"Multiplay-Materials and Manufacturing methods needed to produce"

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***Abstract*- This research paper talks about a product called "Multiplay" which is an elastic exoskeleton sole that can wrap around a shoe and has various attachments such as studs, cleats, and weight alterations to transform an everyday shoe into an ideal shoe for sports. It is mainly used for sports as different sports require different kinds of shoes. The paper explores the various problems in the current shoe industry such as pollution and expenses and how the product resolves the problem with its functionality and works towards sustainability. It discusses the various manufacturing methods and materials in the market right now and narrows down on the one which is the best for the product. It also differentiates "Multiplay" from other similar products in the market with an emphasis on the individuality and safety of the shoe wearer. Finally, it discusses a range of values suitable for certain properties of the product such as tensile strength, elasticity, and shore hardness through which it narrows down on a specific material and manufacturing technique suitable for the production of "Multiplay".**

***Keywords*- elastic, durable shoe sole, sustainability, sports, multiplay.**

Introduction

The Problem

The world is looking for sustainable solutions in everyday products. The shoe industry is widely overlooked for causing pollution and global warming however it greatly contributed to it. Less than 5% of the shoes produced annually are recycled and the other 95% of the 20 billion manufactured (Lee, 2012, 90-99) end up in landfills which take 30-40 years to decompose (Ismael, 2021) and pollute the soil and nearing waterbodies by landfill leachate(Rensburg, 2020, 599-613). There are also numerous environmental concerns while producing shoes such as chromium as a tanning agent for leather is highly toxic and a suspected carcinogen (Rensburg, 2020, 599-613). There can be 65 separate parts in a single shoe, and assembly requires 360 processing steps. A typical pair of synthetic running shoes is thought to have a carbon footprint of 14 2.7 kg CO2-equivalent. This impact is mostly caused by the steps of material processing and production, which account for around 29% and 68% of the total impact, respectively. (Ciceri, 2013, 18-29). Other similar studies in the apparel industry have reported carbon footprints of running shoes ranging between 18 and 41 kg CO2-equivalent/pair (Barling, 2008, #). This shows how the end-of-life process of shoes needs to be greatly improved.

Another big problem faced by the world is that 85% of the world's population lives on less than $30 per day (Roser, 2021). That means 6.5 billion people cannot afford to keep regularly buying sports shoes (Roser, 2021). This stops numerous children from lower income groups from pursuing sports due to the high cost despite their talent and love for the sport.

Thirdly, there are a plethora of sports, and each requires a different kind of shoe to play. the global per capita consumption of shoes for every person in the world is 2.6 pairs of shoes in 2005 (Lee, 2012, 90-99). These shoes have various modifications such as football shoes having studs, badminton shoes having gum soles, and basketball shoes having ankle support. Without the correct modification the chances for injury rise by almost 75%. For example in football, there have been 100,000-130,000 knee injuries among professionals due to inappropriate shoe type and cleat length (Torg, 1974, 261-269). There are a number of factors to take into account, including the number of studs in the rearfoot and toes, which are linked to foot and ankle injuries. For example, more medial rearfoot studs and fewer lateral rearfoot studs are linked to more foot injuries during running, while the number of studs in the toes is a better indicator of ankle injuries. (Domínguez, 2023, #)

The solution

My solution for all these problems is my product named "Multiplay" which is a removable sole that has an elastic feature allowing it to stretch out and wrap around the shoe completely forming an exoskeleton for the existing shoe. This is mainly used for sports as different sports require different kinds of shoes. Multiplay can transform an everyday shoe into an instant functional athletic shoe for the specific sport needed at the time. One just needs to buy a regular shoe and wear my sole under it and they will be able to play different sports. There are various features in my product such as attachable studs and cleats along with weight alterations which can modify a normal shoe into an ideal shoe for sports and reduce injury. For example for basketball, although it is necessary to have high shoe collar high and counter stiffness as it also leads to an increased knee injury (Lam, 2020, 2374-2381), and therefore either one should be implemented in a shoe and not both. Additionally, research shows that using orthotics with arch support and raising the collar height tend to lower the incidence of ankle sprains during landing but may increase loading at nearby joints (Lam & Leung, 2022, 115-127). Whereas for running To increase performance, footwear should be constructed as lightweight as possible, and implement a range of different bending stiffness for individual needs. Shoes with thinner midsoles have lower injury risks at the knee joint. In order to prevent harmful changes in running mechanics, insoles for elite runners should be properly molded to the contour of the foot. Special attention should also be made to the flexibility of the upper. (Hoitz, 2020, 193-215).

Multiplay also has the ability to deal with the problem of supination and pronation as there are various places for the attachments of studs and cleats to go into. The manipulation of the placement studs can also help deal with serious problems such as supination and pronation. Ankle sprains, shin splints, Achilles tendinitis, and other problems may result from excessive pronation and supination, which are gait disorders. Fixing supination and pronation is essential for injury prevention not only for professional athletes but also for the general population (Lacković et al., 2018, 603-607). Alongside this, even the traction or the coefficient of friction between the shoe and the surface has to be looked into. It has been demonstrated that sports surfaces with high rotational friction increase the risk of severe knee and ankle injuries. Athletes may be at risk from excessive rotational friction, defined as exceeding 10 to 12 Nm. Sport shoe designs, that have translational friction of 0.8 with typical surfaces on which they are used and exhibit minimal rotational friction, should allow maximal performance while minimizing the risk of injury. (ISBS-Conference Proceedings Archive, 1993, 6-7). The greatest influence on COF is the tread groove orientation, which accounts for 81% of the variation in COF. Furthermore, individuals who wear shoes with a parallel groove orientation experienced a greater proportion of slips and more severe slips than persons wearing shoes with a perpendicular groove orientation (Blanchette, 2013, 10-18)Therefore for sports such as cricket and football which are played on natural as well as synthetic turf, a higher coefficient of friction of 0.8μ is needed when forces are exerted in an anterior direction and 0.6μ when exerted in a lateral direction. My product helps to customize the shoe's traction to have a coefficient of friction between 0.8μ to 1.2μ to achieve the best desirable traction and agility. It also extends the life of a shoe by protecting it from wear and tear by taking the brunt of the friction. This helps reduce the need for multiple shoes as one shoe becomes ideal for all sports.

Comparison with other similar products

There are other products in the market that are similar to my product but different in a lot of aspects such US 2014/0075787 A1((Juan Cartagena, 2013, #). It is a functional athletic shoe cover that allows for optimizing the shoe for a specific athletic, sport, or daily routine use. The shoe cover covers the mid and lower portions of the shoe and holds devices such as cleats, studs, spikes, or tread patterns in place. The cover is arranged such that the devices are removable and interchangeable, thus avoiding the expense of owning separate shoes for various sports or for different field conditions. US 2014/0075787 A1((Juan Cartagena, 2013, #) is mainly for outdoor sports and doesn't customize for indoor sports that require gum soles such as badminton whereas our invention customizes soles for indoor sports also. They use more rigid material and less flexible material and have a different mechanism to wrap the sole around the shoe whereas our invention is made up of a completely elastic exoskeleton that wraps around the shoe and has various customizations to make it an ideal shoe for sports only flexible material. wherein my product deals with supination and pronation with the help of studs and cleats whereas their product has no mention of supination and pronation. US 2014/0075787 A1 (Juan Cartagena, 2013, #) has ornamental features whereas my product deals with only useful features so will not cater to ornamental features. My product has a gripping feature for easy attachment whereas our invented sole is completely elastic so doesn't need any features like that. My product can have studs either permanently affixed or replaceable but our invention product has only replaceable studs and cleats. My product is mainly centered towards not-so-privileged children and people for whom owning one pair of shoes is luxury so they cannot buy multiple shoes and to make sports more inclusive whereas they have a different target audience. This invention doesn't deal with the specifications of the different coefficients of friction required for different sports that mine does and rather just briefly talks about traction. This product can only be attached to a sports shoe whereas mine can be used with any flat-soled shoe (Juan Cartagena, 2013, #).

Materials and Methods
Materials
Traditional Materials

Currently, the most typical material composition of shoes is made of 25%, polyurethane 17%, ethylene vinyl acetate 14%, thermoplastic rubber 16%, polyvinyl chloride 8%, rubber 7%, another 7%, textiles, and fabrics 6% (Mia, 2017, 402-407). The bulk of outsoles used in modern footwear are made of polyurethane, polyvinyl chloride (PVC), or natural rubber (Jaiganesh, 2022, 1). Polyurethane is used due to its excellent wear qualities as well as its lightweight, good insulation, durability, slip resistance, oil resistance, and capacity to be immediately reaction molded into uppers (Barnatt, 1977, 333). It is used for shoes that are long-lasting and comfortable (Jaiganesh, 2022, 2). Whereas EVA on the other hand is a lightweight material that is simple to mold, resistant to water and moisture, very elastic, shock-absorbing, excellent at insulating heat, and highly durable. (Chopra, 2019, 22-27).

However, due to their complementary good qualities, which are crucial in the creation of pleasant shoe soles, a combination of high-density polyethylene (HDPE) and ethylene propylene rubber (EPR) is occasionally utilized as the material for the polymer-based matrix of the shoe soles. For instance, high-density polyethylene demonstrates higher impact resistance and manufacture ability while also allowing for flexibility in the insole and outer sole of the shoe. Ethylene-propylene rubber, on the other hand, has improved gripping properties and can function at its best in both hot and cold temperatures, increasing the effectiveness of the shoe's sole (Lupti, 2016, 100-110). Microcellular urethane elastomers are used in industrial boots and athletic shoes due to their great performance in shoe soling found applications despite being rather expensive as a performance material. The low weight and large molding of polyurethane made it an intriguing material for the platform's sole application because it outperformed traditional thermoplastic molding methods (Barnatt, 1977, 333). Rubber foams and sandwich-like microstructures with a thin coating of polyvinylsiloxane on the surface perform well in friction testing. A similar material structure can be observed in nature as well (smooth type of insect pads). Even though they have a similar stiffness to materials like soft polyurethanes and PSA, they are less susceptible to abrasive wear and damage because their bulk material's elasticity moduli are higher than those of other materials. A crucial combination is that sandwich-like fibrillar materials and foam-like materials are soft and flexible in compression but strong in tension (Voigt, 2012, 1046-1055).

Textiles are another important part of the shoe as athletes require textiles to maintain the relative position of the foot on the shoe firmly while withstanding potential lateral and braking forces of 4,000 N; be a part of a minimal-weight shoe, which could provide an important competitive edge through decreased metabolic costs; comfortably correspond to their individual, foot shape while maintaining a secure, functional fit (Frederick, 2005, 339-351). These textiles will be important for my product as the sole will have to wrap around the textiles in a manner to not cause discomfort for the consumer.

Sustainable substitutes for making shoes

Hadjadj et al. (2016) found that cellulose fibers enhanced the tensile strength and modulus of their polyurethane-based composite, providing support for the addition of cellulose reinforcement materials to other composites which can be used in footwear (Hadjadj, 2016, 217-223). Furthermore, even mycelium can be used due to the mycelium composite's compressive strength, especially that of the king oyster species, which supported using it for shoe sole applications. The mycelium composite is created using organic, biodegradable, naturally non hazardous ingredients. Mycelium-made footwear would not end up in landfills and would replenish soil nutrients for future growth, which supports biological metabolism (Silverman, 2020, 119-133). These substitutes can be great for reducing the carbon footprint and working towards sustainability.

Manufacturing Methods

New and innovative manufacturing methods in the market

3D printing

3D printing shoes is the new manufacturing method in many shoe-making companies as it can replace the previous large-scale and centralized industrial pattern with highly effective, energy-saving, distributed, on-demand production mode manufacturing products. The intricate and drawn-out process of developing and producing molds is also avoided by 3D printing technology (Gong, 2021, 6). This helps to greatly reduce the initial cost of making "Multiplay" and allows a faster move to mass production. The understanding of foot and footwear biomechanics has been done by the CAD models of footwear currently in use. The CAD model can be used as an objective tool for clinical and engineering decision-making for functional footwear designs due to its capacity to detect weak skeletal and soft tissue components of the foot as well as the load transfer mechanism of the foot and footwear. (Cheung, 2009, 31-46). 3D printing furthermore allows the personalization of the shoe, which is useful as it improves efficiency and reduces costs``Advanced Technologies for Shoe Sole Production," 2020, 6). Every customer is viewed as a prosumer (creator and consumer), able to actively engage in all phases of a product's life cycle, including its conception, development, production, service, and consumption. (Shang, 2019, 194-205). Rather than 3D scanning the foot one is only required to take measurements of the customer's foot and put them into the parametric model to obtain the tailored shoe's last 3D geometry (Amza, 2019, 1-6). This technology can be extremely useful to use in my product as it will allow customizable soles to be produced for the customer allowing optimal comfort. Using active technologies like the Konica Minolta VIVID 910 and IN FOOT USB SCAN allows for final digitization, which is a crucial component of 3D foot designing. These two methods both rely on laser technology. (Spahiu, 2016, 3). The design of the generated sole is characterized by parameters that include the type of shoe (professional or street), type of material, hardness of the material, heel height, and area of contact with the ground. These parameters are used by new software to forecast mathematical models of the CoF. (Salas, 2016, 3495-3516). There are various methods of 3D printing such as solid modeling and hybrid modeling. Solid modeling cannot meet the requirement of a product when it's designed by free-form surfaces such as sports shoes which is where the need for hybrid modeling comes in (Butdee, 2002, 1). Hybrid modeling can significantly make production more efficient by reducing time in the design phase by 35.4% and over 88.4% when 12 sizes of shoes are made (Butdee, 2002,9). I plan on using hybrid modeling to 3D print my sole.

The traditional manufacturing industry model is being significantly altered by the new manufacturing technology represented by 3D printing. It may substantially increase product design efficiency, greatly increase the creative area available to footwear designers, and enable them to produce product prototypes more quickly. (Gong, 2021, 8). For shoes with complicated designs, like sports shoes, roughing and cementing heavily relied on physical labor. Roughing and cementing are crucial steps in the process of connecting shoe uppers and corresponding soles. The shoe business has recently advanced to 3D design, therefore before beginning mass production, 3D models of the shoe upper and sole will be made. (Chiu, 2017, 1) However, the main reason this model isn't more prevalently used is that current processes such as injection molding have economies of scale that result in cost per unit decreases as volume increases. Especially in the case of injection molding, the primary expense is the cost of the part mold. Selling the concept of a shoe that costs several hundred dollars, even if it is customized, becomes a very challenging task given that a single-part mold might cost thousands of dollars (Vasquez, 2009, 52-54). This shows that although starting off with 3D printing will be viable it will eventually become cheaper to use injection molding for my product.

Implementation of 3D printing with companies

Numerous companies have implemented 3D printing and started producing shoes using that method as well. For example, the first generation of 3D printed rugby shoes and soccer shoes, the "new Nike Vapor Laser Talon," were created by Nike in 2013 as the first sports company to use the technology. The "Vapor Carbon 2014" elite running shoe and the "VaporHyperAgility" soccer shoe were then released by Nike (Gong, 2021, 1-8). Adidas' limited-edition "3D Runner" went on sale at the end of 2016, following the launching of their 3D-printed running shoe, "Futurecraft 3D," in 2015. It is possible to customize a running shoe to a user's foot form and individual sporting preferences. Using a "Primeknit" upper weave technology and an outsole and hollow midsole constructed of 3D printing technology, a shoe may be customized to the wearer's foot anatomy and individual sporting habits (Gong, 2021, 1-8). Moreover, Andromeda released a pair of 3D-printed sneakers for American swimmer Michael Phelps in the same year and a limited-edition trainer called "UA Architech" in March 2016 (Gong, 2021, 1-8). Reebok also employed 3D drawing technology to precisely and cleanly "create" 3D shoe parts. Without the need for moulds, innovative layering technology enables the quick, easy, and effective production of customized footwear. For all-around foot comfort and receptive energy feedback, the shoe has a high-rebound outsole and 3D-printed laces that merge the outsole with the top. In April 2016, New Balance modified the "Fresh Foam Zante" 3D-printed concept shoe and rebranded it as the "Zante Generate" (Gong, 2021, 1-8). Furthermore, Nike also attempted to mass-create a sneaker using 3D printing using continuous Liquid Interface Manufacturing, a technique that enables businesses to produce products more quickly than ever before and is used to build the midsole of the shoe. In addition, the finished products are more durable and flexible than conventional injection-molded plastics. (Adidas Reveals the First 3D-printed Shoe It'll Mass-Produce, 2017). These products can be an inspiration for me while working on designing and 3D printing my product.

Traditional Manufacturing Techniques

There are numerous manufacturing techniques for producing shoes. Dynamic curing is a suitable technology for producing shoe sole materials of thermoplastic character. The properties of the new material meet standard requirements for footwear compounds with respect to i) Physical properties; ii) processability by injection molding technology; and iii) gluing ability by adhesives commonly used in the shoe industry (Karger-Kocsis, 2019, 125-154). Then there is additive manufacturing (AM) which has a layer-by-layer fabrication that not only reduces the material used but also makes it easier to fabricate complex geometries (Dong, 2019, 719-728). Furthermore, dynamic vulcanization shoes have improved tensile strength, tear strength, ultimate elongation, flex resistance, and decreased permanent elongation in comparison to shoes created using straightforward melt mixing procedures (Karger-Kocsis, 2019, 125-154). Injection molding is used less in producing athletic shoes as unlike rubber-soled shoes, these shoes always have multiple small, crater-like "voids" on the soles, which could be mistaken for unique shoe print characteristics. The voids are brought about by bubble entrapment at places where the mold has flaws and air entrapment at certain areas during the injection process. Some of the voids locate their placements on the sole at random (Jay, 1985, 233-238). These videos make this process unviable to be used as the sole will be able to withstand the stress and strain of playing sports. Sports shoes' outsoles must be able to withstand physically demanding activity because they are subject to impact and forceful movements. In the manufacturing process, CNTs (carbon nanotubes) are also used as they allow the shoes to maintain their characteristics despite bearing load (Lupti, 2016, 100-110). There are several different types of rapid manufacturing technologies. These include 3D Printing, Stereolithography, Fused Deposition Modeling, and Selective Laser Sintering (Vasquez, 2009, 52-54).The SLS (Selective laser sintering) is a process that provides numerous advantages over conventional manufacturing methods like the facility to produce complex geometries and cost-effective, low-volume manufacture. These features also are helpful for the production of personalized footwear (Vinet, 2010, 2769-2774).

Outsole design

The outsole of the shoe makes contact with the ground and offers grip. The capacity of an individual to perform athletic motions depends heavily on traction. It is clear that a high level of traction is required in a variety of directions given the wide range of movements and the vast number of directions in which these movements are conducted (Groningen, 2016, 12). Particularly because there are an infinite number of conceivable forms, outsole tread design is very hard. Moreover, tread designs serve both functional and aesthetically pleasing functions, particularly in relation to slip resistance (Salas, 2016, 3495-3516). Modern sprint shoes have molded elements in the sole plate that work in conjunction with typically 5–9 detachable metal spikes to produce traction (Vinet, 2010, 2769-2774). The outsole design is the most crucial part in obtaining the traction and grip necessary for the particular sport which will be provided by the studs and cleats at the bottom of “Multiplay’.

Results and Discussion
Suitable Materials

MATERIAL PROPERTIES DATA — **Elastic 50A Resin**

	METRIC [1]		IMPERIAL [1]		METHOD
	Green	Post-Cured [2]	Green	Post-Cured [2]	
Tensile Properties					
Ultimate Tensile Strength [3]	1.61 MPa	3.23 MPa	234 psi	468 psi	ASTM D 412-06 (A)
Stress at 50% Elongation	0.92 MPa	0.94 MPa	133 psi	136 psi	ASTM D 412-06 (A)
Stress at 100% Elongation	1.54 MPa	1.59 MPa	233 psi	231 psi	ASTM D 412-06 (A)
Elongation at Break	100%	160%	100%	160%	ASTM D 412-06 (A)
Tear Strength [4]	8.9 kN/m	19.1 kN/m	51 lbf/in	109 lbf/in	ASTM D 624-00
Shore Hardness	40A	50A	40A	50A	ASTM 2240
Compression Set (23 °C for 22 hours)	2%	2%	2%	2%	ASTM D 395-03 (B)
Compression Set (70 °C for 22 hours)	3%	9%	3%	9%	ASTM D 395-03 (B)

[1] Material properties can vary with part geometry, print orientation, print settings, and temperature.
[2] Data was obtained from parts printed using Form 2, 100 µm, Elastic settings, washed in Form Wash for 20 minutes and post-cured with Form Cure at 60 °C for 20 minutes.
[3] Tensile testing was performed after 3+ hours at 23 °C, using a Die C dumbbell and 20 in/min cross head speed.
[4] Tear testing was performed after 3+ hours at 23 °C, using a Die C tear specimen and a 20 in/min cross head speed.

The following table shows the properties of resin 50A used in form labs printers. It shows the readings in both the metric and imperial measurements but for the interest of this paper only the imperial will be noted.

Tensile testing (3) was performed after 3+ hours at 23 °C, using a Die C specimen cut from sheets. It initially has a tensile strength of 1.61 MPa which then rises to 3.23 MPa was parts printed using Form 3, 100 µm, Flexible 80A settings, washed in Form Wash for 10 minutes, and post-cured with Form Cure at 60 °C for 10 minutes.

Then the stress at 50% and 100% elongation was measured. For the normal materials at 50%, the stress was 0.92 MPa, and at 100% it was 1.54 MPa. Then after they were printed parts using Form 3, 100 µm, Flexible 80A settings, washed in Form Wash for 10 minutes, and post-cured with Form Cure at 60 °C for 10 minutes for the 50% elongation the stress was 0.94 MPa and for 100% it was 1.59 MPa.

The elongation at hardness was then measured to be 100% and after the parts were printed using Form 3, 100 µm, Flexible 80A settings, washed in Form Wash for 10 minutes, and post-cured with Form Cure at 60 °C for 10 minutes the elongation at break was 160%.

The shore hardness was calculated to be 40A initially and then rose to 50A after they were parts printed using Form 3, 100 µm, Flexible 80A settings, washed in Form Wash for 10 minutes, and post-cured with Form Cure at 60 °C for 10 minutes (Flexible 50A, n.d.)

This was initially the material I wanted to use as it has my 3 desired properties tensile strength, elongation, and shore hardness at ranges a little below what I desired especially tensile strength which was at 3.23 MPa when the minimum amount was <10 and the elongation at the break only reached the minimum amount of 100% when desired was <200% and the shore hardness of 50A was more than the minimum amount of 40A but the below-desired amount which was <80A and even tear strength of 3.23 kN/m was below the minimum required which was <15kN/m.

The following graph shows the mechanical properties of the material called EM 23. It has a tear strength of 22.38 kN/m. The ultimate tensile strength is shown to be 21.59 MPa. The shore hardness is 70A whereas the elongation at break is a shocking 560%. This is the ideal material to be used for my product mainly due to the large elongation at the break. (Elastic & Flexible Resin for 3D Printing | EM 21, n.d.). After comparing the various 3D printing material I have found that Em 23 resin is the best to use for 3D printing as it is the only material with high tensile strength, stress at elongation, and shore hardness which also has a high elongation % to break-making it ideal for my elastic shoe which has to endure the strain of being used for multiple sports. The tensile strength was at 21.59 MPa when the desired amount was <15 MPA and the elongation at the break of 560% was much more than when desired amount also at <200% and the however shore hardness of 70A was equal to the desired amount which was <80A and even tear strength of 22.38kN/m was above the desired which was <20kN/m. The elongation, in particular, makes it an ideal material to be used for my prototype and product, and the tensile strength and shore hardness are much higher as compared to resin 50A therefore it is much more suitable to be used for my product.

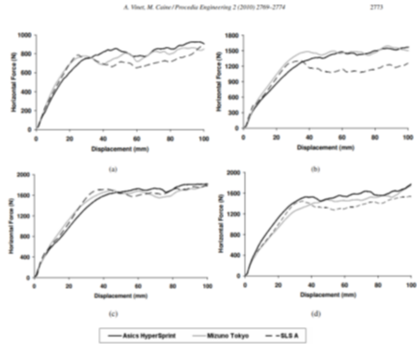


Fig. 3 Horizontal force versus extension at normal loads of (a) 500N (b) 1000N (c) 2000N and (d) 3000N for the Asics HyperSprint, Mizuno Tokyo and SLS A sprint shoes.

The graphical data in Fig. 3 shows the horizontal force recorded through the displacement of the sprint shoes a distance of 100 mm at the various levels of normal loading.

These graphs show increasing displacement of the shoe as the horizontal force increases, and additional graphs (b,c,d) demonstrate this trend as the normal load increases. In these graphs, there are two types of behavior for all loads and all samples: an initial sharp increase of >800 N horizontal load, and then a linear curve maintained across ~80 mm displacement. In all the diagrams the Asics hyper sprint starts off at the slowest rate but eventually reaches the largest horizontal force at the largest displacement, whereas Mizuno Tokyo starts off the fastest but ends up at the lowest horizontal force. SLS A sprint shoes behave about average between the extremes of Asics and Mizuno shoes. Furthermore, as the normal force increases from A through D so does the horizontal force showing that it's directly proportional (Vinet, 2010, 2769-2774).

Breakdown of a shoe by parts and material

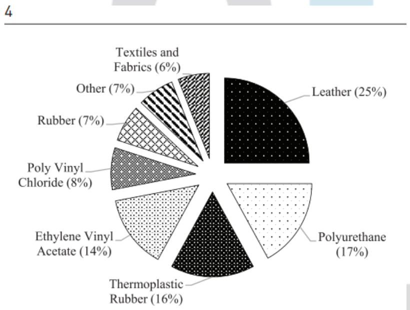


Figure 2. The material composition of an average shoe (wt.%) Source: Rahimifard et al., 2007.

The following graph is a pie chart that shows the material composition of a regular shoe. The most common materials in a shoe are leather and polyurethane which are at 17 and 25% respectively. Then comes thermoplastic rubber. These 3 materials combined make up more than 50% of the shoe. Then there's EVC at 14% and PVC at 8%. Finally, there is rubber and others at 7% and textiles and fabrics and 6% (Rensburg, 2020, 599-613). This graph shows the different materials to make a shoe and can be a good reference point for my product.

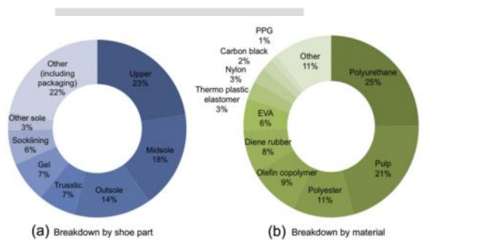


Fig. 1. Mass of a pair of running shoes, by percent, including packaging (total around 850 g) including a) breakdown by part and b) breakdown by material.

The following pie graphs show the breakdown of the mass of a shoe by shoe part and by materials used. In the first bar graph, the percentages of the different parts of the shoe constituting the weight are showcased. Upper and midsole make up 23 and 18 % respectively. The outsole makes up 14% whereas the trusstic and gel make up 7% each. The rest of the mass is made of the various other components listed on the graph. Whereas the second graph shows how much each material contributes to the weight of the shoe. Polyurethane makes up 25% whereas pulp makes up 21%. Polyester makes up 11% and olefin copolymer makes up 9% and Diene rubber 8%. EVA makes up 6% and thermoplastic elastomer nylon carbon black and PPG make up 3 3 2 and 1 % respectively. The remaining 11% is made of other materials (Cheah, 2013, 18-29). This graph is essential as my sole will accordingly be made with the appropriate material to reduce the weight of the sole to make it ideal for playing sports.

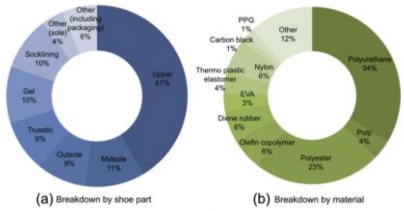
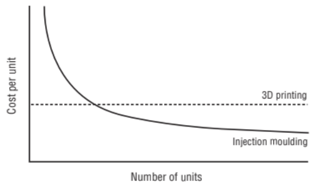


Fig. 4. GWP (kg CO_2-eq) impact of materials by percent within a pair of running shoes including a) breakdown by part and b) breakdown by material.

The following pie graphs show the CO2 emissions caused by the different shoe parts and materials used. The first graph shows that the uppers of the shoe contribute to the majority of the pollution by as much as 41%. The midsole contributes 11% And the outsole and truistic to 9% each. The gel and the sock lining contribute 10% each and the rest is by the other components. Whereas for the materials polyurethane contributes to 34% of the CO2 emissions whereas polyester contributes to 23%. Diene rubber and Olefin copolymer contribute 6% each and EVA to 3%. Thermoplastic elastomer contributes 4% and nylon to 6%. The rest is filled with other materials (Cheah, 2013, 18-29). This is important as shoes greatly pollute the environment and by seeing the material used to make them I can accordingly think about using the materials to help reduce CO2 emissions and work towards sustainability.

Advantages and Process of 3D Printing

Figure 5.5. **Generalised cost curve of 3D printing versus injection-moulding**



Source: Authors' calculations.

The following graph shows the general cost of 3D printing compared with injection moulding. On the x-axis is the number of units and on the y-axis is the cost per unit. The two graphs have extremely varying shapes and gradients. The injection molding graphs have an extremely high initial cost per unit but it decreases steeply as the number of units increases to under the 3D printing cost with a negative logarithmic shape. On the other hand, the 3D printing graph is a straight line with 0 gradients. It has the same cost per unit regardless of how many units are produced. This shows us that 3D printing would be much more economically viable for a small amount of production, however for bigger companies it would be better to use injection molding as the costs decrease over time despite the high initial cost (Faludi, 2017, 181). This is useful as it shows me that 3D printing is a much better method to use for trying out prototypes and for perfecting my design and then for mass production I can think of using injection molding. This graph helps me to choose my production method as 3D printing.

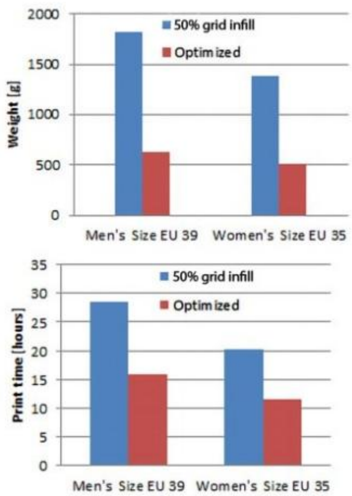
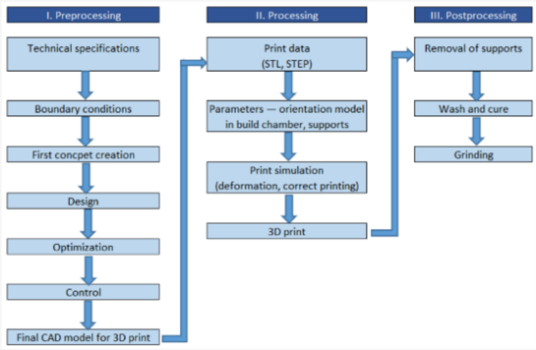


Fig. 5. Process metrics before and after body optimization (for 1 shoe last)

The table shows a method of manufacturing shoe lasts for bespoke shoe production using an additive manufacturing process. The first graph shows how the optimized version of the shoe has a much lighter weight in both the men's and the women's sizes. The weight is less by about 1000 g in both. The second graph shows how optimization significantly reduces print time by about 12 hours for the men's size and 8 hours for the women's size (Amza, 2019, 04001). These graphs illustrate just how useful the process of optimization is in 3D printing and how I can use this process when I start manufacturing my soles to reduce time and weight, both of which are extremely essential for sports products. The weight will be useful as my product should not add too much weight to the existing shoe as that will restrict the sportsman from playing the sports with ease and restrict movement.

Figure 2. A typical production process with photopolymerization. CAD: computer-aided design, STL: standard triangulation language, STEP: standard for the exchange of product data.



The above diagram shows all the steps of the STL (stereolithography) 3D printing process. The graph shows the progression through 3 main steps: Preprocessing, processing, and post-processing. The preprocessing part mainly contains the requirements needed to start the 3D printing process such as technical specifications, boundary conditions, first concept creation, design, optimization, control, and most importantly making the final CAD model. The processing part has only 4 steps: printing the data using SLS, putting the desired parameters, printing the simulation, and doing the final 3D print. The post-processing process is used more for fine-tuning the product and making it have more finesse. It includes the removal of all the supports, washing and curing and finally grinding (Pagac, 2021, 598). This method can be used by me for 3D printing. My sole first goal is to make the prototypes because it is much cheaper and use this process to fine-tune my design before moving forward with mass production. This table helps me understand all the steps that go into 3D printing to better understand the entire process. This is how I expect to work on my prototypes.

Conclusion

After much research, the 3 properties that I plan to look at are tensile strength, elongation, and shore hardness. The main boundaries for these properties are:

1. Tensile strength should be >10 MPa at the very least and preferably >15 MPa.
2. Elongation should be >100% at the minimum and preferably >200%
3. Shore hardness should be >40A at the minimum and preferably <70A
4. Tear strength min >15kN/m and preferably >20kN/m

All of these properties are generally got very easily with traditional manufacturing methods however that is not the goal of the project as it is meant to work towards inclusivity and sustainability which is why 3D printing and material EM23 is the chosen method of manufacturing

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