Speed and Accuracy of High Speed Sintering

Adam Ellis, Antonis Hadjiforados, Neil Hopkinson; The University of Sheffield, Sheffield UK. & Ingo Reinhold; Xaar, Järfälla, Sweden

Abstract

High Speed Sintering is a novel powder based additive manufacturing process that retains the major benefits of Laser Sintering but eliminates some major drawbacks. The process uses inkjet print head and infrared lamps to fabricate parts layer by layer using polymer powder.

The purpose of this research was to evaluate the speed and accuracy of High Speed Sintering by closely following a method published in the research paper of Rapid Prototyping Journal, entitled 'Speed and Accuracy Evaluation of Additive Manufacturing Machines'. This methodology involves the manufacturing of test parts defined in the paper analysis using the method provided, speed and accuracy of High Speed Sintering is assessed and then benchmarked against four other Additive Manufacturing processes.

Based on a theoretical speed evaluation, results show that High Speed Sintering is able to achieved superior average manufacturing speed than the other specified Additive Manufacturing technologies.

Introduction

Additive manufacturing (AM), is defined by the Standard Terminology for AM Technologies as the process of joining materials to make objects from three-dimensional (3D) model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies such as machining.[1] Advantages include geometrical freedom, elimination of tooling, body fitting customisation, part consolidation and shorter lead time. However, extensive adaptation of AM is inhibited due to the current deficiencies and limitations of the process in accuracy, production speed, surface finish, material properties and the initial high cost of AM machines.

A diverse range of AM processes haven been developed and are commercially available, such as Laser Sintering (LS), Stereolithography (SL), Fused Deposition Modelling (FDM), Polyjet and many more. To develop AM as a future core technology as described by Roland Berger Strategy Consultants, cycle time, cost of material and equipment relevant to AM must be comparable with conventional manufacturing processes such as injection moulding and CNC machines.[2]

High Speed Sintering

High Speed Sintering (HSS) is an emerging additive manufacturing technology aiming to address the above issues and provide an AM technology capable of high volume manufacture[3]. The process is similar to LS; however instead of using a laser, a Radiation Absorbing Material (RAM) is printed directly on to the powder surface defining the parts geometry, using an inkjet print head. Then an Infrared (IR) lamp passes over the entire build area. The printed areas are then selectively sintered as these areas absorb significantly more IR energy than unprinted areas. This energy transfer is sufficient to cause the underlying powder to sinter.

Early research on the process from Hopkinson and Erasenthiran suggests that HSS is suitable for high volume manufacturing. This is achieved by retaining the major benefits of AM technologies such as part complexity and elimination of tooling as for Injection Molding.

The purpose of this study is to investigate the speed and accuracy of HSS, aimed to allow genuine conclusions to be drawn about those two principal parameters and compare with other AM processes.

Speed and Accuracy in Additive Manufacturing

During the last decade, an ever increasing number of AM technologies have seen a wide range of applications. However, implementation of AM in industries likes aerospace, automotive, medical and consumer products needs to be facilitated through speed and accuracy evaluations to meet required standards and economics.

Potential stakeholders need to have access to accurate data about the machine's manufacturing speed and accuracy capabilities beyond subjective information offered by machine manufacturers[4]. This is not only necessary for the adaptation of AM but also in order to aid the necessary choice between the wide ranges of AM processes.

The choice of speed and accuracy evaluation method chosen for this study is mainly based on the availability of data for comparison purposes with HSS. Brajlih et al. presented a general method for speed and accuracy evaluation of AM machines, providing an objective comparison among a variety of AM machines, shown in Table 1.[4]

Table 1: Overview of tested AM machines by Brajlih *et al*.

Machine	AM Technology	Manufacturer
EDEN 330	Polyjet	Object Geometries
SLA 3500	Stereolithograph y	3D Systems
EOSINT P385	Laser Sintering	EOS
Prodigy Plus	Fused Deposition Modelling	Stratasys

This work concluded that EOSINT P385 machine, a laser sintering AM technology, achieves the highest average manufacturing speed among the four processes listed in table 2.1. However, when considering the manufacturing accuracy of the parts produced with the above four technologies, dimensional deviations were found to be similar in all the machines except Prodigy Plus, which had greater deviations.

Methodology

For establishing the range of achievable speed, an experiment was designed to evaluate the influence of the two influential factors on HSS manufacturing speed. The experiment is based on a 2k factorial design principle, where the test is performed at a combination of low and high levels of influential factors. This Design of Experiment method is described by F. Dunn, as a method of repeated trials to permit estimation of the effects due to the influence of the variables.[5]

Firstly, the variation in volume ratio is established by altering the test's part wall thickness and establishing two test parts with volume ratio of 0.25 (low level) and 0.69 (high level) as seen in Figure 1.

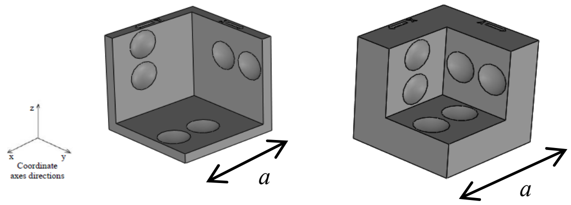


Figure 1: Test parts used for the speed and accuracy evaluation of HSS. Left represents part with low volume ratio and right part with high volume ratio.

The part length is to be 30 mm (dimension *a*), therefore the wall thickness for test part 0.25 is going to be 3 mm and for part 0.69 is going to be 10 mm.

The tray ratio is going to be simulated by placing sufficient number of test parts on the machine's tray in a way to influence the tray ratio from 0.1 to 0.9.

Besides controlling the range of volume and tray ratios, parts are staggered on each other to represent test parts shown in Figure 2. Such setup would allow for checking the prediction that the part's z-height does not significantly influences the average manufacturing speed. This is because parts shown in figure 4.2 have the same volume and tray ratio and are expected by definition to have the same average manufacturing speed despite their z-height (30 mm, 60 mm and 90 mm).

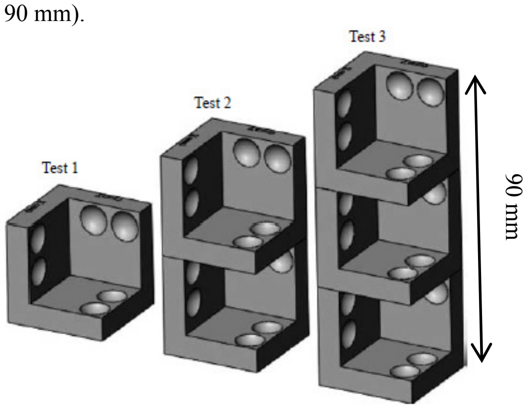


Figure 2: Test part's assembly for experiment repetition and average manufacturing speed.

Therefore the experimental setup were be made of 12 different build tray setups. These enabled the development of a regression model where average manufacturing speed will be evaluated along the range of the two influential factors and thus experimental repetitions are minimized to 12 tray setups.

HSS presents the ability to estimate the build time relatively quickly and easy without performing the experiments and therefore calculate the manufacturing speed. This is because for HSS the built time per layer is constant, irrespective of the part size, shape and amount of the 2D profile printed with RAM material[6].

Acknowledging this comparative advantage, theoretical speed evaluation is carried based on two different bed sizes by making the assumptions stated in table 2:

Table 2: Assumptions made for average manufacturing speed calculations.

	HSS 1	HSS 2
Build Bed Size (mm)	300 x 300 x 300	1000 x 1000 x 1000
Layer Time (seconds)	10	15

Accuracy evaluation will be based on the manufacture of eight parts (four for each volume ratio) in two separate builds, followed by accuracy measurements using a coordinate measuring machine.

Results and Discussion

For comparison purposes, HSS results are plotted against the findings of the study by Brajlih et al. [4]in Figures 3 and 4 to compare the average manufacturing speed for two constant volume ratios against variable tray ratios.

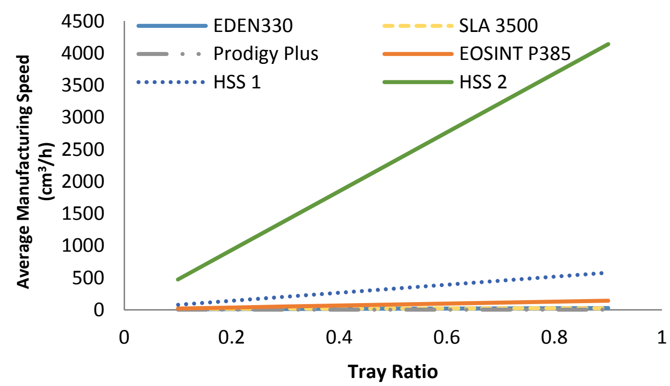


Figure 3: Average manufacturing speed comparison at constant volume ratio of 0.20 and variable tray ratio.

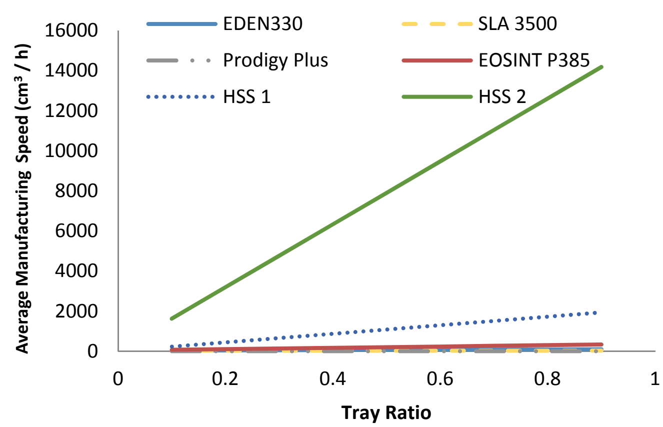


Figure 4: Average manufacturing speed comparison at constant volume ratio of 0.70 and variable tray ratio.

Both HSS build volumes are able to achieve much higher average manufacturing speeds than the rest of the processes, regardless of the ratio value. The effect of tray ratio on the average manufacturing speed is much greater for HSS than the rest of the machines, noticed by the gradient of the line. This is due to the fact that processing time is constant irrespective of the number of parts in each layer. Therefore by increasing the number of parts in the build tray and thus increasing the Tray Ratio, more parts can be fabricated on the same time and as a consequence average manufacturing speed increases.

Based on the above results, HSS can be considered a faster process than the rest processes. Specifically, when compared to EOSINT P385, a laser sintering AM technology with similar process and tray surface.

Additionally, to demonstrate the fact that the processing time of HSS for each layer is the same irrespective of the number of parts, Figure 5 shows a head to head comparison of the manufacturing time for the twelve test tray setups in HSS 1 and LS.

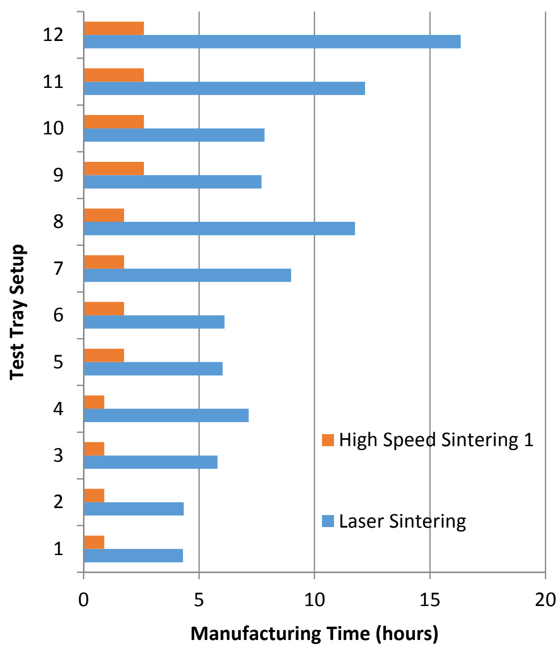
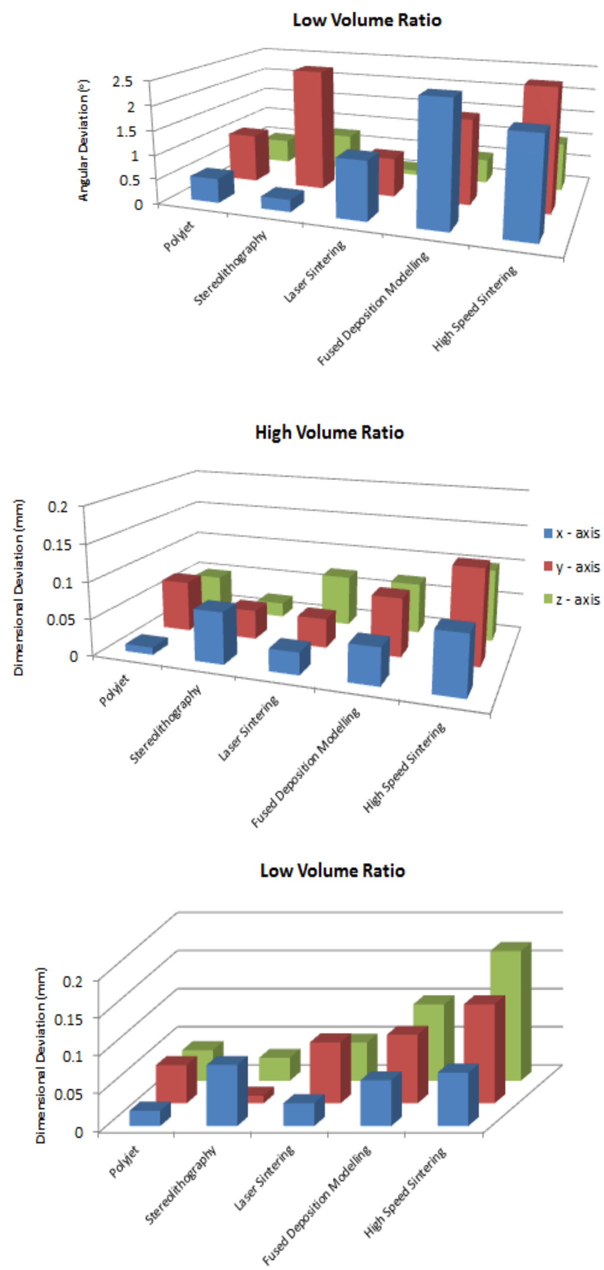


Figure 5: Manufacturing time of HSS 1 and LS for the twelve test tray setups.

From Figure 5 it can be seen that HSS has the same manufacturing time for build tray setups of the same amount of layers and thus height, irrespective of the number of test parts in each build and thus tray ratio.

Furthermore, despite HSS 1 having a smaller tray surface when compares to LS and therefore being able to process fewer parts during each build, manufacturing time for each tray setup is substantially lower. However, due to the differences in the tray surface and number of parts fabricated in each build, direct comparison of manufacturing time cannot be made.

Test results of accuracy evaluation per part were averaged to provide the dimensional and angular deviations across the five processes in terms of low and high volume ratios. These results are provided in Figure 6.



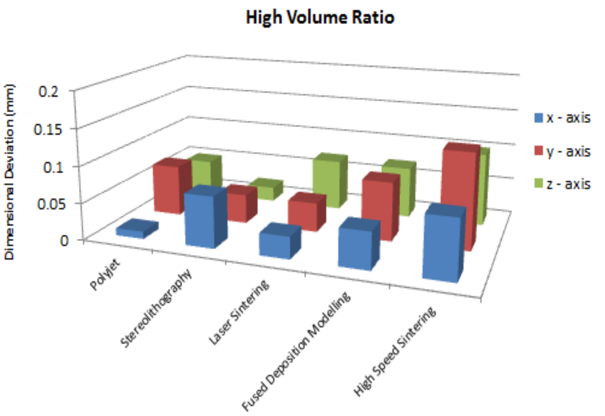


Figure 6: Averaged dimensional and angular deviations of all the processes included in the benchmarking study for low and high volume ratios.

Based on the results presented in Figure 6, bigger deviations can be seen on HSS and especially more noticeable in low volume ratio. At high volume ratio the difference in the deviations across all of the machines reduces however HSS deviations are still slightly over the rest of machines.

Conclusions

The study presented a novel method to describe the average manufacturing speed of AM processes in terms of the fabricated volume per unit of time. In this way, different processes were evaluated based on the specific job height and not on the potential system's capabilities, enabling a more objective comparison.

Benchmarking of the results place the anticipated HSS machine as the fastest AM process among the four other technologies used in the evaluation. The investigation indicates the significant difference in the average manufacturing speed range between HSS and the rest of the processes. Alongside the benchmarking, the exploration of two different HSS bed sizes showed that the process is scalable and applicable to bigger bed sizes.

Furthermore, the inclusion of the influential factors in the study enabled a more in depth understanding of HSS process, which highlighted the process advantage of constant layer time irrespective of the parts in each build. In this way, processing speed for large parts in HSS is likely to be higher than for example LS due to the fact that sintering time is completely independent of the part's cross-sectional area.

In addition, accuracy evaluation of HSS showed greater dimensional deviations in the z-axis, suggesting that predominantly greater shrinkage occurs in the z-axis and thus loss of accuracy. This is because parts, from the start of each build are subject to elevated temperatures for longer time, leading to increased molecular weight.

Consequently, addressing the aforementioned issues identified in the accuracy evaluation to meet commercial qualities and combined with the relative high speed of sintering, as the name suggests, HSS can hold the key in full-scale manufacturing. In this way HSS can be explored as full-scale manufacturing process in a diverse range of industries.

However, besides adopting a feedback control procedure to minimize temperature variations in the build bed, an effective powder management will need to be implemented. In this way, adverse effects of powder degradation will be minimized and therefore consistent powder properties will be maintained at reduced cost for a direct manufacturing process.

On a wider applicability, the results of this study in comparison to other methodologies used in the literature review to evaluate speed and accuracy in the AM industry identify the need for standardization. This is because a variety of different methodologies are currently used for different AM processes thus making the comparison among each evaluation impractical. Along these lines of standardization, assessing the speed of manufacturing in terms of the fabricated volume per unit of time can be a reasonable solution in the AM industry.

Finally, several limitations in the methodology were identified and need to be addressed in future research. To begin with, speed estimations were based on a regression model defined by a combination of 12 different experiments. However, despite the model being statistically significant, the range of average manufacturing speed cannot be tested beyond the levels of influential factors defined. Subsequently, more experiments are needed at levels close to 0 and 1 of the influential factors to ensure the complete range of average manufacturing speed is correctly covered.

Regarding the accuracy evaluation, despite the efforts to minimize the effects of roughness on the measurements, incomplete arcs were found to be inherently unstable when it comes to measurements with the CMM. This is because a small deviation in the surface of the arc can lead to a disproportionate effect on the diameter measurement. Therefore, accuracy results should be compensated with roughness measurements.

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.

References

1 ASTM, F2792 - 10e1 Standard Terminology for Additive Manufacturing Technologies. (2010).

2 Additive Manufacturing. (Roland Berger, Munich, 2013).

3 Helen R Thomas, N. H. a. P. E. High Speed Sintering - Continuing research into a new Rapid Manufacturing process. (2006).

4 Tomaz Brajlih, B. V., Joze Balic and Igor Drstvensek. Speed and accuracy evaluation of additive manufacturing machines. **17(1), pp 64-74** (2011).

5 Dunn, P. F. *Measurement and data analysis for engineering and science*. (McGraw-Hill 2005).

6 C.E. Majewski, D. O., H.R. Thomas and N. Hopkinson. Effect of infra-red power level on the sintering behaviour in the high speed sintering process. **14** (3, pp. 155-160), (2008).