

SUCCESS STORY

Autodesk Inventor™ CAD system software plug-in developed to automatically optimize support structures in DMLS

Optimizing Support Structure Design to Reduce Part Distortion for DMLS Components



Handle Part Case Study – Optimized part orientation and support as defined using the ATLAS software

PROBLEM

With direct metal laser sintering (DMLS), surface temperature gradients and sintering-induced shrinkage can lead to unanticipated residual stress and part distortion if there is not an efficient heat transfer conduit to remove the applied heat at desired rates.

OBJECTIVE

The goal of this project was to codify the design rules of experienced additive manufacturing (AM) design/manufacturing engineers that would automatically generate an optimal part orientation from an .stl file for DMLS. A second objective was to design optimized supports that would minimize distortion of DMLS-printed metal parts. The main focus of the project involved the application of physics-based models to predict the temperature history of a part to optimize orientation for minimal distortion.

TECHNICAL APPROACH

A survey of experienced AM design/manufacturing engineers was conducted to determine the rules used to select an optimal part orientation. These rules were then codified to automatically generate an optimal part orientation. Within the same task, a support minimization objective function and a first-principles heat transfer model for DMLS was assimilated to produce thermal mass and to predict temperature gradients to achieve a predicted minimal part distortion.

A design of experiments (DOE) study was performed to create part artifacts and to identify major factors that would affect distortion. Sixteen experiments were conducted for each of the three material types (17-4 stainless steel, 316-L stainless steel, Ti-6Al-4V) at two different temperatures for a total of ninety-six distinct experiments. The accuracy of the results from the survey was confirmed by characterizing part artifacts from the DOE study and comparing them to the predictions of distortion from the models. Synthesized design rules and empirical insight were codified, developing a software system (ATLAS) that generates optimal orientations with associated support locations to minimize distortion in DMLS printed parts.



**AMERICA MAKES
TECHNOLOGY
DEVELOPMENT
ROADMAP**

This project aligns to:



DESIGN

**ASTM
PROCESS CATEGORY:**
Powder Bed Fusion

MATERIAL:
17-4 Stainless Steel,
316L Stainless Steel,
Ti-6Al-4V

ACCOMPLISHMENTS

This work introduced a new type of model for distortion prediction in DMLS printing: a Thermal Circuit Network (TCN) and a Quasistatic Thermomechanical Model (QTM). The model simulates the support-removal process so that both on-substrate and off-substrate displacement and residual stress can be predicted. The TCN-QTM model was validated against experimental data of disk samples with different dimensions and build orientations, demonstrating a relative error less than 15% in terms of radius of curvature at the top surface of the disks and an agreement in trends of the residual stress. The distorted shapes of a horizontally and vertically built prism predicted by the TCN-QTM model both qualitatively and quantitatively matched the distortion measured by others cited in the literature.

In the case study of simple and complex contoured parts, TCN-QTM was further validated. The TCN-QTM models outperformed novice operators on metrics of maximum distortion, number of attempts, and energy usage. Specifically, maximum distortion was reduced from as high as 0.3 inches to 0.01 inches; the number of attempts to achieve a successful build was reduced from a high of six attempts to a single attempt; and energy usage, as measured by BTU's per part, was reduced by 86%. The combined TCN-QTM model is faster in comparison to existing DMLS prediction algorithms, providing predictions in as little as ten minutes for simple part geometries.

As a direct result of this project, the models have been incorporated into a software plug-in entitled *ATLAS*, to the AutoCAD Inventor™ CAD system for ease of use.

A new company, Atlas 3D, was established and the *ATLAS* software has been commercialized as a cloud service hosted on Amazon Web Services, providing highly scalable computing resources with proven security.

The ability to provide a computationally efficient distortion and stress prediction enables future studies into part orientation and support design optimization for autonomous process design.

PROJECT END DATE

March 2017

DELIVERABLES

- Software plug-in to a CAD solid modeling system that codifies expert design rules
- Software plug-in to a CAD solid modeling system that codifies a heat transfer model of select powdered metals
- Documentation of formal models and expert heuristics for software implementation
- Production and delivery of material characterization results for incorporation into design rules
- Software application introduced in the Precision Tool Manufacturing course
- Train-the-trainer module on supports design and its impact on distortion
- 2-week module on part orientation and support design
- 2-week module on the engineering physics computational models that affect part orientation, support design, and distortion
- IE 2006: Introduction to Manufacturing Processes and Systems (graduate engineering course material at the University of Pittsburgh)

All downloadable deliverables are available to members of America Makes via the Digital Storefront.

FUNDING

\$1.86M total project budget

(\$806K public funding/\$1.05M private funding)

PROJECT PARTICIPANTS

Project Principal:

University of Pittsburgh

Other Project Participants:

University of Notre Dame

Johnson & Johnson

ITAMCO

Autodesk

Public Participants:

U.S. Department of Defense

National Science Foundation

U.S. Department of Energy

4047 Parametric Design for Functional Support Structures for Metal Alloy Feedstocks

NCDMM Headquarters

486 Cornell Road
Blairsville, PA 15717
Phone: (724) 539-8811

Letterkenny Offices

4755 Innovation Way
Chambersburg, PA 17201
Phone: (717) 553-0068

America Makes Offices

236 West Boardman Street
Youngstown, OH 44503
Phone: (330) 622-4299