DEVELOPMENT OF AN AUTOMATED ULTRASONIC WIRE EMBEDDING PROCESS FOR USE WITH MATERIAL EXTRUSION ADDITIVE MANUFACTURING AND RAPID ELECTRONICS FABRICATION

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2020

Dedication

This thesis is dedicated to my family, friends, and colleagues who supported me.

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THESIS

Presented to the Faculty of the Graduate School of
The University of Texas at El Paso
in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Mechanical Engineering
THE UNIVERSITY OF TEXAS AT EL PASO
December 2020

Acknowledgments

I would like to first acknowledge Dr. Ryan Wicker, Director of the W.M. Keck Center for 3D Innovation and especially my advisor Dr. David Espalin for the opportunity given to me to conduct this research and learn so many valuable skills. I give Dr. Espalin my sincerest gratitude for his constant support and guidance as my advisor.

I want to thank the staff and my colleagues at the W.M. Keck Center who have also provided so much help and encouragement along the way. Jose Coronel as was my manager was both a teacher and example of professionalism. Kazi Billah for his unbiased teaching, being a great teacher even from my first day. Emerson Armendariz who aided me in much of the trouble shooting and improvement of this work. Sol Barraza and Christina Pickett, dear friends, whose companionship made hard days of work less of a burden. I give my utmost gratitude to my colleague Angel Vega whom this project would not be possible without, his contributions from the earliest stages of this research to the last were integral to its completion. And lastly, Jennifer Wilhite whose is to thank for guiding me along the writing process from start to finish and always encouraging and pushing me to do better.

Another acknowledgement I would like to give is to the companies who supported this work with their interest in it, offering projects that challenged myself and my colleagues to improve our work and aided us by example of what it meant to be engineers and work as a team with others. Among them I would like to thank Tom Place from Aura Technologies, John Blum from Triton Systems, Kyle Ferguson from Los Alamos National Laboratory, and Jacob Rome from Aerospace Corporation.

Lastly, I would like to thank my parents Laura and Dennis Martinez, who supported and encouraged me to great lengths on my path to become an engineer.

Abstract

Polymers have been used in Additive Manufacturing (AM) by many industries for rapid prototyping. Parts created using polymer AM however are known to be relatively expensive thus limiting them to small volume production and making them inapplicable for mass production, while their inherent porous and anisotropic properties make them mechanically inferior to parts made using traditional methods such as injection molding. As projects demand more efficient designs, and at the same time ask for more complex features, AM, combined with other manufacturing processes, like Ultrasonic Wire embedding, can streamline and consolidate assemblies. In the realm of composite and multifunctional assemblies, the layer–by-layer construction of AM parts allows components to be embedded within assemblies simplifying them and making them compact; thus, overcoming design constraints, and reducing weight and space in aeronautical and aerospace applications. Wire embedding, in particular, allows parts to not only be structural but also utilizes the substrates material properties to insulate wiring away from the environment while also retaining the wire and allowing the integration of bulkheads. Inserting wires however can be a challenge as they must be placed securely, accurately, and below the top layer so as not to interfere with subsequent layers atop them. The tool developed in this research makes use of ultrasonic energy to deform the channel around the wire and ensure consistent attachment. The system developed here makes use of a specially designed ultrasonic horn and mounting system to lay wire within polymer surfaces. The tool integrated into our mulit-3d system which allows parts to be removed form a Stratasys Fortus 400mc printer, placed a CNC on which the ultrasonic wire embedder is mounted, and redeposited in the printer after embedding so that printing can be finished, completely encapsulating the wire and any components placed within the part.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

Additive manufacturing (AM), often referred to as 3D printing, is used to describe a process in which a part is constructed by depositing material in a layer-by-layer fashion based on data interpreted from a computer aided design file (CAD). AM stands out from traditional casting and machining processes in that it creates less waste, requires less tooling and setup, and produces parts with complex features and internal geometries that are not possible through other traditional methods. Within the realm of AM, there are multiple unique methods of production that all use a myriad of different materials ranging from the hardest of metals, such as tungsten, to the softest of plastics like thermoplastic polyurethane. This paper revolves specifically around the uses of Material Extrusion (ME) and the production of plastic parts. In ME, a polymer already extruded into a long wire is fed into a heated nozzle where it is softened into a semi liquid state and then precisely deposited on a flat build platform to build individual layers of a part. Each layer self-hardens in the environment of the build plate and the subsequent layer is then built atop it. The part's geometry and placement are optimized for each case to fit within the build envelope, limit defects, shorten print time, and consider the asymptotic nature parts will always have when produced using the ME process.

Since the resurgence of AM in recent years, many improvements have been made to ward off previous frustrations associated with the processes. As a result, AM has expanded into multiple industries and been applied to several projects, mostly as a method of rapid prototyping, but more recently as a means for complex final parts that cannot be constructed by any other means. By themselves, AM parts have limited functionality and can only fulfil a limited number

of applications due to their lower strength compared to solid injection model parts and subsequent limitations in production numbers due to the steep cost curve. But when combined with other technologies, the range of suitable applications opens greatly especially in the aerospace and aeronautical industry where often low numbers of custom-tailored parts are needed for specialized applications. Work previously done by Espalin et al. (2014) at the W.M. Keck Center for 3D Innovation at the University of Texas at El Paso demonstrated the possibilities of multi-functionality in 3D printed parts and methods to implement electrical components into polymer substrates. The introduction of wiring and components such as bulkheads or sensors means that assemblies can be compacted and serve multiple roles while also incorporating the advantages in rapid prototyping offered by AM allowing designs to be modified throughout the process. Small adjustments from one design to the next that would ordinarily cost weeks and thousands of dollars to rework a production line can be bypassed by at any point at the press of a few buttons.

This work demonstrates methods for implementing copper wires for component connections in multifunctional parts. While embedding copper wire into the substrate does come with challenges, the merits of copper outweigh both inks and filaments. The high resistivity of conductive filaments and short lifespan of conductive inks severely limits the number of applications in which parts fabricated using these methods can be used. Though difficult to accurately place and conceal, a solid copper wire is inexpensive, readily available, and has a higher conductivity; all traits that that will lead to more reliable and longer lasting parts.

This research is focused on overcoming the issues previously found with the implementation of solid copper wires into AM parts and creating tooling alongside a manufacturing process to expedite the manufacturing of unique multifunctional parts. In this

multilayered process, the print is interrupted at a predetermined layer so that components can be embedded into preprinted channels using ultrasonic energy. The deformation of these channels by the ultrasonic energy securely holds the wires in place below the highest layer so they do not interfere with the print when it is resumed. Since this system is separate from the FDM printer itself, our multi 3D system is used to transfer the printed part to the wire embedding station and then back so the print can be resumed in order to encapsulate the wires and components within the substrate (Coronel, 2015). The Multi3D System includes two Stratasys Fortus 400mc FDM machines, a CNC router on which the ultrasonic horn is mounted with a variety of other tools, and a Yaskawa robotic arm that is used to transfer the build plate between machines. This complex system is what makes it possible to construct these multifunctional and multi composite parts. The ultrasonic system is made up of 3 main components that were all selected and modified for this application. The ultrasonic horn was modified to be integrated with the wire feeding system. Both are mounted to a custom chassis that was designed in house to accommodate a load cell to measure the forces being applied. The wire feeding system was developed based on previous experiences and literature review from similar mechanisms.

1.2 Motivation

Engineers and scientists are not only the people who ask "Why?" They are the ones who cannot rest until they solve the problem. As technology evolves, the problems engineers and scientists must solve have only become more complex. In many cases, assemblies and designs have become cumbersome as design and manufacturer engineers must accommodate far too many criteria, forcing them to make compromises in design or available features.

The consolidation of assemblies into single parts and ease of redesign and specialization offered by advanced manufacturing methods leads to more efficient systems, faster manufacturing, and weight savings which are vital because every ounce counts in aeronautical and aerospace engineering applications. Ultrasonic embedding is just one of many methods paving the way towards significant strides in the development and improvement of future manufacturing methods. Advanced manufacturing methods lead to more efficient systems and manufacturing processes. Even more important to the aeronautical and aerospace engineering applications is ultrasonic embedding's potential to make significant weight savings through the consolidation of assemblies into single parts.

The use of ultrasonic embedding in composite multifunctional parts is one of the building blocks the W.M. Keck center is developing in its goal of completely automated manufacturing of electromechanical assemblies. Now more than ever, there is an emphasis in industry on consolidating designs and expediting the design process. The rapid prototyping offered by AM when combined with other processes, such as pick and placement systems and laser soldering, can lead to products that can be designed and build on a case-by-case basis. Perfecting the ultrasonic embedding process is a bridge that must be crossed before all these processes can be combined into one machine to even further the capabilities of these process. The W.M. Keck