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DEVELOPING AND OPTIMIZING A PROTECTIVE SKATEBOARD SHOE PATCH DESIGNED TO EXTEND THE LIFE OF THE SHOE

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ABSTRACT

The objective of this project was to develop and optimize a protective patch for skateboard shoes that will extend the lifespan of the shoe. Essentially, this will be done by adding a material to the shoe in the form of a patch that has a high wear resistance factor, which will keep holes from forming on the upper portions of the shoe. Our Materials Science & Engineering Senior Project team fabricated two different polymer based patches, the first being a polyurethane based thermoplastic which contains various volume fractions of either silicon carbide (SiC) or alumina (Al_2O_3) ceramic powders, and the second being a polyurethane based thermoset material with no ceramic powders added.

Several design requirements regarding mechanical and material property performance and user feedback were implemented for this engineering endeavor, and each was tested to validate whether or not the material was successful. Design requirements include a patch thickness of less than 1.6 mm, a true stress value greater than 10 MPa, a true strain value greater than 1, a glass transition temperature less than – 25 °C, a wear lifetime greater than 100 kick-flips, a patch wear resistance factor that is five times greater than the shoe material wear factor, a

friction coefficient between 0.6 – 0.8, and an adhesive lifetime that is greater than the patch lifetime.

To measure the mechanical properties of both materials, our team performed iterative tests which included tensile strength and elongation, Shore A hardness, wear resistance, friction, and user feedback, while simultaneously augmenting variables such as volume percent of ceramic particles, grain size, Shore A hardness, and material selection to maximize on these properties. Results from mechanical testing and user feedback concluded that the thermoplastic polymers had succeeded with respect to all design criteria except for wear resistance, and thus the thermoplastics have been deemed a failure. Results from the mechanical testing and user feedback conclude that the thermoset polymers have exceeded all design criteria except for adhesive lifetime, which will require additional work to find an acceptable adhesive. Although the thermoset adhesive tests technically failed, we consider the thermoset materials to be a success because the ultimate goal was to develop and optimize a patch material that will extend the life of the shoe. A skater was able to do more than 1000 kick-flips with the thermoset patch, demonstrating that the elastomer gives the required wear resistance against the abrasive grip-tape of the skateboard. The thermoset elastomer, adhered well to the shoe, works excellently, and had been well received by skaters in initial tests.

1. INTRODUCTION

In order to discuss the patches and the physics behind their design, we must first understand the physics behind the "ollie", and how it can create holes in the fabric that makes up the upper portions of the shoe. An ollie is a basic skateboard trick that is required when performing most other skateboard tricks, and involves snapping the back of the board down to the ground with the back foot while jumping and then sliding the top of the front foot up the board to counter the initial rotation. This creates an airborne effect for the skater, allowing them to jump over or off of objects, flip the board with their feet in midair, or grind on rails.

The problem comes from the abrasive interactions between the grip-tape of the skateboard and the upper portions of the shoe. All skateboards have a top layer of silicon carbide or aluminum oxide grip tape that is very similar to sand paper. This material creates a high level of friction between the skateboard and the rubber bottoms or soles of the shoes during an ollie, which helps the skater stay on the skateboard when performing tricks in the air. Although this works well with respect to the top of the board and the sole of the shoe, it is extremely destructive to the sides and top portions of the shoe. These portions of the shoe are usually made of weak fabrics like cloth or suede, which shred easily after repetitive contact with the grip-tape. After interviewing skaters at several skate parks and on the University of Utah campus, we had learned that for an everyday skater, these materials can wear out in just a few months, thus rendering their shoes inoperable. Purchasing new shoes every time holes are created is expensive and wasteful, and current repair methods are not very effective.

There are several companies that have been attempting to tackle this problem using repair patches, including *SkateAid*, *Ollie Guard* and *Stick and Flick*, but these companies use weak fabrics as their base material for their patches. The online reviews for these products are decent, yet they are impossible to find in local skate shops and must be purchased online only, which poses these questions: Do these companies actually have a decent product? If so, why aren't they more widely used/found/sold? Is it a marketing problem, or is their product too mediocre to be worth mass producing and mass marketing?

We believe that these companies haven't been very successful because their repair patches don't last very long – mainly due to the fact that these patches are made out of similar shoe materials. This is clearly a materials science related problem that can easily be overcome by using materials expertise to find a more durable base material for the repair patches.

Upon this realization, we set out to find a tough yet flexible material that can withstand the abrasive forces that occur while performing ollies and flip tricks, while conforming and flexing with the movements of the shoe while the skater skates without hindering performance, and would ultimately increase the life of the shoe.

2. LITERATURE REVIEW

After reviewing previous attempts of solving this problem, we discovered that there isn't much scientific research about skateboarding. A 2006 study performed by the Journal of Applied Biomechanics corroborates this notion by saying that "Despite… the sport's large and growing number of participants, skateboarding is poorly represented in the scientific and clinical literature." [1] There is a wealth of information, however, about wear of polymers and polymer-based composite materials. For example, an extensive review of solid particle erosion found that there are applications where the synergistic effects of both particles and fibers could improve the wear resistance of the polymer matrix [2].

Sliding wear is typical of the action of the skate shoe with the grip-tape when performing an ollie. The sliding wear can be reduced by adding nanoparticles as well as short fibers to both thermoplastic and thermoset polymers, although wear mechanisms are poorly understood [3]. Durand, et al. [4] found that larger ceramic particles resulted in improved wear resistance when added to a thermoset epoxy matrix under sliding wear conditions. The optimum particle size, which was 20 μm in their study, was dependent on the sliding velocity and applied load. Using Taguchi methodology, it was possible to show that applied load and sliding distance had a greater effect than sliding speed for epoxy-SiC particle composites, where the SiC particles greater reduced the amount of wear [5]. It is important to use characterization techniques which allow one to assess the type of wear mechanisms occurring on the microscopic level in order to optimize performance [6]. While dynamic laboratory properties are important in predicting wear behavior [7], it is important to get skate user feedback about wear performance.

A wide variety of elastomeric materials are available which can conform to the skate shoe. These include polyisoprene (natural rubber), styrene-butadiene-rubber (SBR), ethylene propylene diene monomer (EPDM), polyurethane, polychloroprene (Neoprene), nitrile butyl rubber, silicone, and fluorosilicone. Filler particles have been used for years to improve the wear resistance of elastomers, the most common being the use of carbon fillers in SBR tires. The interfacial bonding between the abrasive particle and the elastomer is essential for improving the wear resistance [8]. When glass spheres of different sizes were bonded into poly dimethyl silicone, the wear rate increased with increasing filler volume, except for the largest spheres [8], demonstrating that adding abrasive fillers does not always increase wear resistance.

Polyurethane was selected based on the literature study because it has well-known wear resistance in many abrasive application, including liners [9]. Shore A hardness is often used to correlate with wear resistance, with higher hardness, in the range of 40-90 leading to improved wear resistance [9]. The high elongation of the polyurethane allows it to interact with hard particles without a filler added.

Polyurethanes are formed by reacting a polyol (an alcohol with more than two reactive hydroxyl groups per molecule) with a diisocyanate. Most polyurethanes require a catalyst and temperature and these will be called thermosets, even though they are much softer than cross-linked epoxies. Other polyurethanes are used as inks and are prereacted so that when their solvent is evaporated, they leave a thermoplastic polyurethane. These thermoplastic polyurethane resins (PUR) are more readily adapted to adding a filler. A recent study where 5 vol. % ceramic particles were added to a PUR showed high Young's modulus, but decreased wear resistance [10].

Most of what we were able to find were personal testimonies regarding how easily skaters can develop holes in their shoes, as well as user reviews of existing products. These reviews converged towards several different issues, including how weak the patches are which leads to the frequent purchasing and replacement the repair patches, and how people wish there was a more durable material available.

3. PRODUCT DESIGN AND SPECIFICATIONS

The design and specifications of our skateboard shoe patch reflect the overall patch system and its subsystems, which includes the patch surface to skateboard grip-tape interface, and the adhesive to shoe interface.

With respect to the patch system overall, the patch material must not enter a glassy transition state under skate-friendly weather conditions. The correlating specification states that $T_g < -25$ °C. Also, the material must be able to conform and flex with the shoe as the skater skates, without hindering the skater's ability to do so. The correlating specifications state that the patch material must experience a true stress value greater than 10 MPa, a true strain value greater than 1, and have a patch thickness of less than 1.6 mm.

With respect to the patch surface to skateboard grip-tape interface, the patch material must exhibit levels of friction that have been deemed favorable by users, and must outlast the shoe material by a factor of five at a minimum. The correlating specifications state that the range of friction coefficients must be between 0.6 – 0.8, the patch material must be able to accommodate a minimum of 100 kick-flips, and the patch lifetime must be at least five times greater than the shoe material.

With respect to the adhesive-to-shoe interface, the deign requirement states that the adhesive must outlast the patch material, and operate well under skate-friendly weather conditions.

We used both a PUR (thermoplastic) and a thermoset in order to test these design specifications. The first material is a polymer-ceramic composite of various volume fractions of a thermoplastic elastomer, hereafter called Polymer A and either granulated SiC (silicon carbide), or powdered Al_2O_3 (alumina). The Polymer A component will theoretically add an elastomeric medium with friction similar to the bottom of the shoe which will add more stability and control for the skater and the board. The suspended ceramic particles will provide grit and add to the total friction, as well as keep the polyurethane from shredding quickly over time by utilizing a "grip and slick" motion as opposed to a "sliding" motion, thus adding to shoe lifespan. The addition of ceramic particles has been known to improve elastic modulus and can theoretically add more control, although the downside may be a lower wear resistance[10].

The second material is a thermoset elastomeric material, which will be referred to as Polymer X from now on. These two elastomers were chosen from a wide variety of elastomers in order to meet the design criteria, as discussed above.

Both versions of these patches will be thin and flexible, come in many colors, and will be applied to the shoe with a pressure sensitive adhesive. The user can also customize the shape they need for their specific shoe by being able to cut the patch with scissors in order to customize the perfect shape for shoe application.

4. PROJECT PLAN AND PROCEDURE

Slip Preparation

The project plan for the thermoplastic polymer-ceramic composite material involved adding SiC or Al_2O_3 in defined volume percentages to Polymer A. Slips were made by adding 50 grams of the polymer suspension to a 125 mL high-density polyethylene (HDPE) milling bottle, adding the desired amount of ceramic powder, adding 250 grams of spherical (15 mm diameter yttria tetragonal polycrystalline (Y-TZP) media, and adding various amounts of ethanol to adjust the viscosity of the polymer. The slurries were mixed for two hours at ~ 100 rpm on a roller mill and viscosity was measured with a LV-4 spindle using a Brookfield DV-2+ viscometer at spindle speeds varying between 10 and 100 rpm. The slips were degassed in a vacuum jar and cast on silicone coated polyethylene terephthalate (PET) sheet using a doctor blade.

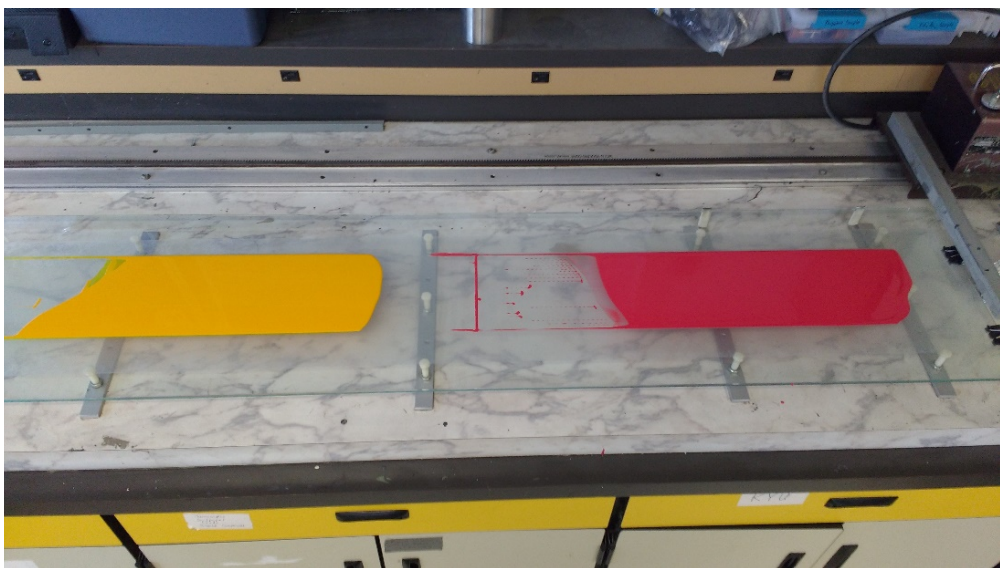

Figure 1 - Slips after casting on PET sheet

The slips were dried overnight at ~ 75 °C. Selected tapes were heat laminated at 80 °C for one minute using a pressure of 100 MPa in order to bond multiple layers of the thermoplastic polymer composites together when thicker materials were desired.

Hardness Testing

The thermoset materials were prepared so as to have varying hardness, and both the thermoplastics and thermosets were measured for hardness using a Phase II PHT-961 Shore A Durometer Stand with a PHT-960 hardness testing device which can be seen in Figure 2.

Figure 2 - Shore A Hardness Tester.

This thermoset polymer did not have ceramic particles in it, but its hardness was changed by controlling the density of cross-linking in the polymer. The thermoplastic polymer-ceramic composite was tested to see what effects the addition of ceramic particles had on hardness.

Tensile Property Testing

The thermoplastic and thermoset tapes of various hardness were punched into dog bone shaped tensile samples with a gage section of 6.35 mm wide by 33 mm long, with a total length of 115 mm and 25 mm wide grips (ASTM-D412-Type C). The as-cast tapes were nominally 130 μm in thickness and were pulled with ASTM D 882 line grips using a 1 kN load cell attached to an Instron 5969 testing machine. The strain rate was fixed at 30 % per minute. True strain, assuming uniform deformation in the gage section, was plotted against true stress. An example of a test in progress is shown in Figures 3 and 4.

Figure 3 - Test set-up showing load cell, grips, and sample ready to be tested.

Figure 4 - Test in progress showing excellent elongation of 90 Durometer Polymer X.

Wear Properties

To measure the wear properties of these materials, we punched samples into 1.27 cm diameter wafers, and attached them to a rotational sample polisher using both a 4 and 6 sample polishing wheel, which allowed us to maintain a constant RPM and orthogonal load. We then tested the different materials for their wear resistance properties. The following is an image of the rotational wear test in progress.

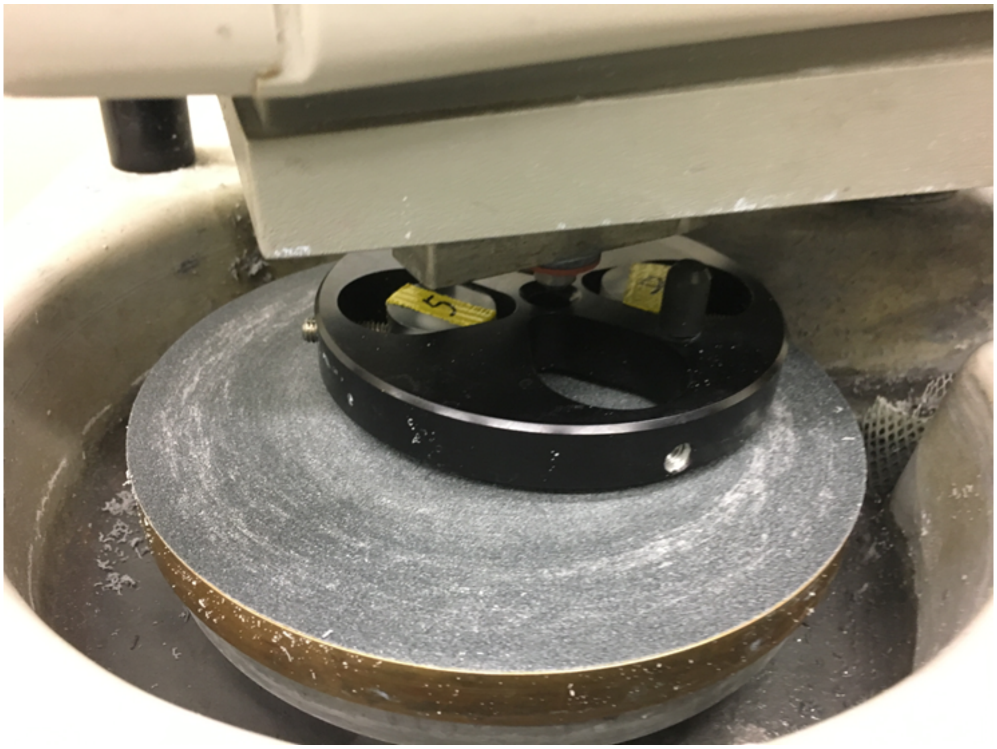

Figure 5 - Rotational Wear Resistance Test in Progress

Several of these samples were also sent to Taber Company, Inc. They performed a professional wear resistance test (ASTM D3389) on these samples.

Friction Properties

To test the materials for friction coefficients, all materials were cut into square samples roughly 6.5 cm^2 in size, and attached to a cylindrical loading weight. Each sample was then placed on an aluminum plane set at an initial angle of 0º. The plane was then slowly lifted using a sliding block beneath the plane to maximize a linear increase in angle, which can be seen in Figure 7. The tangent of the angle at which sliding had occurred is the coefficient of friction between two material surfaces. This test was performed on four different substrates, including bare aluminum, and 120, 240, and 400 grit polishing paper, and repeated six times for each material. The coefficient of friction was taken to be the average between all six tests.

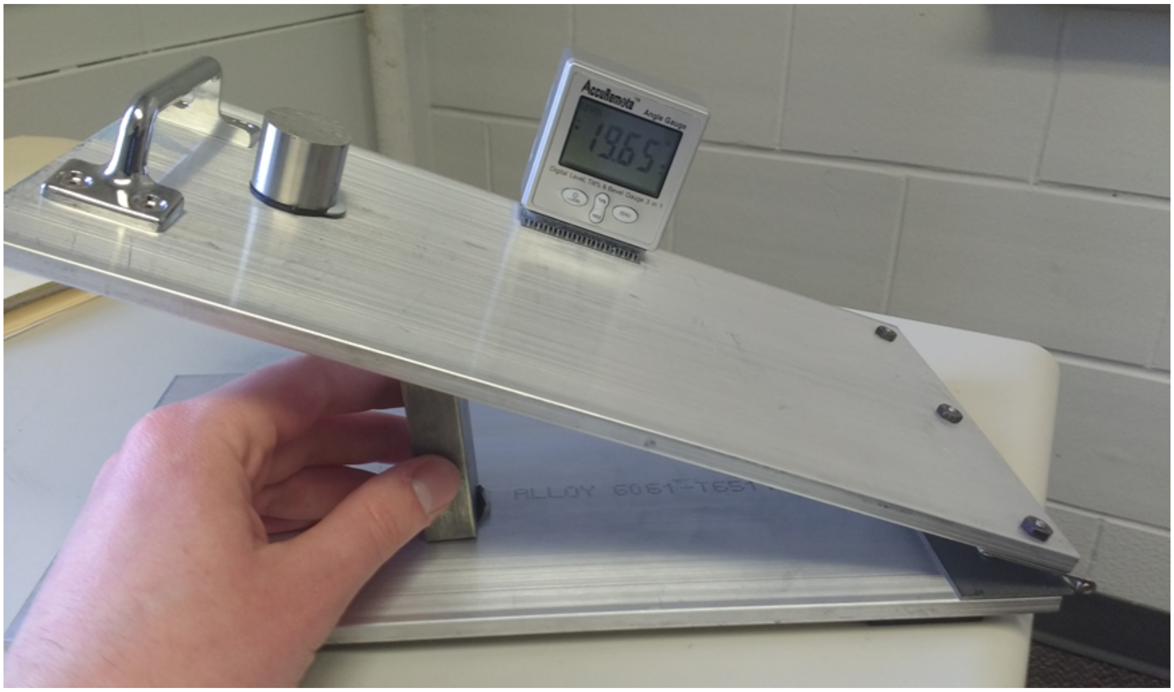

Figure 6 - Friction Test with Aluminum Plane

Adhesion Properties

To save money on materials, this test was performed using scrap pieces made from the negatives of the dog bone punch-outs that were used for tensile strength testing. Each adhesive test was performed on both suede (left) and canvas (right), and tested out 8 different adhesives, including several types of super glue, Loctite, and several 3M track tapes that were donated to our team for this project. Each was allowed to cure for 48 hours, after which we determined qualitatively which adhesives worked better than others. The following is an image of said adhesion test.

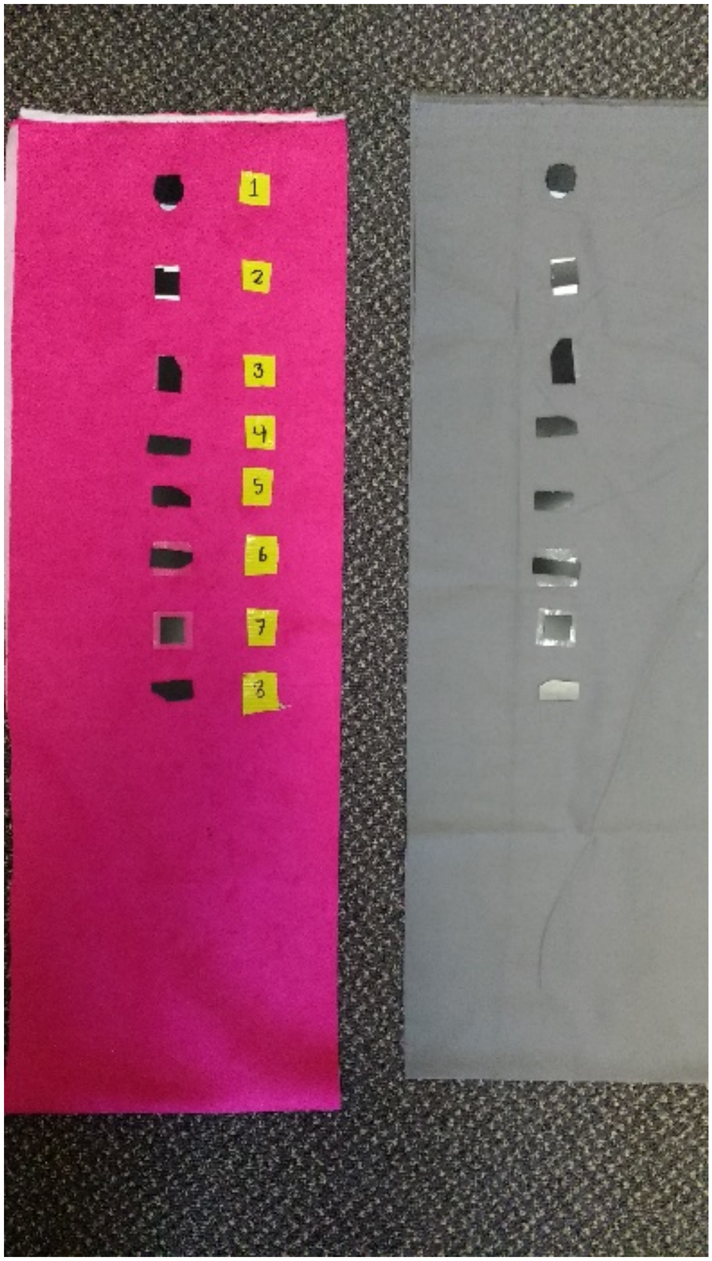

Figure 7 - Adhesion Test.

5. RESULTS AND DISCUSSION

Viscosity

Figure 8 shows the shear-thinning behavior of the slips, which is desirable for tape casting since the slip is sheared at low viscosity as it goes under the doctor blade and then increases in viscosity after the blade has passed. Higher solids loading increased viscosity as expected.

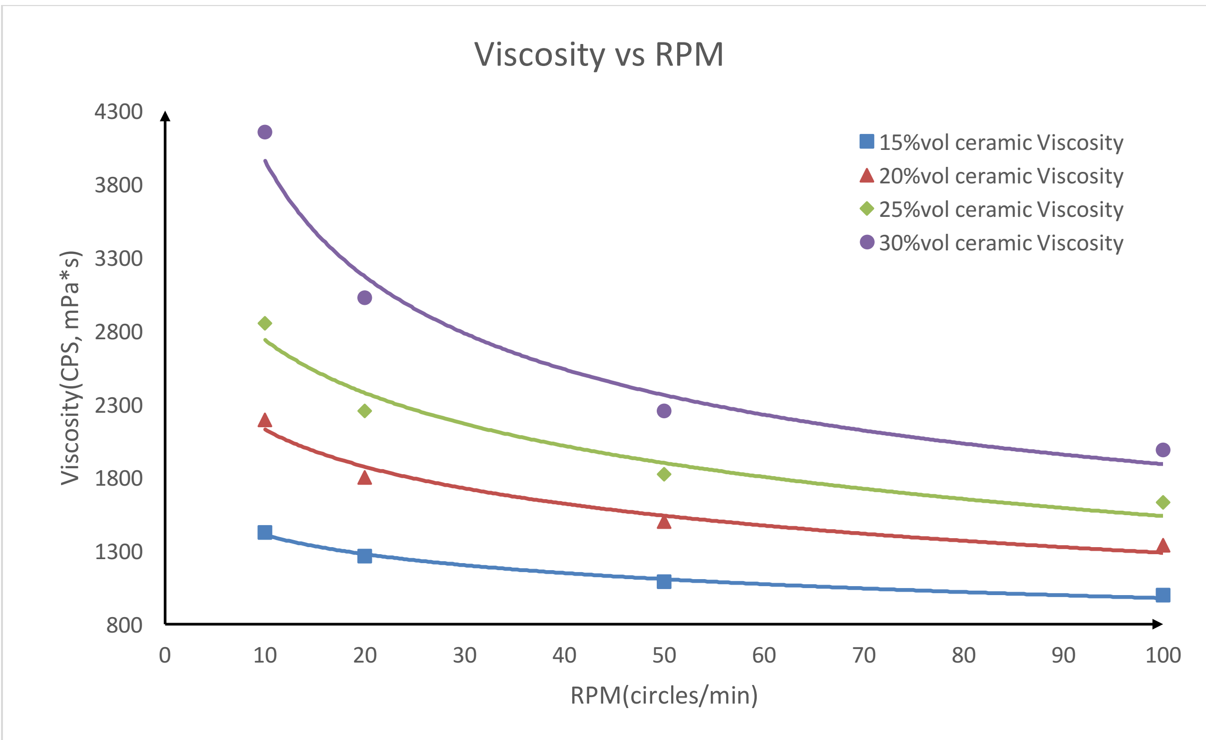

Figure 8. Viscosity as a function of shear rate and volume loading of alumina particles.

Shore A Hardness Properties

As seen in Figure 9, increasing the concentration of alumina resulted in an increase in average hardness of the thermoplastic materials. The hardness of the thermoset materials is controlled by the amount of isocyanate added and these materials ranged from about 40-95. It was possible to make materials with similar hardness values by both methods.

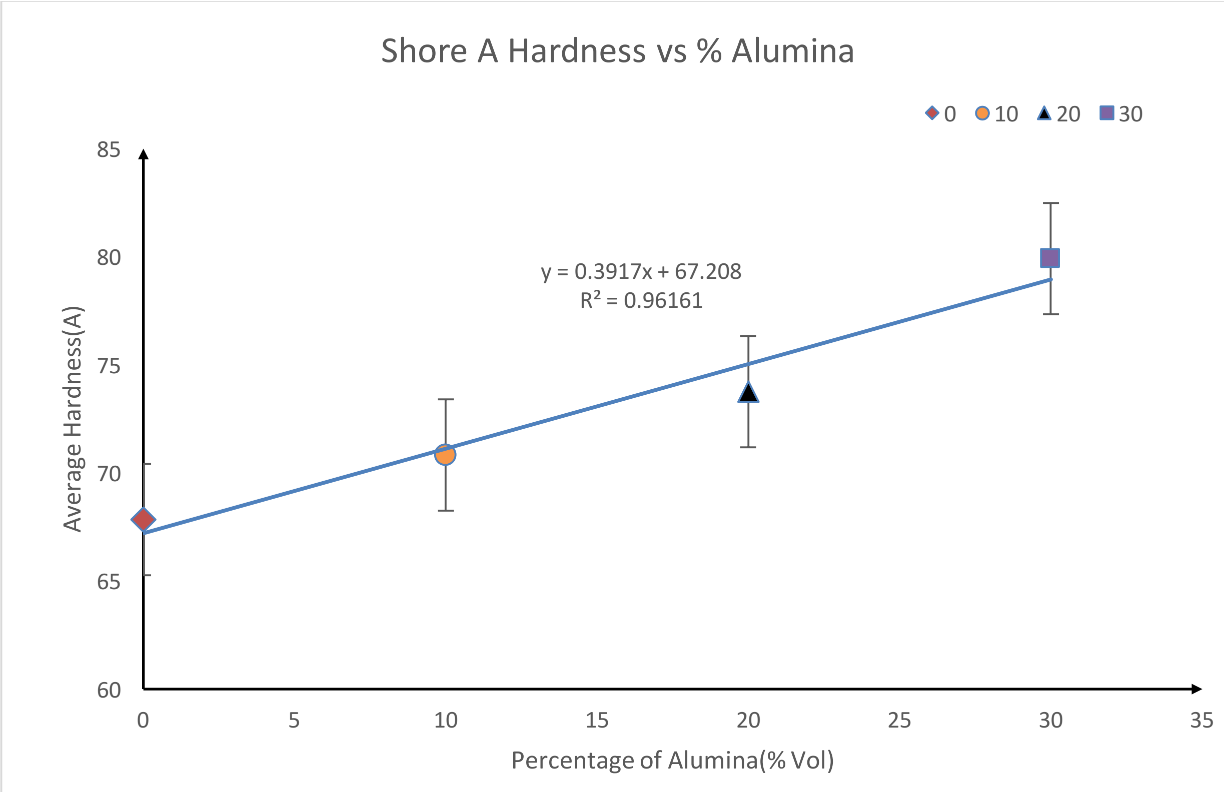

Figure 9. Effect of alumina loading on the hardness of thermoplastic polyurethane.

Tensile Properties

As seen in Figure 10, the true stress experienced by the thermoplastic polyurethane-alumina composites decreased as the concentration of alumina was increased, as expected. Although a linear relationship is shown for these data, it is likely that a polynomial fit would be more appropriate, but more data are needed to verify this assumption. Material A with 10 vol. % alumina meets the design criteria. The insert in Figure 11 clearly shows that higher hardness results in lower tensile strength for thermoplastic materials, consistent with expectation. Figure 11 also compares the thermoplastic materials to the thermoset materials.

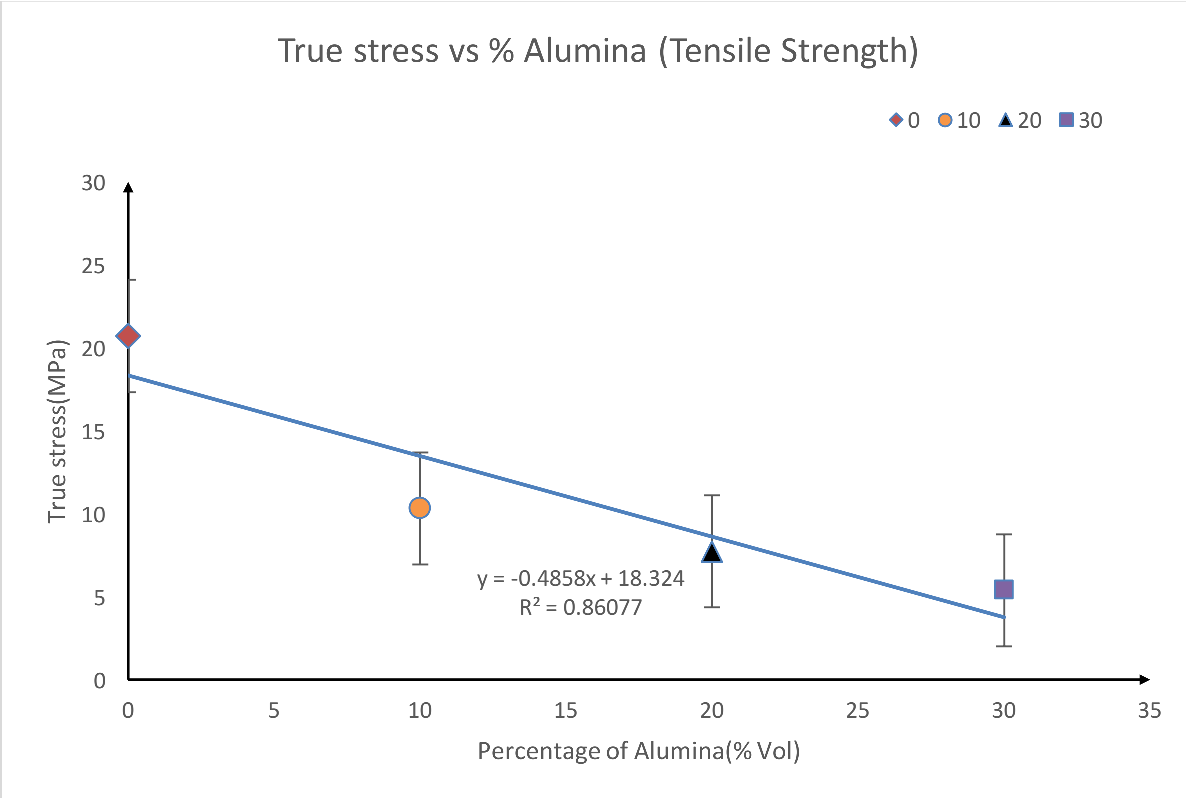

Figure 10. True stress as a function of alumina added to thermoplastic A.

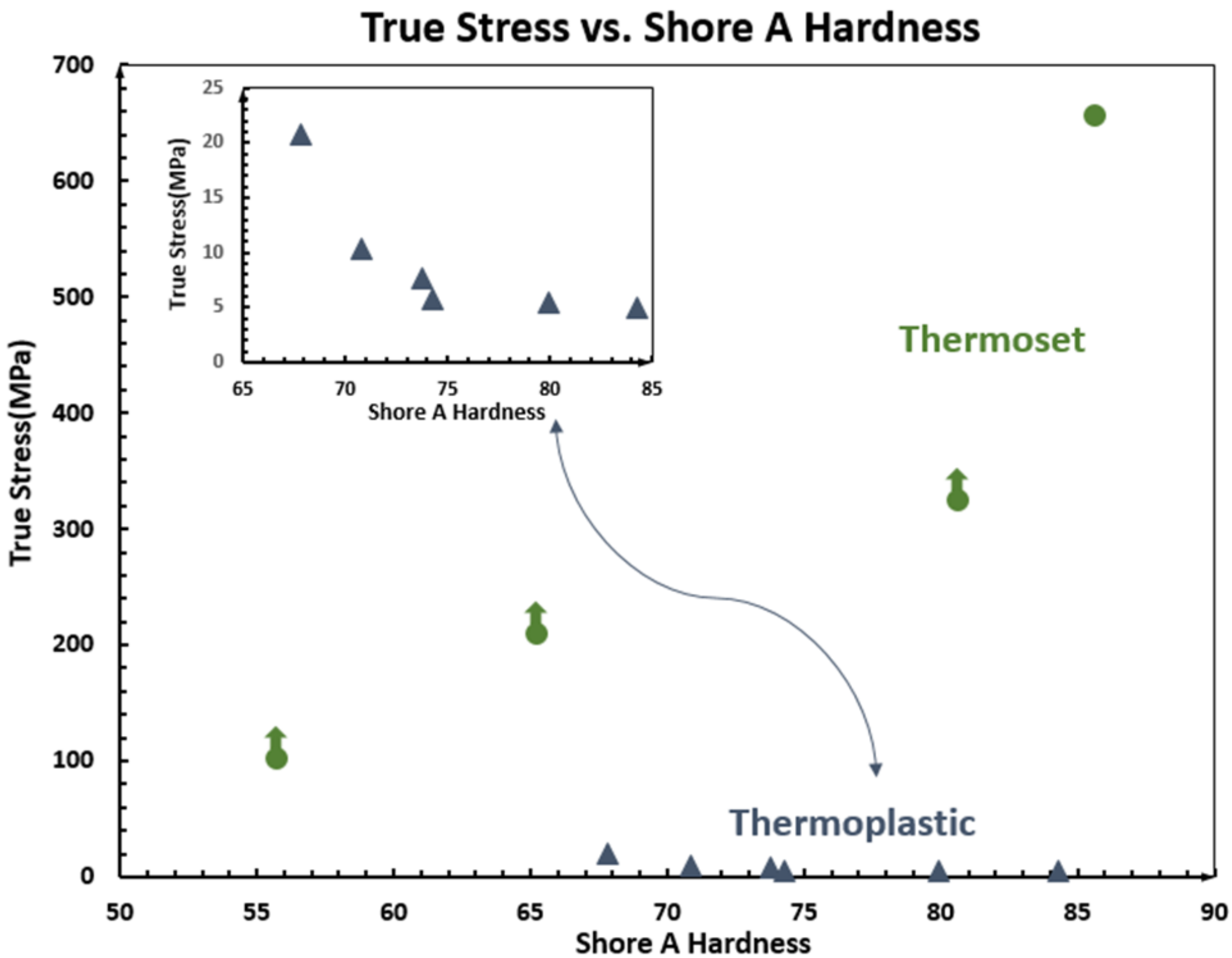

Figure 11. Tensile stress as a function of hardness for both thermoplastic and thermoset materials.

Figure 11 shows that the thermoset materials (green circles) can experience stress that is two orders of magnitudes higher than the thermoplastic materials (blue triangles) before mechanical failure. The arrows above the green data points refer to the fact that the elongation of these samples had actually exceeded the height limit of the Instron tensile machine that was used without mechanically failing, and this machine has a maximum height of over 3 meters! The thermoset materials have exceeded expectations for this design requirement and are deemed a success.

The true strain experienced by the thermoplastic dog bones decreased as the concentration of alumina was increased, as demonstrated in Figure 12. The ceramic particles limit the % elongation, but all materials tested had at least 60 % elongation at failure. The samples containing pure polyurethane, 10 vol. % alumina, and 20 vol. % alumina achieved a true strain value that was greater than 1 and thus satisfied this design requirement. The 30 vol. % alumina sample did not meet this requirement.

Figure 13 compares the thermoplastic and thermoset materials. All thermoset materials showed over 200 % elongation. The thermoset materials have a true strain value that is 1.5 – 10 times higher than the thermoplastic. All thermoset materials tested met the strain requirement.

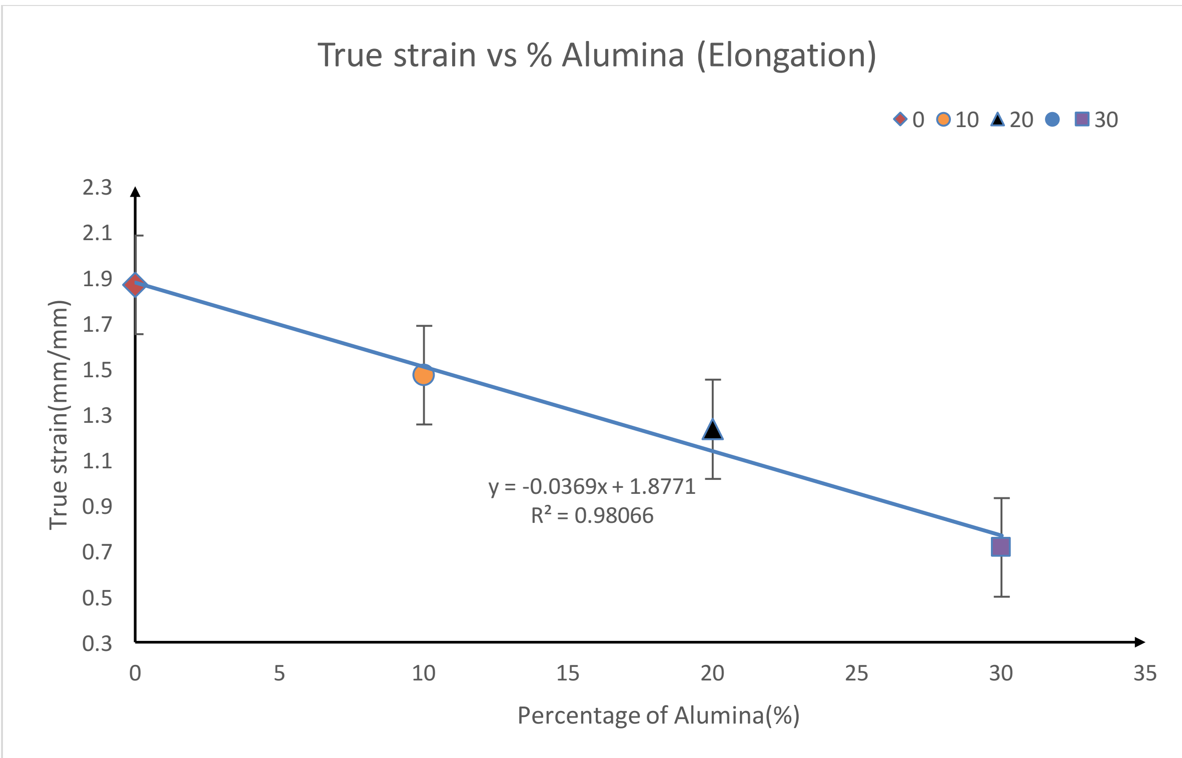

Figure 12. Strain as a function of alumina added to thermoplastic A.

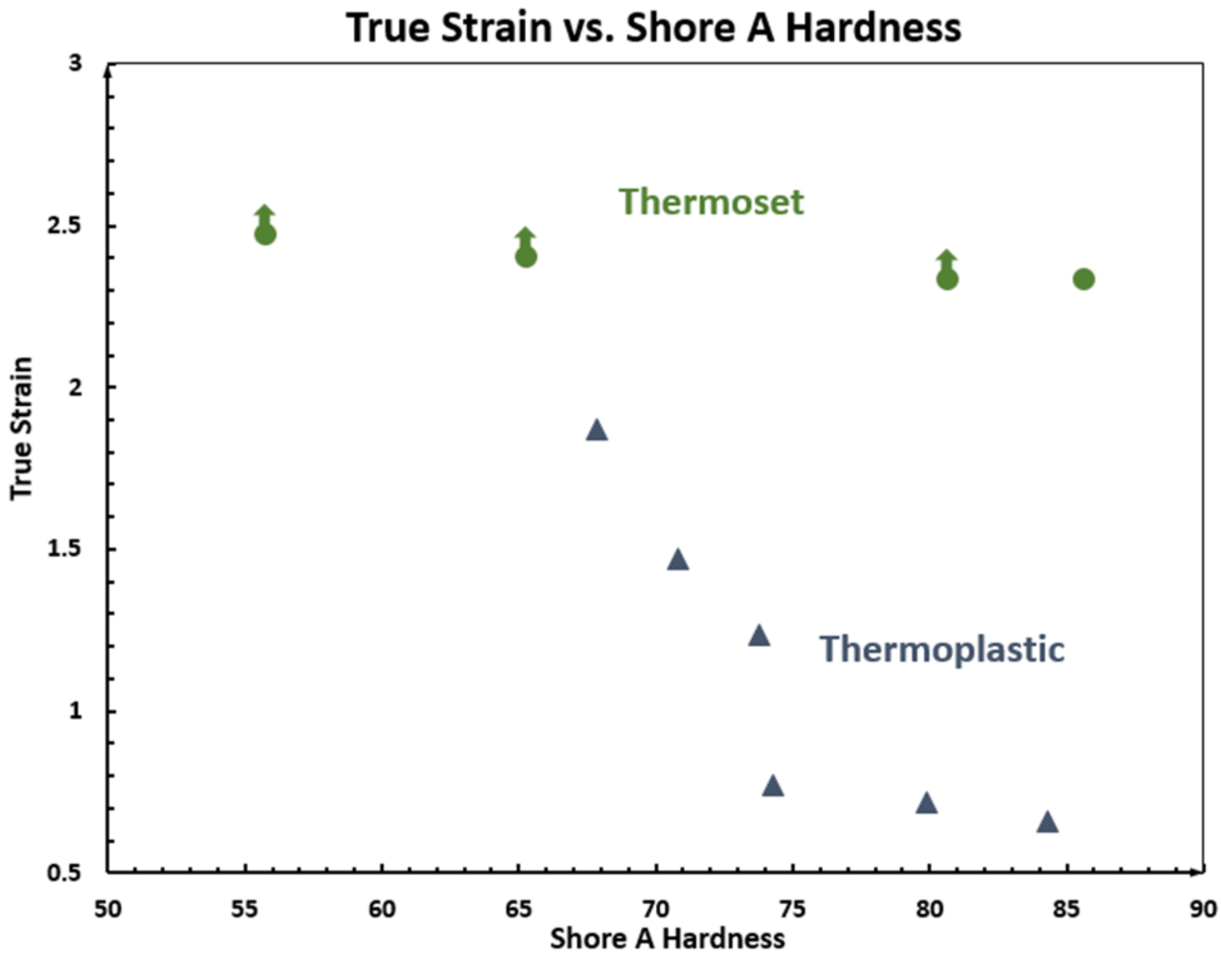

Figure 13. Strain as a function of hardness for thermoplastic and thermoset elastomers.

Wear Properties

Figure 14 shows the wear rate vs number of cycles during a linear wear test conducted by the Taber Company. Both materials had similar hardness, yet material X showed very small wear in comparison to material A, which indicates that Shore A hardness is not a requisite requirement alone for defining wear in these elastomeric materials.

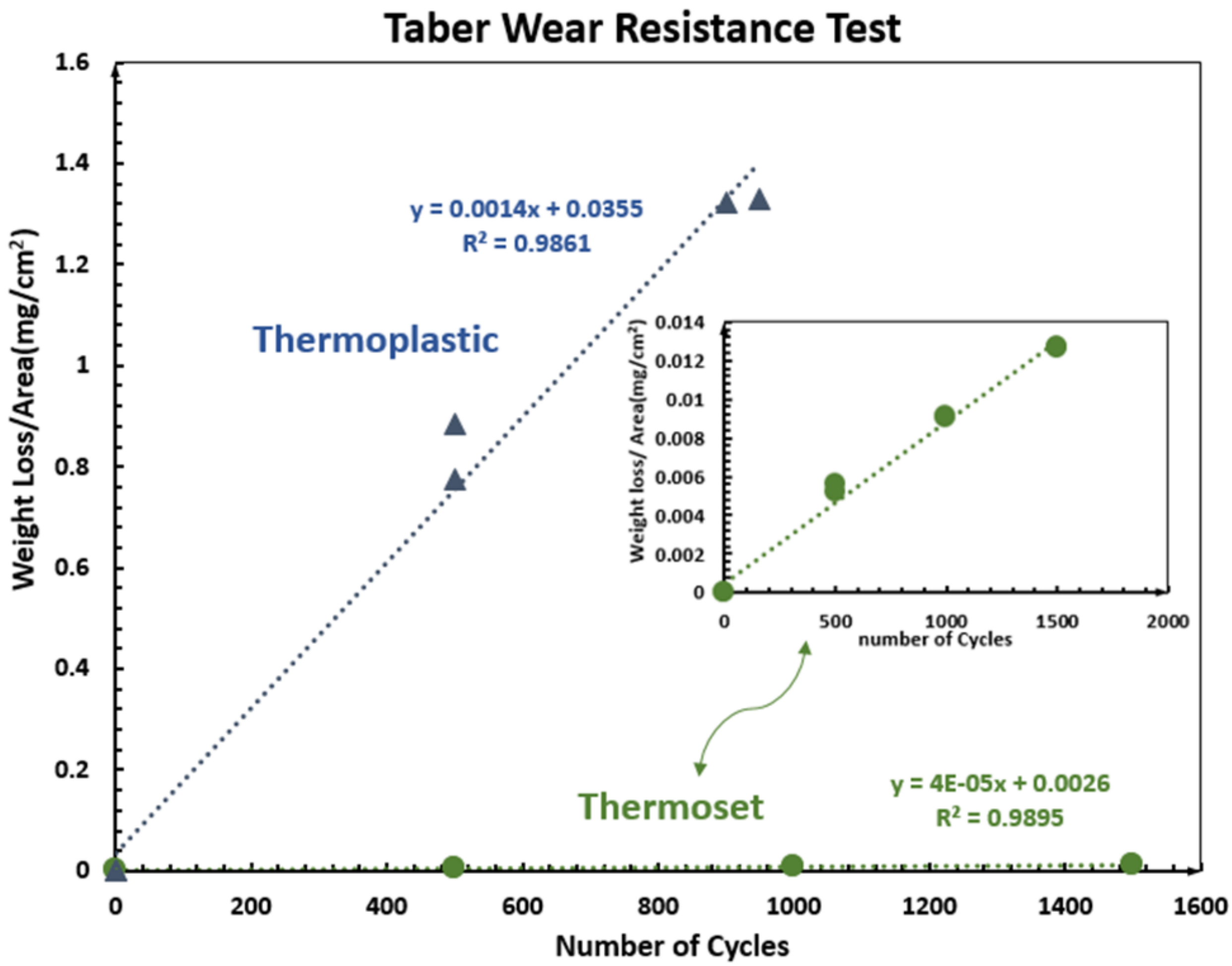

Figure 14. Wear rate as a function of distance travelled for thermoplastic A and thermoset X materials of similar hardness.

Note that although it was difficult to translate lab based static loading wear resistance tests to the real world dynamic loading that actually occurs when a skater performs an ollie, we know from user testing that the thermoplastics wear out just as quickly as the shoe materials themselves, and thus have been deemed a failure.

The wear data from the thermoset materials on the other hand was a huge surprise, for they have a relatively negligible wear rate, and a very high wear resistance factor – one that is over 145 times higher than the thermoplastics and shoe materials themselves! The 60 A thermoset material has been deemed the most successful out of all samples tested.

Friction Properties

Figure 15 shows how each of the thermoplastic and thermoset samples of varying hardness interacted with a 120 grit grip-tape surface in static friction tests. We chose to use the 120 grit grip-tape for exhibiting this data because it is the closest we had to the average grip-tape grit found on a skateboard, which is around 150.

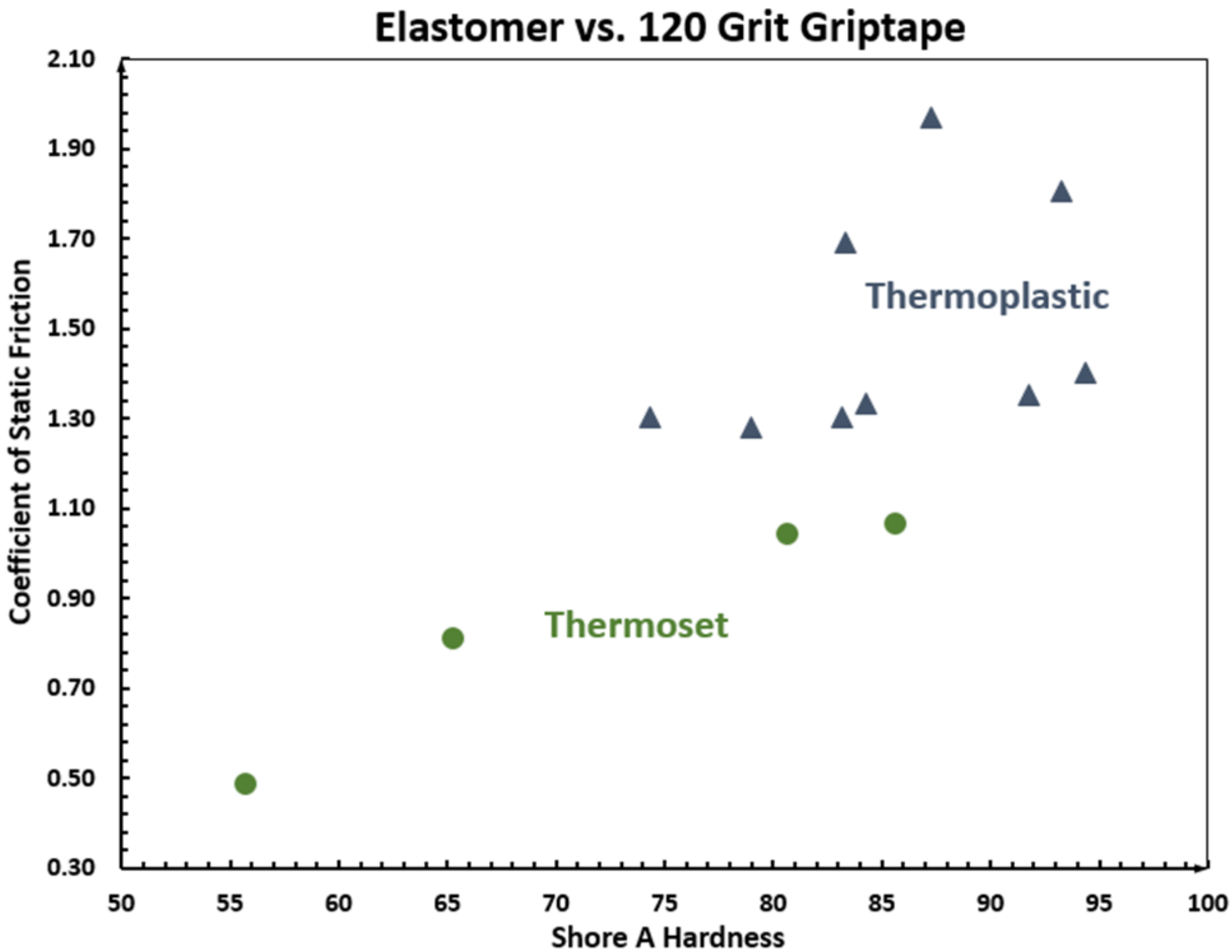

Figure 15. Static friction as a function of Shore A hardness.

As we can see from the graph above, the thermoset materials have friction coefficients that land within or near the ideal range of 0.6 – 0.8, which was determined and confirmed by user testing.

An interesting observation occurred during these tests with respect to using different grits. The coefficient of friction was seen to decrease as the grit was lowered (or coarsened; as the particle size on the surface of the substrate material was increased). This pattern was interesting because we had assumed that the friction would increase with a lower grit due to the increased coarseness of the substrate. We postulated that the reason we are seeing the opposite occur is that the higher grit sandpaper has larger grains, which corresponds to less surface to surface contact during measurements. This results in less friction when compared to the higher grit substrates which have smaller grains, more surface to surface contact, and higher friction coefficients.

Adhesion Properties

In order to find an adhesive which would work well, the 3M company was contacted, as well as companies which work with polyurethanes. It was expected that isocyanate-based glues (Superglue) would work well, but this proved not to be the case. A nitrile high-performance adhesive (3M grade 1099L) was used to adhere both material A and material X to skate shoes. The skaters were initially impressed with material A until they tested material X, which allowed them to perform over 1,000 kick-flips (see Table 1). Even in this case, the adhesive started to

Table 1
Performance Data Based on Skater Feedback

Material	Number of Kick-Flips Until Hole Forms in Shoe
New Pair of Vans Shoes	70-80
Stick & Flick Competitor Patch	55-65
Thermoplastic A	50-60
Thermoset X	>1,000 (note that patch showed little wear)

release and a stronger adhesive would have allowed the patch to outlast the sole of the shoe. It is desired to have a pressure sensitive adhesive (PSA) so that the adhesive is already adhered to the elastomer and only needs to adhere to the fabric or hard polymer at the base of the shoe.

A number of PSA adhesives have been evaluated but none has proven to be satisfactory. It is likely that the surface morphology of material X will need to be altered in order to solve the adhesion issue. Many of the adhesives which worked will on one fabric, didn't work on another, or didn't adhere well to the hard polymer base. This is an important issue to solve and would have received more attention earlier in the project had we know that it would be a difficult problem to solve. The adhesion issue was never satisfactorily solved and is the only design issue remaining. Unfortunately, it is a very important issue and one that must be resolved in order to make a successful shoe patch.

6. FUTURE WORK

The main area for future work is to solve the adhesion problem. The key, we believe, is to increase the surface roughness of the elastomer to increase adhesion, as well as continue to work with adhesion experts to find the right solution.

The high wear resistant and high grip properties of the thermoset material allow it to be applied in many ways to solve different problems. One problem we want to use this material to solve has to do with the high grip material property and how it can benefit snowboarders. The problem is that snowboarders, before getting on a chairlift, must disconnect their board from one of their boots in order to sit properly on the chairlift. Since the snowboard is heavy and only attached to one boot, they tend to rest the blade or side of the snowboard on top of the disconnected boot, which – during a turbulent chairlift ride - tends to slice up the shoe laces of the boot. We want to add a high grip patch to the top of the disconnected boot upon which the blade of the board can rest, which will keep the snowboard from sliding back and forth and eventually ruining the laces of the boot.

We also wanted to use this high grip material property to help construction workers that require non-slip knee-pads while they work. Although there are non-slip knee-pads available, the reviews say that the rubbery material quickly becomes rigid and loses its grip, so incorporating this material could potentially solve this problem.

We were also considering using the high wear resistant property and the high grip properties to help out professional carpet-rollers, for they tend to roll large sections of carpet by repetitively using the toes of their shoes to push the roll. This can wear out the shoe material over time and create holes, thus this is a perfect application of the thermoset material.

7. **BUSINESS, SOCIAL AND ETHICAL CONSIDERATIONS**

Once the adhesive related obstacles have been overcome, we plan on commercializing these patches in order to get it into the hands of skaters who need this product. As engineers, we aren't too experienced with the business side of things, so we met up with a newly established local lifestyle brand called SOGO, and they are currently helping us put together a business plan for these patches. They are also helping us establish a foothold in the social networking scene and assisting us with marketing and sales.

We believe that the social impact created by this product will help skaters maintain the quality of their shoes for longer, which means less unrecyclable shoes in the dump, and more money in the pockets of skaters, which could allow them to purchase higher priced shoes knowing they can use our patches to protect them, which would benefit both the customer and the shoe manufacturers and retailers.

With respect to ethical considerations, this thermoset material can be recycled [11], although not at the curbside. Each patch, however, has been engineered to outlast the shoe itself. In other words, however someone decides to recycle their shoe, the patch can be recycled in a similar manner. Since the shoe patch extends the life of the shoe, so for every pair of skate shoes in the dump, there would only be a single patch to accompany it, as opposed to several shoes in the dump due to higher wear rates.

8. SUMMARY AND CONCLUSIONS

In conclusion, the material X thermoset has exceeded all design criteria with the exception of adhesion. Via mechanical testing and user feedback, we have honed in on what we and our skaters consider an optimized material. This material can indeed conform to the 3D shapes of a shoe, and flex with the shoe and the skater skates without hindering performance, has a surface that doesn't hinder the skater's ability to flip the board correctly, and has a wear resistance factor that allows it to virtually outlast the sole of the shoe. Once we determine the proper way to adhere the patch to the shoe, we will have a product that will extend the life of the shoe.

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