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Investigating Abrasive Flow Finishing of 3D Printed Meso Scale Channel

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Abstract*: Three-dimensional printed parts and components have a wide range of applications, and the number of applications is growing by the day. Outer surfaces experience severe poor finishing due to the nature of 3-D printing, i.e. the addition of layers. 3-D printed parts must be finished if they are to be used as prototypes or functional parts. To finish a piece can also be difficult, especially if it contains passages that would be on the meso-scale or below it. The idea of this research is to use a non-traditional Abrasive Flow Machining (AFM) process to finish meso-scale passages in Fused Deposition Modeling (FDM) printed components. The FDM process is used to design and fabricate components with two different passage sizes. Tooling for finishing these components with One-Way and Two-Way AFM is also designed and manufactured. First, experiments are performed on a larger 3mm passage width by modifying an existing media. Following the successful passage of the media through this passage, further experiments are carried out on a smaller 1mm passage. Because the modified existing media could not be passed through a 1mm passage, a new media was formed using a bio-coagulant called Xanthan Gum, which acts as a thickening and binding agent. Further experiments on Two-Way AFM with newly synthesized media were carried out by varying the ratio of its components, which resulted in successful media flow through a 1mm passage. As a result of the research, AFM has been identified as a feasible choice for finishing 3-D printed parts with meso-scale passages up to 1mm in width. Xanthan Gum has also been discovered to be a promising media binding and thickening agent. Further research into micro-domain passages can be conducted based on the results of this study.

***Keywords*: abrasive flow machining, complex Meso structure, fused deposition modeling, media.**

1. Introduction

3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. Also known as rapid prototyping. The purpose of an additive manufacturing is to quickly convert a thought into a physical object. 3D printer creates the object by adding layer upon layer of material until the final shape of the object is formed. The object can be made using a number of printing materials, including plastics, powders, filaments and paper.

The materials to be selected depend on the type of rapid prototyping technology used.

A. Fused Deposition Modeling (FDM)

FDM is an additive manufacturing technology commonly used for modeling, prototyping, and production applications.

The thermoplastics are liquefied and deposited by an extrusion head, which follows a tool-path defined by the CAD file. Thermoplastics are used like acrylonitrile butadiene styrene (ABS), poly lactic acid (PLA), and elastomers.

In the physical process of model fabrication, a filament is fed through a heated element, and becomes molten or semi-molten.

The liquefied filament is fed through a nozzle, using a solid filament as a piston, and deposited onto the partially constructed part. The newly-deposited material fuses with adjacent material that has already been deposited. The head moves on the X-Y plane and deposits material according to the geometry of the currently printed layer. After finishing a layer, the platform holding the part moves vertically in the Z direction to begin depositing a new layer on top of the previous one. After a period of time, the head will have deposited a full physical representation of the original CAD file which depends on the volume of printed part.

B. Stair Stepping Effect

Like other additive manufacturing process, the stair stepping effect is the main reason of a low surface quality in FDM due to layer nature of the process.

There are two commonly used methods to increase surface quality. (a)Secondary or post process may be utilized (b) Layer thickness, build direction, different process parameters, can be evaluated. However, both options will increase the cost due to material consumption, machine time, labor. Expected to increase with increasing layer thickness and decrease with increasing inclination angle.

C. Abrasive Flow Machine (AFM)

AFM is used for deburring, roundness of sharp edges, polishing and smoothening internal intricate surfaces is finished by a self-deformable tool which is in the form of a visco-elastic media. Media composed polymer based on the visco-elastic matrix is thoroughly mixed with abrasive particle and additives. Due to its visco-elastic nature, this media can flow through

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inaccessible areas passages. Appropriate tooling is required in this finishing operation to direct the media only on to the surfaces that required finishing. The media passes through the tooling for several cycles until the required finish is obtained. The direction of flow of media, which is in a single direction or both. Throughout the operation, media extrude in uni-directional across the complex passes. AFM setup having an internal passes, hydraulically actuated reciprocating piston and recycling unit.

D. Working Principle of AFM

Media have an important role in fine finishing and passes into inaccessible intricate passes. Which is used as a multi-point cutting tool and perform extruded back and forth in two vertically opposed cylinders. The polymer chain holds the abrasive particle flexibly and moves in the direction of extrusion pressure. Radial force is responsible to the penetration of the abrasive on the work-piece material. Axial force is responsible for material removal by shearing action in the kind of microchips. Tooling plays a major role in this process. So fabricate tooling or fixture design should be done properly.

1) AFM Media

Media generally consists as base, abrasive particle and additives. Abrasive media having ability to precisely finish the selected surface and also flow into the restricted passes.

Media have property like visco-elastic, self-deformability, adhesiveness, porosity and permeability using natural polymer base, additives and abrasives of different mesh size and concentration.

2) Base

Natural polymer can be used as a base for new media which is a waste in the environment. By adding additives like marble powder to made a base. which act as a clogging agent and trapped the abrasive particle.

3) Abrasive Particles

Abrasive particle like as cast iron, silicon carbides (SiC) and aluminium oxide (Al_2O_3). act as multi-point cutting tool.

Which type of abrasive is used depends on surface hardness of work-piece and mostly abrasive used as most probably the hardness of abrasive must be greater than work-piece.

4) Additives

Additives provide improving the bonding property and required viscosity to the base and abrasives.

Waste vegetable oil (like karanja oil) used to proper bonding and flow ability to media.

E. Mechanism of Material Removal

The material is ploughed by the fine active abrasives grain which comes in contact with the work material as the rub over the metal surface with high pressure. The material flow occurs in the direction of the motion of abrasive particles as well as in lateral direction, resulting into the formation of the leaps. Due to continued work hardening which results in embattlement and fragmentation of the lips into microchips.

2. Literature Review

Even though research in this field has been going on for a long time, there is a lot of literature out there about finishing 3D printed meso scale passes heat exchange devices for heat dissipation. However, there is a scarcity of literature on meso scale device finishing. The literature review is divided into four sections for clarity, as shown below.

Bouland et al. [24]. The AFM method was used to test the MRR and assess surface roughness on the face of LPBF-built Ti-6Al-4V parts with different construction orientations. As a result, for a selected Ti-6Al-4V part made up of an EOS M280 LPBF system, a combined manipulative machining allowance was provided to account for both AM and AFM practise. For CFD simulations, the Carerau-Yasuda model was used as a non-Newtonian fluid.

Wang et al. [25]. Due to the staircase effect and balling effect, metal surface finishing is a crucial task in additive manufacturing. SLM used aluminium and titanium grilles to create the effect of finishing on both the outer and inner surfaces. Surface defect "balling effect and powder adhesion" was caused by additive manufacturing. After completing the AFM polishing process, the poor surface caused by the inbuilt "balling effect" was improved, as was "powder adhesion."

Duval-Chaneac et al. [26]. Non-heat-treated and heat-treated AFM were investigated using steel 300 SLM surfaces in four different media with varying abrasive percentages (35, 50, and 65%) and media viscosity. The roughness of the surface at the start is between 12 and 14 micrometres. Unlike AFM, four Materials were used for relative analysis, each with a different material viscosity and abrasive grain density. There is al surface roughness varies between 2 and 10 micrometres. The average increase in compressive residual stress at right angles to AFM media flow on non-heated SLM surfaces was predicted to be 360 MPa. Additionally, on heat-treated SLM surfaces, compressive residual stress is usually increased.

Nagalingam et al. [27]. For finishing the intricate internal surfaces of FDM components passes, describes hydrodynamic flow cavitation conditions and freely balanced particles. Adding micro abrasive media to a cavitating flow and limiting surface wear due to cavity corrosion could be a useful tool for organising specimens with a poor finish and high surface roughness.

Mali et al. [3]. This analysis also makes reviewing the suitability of developed alternative, polymer-based abrasive gel media for finishing 3D printed components by additive manufacturing parts using one-way AFM. It was realistic to achieve a surface finish of Ra 21.37 mm on the outer surface and Ra 6.27 mm on the inner surface. The most desirable parameters for rheological behaviour of SPAGM viscosity are 50% abrasive density and 120 abrasive particle mesh size.

Leong et al. [28]. We searched into how to effectively remove abrasive-jet deburring from mock-up jewellery made by SLA. To direct the most practical method for praising the CADCAM jewellery method. Experiment design employs techniques such as optimal search, factorial design, and classical design to find the most favourable conditions for the valuable parameters. The factorial design technique aids in the screening and recognition of key deburring cycle parameters such as air pressure and blasting time.

Tan et al. [29]. The goal of this study is to see if improving the surface roughness of Inconel 625 side surfaces by 45 percent after 30 minutes. After 30 minutes of ultrasonic cavitation, side surface roughness enhancements of up to 45 percent were recorded on direct metal laser sintering specimens. As a result of the findings, it appears that surface abnormalities can be eliminated. Existing post-process finishing techniques have been discriminated against due to UCAF ability to efficiently eliminate surface irregularities without causing significant changes to the original surface of the DMLS.

Kumar et al. [30]. Silicon carbide with naphthenic oil mixed media exhibits high quality relevant for natural rubber media when tested on butyl rubber aluminium and En8 material. When upgrading to a higher mesh size, regardless of surface conditions, a mesh size of 220 is fine compared to 800 to 1200. Complex viscosity and creep compliance change by up to 80%-87% when abrasive loading is increased by 47%. Creep compliance in complex viscosity is reduced by 71% and 33% when the size is changed from 220 to 1200. The 43 percent increase in oil loading is expected to increase creep compliance and complex viscosity properties to 99 percent.

Mali et al. [31]. Taguchi method L18(6137) mixed orthogonal array was used to work on Al/15 wt % silicon carbide metal matrix composites. Various responsible characteristics, e.g. The fraction of increase in Ra based on variation Services amounts to up to 79.39 percent in Ra and Rt in microns and MR in milligrams. At 100, 30 abrasive wire cycles, 6 MPa extrusion pressure, 67 percent abrasive concentration, and "L" grade media viscosity. The recommended parametric combination with the above-mentioned range gives the surface a high finish.

Jain et al. [32]. On aluminium and brass, finding material with a larger abrasive mesh size improves both material removal rate and surface roughness value. The rate of removal of artefacts increases as the percentage of abrasive content in the medium increases, while the roughness value of the surface decreases. In comparison to harder materials, softer materials have a higher rate of substance removal and a higher rate of surface roughness enhancement (Ra).

3. Materials and Methodology

A. Materials

Work-piece: Acrylonitrile butadiene styrene (ABS)

Media: Xanthan gum powder, Si-C abrasive, naphthenic oil, paper pulp, guar gum, marble dust and water.

Tooling / Fixture: Nylon

B. Methodology

Design & fabrication of the meso-scale components. Design & fabrication of the fixture. Modify existing media and perform experimentation with it. Identification of base, liquid & abrasive for new media. Prepare different media for abrasive flow machine. Experiment on one-way & two-way AFM.

1) Fabrication of AFM Tooling

The fabrication of tooling for one way AFM to meso channel used by fused deposition modeling. Therefore, heated extruder head in which fed an acrylonitrile butadiene styrene (ABS) of filament. The movement of the extruder head is controlled by computer. So continuous passing thread of Acrylonitrile butadiene styrene (ABS) through a heated nozzle. Therefore, thread melts as it passes through the nozzle and gets solidify as it touches the bed or layer below it. Acrylonitrile butadiene styrene and acetone are applied to bed before starting print a layer so that the tooling does not get deformed and could be easily removed after the print is done.

Meso channel of 1mm and 3mm component designed which dimensions 30*30*10 by using AUTODESK FUSION 360 Software and FDM machine used of chemical as acrylonitrile butadiene styrene (ABS).

2) Designing of Tooling

- Tooling worked as hold the work-piece in the machine and also express the sustainable polymer abrasive media.
- Metal or nylon is used to be made fixtures.
- Tooling is designed in such a way that the media flows with high pressure. So in taper shaped tooling designed.
- The work-piece to be finished is keeping inside the fixture/tooling for essential finishing operations.
- The fixture/tooling is tightened using two sets of nuts and bolts.
- To avoid any leakages of the media, the design of tooling will depend on the shape and size of the work-piece.
- Therefore, two fixtures have been made top and bottom and meso component placed in between and properly aligned.
- Therefore, firstly made CAD MODEL of the nylon fixture with the dimension of 110mm diameter and 55mm thickness and where all significant parameters in concern which mentioned.
- Consider the most significant parameter spindle speed like 1500 rpm, feed 50 mm/min. and depth of cut 0.5mm.
- The work is held in a vice and table has three-axis movement in a special fixture of bolted to the machine table.
- In two-way AFM main problem occurred abrasive media is leakage between two nylon fixture by using two highly pressurized opposite cylinders worked in two way AFM
- Thereafter we solve out the problem by using rubber material used between two fixtures and proper gripped it.

4. Experimentations, Results and Discussion

A. Experimentation on one-way AFM

- Initially trial the existing media which consist of SiC abrasive particle act as a multi-point cutting tool, paper pulp and marble dust as polymer, guar gum as a binder, naphthenic oil as the synthesizer using for 3mm size of channel.

- But media was made highly thick and not pressurize as required to pass into channel.
- So dilute the media by increase amount of oil gradually and also increase the running time of machine. Then passed the media into the 3mm channel at on condition that 250ml. oil runs with pressure.
- Therefore, result has been found the media passed throughout the 3mm size of channel.
- So now we taken a 1mm size of channel to passing the media using by same previous media composition.
- And again trial to run the media into the passes but that media is not passed through the channel due to the highly viscous and choked at the starting position at inlet also even dilute the media.
- So this media is unsuitable for finishing the 1mm channel. Therefore, results have been found which shown in table.

B. *Experiments on two way AFM*

- Hence synthesized a new media by replacing guar gum binder to Xanthan gum powder.
- Xanthan gum powder work as a shear thickening process and stabilizer to prevent ingredients to separating.
- Chemical formula $C_{35}H_{49}O_{29}$ (monomer)
- Molar mass 933.748 g/mol.
- Can be produced from simple sugar (glucose and sucrose) using a fermentation process.
- It helps to prevent oil separation by stabilizing the emulsion and also suspend the solid particles.
- It's commonly used in food industry as salad dressing and sauces, bakery products.
- It not changes color and flavor of foods.

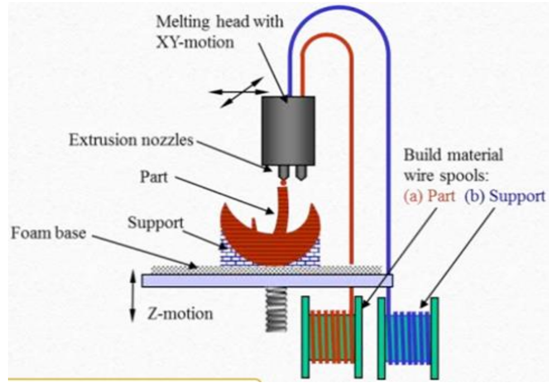

Fig. 1. Fused deposition modeling

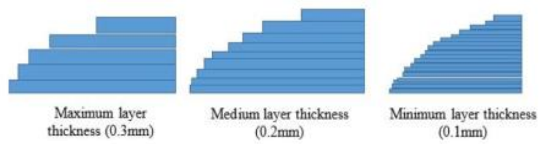

Fig. 2. Stair stepping effect to layer thickness

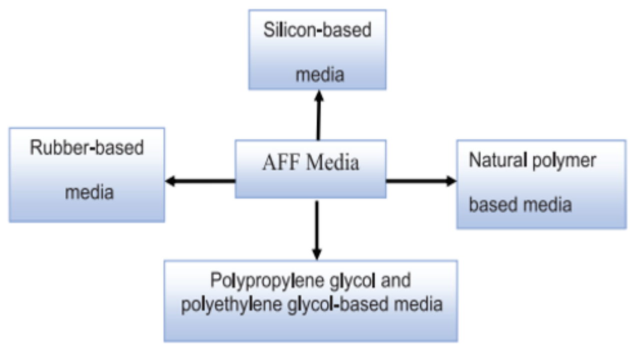

Fig. 3. Various type of abrasive media

Table 1
Experimentation using naphthenic oil for 3mm channel

S. No.	Media composition	Size of channel (mm)	Amount of oil in ml.	Running time in minutes	Media Pass/not
1.	SiC abrasive, paper pulp and marble dust, guar gum, naphthenic oil	3	50	3	Not
2.	SiC abrasive, paper pulp and marble dust, guar gum, naphthenic oil	3	100	3	Not
3.	SiC abrasive, paper pulp and marble dust, guar gum, naphthenic oil	3	150	3	Not
4.	SiC abrasive, paper pulp and marble dust, guar gum, naphthenic oil	3	200	5	Not
5.	SiC abrasive, paper pulp and marble dust, guar gum, naphthenic oil	3	250	5	Pass

Table 2
Experimentation for 1mm channel

S. No.	Media composition	Size of channel (mm)	Amount of oil in ml.	Running time in min.	Media Pass/not
1.	SiC abrasive, paper pulp , marble dust, guar gum, naphthenic oil	1	50	3	Not
2.	SiC abrasive, paper pulp, marble dust, guar gum, naphthenic oil	1	100	3	Not
3.	SiC abrasive, paper pulp , marble dust, guar gum, naphthenic oil	1	150	3	Not
4.	SiC abrasive, paper pulp ,marble dust, guar gum, naphthenic oil	1	200	5	Not
5.	SiC abrasive, paper pulp, marble dust, guar gum, naphthenic oil	1	250	5	Not

Table 3
Experimentation used by Xanthan gum powder

S. No.	Name of media	Media composition	Size of channel (mm)	% ratio of abrasive: oil: water in mixture.	Running time in min.	Media Pass /not
1.	SX.010	SiC abrasive, Xanthan gum, naphthenic oil, water	1	55:40:05	3	Not
2.	SX.020	SiC abrasive, Xanthan gum, naphthenic oil, water	1	50:45:05	3	Not
3.	SX.030	SiC abrasive, Xanthan gum, naphthenic oil, water	1	45:50:05	3	Not
4.	SX.040	SiC abrasive, Xanthan gum, naphthenic oil, water	1	40:55:05	3	Not
5.	SX.050	SiC abrasive, Xanthan gum, naphthenic oil, water	1	35:60:05	5	Pass

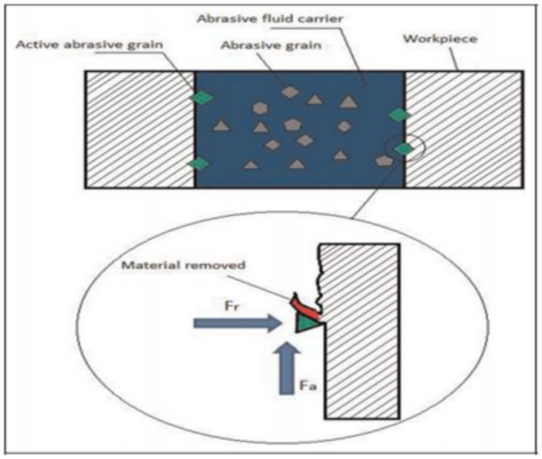

Fig. 4. Force acting on single active abrasive grain

Fig. 5. Image of AHA 3D printing machine

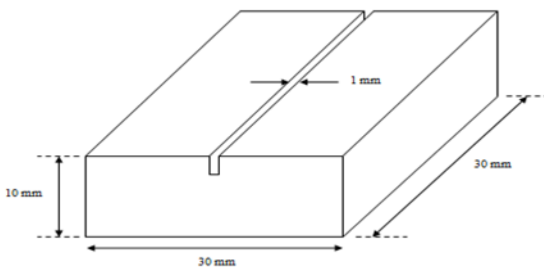

Fig. 6. CAD model of 1mm meso component

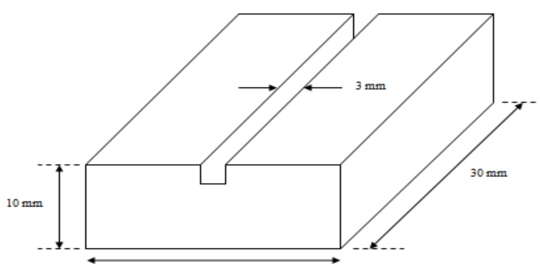

Fig. 7. CAD model of 3mm meso component

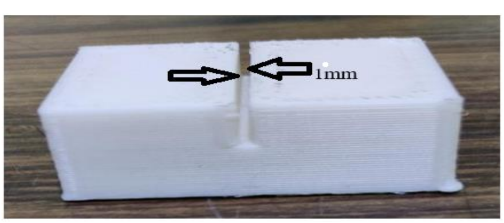

Fig. 8. MESO component design by FDM

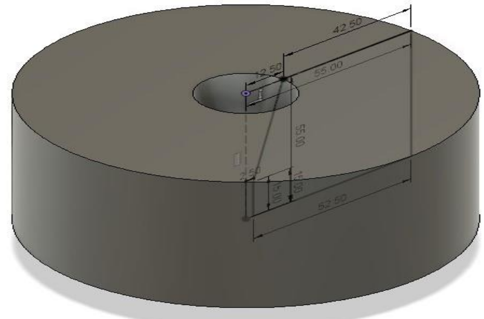

Fig. 9. Isometric view of CAD model

Fig. 10. Picture of two-way AFM

Fig. 11. Alignment using rubber material

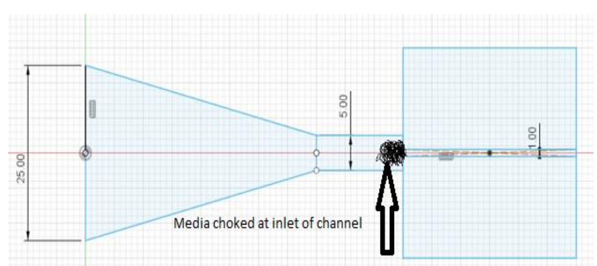

Fig. 12. Shows the media where choked

5. Conclusion

In AFM using semi-solid media consist polymer base and abrasive particle, oil and water mixed in definite proportion is extruded under pressure throughout the surface to be machined.

- Finishing of 3-D printed parts paper pulp used in media then face the difficulties for less than 3mm passes. Even after dilute this media then not passed through the channel.
- Xanthan gum powder used in media as a binder then result shows media is passed through the 1mm channel. Environment friendly and low cost media has been synthesized.
- Finishing to 3-D printed meso scale parts by using abrasive flow machining is possible.

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