High Speed Sintering: The influence of print density on feature resolution and accuracy

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Abstract

High Speed Sintering is a novel additive manufacturing technology which uses an InkJet printhead and infra-red radiation. The printhead deposits a radiation absorbing material directly onto a powder bed, the entire bed is then irradiated by an infra-red lamp. Areas printed with radiation absorbing material will absorb sufficient energy to sinter, whereas areas without will not. Another layer of powder is deposited and the process repeats until the part is complete. To date, a large proportion of research has used the maximum print density possible, very little research has focused on how altering print density influences the minimum feature size and dimensional accuracy. As such this research was designed to investigate how print density influences feature resolution, accuracy and powder removability. Results showed improved powder removal and feature resolution can be achieved using a print that is not fully dense. However, beyond a certain point the print density becomes too low and the parts fail. Thus it is imperative that the correct balance is struck if parts are to be manufactured successfully and possess improved accuracy and feature resolution.

Introduction

High Speed Sintering (HSS) is a layer by layer manufacturing technique developing in the area of additive manufacturing (AM).[1] AM is a growing manufacturing technology, initially limited to use for rapid prototyping (RP) and tooling, HSS is now being developed for a range of industries, such as the automotive, aerospace and medical, as well as many other smaller sectors.[2]

The growth of Additive Manufacturing from rapid prototyping requires parts with specific dimensions and feature resolution to fulfil the increasing demands placed on the technology.[3] HSS has been designed to improve upon the negative aspects of similar AM processes, such as Laser Sintering (LS), especially with respect to build times and machine costs.[4] An improved understanding of the HSS process through assessment of parts design freedom and feature resolution will further enhance its commercial potential.

Print Density

To investigate the influence of print density, two approaches are viable, grey scale images or dithered patterns. Grey scale offers complete coverage of the desired area with the level of grey scale determined by the volume of the droplet ejected from the printhead. A dithered pattern, however, is a matrix of printed dots and does not cover the entire area, in this case the print density is determined by the density of the dots (**Figure 1**).

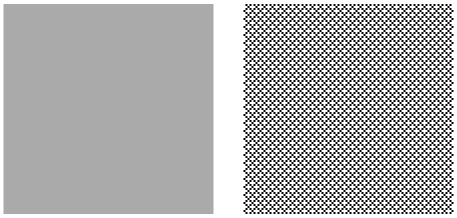

Figure 1: Grey scale (left) vs. dithering (right)

The printhead in the current HSS machine is not capable of printing variable droplet volumes and is therefore not capable of printing a grey scale image. Being 1-bit, the printhead is binary, either a droplet is printed or it is not, therefore, using a dithered pattern was used to affect print density. Dithering converts 8-bit greyscale images to 1-bit monochrome images, where the various levels of grey in an 8-bit image are approximated via various densities of black dots in a 1-bit image.[5] Thus, a change in greyscale level in an 8-bit image corresponds to a change in dot density in a 1-bit image. The 8-bit scale ranges from black at 0 to white at 255, therefore, the approach here was to first manipulate the grey scale using a value within this range. These grey scale images were then converted into a dithered pattern using ImageJ, an open source java based image processing software. As the dithering process is based on an algorithm, many exist which exist which all lead to slightly different patterns. In this case the chosen dithering was Bayer 4x4 as this gave the most even distribution of pixels. To enable the effect of print density on feature resolution and accuracy the test specimen was manufactured using different print densities across the range from 28-227.

As the print density corresponds to the amount of radiation absorbing material deposited on the surface, it was anticipated that as the print density increased this would lead to an increased amount of energy absorbed and thus influence accuracy and feature resolution. As Nylon 12 is the current standard material for HSS, this was the chosen material with which to perform the experimental builds.

Experimental Design

Feature resolution is the smallest dimension a system is capable of reproducing. Stereolithography can typically produce a minimum thickness of 250µm, and for Laser Sintering (LS) ~150µm. As HSS is novel technology it is vital to determine the finest features which can be reliably reproduced and remain undamaged when unsintered powder is removed. As such, a test specimen was designed to probe the ability of HSS to produce fine features that survive the bead blasting post-process procedure to remove unsintered powder and to investigate powder removability and dimensional accuracy.

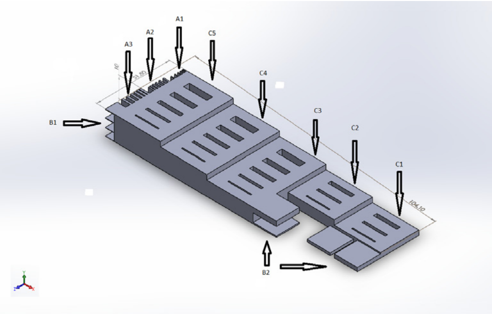

Figure 2: CAD rendering of the test sample

The test specimen is labelled into two different groups, Group A to test powder removability and whether fine features survive the bead blast process and group B to test dimensional accuracy. **Figure 3** shows Group A, the features provide five different gap thicknesses to test powder removability. Each block compared has the same gap sizes with a range of 0.25-1.25mm. The depths for the gaps of blocks 1, 2 and 3 vary (in the x-axis) and are 1.5, 2.5 and 3.75mm respectively.

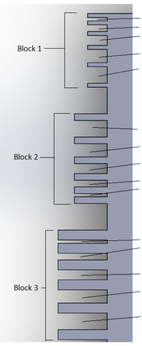

Figure 3: Negative features in the test specimen

Figure 4 shows Group B, which consists of two blocks of four spaced out features. The features in block 1 increase in size from 100µm to a thickness of 250µm, which is the minimum printable thickness for an individual layer on the HSS machine. This therefore tests the feature resolution capabilities for different greyscales. The features in Block 2 have slightly thicker features ranging between 0.5 and 2mm.

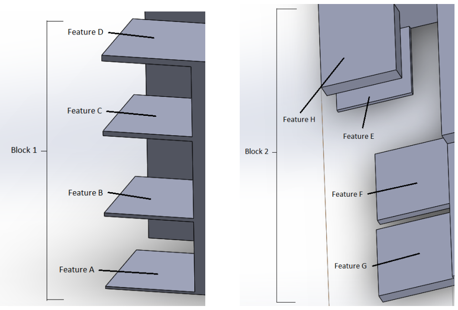

Figure 4: Close up of Group B Block 1(left) & close up of Group B Block 2 (right)

Results and Discussion

Group A: Powder Removal

Figure 5 shows the amount of trapped powder in Group A Block 1 for each greyscale. It is clear that powder removability was affected by print density. It was not possible to remove powder from the smallest gap (0.25mm) on any of the parts, regardless of print density. For a fully dense print, half of the power was removable from Gap A. However, as the print density decreased the powder removability increased until greyscale 142 at which the powder removability reduced back to 50%. At lower print densities than 142 the specimen was damaged by the bead blasting process. Gaps B to E shows a clear trend for a decrease in trapped powder, as the gap sizes increase.

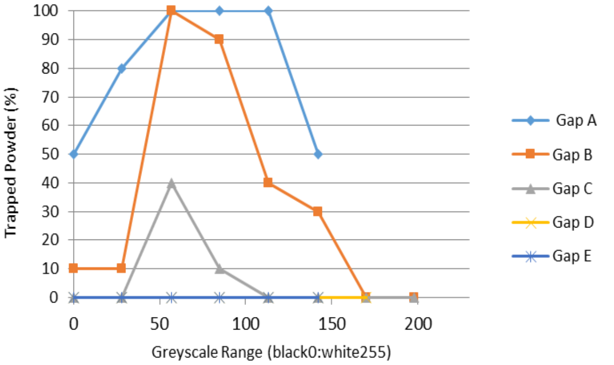

Figure 5: Effect of greyscale against % of trapped powder in Group A Block 1

There are noticeable high peaks in the results for G/S 57 at all the gaps. The narrowest gap from which all powder was able to be removed at all print densities was Gap D, 1mm.

Figure 6 shows the amount of trapped powder in Group A Block 2. The increase in height of the features from 1.5mm to 2mm between block 1 and 2 resulted in more features with less degradation, surviving the post processing stage. The smallest gap A shows similar difficulties to block 1, with the lowest level of trapped powder being 70% at G/S 198.

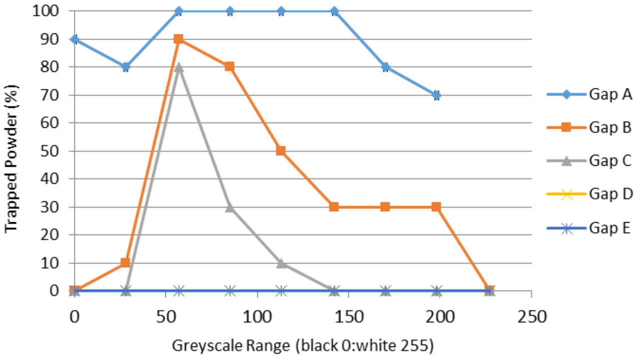

Figure 6: Effect of greyscale against % of trapped powder in Group A Block 2

Figure 7 shows the variations in the amount of trapped powder in Group A Block 3.

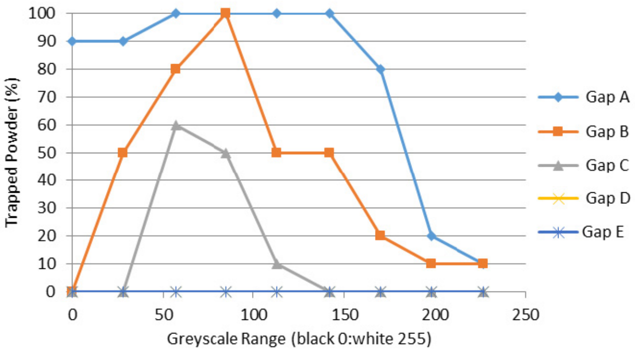

Figure 7: Effect of greyscale against % of trapped powder in Group A Block 3

Out of the three blocks in group A, block 3 is the only one where all the features creating the gaps survived the post processing stage for print densities, including G/S 227 which can be seen in **Figure 8**.

This shows that the depth of 3.75mm for block 3 is sufficient to allow powder removability, whilst as the same time preventing degradation with the geometry of the part. As shown by the results for gaps D and E, the width for a gap size still needs to be a minimum of 1mm to successfully ensure there is no trapped powder remaining.

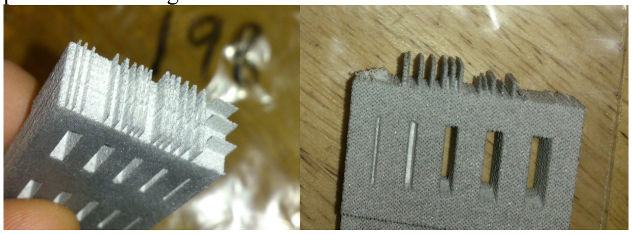

Figure 8: G/S 227 after bead blasting (left) & G/S 198 after bead blasting

The results for different blocks in group A show a similar trend with respect to powder removability. When comparing gaps of identical width but varying depths it would appear that the influence of different G/S for each test specimen, resulted in greater variations of trapped powder, when compared to the effect of varying the depths of the gaps.

Group B: Dimensional Accuracy

Figure 9 shows the measurements for the features in group B Block 1. The smallest features in the highest greyscale, 227, and therefore lowest print density did not survive the bead lasting process. G/S 198 has similar problems with the smallest 100 micron thick feature, which also failed. This shows that print density is indeed a factor in dictating the minimum possible features.

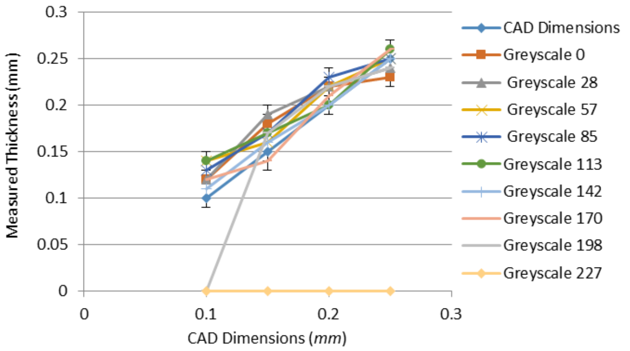

Figure 9: Comparing measured feature thickness against CAD dimensions for Group B Block 1

It is clear that for G/S 0, depositing full black ink does not necessarily result in a more accurate feature resolution, as G/S 142 is the closest in the range for the features, with respect to the original CAD dimensions.

The majority of the measurements taken, were slightly larger than the CAD geometry. Since this is occurring in the z-axis it cannot be attributed to liquid ink displacement, which normally occurs along the x-y plane. Instead this is most likely a result of excess powder on the surfaces not being completely removed, due to the limited time the bead blaster could be held over these more fragile areas. Since the un-sintered powder surrounding the manufactured parts acted as a support for the tiny features, when removed the result was the exposed features could easily be deflected by the air pressure of the nozzle.

Figure 10 shows the measurements for the features in group B Block 2.

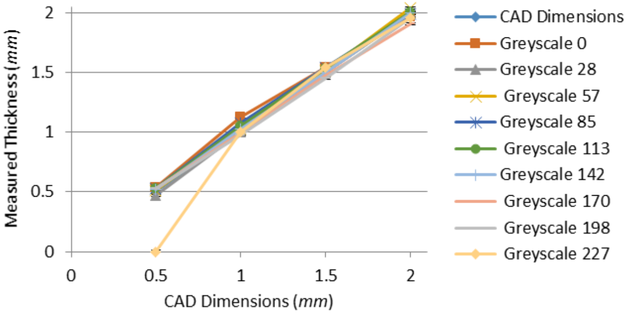

Figure 10: Comparing measured feature thickness against CAD dimensions for Group B Block 2

This shows that print density does influence the minimum feature size, with G/S 227 being unable to produce a feature 0.5mm thick. Subsequently the variation in G/S did not result in large fluctuations in accuracy. Although the data appears more varied for block 1, this is an artefact of how small the measurements are, since on average, the largest variation in measurements between G/S for successful features, is very small at around 50 microns.

Conclusions

A reduction of print density proved to have equal powder removability compared to full density, whilst displaying improved minimum feature resolution.

Reducing the print density too much, however, resulted in poor feature resolution as insufficient energy was absorbed to sinter the material. The results showed that Greyscale 142 possessed the best trade off with equal powder removability, compared to the full print density, whilst displaying improved signs of accuracy with respect to the minimum feature resolution.

This work has shown that print density does indeed influence accuracy and feature resolution and that the print density may be tailored to suit the requirement of the part being manufactured.

Further work should investigate the use of variable print density within in a single part which may offer the ability to produce both fine features and easy powder removal.

References

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Author Biography

Adam Ellis received his Masters (2007) and PhD in Chemistry (2011) from the University of Sheffield. He was then an independent research fellow before moving to the Department of Mechanical Engineering to join the Centre for Advanced Additive Manufacturing at the University of Sheffield in 2012.