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Evaluation of 3D printed materials used to print WR10 horn antennas

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Abstract. A WR10 waveguide horn antenna is 3D printed with three different materials. The antennas are printed on a fusion deposition modeling delta 3D printer built in house at Chalmers University of Technology. The different plastic materials used are an electrically conductive Acrylonitrile butadiene styrene (ABS), a thermally conductive polylactic acid containing 35% copper, and a tough Amphora polymer containing at least 20% carbon fiber. The antennas are all printed with a 0.25 mm nozzle and 100 μm layer thickness and the software settings are tuned to give maximum quality for each material. The three 3D printed horn antennas are compared when it comes to cost, time and material properties.

1. Introduction

When fabricating prototypes or producing complex or hollow structures fast and at a low cost, not many fabrication techniques can offer this. 3D printing can be a very cost effective solution, it can reduce lead times, improve the design and/or lower the weight of the structure [1].

There are several different 3D printing techniques available all with both pros and cons. Stereolithography and DLP (Digital Light Processing) produces very accurate prints but the different types of materials available is limited. SLS (Selective Laser Sintering) can print metal and plastic without support material but it is far more expensive and not as fast as other techniques. FDM (Fused Deposition Modelling) is the most common 3D printer technology with an increasing amount of users and subsequently increasing amount of printable materials. The choice of 3D printer depends on the desired quality, material, cost and build speed.

Previous work has been done on 3D printed antennas using stereolithography [2]. In this project we are focusing on the FDM technique, mainly because of the amount of materials available. Several aspects need to be considered when printing with an FDM printer and the most prominent for this project will be explained below. The printed material will shrink when cooled down and depending on the material this can be quite extensive. This will give rise to warping, where the recently printed layer shrinks and slightly deforms the previous layers, hence forces the structure to curl upward. As this is a problem that effects the bottom layer the most this problem can be heavily reduced by having a heated bed, where the print surface is at elevated temperatures. Another problem is delamination which will occur if the layers do not bond properly. This occur if the temperature out of the nozzle is too low, if the layer height is too large or in some cases if the cooling of the previous layers are excessive. Cooling of previous layers are necessary when printing small structures to ensure that the current layer are printed on a solid surface, which is important for quality prints. The print quality is of course the main

Table 1. Maximum operating temperature, Flexular Modulus and Density for the different materials

	Maximum Temperature (°C)	Flexular Modulus (GPa)	Density (g/cm^3)
Conductive ABS	88	2	1.3
CopperFill	60	7	4.0
Carbon Fiber	80	6.2	1.4

aspect when 3D printing and print speed, bed temperature, nozzle temperature, layer height, nozzle size, cooling and several other aspects needs to be considered. The surface roughness can also have an impact on the performance of the horn antenna which of course needs to be taken into account [3].

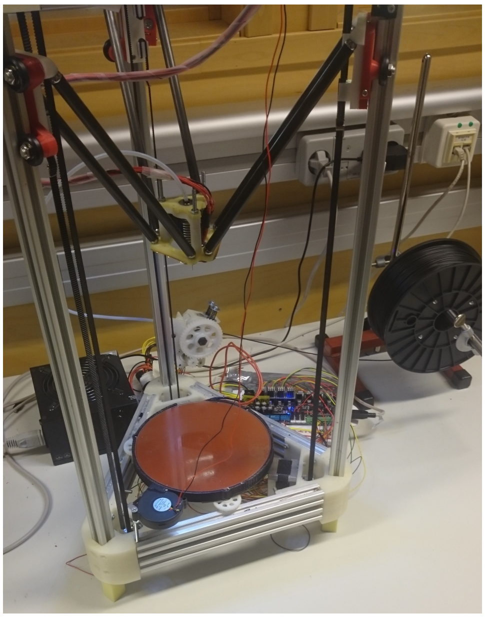

Figure 1. In house built FDM 3D printer of delta type with heated bed.

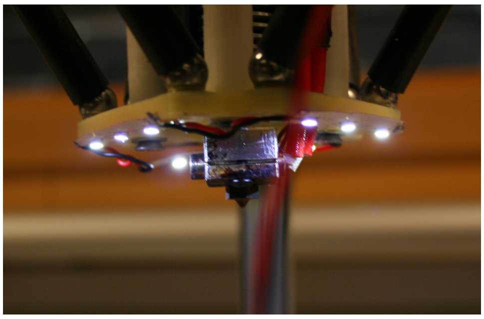

Figure 2. Extruder with hardened steel nozzle for printing carbon fiber filament.

This paper presents a horn antenna printed with three different materials. The aim was to combine functionality with a low cost using a 3D printer built in house at Chalmers University of Technology. The 3D printer is an FDM delta printer capable of 350°C nozzle temperature and 130°C bed temperature, see Figure 1, 2. The different plastic materials used are electrically conductive Acrylonitrile butadiene styrene (ABS), ColorFabb CopperFill PLA, which is polylactic acid containing 35% copper, and ColorFabb XT-CF20, Amphora polymer containing at least 20% carbon fiber. The goal is to print a horn antenna that is mechanically robust, heat resistant and/or can be electroplated without the use of a seed metal. The electrically conductive ABS has a resistivity of 4.8 Ω·m, a flexible modulus of 2 GPa and a maximum operating temperature of 88°C, see Table 1. The high operating temperature is a nice feature but the thermal conductivity is very low at 0.17 W/mK. As a complement to the soft and thermally isolating ABS we have the CopperFill PLA that is very hard and with a thermal conductivity so high that it is problematic to print because of thermal creep. This material is however heavy and brittle. The carbon fiber material is neither electrically or thermally conductive, but it is mechanically hard and durable. The three printed antennas in this paper have been reprinted until they reached similar quality as the others, but they all have different settings.

2. Design

The horn antenna was designed in Google Sketchup and can be seen in Figure 3. The design is a rectangular horn, a round flange and a WR10 waveguide. The WR10 has an opening of 2.54 mm x 1.27 mm and the total length of the structure is 49.27 mm, the width 26.66 mm and the height 20.81 mm. The total volume of the design is 3.025 cm^3.

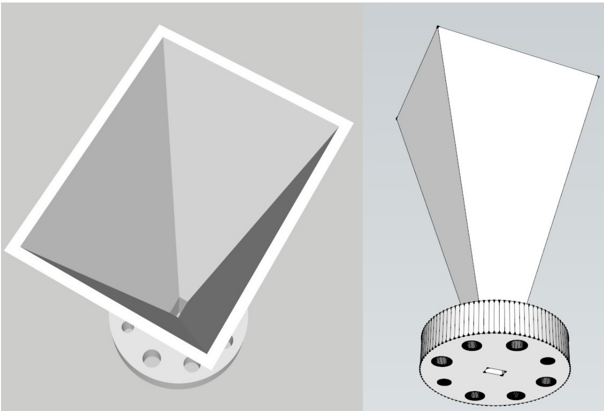

Figure 3. WR10 waveguide horn antenna. The total length is 49.27 mm, the width 26.66 mm and the height 20.81 mm.

3. Fabrication

The aim was to print all materials with the same quality, using a 0.25 mm nozzle diameter and 100 μm layer height.

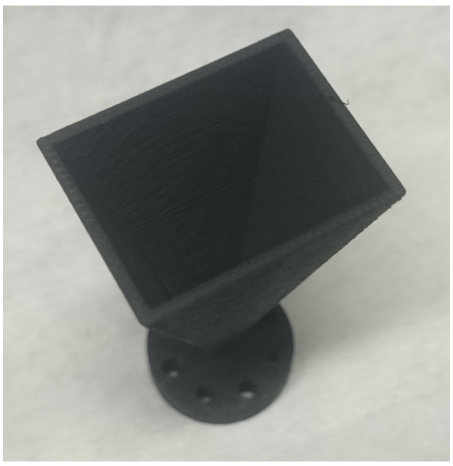

Figure 4. Electrically conductive ABS horn antenna.

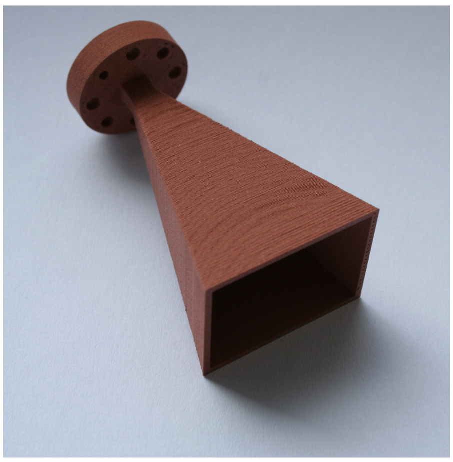

Figure 5. Thermally conductive PLA containing 35% copper.

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The conductive ABS needs to be printed on a heated bed to avoid warping and the temperature needs to be high enough to ensure good lamination between the layers. The bed temperature was 70°C and the nozzle temp was 240°C. Cooling of extruded plastic is necessary to ensure high quality and even though the part was cooled by a fan each layer had to be slowed down to wait for the previous layer to cool down and solidify. The thinnest part of the structure had to be slowed to a speed of 15%. The final product weighted 4.15 g and measured 49.3 mm length, 26.8 mm width and 20.9 mm height, see Figure 4. The total print time was 3h36min with a material and electricity cost of approximately €0.13.

The CopperFill have less inclination to warp and does not require a heated bed to print. However, because of the high content of copper – 35% – the thermal conductivity of the material is high. This introduces a problem, if the filament feed rate is too low the filament temperature will rise further up in the extruder and soften the plastic with a clogged nozzle as a result. Without changing the nozzle diameter the only choice to reduce clogging was to increase the filament feed rate by increasing the print speed and to decrease the nozzle temperature. The upside of a thermally conductive plastic is that when printed the layers cool down very fast and can be printed on within a few seconds. The weight of the CopperFill antenna was measure to 12.10 g and the measured length was 49.3 mm, width of 26.7 mm and height of 20.8 mm, see Figure 5. The increased print speed gave a print time of only 1h18min but because of the higher price/kg and with the high density material the total cost reached €0.80.

ColorFabb XT-CF20 is a very durable and stiff material that needs not only a heated bed but also a hardened steel nozzle because of the abrasive nature of the carbon fiber. When printing this material it has a tendency to gather excess material on the side of the nozzle as a viscous drop that, when released, can destroy the print. To avoid this somewhat the print speed needs to be reduced. The carbon fiber antenna weighted 4.36 g and measured 49.3 mm length, 26.7 mm width and 20.8 mm height, see Figure 6. The total print time was 2h35min with a material and electricity cost of approximately €0.30.

From a visual inspection the quality of the three different antennas are similar and none of the antennas needed any post-processing.

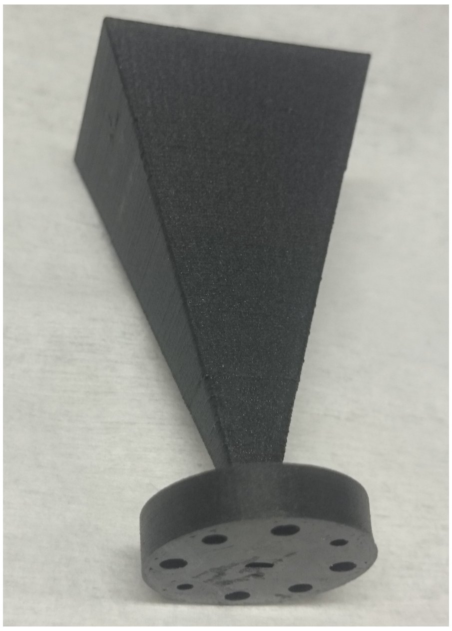

Figure 6. the horn antenna from the Amphora polymer containing at least 20% carbon fiber.

4. Discussion

When considering the antenna application with these materials it is well worth to discuss quality and post-processing. There is a limitation on quality with the CopperFill PLA because of the thermal creep and the minimum required filament feedrate. It is however possible to print the ABS and the carbon fiber Amphora with 50 μm layer thickness, which would improve the quality quite a bit, this will however double the print time. It is also possible to reduce the nozzle size for ABS to 0.1 mm with 20 μm layer thickness, with even higher quality prints as a result. This would however give print times for the ABS antenna of 3-4 days.

For the post-processing it can be required for the carbon fiber antenna because of the tendency of drops to form on the nozzle, it was however not needed during these prints. If a smoother surface is needed the ABS is the best bet, as it can be printed at higher quality and also has the possibility to be treated in acetone vapor or acetone bath, which will melt and smooth out the rough parts.

The cost of the printed ABS antenna was 6 times less than the CopperFill antenna. However, the cost for all materials were below one Euro, including the cost of electricity and can be considered to be very low cost compared to the current options. The time to print the antennas are almost 3 times longer for the ABS antenna compared to the CopperFill antenna but also here this is a very short time compared to weeks of lead time.

5. Conclusion

Three different materials were used to print a WR10 horn antenna. From visual inspection the quality of the different materials were almost the same. The time to print the materials ranged from 1h18min for the CopperFill to 3h36min for the ABS with the carbon filled Amphora in the middle at 2h35min. The cost of the antennas including electricity to power the 3D printer was calculated to be a mere €0.13 for the ABS, €0.30 for the carbon fiber material and €0.80 for the CopperFill PLA. The different properties of the materials was noticed either by how difficult it was to print the PLA containing copper because of the high thermal conductivity, from the toughness of the carbon fiber antenna or the electrical conductivity of the ABS antenna. It was also clear that the antenna design could have been more complex as the 3D printing of these antennas did not pose any difficulties from a design point-of-view.

Acknowledgments

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