurate measurement tool used across a wide range of materials and industries. Bowling has been utilizing Shore D durometers for over fifty years to better understand the importance of hardness relating to our sport.

The American Society for Testing and Materials[2] (ASTM) maintains over 12,000 standards that operate globally, one of which documents a standard use, design and calibration for durometers. Shore D durometers operate by having an indenter needle of a tightly specified shape press into materials under a regulated spring force and pressure. One point of difference on the scale relates to one thousandth of an inch (0.001") of penetration into the material.

The ASTM standard calls for all calibrated durometers to be designed such that it is estimated that there is only a range of +/- 2 points of hardness across the thousands upon thousands of calibrated durometers that exist. This means that given any group of calibrated durometers testing the same material, we would expect them to all agree on how far they penetrate the material to a range of 0.004". This does not mean that any one durometer in a controlled lab setting will have inconsistent results.

Measurement system analysis conducted on the USBC durometer shows USBC's gauge discrimination to be +/- 0.7 points. Yes, there are several factors that can affect durometer readings such as material consistency, temperature, humidity and test operation. USBC has published standard operating procedures to create consistency for these factors.

Additionally, USBC strives to continuously improve the standard operating procedures for all our equipment testing devices when research data supports that the changes reduces the measurement uncertainty / decreases the gauge discrimination.

These reasons are why durometer testing is best conducted in a laboratory environment where the testing environment and procedure can be tightly controlled.

[1] Durometer
[2] ASTM

PRIOR FIELD TESTING

Since the onset of USBC's recent field tests in 2020, the data has been very clear that urethane balls across all manufacturers are softer after they have been used.

Urethane hardness data collected at the 2020 US Open[3] showed that nearly all 20 urethane models tested lost hardness on average with the overall data showing a 2.4D decrease. The model that softened the most dropped 5.6D on average from approval. The data also showed that models advertised as blended urethane/reactive changed less than pure urethanes.

The data collection continued at the 2020 World Series of Bowling[4] where we also collected results on reactive balls. Like the blended urethanes, we saw little to no change in reactive balls, but urethanes as a whole dropped 2.1D on average with the most extreme model dropping 5.4D on average.

Key Takeaways

- Data indicates the effect of urethane balls becoming softer with use over time eventually levels out, and the ball's hardness stabilizes.
- Reactive shells showed little change in hardness after use when tested in the field.
- Duplicating the USBC field test is difficult for a tournament operator because of the time and manpower required, the number of variables and the cost.

WHY URETHANE GETS SOFTER WITH USE

For many bowling ball experts, the idea that urethane balls could get softer is counterintuitive. When a new ball is manufactured, it continues to "cure" over time. Chemical bonds continue to make new connections throughout the material as molecules continue to move and shift within the material. Unused bowling balls newly off the manufacturing line initially get harder over time. USBC has monitored this and agrees.

However, what occurs with use of a urethane ball is a different story.

Used equipment has always shown the opposite in that used urethane balls get significantly softer with use. USBC research has highlighted three key aspects that appear to be the root cause of the softening.

- Friction-causing shear forces within the coverstock
- Oil on the coverstock can degrade the urethane and impact measurements
- Altering the surface of the coverstock with chemical solvent

Testing Procedure

The act of rubbing urethane balls creates friction plus shear forces inside the elastomeric urethane shell material. This rubbing action during bowling comes from several potential sources:

- The friction between the ball and the lane.
- The carpet belt taking the ball out of the pit over to the ball door.
- The belts sending the ball back up the ball track to the ball return.
- The wheels lifting the ball to the top of the ball return.

Possible explanation

This rubbing action and associated shear forces created in the shell can break down the molecular bonds holding the material together. This weakens the material and can show up as a loss of

[3] 2020 US Open Hardness Report
[4] 2020 World Series of Bowling Findings

hardness as it is easier for the durometer needle to penetrate the shell material.

Reactive shells have plasticizer mixed with a harder urethane component (compared to the urethane components in a urethane ball as the plasticizer will soften the final ball). The plasticizer interferes with the chemical reaction acting to shorten the polymer chains, which makes the reactive material more rigid and less elastic.

This results in a more brittle shell that can crack more easily. This rigid shell stretches less due to shear forces resulting in less hardness change due to rubbing. The reactive material has shorter polymer chains separated by liquid plasticizer, and the friction stresses are harder to stretch in these already-shortened polymer chains.

Friction and Shear Forces

Shear forces are forces applied to a body that result in shear strain (attempting to cut / shear an object in half). Imagine you are holding a pencil in both of your hands such that only a small portion of the pencil is exposed between them. Now, with one hand, you push as hard as you can, and with the opposite hand, you pull with all your strength. This will cause a large amount of shear strain within the exposed portion of the pencil. The forces imparted by your hands will be attempting to shear the pencil in half, and if you are strong enough, the pencil breaks.

Now imagine the same scenario with a large rubber band instead of a pencil. Your forces stretch the rubber band to an extreme – and again – if the forces are strong enough, the rubber band will break.

Additionally, if you continue to stretch the rubber band back and forth, the stretched region will weaken, and it will become easier to break.

Shear forces are forces that result in shear strain within an object that tries to shear the object in half.

When friction is applied at the bottom of a bowling ball as it travels down the lane, something similar is happening. Friction is pulling the surface of the ball in one direction while a combination of inertia (the ball's tendency to maintain its current speed and direction) and the connections between the molecules within the coverstock are trying to keep the same part of the ball from changing direction – pulling the cover in the opposite direction.

This creates shear strain within the outer layers of the coverstock and ultimately results in breaking down or damage to the outer layer of the ball. As a urethane ball is used, we believe it is stretching, deforming and, in some cases, even breaking some of the molecular bonds in the coverstock, resulting in a drop in hardness.

To research this concept, we designed two tests where we measured the hardness before and after:

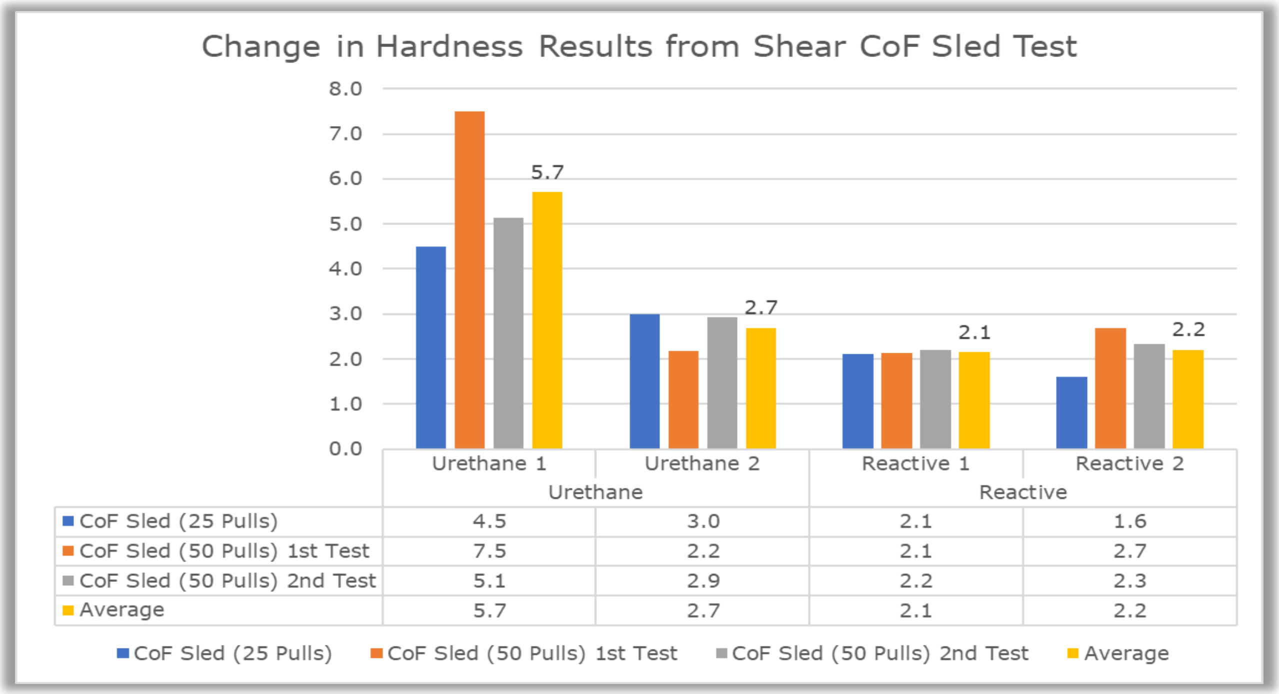
- Apply friction to the coverstock using a COF (coefficient of Friction) measurement system
- Apply friction to the coverstock by recreating how a ball impacts the lane equipment (pin deck area, back-stop, ball return, etc.)

Shear Testing #1: COF Measurement System

Every bowling ball approval sample gets tested for coefficient of friction (COF) via USBC's standard operating procedure. A ball is placed in contact with a standard synthetic lane sample and fastened into a sled such that it can be pulled without rolling. This allows us to measure the force being exerted to drag the ball and convert that into a COF measurement.

It also creates a wear-down spot where the ball touches the lane panel in which we can test hardness before and after subjecting the balls to shear forces.

We tested two different urethane models and two different reactive models and found the following results:



	Urethane 1	Urethane 2	Reactive 1	Reactive 2
	Urethane		Reactive	
CoF Sled (25 Pulls)	4.5	3.0	2.1	1.6
CoF Sled (50 Pulls) 1st Test	7.5	2.2	2.1	2.7
CoF Sled (50 Pulls) 2nd Test	5.1	2.9	2.2	2.3
Average	5.7	2.7	2.1	2.2

First, we measured the bowling balls for hardness. Then our initial test pulled the balls back and forth with our COF device 25 times. The contact point that experiences the shear forces in the testing is quite small, approximately one quarter of an inch in diameter or less. Because of that, we were only able to acquire 5 test points with the durometer in the worn-down region.

After 25 pulls, we saw larger changes in hardness with the urethane samples than we saw with the reactive samples. We then continued to test two more locations on each ball for 50 pulls with the COF device.

Overall, the urethane balls changed an average of 5.7 and 2.7 points of hardness, respectively, and the reactive balls experienced an average change of 2.1 and 2.2 points of hardness.

Shear Testing #2: Ball Return Wheel Friction

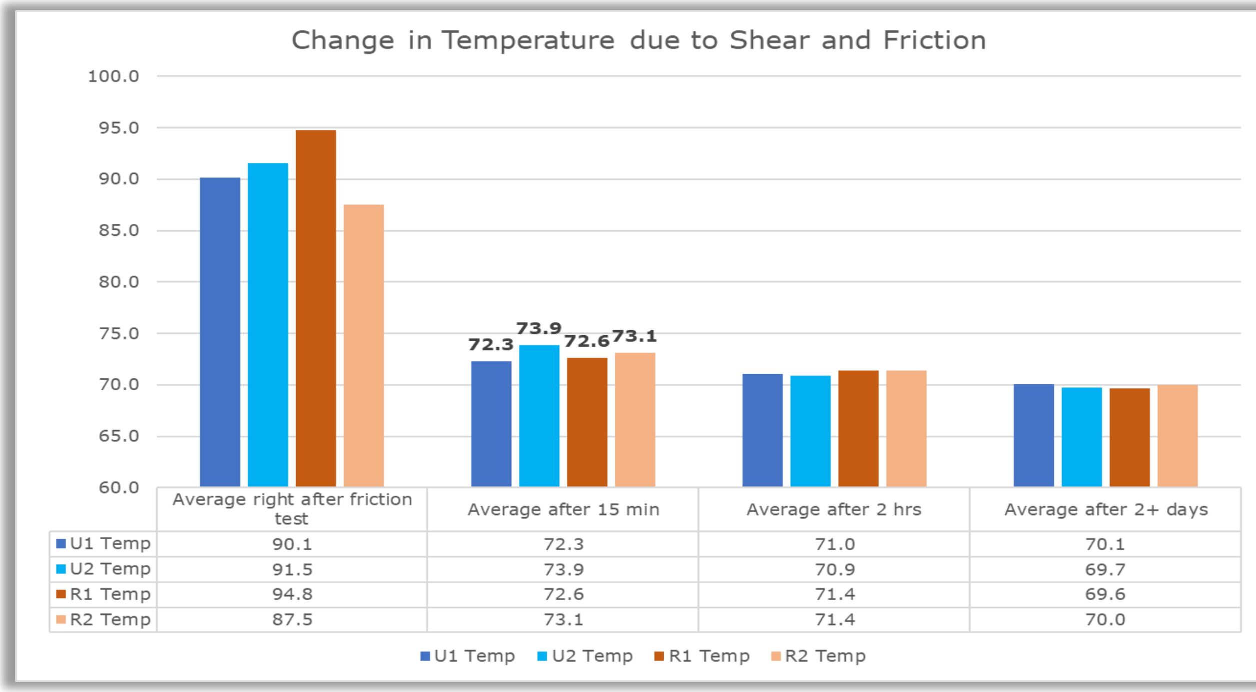
The friction that the ball experiences on the lane is not the only potential source of wear and tear that could break down the coverstock. The ball is also colliding with the pins, constantly being rubbed by the moving carpets in the pits, hitting and skidding to a stop in contact with the ball stop cushions, accelerators launching the ball back through the underground ball returns and a series of wheels designed to bring the balls back up to the bowlers at the ball return – there are many sources of shear forces that can be reducing the surface hardness of these bowling balls.

In our next test, we simulated the ball lift mechanism creating friction from lifting the ball at the ball return. The balls tested were placed on a ball spinner and as the balls spun around, a ball return wheel was held against the balls for 20 seconds.

This created a wear band around the ball that was used to check the hardness change. The wear band was approximately one inch wide, allowing more area for checking the hardness so that we could perform our normal 10-spot average.

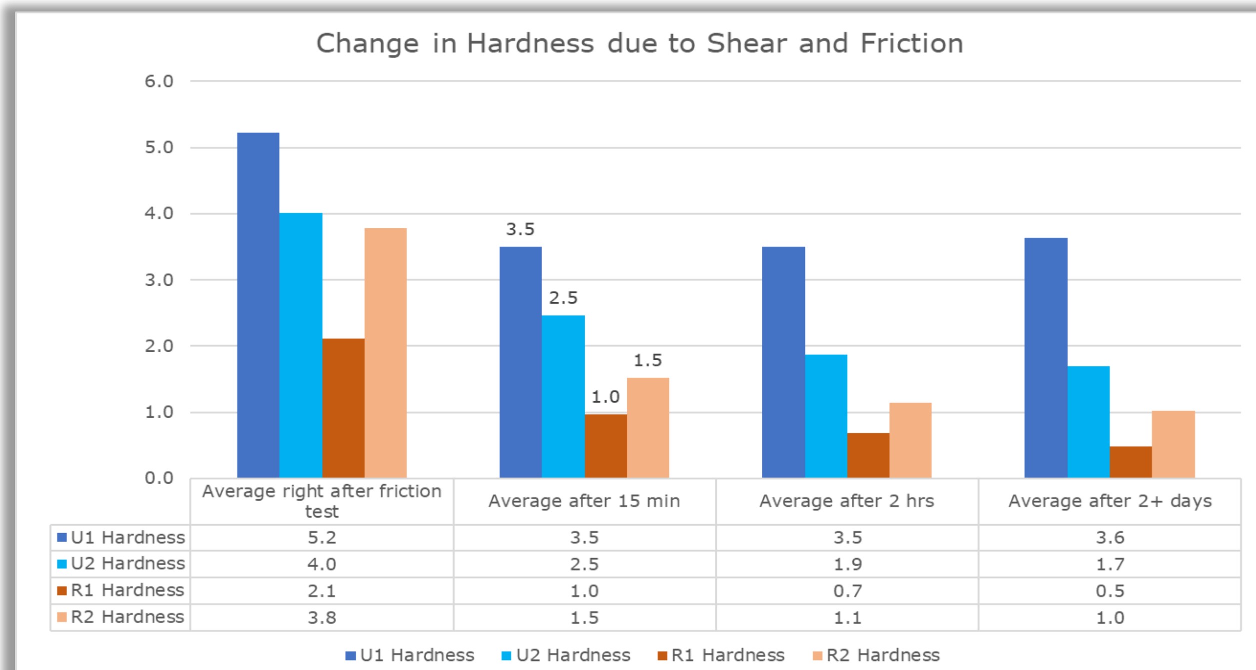
The friction generated heat, and some of the initial hardness change was a result of the temperature change. The ball surface in the wear band immediately after spinning the ball measured about 85-95 °F.

After a 15-minute wait period, the temperatures dropped to 72-74 °F, which is within our normal testing range. Waiting an additional 2 hours, we saw temperatures return fully to the ambient temperature of the room.



	Average right after friction test	Average after 15 min	Average after 2 hrs	Average after 2+ days
U1 Temp	90.1	72.3	71.0	70.1
U2 Temp	91.5	73.9	70.9	69.7
R1 Temp	94.8	72.6	71.4	69.6
R2 Temp	87.5	73.1	71.4	70.0

At each period of time the temperatures were checked, we also evaluated hardness within the wear band and found the following:



	Average right after friction test	Average after 15 min	Average after 2 hrs	Average after 2+ days
U1 Hardness	5.2	3.5	3.5	3.6
U2 Hardness	4.0	2.5	1.9	1.7
R1 Hardness	2.1	1.0	0.7	0.5
R2 Hardness	3.8	1.5	1.1	1.0

We observe the largest differences in hardness immediately after the shear forces were applied. The balls were still heated up in the area of wear, so we can say that the differences observed immediately are a combination of wear-down and temperature affects.

After allowing 15 minutes for the balls to cool, the hardness came down as the balls returned to ambient temperature. After 2 hours, the balls completely cooled off, yet we still observed lowered hardness values than what the balls were originally. Two days later, testing the wear band again showed us the same results, further illustrating these samples have been permanently damaged.

To remove the damage, the balls were sanded to a fresh 500-grit Abralon surface following USBC's ball approval SOP. After sanding, the urethane balls returned to within 1 point of their original baseline hardness from before any testing. This indicates that the damage is isolated to just the outermost layers of the bowling balls.

However, we have not been able to fully restore the original hardness of our samples. Sanding the balls itself is another example of applying shear forces to the surface of the bowling balls.

Additionally, in this data, we also see the urethane samples changing in hardness more than the reactive samples. At their core, reactive and urethane chemistry are essentially the same thing, polyurethanes – a polymer made by combining a polyol with an isocyanate.

That being said, polyurethane chemistry can be formulated to make a wide diversity of products from foam cushions to bowling balls. The key difference between reactive and urethane bowling balls is the amount of cross-linking- think how many times these molecules connect to one another. The design of urethanes allows them to behave more elastically- think rubber bands.

The way reactive balls are made results in a much more rigid structure- think pencil. Additionally, reactive balls have plasticizer that prevents the urethane from curing together entirely throughout the shell. This means there are areas of very tightly connected urethane polymers and areas of no polymer connections at all throughout the material.

The rigid structure of the urethane bonds in reactive balls appears to be minimizing the damage that shear forces do. However, the elastic urethane allows the material to stretch due to shear forces, and this repeated stretching back and forth breaks the bonds and softens the shell.

Key Takeaways

- Shear forces like friction damage coverstocks and reduce hardness in both urethane and reactive balls.
- Urethane balls are affected more strongly than reactive balls.
- Resurfacing the balls helped restore some of their original hardness but was not able to return samples to their original hardness.

OIL IMPACT ON HARDNESS

When we observe differences in how urethane and reactive balls behave, it is logical to consider if the differences are due to oil. After all, our main determination for what is a reactive ball versus a urethane ball is to what extent the coverstock absorbs oil or not.

At the onset of USBC's recent hardness studies back in 2019, we determined it was important to understand the effects of lane oil on hardness measurements, so we conducted a series of experiments and found the following:

- Testing through lubrication can allow the durometer to penetrate deeper, resulting in softer readings.

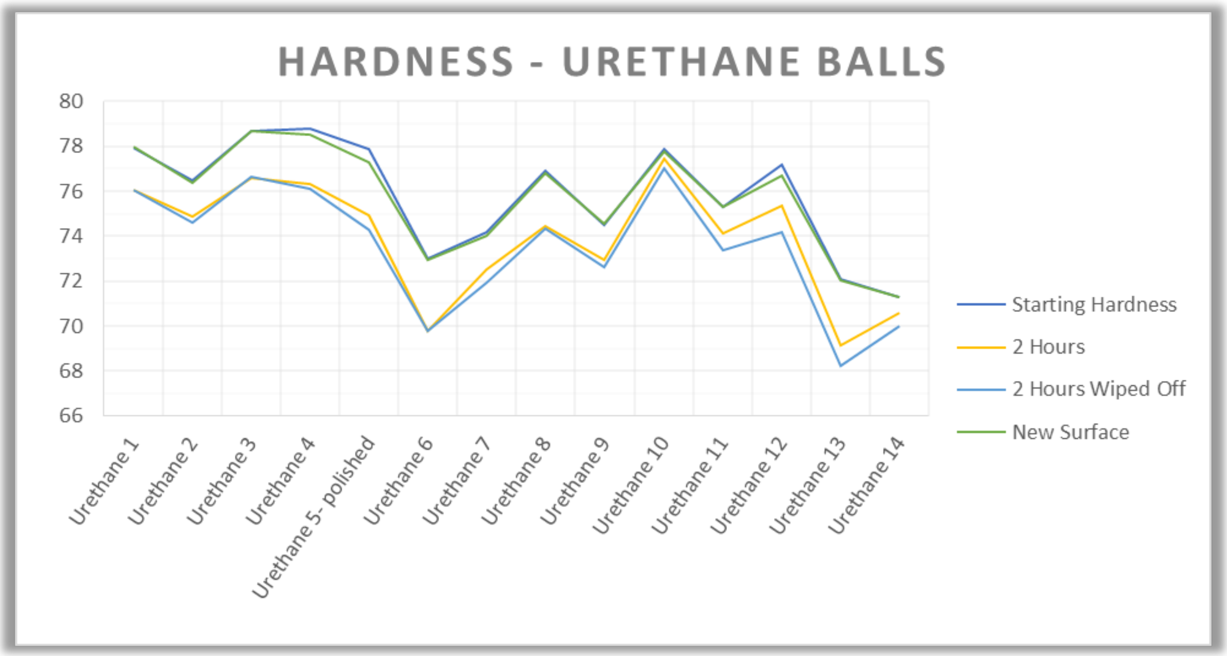
The durometer manufacturer confirmed testing through lubrication is outside of the scope of how durometers should be used.

Testing Through Lane Oil

Our procedure for testing hardness through lane oil was to use our precision oil pump that USBC uses for oil absorption testing to apply a precise amount of oil to each sample. The oil was then spread throughout a three-inch diameter circle on the bowling ball. We tested nine different urethane models five ways:

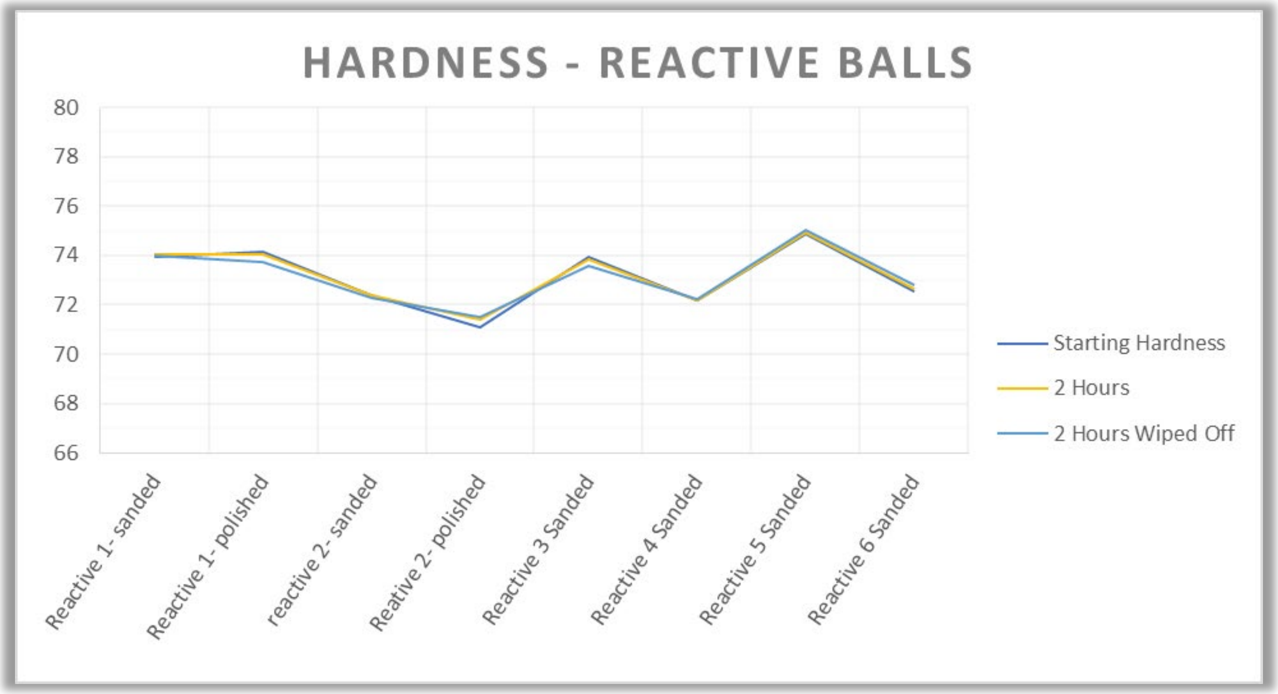
- Baseline prior to applying oil
- Testing immediately through the oil
- Wiping the oil off with a dry towel and retesting
- Testing through oil that has been applied to the ball for 2 hours
- Wiping the oil off with a dry towel and retesting

The results showed the following:



Here we see that balls changed in hardness anywhere from just under 2 points to as much as 3.6 points when tested through oil. The hardest values came from testing before any oil was applied. The softest values came from when oil had been on the covers for the longest amount of time. Cleaning the balls with a dry towel was ineffective at removing the effects of oil from the test.

We also conducted the testing on eight reactive samples, but we omitted the step of wiping off the balls with a dry towel as all the samples absorbed the oil well within the two hours the oil was applied . The results here showed that testing through oil has no measurable effect on reactive balls.



As hardness was tested through oil or oiled sections of reactive balls, there was not a difference in hardness. We believe this difference can again be explained in terms of the chemical differences between reactive and urethane covers. Urethane tends to be more elastic in nature, so as the durometer presses into the material, it is bending and distorting the polymer chains out of its way.

The addition of the lane oil reduces friction between the indenter needle and the material and allows the polymer chains to bend and flex easier. This allows the durometer to penetrate deeper into the material, resulting in softer hardness readings.

On the other hand, reactive samples having more rigid structure means the durometer has to work harder to dig down into the material. The difficulty in pushing that material out of the way seems to be unaffected by the introduction of oil to the testing.

We discussed our findings on this with the durometer manufacturer, and they agreed that lubrication of the durometer indenter can influence the results of the durometer and should be avoided when possible. That is why as we moved into our field tests in 2020, we intentionally added a cleaning process where all the balls received would be cleaned with isopropyl alcohol to remove as much of the oil from the testing process as possible.

This is an additional reason why conducting field tests to measure hardness is a very difficult task to perform accurately and fairly.

Taking all of this into consideration, to say urethanes do not get softer and only measure softer due to lane oil is just not true. Friction can damage the outer layers of the shell, reducing hardness. Lane oil can lubricate the polymer strands in the coverstock, making them more susceptible to change, which can influence the durometer results and can also lead to furthering the degradation of the outer shell.

The data has been very consistent from the start. Used urethane balls get softer. Reactive balls exhibit little to no change.

Key Takeaways

- Lane oil is a factor causing urethane balls to get softer with use
- The influence of oil can influence the cover of the ball itself and the consistency of the durometer reading
- Reactive balls exhibit little to no change in hardness due to oil

URETHANE PERFORMANCE TESTING

In addition to the testing being conducted in the field to monitor how the hardness of urethane balls is changing over time, the equipment specifications team has been conducting additional research at the International Training and Research Center utilizing E.A.R.L. (USBC's automated ball throwing robot) and other research tools to better understand performance implications.

To select balls for testing, the two most popular urethane balls currently on the market were chosen. The balls were tested in the research center with E.A.R.L. so that we could monitor the change in hardness over time as well as key performance metrics.

To isolate variables and maximize E.A.R.L.'s repeatability, each ball was drilled with a balance hole directly through the CG marking to remove the top weight of each ball. Then, each ball was scribed with the same grip center and layout to ensure consistent amounts of flare from ball to ball.

The chosen pattern was a 39' sport pattern with a volume of 27.81 mL.

This laboratory testing was not designed to reflect real-world conditions such as pattern migration with multiple players. The tests do not simulate ball performance on the PBA Tour.

Test #1: Separate Urethane Ball Model Testing

We began testing with each urethane ball model separately. Because of variations in manufacturer, coverstock and core properties, a side-by-side comparison will not help us to identify the effects of hardness changes on performance.

We identified where we needed the laydown point to be and adjusted until we found the pocket.

Testing Procedure

- Each ball was checked for hardness out of the box.
- Each ball was prepared to 2000-grit with a sure spin sanding device.
- Each ball was thrown for a 10-shot baseline and cleaned with isopropyl alcohol and tested for hardness immediately after the test.
- The bulk of the testing consisted of 30-shot experiments using E.A.R.L. to try to maximize striking.
- Throw 30 shots with E.A.R.L., adjusting to maintain the pocket throughout the test.

Earl Settings:

- Ball Speed – 18 MPH
- Rev Rate – 480 RPM
- Axis Tilt – 10 degrees
- Axis Rotation – 40 degrees
- Laydown and trajectory – Adjusted to keep pocket with a consistent breakpoint

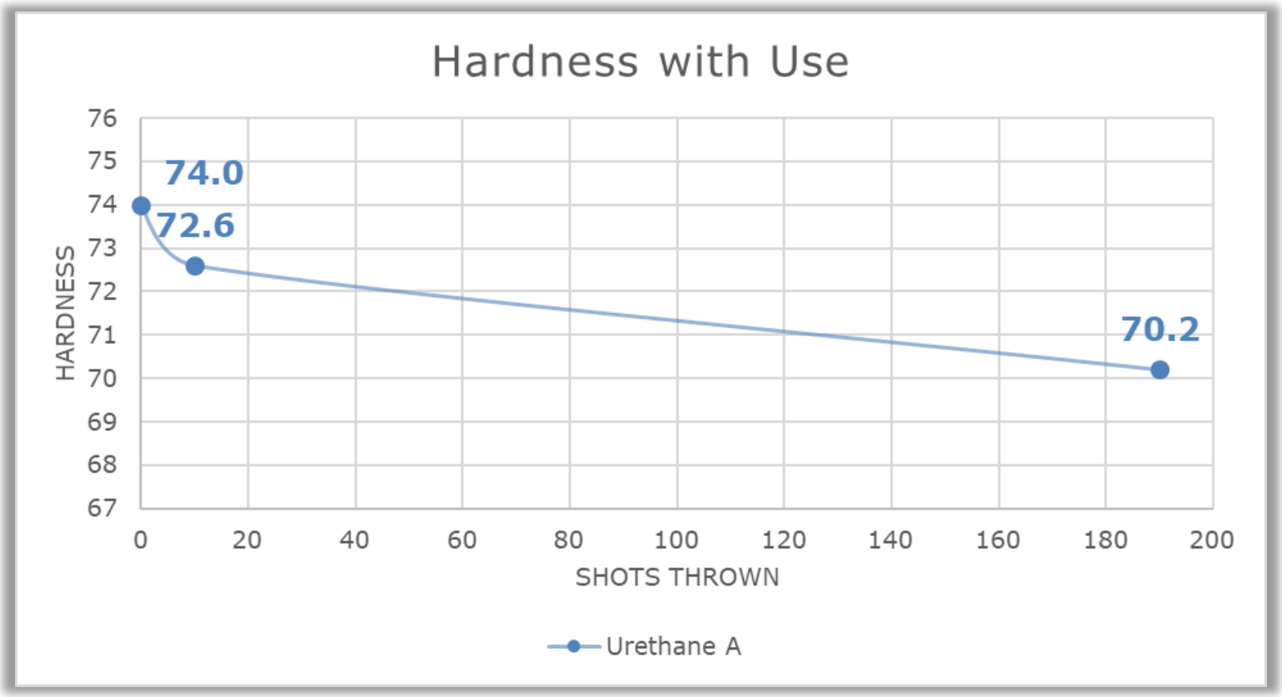
Additional notes:

- The oil pattern was re-applied in between tests and allowed to rest for at least 20 minutes.
- Each ball was thrown for a total of 190 shots (baseline, plus six sets of 30).
- Balls were cleaned and tested for hardness the following day after they were tested. This was to minimize the impact of oil on the testing.

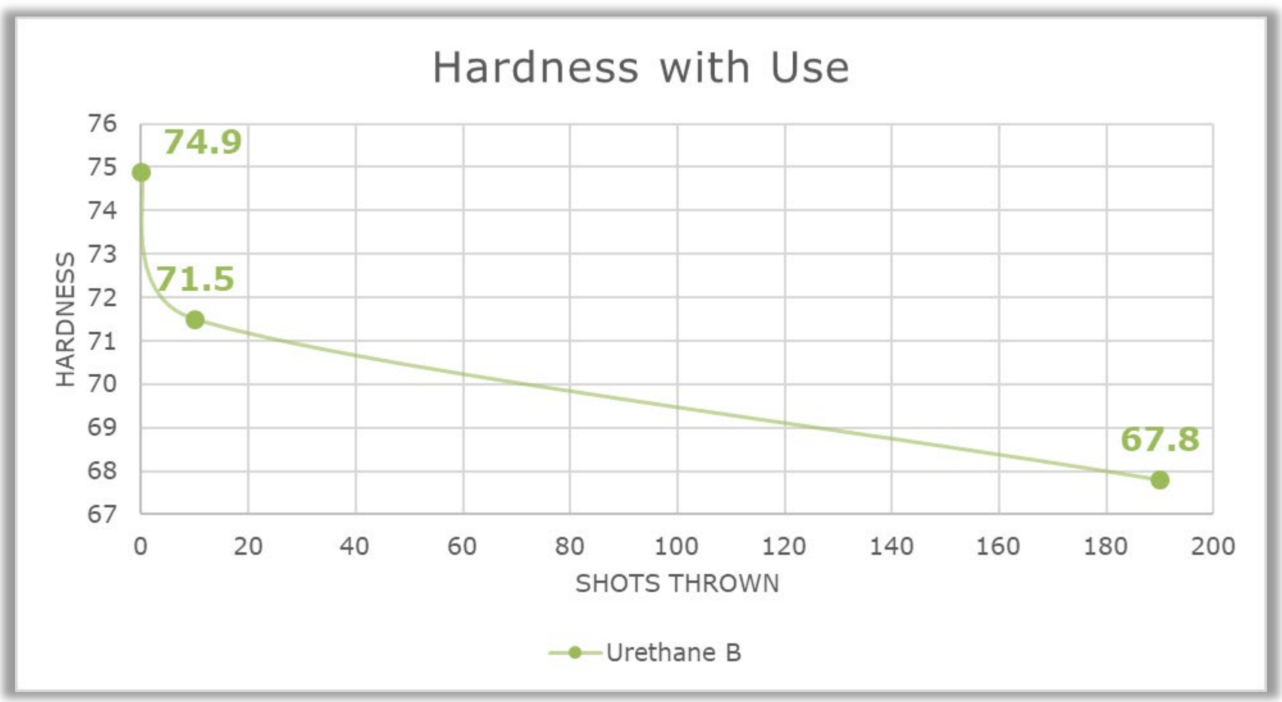
Test Results

Hardness Findings

Ball Type	Out of Box Hardness	Hardness After 10 Shots	Hardness After 190 Shots
Urethane A	74	72.6 (-1.5)	70.2 (-3.8)
Urethane B	74.9	71.5 (-3.4)	67.8 (-7.1)



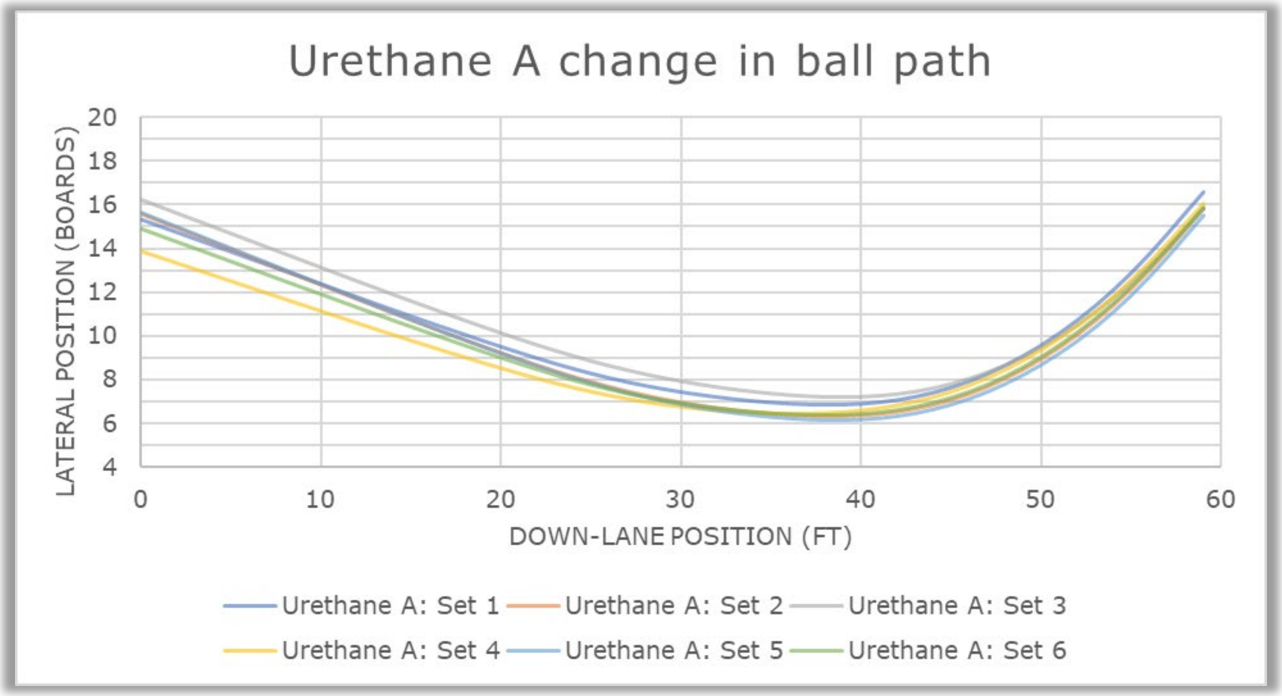
Similar to the findings in the field, we saw a large drop in hardness with this ball type losing 3.8 points of hardness after only 190 shots (approx. 12-13 games when used every shot).



For this urethane model, we see that in the same amount of use (12 to 13 games), we observe a loss of -7.1 points of hardness. This illustrates that urethanes are not all chemically the same, and the same amount of use does not affect their hardness the same.

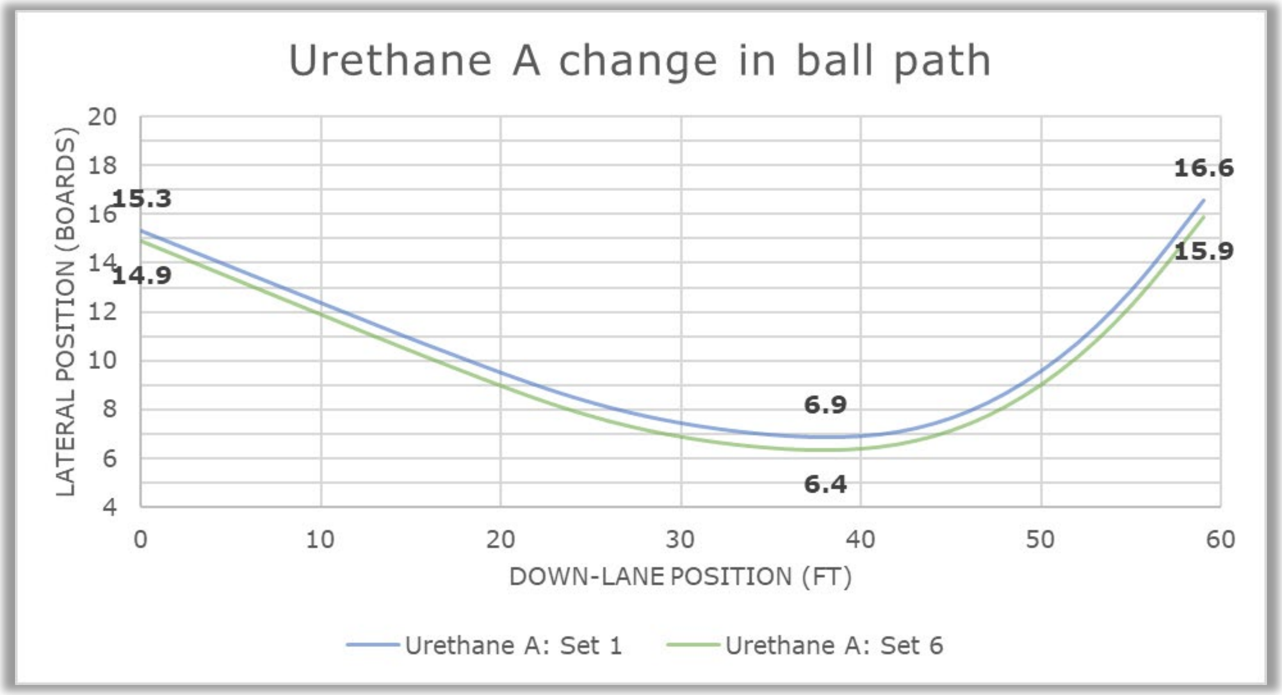
Ball Path Findings

We can estimate the effect of this drop in hardness on the shape of the ball paths by looking at the balls' performance in each of the consecutive tests.

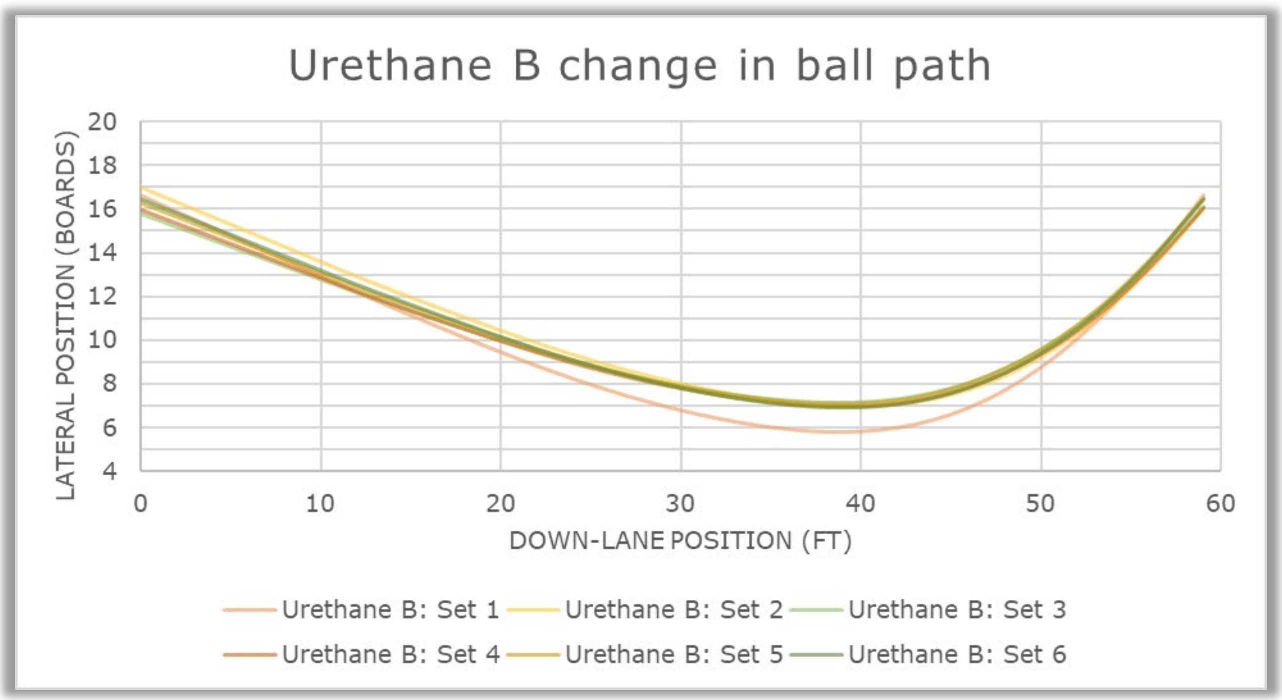


In the above chart, we see the average ball path for all three samples across each 30-shot test. We can see that for each individual test, the laydown and launch angles needed adjustment to maintain the goal of hitting the strike pocket from a breakpoint on the 7 board at 40 feet down the lane.

If we compare the 1st and the 6th sets, we see little difference in the ball path shape despite the 3.4 points of hardness lost.

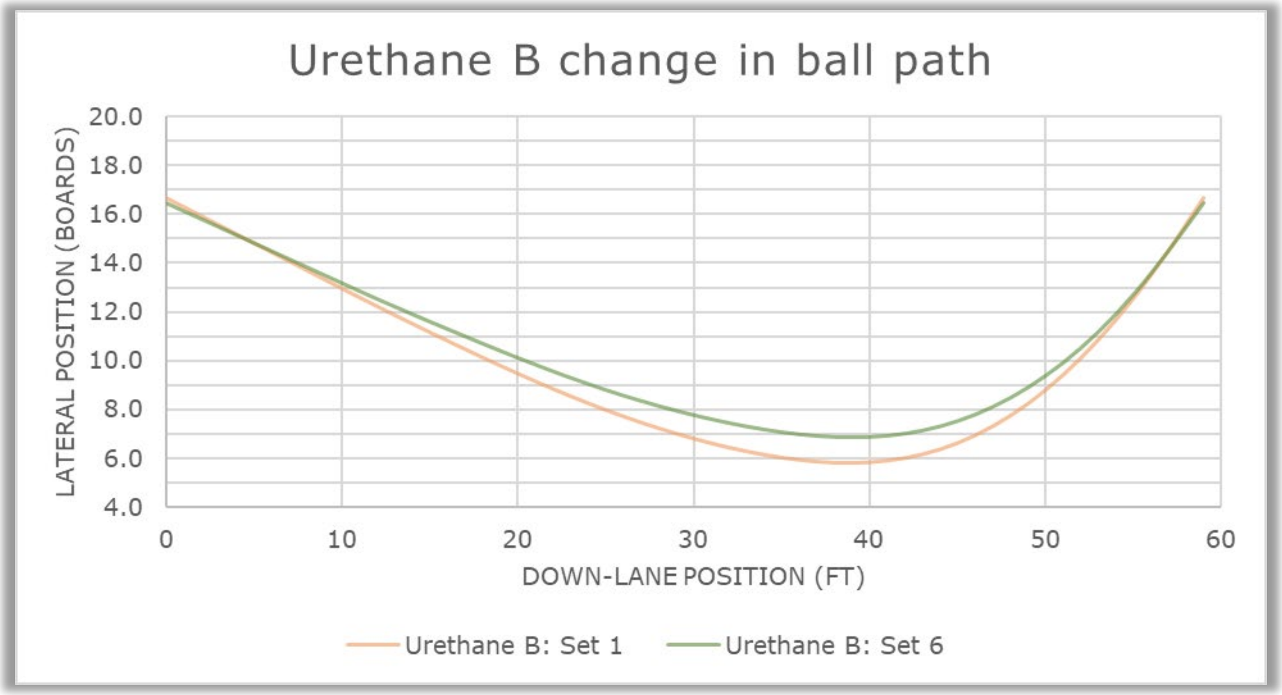


Continuing the analysis used on the previous model for Urethane B, we can examine the average ball paths for all samples across each of the six 30-shot tests to evaluate how the model changed with use.



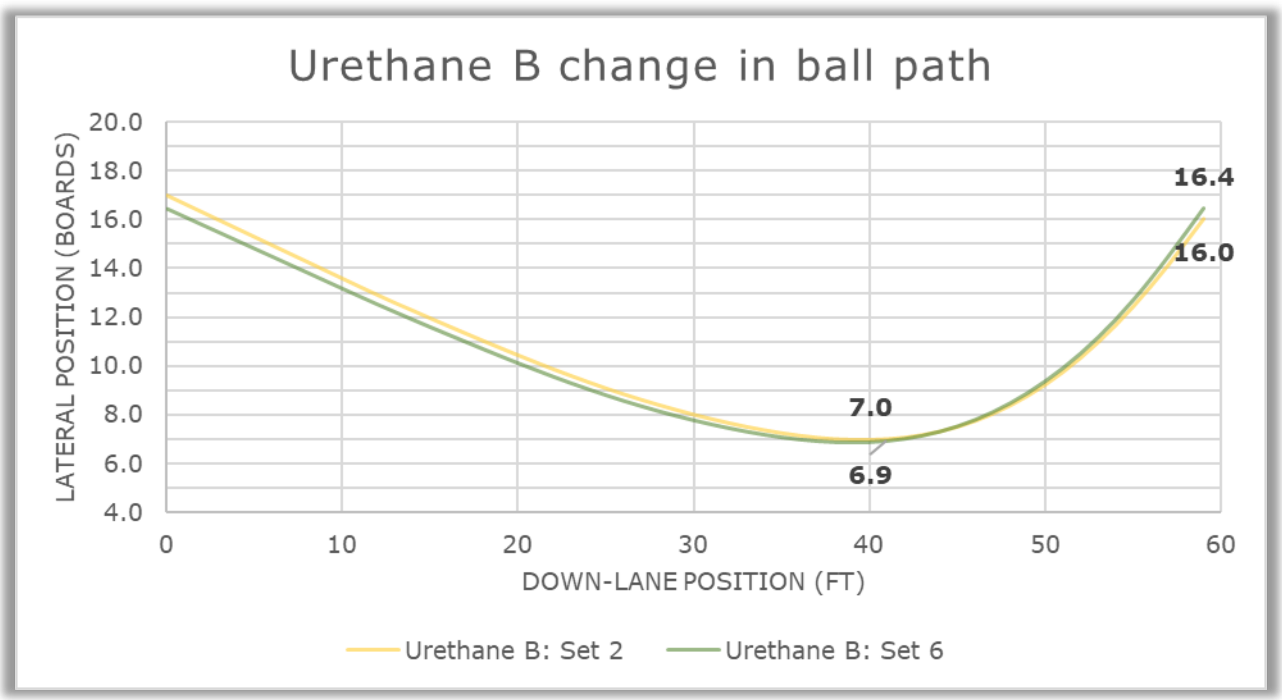
The strongest set, where the ball path began furthest inside, went out to the widest breakpoint and returned to the pocket, was the very first set. The rest of the sets were all very similar.

If we compare sets one and six, we see the following:



We see, on average, these paths were about 1 board different at the breakpoint and returned to the same position at the pins. Based on the Sport Bowling pattern we are using, one that does have left-to-right taper of the oil, one board of room at the breakpoint is not outside of normal occurrence.

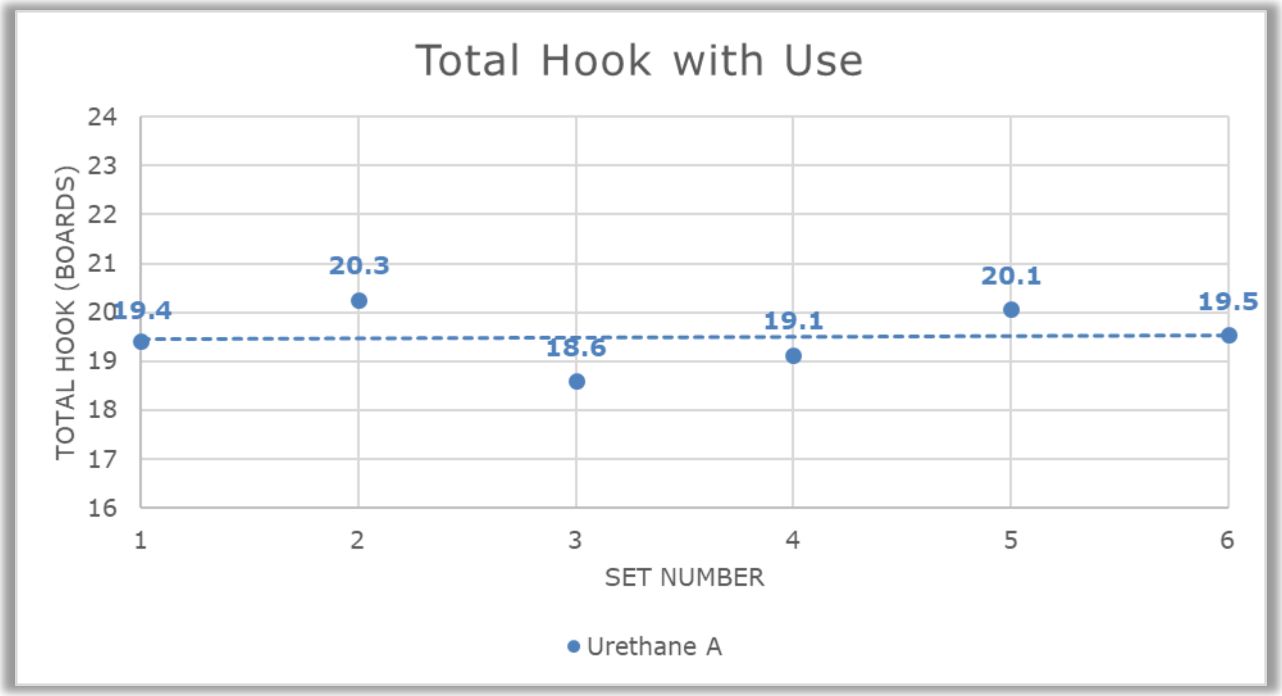
If we examine the difference in sets 2 and 6, we find they were thrown on more similar lines of action and there is very little difference, just like what we saw with urethane A.



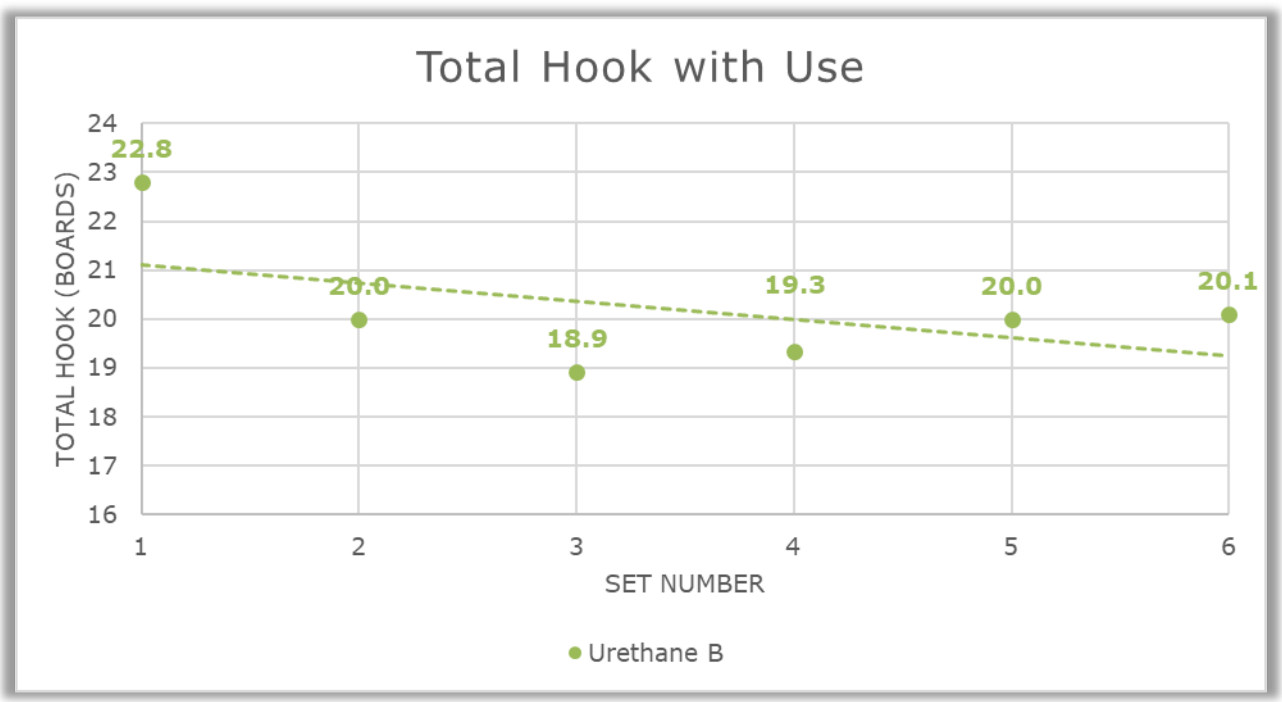
Here, we have observed nearly twice the drop in hardness with this urethane model, and still we see little difference in ball shape performance with use.

Total Hook

In terms of total hook, we also see minimal trends relating to the loss in hardness. Total hook remains similar throughout the testing, and the slight variations relate more closely to the angle of attack on the pattern rather than the observed loss in hardness.

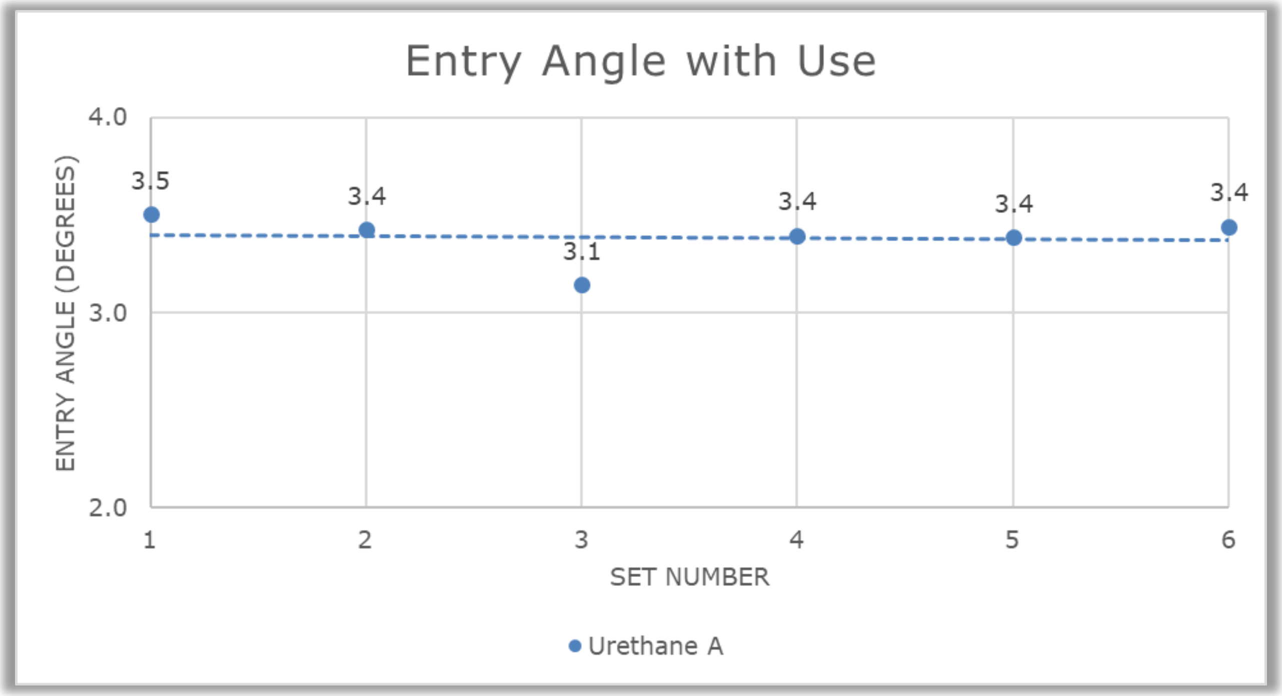


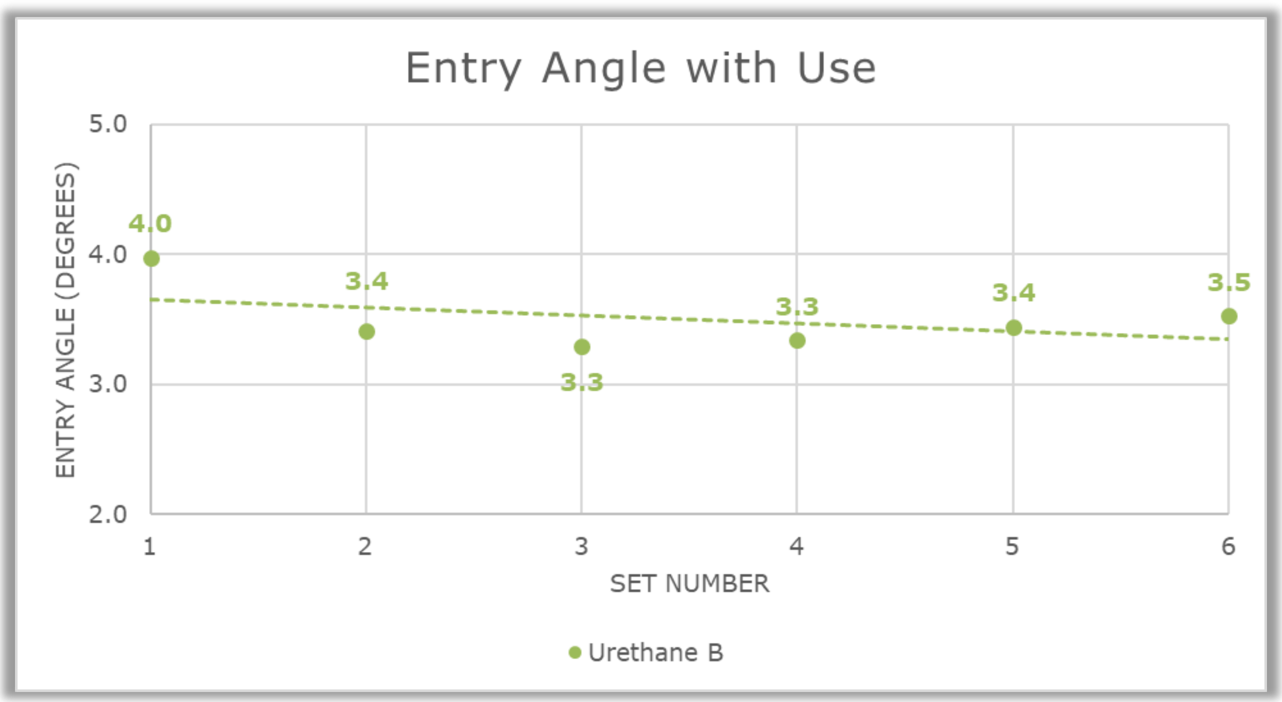
Just like the testing with urethane A, the differences in hardness measurements for Urethane B do not correlate to differences in total hook or entry angle of these samples.



Entry Angle

Entry angle tells the same story; there is no observed trend relating the entry angle achieved by the ball to the observed loss in hardness.





Key Takeaways

- Hardness changes in urethane balls due to use minimally impact performance characteristics.
- Different brands of urethane balls exhibit different decreases in hardness when put through the same use.
- With only 12 to 13 games of use, we can see similar decreases in hardness to what USBC data showed in the field tests.

- The hardness change from ordinary use does not correlate to ball path, total hook or entry angle performance.

Test #2: Same Urethane Models, Varying Hardness

For test 2, USBC tested two balls of the same urethane ball model but with very different hardness readings out of the box.

- Urethane A = 78.6 Hardness
- Urethane B = 73.4 Hardness (softer by 5.2 points)

Testing Procedure

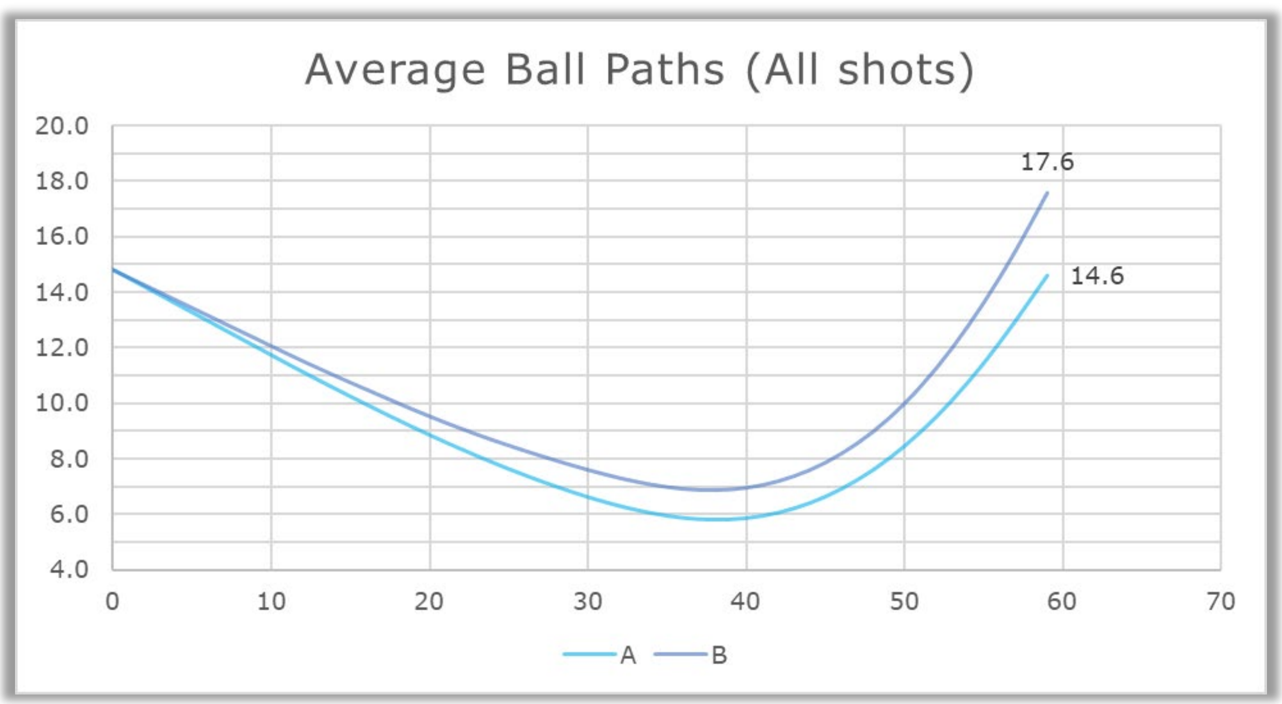
All of E.A.R.L.'s testing parameters were the same as Test 1 and 2 with some slight adjustments in rotation of shots between both balls. We threw seven series of 6 shots (3 of each ball) in an ABBAAB fashion:

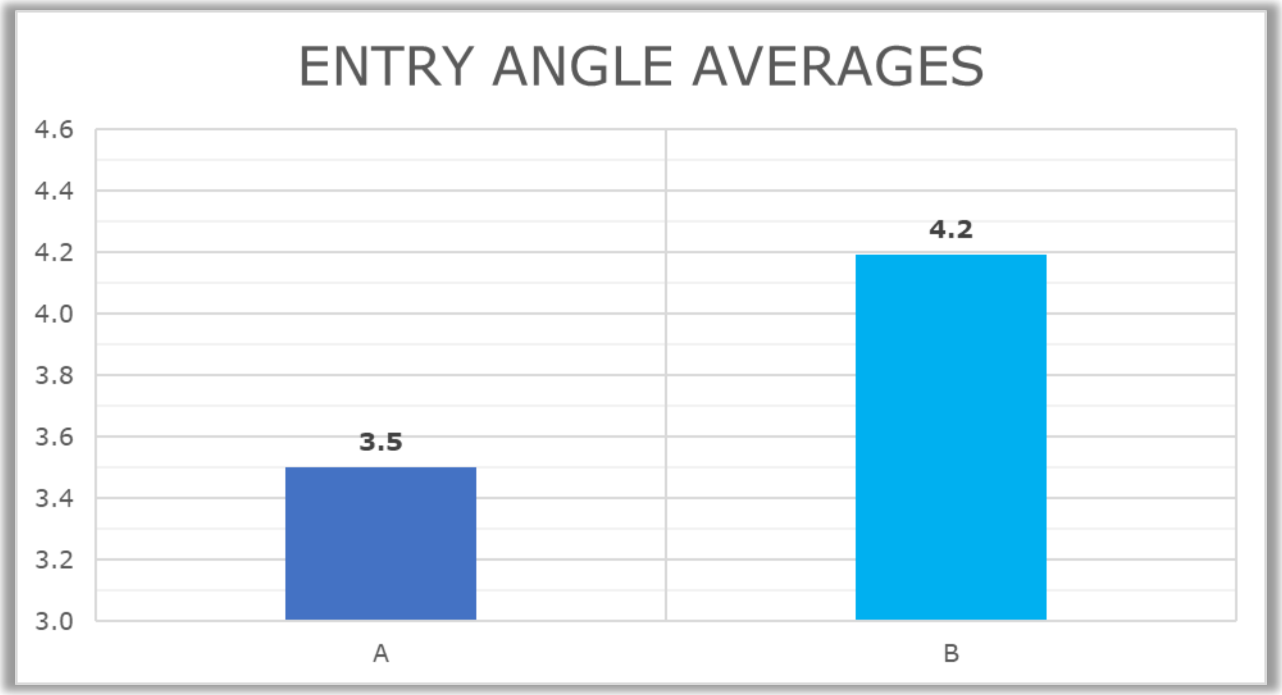
- Shots 1~6 ABBAAB – Practice allowing the balls to acquire some oil
- Shots 7~12 BAABBA – moved laydown 0.5 boards left, 1st Line for data
- Shots 13~18 ABBAAB – moved laydown 0.5 boards left, 2nd line for data
- Shots 19~24 BAABBA – moved laydown 0.5 boards left, 3rd line for data
- Shots 25~30 ABBAAB – moved laydown 0.5 boards left, 4th line for data
- Shots 31~36 BAABBA – moved laydown 0.5 boards left, 5th line for data
- Shots 37~42 ABBAAB – moved laydown 0.5 boards left, 6th line for data

Additionally, prior to testing, these balls were finished to 500 grit to better match the surface many of these balls are used at in the field.

Test Results

Ball Paths





Key Takeaways

- Ball hardness at manufacture clearly impacts performance.
- Testing the same model urethane ball with 5.2 variance in hardness out of the box provided a clearer indication that hardness does influence performance.
- The softer ball reads the oil much stronger and immediately begins hooking more than the harder ball, resulting in a difference of 3 boards at 59 feet when entering the pocket.
- In this test, we showed that 1 point of hardness equates to 0.6 boards more hook.
- Also, the softer ball had 0.7 degrees more entry angle on average.
- In this test, we showed that 1 point of hardness equates to 0.13 degrees more entry angle.

Test #3: Soaking Bowling Ball Test

This was a test to further investigate ball hardness. In this test, polyester, urethane and reactive shells were artificially softened with solvent, specifically Methyl Ethyl Ketone (MEK). This solvent was used in the 1970’s to soften polyester balls and is the reason for the development of the original 72D hardness spec. Back in the 1970’s, some pro bowlers began experimenting with solvents to soften polyester shells.

In this test, USBC set out to identify the change in hardness, footprint and total hook related to chemically altering bowling balls.

Soaking balls in MEK altered the urethane ball hardness and performance the most. While the polyester changed its amount of hook similarly to urethane, its hardness change was much less. The polyester and reactive balls had a similar change in hardness (much less than urethane), but the reactive had the least change in hook due to soaking. Also, the reactive shells tended to return to their original hardness after a day or longer, unlike the polyester and urethane shells.

Testing Procedure

For safety reasons, USBC strongly discourages attempting to replicate this test outside of a professional laboratory.

Methyl Ethyl Ketone (MEK) is a potentially dangerous and hazardous material. Alteration of a ball as was done in this test makes the ball immediately illegal for USBC competition. Anyone found using a ball altered in this manner in USBC competition will be subject to suspension from membership under Rule 17a[5] (Unfair Tactics). Per Rule 17a, an individual can be charged with attempting to gain an unfair advantage in league or tournament play for directly or indirectly tampering with bowling balls so that they no longer meet USBC Specifications.

For these reasons, USBC is intentionally not disclosing the exact test procedure publicly as it relates to the use of MEK.

Earl Settings:

- Ball Speed – 17 MPH
- Rev Rate – 350 RPM
- Axis Tilt – 10 degrees
- Axis Rotation – 45 degrees
- Lay down point – 16 board
- Launch angle -1.2 to -1.9
- Ball surface (reactive and urethane) – 2000 grit
- Ball surface (polyester) – Factory polish
- Oil pattern – 2022 PWBA pattern

Additional notes:

- The test consisted of throwing each ball 5 times and recording the average location.
- The urethane and reactive balls had similar core dynamics with similar flare potential and RG values. The polyester ball has a traditional non-flaring, 3-piece core.

Test Results

All balls were thrown along the same ball path in order to allow the difference to show up as the board location at the pins or the change in boards from the starting point for each ball before any soaking. A reactive ball was lined up to hit the pocket, and the urethane and polyester balls were lined up to hit to the right of the pocket at the start.

Change in Hardness

From the 2-hour soak test in MEK, the two urethane balls changed their hardness the most, dropping 21 and 24 points in hardness down to a hardness of 49D and 52D. Urethane #1 changed its hardness the most followed by Urethane #2. The polyester ball dropped 9.0 points in hardness but never dropped below 77D after 2 hours of soaking in solvent.

There is a possibility that the outer skin of the polyester balls was softer, but the durometer needle was penetrating through the soft skin and measuring harder polyester material below the outer skin. The polyester ball was eventually soaked for a total of 3.5 hours to reach the point where soaking in solvent dropped the hardness below the prior hardness spec of 72D.

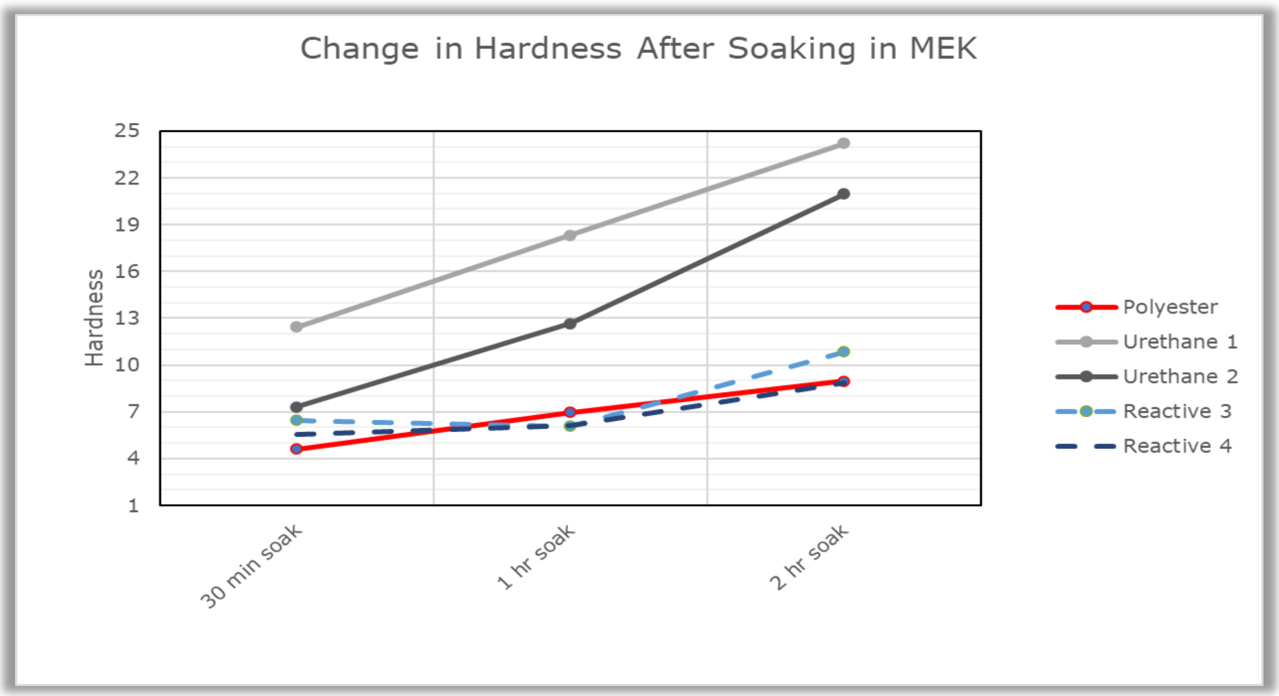
The reactive shells changed 8 to 10.9 points in hardness but returned to their original hardness over a weekend, even getting a little harder than their original hardness.

Shell	Hardness starts	Hardness after 2 hr. soak	Change in hardness	Hardness after 1-3 days	Hardness changes after 1-3 days
Reactive 3	74.0	63.1	10.9	76.0	-2.0
Reactive 4	75.0	66.0	8.0	75.6	-0.6
Polyester	86.4	77.4	9.0	75.8	10.6
Urethane 1	73.1	48.9	24.2	55.0	18.1
Urethane 2	72.7	51.7	21.0	54.8	17.9

[5] USBC Playing Rules 17a and 18

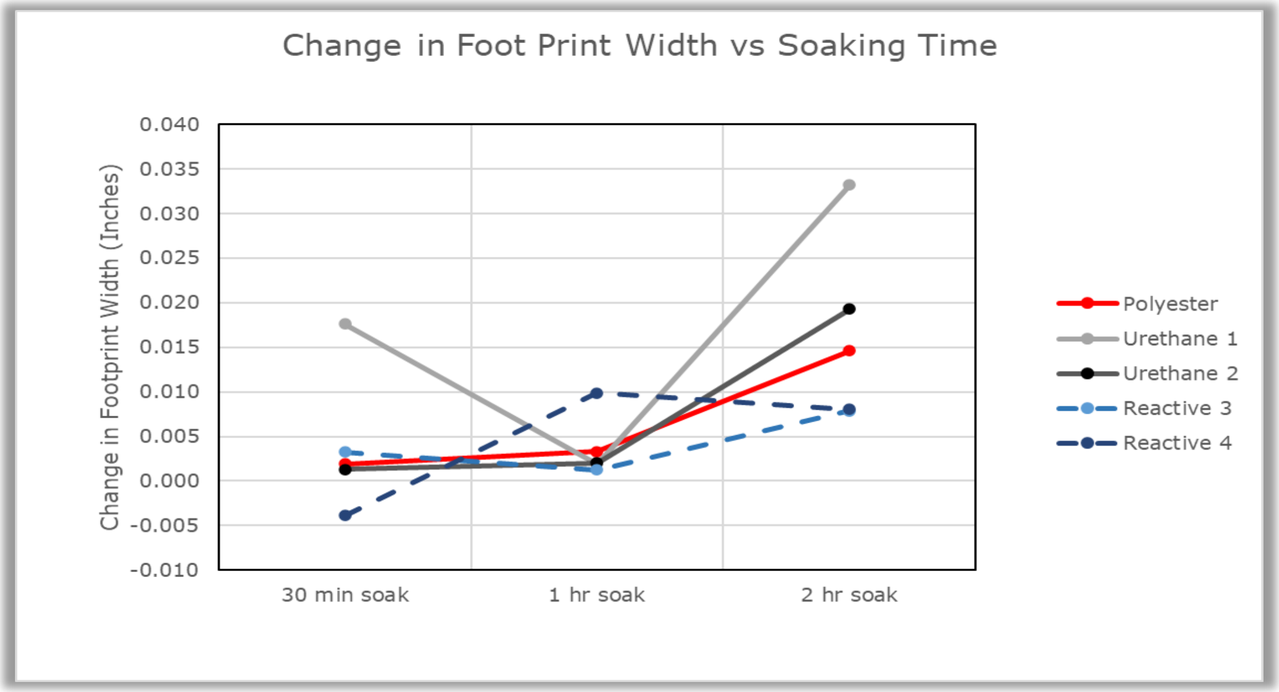
Notes:

- Negative numbers shown in the table above represent balls getting harder, not softer
- Positive changes are generally softer
- Numbers on Y-axis are point of softening



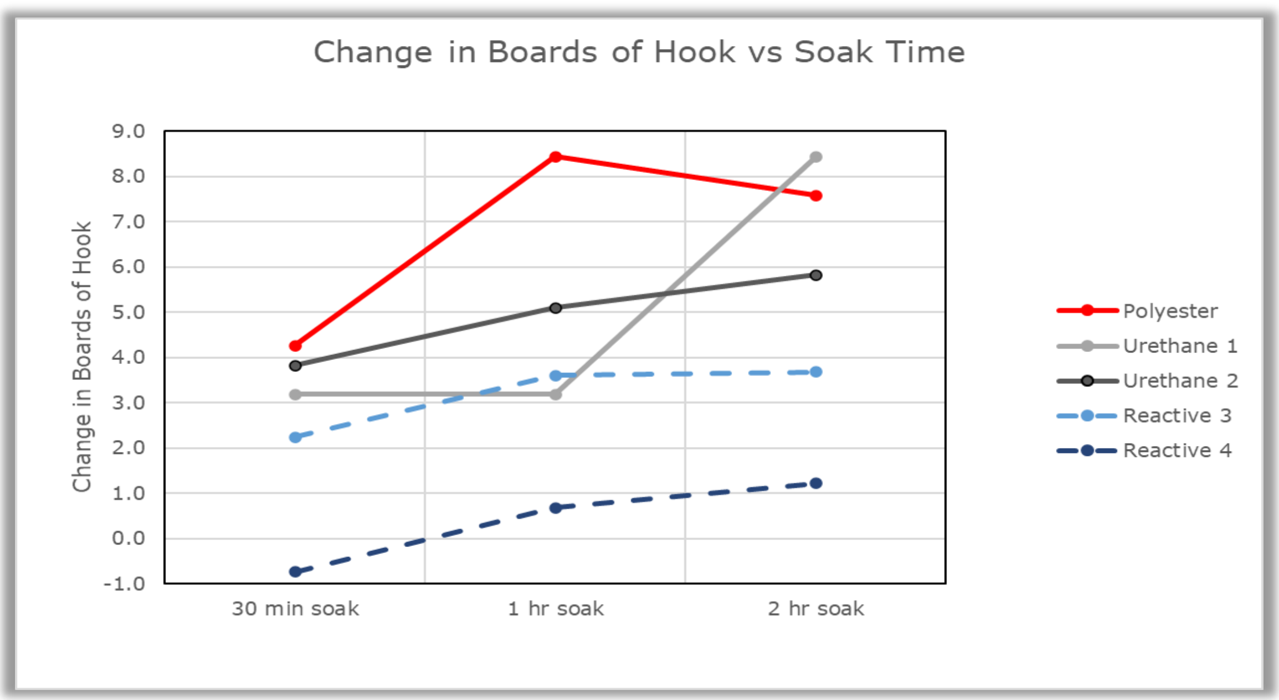
Footprint width

The urethane balls had the most change in footprint width due to soaking in solvent (changing .019" and.033"), which potentially is a result from these balls changing the hardness the most. The footprint of the polyester changed .015". The reactive shells both changed the least at .008".



Total Hook

Urethane #1 gained the most hook from soaking the ball, increasing its amount of hook by 8.4 boards compared to the ball before being soaked. The polyester balls were 2nd in boards gained at 7.6 boards of hook from 2 hours of soaking even though this ball only fell to 77D hardness. Urethane #2 was next at 5.8 boards of increased hook. The reactive shells had the least increase in hook from solvent soaking at 1.2 and 3.7 boards increase.



Key Takeaways

- It has been documented since the 1970's that solvents can soften polyester shells, resulting in more hook. This was verified again in our test.
- Urethane balls softened more than polyester and also showed a greater increase in hook compared to polyester after soaking.
- Reactive balls were the least impacted. Their hook increase due to soaking was minimal. Reactive balls returned to their original hardness or got harder over time after soaking.
- In general, soaking balls in MEK solvent changes urethane and polyester shells much more than it changes reactive shells. Urethane shells had by far the most change in hardness.

CONCLUSION

Findings continue to show the hardness of urethane balls drops through ordinary use over time. USBC spot checks urethane equipment regularly and has never measured an unused urethane ball outside of the manufacturing specification.

This 2022 report summarizes additional research projects completed this year. The results provide clear data to allow bowling's stakeholders to share a common set of facts.

- Urethane bowling balls get naturally softer with use. USBC data shows friction and shear forces along with lane oil exposure are contributing causes. However, this natural softening of bowling balls through use minimally impacts performance, if at all.
- Lower ball hardness at manufacture clearly impacts performance. Testing two versions of the same model urethane ball with different hardness out of the box shows very different performance. The softer ball is stronger.
- Chemically altering bowling balls to make them softer significantly impacts performance. The softer altered balls are stronger.

These are important findings. USBC does not have data to justify removing used bowling balls from competition due to hardness changes from ordinary use. Field testing whether bowling balls are below a hardness number doesn't provide enough information to know if a given ball creates an advantage. You need to know what caused the ball to reach the hardness number. Ordinary use is minimally impactful while a ball manufactured below specification or altered has an advantage.

The fact that changes in ball hardness from ordinary use minimally impacts performance should not lead to a conclusion that ball hardness doesn't matter. This study indicates hardness changes due to friction and oil (ordinary use) compared to hardness changes due to manufacture or chemical alteration are different.

Additional research is needed to better understand the relationships between hardness differences and performance differences. From the data the relationships are based on cumulative and interactive effects between several variables – shell chemistry, oil exposure, chemical soaking, and shear forces from natural use.

USBC equipment specifications are designed to set boundaries on the manufacturing of bowling equipment to address that side of the issue. USBC rules then prohibit tampering with approved products. USBC believes proper governance is in place on this topic.

Manufactured hardness is a physical property of bowling balls that has clearly been demonstrated to have performance implications. Therefore, it is essential that manufacturing regulation in this area continues to ensure that the performance range allowed for bowling balls is maintained.