Research of creating mold for crayons with use of additive manufacturing technique

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Abstract. For crayons manufacturing are often used big mold from steel. These molds are good for mass production, however they tend to be expensive and not suitable for low volume of production. Goal of this paper is to figure out, if these molds can be created by additive manufacturing technique, what materials are suitable for the job and how final products compare with products on the market manufactured with traditional methods.

1. Introduction
In current times, companies are trying to provide products, that are different from their competitors. In case of crayons that could be, by using more ecological materials, providing different colors, or have interesting shape.

Crayons, as waxed base drawing media are around 200 years old. Over that time there was a lot of development and improvements in used materials, and manufacturing techniques. [1] Based on type of crayon, or any waxed based drawing media, there are multiple ways of manufacturing. Most common technique for our type of crayon is molding or extruding. This is mostly done in big molds for high volume production. [2] In case company just want to manufacture lower quantities to test these variations, creating custom mold from materials like aluminium, or copper is not financially viable option. [3]

Additive manufacturing can however create products, that are relatively cheap to manufacture. Designers can also explore new shapes and are no longer limited by manufacturing technique which are relaying on removing material [4]. More advanced devices can also use wide range of materials with big range of properties like strength, melting temperature etc. Tolerances of parts manufactured by additive manufacturing could be also very good [5].

There are however several factors, that we need to consider during the designing the custom mold for the crayons. First is material, that is going to be cast into the mold. Crayons on the market are manufactured from paraffin mixed with color pigment. They can also contain glitter or perfume. They are naturally greasy and do not mix with water. Melting temperature depends on the exact composition but generally is under 60 °C. Material is mixed in factory, and then is pumped into molds of the desired shape. With one mold there can be manufacture up to 2400 crayons at once. Example of this device is on figure 1. [6]

For molds there is also requirements of be able to withstand multiple cycle of temperature change. Additional vents and paths for regulating temperature may be also required. Quick changes in
temperature can however cause inherent stress in, which may damage product and can shorten lifespan of a mold. [7]

![Figure 1. Example of machine for mass production of crayons](image)

Material for our crayons is from different material. Main ingredients are sunflower oil, Solid Ink and starch. Mixed material is starting to melt around 90°C and for pouring temperature at least 110 °C is required. This will be also our target temperature for creating mold.

Another requirement is dimensions and shape for these crayons, which was given as block with triangle base 50 mm on perimeter, and height of 100 mm. This requirement was later slightly modified by adding small radius on the edges due to manufacturing requirement.

Next requirement was price, where one mold should be manufactured with budget of 200 € without research and development. The number of manufactured crayons is expected from 2000 to 6000 crayons with various colors in 2-3 months.

2. Material selection

Main problem is melting temperature of casting material. It is unreasonable to use material as ABS or PLA. Even, when their melting temperature is over 200 °C, their translucent temperature is around 60-80 °C. Same limitation apply for material like Nylon, CPE or PET-G. That temperature would change shape of mold after first batch. There is also limitation, what can we manufacture. Considered materials, that are suitable for use in high temperatures and compatible with 3d printers on our department are listed below.

2.1. Onyx

Nylon reinforced with micro carbon fibers is the main proprietary material used in Markforge printers. It has higher strength and hire stiffness then Nylon, but more importantly it has higher thermal resistance up to 140 °C. It can also create smooth surface finish along Z axis. It is however expensive to manufacture.

2.2. HSHT Fiberglass

By reinforcing Onyx with High Strength High Temperature Fiberglass, we can push temperature resistance up to 150 °C. This material is also improving strength of the printed part. Disadvantage is higher price of the material and also printing time is significantly higher, therefore this is for us considered as final option for manufacturing. [8]
2.3. **TPU (TPE-U)**
Thermoplastic polyurethane is material with high elasticity. Main idea to use this polymer is make it easier to remove final cast from mold and do not damage final shape of the crayon. It has also good oil and grease resistance. This material is elastic in room temperature, and it is similar to silicon-based molds.

2.4. **Nylon CF15 Carbon**
Material from Fillamentum is Carbon Fiber reinforced nylon with high temperature resistance. Another advantage is chemical resistance and low thermal expansion. Other features like high hardness and high stiffness are not important in this case. This material cannot be printed with regular printing head. [9] It requires special printing head because of abrasive damage created by chopped carbon fiber inside the filament. It Also requires closed warm environment while printing. While this material has very good thermal and strength properties, final surface is rough. While it is similar to onyx, it has different composition, and it is used on different printer. It is also using bigger nozzle diameter at 0.6 mm, while onyx is printed with 0.4 nozzle.

2.5. **PC / PTFE**
Polytetrafluoroethylene is compound mostly find in food industry, because is non-reactive, has good natural lubrication and good thermal resistance. For manufacturing on 3d printer it is mostly combined with Polycarbonate as a base. Different manufactures however giving different requirements on printing recommendation, but in general nozzle on 3d printer needs to be able to heat up to 350 °C, heated bed up to 110 °C and good thermal regulation of printing area is also required. [10,11]

3. **Designs**
We experimented with multiple options and designs, where each version provided input for improvement in next version. Main factor for making design was to create the mold in a way, that it could be manufactured by additive manufacturing. Price of each mold was then calculated as price of material and price of printing. Price for printing is based on time needed to finish print and specific printer.

3.1. **Unsuccessful versions**
We started to experiment with existing models, that was providing by student company, that is developing these new crayons. First version was tested with Material TPU and with mold as shown on figure 2. Mold would be from two mirrored parts and if successful would cost around 12 € per mold.

![Figure 2. First version of mold](image)

Main problem was to manufacture mold with sufficient quality. We were unable to manufacture walls of the mold, that would meet required standards. Second problem was during pouring process,
when material would solidify too quickly, and it would block the input funnel. This prototype, while was not working, gave us valuable feedback on future design.

In second version we created 3-part mold, to create required shape. We also change material to Nylon CF15 Carbon.

With this variant we improve print quality of the walls as the walls was printed parallel with build plate. We also verified if the mold is able to withstand required temperatures. Price for this type of mold is around 35€. Main increase in price is due to more expensive material and different printer.

With these results, we decided change design around manufacturing requirements for this specific material. Reason for changing this mold was that crayon broke in half while removing from mold. Manipulation was also difficult, and this solution was not good for planned volume. This model however proved, that crayon will not stick at walls of mold and the liquid will not solidify too early.

3.2. Working prototype
The main change in next variant was to make mold from one part and for removing crayon from mold use custom ejection tool. We also tried to make walls at small angle under 0.5°. That would change final diameter on the end very slightly, but it could help with ejecting. We also tested, if the tip of the crayon could be shaped by the ejection tool, however we were unable to manufactured ejection tool with sufficient quality. Therefore, we used ejection tool without tip. We also tried different printing orientation of the mold.
This variant proved to be working reasonably well. There is however requirement to use big force for ejection, that can be reduced by using sunflower oil as a lubricant and ejecting it before it will completely cool down. For now, this is considered as acceptable drawback. We can also smoothen the walls inside the mold by switching material to Onyx. Final crayon is on figure 7. The print orientation does not have significant impact on the surface finish of the crayon.
Price of this working prototype is 50€. While there is the similar amount of material as in previous designs, print time is significantly higher due to requirement of small layer height.

3.3. Future development
The final challenge was to do multiple crayons at the same time. Based on our experience with one part mold we designed two molds. First proposed model is on figure 8 with custom ejection tool on figure 9. Main advantage is that we can keep flexibility of scalability of manufacturing in the future. This prototype is currently under testing and optimization.

![Figure 8. Mold for making 6 crayons at the same time](image1)

![Figure 9. Ejection tool for mold](image2)

Price of this assembly is around 80€ together without screws and bolts from Nylon CF15 Carbon, or 150€ by using Onyx with HSHT Fiberglass. This design was also accepted for future development. We are also planning to use HSHT material as our final solution to ensure longevity of the mold, however the Nylon CF15 Carbon is sufficient for further testing.

Our second design contains 16 chambers, each with spiral for liquid coolant, or heating, based on liquid temperature. This design was created as a concept for better thermal management during crayons casting. It is however expensive to manufacture, and thermal management can be done in different ways, that are cheaper. Design, as a concept can be used for further investigation, if necessary.

Main parts of this mold are input and output for the liquid, distribution pipes and spirals around each chamber. Front and top views with internal walls are on figures 10 and 11.
4. Conclusion
Aim of this work was to create mold by additive manufacturing technique for crayons. One of the main concerns was consider material, that can withstand required temperatures during casting the material into mold. Then we proceed with testing to manufacture mold, where we figure out, that because of difficulties with manufacturing process some materials are not suitable for this specific task. After this selection we started to look for best manufacturing parameters to achieve optimal result so final crayon can be easily ejected from the mold. We experimented with different shapes and different printing directions. After finding acceptable solution we continued with final design for the mold.

Our first successful test was one piece mold with separate ejection tool. This mold was manufactured from Carbon Fiber reinforced Nylon. Main problem for this design seemed to be correct ejecting temperature. This can be managed by time management or by reheating the mold itself. Based on that we continued with two separate designs to scale up production, where one of them was approved for future development. For manufacturing multiple crayons at once, we decided for hexagon configuration, because shape of the crayons allowed us to create maximum number of chambers per used material. This mold is still in testing. As a main problem is force needed for ejection of final crayons from the mold. This can be however improved by lever mechanism or by temperature management. Using sunflower oil as lubricant also helped with lowering ejecting force. This mold is also good for scaling up production by manufacturing more of them, if necessary. Six chambers per mold is now currently maximum, that is suitable with this specific configuration. For molds with more than six chambers, more research is required.

In comparison with crayons on the market, surface finish on our crayons is not as smooth, but considering crayons will be wrapped in paper, that is not an issue. The surface finish can be also improved by switching material for mold to Onyx. The 3d printer using Onyx can also print with higher accuracy, which will further increase quality of the print. Using PTFE is currently not suitable option due to difficulties maintain correct printing parameters.

For the future development we are expecting only small changes in the overall design, because of proven and tested form. Future development is still required for optimizing for ease of use. However, concept is working, so for now, we are not considering future research.
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