Identification of Toolmarks Present on Additive Manufactured Components

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ABSTRACT

Additive manufacturing, commonly referred to as "three-dimensional (3D) printing," is defined by ASTM International as the "process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies" [1]. Toolmarks present on multiple 3D printed components were identified to be produced by the same nozzle. The identification of these toolmarks serve as a "proof of concept" that toolmarks can be produced by a 3D printer nozzle and that the toolmarks can be reproducible.

Introduction

Additive manufacturing allows for the production of components with complex internal and external geometries and parts that are otherwise difficult to manufacture with traditional, subtractive machining methods. One of the most common additive processes used commercially and favored by hobbyists is known as fused deposition modeling, a process developed by S. Scott Crump, a co-founder of Stratasys **[2]**. Fused deposition modeling, also known as fused filament fabrication, is a material extrusion process in which filament feedstock is extruded in a series of layers through a heated deposition nozzle. Feedstock can be defined as "bulk raw material supplied to the additive manufacturing building process" **[1]**.

Before a physical object can be produced, a component is designed using computer-aided design (CAD) software. This CAD software is used to convert the virtual design to a stereolithography (STL) file format, a file format that approximates the surface geometry of a virtual object as an array of interconnected triangles (tessellation). Although there are other types of file formats, such as an Additive Manufacturing File Format, STL files are most commonly used. The data files are then "sliced" into a series of layers, which directs the nozzle(s) to extrude melted filament in a layer-wise fashion until the object is complete.

During the extrusion process, the nozzle has the potential to make physical contact with the printed component (**Figures 1 and 2**). Conditions such as an unlevel moveable bed platform, unsecured nozzle, uneven layer deposition, and/or an irregular feed rate may contribute to the production of these marks. Nozzles used in material extrusion processes are commonly made of brass or steel and come in sizes ranging from 0.2 mm to 1.2 mm; however, 0.4 mm is commonly used **[3]**. Direct examination of the physical nozzles and manufacturer consultation indicate turning as a common manufacturing method used to produce extrusion nozzles.

Figure 1: Side view of an extrusion nozzle

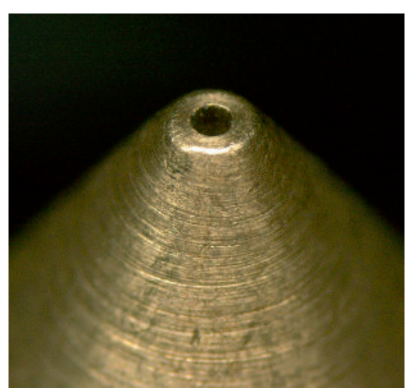

Figure 2: Top view of an extrusion nozzle

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Materials & Methods

A Raise3D N2 printer using 1.75 mm Polymaker Polymax PLA filament and a Raise3D 0.4 mm brass nozzle heated to 205 degrees were used to produce five fingerprint exemplars (**Figure 3**). The selection of the fingerprint was used because the overall geometry of the design was not complex and allowed for maximum movement of the brass nozzle due to the ridge infill.

Figure 3: 3D printed item

Within the infill, there were several areas that exhibited striated toolmarks consistent with having been produced by the extrusion nozzle. Each set of toolmarks were in a similar position among the multiple samples and were subsequently intercompared using a Leeds Comparison Microscope at various magnifications (**Figures 4-6**).

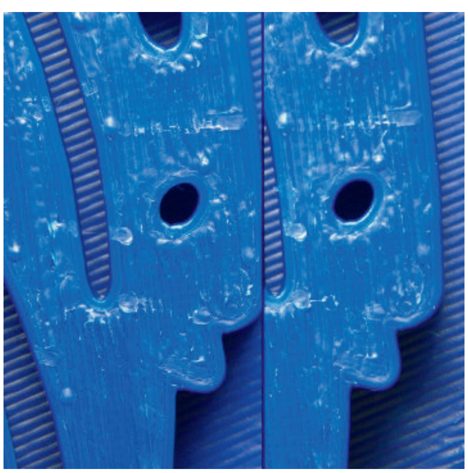

Figure 4: Comparison photograph of 3D printed artifacts

Reproducible toolmarks were present on five fingerprint exemplars. For material extrusion processes, it is common for

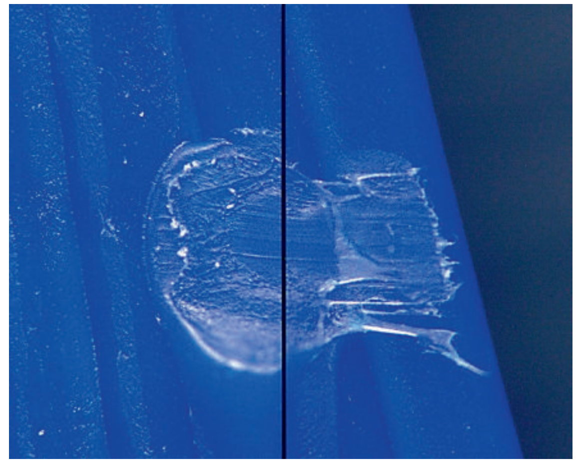

Figure 5: Striated toolmarks from nozzle within the infill

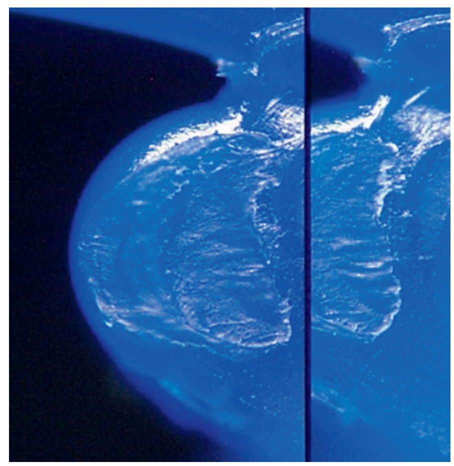

Figure 6: Reproducible toolmarks near nozzle detachment point

the nozzle to be removeable. As such, any opinion rendered should be in relation to the nozzle itself and not to the printer.

Since material extrusion processes often require the periodic replacement of the nozzles, different nozzles were installed in the printer to produce additional fingerprint exemplars. The toolmarks produced by different nozzles were intercompared to evaluate whether the marks made by different nozzles would be distinguishable . Although there was disagreement in the microscopic marks, this area requires additional research.

Conclusion

The results of this study serve as a proof-of-concept for the Firearm/Toolmark Examiner that the nozzles used in material extrusion processes may leave reproducible toolmarks. The overall principles and theory behind toolmark identification remain the same; however, the substrate in this scenario is extruded plastic. The rate of nozzle wear remains unknown and requires additional investigation.

Remarks

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