High Speed Sintering – Early Research into a New Rapid Manufacturing Process

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Abstract

Rapid Manufacturing (the production of end use products by layer manufacturing techniques) has grown significantly in recent years and has started to revolutionise some areas of manufacturing. Among the main drawbacks for commercially available techniques are machine cost and build speed. This paper describes some initial research into a new process called High Speed Sintering.

The High Speed Sintering process (UK patent No. 0317387.9) involves the sintering of 2D profiles of layers of powder without the need for a laser. Experiments performed on a simple lab apparatus have shown how the addition of carbon black to standard nylon powder can increase the rate of sintering such that an entire layer may be sintered in 5 seconds using an infra-red lamp. The effects of composition of carbon black on material properties are shown and may be traded off against build speed. Thermal control of the process is vital and the effects of altering the position and power used with an infra-red lamp are presented.

Eliminating a laser reduces machine cost and build time, combining these factors will make the High Speed Sintering process suitable for high volume manufacture. Cost predictions show that the process will be viable for the manufacture of standard products in volumes over 100,000.

Background

A previous study by the Rapid Manufacturing Research Group (then at De Montfort University, UK) in 2000 into the economics of using RP machines for medium to high volume manufacture suggested that selective laser sintering (SLS) machines may be used to produce small components in volumes up to 14,000 more economically than injection moulding (1,2). Since that time SLS has evolved as the most suitable process for Rapid Manufacture (RM) among the current range of available technologies and is used to manufacture products as diverse as bespoke hearing aids, aircraft ducts and parts for formula 1 racing cars (3). Despite these successes, SLS has not been used for medium to high volume series production (hearing aids are produced in high volumes but each one is bespoke so this does not constitute high volume *series* production). The economic study in 2000 indicated that one of the major sources of cost for parts made in series production on SLS machines was machine cost. Machine cost for parts is dictated by the cost of the equipment required for manufacture and the speed of production achieved. Thus by reducing the cost of a layer manufacturing machine and increasing its throughput, a far more competitive process, suitable for medium to high volume series production may be achieved.

The most obvious way to reduce the cost and increase the speed of an SLS machine is to eliminate the requirement for a laser. Eliminating the laser requires an alternative method for selectively sintering powder. The High Speed Sintering (HSS) process works by varying the absorbance of incoming radiant energy such that selected areas of the surface absorb sufficient energy to elevate the temperature to the melt point while other areas, that absorb less energy, do not exceed the melt point (see Figure 1).

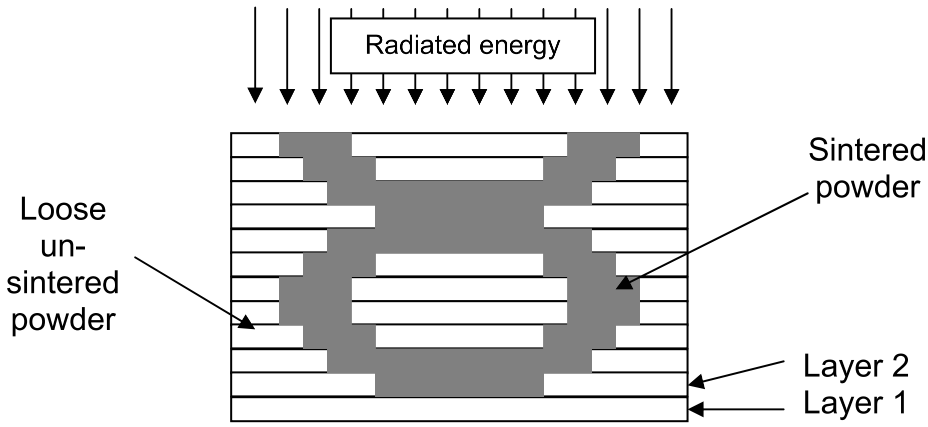

Figure 1. Cross sectional view of the High Speed Sintering Process

There are a number of methods that will allow selected sections of the surface of the build bed to absorb more radiation than other areas including:

1. Using a part powder that absorbs energy more readily than the support powder
2. The addition of a secondary material to promote energy absorbance in the required areas
3. Using a mask to restrict incoming energy to selected areas of the surface

The work reported here involved the addition of different amounts of carbon black to nylon powder (as suggested in approach 2 above) but also used a mask to selectively sinter the shapes required (as suggested in approach 3 above). The use of a mask as suggested in approach 3 is effectively the method used in the selective mask sintering process that is being developed by Speedpart (4). Rather than using a mask it would be possible to deposit the secondary material as suggested in approach 2, for example by using conventional jetting techniques. Printing of a secondary material is an attractive option as it is a widely used technology that is capable of achieving resolutions tighter than those of current SLS. However in this initial experimental work the secondary material was simply pre-mixed with nylon powder and masks employed to achieve selective sintering

Experimental Method

Powder mixing was performed using Duraform Nylon 12 powder along with carbon black MONARCH® 800 by first weighing the powder and then mixing with 10 KG PA material by rolling the tub for 2 hours. Figure 2 shows a simple bench top apparatus that was used to sinter various combinations of nylon/carbon black powder using a 2KW short wave infra-red lamp.

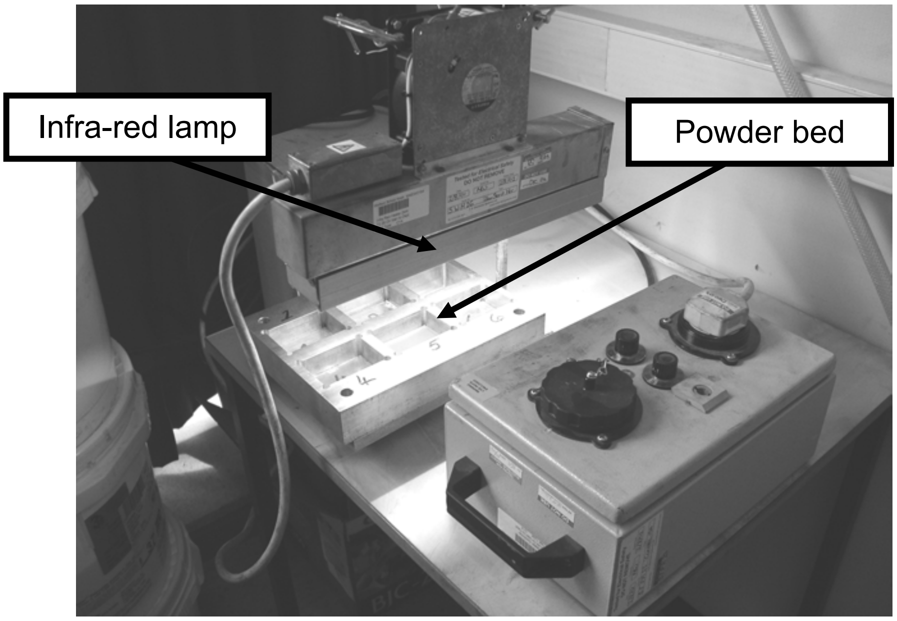

Figure 2. Bench top High Speed Sintering apparatus

Prior to performing sintering experiments a thermal imaging camera was used to observe the temperature variations across a small exposed layer of powder. Having established a reasonably even temperature distribution across the powder surface, experiments were performed to investigate the time required to sinter different combinations of powder from room temperature. Along with the sintering rate, observations of shrinkage rate and powder transfer during sintering were made. The bench top apparatus had no method for pre-heating, this resulted in warpage of samples and made the build up of multi-layer components very difficult. In order to overcome this, a Vanguard SLS machine from 3D Systems was modified so that sintering via the infra-red lamp could be achieved in more conventionally pre-heated SLS conditions. Figure 3 shows the modified Vanguard machine with the infra-red lamp secured to the roller mechanism. The modified SLS machine allowed for the production of multi-layered parts in a variety of powder compositions.

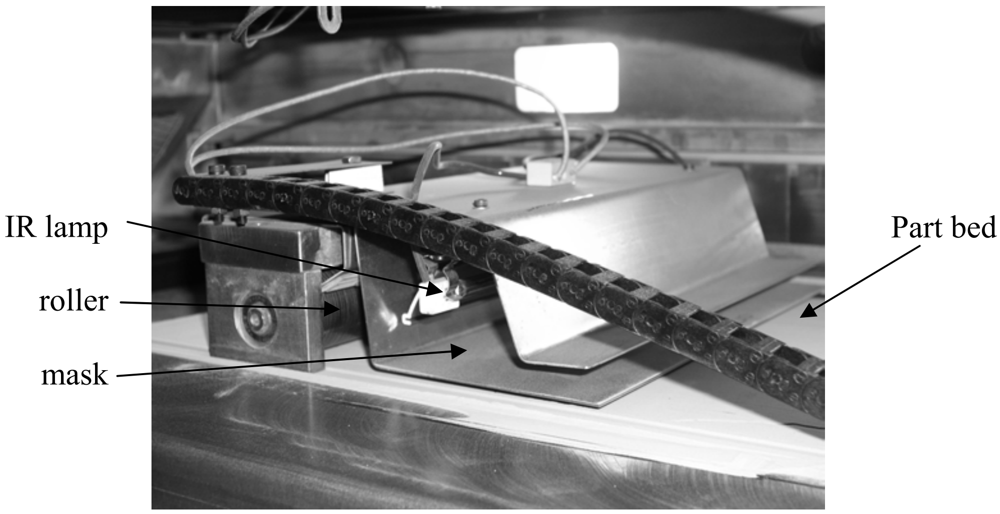

Figure 3. Infra-red lamp and mask mounted to the roller mechanism on an SLS machine

One problem with the SLS machine was the repeatability of the position of the roller mechanism and hence mask on subsequent layers. Figure 4 shows the result of this lack of repeatability in positioning between layers.

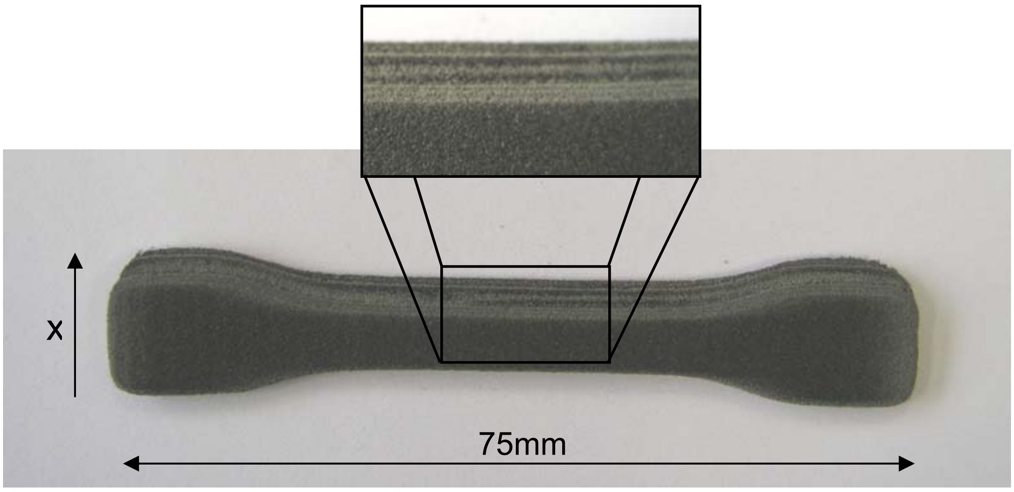

Figure 4. Tensile test piece created on the Vanguard SLS machine using a mask with a tensile test shape

Rather than creating a mask in the shape of a tensile test specimen, a series of rectangular slabs of the required height were built and these were then cut using a CNC milling machine to create tensile test specimens that conform to BS EN ISO 527-2:1996. All samples were cut with a smooth finish to avoid any surface cracks that may invalidate tensile test results. Figure 5a shows a rectangular slab comprising 20 x 0.1mm layers of nylon powder with added carbon black. Figure 5b shows a tensile test piece cut by CNC from a rectangular slab shown in Figure 5a.

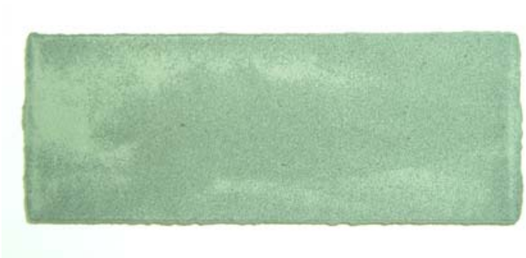

Figure 5a. Rectangular slab from the SLS Vanguard machine

Figure 5b. Tensile test piece machined from a rectangular slab.

Parts made on the initial desk top system were subject to SEM analysis in order to view the nature of sintering and porosity in sintered samples.

Results

Figure 6 shows the temperature gradient across the surface of a small (70mm x 50mm) powder bed used in the initial tests for desk top sintering. Figure 6a shows the temperature gradient when the IR lamp was suspended 40mm above the bed surface. Figure 6b shows a considerable improvement in the temperature gradient achieved when the IR lamp was suspended at a height of 70mm above the bed surface.

Figure 6a. IR lamp 40mm above surface

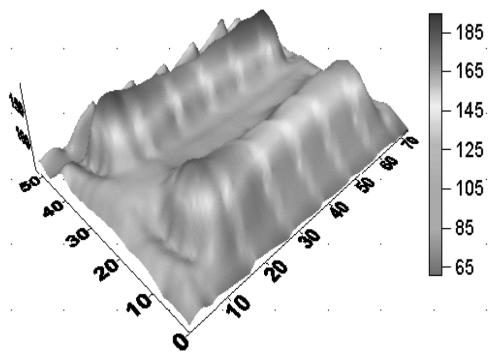

Figure 6b. IR lamp 70mm above surface

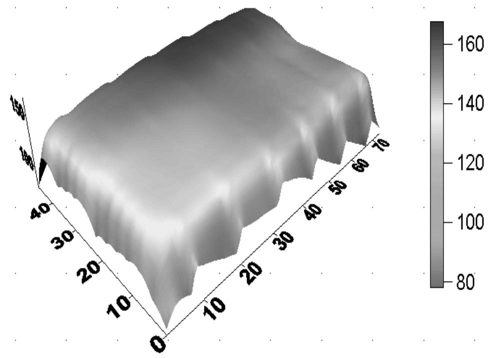

Figure 6. Temperature variation across the powder bed surface for desktop sintering

Figure 7 shows the effects of percentage composition of carbon black (by weight) mixed with nylon powder on the time required to sinter powder. As expected carbon black absorbs infra-red energy at a higher rate than nylon and heats up more quickly than nylon. It is suspected that the particles of carbon black heat up and transfer thermal energy to surrounding particles of nylon by conduction and radiation thus causing the nylon to reach its melt temperature and sinter. Figure 7 also shows that increasing the intensity of infra-red radiation increases the rate of sintering.

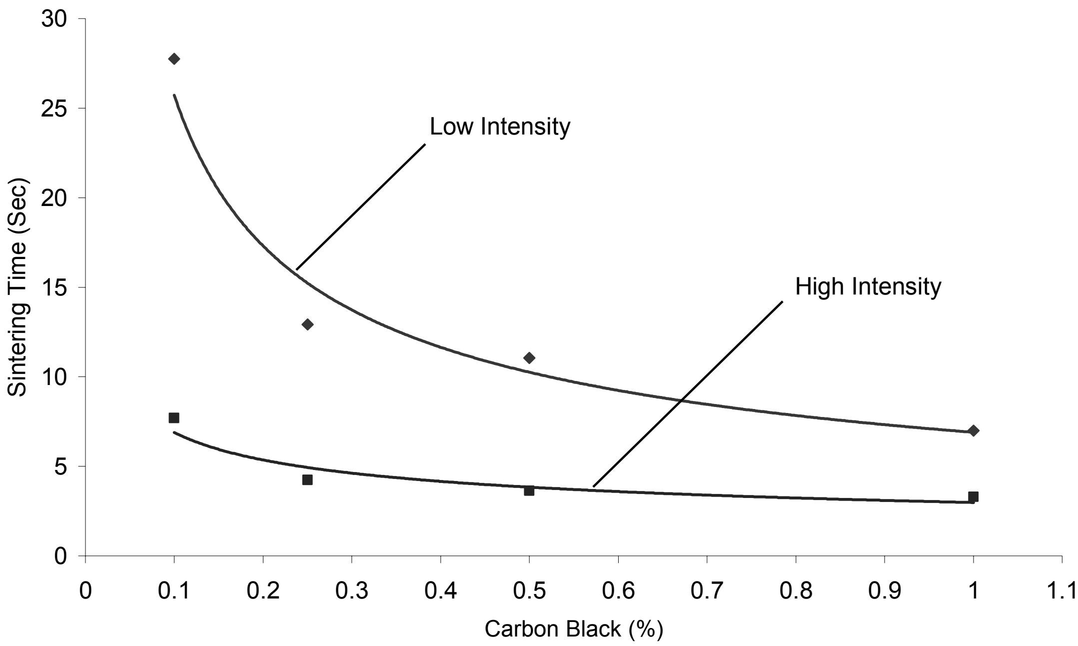

Figure 7. Effects of carbon black and radiation intensity on sintering time for nylon

Figure 8 shows the degree of shrinkage caused during sintering through a square mask measuring 20mmx20mm. The size of the sintered material inside the unmasked area is ~16mmx16mm representing a significant linear shrinkage of ~20%.

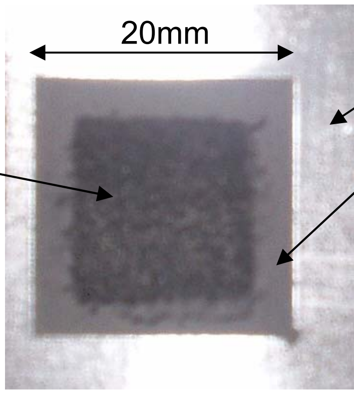

Figure 8. Shrinkage caused during sintering through a mask

Table 1 shows results from tensile tests of parts tested according to BS EN ISO 527-2:1996. The results show that parts created by HSS using carbon black have superior tensile properties to conventionally sintered SLS parts. Of particular note is the increase in elongation to break of HSS parts as this property represents a fallibility for SLS in some end use applications.

Process	Composition of carbon black (% by weight)	Young's 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

* details obtained from www.3dsystems.com

Table 1. Effects of carbon black on mechanical properties of parts made by HSS

Figure 9 shows SEM images from the surface of single layer parts produced on the desktop sintering system with magnifications of 50x (a) and 250x (b). The images show a high degree of necking between nylon particles suggesting that good mechanical performance should be achieved (this is consistent with the tensile test results presented in Table 1). To date no similar images for parts created on the Vanguard machine under pre-heated conditions have been taken. It is possible that the parts produced on the Vanguard machines have a higher degree of necking due to pre-heating. The images in Figure 9 show small light coloured particles, it s not clear yet if these are carbon particles (D50 ~ 2μm) that are present on the surface of the larger nylon particles (D50 ~ 60 μm), EDX analysis will be required to establish this.

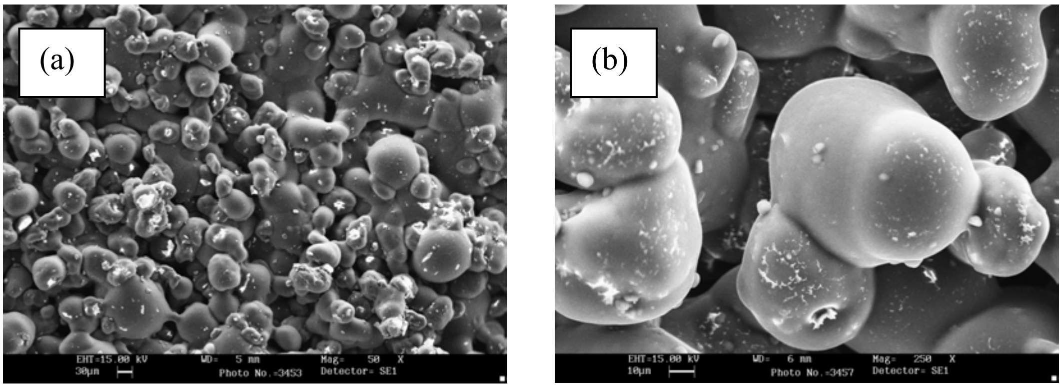

Figure 9. SEM images of sintered parts

Potential for high volume manufacture

In order to compare machine costs per part for HSS with those for SLS, the results from a previous study (1,2) have been used. Figure 10 shows a plan view of how a series of the parts used in the previous study could be oriented on a platform the same size as that used in the previous study (EOSP360), this is a layer of 70 parts.

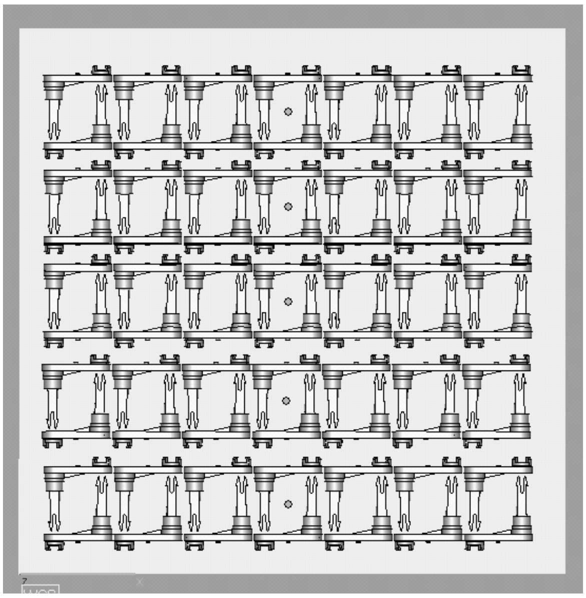

Figure 10. Plan view of layout of 70 parts on a build bed

Each part in Figure 10 has a height of 12mm (=120 slices) so an allowance of 150 slices for each layer of parts is assumed. In order to build 1050 parts, 15 layers of parts would be required with a total of 150x15 = 2250 slices. Figure 7 shows that sintering of a complete layer can be completed in 5 seconds, so allowing time for powder deposition (5 seconds), pre-heating (5 seconds) and depositing a radiation absorbing material (15 seconds) then a total time per slice of 30 seconds may be assumed. This results in a total build time of 1125 minutes (18.75 hours) to build 1050 parts. Table 2 shows the details from the previous cost analysis along with assumed data for an HSS machine with calculated machine costs to produce parts shown in Figure 10. This indicates a saving of an order of magnitude (from 0.52 to 0.05 euros) in terms of the machine costs to produce parts by HSS in place of SLS.

	SLS details from previous cost analysis	Assumed details for HSS machine
Machine cost (euro)	340,000	100,000
Depreciation	8 year straight line	8 year straight line
Machine depreciation cost/year (euro)	72,950	12,500
Maintenance cost/year (euro)	30,450	10,000
Machine cost per year (euro)	72950	22,500
Parts in build	1056	1050
Time to complete build (hours)	59.78	18.75
Production rate per hour	17.66	56
Machine utilisation (%)	90	90
Hours per year in use	7884	7884
Parts per year	139,269	441,504
Machine cost per part (euros)	0.52	0.05

Table 2. Machine costs from previous analysis with SLS and potential using HSS

Discussion

The cost analysis shown in Table 2 assumes that HSS will use a build platform with similar dimensions to a current SLS machine (EOSP360). However, for higher volume production, platforms with a larger area will be able to increase throughput significantly and hence reduce machine costs further.

The use of a secondary radiation absorbing material (in this case carbon black) is likely to add some cost to materials when compared with SLS. However increased use of powder materials for layer wise sintering processes are likely to bring down costs by economies of scale.

The figures for SLS shown in Table 2 suggested that SLS may be used to manufacture products in volumes up to 14,000 at a lower cost than by injection moulding (1,2). The figures for HSS in Table 2 suggest that this process should be economically viable for series manufacturing volume significantly greater than 14,000. Furthermore the results from the tensile tests suggest that parts made by HSS should have sufficient mechanical properties for a wide range of applications.

It should be stressed that in addition to the HSS process described in this paper there are other processes such as Speedpart (4), Selective Inhibition Sintering (5) and Electrophotographic Layer Manufacturing (6) that employ the concept of processing entire layers of powdered material simultaneously rather than by a scanning laser. All of these processes, and others using similar concepts will be likely to achieve significant reductions in machine cost, build time and machine cost per part when compared with SLS.

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