Development of control system for mixing and extruding multi-material in 3D printing

FULL First Author[1, a *], FULL Second Author[2,b] and FULL Last Author[3,c]

[1]Full address of first author, including country

[2]Full address of second author, including country

[3]List all distinct addresses in the same way

[a]email, [b]email, [c]email

* please mark the corresponding author with an asterisk

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Abstract. This paper will consist of building a functional multi material extrusion machine that will allow to build on a large scale using non-conventional materials. Large 3D printer will be utilized as a ready start up platform to build an additional extrusion mechanism. The study will focus on the mechatronics and development of the machine, thus leaving the chemistry discussion of two component materials to a minimal side.

Introduction

3D printing as an additive manufacturing process, making objects from 3D model data [1], was strongly established with the use of plastic materials in the form of solid filament windings, known as Fused Filament Fabrication (FFF) [2]. There is a large knowledge base collected on the mechanical properties of the most common filaments used [3]. The tensile strength and elastic modulus of printed components using realistic environmental conditions for a selection of open-source 3D printers find an average tensile strength of 28.5 MPa for ABS and 56.6 MPa for PLA with average elastic moduli of 1807 MPa for ABS and 3368 MPa for PLA [4].

The availability of different scale printers and wide selection of materials offer great benefits of rapid prototyping and creating models that were previously impossible to manufacture using traditional manufacturing methods. One example is printing of epoxy structures that have a fiber as reinforcement. Young's modulus of these materials exceeds up to 10 times higher values compared using commercially available 3D-printed polymers, while maintaining comparable strength values [5]. Two component materials combined with complex geometry enabled by 3D printing offer great mechanical properties and reduced weight of the product against components that are made by using traditional manufacturing methods [6].

As of July 2018, the most used 3D printing method is by far the FFF (also known as FDM) with share of 69 percent. This is then followed by Stereolithography & Digital light processing, Selective laser sintering, Material Jetting and Metal Sintering [7]. However, a new additive method emerges with great present and future projection. This 3D printing method is called multi-material extrusion and is currently applied for different purposes such as tissue engineering/ multi-colored surgical parts in medical field, reducing environmental impact on pollution [8].

This paper is focused on multi-material extrusion involving Epoxies, field which is not very widely developed and offers great opportunities. The method used is going to utilize two components consisting of hardener and resin, which are mixed together, and then cured by the chemical reaction

[9]. Since this process is going under development, this project will aid in the further development of this type of layered manufacturing.

While the conventional extrusion-based 3D printing involves melting of solid material for extrusion, this project is focused on extrusion of viscous material(s). The purpose of this project is to develop a system to mix and extrude two component material(s) and to control the process in 3D printing. The most common way of cure an epoxy in 3D-printing systems is to use external heat source [10]. The motivation behind multi-material extrusion in this project is to develop a starting point for a system that allows for a mixing and extruding different biomaterials without external heat source. While separate research is being done for the biomaterials, two component mixtures such as epoxies are used in this project as an experiment of extruding different materials. Epoxy was used because of its highly beneficial properties such as high adhesion strength and good process ability. The uncured epoxy resins have only poor mechanical, chemical and heat resistance; by reacting the linear epoxy resin with suitable curatives, three-dimensional cross-linked thermoset structures can be obtained. This is ideal for the mechanical and thermal properties, resulting in high modulus, failure strength and great bonding for many industrial applications [11].

System description, key components and measured values

Table 1 Table for listing the components including the specs and limitations

S.N.	Component id	Description	Specification	Qty
1	400011-10	Dual cartridge, Material storage for plunging	400ml size with a 1:1 mix ratio,	1
2	DLA-24-20-A-200-POT-IP65	Linear actuator	24 V, 200mm stroke length	1
3	TQ0425-20	SMC tubing 20m roll	Chemical resistant	1
4	KFG2H0425-02s	Straight connector	¼ thread, stainless	4
5	KFG2L0425-02S	90 Degree connector	¼ thread, stainless	2
6	MC05-18	Mix nozzle	5mm ID x 18 EL	100
7	Mixer	Cast aluminum mixer	2x ¼ thread into bayonet nozzle attachment	1
8	TS60CWP	Cartridge kit	Chemical resistant, 200ml	2
9	MTA2-1/4-1/4-BR	Adaptor	¼ thread, brass	2
10	Mounting for cartridges	Mounting and fastening of the cartridges to the existent frame		1

Extruding two different materials need a plunging mechanism and mixing them before extrusion. The two materials were plunged through a dual cartridge (component 1 in table 1) using a linear actuator, which was connected with a plunging system to the cartridge. The designs for this project was based on the extrusion of using 185mm long dual cartridge. The plunging system was modular designed as seen in figure (x), for it to be used for different lengths of cartridge. Increasing the stroke length of actuator and the length of the plunger allows to extrude materials through longer cartridges. The speed of the actuator movement was controlled to have desired rate of extrusion of the materials. To avoid the additional weight and its resulting effect on the beam where the printing nozzle of the extrusion exists and the complexity of the mount design, the actuator, plunging system and the cartridge were not directly mounted on that beam. They were mounted on the other beam in the frame of the 3D printer and connected to the nozzle through tube and mixing interface. This location further allowed the variability option of the cartridge length depending on the need of the printing size.

The cartridges were intended for single use only. Once the print or the material in them gets finished, they must be manually removed and replaced again for the next print. This means that their placement and removal from the structure is a process that will often take place, so an easy access and a simple replacement solution was provided. It had been chosen a system of two separate cartridges, however they were mounted next to each other placed in parallel. This allowed greater play and flexibility in design, as they must have been integrated with the plunging mechanism. It was designed two cylindrical cavities lying horizontally and attached to the outer beam in where the two individual cartridges would be inserted. These were two through-holes, with the outer dimensions of the cartridges, which allow the coupling of the tubes together with the fixing elements.

The materials plunged through the cartridge were dispensed separately through to the printing head. Connectors were used for avoiding any leakages in the system. Adapters were needed for the fitment between threads of the connector and the cartridge. Size of the cartridge restrict the size of the printable object and sizing of the tubes restrict the maximum material flow.

The mixer allows for two material feeds join and starts mixing to initialize the chemical reaction between the hardener and the resin. Further mixing was aided by using replaceable static mixers that have mixing elements inside, which causes the flowing material to blend together while flowing through. The mixer must be removable and must withstand chemicals, allowing to clean it through after each print. To aid the cleaning within the mixer, a check hatch is in the section where the resin and the hardener start to blend together.

Testing parameters. For the extrusion, we should know how much the extrusion mechanism extrudes with certain parameters. We should be able to set datapoints with different feed speeds and have a linear graph that shows the behaving of certain materials in our extrusion system. The material is extruded to containers where it is easily measured and datapoints taken from that.

Control system implementation. What control system was used, why and how.

Control system parameters. What kind of values were used for testing and presenting the final values.

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Summary

If you follow the “checklist”, your paper will conform to the requirements of the publisher and facilitate a problem-free publication process.

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