LASER PRINTED ELASTOMERIC PARTS AND THEIR PROPERTIES

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Abstract

The precise deposition of polymeric toner powder by laser printing is reliant on having powder particles with appropriate flow and uniform charge properties. Nanometer sized particles known as flow control agents (FCA) and charge control agents (CCA) are used to modify powder behaviour to provide the appropriate characteristic for printing. This paper shows how varying the quantity of FCA applied to the surface of Somos201 particles can affect the elongation to failure and ultimate tensile strength of laser printed tensile test specimens.

1. Introduction

For over fifteen years researchers have recognised the potential of using electrophotography, the basis of laser printing, to build three-dimensional objects (Bynum, 1992; Grenda, 2001; Cormier *et al.*, 2002; Kumar, 2000). Broadly speaking the process involves the precise deposition of fine polymeric powder toner (build and support material) which is subsequently thermally fused to form solid layer. This process offers many key advantages for layered manufacturing applications including high speed (up to 1000 pages per minute) , excellent resolution (up to 2400dpi) and layer thickness from 5- 50micron. Although electrophotography has been employed to produce masks in Cubital's Solid Ground Curing (SGC) system and SinterMask's Selective Masking Sintering (SMS) process, it has not been used to directly deposit material in a commercial system to date (Larsson, 2003). This is due to a number of challenges including the lack of functionalized toner for applications beyond text and images. Feasibility work has already moved beyond the conventionally printed polymers (styrene, acrylic, polyester) to include: HDPE, PVA, LDPE, PP and a soluble acrylic material. (Cormier *et al.* 2002; Banerjee and Wimpenny 2006; Banerjee and Wimpenny, 2008). The need arose during the EU funded Custom-Fit project to develop a flexible "rubber-like" toner for the manufacture of customised helmet liners and motorcycle seats. As a logical starting point for the research it was decided to take an existing powder material (Somos 201), used in laser sintering, and adapt it for use in the laser printing process.

A surface coating method, developed by Banerjee and Wimpenny (2006) for the production of toners from standard polymeric powders, was used to prepare an experimental toner formulation based on Somos 201 powder. To enable printing by electrophotography toner particles should ideally be uniform in size and relatively spherical in shape. However, Somos 201 powder is neither uniform in size or shape (See Figure 1). To compensate for the non-uniform size and surface interactions, particles must be coated with a flow control agent (FCA). While FCA is used currently in both laser printing toners and laser sintering polymers the amount required for printing Somos 201 is outside the window of the current art. Although Banerjee and Wimpenny (2007) expressed concern that high levels of FCA may have a negative impact on part properties to date this has not been robustly quantified. The purpose of the research described in this paper is to quantify the effect of FCA on the mechanical properties of parts and explore how the toner and sintering variables can be optimised.

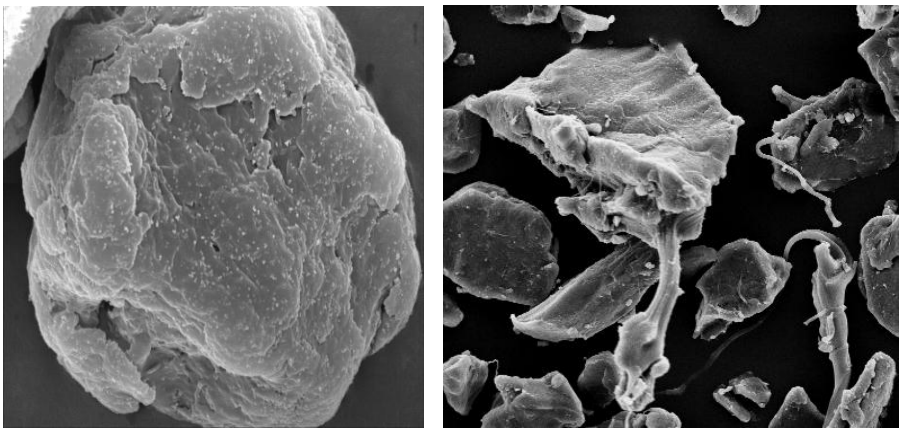

Figure 1 – Comparison of standard toner (left) versus Somos 201 powder (right)

2. Methodology

Two sets of trials were conducted within the scope of this research. The first set aimed to establish if the addition of FCA affects the strength of Somos 201 powder thermally fused in an oven. The results from the first set of trials indicated that a more comprehensive experimental programme using a full factorial Design of Experiments (DOE) should be conducted to provide a more information on the influence of FCA on the material properties and to establish the relative magnitude of its effects compared to sintering duration and particle size. The second set of trials was based on thermal fusing of the powder using a medium wave IR radiant heater.

2.1 Oven Sintering Trials

All tensile testing samples were prepared from commercially available Somos 201 laser sintering powder. Although the precise composition of Somos201 is proprietary, analysis indicates that it has a chemical composition similar to polybutylene terephtalate (PBT). Before preparing the toner the standard Somos 201 powder was sieved and classified by size. These trials used two particle sizes: D50 of 30 micron and D50 of 17micron. Next approximately 200g of each sample size was surface coated with fumed silica HDK20TX (particle size 170 to 250 nm) by mechanical mixing using a CKL Multimix mixer.

Dog bone specimens (gauge length 40 mm) for tensile testing were then produced by filling a ten cavity aluminium mould to a depth of 2mm with the 30micron Somos 201 powder (as shown in Figure 2). The mould was preheated (100^{o}C) prior to filling and then placed in a preheated oven for 3 minutes to fuse the powder. Samples were prepared using different oven temperatures as shown in Figure 3.

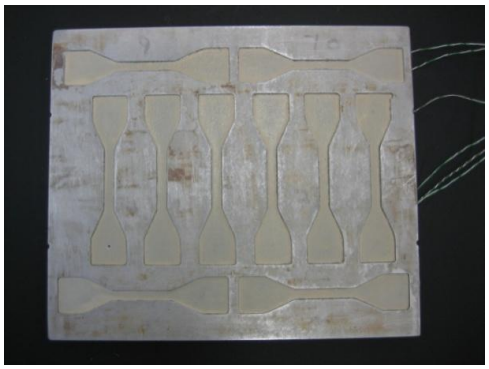

Figure 2 - Tensile Specimen Mould

Test Matrix: Flow Control Agent & Temperature		FCA coating (% by wt)		
		0.00%	0.30%	0.60%
Temperature (C)	160	•	•	
	170	•	•	•
	180	•	•	

Figure 3 - Test Matrix for Oven Sintered Specimens

Although oven sintering is not ideal for producing 3D parts it was used for this initial set of trials on the basis that it would form a reliable benchmark for future experiments employing other heat sources. After the specimens were sintered, they were removed from the mould and tensile tested to failure. The fractured surface of the specimens was then inspected using a scanning electron microscope (SEM).

2.2 Full Factorial Experiment: Infra-red Sintering Trials

A 2^3 full factorial experiment was designed to show the effect of particle size, FCA content and sintering duration. The same powder preparation method and ten cavity aluminium mould, as described above were used for this experiment; however a 12 kW infra-red radiant heater (Flare-FSH8) was used as the heat source (see Figure 4). IR radiant heating is the most likely thermal fusing method to be employed in a commercial laser printing layer manufacturing system.

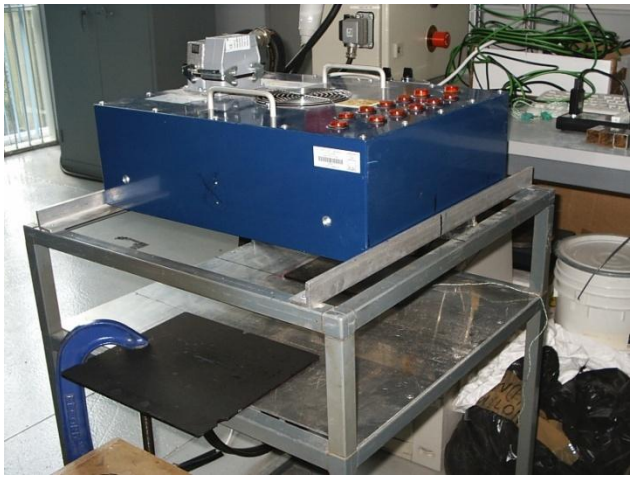

Figure 4 – IR radiant heater sintering set-up

All eight combinations of the factors were tested as shown in Figure 5. After the specimens were sintered, they were removed from the mould, tensile tested to failure and then inspected by SEM.

2^3 DOE: Factors and Levels		Factor Levels	
		low	**high**
A	Somos 201 Particle Size (microns)	17	30
B	Sinter Duration at full power (seconds)	20	40
C	FCA coating (% by wt)	0.0%	0.3%

Figure 5 – Factors and Levels for Full Factorial Experiment

3. Results and Analysis

The results of the initial set of experiments with and without 0.3% FCA are shown in Figure 6. For specimens processed at 180°C the average peak stress without FCA was 6.29 MPa while specimens with 0.3% FCA withstood only 0.99 MPa. The trend that strength decreased when adding FCA held at every processing temperature although it is less pronounced at 160°C which is probably because it is below the material melting point of 172-180°C.

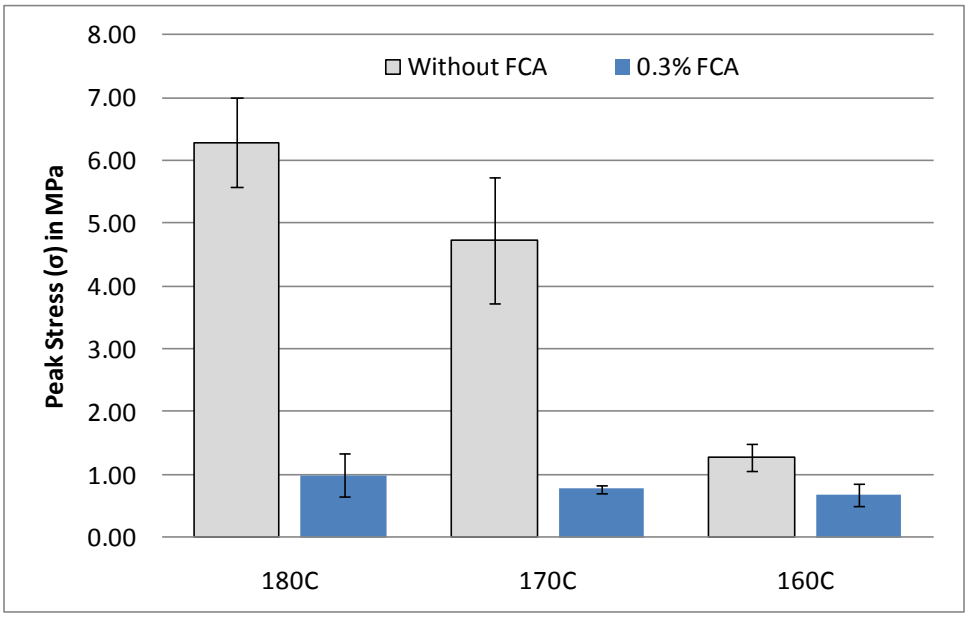

Figure 6 – Average TPE specimen strength with and without FCA

It can be seen from Figure 7 that increasing the amount of FCA adversely affects the strength of the specimens made with the 30 micron particle size powder. The uncoated Somos 201 composition had a strength of 4.73MPa. The addition of 0.3% FCA reduced the strength by around 85% to just 0.77 MPa. A coating of 0.6% of FCA reduced the strength to 0.36MPa, only 8% of the original value. Further addition of FCA resulted in samples that were so fragile that they were unsuitable for tensile testing. SEM images of coated and uncoated samples (see Figure 8) show that the addition of the FCA results in poorly fused samples with little evidence of coalesce of the polymer particles.

These results suggests that using FCA to compensate for toner particles of non-uniform size is only appropriate up to 0.6% by weight within the sintering range tested because exceeding this limit severely compromises the sinterability of the material. To maximise specimen strength the FCA surface coating should be kept to the absolute minimum required to enable deposition by laser printing.

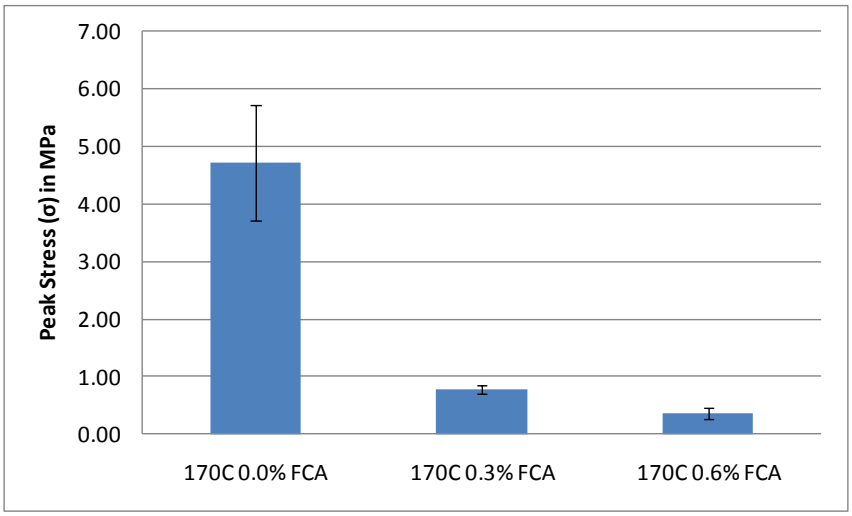

Figure 7 – Effect of FCA on TPE Specimen Strength

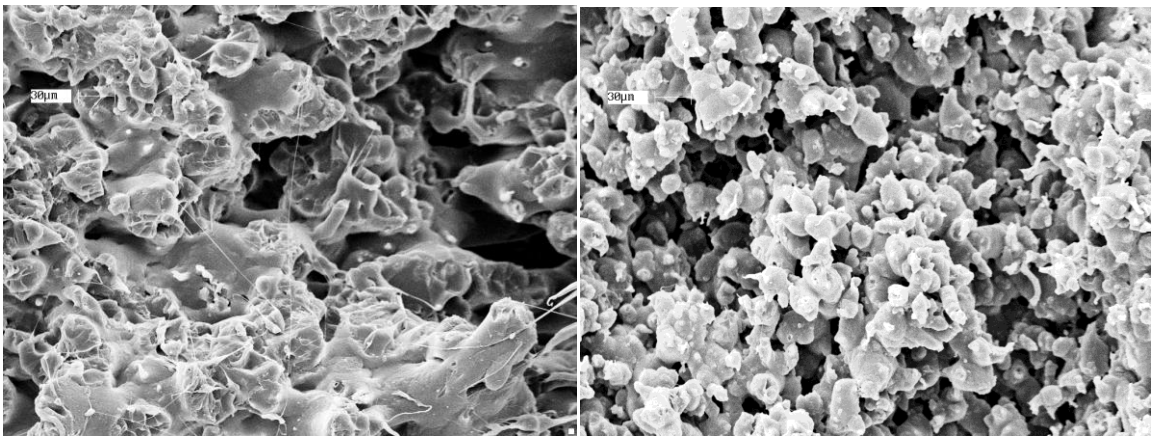

Figure 8 – SEM images of oven sintered specimens without (left) and with FCA (right)

Although the results of the first set of trials clearly indicated that a coating of FCA adversely affects the strength of sintered samples the magnitude of this effect for different toner particle sizes and sintering duration was only established after completion of the more comprehensive second set of experiments. The strength of the IR sintered specimens varied from just under 0.5 to nearly 2MPa with a median value of 0.92MPa. In comparison the published tensile strength of laser sintered Somos201 samples ranges from 1.4 to 3MPa depending on the processing conditions (EOS data sheet dated 06.02.03). The effects of those three factors and their interactions are shown as a Pareto chart in Figure 9. Only two of the main effects: particle size and percentage of FCA proved statistically significant along with their two-way interaction.

Particle size had the most pronounced effect on specimen strength with the percentage of FCA used following close behind. Sintering duration and the other interactions were below the decision limit and therefore are not statistically significant at the 95 percent confidence level so they have not been labelled on the Pareto chart.

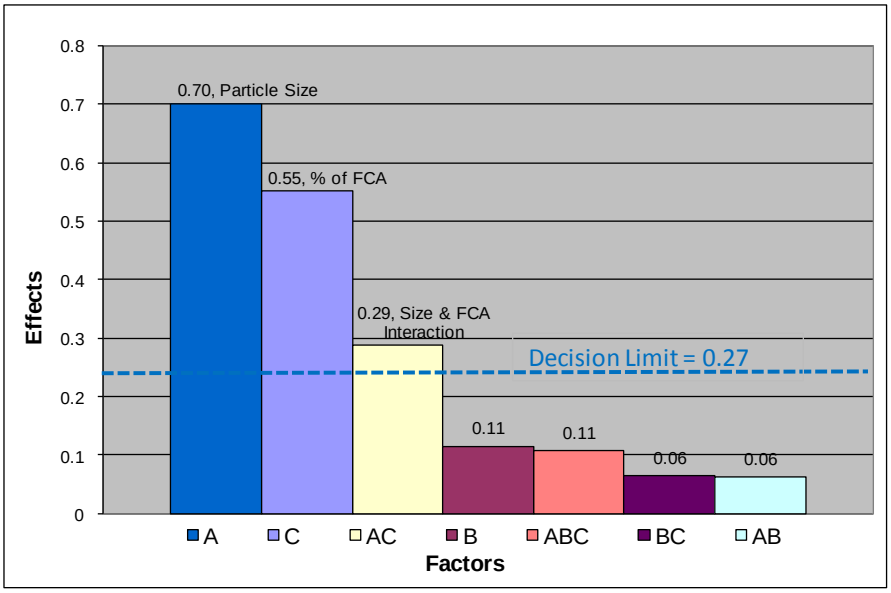

Figure 9 – Pareto Chart of DOE Effects

Figure 10 shows the effects of particle size and FCA on the Peak (UTS) strength of the specimens tested. As the particle size increases from 17 to 30micron the strength of the sample decreases by 0.7MPa. This suggests that smaller particles more readily absorb the infra-red (IR) radiation and fuse. This is confirmed by the SEM images in Figure 11 which shows particle coalescence at depths of 200 to 250 microns on the side exposed to IR (the bottom surface as shown in the images) for the sample made of 17 micron powder while the sample made from 30 micron powder shows coalescence to only 100 microns or less. Figure 10 also shows that as the amount of FCA used increases to 0.3% the specimen strength drops by 0.55MPa, which reinforces the observations made during oven sintering.

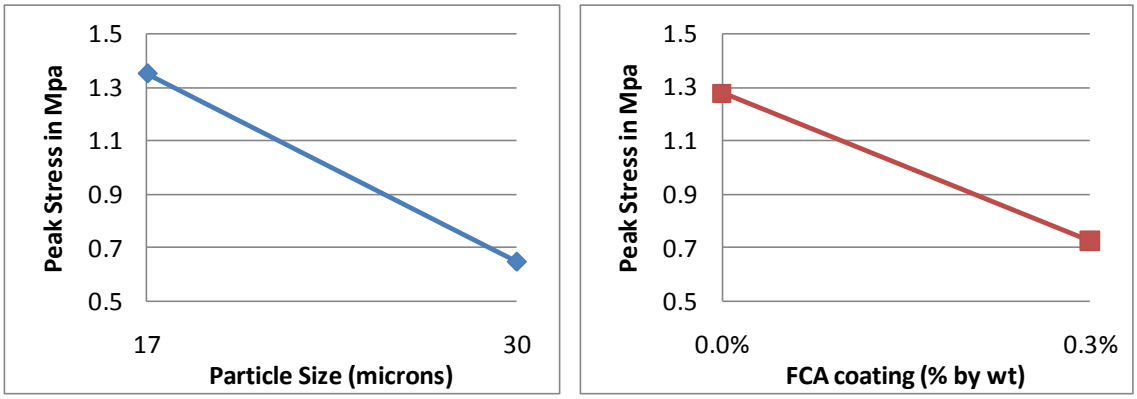

Figure 10 – Effect of Particle Size and FCA on Peak Stress

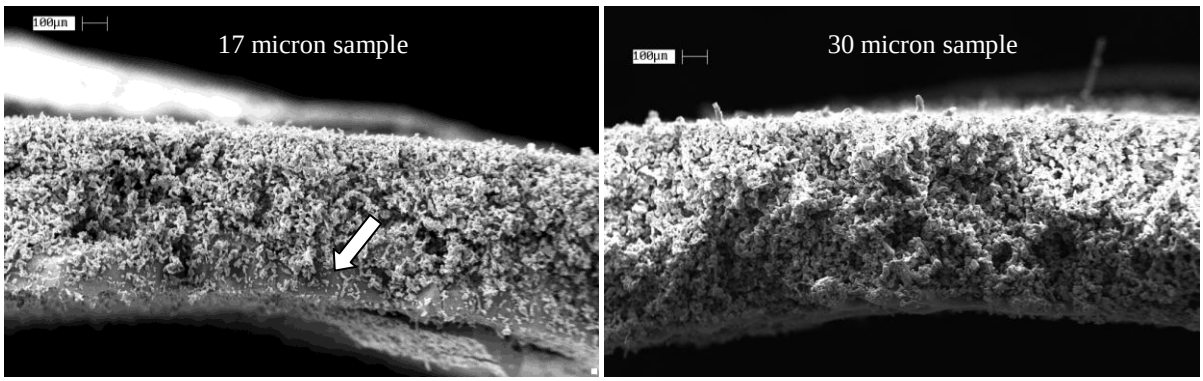

Figure 11 – SEM image of fractured surface of tensile specimens

Figure 12 shows the interaction plot between particle size and the amount of FCA added. The relatively steep slope of the line representing samples made from 17 micron powder shows how detrimental the addition of FCA was on specimen strength. The strength was reduced on average by 0.84MPa. The weakening effect of adding FCA to samples made from 30 micron powder was also evident, but less severe. Samples made from 30 micron powder suffered an average reduction of only 0.26MPa (as shown by the shallower slope on the graph). Within the range tested, this data clearly demonstrates that the addition of FCA has a greater affect on samples made from the smaller (17 micron) particle size powder.

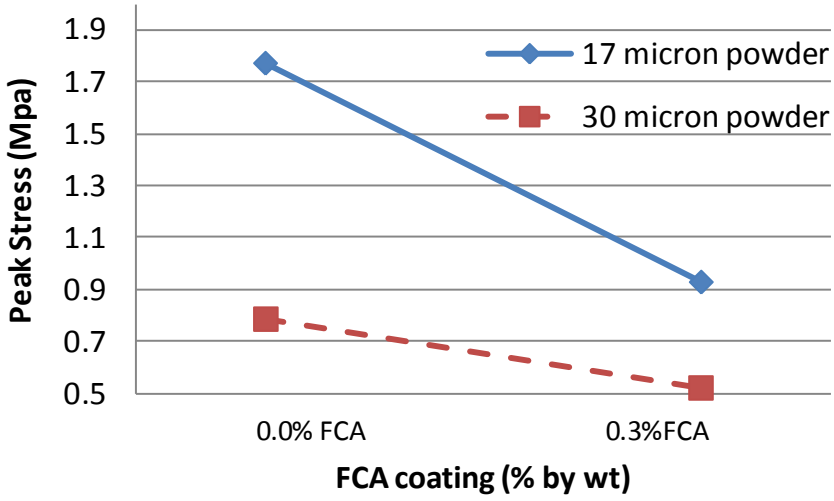

Figure 12 – Interaction plot between particles size and FCA

4. Conclusions and Future Work

This work highlights a potential problem with laser printing toner materials with high quantities of FCA, which has been shown to inhibit sintering in both the oven and infra-red sintering trials. Although the addition of FCA may be necessary to provide the non-uniform Somos201 toner particles with the appropriate flow properties for laser printing its use should be minimized to achieve improved part properties. Furthermore, an upper limit of 0.6% FCA by weight has been established, beyond this level integrity of sintered bodies made from Somos 201 is severely compromised. This work has also shown that the 30 micron powder is less susceptible to the adverse effects of adding FCA. This suggests that it may be a preferable basis for a commercial toner, assuming that it can be sintered more effectively when processed layer-by-layer. Future work will focus on producing specimens without the use of a mould where the toner powder is deposited by electrophotography. The potential to apply pressure during (or soon after) deposition may help to encourage more effective coalescence of the particles coated with FCA leading to improved properties. Moreover, fusing relatively thin layers (30-40microns thick) deposited by laser printing may produce samples with higher integrity than achieved by bulk sintering 2mm thick layers, as undertaken in these trials. The investigation of this hypothesis will form the basis for a future paper.

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References

Banerjee, S. and Wimpenny, D.I., (2006) "Laser Printing of Polymeric Materials" Proceedings from the Solid Freeform Fabrication Symposium, Austin, Texas, pp. 366-374.

Banerjee, S. and Wimpenny, D.I., (2007) "Rapid Manufacturing of Thermoplastic Parts by Laser Printing", Proceedings from the International Conference on Polymers & Mould Innovations", Ghent, Belgium, April 2007.

Banerjee, S. and Wimpenny, D.I., (2008) "Laser Printing of Soluble Toner for Rapid Manufacturing", Proceedings from the 2nd International Conference on Additive Technologies, September 2008, Ptuj, Slovenia.

Bynum. K.D., (1992) "Automated manufacturing system using thin sections", US Patent 5088047.

Cormier D., Taylor, J., West, H., (2002) "An investigation of selective colouring with 3-D Laser printing", *Journal of Manufacturing Processes*, Volume 4, Number 2.

E.J. Gutman, G.C. Hartman, (1992) "Triboelectric properties of two-component developers for xerography", *Journal of Imaging Science and Technology*, Volume 36, pp. 335.

Grenda E.P., (2001) "Apparatus of fabricating 3 dimensional objects by means of electrophotography, ionography or similar process", US Patent 6206672.

Kumar A.V., (2000) "Solid free form fabrication using powder deposition", US patent 6066285

Kumar A.V., Dutta A., (2003) "Investigation of an electrophotography based rapid prototyping technology", *Rapid Prototyping Journal*, Volume 9, Number 2, pp. 95-103.

Kumar A.V., Dutta A., (2004) "Electrophotographic printing of part and binder powders", *Rapid Prototyping Journal*, Volume 10, Number 1, pp. 7-13.

Larsson, R. (2003) "Method and device for manufacturing three-dimensional bodies", US Patent 6531086.

Scharfe M., (1983) “Electrophotography principles and optimization”, Research study press, UK

Schien L.B., (1999) “Recent advances in our understanding of toner charging”, *Journal of Electrostatics* , Volume 46, pp. 29-36.

Thourson, T.L., (1972) “Xerographic Development Processes: A Review”, *IEEE Transactions on Electron Devices*, Volume ED-19, Number 4, April, 1972.