High Speed Sintering - Continuing research into a new Rapid Manufacturing process

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Abstract

High Speed Sintering (HSS) is an emerging layer manufacturing technique aiming to break into the lucrative field of Rapid Manufacturing (RM). The process is likened to Selective Laser Sintering (SLS), however, instead of a laser dictating the sintered cross sectional area of each layer, the desired area is first printed using a Radiation Absorbing Material (RAM) and then sintered using an inexpensive infrared lamp. This paper begins by describing the sintering process in more detail and then outlining the overall manufacturing cycle. It then continues by describing the experiments performed to investigate the current problem concerning the hardness of excess powder within the powder bed. This problem arose due to the continual exposure of the whole bed to infrared radiation from the lamp. The experiments showed that as the power of the IR lamp increased, the hardness of the bed also increased. Furthermore, at higher IR power levels it was found the excess powder produced a solid tile which could only be broken down by a glass bead blaster.

Keywords

Rapid Manufacturing, High Speed Sintering, Inkjet Printing, Infrared Radiation.

Rapid Manufacturing

Rapid manufacturing, (the production of end use products by layer manufacturing) is becoming a viable manufacturing process within numerous engineering firms. Existing studies [1,2] have shown that selective laser sintering can be used to manufacture small components in volumes up to 14,000. After this, machine cost and build speed inhibit any higher economical production runs. Furthermore, Phonak Hearing Systems and Siemens Hearing Instruments have drawn on Stereolithography's qualities by using the technology to manufacture bespoke hearing aids. With SL, a batch of 75-100 hearing aids shells can be manufactured in six to eight hours [3].

In recent years, a number of other organizations have begun to pursue the design of layer manufacturing technologies which directly cater for Rapid Manufacturing. Speedpart [4] have developed and marketed a process that masks a plastic powder bed which is then exposed to IR radiation. This enables sintering of an entire layer in a layer manufacturing cycle time of 12-14 seconds [3]. Desktop Factory [5] also have a machine on the market which uses an inexpensive halogen light source and drum printing technology to build parts layer by layer from plastic powder [3]. In comparison to SLS and HSS, their build area is small; however their manufacturing method is similar to the technologies discussed here. Finally, two university based research projects are also developing potential RM processes. Firstly, the University of Southern California is developing a process called Selective Inhibition Sintering (SIS) [6,7]. This process prints a sintering inhibitor at the outline of a desired geometry. Infrared radiation then exposes each layer, sintering the desired cross-sectional area. Finally, electrophotographic rapid prototyping (ERP) is being developed at the University of Florida. The process works by picking up and depositing powder using electrostatic forces [8,9]. Negative charge is deposited onto a photoconductor drum. A UV beam then scans and discharges selective regions upon the surface of the drum. Powder is deposited on these newly created discharged areas and as the roller rotates, then transferred to the build area. Each layer is sintered by exposure to radiant heat [8,9].

These processes possess varying manufacturing methods, yet all have two key aspects which provide them with the potential to be RM processes; firstly, sintering occurs in a time that is irrespective of the size, amount and shape of the 2D profiles in each layer and secondly, the deposition or masking of a 2D profile is performed relatively quickly. These advantageous characteristics enable part cost to be reduced and therefore open up opportunities to manufacture at increasing part volumes.

Introduction to High Speed Sintering

In the last three years, a new layer manufacturing process has been developed at Loughborough University. The process has some similarities to both Selective Laser Sintering (SLS) and 3DPrinting (3DP); however its novel differences suggest that in the future it may possess the capability to compete with injection moulding. Instead of an expensive laser dictating the sintered cross sectional area of each layer, the desired area is first printed using a radiation absorbing material (RAM) and then sintered by exposing the whole part bed to infrared (IR) radiation – see Figure 1. The key to the process is that the RAM absorbs the IR radiation at a higher rate than the unprinted areas of Nylon powder. In a matter of seconds, the printed RAM absorbs and transfers enough thermal energy to enable the underlying nylon powder to reach its melt temperature and initiate viscous sintering. This process has been named 'High Speed Sintering' (HSS) and international patent applications have been applied for.

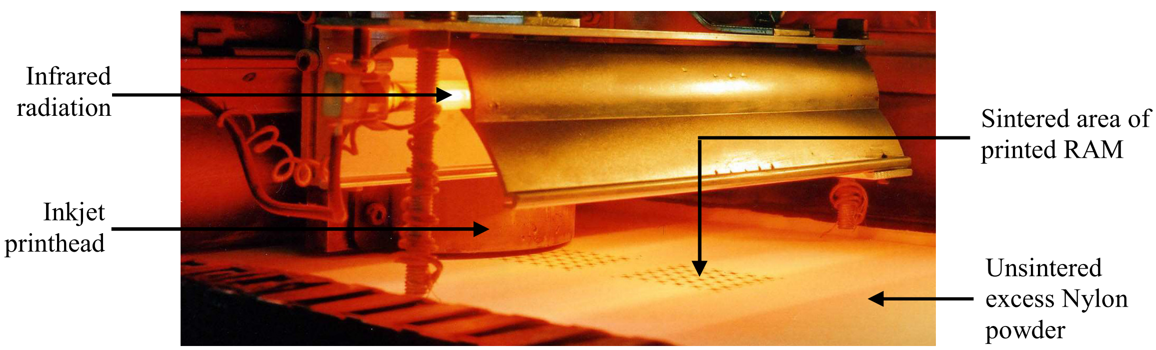

Figure 1 – High Speed Sintering

HSS offers many advantages over SLS. The removal of the laser within HSS not only reduces the machine cost significantly but also increases the build speed dramatically. The increased build speed is a result of the infrared radiation system; the time consuming scanning of the laser across the powder bed is eliminated and sintering occurs in a time that is irrespective of the size, amount and shape of the 2D profiles in each layer. These advantageous characteristics hold the key to HSS's progression into the field of rapid manufacturing.

Process Development

In 2003 Hopkinson and Erasenthiran proved that the addition of carbon black to a standard Nylon powder increased the rate of sintering such that an entire layer may be sintered in 5 seconds using an infra-red lamp [10]. They then manufactured tensile test specimens via HSS and found that the mechanical properties of the HSS material were better than that of equivalent SLS parts – see Table 1 [10].

Process	% (by weight) of carbon black mixed with Duraform	Youngs' Modulus (MPa)	UTS (MPa)	Elongation at break (%)
SLS*	0	1600	44	9
HSS	0.25	1633	47.5	18
HSS	2	1666	46.4	15

* provided by 3Dsystems.com

Table 1 - HSS and SLS part properties

The success of the initial experiments performed by Hopkinson and Erasenthiran led to industrial support of the project. An SLS machine was given from 3D systems to the Rapid Manufacturing Research Group (RMRG) at Loughborough University enabling the creation of a HSS test rig. The test rig was then used to experiment HSS via masking and to begin investigating HSS via deposition of a secondary material to promote energy absorbance.

HSS via masking was investigated by Thomas, H.R. in 2005. A series of masks were attached to the roller and the bed was filled with premixed Nylon 12 and carbon black (2% by weight). The unmasked area of the bed was then exposed to IR radiation. Sintering was successful; although, the repeatability of the roller position was poor. This made it difficult to produce multi layer parts as it was impossible to place the mask in the same position each time. At this point it was decided to proceed onto the second method of sintering.

The second method (HSS via deposition of a secondary material to promote energy absorbance) described was achieved by selectively printing a Radiation Absorbing Material (RAM) onto the powder bed. The HSS test rig was adapted for this new role by attaching an inkjet printhead and Infrared lamp onto the roller. This setup is illustrated in Figure 2 and Figure 3.

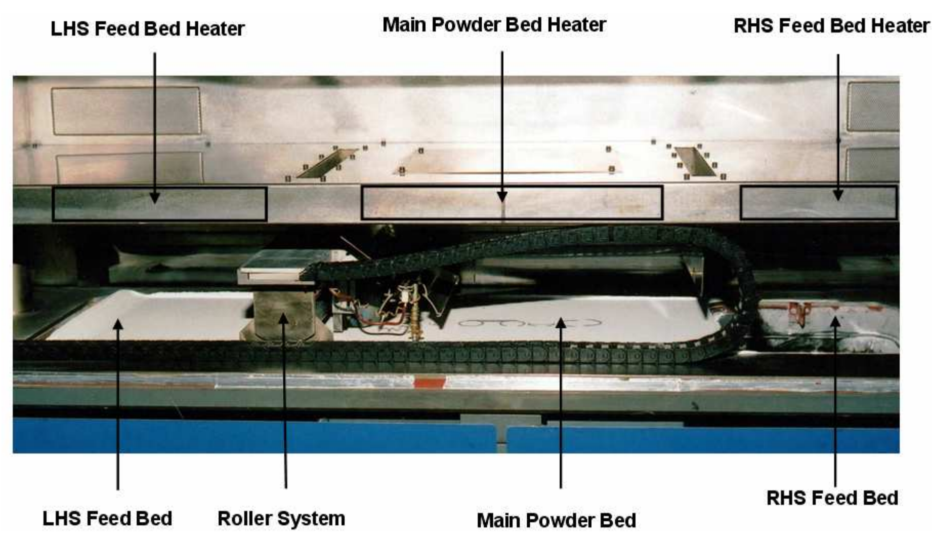

Figure 2 – The HSS machine

A HSS manufacturing method was then developed and automated by creating and running a C programme to control the position of the roller, powder bed heights, when the inkjet printhead prints and when the IR lamp exposes the bed to IR radiation. Figure 3 illustrates a close up of the build area.

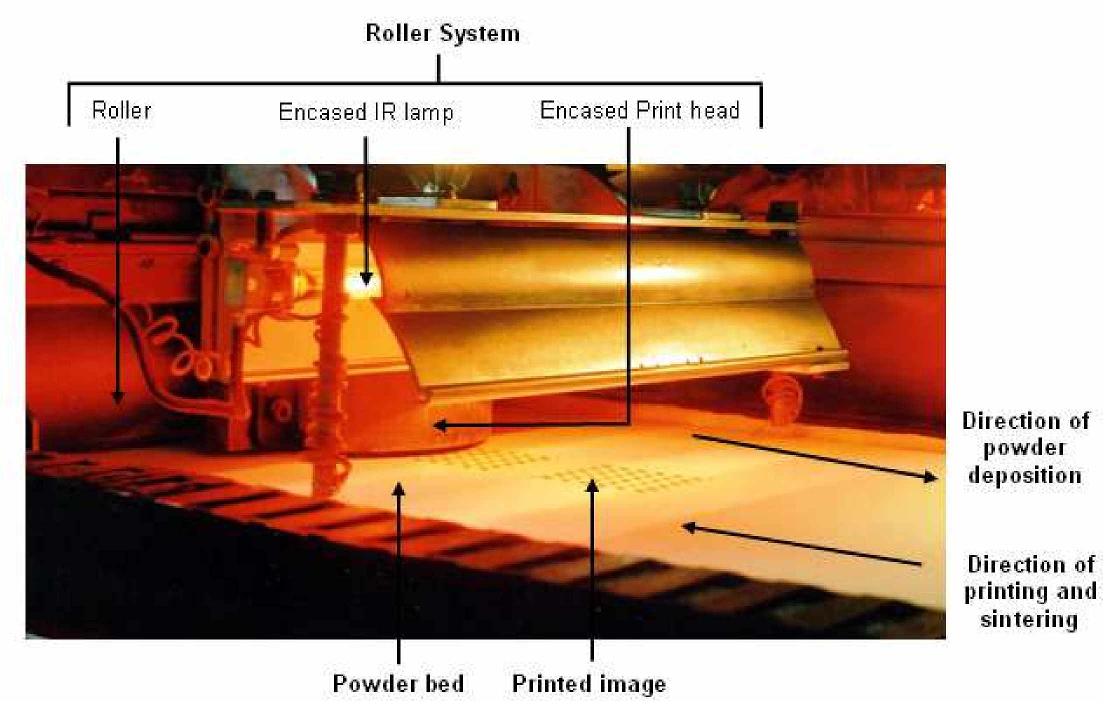

Figure 3 – A close up of the HSS build area

The manufacturing method is currently being optimized; however, the current cycle operates as follows:

- A layer of Nylon powder is deposited onto the build area (from left to right).
- Using a radiation absorbing material (RAM), a 2D profile is then printed onto the Nylon powder
- Following the printhead, an IR element, exposes the image as the roller traverses the bed (from right to left).
- The RAM then absorbs the IR radiation at a higher rate than the Nylon powder.
- The RAMs thermal energy is then transferred to the nearby Nylon powder. The Nylon powder then reaches its melt temperature and viscous sintering is initiated.
- The desired 2D profile has now been sintered.
- Another layer of powder is deposited onto the build area and the process is repeated until the required geometry has been manufactured.

Current Manufacturing Issues

One of the main issues that arose during the process development of HSS was the hardness of the excess powder within the HSS part bed. Compared to SLS, the HSS part bed receives more thermal energy due to the scanning of the whole part bed by the Infrared lamp thus causing partial sintering. Although the partial sintering of the excess powder does not affect the properties of the part, it does affect part removal. Therefore, it was decided to explore this problem further and investigate the effect of a change in IR power level, upon the hardness of excess powder within the HSS part bed. It was anticipated that the results from the investigation would highlight which heat sources provided the thermal energy that caused the partial sintering of the main part bed. This information would then be used to eradicate the problem and enable easy excess powder removal within the process.

Initial observations of the process had shown that once a part has been manufactured, and the machine allowed to cool down overnight, more than half the excess powder within the part bed had been partially sintered. It was also found that the excess powder exhibited different characteristics, depending upon its position within the bed. Figure 4 illustrates three areas in which distinct differences were observed.

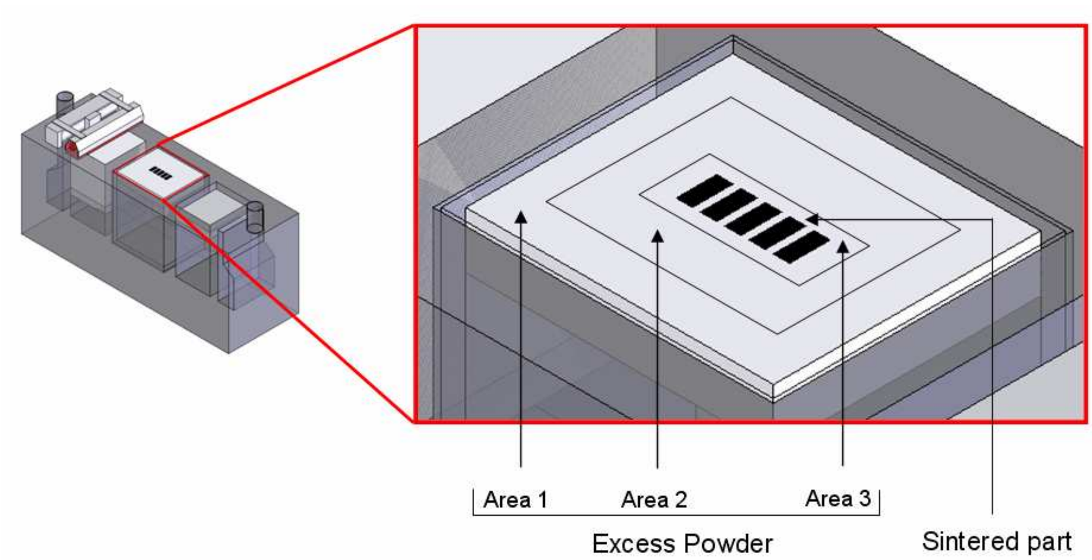

Figure 4 – Areas of partial sintering within the HSS part bed

Powder in area 1 remained soft and was very easily removed from the bed. Powder in area two was significantly harder and a scalpel had to be used to break away the powder. Finally, powder in area three was almost as hard as the part itself and had to be removed using a shot blaster – see Figure 5.

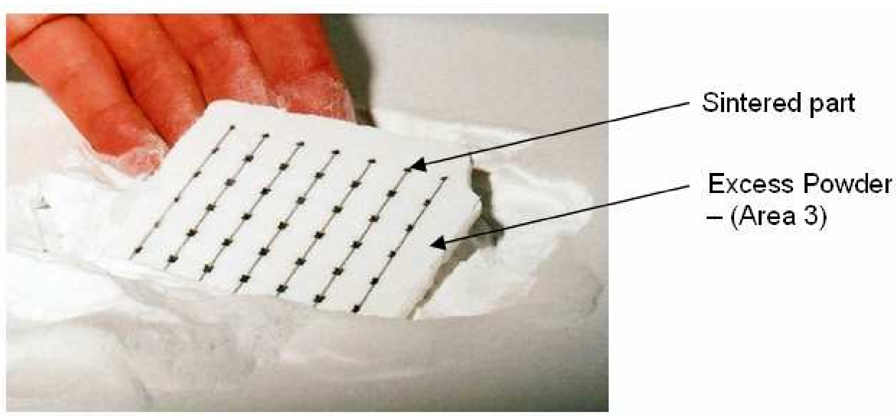

Figure 5 – Partially sintered excess powder around part

Due to the variations in powder hardness across the whole part bed it was decided to perform a series of experiments that would map the hardness of the excess powder throughout the whole powder bed.

The experiments were performed by processing 20mm of Nylon 12 powder using different part bed heater temperatures and IR power levels – see Table 2. Additionally, no RAM was printed onto the bed during the experiments. As a result, this eliminated any effect that the thermal energy emitted from a part would have on the excess powder within the bed.

Experiment Number	Temperature setting for IR part bed Heater	IR lamp Power level (0 – 10)
1a, 1b, 1c	100	0, 5, 7
2a, 2b, 2c	105	0, 5, 7

Table 2 - Experimental IR power levels to test powder hardness

Finally, it is important to note that, at present, the temperatures of the part bed heaters are not calibrated to °C and the numbers merely provide a reference point for the experiments.

Methodology

Each experiment started by placing virgin powder into the left hand side feed bed and main part bed. The initial levels of the beds are shown in Figure 6.

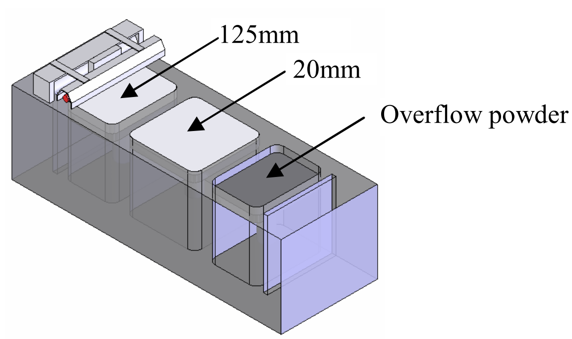

Figure 6 – Powder bed heights (Powder Hardness)

The machine was then left to preheat for two hours. Once the main part bed and left hand side feed bed had preheated to appropriate temperatures, the beds were then raised to their manufacturing temperatures. The C programme was then programmed to process 200, 0.1mm, layers and the build was started. Once the cycle had finished, the bed heaters were all switched off and the machine was left to cool down overnight. The following morning, the build chamber was opened and a mask placed onto the powder bed – see Figure 7.

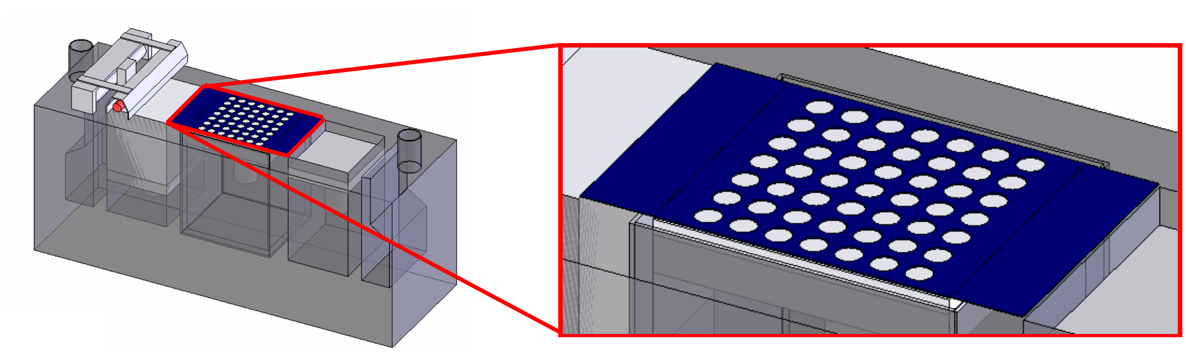

Figure 7 – Plate to locate positions to test powder

A random number generator was then used to create a list of the order in which each hole was to be tested. A Ridsdale hardness tester (normally used to test the hardness of compacted sand in a casting mould) was then inserted into each hole and a hardness level was recorded – see Figure 8.

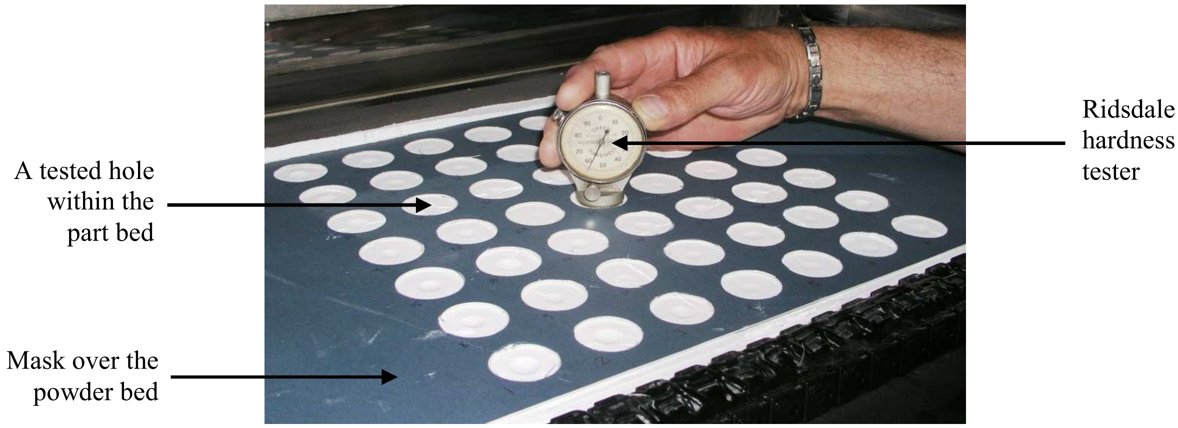

Figure 8 – Taking a powder hardness reading

Once all the measurements had been taken, the powder was removed from the machine and fresh virgin powder placed into the machine. The next experimental variables were then tested in exactly the same way.

One further experiment that was performed was the measurement of bed hardness in an SLS machine. The measurements of the powder bed hardness were taken after a normal SLS build and recorded in exactly the same way that is described above. The results are shown in the next section and are used as a comparison to the hardness of the HSS bed.

Results and Discussion

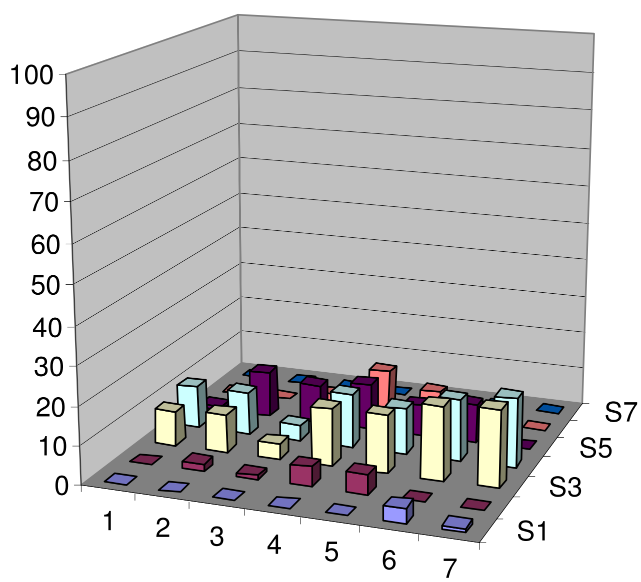

Figure 9 – The SLS part bed, part bed heater = 172˚C

Figure 9 illustrates the powder bed hardness in an SLS machine. The part bed contains soft powder and the SLS parts were easily removed from the bed. The results demonstrate that in this case, the SLS part bed heater had very little effect upon the hardness of the excess powder. Furthermore, it was observed that the excess powder located next to the SLS parts exhibited a similar softness to that of the rest of the powder bed. This leads to the observational conclusion that SLS parts do not emit enough thermal energy to the surrounding excess material that initiates any degree of sintering.

The next three figures illustrate the first set of HSS part bed harness tests.

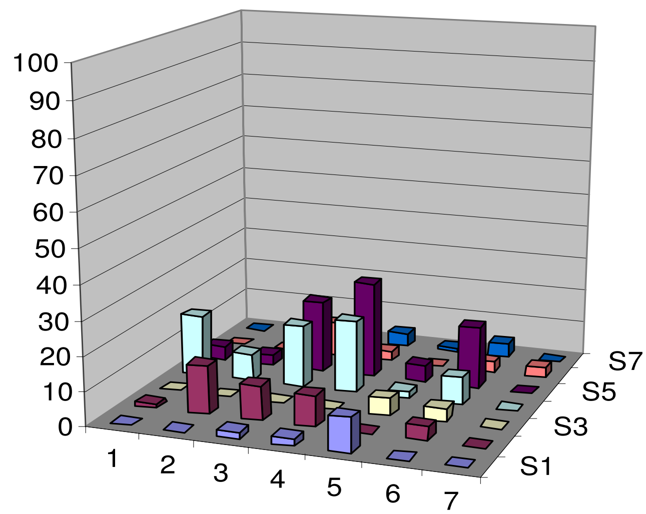

Figure 10 – Exp 1a: Part bed = 100, Infrared power level = 0

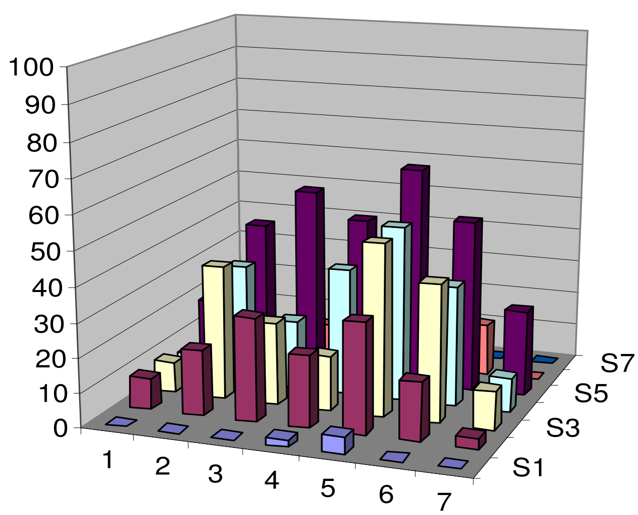

Figure 11 - Exp 1b: Part bed = 100, Infrared power level = 5

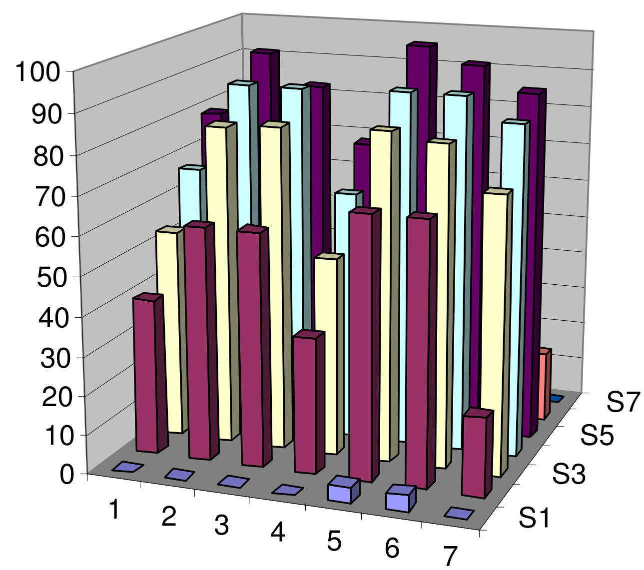

Figure 12 - Exp 1c: Part bed = 100, Infrared power level = 7

This first set of HSS results illustrate the range of powder bed hardnesses when the powder bed heater was set to 100 and the IR power; 0, 5 and 7.

Figure 10 shows that when the bed is not exposed to IR radiation from the lamp, it remains soft. This is a similar powder hardness to that achieved in SLS – see Figure 9. However, once the bed is exposed to IR power levels 5 and 7, the hardness increases dramatically to level that would make it very difficult to remove parts. At power level 5, the stiff tile can be broken by hand however, at power level 7, the powder tile can only be broken down by a scalpel or shot blaster. Furthermore, the results show that the immediate front and back of the machine remain soft due to firstly, the IR radiation emitted from the lamp not exposing the extremes of the bed and secondly, the thermal energy within the powder bed is able to dissipate through the machine bed walls.

The next three images show the results taken when the part bed heater was set to 105.

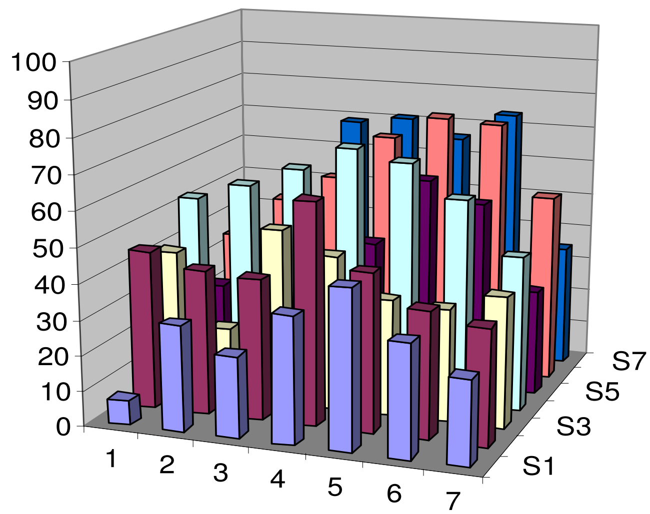

Figure 13 – Exp 2a: Part bed = 105, Infrared power level = 0

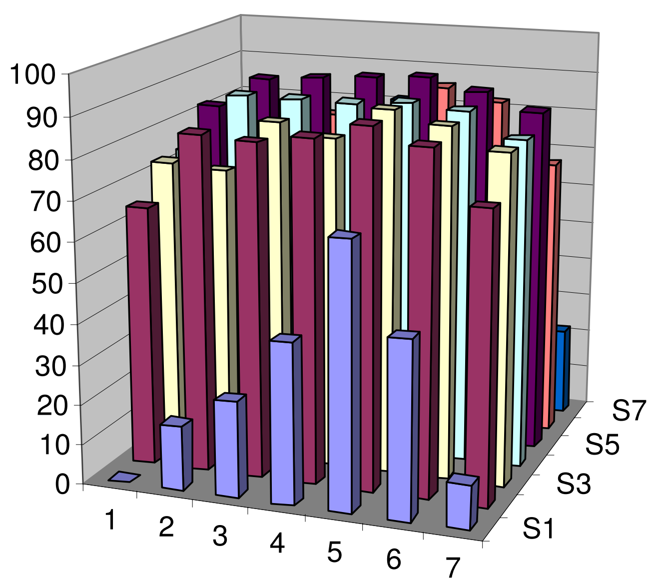

Figure 14 - Exp 2b: Part bed = 105, Infrared power level = 5

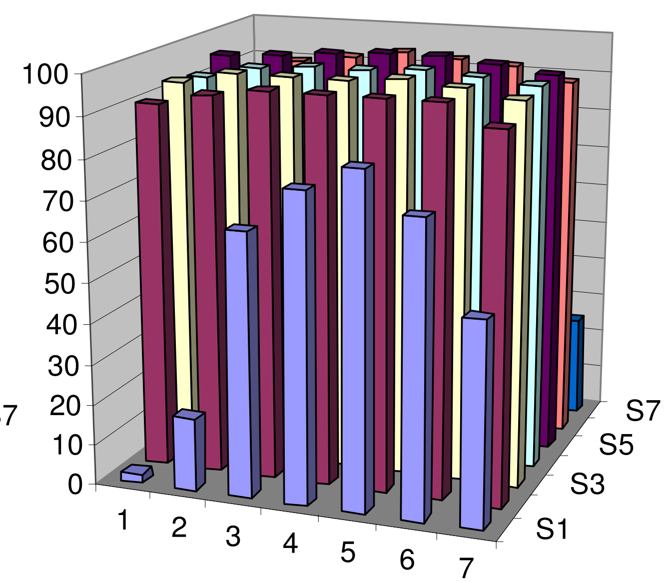

Figure 15 - Exp 2c: Part bed = 105, Infrared power level = 7

The second set of results illustrates a further increase in powder bed hardness when the part bed is exposed to IR radiation. To begin with, when the bed is only exposed to thermal radiation from the part bed heater, it exhibits a medium powder hardness - Figure 13. At this level, the powder can be broken up by applying some force with hands. Compared to Figure **10**, there is a significant difference, thus providing the conclusion that the part bed heater does have an effect upon the part bed hardness within the HSS test rig.

Figure 14 and 15 illustrate further the effect of exposing the already medium level powder hardness to IR radiation from the lamp. In these two experiments, the tile was solid and could only be broken up using a scalpel or shot blaster.

Experimental Conclusions

The experiments have shown that the additional thermal energy delivered to the bed by the IR lamp, results in an increased hardness of the powder. As the power of the IR lamp increases, the hardness of the bed also increases. However, the bed hardness is also influenced by the power of the main part bed heater. This illustrates the necessity to balance the power of part bed heater and IR lamp to enable easy powder removal. To understand the problem further, the following studies are planned:

1. Investigation to determine what kind of sintering is occurring to the excess powder within the main part bed i.e. solid state sintering or viscous sintering.
2. Measurement of the amount of thermal energy emitted from the IR lamp at power levels 0–10.
3. Calibration and measurement of the amount of thermal energy emitted from the part bed heater.
4. Measurement of the absorbency of Nylon 12 at a range of IR wavelengths.

References

1. Hopkinson, N. and Dickens, P.M. (2001), “Rapid prototyping for direct manufacture”, Rapid Prototyping Journal, Vol 7 No.4, pp.197-202.
2. Hopkinson, N. and Dickens, P.M. (2003), “Analysis of Rapid Manufacturing - Using Layer Manufacturing Processes for Production”, Proceedings of the Institute of Mechanical Engineers (Part C), Journal of Mechanical Engineering Science, Vol 217, Number C1, pp31-39.
3. Wohlers, T. (2006), “Wohlers report 2006”, Colorado: Wohler Associates, Inc.
4. Speedpart Technology (2006). <http://www.speedpart.se/index.html>, [accessed 11/06/06].
5. Desktop Factory (2006) http://www.desktopfactory.com/ [accessed 18/07/06].
6. Asiabanpour, B., Palmer, K. and Khoshnevis, B. (2004), “An experimental study of surface quality and dimensional accuracy for selective inhibition of sintering”, Rapid Prototyping Journal, Vol 10 No.3, pp.181-192.
7. Khoshnevis, B., Asiabanpour, B., Mojdeh, M. and Palmer, K. (2003), “SIS- a new SFF method based on powder sintering”, Rapid Prototyping Journal, Vol 9 No.1, pp.30-36.
8. Kumar, A.V. and Dutta, A. (2003), “Investigation of an electrophotography based rapid prototyping technology”, Rapid Prototyping Journal, Vol 9 No.2, pp.95-103.
9. Kumar, A.V. and Zhang, H. (1999), “Electrophotographic powder deposition for freeform fabrication”, 10th Solid Freeform Fabrication Proceedings, pp.639-646.
10. Hopkinson, N., and Erasenthiren, P.E. (2004), “High Speed Sintering - Early Research into a New Rapid Manufacturing Process”, Proceedings from the 15th SFF Symposium, Austin, Texas, August 2-4, pp 312-320, ISSN 1053-2153.