Title:
Leveraging Advanced Design and Novel Rapid Manufacturing Solutions to Respond to the COVID19 Pandemic

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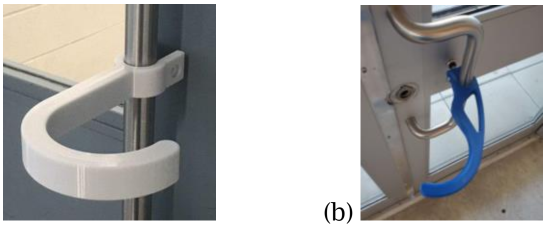
Introduction:
Coronavirus refers to a range of viruses ranging from the common cold to more severe illnesses like SARS (Severe acute respiratory syndrome) and MERS (Middle East respiratory syndrome). The disease caused by the new coronavirus has been named COVID-19 [8]. This virus was and still is very contagious and is easily transmitted via respiratory droplets, direct contact with infected persons, or by contact with contaminated objects and surfaces [2]. At the time of this research, there was no vaccine available for this pandemic and the main ways this virus could be stopped were:

- social distancing and proper use of personal protective equipment (PPE), such as face masks and face shields, and
- eliminating the transmission of the virus particles to your face from touching infected surfaces.

It is known that the novel coronavirus can live from hours up to days on different surfaces. Public health officials suggested that it would be safer if people could decrease the number of times, they touch their faces. The reason being, the virus could enter through the points of entry to our body, such as mouth, nose, and eyes. One study determined students touched their faces an average of 23 times an hour [5]. By calculating how much virus might be on each person's hands, the researchers were able to confirm that the touching posed a serious risk of disease transmission. A recent study found that, for most people, face-touching is a way of coping with stress, regulating emotions and stimulating memory [6]. Therefore, the overarching goal of this research is to reduce the disease vectors by designing, testing, optimizing, and fabricating a parametric set of hands free door handle product solutions. Several hands-free door handles were developed so that the commonly touched surfaces, i.e., a door handle or knob, are not touched by a person's hands or fingers during the opening and closing of doors. The forearm is used for opening doors. Novel low cost rapid tooling solutions are developed in tandem with the design activities. The specific sub-goals are:

1) Develop a 'pull' door bracket to mount onto fixed door handles or bars (Fig. 1).
2) Develop a 'twist and pull' and a 'twist and push' bracket to mount onto commercial doorknobs, including selected rotary and lever handle models.
3) Develop parametric models (this provides a basis for a universal solution for a range of doorknob styles and rapid tooling solutions); and
4) Develop rapid tooling solutions with integrated cooling systems to readily mold replicates.

This research paper focuses on items (1) and (4).



(a) (b)

Fig. 1: (a) Original J-hook model, (b) offset bar optimized J hook model.

<u>Main Idea – Research Approach and Contribution:</u>
The process flow for this research is presented in Fig. 2. All products were designed in using Solidworks and Fusion360 CAD software. Finite element analyses were performed using CATIA V5, and topology analyses were done using Solidworks simulation tools. Several door and door handle designs were reviewed. Force, moment, and motion analyses were done to determine pull and twist forces, and comfortable engagement. Internal and beta testing highlighted issues related to comfort and usability. Three J-hook family of parts solutions were developed. Representative design solutions are illustrated in Fig. 3 and realized using a material extrusion additive manufacturing (AM) process.

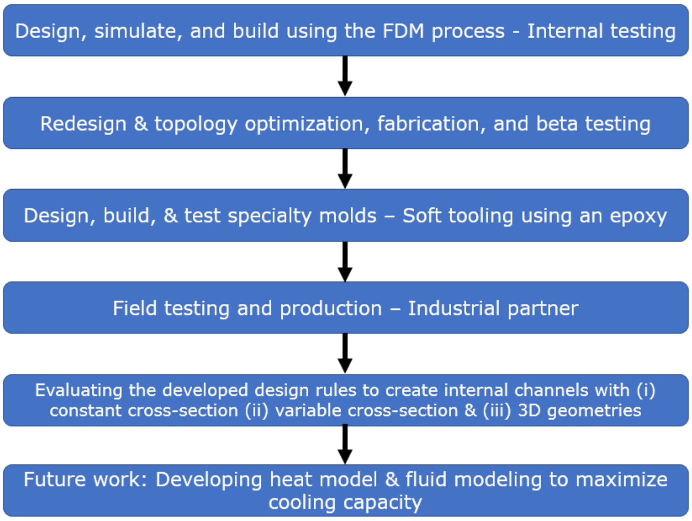


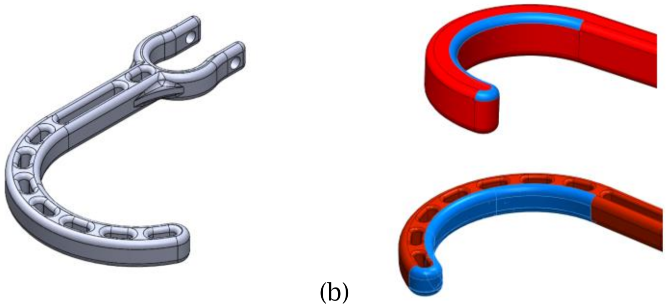
Fig. 2: Research process flow.

The Fortus 400 MC fused deposition modelling (FDM) process was employed to fabricate the alpha and beta prototypes using ABS (acrylonitrile butadiene styrene) material. The J-hook shown in Fig. 1 takes 3.5 hours to build and uses 138 cc of material. The material costs $36.60 (US). The J-hook type II lever handle in Fig. 3 (b) takes 11.5 hours to be built and requires 255 cc of material ($67.70 US for the material costs). The design to product realization time period is compressed, but this process is too expensive and time consuming for leveraging it for general public / commercial purposes. Therefore, the product design and 'design for manufacturing' strategies are addressed in tandem to optimize the designs for molding. Novel mold fabrication solutions are developed. Autodesk Moldflow simulation software is used to determine problematic areas, and to provide insights into the feeding system design. Aremco 805, a high temperature thermally conducive epoxy, is used to make the soft tooling [1], and TECHNOMELT PA 7846 BLACK, a high melting temperature thermoplastic, is utilized for the molding material [3]. This is a durable material that can withstand moisture and a variety of environmental conditions. ABS is prone to moisture absorption and products built by ABS will degrade. However, the working temperature of the TECHNOMELT PA 7846 BLACK is 200°C, so building tooling directly from AM processes such as FDM is not feasible. Other AM processes, such as a powder bed system, are costly. Therefore, the flexibility of the FDM process is leveraged indirectly.

(a) Pull (b) Twist and pull (heavy doors) (c) Twist and pull (office and residential)

Fig. 3: (a) J-hook type I for pull only doors, (b) J-hook type II for twist and pull level style doorhandles, (c) J-hook type III, for spherical and tapered residential and office doorknobs.

Design for Manufacturing approaches are explored to ensure that the designs can withstand the loading requirements but are also moldable. The contact area must be comfortable to the users. The final design for J-hook I is shown in Fig. 4.

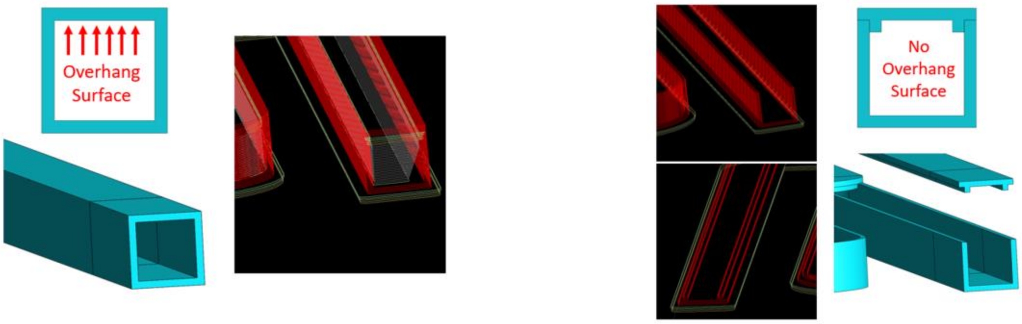


(a) (b)

Fig. 4: (a) Optimized J-hook type I design, (b) contact area of the original and new designs highlighted in blue.

Cooling lines need to be incorporated as the mold body is thick, and to shorten the cooling time. Conformal cooling approaches were investigated. An intricate solution is utilized to illustrate the proof of concept. The soluble support material (SR30) used for the Fortus 400 MC is employed to create complex cooling channels. This solution leverages the advantages of the AM and FDM processes in an indirect manner, and does not introduce support structures, which is a problem with the state-of -the-art conformal cooling solutions [7]. Specialty tool paths for the cooling channel patterns were created manipulating the Insight® process planning software. Both the ABS build material [4] or support material can be employed to fabricate a mold cavity pattern. Here, the soluble support material is used for this as well. To create the cooling channels, the SR30 soluble support material is embedded inside the Aremco 805 epoxy. When the epoxy is fully cured, the mold section is placed inside the support removal tank. Once the embedded support material is exposed to the support removal solution, it is removed, and a channel is created inside the epoxy enclosure. The channel test experiment is shown in Fig. 5. Several design rules (i.e. split rule) were developed and leveraged to avoid using additional support structures on the inside of the complex channels (Fig.6). Fig. 7 shows the mold assembly and a fabricated component. The mold build time is around 108 hours, and the mold insert epoxy material costs are less than S330.00 (US). The mold building time includes the time to build the sacrificial cooling channel components, curing the epoxy (24 hours, which can be reduced to 3 hours using a heat cycle and controlled temperatures), and dissolving the soluble material. Using the Technomelt, the product material costs are $6.15 (US). This is a significant price reduction while using a more robust and durable material. Ancillary hardware costs are less than $50.00 (US). The pouring and cooling times are 1.5 min. An inhouse injection testing system is employed. The cycle times should be lower using commercial injection molding machines. Because of the cooling system, the solidification time is minimal.

Fig. 5: CAD design of the cooling channel experiment – The red section is made of soluble support material, (b) embedding the soluble support material, (c) pouring Epoxy Aremco 805, (d) after dissolving the support structure and testing the channel.

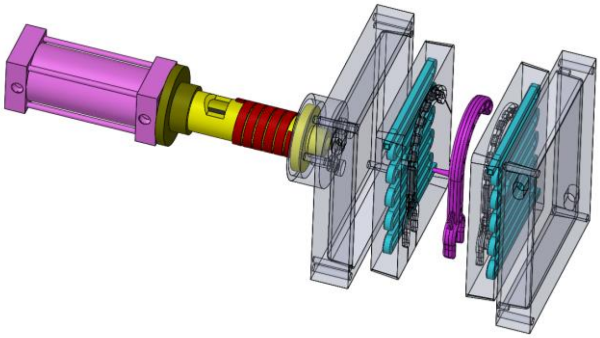


a) b)

Fig. 6: (a) Cooling channel designs as one-piece design, (b) Split design to avoid using support structure for overhang surfaces.

Conclusion:

Advances in developing rapid tooling are continuing to progress. The urgency for specialty products is heightened during this COVID-19 pandemic, but a rapid tooling solution needed to be developed as well as the products. Several hands-free door handles variants were designed The FDM process helped quickly validate design ideas, but it cannot be effectively used for higher production volumes. Using epoxy and the FDM AM process in an unconventional manner, a mold with a moderately complex shape and intricate conformal cooling channels is manufactured without support structures. By using the rapid tooling solution and leveraging 'waste materials' in this work, the build time for the J-hook was significantly reduced from 3 hours (FDM) to less than 2 minutes (injection molding). Additionally, the dimensional error of the injection-molded J-hook is less than 3 % and the warpage is almost 1 mm across the length of the component. In contrast to expensive conventional mold making processes, less than $500 (US) is used to build this tooling setup and the material piece price of the J-hook is reduced from $36.60 (US) to less than $6 (US). This technology opens up opportunities to manufacture molds that could reduce the cooling cycle significantly compared to conventional injection molding processes, where introducing conformal cooling channels with the desired geometry currently is not feasible.



a)

b)

Fig. 7: (a) Epoxy mold design exploded view, where the purple geometry represents the part, and the blue channels represent the cooling channels inside the mold; (b) a molded part.

Future work:

Future work activities include investigating more complex cooling designs for other products. Molds that include varying cross-sectional geometry, and 3D (non-planar) cooling channels, will be explored.

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