Use of an Alternative Ink in the High Speed Sintering Process

Luke Fox†, Adam Ellis† & Neil Hopkinson†

†Department of Mechanical Engineering, The University of Sheffield, Sheffield, S1 3JD, UK

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Abstract

High Speed Sintering is a polymer Additive Manufacturing process, which builds parts by the use of inkjet printing and infrared lamp technology, as opposed to lasers and optics used in Laser Sintering. For High Speed Sintering to be a viable method to build fast moving consumer goods the ability to use different inks is critical. This research investigated the effects of using two separate inks in the High Speed Sintering process. This work shows it is possible to use inks from different suppliers, which opens up a wider supply chain.

Introduction

Additive manufacturing (AM) is defined as the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies'.[1] Previously the main function of AM has been for prototyping and tooling, whereas there is now a further push towards the manufacture of end use products. Additive manufacturing can allow a reduction in process steps from design using a 3-D modelling software to building of complex parts in a single step, without the need for expensive tooling.[2] Tooling is often a limiting factor in traditional manufacturing effecting the time required for design iterations.

Laser sintering (LS) is a powder fusion based AM technique. The process involves the scanning of the surface of the powder, typically 100 µm thick, with a laser melting the polymer powder to form a solid 2-D shape.[3] A new layer of powder is then deposited on the build area, allowing the process to repeat building several 2-D images on top each other. This repetition creates a 3-D object of the melted polymer powder. The unsintered powder acts as a support to the built part, this powder is then removed at the end of the manufacturing process to reveal the part. This supporting powder allows access to complex geometries which other AM processes would require sacrificial supports to build. The process produces parts of relatively high structural properties which allows them to be used in a wide range of applications.

High Speed Sintering (HSS) was initially developed at Loughborough University and continued at the University of Sheffield. The process is similar to that of LS as parts are built by a layer by layer process on a polymer powder. The major difference between LS and HSS is that in HSS, an infrared (IR) absorbing ink and an IR lamp are used to melt the polymer powder rather than a laser. An inkjet print head is used to print the image of each 2-D layer and then the whole bed is exposed to IR radiation, which causes the areas of powder where the IR ink is present to sinter, leaving the rest of the powder unsintered.[3] HSS is therefore faster than LS as layer times are independent of part dimensions. HSS also eliminates the need for expensive lasers and optics has incurs fewer problems when applying to a large build area, as the use of multiple lasers is costly.

HSS still retains many of the advantages seen in LS compared to other AM techniques. Mechanical properties of HSS parts are comparable with, and sometimes considerably higher, than those created by LS. HSS is also able to process many polymers, including a wider range of elastomers with high melt viscosities that are not suited to LS.[4]

The increased speed in which HSS can manufacture parts in comparison to LS, the production of fast moving consumer goods (FMCGs) becomes more credible. For HSS to be a manufacturing technique a wide supply chain needs to be in place. Therefore it is critical that different IR absorbing inks can be used in the process without having a detrimental effect on parts. Allowing a more competitive market place reducing the cost of a critical material in HSS. This work therefore investigated the replacement of an IR absorbing ink from one supplier with that produced by an alternative supplier. Both inks chosen used carbon black as the IR absorber. The Sunjet ink has been used to manufacture many parts previously, this is the only ink used to date in literature.[5-7]

Experimental Methodology

Both inks tested use carbon black as the infrared absorber and the carrier for the ink is petroleum distillates, these were used as obtained from suppliers.[8, 9]

Build parameters used were the same for both inks, see Table 1. The powder used for the parts was 100 % used PA 2200 powder.

Table 1. Machine parameters to build parts

Ink	Build Bed / °C	Build overhead / °C	Feed bed / °C	Feed overhead / °C	Preheat stroke / % @ mm/s	Sintering stroke / % @ mm/s
Sunjet	169	175	120	140	100 @ 170	100 @ 120
Nazdar	169	175	120	140	100 @ 170	100 @ 120

The build layout of the tensile test pieces is shown in Figure 1. The tensile test pieces were built in the XY direction. For each infrared absorbing ink 6 tensile test pieces were built. Parts have previously been built in this configuration to compare the effect of bed temperature and infra-red lamp energy on part properties.[10]

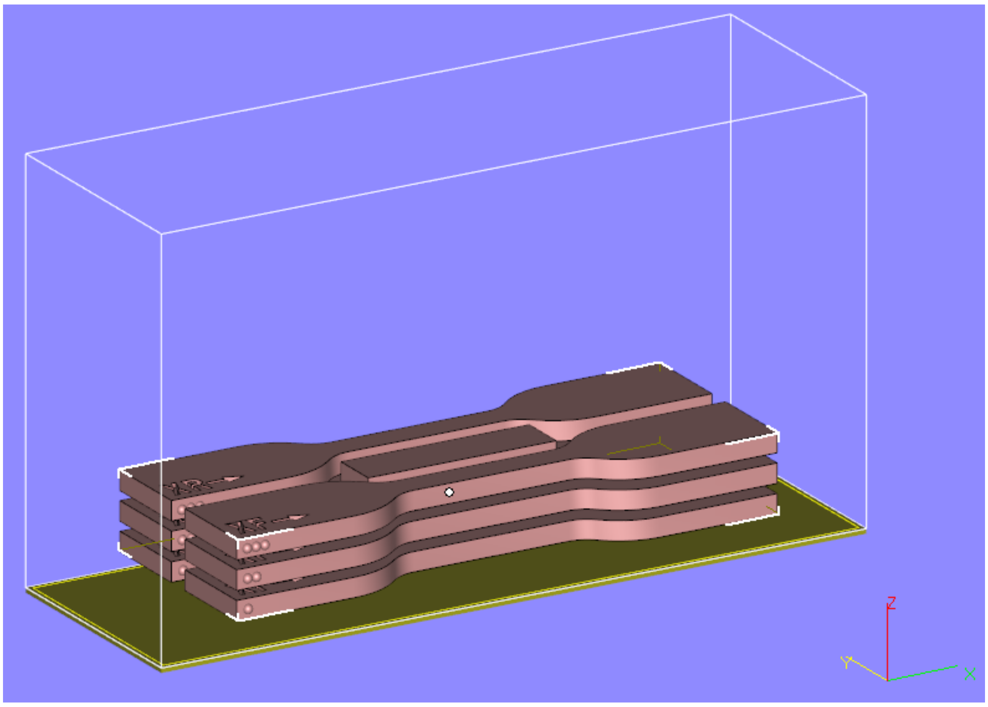

Figure 1. A diagram showing the build layout of the tensile test pieces built in the XY direction.

Parts were measured using Vernier callipers to calculate the part volume to determine the part density. An OHAUS Pioneer ™ PA64C analytical balance was used to obtain the mass of the parts.

Tensile tests were carried out in accordance with ASTM D638-10 using a Tinius Olsen H5KS Benchtop Materials Testing machine. The rate at which the tensile test pieces were pulled at was 5 mm / min. A stress-strain curve was obtained for each specimen. The interesting mechanical properties from the curve are elongation at break (EAB), ultimate tensile strength (UTS) and Young's modulus (YM).

Results and Discussion

Stress-strain curves for parts made with either ink were produced by the Tinius Olsen tensile tester. Figure 2a and b show stress-strain curves for parts made with either ink when tensile tested. These figures show the ductile nature of HSS parts not always seen in AM, these graphs demonstrate that the parts undergo ductile failure.

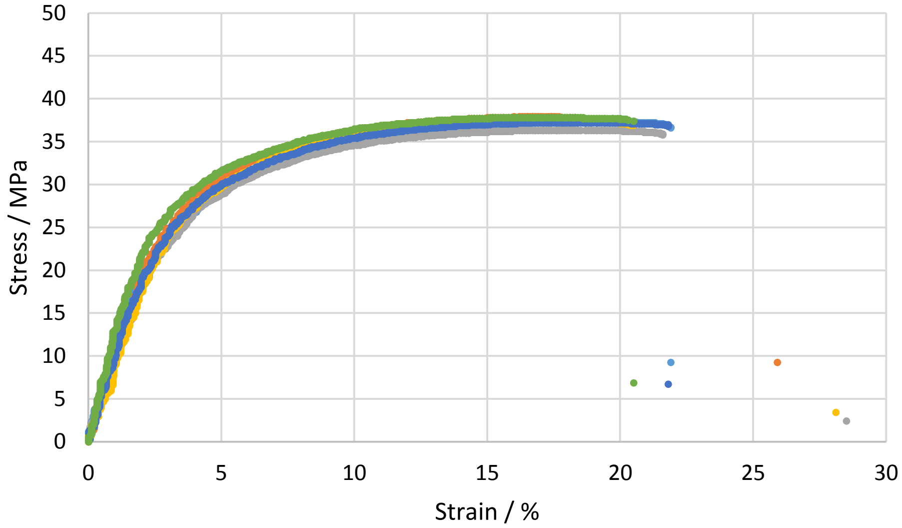

Figure 2a. Stress-strain curve of parts using the Sunjet ink

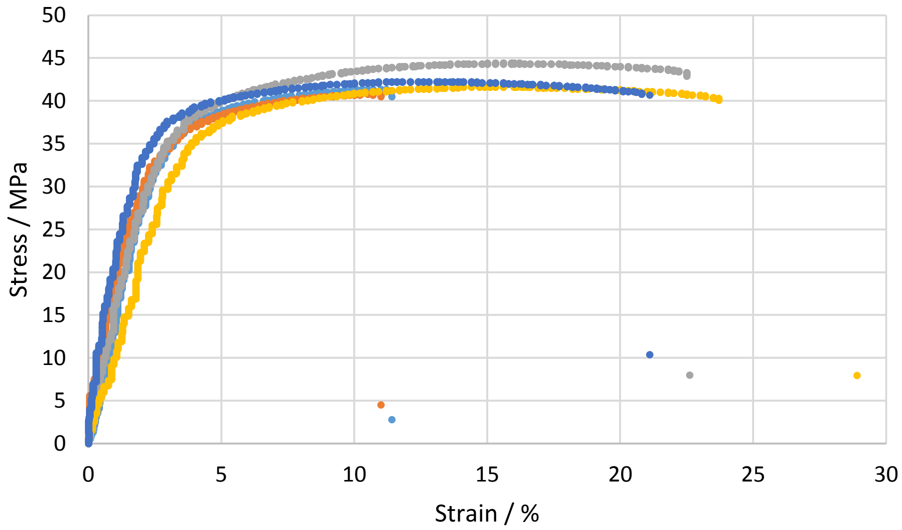

Figure 2b. Stress-strain curve of parts using the Nazdar ink

Figure 3 compares the Sunjet and Nazdar ink used in the HSS process as the infra-red absorber and how it affects the ultimate tensile strength (UTS) of the part.

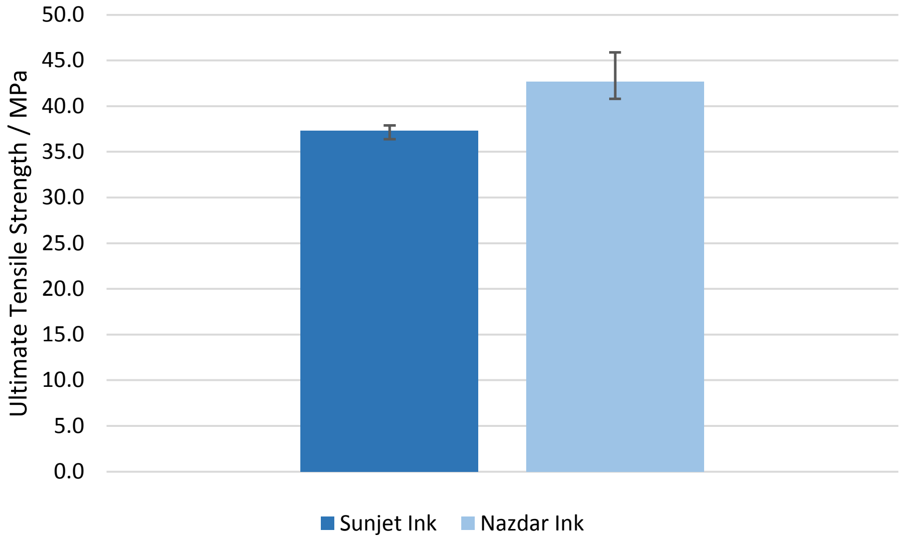

Figure 3. Graph showing UTS of the Sunjet and Nazdar ink.

Figure 3 shows an increase in the strength of the parts when the RAM used is the Nazdar ink. The parts built using Nazdar ink have an average UTS of 42.7 MPa in comparison to 37.3 MPa for the Sunjet ink parts. The range is larger for parts built with the Nazdar ink in comparison to those built with the Sunjet ink however the lowest UTS parts made by the Nazdar ink are higher than highest UTS of the Sunjet parts. The tensile strength of laser sintered parts is higher than the Sunjet parts but within the range of the Nazdar parts at 48 MPa.[11] Figure 4 compares the ink effect on the elongation at break property of parts made by HSS.

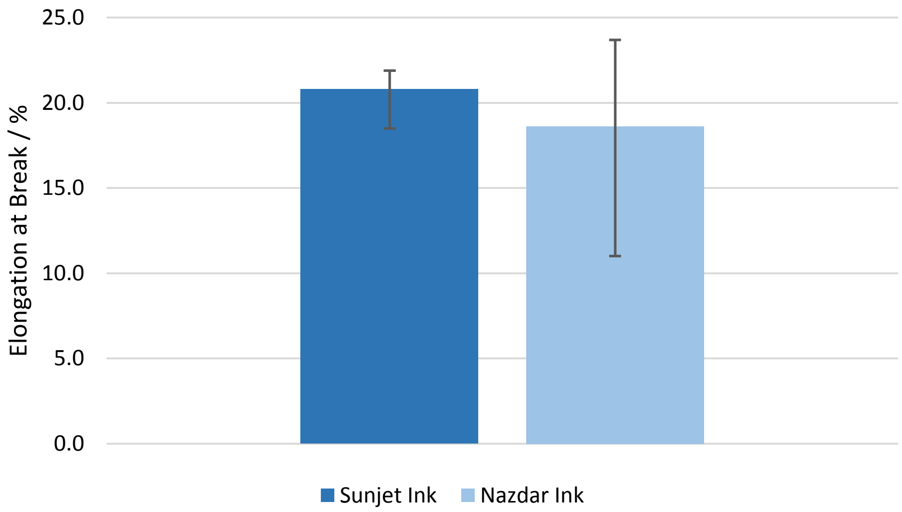

Figure 4. Graph showing EaB of the Sunjet and Nazdar ink.

The parts built by using the Sunjet ink have an average 20.8 % EaB in comparison to 18.6 % for parts made by the Nazdar ink. The elongation at break of the Nazdar ink is skewed to a lower value by a layer of tensile test pieces which had lower than expected EaB values. The lower values were obtained from tensile test pieces that were built on bottom of the stack of the test pieces. Hence these test pieces would be exposed to elevated temperature in the build bed longer than the rest of the specimens. These pieces therefore lowered the average and made the error bars larger. Whereas this was not observed in the parts built using the Sunjet ink hence a smaller range bar was obtained. The parts EaB made with both the Sunjet and Nazdar ink are comparable to that observed for laser sintered parts which is 18 %.[11] Young's modulus is another tensile property, see Figure 5.

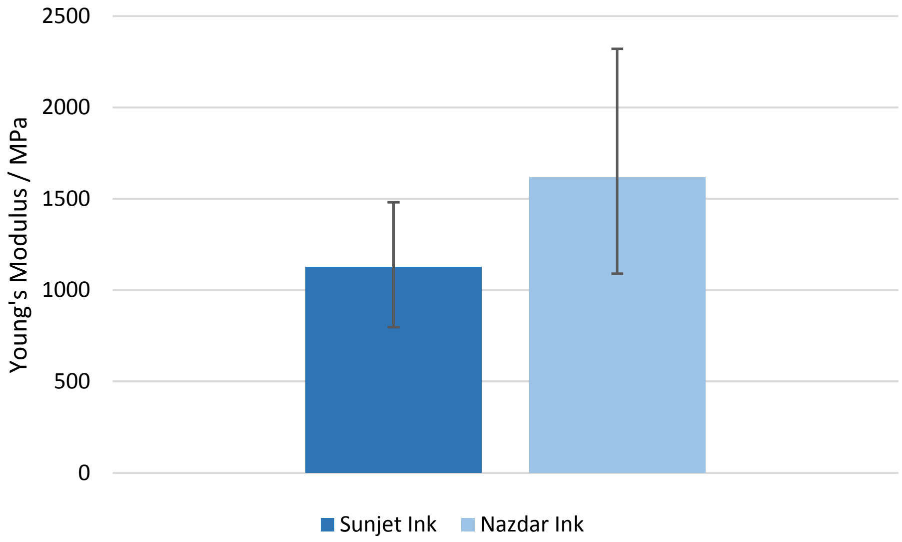

Figure 5. Graph showing Young's modulus of the Sunjet and Nazdar ink.

The Young's modulus of the Sunjet parts have an average of 1127 MPa whereas those made using the Nazdar ink have an average of 1615 MPa. The YM of both inks are comparable although the range bar of the Nazdar ink is larger than that of the Sunjet ink. The range bar is larger due to there being two outliers both of which are from the tensile test specimens on the top layer of the tensile test pieces built. The average YM for the parts are within the range hence cannot be distinguished. The YM for laser sintered parts is a comparable 1650 MPa, which is within the range of the Nazdar parts whereas this is not within the range of Sunjet parts.[11] Density of parts gives an indication of porosity and how sintered together the powder material of the part is. Figure 6 shows the density of parts made by using the two different RAM's.

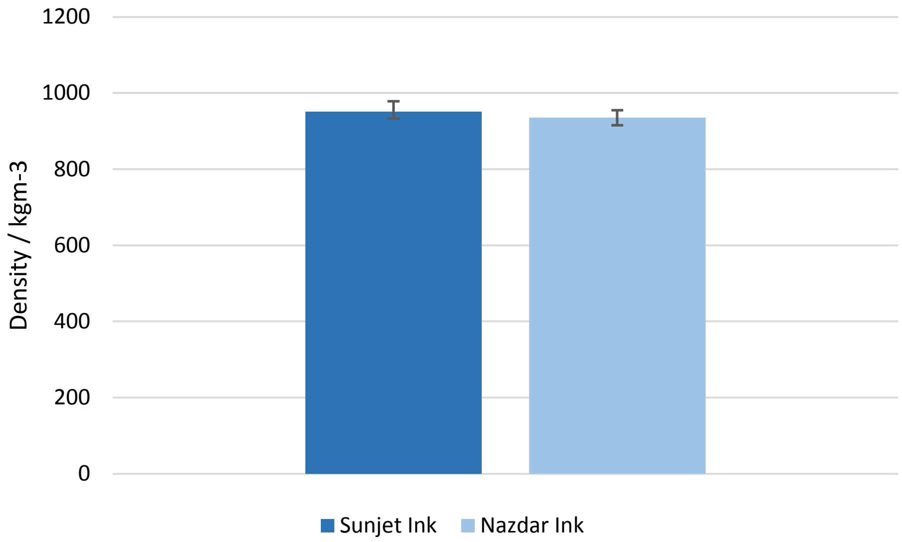

Figure 6. Density of parts made using Sunjet and Nazdar ink.

The density of the Sunjet parts is 951 kgm^{-3} in contrast to 935 kgm^{-3} for the Nazdar parts. The density of the parts is similar built using either ink and hence indicating the ink used has little effect on the porosity and density of the parts produced. This density is comparable to parts made by laser sintering which is 930 kg m^{-3}.[11] These density values are within range bars which indicates a similar porosity of parts made by either ink or laser sintering.

Conclusions

The experimental data from this paper displays that it was possible to build parts using two different inks from different suppliers. With parts with either ink producing similar properties including density and tensile properties. All parts were built with used powder and at ideal parameters for the previously untested Nazdar ink. Hence the Nazdar outperforming the Sunjet ink in certain tests is not unexpected although the difference between the ideal parameters is small. Future work would involve a design of experiment around the parameters ideal for both inks to get a fuller view of the performance range of both inks. This investigation was carried out on used powder. Used powder and its comparison to virgin has been examined in laser sintering [12] but only preliminary work has been carried out for High Speed Sintering.[6] There has been no significant evidence of the influence on powder age on the effect of mechanical properties in HSS. Powder recyclability could be an essential area to research for the commercialisation of HSS.

Acknowledgements

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