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Developing new laser sintering materials for snowboarding applications

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Abstract

Over the past two decades Additive Manufacturing has radically shifted the way that many sports companies design new products. Burton Snowboards is one of these companies. They utilize a technology called laser sintering to streamline the prototyping process for many of their rigid snowboard binding products. Laser sintering is a manufacturing technology that takes digital files and constructs parts in three dimensions by depositing and consolidating layers of material using a laser. Currently, one of its biggest limitations is the restricted range of polymer materials that are available. The most common polymer materials used in laser sintering are Nylon-12 or Nylon-11. While these materials allow for the creation of robust rigid functional prototypes like snowboard binding baseplates or high backs, their ductility and elasticity is limited. The Burton product line includes many parts that demand more flexibility, especially for cold weather application such as straps, padding, or footwear components. This paper will discuss a scientific research collaboration between Loughborough University and Burton Snowboards to identify, characterize, develop, and test a new elastomer laser sintering material. Polymer characterization tests were completed at Loughborough University and laser sintering processing trials were performed at Burton Snowboard's Rapid Prototype laboratory. This targeted development process has implications beyond snowboarding and could be applied to other areas of the sporting goods industry where flexible materials are required, including footwear or personal protective equipment.

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1. Introduction

Laser sintering is an additive manufacturing technology in which a laser is used to construct 3-Dimensional parts layer-by-layer from consolidated polymer, ceramic, or metal powder.^[1] The focus of

this work will be on polymer laser sintering. The adoption of Additive Manufacturing has become widespread throughout many industries, but the creation of highly flexible parts is a problem that arises with popular materials such as polyamide-11 and polyamide-12. Even though parts manufactured from these materials are strong enough to be used as functional prototypes, their limited range of mechanical properties can constrain engineers and designers. Burton Snowboards, a snow sports company based in Vermont, USA is an industrial collaborator for this research work. They currently utilize additive manufacturing techniques to streamline the design process for many of their snowboard binding products, as shown in Figure 1. In fact, laser sintered Nylon-12 parts are robust enough to use as ‘On-Snow’ functional prototypes of snowboard binding baseplates or highbacks. The additive nature of the process also allows for widespread geometric freedom. However, the Burton product line includes many products that demand more flexible properties, especially for cold weather applications.

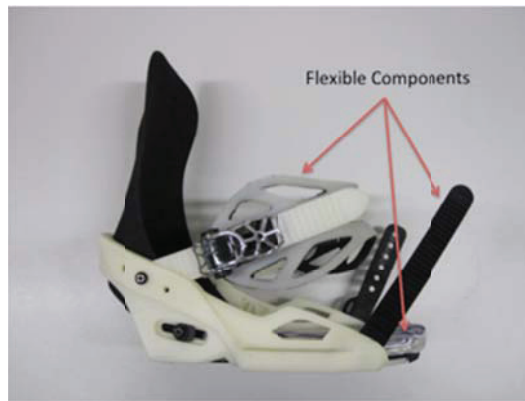


Fig. 1. Burton Snowboard prototype binding made via the laser sintering process

There are few commercially available elastomer materials (examples include ALM TPE-210s and 3D Systems Duraform Flex) on the market, and they are typically more expensive compared to standard polyamide powders. Subsequently, there has been only a narrow academic focus on elastomer laser sintering materials and especially on understanding their development. There is no single consensus on the appropriate method to develop suitable materials for laser sintering however there are core material characteristics that have been identified as key for successful laser sintering.^{[2][3]} Table 1 lists some of these key polymer characteristics, however only the super-cooling ‘process window’ will be discussed in depth for this work.

Figure 2 summarizes the key thermal considerations for laser sintering in the context of a Differential Scanning Calorimetry (DSC) thermogram. The process works by depositing thin layers of polymer powder ($\sim 100\mu\text{m}$) onto a heated build platform. For polyamide materials, the part bed temperature is determined by selecting a temperature between the melting and re-solidification peaks, the so-called super-cooling window. A small super cooling region could result in processing difficulty because the material may start to transition to a melt phase at lower temperatures. This could inhibit polymer flow across the part bed. In addition to DSC, hot stage microscopy has been used to optically observe the consolidation of two polymer particles.^[4] This was used as a practical measure of viscosity and surface free energy; which are both key properties responsible for obtaining near fully dense parts from laser sintering. After a layer of material is deposited on the part bed the laser provides the necessary energy to melt the material and initiate liquid phase sintering in the Stable Sintering Region.^[5] The part cross-section hardens as the temperature decreases after laser interaction and as subsequent layers are deposited

over the sintered layer. Unsintered material around the affected part acts as a support structure and the full part bed is cooled naturally back to room temperature once all layers are complete.

Table 1. Key Characteristics for Laser Sintering

Characteristic	Description
Super-cooling window	Large window allows for a range of process control and favors higher quality parts
Sintering Rate	Influenced by viscosity and surface free energy of the material; controls process speed and quality of sintered part
Thermal Stability	Determines the process parameters and potential properties
Particle Size	Responsible for surface finish and ease of processing
Recyclability	Retain processing ability and part properties when powders are reused

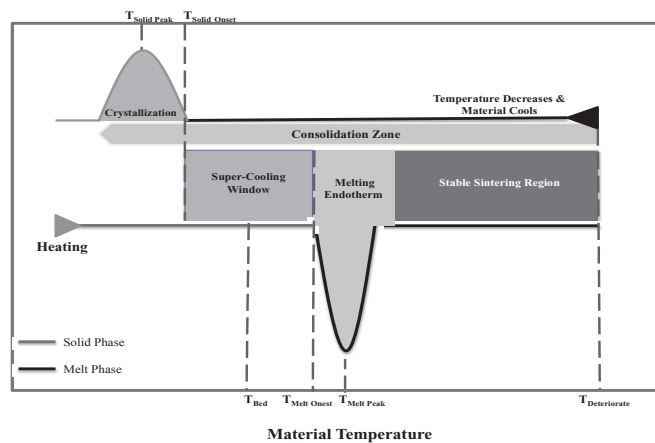


Fig. 2. Idealized thermal characteristics for a laser sintering material

Not only are the material's characteristics for processing in a laser sintering machine key, but the performance of the parts under conditions commonly found during snowboarding are equally as important. Currently there are no commercial laser sintering materials that fulfil these requirements for winter sports applications at Burton including attributes of high strength, flexibility, quality surface finish, and the retention of all these properties in cold environments.

2. Experimental Methods

The experimental material that was used during this process was a low molar mass elastomer material from BASF. Differential Scanning Calorimetry is a thermal measurement technique that tracks the heat flow during phase transitions. It is a common technique used for characterizing polymer laser sintering materials. A TA Instruments Q200 was used to perform the thermal analysis on the elastomer sample. The ASTM D3418-08 protocol was followed for heating and sample preparation.^[6] Two separate samples of mass $6.6 \pm 0.1 \text{ mg}$ from the virgin batch of material were heated from $20\text{--}220^\circ\text{C}$ at $10^\circ\text{C}/\text{min}$. Samples were sealed inside an aluminium container and nitrogen gas was used as a coolant at a flow rate of $50 \text{ cm}^3 \text{ min}^{-1}$. Results were analyzed using TA Universal Analysis Software. Hot stage

microscopy was used as a practical measurement of the coalescence of the elastomeric powder particles. A Leica light microscope with a dynamic heating rate program between 40°C - 220°C at 10°C·min⁻¹ was used to observe the behaviour of a thin layer of the polymer particles on a glass microscope slide.

Tensile test specimens were produced by laser sintering on a 3D Systems Vanguard machine. The machine parameters are listed in Table 2. Tensile specimens were built in each of the major build orientations XY (flat), XZ (on edge), and ZX (vertical). The first direction listed accounts for the axis on the longest build dimension and the second direction is the axis on which the next largest dimension occurs. Two sets of five were constructed so that one set could be conditioned at room temperature and the other in -20°C temperature conditions for 18 hours. The samples were tested on an MTS machine at a test speed of 100mm/min according to Burton qualifying standards. Additionally two hardness samples were constructed according to ASTM D2240 for ambient and cold testing at -20°C conditions for 18 hours [7].

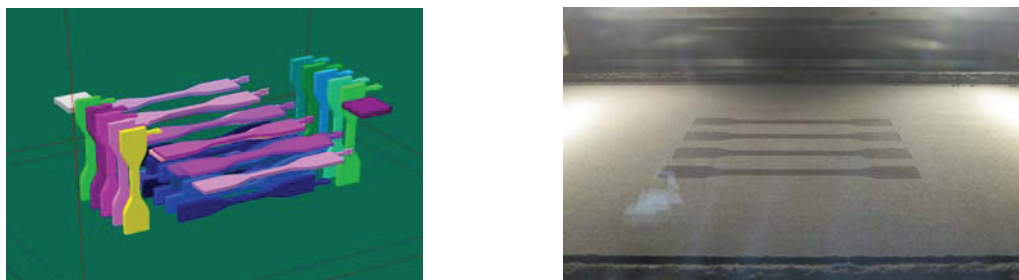


Fig. 3. a-b Laser sintering tensile and hardness specimen build on 3D Systems Vanguard

Table 2. 3D Systems Vanguard settings

Parameter	Setting
Bed Temperature	95°C
Laser Power	12 Watts
Scan Speed	
Scan Spacing	0.15 mm
Layer Thickness	100 microns
Roller Speed	127 mm/s

3. Results and Discussion

The current state of commercially available laser sintering elastomer materials were not meeting the requirements for Burton Snowboard's prototype needs. This collaboration sought to address these needs in two ways, first to develop a robust methodology to identify what makes a material suitable for the laser sintering process and secondly to use this knowledge to select and test a material to address the requirements of Burton. Figure 4 shows the DSC results and the thermal behaviour of the chosen elastomer material. Highlighted below is the distinct process window that suggests the material can be processed at a point close to the melting point and over a significant range of energy input parameters. The peak melt point is roughly 130°C and the melt region does not initiate until around 120°C. In the top right corner of Fig. 4 the hot stage microscope images are shown. These visually illustrate the liquid phase sintering process that takes place during and after the laser interaction with the polymer material. Overall the thermal data was strong evidence that the material would be predicted to process successfully in the laser sintering machine.

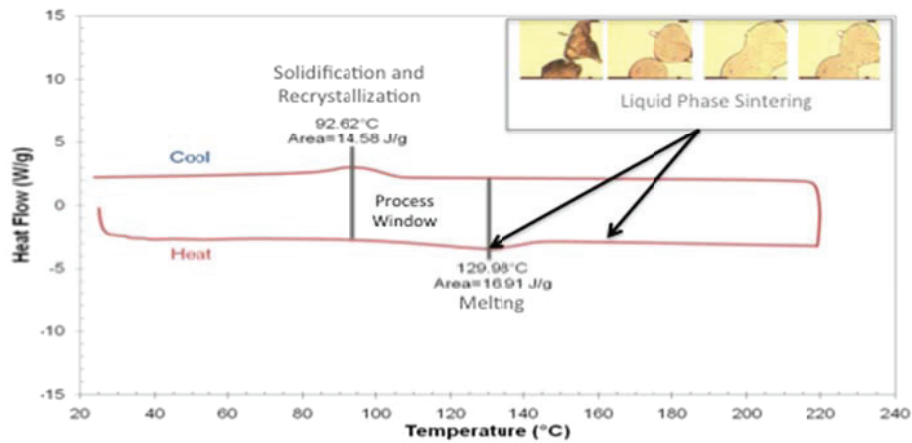


Fig. 4. DSC Thermograph showing process window, melt point, solidification point, and liquid phase sintering images

However, choosing a material that was suitable for laser sintering was only the first step of this development process. At the onset of this process an elastomeric material was chosen so that, when processed via injection molding, would fit the requirements for Burton's prototyping needs. Laser sintering can give properties that are not always similar to those from injection or compression moulding. Figure 5 (a-c) shows the effect of build orientation and temperature on parts created with this chosen material.

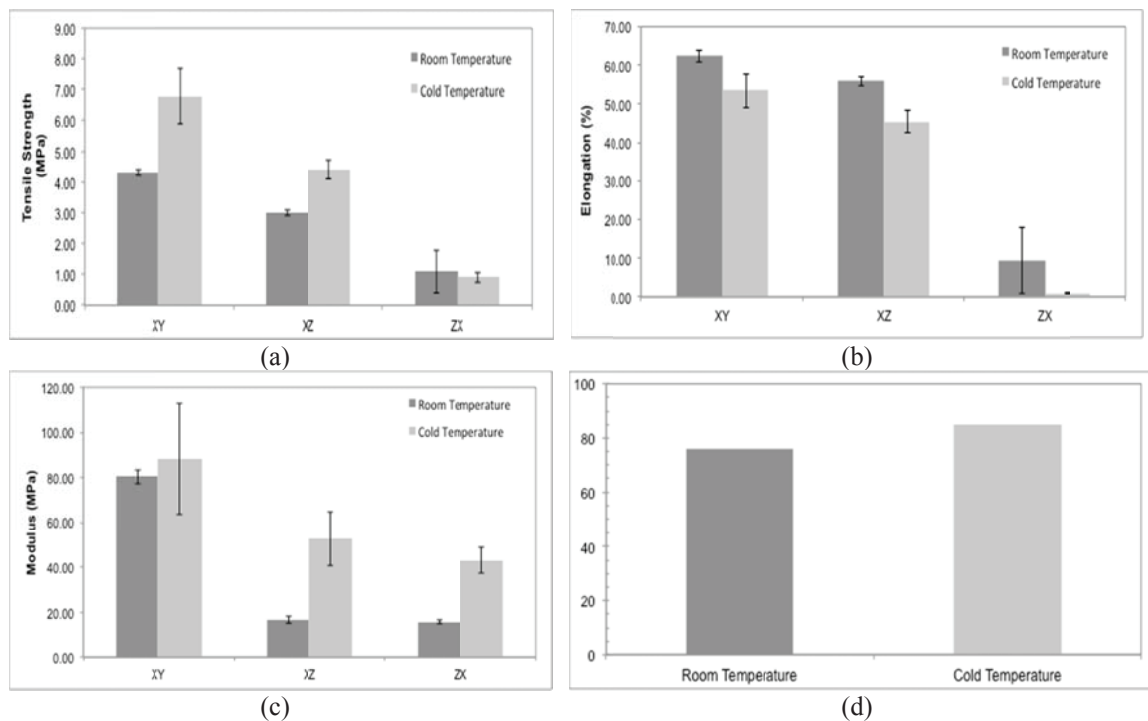


Fig. 5. (a)-(c) Tensile test results for different build orientations & variable temperature; (d) Shore A hardness values at various temperatures

The anisotropic behaviour of the mechanical properties at the three orientations is typical of the process and is an inherent property of the layer based manufacturing process. The parts built in the ZX or vertical direction were by far the weakest of the three groups. The mechanical properties data reinforce the basic design criteria for orientating and building parts with the process. The actual magnitude of the tensile properties data was also promising because elongation was much greater than what is usually seen with a typical polyamide-12 part and was in the acceptable range for Burton requirements.

The impact of extended exposure to cold temperatures was a key test for the context of snowboarding where general use creates extreme operating conditions. The effect of -20°C temperatures on the mechanical properties for the material was promising as it did not seem to change the results greatly. As is typically seen with polymer parts in cold conditions, the tensile strength and modulus improved while there was a slight decline in elongation at break. Hardness samples were also built during this material trial. The Shore-A hardness results are shown in Figure 5(d). The Shore-A hardness was 76 and this increased to 85 with prolonged exposure to lower temperatures. Again this is typical polymer behaviour and was acceptable for the intended prototyping use for Burton. Overall, consistent with the measured thermal behaviour, the laser sintering process has been shown to be successful and a range of attractive mechanical properties have been determined for the elastomeric material.

5. Conclusion

The results presented here showcase a successful industrial collaboration between Burton Snowboards and Loughborough University. The development and implementation of a strategic material selection process for laser sintering will have implications beyond the snowboarding industry. The method described here could impact other users of the process in the sporting goods industry who require flexible components, often in complex and variable shapes, in applications like footwear or personal protective equipment. Additionally, one of the inherent benefits of additive manufacturing is the potential for highly customizable parts. With this new materials development process the range of materials will only expand and thereby offer designers more creative freedom to improve their products.

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