EXPERIMENTAL INVESTIGATIONS AND SHAPE REALIZABILITY STUDIES IN SELECTIVE LASER SINTERING

by

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Dedicated to

My Parents and Teachers

Certificate

This is to certify that the thesis entitled **'Experimental Investigations and Shape Realizability Studies in Selective Laser Sintering'** submitted by **Senthilkumaran K** to the Indian Institute of Technology Delhi, for the award of the degree of *Doctor of Philosophy,* is a record of the original bonafide research work carried out by him under my guidance and supervision. The results contained in it have not been submitted in part or full to any other institute or university for the award of any degree/diploma.

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(K. Senthilkumaran)

Abstract

Rapid prototyping (RP) is an additive manufacturing process for low volume, high value and custom-designed parts. These parts can be made out of common engineering thermo-plastics such as polyamide, ABS, poly carbonate, polyphenylsulfone (PPSF) to metal parts such as titanium, stainless steel and tool steel. Many RP technologies which have been introduced in last twenty years have helped in reducing time to market a product, cut trial costs, and improved product quality by giving design and manufacturing professionals a tool to quickly verify and fine-tune designs before committing for expensive tooling and production. Selective Laser Sintering (SLS) is one of the commercially successful RP processes developed at University of Texas, Austin. SLS is a powder based technology in which pulverized powder particles are sintered using heat available from a scanning laser beam. After two decades of its use as a prototyping tool, SLS finds an important role as a manufacturing process for small batches of custom designed parts. Since the new found applications of SLS parts as final end use products are expanding rapidly, the demand for more accurate parts is also increasing. Present work is an attempt to investigate sources of inaccuracies in SLS parts and development of methods to achieve better part accuracy in SLS process.

The present research looks at improving both dimensional accuracies as well as geometrical accuracies in SLS process. The present study has been carried out using both computational methods and extensive experimentation. The material chosen for all studies is Polyamide 12. Most of the research and methodologies presented in the thesis is not material specific and can be applied across wide variety of materials used with SLS process.

Some of the major factors which add to inaccuracies in SLS process have been identified and methods to over come have been proposed and results of improvement have been demonstrated experimentally and in some cases through computational algorithms. Some of the part building strategies which are presently adopted by SLS users and equipment manufacturers are revisited as they add to significant errors in parts produced. These include Laser beam compensation, scanning mirror inertia compensation, scanning with & without contouring and positioning errors due to rasterization. In each case the effect of these strategies on part accuracies is studied experimentally.

Decisions made at process planning stage such as orientation of part in build volume and direction of scanning are found to have strong influence on part accuracies. The results of varying these on part accuracies are presented. It is found that one of major sources of errors in SLS parts arise due to highly simplified models used for characterization of shrinkage. Linear models of shrinkage which are presently in use do not capture shrinkage effects accurately. Nonlinear models are necessary for improving accuracy of parts and the same have been developed as a part of this work.

It is not only important to model the shrinkage accurately but it is equally important to compensate them accurately. Constant shrinkage factors along x and y directions as implemented and practiced can not improve part accuracies beyond certain precision. A scan length specific compensation scheme which works better for SLS process has been proposed presently and its effectiveness is demonstrated through computational and experimental tools. Experiments carried out with new shrinkage model as well as with new compensation scheme have shown significant improvement in the accuracy up to 55- 62 %.

Improvement of shape accuracies has been studied by two different approaches. Firstly the process parameters which affect shape accuracies have been identified and effect of the same on accuracy is studied using more scientific approach to experimentation. The results presented show that decisions regarding process parameters are crucial for realizing better geometric tolerances. It is further shown that size factors too affect shape accuracies and needs to be considered at process planning stage.

Towards the end some simple manufacturability guidelines are proposed which when followed can yield parts with improved accuracies. The proposed guidelines fall under two categories namely part design guidelines and process planning guidelines. These guidelines are found necessary as the literature and information available on SLS process is scanty. In the absence of part/process design handbooks for SLS process and also non availability of process simulation programs/software, the proposed guidelines have a value. Most of the guidelines proposed are new. Some of them though were proposed earlier by other researcher, there was no experimental and quantitative validation of the same which could be found. The same has been attempted in this work.

Overall the thesis demonstrates that by integration of computational algorithms, process control and improved process planning can lead to significant improvement in accuracy of SLS parts. The results presented in this thesis will help SLS machine manufacturers, part designers and process planners to come up with parts with improved accuracies.

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