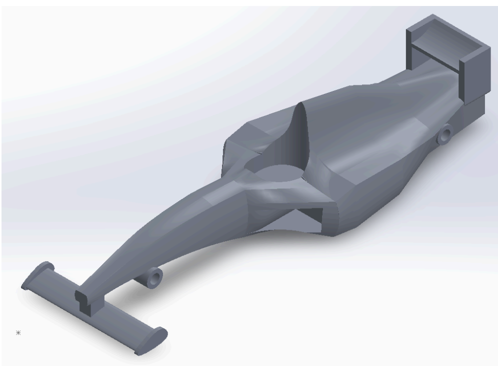
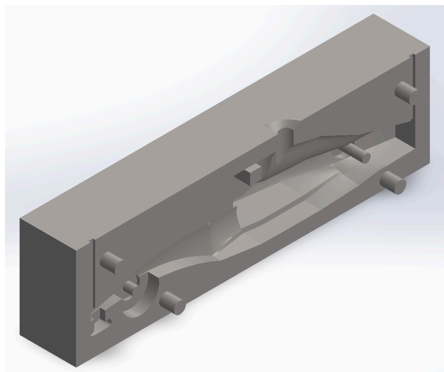
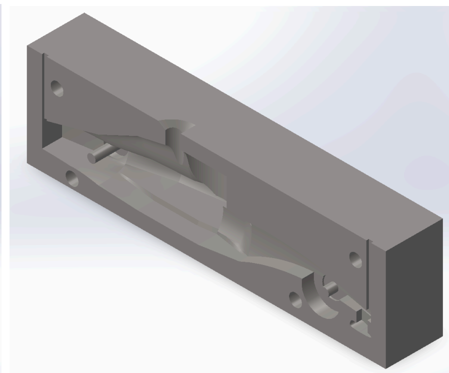
MATERIALS AND PROCESSES IN MANUFACTURING FINAL PROJECT REPORT

Background Research:

Traditionally car model replicas are created mainly using die casting and injection molding. Die casting involves forcing molten metal into a highly-pressurized cast which holds the shape of the desired model. The mold is enclosed tightly together until the desired model is formed. This manufacturing process is used for the car body. This produces strong durable parts with good dimensional accuracy. Die casting is not used to create every part of the car model due to cost effectiveness. Another popularly used process is injection molding with plastic. Plastic is injected for wheels and other small accessories of the car. This allows for complex, detailed shapes with high repeatability and fast production. Other methods used such as the stamping process on sheet metals such as aluminium sheets allow for high speed production of thin metal components like base plates and chassis.

Car Body Production:

For my project, I chose to replicate a model of a F1 race car. The overall dimensions of the replica will be 2” x 2” x 6”. The car body will be made out of A356 aluminium alloy. This material was selected because it is a common metal used for casting since it has optimal flow, fill, and solidification properties. From this it is decided that metal casting will be the process used to make the car body, specifically sand casting. Sand casting is chosen instead of the traditional die casting due to a few reasons. One main reason is because of the complex geometry of the F1 race car model. It would be significantly easier and cheaper to make a sand mold for this model than machine a die mold. Adding on to this, in general the die mold is a lot more expensive than the sand mold. Due to this die casting is cost effective when used for high volume production, however in this case only one model is being made so sand casting would be the cost effective option. Lastly, one big advantage of die casting is its excellent dimensional accuracy but because this is only a model with no practical functionality, dimensional accuracy is not a big concern so the more cost effective though larger tolerance sand casting will suffice.

Sand casting is a widely used and cost-effective manufacturing process in which molten metal is poured into a sand-based mold to form complex shapes. The process begins with creating a pattern of the desired part, which is used to shape a cavity in the mold made from packed sand. This pattern will be a 3D printed resin model of the F1 car body. A core made of sand is used to fill the cockpit area. A gating system (comprising a sprue, runners, gates, vents) is incorporated to direct the molten metal into the cavity. Once the pattern is removed, molten metal is poured into the mold, allowed to cool and solidify, and then the sand mold is broken apart to retrieve the casting. Finally excess metal is trimmed off to clean off the part.

Getting into details and specifics, the material used is A356 aluminium alloy so the molten metal will be poured at around 730 °C for good flow and fill to fill the mold before the metal solidifies. Vents are placed to ensure uniform mold temperature. The geometric designs of the gating system for optimal pouring can be calculated as well using Bernoulli’s theorem and the law of mass continuity. This is significant because the molten metal should have a constant flow rate in order to maintain contact with the mold walls, which prevents entrapment of air that would result in defects in the final model. In these calculations it is assumed that the fluid is incompressible. The material properties used are that of A356 in liquid form. The flow is also assumed to be frictionless as well so c = 1.

$$v = c\sqrt{2gh} = 1 \cdot \sqrt{2 \cdot 9.81 \cdot 0.15} = 1.716\, m/s$$

$Q = A_2 v = 0.0001 \cdot 1.716 = 0.000172\, m^3/s$

$Re = \frac{v d \rho}{\mu} = \frac{1.716 \cdot 0.01129 \cdot 2400}{1.2 \cdot 10^{-3}} = 18747$

The flow velocity assuming frictionless flow is calculated to be 1.716 m/s and this results in a flow rate of 0.00172 m^3/s. This is estimating the height of the sprue (pouring height) to be 0.15 m and the cross sectional of the area at the bottom of the sprue to be 1 cm^2 or 0.001 m^2, which is a reasonable estimate for the size of the car model. The Reynolds number is then calculated from material properties of liquid A356 aluminium. From the Reynolds number we see that this is flow that has properties of both laminar and turbulence. This means there needs to be constant pouring to minimize air entrapment and formation of air bubbles.

$\frac{A_1}{A_2} = \sqrt{\frac{h_2}{h_1}} = \sqrt{3}$

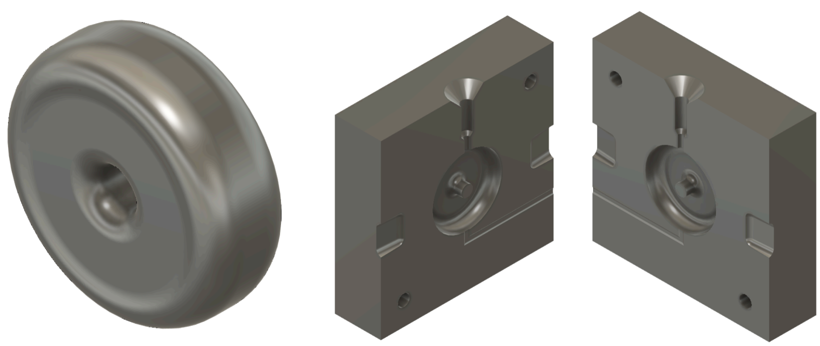
$A_1 = A_2\sqrt{3} = 0.0001\sqrt{3} = 0.0001732\, m^2$

$d = 2\sqrt{\frac{A}{\pi}},\ d_1 = 14.85mm,\ d_2 = 11.29mm$

$tan(\theta) = \frac{r_1 - r_2}{h},\ \theta = tan^{-1}(\frac{0.00742 - 0.00564}{0.15}) = 6.45°$

The area at the top of the sprue can be calculated as well. With both the area at the top and bottom of the sprue, the diameters can be simply calculated. From this the overall sprue taper angle is established to be 6.45°, this angle will ensure that the flow rate is constant throughout to maintain contact with the sprue walls and optimize fluid flow while pouring.

Wheel Production:



The wheel of the car will be injection molded to accommodate the curved geometry of such a small part because of injection molding's ability to support complex geometries of various sizes. Injection molding also is a relatively fast, high production process, which is significant in this case as four wheels will be needed. The material selected will therefore be PLA or Polylactic Acid since injection molding is used to manufacture polymer parts and PLA is a commonly available thermoplastic. The injection molding process starts with PLA pellets being fed into a heated barrel. This barrel would be heated to around 300 °C. The plastic melts and is pushed forward by a plunger. Molten plastic is injected under high pressure into a metal mold cavity. The part cools and solidifies, then the mold is opened through prying and the part is ejected from the mold and cleaned up. After all four wheels are manufactured, the wheels are attached to the car body to be assembled.

To create molds of the wheels for injection molding, conventional machining or material removing process is required, specifically milling. Material is removed from a stock sized 1.875" x 1.875" x 0.5" by rotating multi-toothed cutters while translating the workpiece that is the stock. The stock should be a metal as metals are thermally resistant to temperatures that would melt plastics. Therefore, the material of the stock would be 6061 aluminium alloy as this is a commonly available stock metal that is relatively cost effective and easy to work with for High Speed Steel (HSS) cutting tools that are normally used for most milling operations. Assuming recommended parameters for cutting 6061 aluminium are used and detailed calculations of the milling procedure can be found.

$Spindle\ Speed = 10000\, RPM, Feedrate = 60\, in/min = 1524\, mm/min$

$Depth\ of\ Cut = 1\, mm, Width\ of\ Cut = 5\, mm$

$Rake\ Angle, \alpha = 10°\ , Chip\ Ratio,\ r = 0.5$

$Cutter\ Diameter, D = 10\, mm, Number\ of\ Teeth = 2, Cutting\ Force/Unit\ Width = 1000\, N/mm$

$Undeformed\ Chip\ Thickness,\ t_0 = \frac{Feedrate}{Spindle\ Speed \cdot Number\ of\ Teeth} = 0.0762\, mm$

$Chip\ Thickness,\ t_c = \frac{t_0}{r} = 0.1524\ mm$

$Shear\ Angle,\ \phi\ =\ \frac{r\cos(\alpha)}{1 - r\sin(\alpha)} = 28.33°$

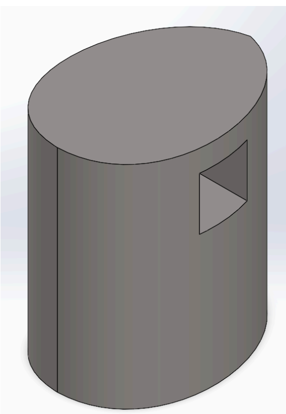
$Cutting\ Force,\ F_c = 1000\ N/mm \cdot 5\ mm = 5000\ N$

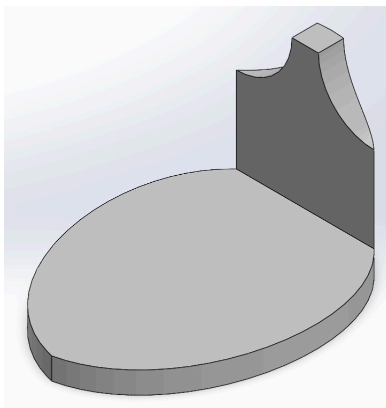
$Cutting\ Speed,\ V = \frac{\pi DN}{60000} = 5.24\ m/s$

$Cutting\ Power,\ P\ =\ FV\ =\ 26.2\ kW$

The cutting tools used are made of HSS (High Speed Steel): 0.125” ball end mill, 0.0625” ball end mill, 0.1” center drill, and 0.1285” drill. HSS is available to comfortably cut through 6061 aluminium. The Tormach 770M mill (From the MECE Machine shop) will be used for the milling procedure. It has a max travel of 14” x 7.5” x 13.25” which is more than enough for a 1.875” x 1.875” x 0.5” workpiece. The max feedrate is 135 in/min and the max spindle speed is 10000 RPM which are sufficient for the operations needed.

Cockpit Production:

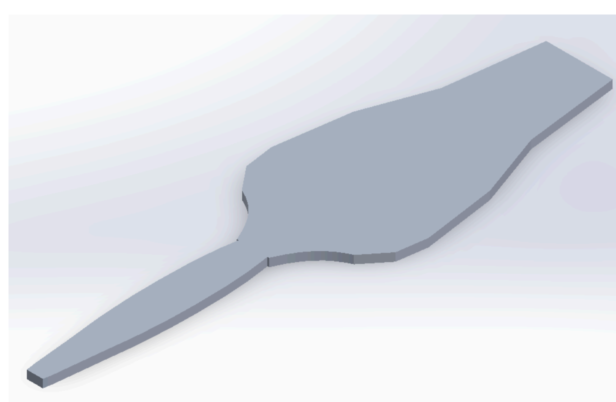




The cockpit seat will be produced through FDM 3D printing, an additive manufacturing process. The selected material will be PLA or Polylactic Acid, a common thermoplastic used for FDM 3D printing. 3D printing results in high quality parts with excellent dimensional accuracy for complex geometries of any size. Due to the small size of the cockpit seat, 3D printing will be optimal as it will be an accurate, time and cost efficient process. In the original mold, there was a core used to create negative space in the body. This negative space is the cockpit area. The 3D printed seat will fit snugly into this area. Outside of the 3D printed seat being a tight fit, it will be super glued down for extra security.

FDM 3D printing involves melting and extruding thermoplastic filament in layers to build parts. Filament is fed into a heated extruder nozzle that then deposits the melted filament on a build platform in successive layers as the nozzle moves vertically. The material solidifies quickly after extrusion and bonds with the previous layers. Settings such as the percentage of material (infill) and layer height can be controlled for strength and quality. The printer used for printing the cockpit seat will be the Original Prusa i3 MK3S+ (from the MECE Machine shop). The build area size will be 250×210×210 mm which is more than enough for the cockpit seat. The print will be run at settings of 30% infill for enough strength and 0.1 mm layer height for a fine, high quality print. The model of the cockpit seat will also have tolerances of -0.15 mm to accommodate for the expanding of plastic as it cools but also maintaining a tight fit of the seat in the cockpit area.

Chassis Production (Waterjet for extra credit):



The chassis of the car will be made of 6061 aluminium alloy. It will be 0.125’ thick therefore a 0.125” sheet of 6061 aluminium can be used. Being able to use the stock material provides efficiency and 6061 is a common stock sheet metal that boasts great durability and machinability for a great cost. It definitely provides enough strength and durability for a replica model, while being cost effective. Since the chassis is just a contour on sheet metal, a cutting machining process will suffice. Additionally since 6061 aluminium alloy is selected, the waterjet cutting process will be used because waterjet cutting can cut metal while similar alternatives like laser cutting machining normally cannot. Waterjet cutting has moderate dimensional accuracy which suffice for a chassis that is being attached as a contour to the body of the model. After the chassis is cutted it can be cleaned up by smoothing the cut edges and finally integrated to the body by simply super gluing.

Waterjet cutting uses high pressure and high velocity water to cut through material. When cutting metal such as aluminium in this case, abrasive particles are added in the water. It is a cold cutting method which means no heat is generated during the process, which prevents thermal distortion or material hardening. The jet of water erodes the material along the desired path, guided by CNC (computer numerical control) for precision. Using parameters for cutting 0.125'' thick 6061 aluminium alloy, some specifics of the procedure can be calculated.

$Cutting\ Speed\ =\ 0.75\ in/min,\ Water\ Pressure\ =\ 60000\ psi\ =\ 4.137 \cdot 10^{8}\ Pa$,

$Flow\ Rate,\ Q\ =\ 1\ L/min\ =\ 1.667 \cdot 10^{-5}\ m^{3}/s$, $Efficiency,\ \eta\ =\ 0.85$

$Contour\ Length\ =\ 16\ in$

$$Cutting\ Time\ = \frac{Contour\ Length}{Cutting\ Speed}\ =\ \frac{16}{75}\ =\ 0.213\ min\ =\ 13\ s$$

$$Power,\ P\ = \frac{pQ}{\eta} = 8.1\ kW$$

A 75 in/min cutting speed is recommended for the material. The Ward Waterjet A-0612 (from the Makerspace) will be used in this procedure. It has a max cutting speed of 500 in/min so this machine will be sufficient.

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