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Review on Design of Extrusion System for Semi-Solid Material Based Additive Manufacturing

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Abstract: The advent of additive manufacturing dates back to the 1980s and was first developed in Japan. After then, other different techniques gradually emerged under the label that is now known as '3D printing.' Today, we observe the widespread application of additive manufacturing across a variety of industries. Typically, 3D printing is used extensively for creating prototypes of CAD models out of materials like PLA and ABS. Other new areas of additive manufacturing include Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), and resin-based 3D printing. Cement-based 3D printing is another area of additive manufacturing that has so far had a moderate level of adaptation.

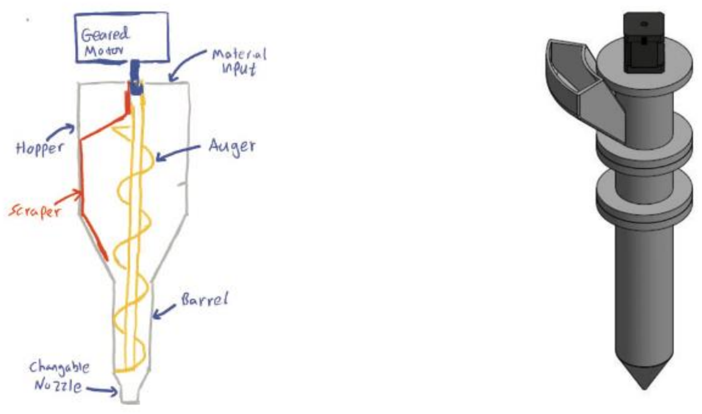
Concrete 3D printing can be used for a variety of purposes, from building massive structures to creating medium-sized exhibition artifacts. The hopper system is the main component of a concrete 3D printer. There are several different extrusion system design options for 3D printing concrete. The extruder is designed to deliver mass flow rather than funnel flow. A funnel flow occurs when the material is deposited in the hopper body's inner cross-section. Consequently, it is crucial to base the extruder's design on the material that will pass through it.

IINTRODUCTION

An elementary procedure is used in additive manufacturing that uses cementitious materials. The cementitious material used in this procedure is kept in a sizable tanker and transferred to the extruder system using a pump. The extruder system is made up of a hopper and an auger shaft that is powered by a wiper motor. The material is mixed in this shaft in order to ensure that it flows properly and is deposited on the printing bed. It is essential to keep the material's mass flow rate consistent during the whole procedure. The auger shaft's spinning speed is managed to achieve this. Additionally, it is essential to guarantee that the extruder system is continuously fed with the material. In conclusion, the wiper shaft and the pump must work together seamlessly.

A manually fed extrusion system is another form of extrusion system. For these extrusion systems, a hopper with a substantial volume is typically designed. It is not necessary to use a pump because the material is fed manually. However, the hopper is built with certain protocols to guarantee a steady flow. The hopper's length is flexible, but it must have a conical angle of slope that is calculated. Mass flow only happens when the hopper's conical slope angle is chosen based on the type of material that passes through it. The conical slope angle is primarily determined by the material's inherent characteristics, such as the effective angle of internal friction, the angle of wall friction between the material and the hopper material, and the density of the material to be deposited.

Figure 1.1 - Hopper Type Extrusion System and Pump Fed Extrusion System

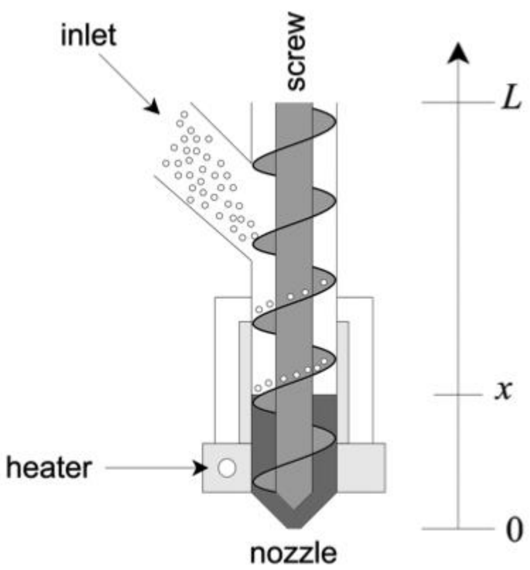


II. LITERATURE SURVEY

Over seven research papers were analyzed as part of the study. Each contained some important knowledge about the printing system and the extrusion system. Four significant studies, however, drew our attention. We plotted key points that are essential for developing a desired extrusion system for concrete additive manufacturing.

We discovered the research on the use of a screw extruder for Polymer-based 3D printing in a paper published in ASME 2016 DSCC by Dylan Drotman, Mamadou Diagne, Robert Bitmead, and Miroslav Krstic [1]. Although the material is unrelated to our area of interest, the research and procedure produced useful findings. There were three different zones on the screw conveyor: the transport zone, the melting zone, and the mixing zone. The concept is straightforward: the material is first delivered into the screw portion, after which it is heated further to melt. The substance is then combined and exposed to high pressure so that it can be ejected out. The study's findings showed that the heat source had an impact on the material's consistency both at the output and the input. Convection from ambient temperature and conduction from the extruder body were two key elements in the melting of the material inside the extruder system.

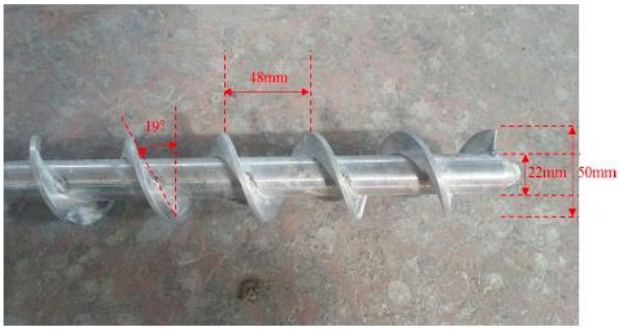
Figure 2.1 - Depiction of the screw extrusion process for 3D printing



Another work by Jun Ho Jo, Byung Wan Jo, Woohyun Cho, and Jung-Hoon Kim on concrete 3D printing was published in the International Journal of Concrete Structures and Materials [2]. In this paper, the end-effector mechanism for the nozzle is based on a screw type. A designed screw with a 300 mm length, 48 mm pitch, 50 mm outer diameter, and a 19° blade angle was employed. After the system underwent experimental testing, it was discovered that the screw-type nozzle produced better material control and smoother material ejection. Comparatively, it was discovered that regulating the material layers was difficult using the pump feeding method.

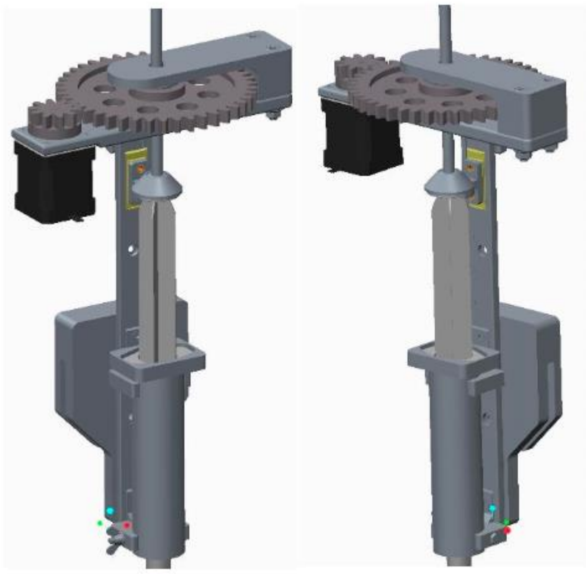
They tested a variety of pitch-to-diameter ratios for the screw and found that a ratio of 0.96 produced extrusion with enough pressure to extrude ordinary mortar. The speed at which the screw shaft rotated, which in turn controls how much material is extruded, was a contributing factor.

Figure 2.2 - Designed Screw for the 3D Printer



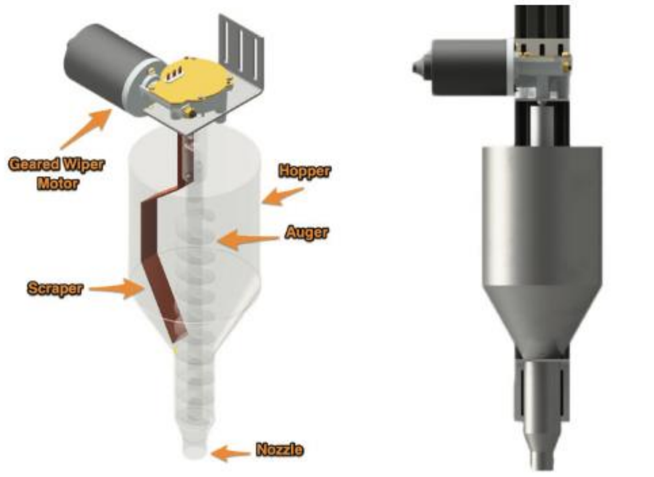
Petr Zeleny and Vojtech Ruzicka's study in the MM Science Journal [3] analyzed three different types of extrusion systems. They used a revolving screw that was placed within a body that was being heated from the outside to begin extrusion. This is how 3D printing is often done. The following technique produced printing using a screw pump. Finally, a piston was used to achieve extrusion. In order to achieve printing, a syringe was employed in this method, propelled by a motor with determined force, gear ratios, and power. Subsequently, it was determined that the printer should be operated in cold settings in order to perform multi-layer printing through this procedure since the substance might not solidify.

Figure 2.3 - Piston Extrusion Mechanism



The last paper we reviewed was one published by Abdulrahaman Albar, Mohammad Rafiq Swash, and Seyed Ghaffar in IEEE [4] on the design, and production of an extrusion system based on hoppers. To prevent funnel flow, the hopper's design adhered to certain rules. In order to remove any sediment that had accumulated on the hopper's inner cross-section, the hopper system additionally included a scrapper plate. Additionally, this design offered much nozzle flexibility to produce various 3D-printed concrete shapes. There was no auger design involved because the author used an auger shaft that was readily accessible.

Figure 2.4 - Rendered view of the Proposed Extrusion system



a) Transparent render of the proposed extrusion to show the key components.

b) Assembled Render

III. SUMMARY OF LITERATURE REVIEW

Four educational research articles based on extrusion methods for additive manufacturing were studied for this paper. To design an effective end-effector system for a seamless 3D printing process, we have sketched out a number of strategies and methods. Below is a summary of every paper and article.

3.1 Table of Literature Survey

Paper Reference	Author and Year of Publication	Features of Paper
[1] Paper 1	2016 Dylan Drotman, Mamadou Diagne, Robert Bitmead, and Miroslav Krstic	Multi-zone nozzle system to transport, melt and mix the material.
[2] Paper 2	2020 Jun Ho Jo, Byung Wan Jo, Woohyun Cho, and Jung-Hoon Kim	Custom designed Auger Shaft used and concluded screw type nozzle printing is better.
[3] Paper 3	2017 Petr Zeleny, Vojtech Ruzicka	Three different extrusion systems were used. One unique type based on syringes was discussed.
[4] Paper 4	2019 Abdulrahaman Albar, Mohammad Rafiq Swash, and Seyed Ghaffar	This paper employed a hopper-based extruder with a multi-nozzle system.

IV. CONCLUSION

After reading the above publications, it is clear that there are various approaches to designing and producing an end-effector system for cement-based additive manufacturing. The most effective way to efficiently mix and deposit the material is with a screw shaft, sometimes referred to as an auger shaft. Additionally, the ideal auger shaft design is explored in order to achieve the finest outcomes.

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