FINAL REPORT

RELIABLE MOLD DESIGN FOR SMALL CARBON FIBER PARTS

Prepared by The Jayhawks
Stefano Bernardo
Kyra Dutton-Piskorik
Amitoj Singh
William S. Trujillo
Mechanical Engineering Technology Students
Northern Alberta Institute of Technology (NAIT)

Report Distributed on April 21st, 2021

Prepared for Rick Chetram, Scott Sparling, Michelle Zhang
MCEN2471 Instructors
NAIT Mechanical Engineering Technology

EXECUTIVE SUMMARY

The purpose of the following report is to present The Jayhawks' method of mold production for small parts that the University's Formula Student team can implement for assured results in the fabrication of their race car. The body of this report contains information about the sponsor, the project, and a technical description of The Jayhawks' final design, followed by any manufacturing considerations and final recommendations. Methods chosen for the design process include a reusable fixture board that is cut on the team's CNC router, SLA 3D printed part models to create the part mold, and a specialized sealer coating that prepares the mold for use in a single step. Through the final design, the total time required to create a part mold was reduced to roughly 26 hours (time dependent on part size) and roughly 30 minutes of direct labor time. Part molds produced using the designed method are expected to have high durability and accuracy to the 3D CAD model, while greatly reducing the direct labor times associated with preparing the mold. Some recommendations The Jayhawks have for the team for further improvements are integrating topology optimization[1] to minimize the amount of material used in the 3D print and recommended release tools for safely removing parts from molds without risk of damage to the coating.

Topology Optimization [1] is a method of computer aided design that uses finite element analysis to mathematically determine the least amount of material that can be used in a given structure (Velling, 2020).

ACKNOWLEDGEMENTS

Acknowledgement from the team:

The Jayhawks would like to acknowledge the University of Alberta's Formula Student team for providing valuable information regarding the project and the current process used for mold production. The team would also like to acknowledge NAIT and the instructors of this technical project for facilitating the team with questions and concerns found throughout the semester. A special thanks to Mr. Rick Chetram for providing his insight and project management experience to the team particularly with technical writing, the project plan, and team charter. Finally, the team would like to acknowledge the various product suppliers that have been in contact with the team and have provided information from which we have based sections of our report on: Münch Chemie International, Home Depot, Formlabs, and the Elko Engineering Garage.

Sincerely,
The Jayhawks

Acknowledgement from Stefano Bernardo (team liaison):

I, Stefano, would like to extend a special thanks to the team at the University of Alberta for welcoming me to be a participating member of Formula SAE for 26 months to date. I particularly found interest in the construction of the car and how the designs that came from 3D CAD models became real world objects. As I continued school and started my program at NAIT, the team still welcomed me and slowly the language of engineering began to make more sense as I went further into my courses at NAIT. Throughout my time helping at U of A, I always paid careful attention to the process and what kind of improvements the team could use in order to get to that next step in competition, so it was natural for me to create a project like the one before you to conclude my time at NAIT and the U of A.

In addition, I would like to extend special thanks to select members of the team who I feel have given me opportunities or valuable information throughout my time with them[redacted] and the entire Formula Racing Team at the University of Alberta. You each welcomed me and allowed me to pursue my interests in race car design & manufacture; for this I am eternally grateful.

One final thanks goes out to Mr. Scott Sparling for allowing me the opportunity to have this subject as the basis of my technical project here at NAIT.

Sincerely,
Stefano Bernardo

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1.0 INTRODUCTION

The Society of Automotive Engineers (SAE) presents Formula SAE–or commonly referred to as Formula Student–as a student design competition for engineering undergraduate and graduate students to develop, fabricate, and race a student designed vehicle on a closed-circuit track (SAE, 2019). University teams are challenged to demonstrate a variety of performances throughout a series of Static and Dynamic events and are ranked based on the creativity and functionality of design (SAE, 2019). Three competitions are hosted in North America, and in 2019, 224 teams participated with an average team of 23 participating members (SAE, 2019)–in 2019 the University of Alberta had 10 participating members attend the event at Formula North (Barrie, Ontario, Canada).

With less than half of the participating members of other teams, the University of Alberta is a relatively small team of students that is competing in these events. Because of this, the team's most prominent struggle is time–often finishing the car on the road to competition or not at all. The Jayhawks are tasked with finding an improvement to the production processes of small part molds that the Formula Student team can use for assured results–allocating less time to fixing failed work and more time to complete the design/fabrication.

Utilizing knowledge gained through Tool & Fixture Design, Modern Manufacturing, Cost Estimating, Fluid Mechanics, Strength of Materials, Productivity Improvements, and Quality Assurance, the Jayhawks have come up with the solution of a high reliability process of producing vacuum molds for small carbon fiber parts.

Figure 1: U of A's Model UA-20 (Alberta FSAE, 2020)

1.1 Background and Problem Statement

The University of Alberta's Formula Student team has been participating in Formula SAE events for 23 years with varied success. For several years, the team experimented with producing carbon fiber parts and again with varied success. Two issues have been prominent in the past trials: first is that processes that require more "hand feel" or "by-eye" measurements take longer to produce and increase likelihood of failure; secondly, processes with no user input (i.e. machining molds from raw stock) are typically costlier. This report is compared to the latest process used by the team for production of small carbon fiber parts which is explained below.

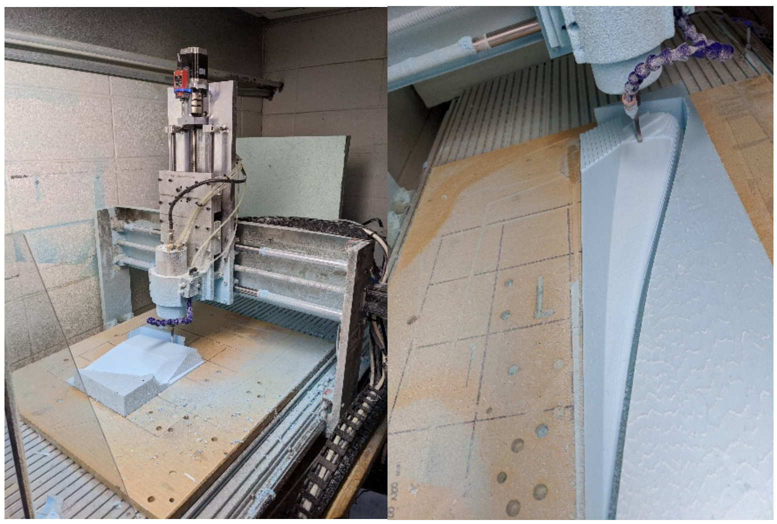
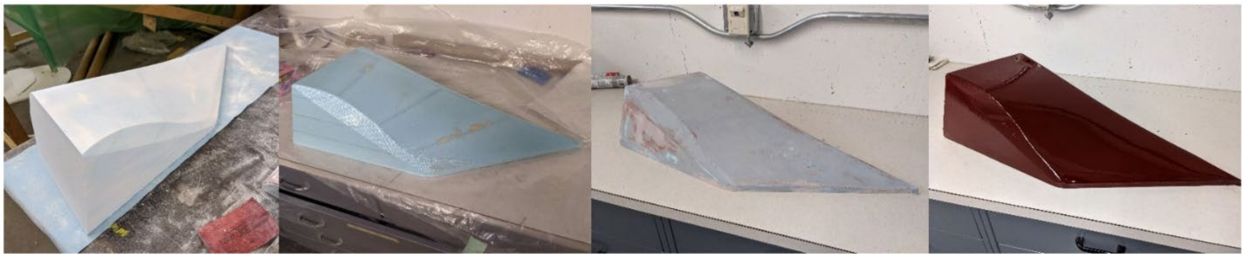


Figure 2: Foam Part Model on CNC

The production process starts after the desired parts are designed and modeled in SolidWorks. The process begins with contouring high-density insulation foam on a CNC milling machine that is available to the team in their dedicated shop. Due to the *z* height limitations of the CNC, part models that are taller than 2.5 inches must be segmented into layers which are later glued together to replicate the entire part. Currently there is no method of locating layers during the glue process, so layers that are glued "by-eye" may be offset and require additional forming by hand to get the part down to the correct shape. Once the foam part model has been contoured/assembled more hours of post processing are required to prepare the mold for usage.



1 2 3 4

Figure 3: Multi-Stage Process to Prepare Molds

As seen in figure 3, many steps of post processing are required, adding an estimated 100+ hours to the process to move from stage 1 to stage 4. In the first stage, the layered foam model is hand sanded to correct any defects made by the gluing stage and the whole model is sealed with layers of body filler in preparation for the 2nd stage of post processing. A repeated process of filling and sanding also occurs at this stage in order to ensure a proper sealing of the foam and to keep the desired shape of the part model. After the part model has been sealed with filler, a single layer of fiberglass is laid onto the model (as seen in figure 3, stage 2) for rigidity to withstand the forces applied under vacuum. The part model once again goes through a process of filling and sanding until the model has been filled of all low spots and sanded smooth for the final stage. The final stage in the current process involves the application of a gel coating which is applied to attain the required surface finish needed for releasing apart from the mold. The gel coating is the final stage of post processing required prior to applying the mold in the vacuum infusion process and the model is now ready for use.

Since the designed part models are made to replicate the 3D CAD models, no consideration is currently being made for how the vacuum bag seals to the mold. Current lay-ups are done by creating an envelope vacuum bag of which the laid-up mold can be moved into. Two issues that this method creates is that first, the vacuum bag is susceptible to air leaks as the geometry of the envelope bag is often too complex to accommodate the shape of the part, and second, the carbon fiber material can shift as its moved into the vacuum bag resulting in defective parts. An image of the current vacuum bag set-up can be seen below in figure 4.

Figure 4: Current Vacuum Bag Set-Up

Although precautions are made to prevent failed parts, pin-holes in the fiberglass and filler layers allow resin to absorb into the foam under vacuum pressure (seen in figure 5), dissolving the mold from the inside-out. The failed mold effectively wastes all the time and materials put into creating the part, and for a small team like the U of A, this lost time is detrimental to successfully completing the car for competition.

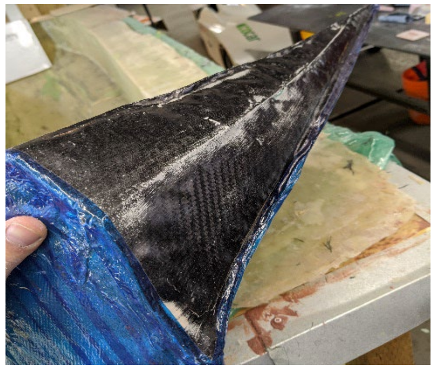


Figure 5: Failed Part Mold

1.2 Objectives and Goals

The objective of the project is to streamline the mold-making process currently being used by the team at U of A. The primary goal of the project is to decrease the direct labor time required to make the molds while also maintaining a high degree of repeatability and accuracy to the designed part models. The designed mold also has to meet the team's standards regarding the finished parts made from the mold and, overall, the design should be simple. A secondary goal was for the presented design to be cost-effective and use available resources where applicable.

1.3 Scope and Constraints

The intended use of this report is to improve the process that the University of Alberta's team can use for producing small carbon fiber part molds to allocate more time to other areas of building the car for competition. As such, this report will cover the proposed process for making small part molds, insights into the materials and technologies used, and an overall process plan to guide the team in implementing this process.

The scope and constraints of this project have been set based on the assumption that the University's team is already familiar and capable of the processes in the mentioned areas. Those areas of research that are beyond the scope of this project are:

- Analysis of carbon fiber weave types, material thickness, or fiber orientation.
- Information regarding the vacuum infusion process such as consumables, and steps in the process.
- Required curing times/temperatures for making carbon fiber parts off the designed mold.
- No physical build will be made throughout the duration of this project.

1.4 Design Specifications

The final design must be able to produce carbon fiber parts with a high degree of accuracy and must outline all required processes to be fully functional. Forces and material properties must be considered, and calculations should be displayed as required. A complete bill of materials as well as cost and time estimates must also be included. Environmental considerations and relative usage of materials have also been considered as a way of minimizing waste. The proposed method must also be simple and easy to implement, not requiring advanced skills or specific operators to produce.

2.0 CONCEPTS

This section consists of an overview of The Jayhawks' initial design development process, with a comprehensive explanation of the 3D printing technology used for the mold design. A detailed explanation of the resin used, surface finish and tolerance information regarding the 3D printing is available in this section. The team made sure that intricate details for each of these processes, along with the rationale behind them are present. The team also explored environmental considerations to include in the design and finally, the advantages and disadvantages of the Stereolithography (SLA) technology are listed to conclude this section.

2.1 Preliminary Design (4 Blockers)

The team initially considered a range of ideas such as an all MDF mold, foam-over-block (plug) design and vacuum forming. Over time, the ideas were refined to the point where the team decided to go the 3D printed route, with the mold mounted on an MDF fixture board. The team found this combination of ideas to work out most effectively in terms of time savings and simplification of assembly and mold making. Each of the members submitted two ideas which were then combined and refined to create a single 4-blocker as a basis for the preliminary design as seen in figure 6 below.

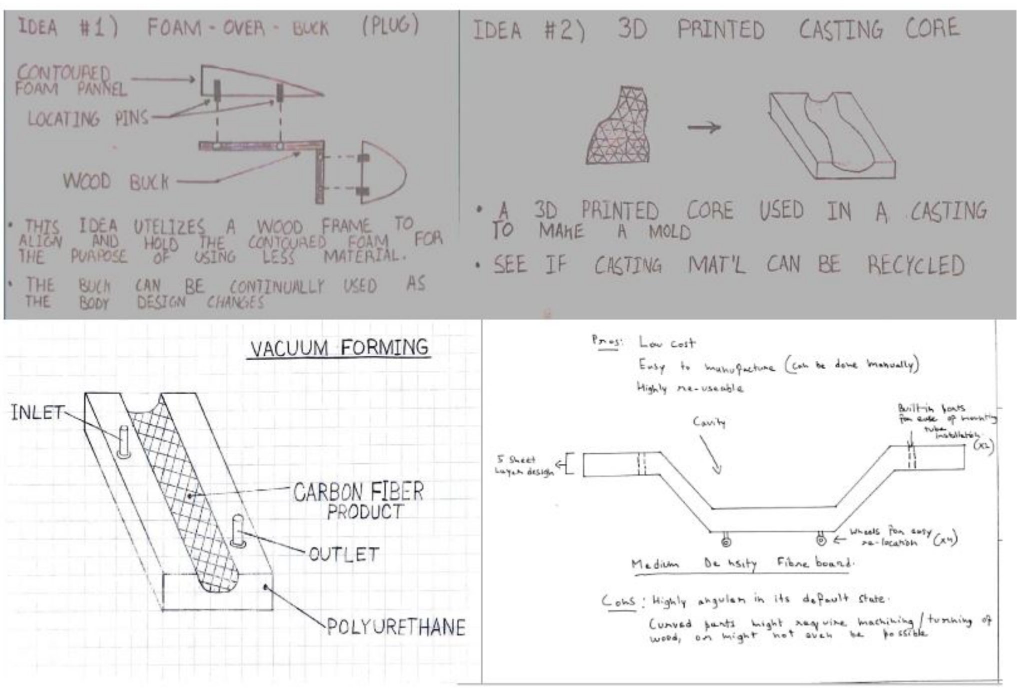


Figure 6: The Jayhawks' 4-Blocker

2.2 3D Printing Technology

The 3D printing technology has completely revolutionized the way many products are manufactured. High tolerances, smooth finishes and repeatability of design are now achievable at a scale never thought possible. After considerable research into various mold-making techniques as detailed in the team's 4-Blocker, a collective decision to use the 3D printing technology to manufacture the mold was made. It would result in relatively quick manufacturing and ease of maintenance/repair. 3D printing itself is quite a diverse field of electronic devices and techniques. Research into different types of 3D printers along with their benefits and shortcomings was performed as a result.

2.2.1 Stereolithography (SLA)

Stereolithography (SLA) excels at producing parts with tight tolerances and smooth finishes. Stereolithography resins are liquid UV-curable photopolymers (in other words, forms of liquid resin that can be hardened into plastic). Material properties vary according to formulation configurations. Materials can be soft or hard, heavily filled with secondary materials like glass and ceramic, or imbued with mechanical properties like high heat deflection temperature or impact resistance (3D Hubs, 2021). Stereolithography's biggest advantage is also speed since parts can be produces mostly within a day. This is also the best type of 3D printing technology for functional prototyping, tooling and mold making (Formlabs, 2017). Some of the other technologies researched, while giving promising results, could still not compare to the kind of benefits that could be achieved using SLA. Some of the other technologies researched were Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM) and Multi-Jet Fusion (MDF).

Selective Laser Sintering (SLS) and Multi-Jet Fusion (MJF) are similar types of 3D printing technologies that use various thermoplastic nylon powders, which solidify into plastic. While SLS uses laser to scan and sinter each cross-section, MJF uses an inkjet array to apply fusing agents to the nylon powder, after which a heating element passes over the product to solidify the material (Formlabs, 2017). Parts manufactured using the SLS technology result in rougher surface finishes which might not be very ideal for a mold, since a smooth finish is essential for high accuracy and repeatability (3D Hubs, 2021). Compared with the SLS technology, MJF is also preferred if higher dimensional accuracy is required; however, MJF is still no match for the precision achieved using stereolithography technology. Fused Deposition Modeling (FDM), on the other hand, is a technology where a plastic filament is extruded layer-by-layer onto the 3D printing platform (Papp, 2020). Although FDM is highly cost-effective and quick, the parts produced are quite rough in terms of their surface finish and lack strength (Formlabs, 2017). Therefore, while this technology is good for producing smaller parts which are not very significant from an engineering standpoint, mission-critical parts generally cannot be produced using this technology.

2.2.2 SLA Resin

The Formlabs Standard Black Resin (RS-F2-GPBK-04) (Formlabs, 2021) is a suitable material selection for the application of SLA 3D printing in a male-mold-making-process combined with vacuum resin infusion. The resin is compatible with the Form 2 printer which is available to the University and is the most cost-effective option. The most pressure the mold needs to withstand is a perfect vacuum pressure of 14.7 psi, and according to the Formlabs materials property data, (Formlabs, 2021) the Standard Resin has a flexural modulus of 181 ksi pre-cured and 320 ksi post-cured, and a tensile modulus of 234 ksi pre-cured and 402 ksi post-cured. This data is evidence that the chosen resin is more than capable of withstanding the vacuum resin infusion process without warping or causing other deformations to the mold.

2.2.3 Environmental Considerations

When working with SLA resin, it is important to consider the environmental and health impacts it can have. There are environmentally friendly SLA resins available that use soybean oil, for example, which break down much faster than a traditional resin (All3DP, 2021). Unfortunately, it is not realistic to use a biodegradable resin with the Form2 printer available, as Formlabs does not produce an eco-friendly resin and third-party resins often produce unreliable parts and may damage the SLA printer (Formlabs, 2021). Given that this project targets small molds with production at low to medium frequency, it is not a concern about how much waste will be produced.

2.3 Surface Finish and Porosity

Surface finish obtained using the SLA is quite smooth when compared to the other 3D printing technologies. With tight dimensional tolerances obtained as a result of the UV curing within SLA, the final surface finish is quite desirable from the perspective of mold making and engineering parts (Shop3D, n.d.).

2.3.1 Sealer Coating

Due to the porous nature of plastic 3D printed models, a coating must be applied to the surface to prevent the model from absorbing resin under vacuum, as well as ensuring a smooth surface finish from the part mold. For a sealer to be deemed appropriate for this process it must fulfill two criteria. First, the coating must be self-leveling; this feature is to ensure that the resolution (visible layers) of the print does not translate into the finished part, while also saving time by eliminating the need for post processing of the 3D model. Second, the chemical composition of the coating must be such that it does not react with any other materials throughout the process (the 3D model, fixture board, epoxy resin, etc.).

The proposed coating for this application is Mikon 399 MC from a German company Münch (Münch, 2021). This product is specially designed for producing reliable, high quality molds, and because it is compatible with a variety of porous surfaces including MDF and plastics the Mikon coating will not react with other materials. The coating is also self-leveling designed for a maximum of 2-3 coating layers with a maximum thickness of 3 microns (Münch, 2021). The product is to be paired with a wax release agent prior to use (additional information can be found in the appendices).

2.4 Precision and Tolerance

SLA printing creates accurate, precise components. To create accurate and precise parts, multiple factors must be tightly controlled. The combination of the heated resin tank and the closed build environment provides identical conditions for each print and provides better accuracy. Since SLA uses light instead of heat, the printing process takes place at close to room temperature, so printing parts do not suffer from thermal expansion and contraction artifacts (Nutma, 2019). SLA produces a smooth surface finish; visually accurate parts are made each time. SLA printing has a dimensional tolerance of ±0.15% and a lower limit of ±0.01mm (Formlabs, 2019).

2.5 Advantages and Disadvantages

Advantages of SLA (Formlabs, 2019):

- High quality 3D models;
- Strong pattern like structures/finished products;
- Better resolution;
- Fast process (print time depends on height of 3D model);
- Unused resin can be saved.

Disadvantages of SLA (Formlabs, 2019):

- More expensive;
- No option for composite print;
- Resin can be cured in sunlight, prone to spilling;
- Removing model and draining excess resin can be time consuming;
- Completed models need to be washed, cured and dried;
- Material might warp when peeled away from printing bed;
- Large materials are likely to warp underneath their own weight.

3.0 FINAL DESIGN

The final design of this project allows the team to accurately translate 3D CAD models into functional production molds by using 3D printed models secured to a fixture board that is coated in a specialty sealer. Molds for small parts can be made with minimal error and to a high degree of accuracy in addition to a substantial reduction in associated labor time. Each component of the designed system can be seen together in figure 7 below and a technical description of each part is to follow (a complete bill of materials can be found in the appendices).

3.1 Technical Description of Parts

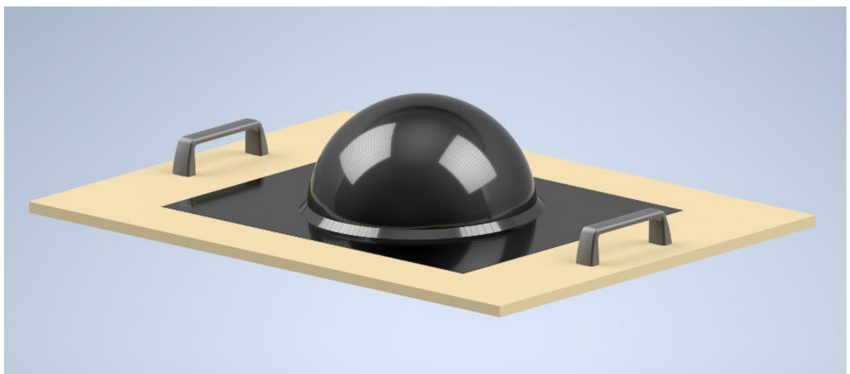


Figure 7: Designed Part Mold

3.1.1 Fixture Board

The fixture board is produced using Medium Density Fiberboard (MDF). The thickness of MDF used by the team is ½ inch. MDF was used since it is not only cheap and widely available off the shelf, but it is also easily machinable. The CNC machine is used to drill the bore for the mold and holes for handle in. It is also strong enough, as observable from the team's analysis to withstand the force due to the pressure form the vacuum bag (Cabinet Joint, 2016).

3.1.2 Handles

The consideration of handles was made for easy handling and ergonomics. The handles have been chosen from the Carr Lane catalog (see Appendix 2, bill of materials).

3.1.3 Part Model

The part model is 3D printed using SLA technology and is divided into sections depending on the overall size of the desired part. Part models made from two or more segments are to be manufactured with special features to aid in assembly and ensure accuracy of the assembled model; these are discussed in further detail in section 5. 3M Scotch-Weld Urethane adhesive will be used to mate the parts particularly due to the rapid hardening time of 5 minutes and total cure time of 24 hours. This structural adhesive has a shear strength of 1200 psi and a peel strength of 25 lb/in.

3.1.4 Sealer Coating

The coating is the Mikon 399 MC from Münch Chemie International and is used in this process to prepare the assembled model board in a single step. Mikon 399 MC is a specialty coating designed as a tooling board sealer for the sole purpose of reducing the production time of molds. The product can be used in a spray application or brush/wipe application (Münch, 2021). The coating is compatible with woods, plastics, composites, and epoxy tooling boards however it was not determined if the coating could be used with high density foams. Estimated usage for this product is approximately 25 grams per square meter at a cost of $214.48 per bottle–further described in the cost estimates section. The mold is ready for use in three applications or less with a total coating thickness of 3 μm.

4.0 ANALYSIS AND RESULTS

4.1 Estimated Time to Produce

4.1.1 Minimum Time Required

The time to print each component of the part model varies between designs based on size; however, the team estimated the time to produce a $10\ \mathrm{in}^2$ hemispheric male mold. The time estimates are as follows:

1) Adhering part segments: The mold itself is adhered to the fixture board using Bondo Putty takes around 5 minutes, but the putty itself takes about 24 hours to cure;
2) Cut the fixture board: Using the manufacturing simulations by the team in Fusion 360, cutting the fixture board should take about 1 min 20 sec;
3) Assembling the fixture board: Assembly takes about 10 minutes only since the only part to assemble is the installation of the handles;
4) Mount part model to fixture board: This process takes around 1 minute before sealer coating;
5) Sealer coating cure time: For 3 coatings, it would take roughly 15 minutes to cure.

Total estimated Time: Print Time + 26 hours

4.2 Estimated Cost to Produce

The costs associated with the mold design are variable as they depend on the shape and size of the part mold, as well as consideration towards number of sealer and release agent coats required, based on each specific application.

The following costs can be broken down and multiplied by the dimensional properties of the part mold for accurate cost estimating.

The SLA resin (Formlabs Standard Black Resin - RS-F2-GPBK-04) costs $149.00 USD plus tax per 1-litre cartridge; this reduces to a rate of $3.06 CAD + Tax/in^3 (Formlabs, 2021):

$$\frac{\$149.00\ \mathrm{USD}}{1\ \mathrm{L}} \times \frac{1\ \mathrm{L}}{61.0237\ \mathrm{in}^3} \times \frac{\$1.2525\ \mathrm{CAD}}{\$1.00\ \mathrm{USD}} = \$3.06\ \mathrm{CAD/in}^3$$

The Medium Density Fiber Board (MDF) is sourced from Home Depot (2021) in 49 in x 97 in tiles (4753 in^2) for $34.62 CAD plus tax, which results in a less-than-one-cent-cost per square-inch:

$$\frac{\$34.62}{4753\ \mathrm{in}^2} = \$0.007\ \mathrm{CAD/in}^2$$

The variable costs below cannot be calculated for a specific application, as there are numerous factors that contribute to how much is used.

Adhesive for the mold pieces can be purchased in 4-ounce tubes from McMaster-Carr (2021) for $41.22 USD plus tax, which works out to $12.91 CAD plus tax per ounce:

$$\frac{\$41.22\ \mathrm{USD}}{4\ \mathrm{oz}} \times \frac{\$1.2525\ \mathrm{CAD}}{\$1.00\ \mathrm{USD}} = \$12.91\ \mathrm{CAD/oz}$$

The Bondo® putty can be purchased at Canadian Tire (2021) in 3.1-kilogram buckets for $44.99 CAD plus tax, which is approximately $0.01 CAD plus tax per gram:

$$\frac{\$44.99\ \mathrm{CAD}}{3.1\ \mathrm{kg}} \times \frac{1\ \mathrm{kg}}{1000\ \mathrm{g}} = \$0.01\ \mathrm{CAD/g}$$

The sealer coating from Münch is €145.00 EUR plus tax for a 1.2-kilogram bottle, in other words it costs $0.21 CAD plus tax per gram of sealer (Castro Composites, 2021):

$$\frac{€145.00\ \mathrm{EUR}}{1.2\ \mathrm{kg}} \times \frac{1\ \mathrm{kg}}{1000\ \mathrm{g}} \times \frac{\$1.48\ \mathrm{CAD}}{€1.00\ \mathrm{EUR}} = \$0.21\ \mathrm{CAD/g}$$

1L of the accompanying release agent from Münch can be bought from AERONTEC for R465.73 (see Appendix 3). This is equivalent to \$0.66 CAD plus tax per cubic inch:

$$\frac{\text{R465.73 ZAR}}{\text{1 L}} \times \frac{\text{1 L}}{61.0237\text{in}^3} \times \frac{\$0.087\text{ CAD}}{\text{R1.00 ZAR}} = \$0.66\text{ CAD/in}^3$$

The handles and screws are a fixed price per board since two handles and four screws are required to assemble each fixture board no matter the shape or size of the part mold.

The pull-handles are from Carr Lane (2021); they are sold individually at \$6.16 USD plus tax, which totals \$15.43 CAD plus tax per fixture board:

$$\frac{\$6.16\text{ USD}}{\text{1 handle}} \times \frac{\$1.2525\text{ CAD}}{\$1.00\text{ USD}} \times 2\text{ handles} = \$15.43\text{ CAD}$$

The corresponding screws are 5/16”-18 UNC, and cost \$9.91 USD per pack of 50 screws (McMaster-Carr, 2021). \$0.99 CAD plus tax is the cost of four screws for each fixture board:

$$\frac{\$9.91\text{ USD}}{\text{50 screws}} \times \frac{\$1.2525\text{ CAD}}{\$1.00\text{ USD}} \times 4\text{ screws} = \$0.99\text{ CAD}$$

The total fixed cost per fixture board results in \$16.42 CAD plus tax.

4.3 Stress Calculations

The stress calculations were performed on a 10-inch diameter hemispheric mold taken as a reference point, closer to what the real dimensions of such a mold are expected to be. A pressure of 14.7 psi_{vacuum} exerted uniformly on the hemispheric surface by the vacuum bag is assumed and is also what the pressure would be approximately in practice.

Given:

$$\text{Mold } \emptyset = 10 \text{ in}$$

$$\text{Mold radius} = 5 \text{ in}$$

$$\text{Pressure} = 14.7 \text{ psi}_{\text{vacuum}}$$

Cap surface area of the mold (Ac):

$$= 2\pi rh$$

$$= 2\pi r^2$$

$$= 2\pi(5 \text{ in})^2$$

$$= 157.079 \text{ in}^2$$

Force calculation:

Since vacuum pressure is uniform across the surface:

$$\text{P} = \frac{\text{F}}{\text{A}}$$

Therefore:

$$\text{F} = \text{P} \times \text{Ac}$$

$$= 14.7 \text{ psi}_{\text{atm}} \times 157.079 \text{ in}^2$$

$$= 2309.194 \text{ lbf}$$

Converting to kN:

$$1 \text{ lbf} = 4.448 \text{ kN}$$

Therefore:

$$= (2309.194\ \text{lbf} \times 4.448\ \text{N}) \times (1\ \text{kN} \div 1000\ \text{N})$$

$$= 10.2713\ \text{kN}$$

$$\approx 10.3\ \text{kN}$$

Now, taking physical properties of MDF into account (Weyerhaeuser, 2021):

$$\varepsilon = 2500 - 5000\ \text{MPa}$$

$$\rho = 600 - 800\ \text{kg/m}^3$$

Assuming an off-the-shelf MDF board that is 13 mm thick:

$$Internal\ bond\ strength = 0.75\ \text{MPa}$$

$$= 0.75\ \text{MPa} \times (\frac{1000\ \text{kN}}{\text{m}^2} \div 1\ \text{MPa})$$

$$= 750\ \text{kN/m}^2$$

$$Bending\ strength = 38\ \text{MPa}$$

$$= 38\ \text{MPa}\ \times (\frac{1000\ \text{kN}}{\text{m}^2} \div 1\ \text{MPa})$$

$$= 38000\ \text{kN/m}^2$$

Therefore, a 10-inch diameter hemispheric mold is well within the limits of the strength of the MDF board used. A diagram of the forces applied can be seen in figure 8.

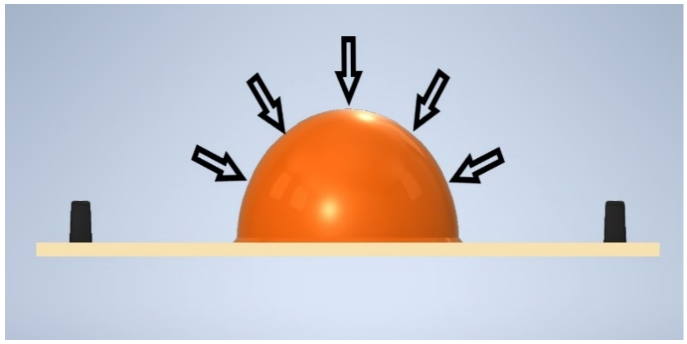


Figure 8: Pressure on Mold Due to Vacuum Bag

5.0 MANUFACTURING CONSIDERATIONS

5.1 3D Model Features

Certain model features have been integrated into the 3D models to aid in the assembly process. Those features are described in further detail below.

5.1.1 Locating Buttons

Locating buttons on the mold model are used to align surface edges together using a 3M scotch-weld urethane adhesive to bond the 3D pieces together.

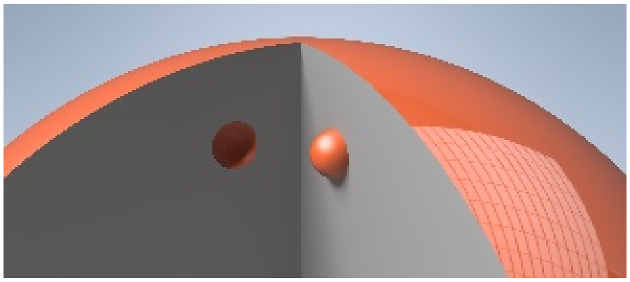


Figure 9: Locating Buttons

5.1.2 Center Plug

To mount the 3D mold model to the fixture board a center plug is used at the base of the mold model part to attach the part to the fixture board.

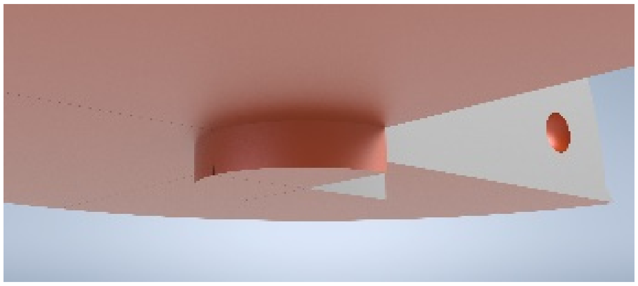


Figure 10: Center Plug

5.1.3 Relief Edge

Relief edges are used on the mold model part to prevent any mechanical locking on any right angles on the mold.

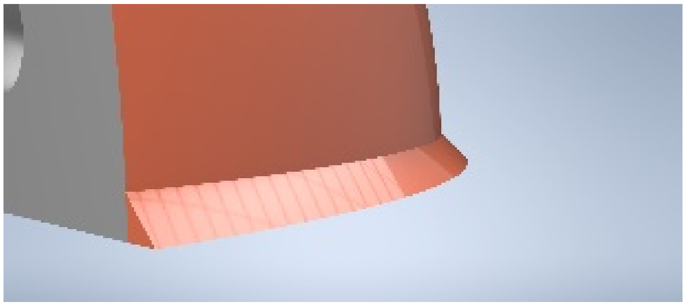


Figure 11: Relief Edge

5.1.4 Fixture Board

The fixture board is designed for easy handling of the finished mold model and for simple geometries for sealing the vacuum bag. A center bore is cut at the center of the board for adhering the part model and four thru holes are drilled at the ends of the board for fitting handles to make lifting the board easier.

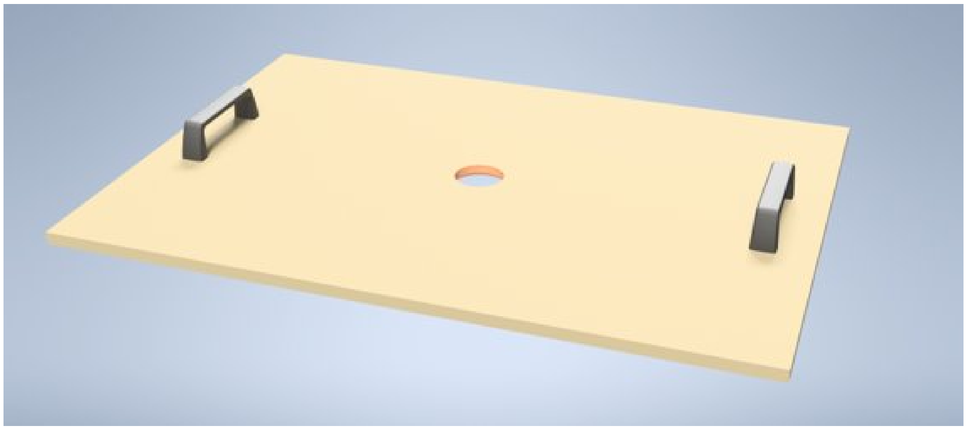


Figure 12: Fixture Board & Handles

5.2 Recycling of the Fixture Board

The fixture board is designed for easy handling of the finished mold and for simple geometries to be used for sealing the vacuum bag. Considering any environment topics, the MDF fixture board has an 1/8” extra thickness added for reuse purposes for future molds.

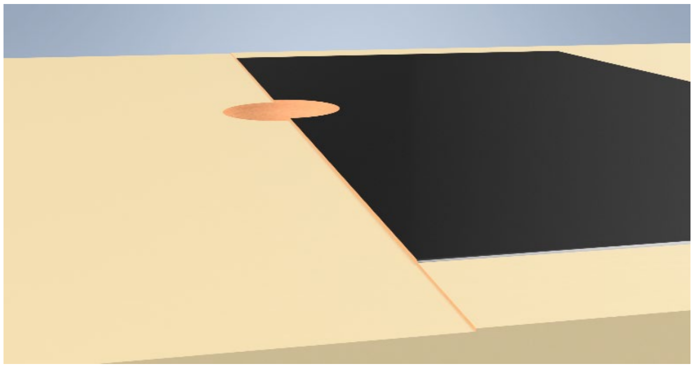


Figure 13: Milling Fixture Board for Recycling

6.0 CONCLUSIONS

Overall, the project has gone quite well with minimal issues arising, and any complications we encountered were resolved quickly. The team was introduced to the project by the University of Alberta's SAE formula team for producing small cost-effective carbon fiver parts, with minimal production time. The team decided on using SLA 3D printing technology to manufacture the small mold design in hopes that it would apply quick manufacturing for future parts to allow more time to be used in other parts of the car design. The team's final design of the project allows for easy handling of the mold so that no damage is taken and a sample part with a 10-inch diameter was used to replicate the size of molds the team was targeting.

7.0 RECOMMENDATIONS

Recommendations The Jayhawks have for the team at U of A are listed below in order of decreasing importance:

- Purchase Mikon 399 MC sealer coating;
- Consider relief angles when designing parts to be made;
- Integrate Topology Optimization to 3D part models;
- Purchase recommended tools to aid in part release.

7.1 Lessons Learned

In hindsight, there are areas in the project where The Jayhawks could have improved the functionality or manufacturability of the final design in order to better help the University team integrate the designed process. These possible improvements are mainly regarding manufacturing costs and particularly the SLA 3D printing.

Areas of research The Jayhawks could have used to create a more attainable final design are:

- Topology Optimization to reduce the direct material cost from the 3D printing;
- Finding whether the Mikon coating can be used on high density foams without deforming;
- Integration of 3D models into high density foam to reduce cost (coating compatibility granted);
- Frequent communication with the Mikon supplier for more detailed information.

7.2 Recommendations

As a team, The Jayhawks have the following recommendations and advice for future work, follow-up phases, and/or other related projects. Topology Optimization for further decreased costs in producing 3D models; and further research into compatibility of the coating with basic high-density insulation foam (requests for information from Münch Chemie have been unfulfilled).

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9.0 APPENDICES

9.1 Force Calculations (Appendix 1)

9.2 Mold Component Drawings (Appendix 2)

9.2.1 Fixture Board

9.2.2 SLA Part Model

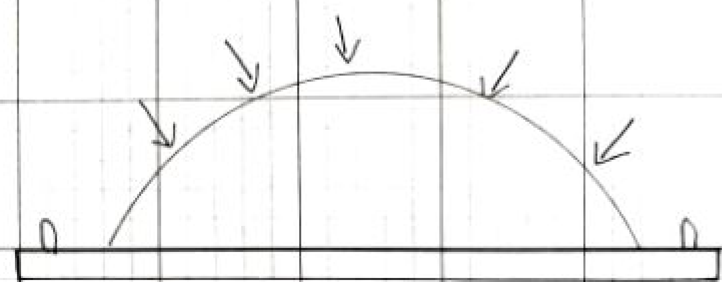
9.3 Coating Information & Order Sheets (Appendix 3)

9.3.1 Mikon 399 Sealer Coating

APPENDIX 1: FORCE CALCULATIONS

Mold ∅ = 10in.

Pressure = 14.7 psi (Uniform)



Now.

$r = 5in$

Cap surface area

$A_c = 2\pi r^2$
$= 2\pi(5in)^2$
$= 157.079\ in^2$
$= 157\ in^2$ approx

Ac

Force Calculation

$P = F/A$ (Uniform pressure)

$\therefore F = P \times A$
$= 14.7\ psi \times 157.079\ in^2$
$= 2{,}309.194\ lbf$

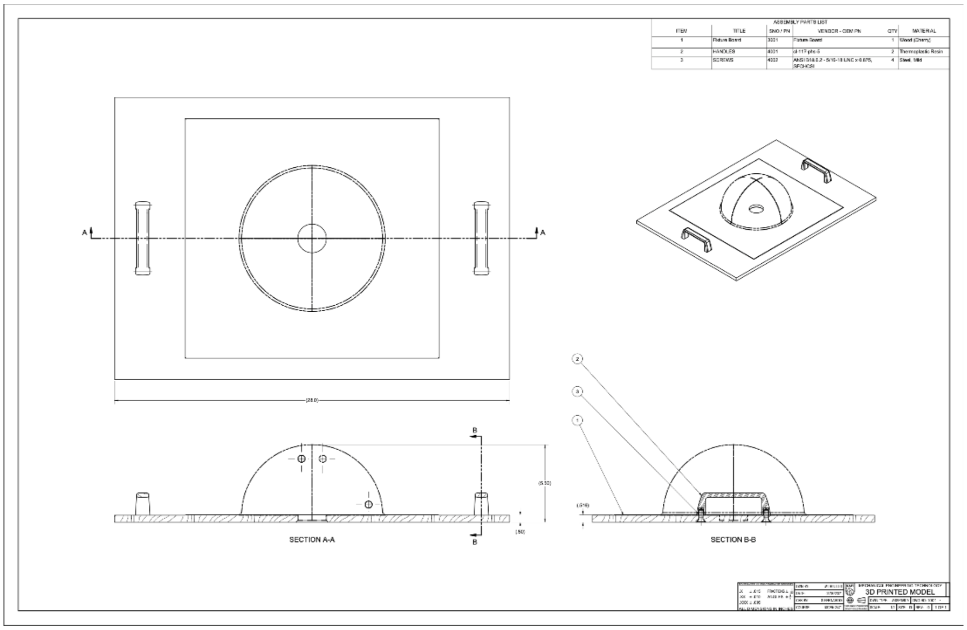
Convert to kN

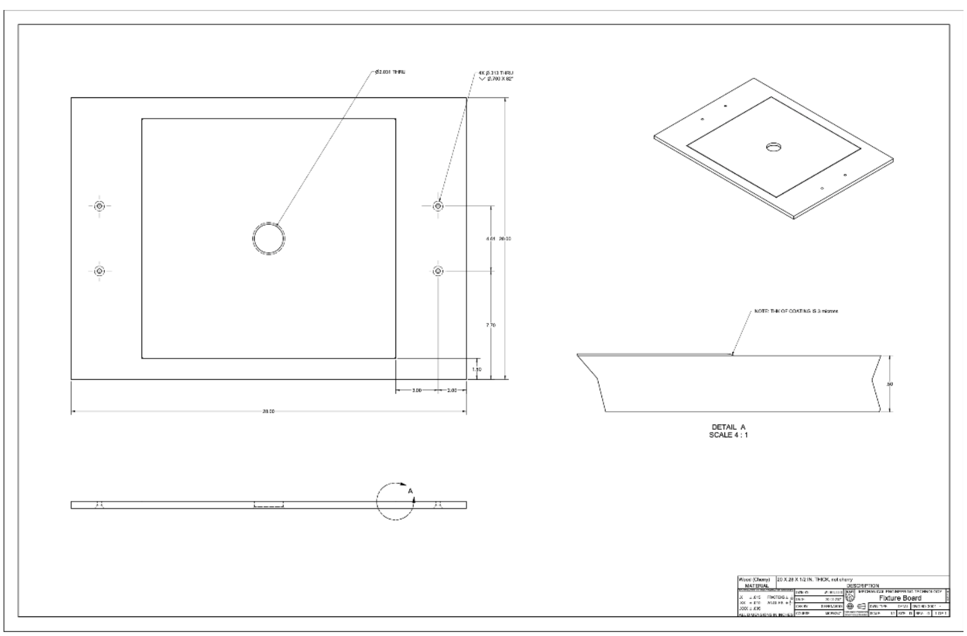
$1\ lbf = 4.448N$
$= 2{,}309.194\ lbf \times \frac{1kN}{1000N}$

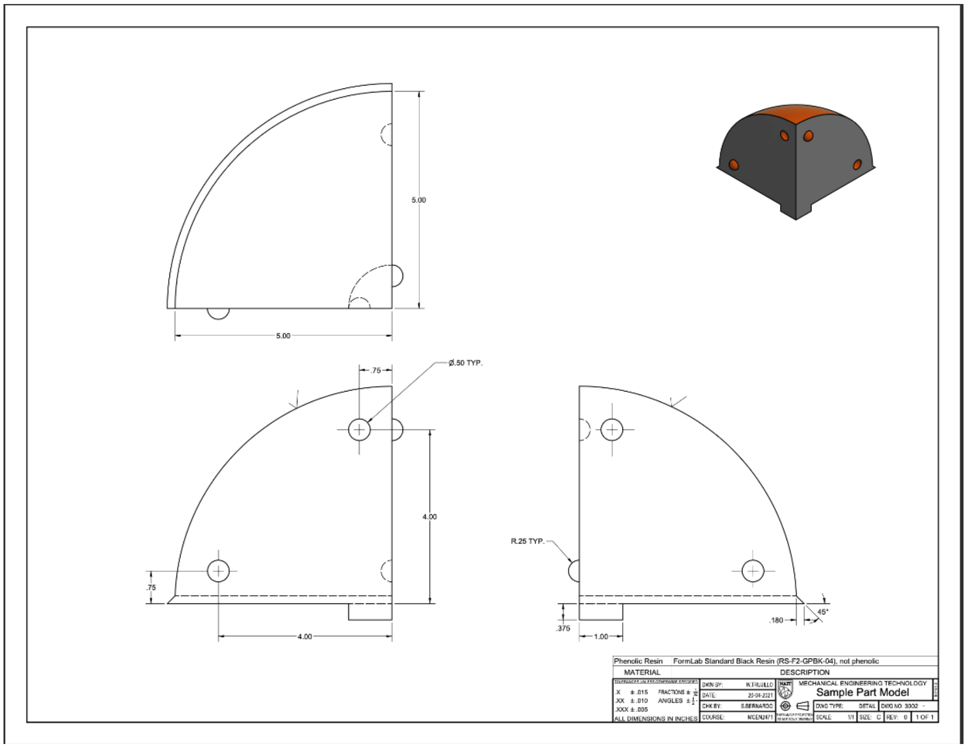
$= 10.2713\ kN$
$= 10.3\ kN$ approx

F

APPENDIX 2: MOLD COMPONENT DRAWINGS






5.00
5.00
.75
Ø.50 TYP.
4.00
.75
4.00
R.25 TYP.
.375
1.00
.180
45°
Phenolic Resin
FormLab Standard Black Resin (RS-F2-GPBK-04), not phenolic
MATERIAL
DESCRIPTION
.X ±.015 FRACTIONS ±
.XX ±.010 ANGLES ±
.XXX ±.005
ALL DIMENSIONS IN INCHES
DWN BY: W.TRUJILLO
DATE: 20-04-2021
CHK BY: S.BERNARDO
COURSE: MCEN2471
MECHANICAL ENGINEERING TECHNOLOGY
Sample Part Model
DWG TYPE: DETAIL
DWG NO: 3002 -
SCALE: 1/1
SIZE: C
REV: 0
1 OF 1

APPENDIX 3: COATING INFORMATION & ORDER SHEETS

AERONTEC

QUOTE

P.O Box 683
Howard Place
Cape Town
7450
South Africa

14C Warrington Road
Claremont
Cape Town
South Africa

Phone: 021 - 671 2114
Fax: 021 - 674 6622
E-mail: orders@aerontec.co.za

VAT Reg No.	4590198125
Quote No.	SQ007259
Date	07 Apr 2021

Customer Name:

Cash Sales Cape Town
Vat Reg No.

Delivery to

Credit terms: COD

Processed by: John

Customer Account No	Order Ref.	Delivery Note	Page
COD001			1 of 1

Stock Code	Description	Qty	Unit of Measure	Unit Price	Discount %	Excl. Value
RA030	Mikon W99+ Liquid Wax 250 °C	1.00	LT	465.73		465.73

Unless indicated, this quote excludes Courier Costs

Bank	Investec Bank Limited
Branch No.	580105 / 100 Grayston
Account No.	10012583276

Less : OVERALL DISCOUNT		0.00
SubTotal	ZAR	465.73
VAT	ZAR	69.86
TOTAL	ZAR	535.59

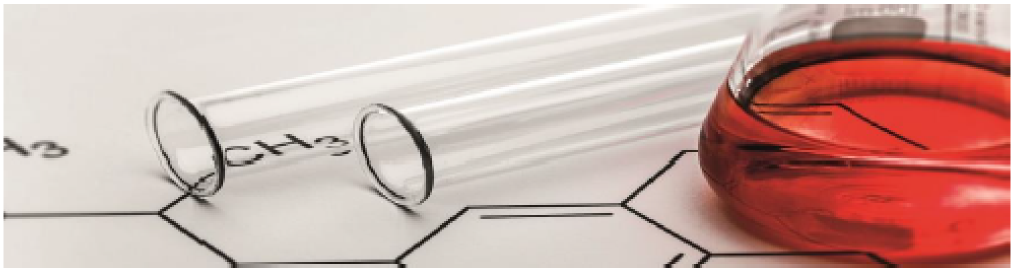
07 Apr 2021

Due to the extremely unstable exchange rate we are unable to quote our normal 30-day validity period.

Company Registration No. 2017/525990/07

QF_QMS_F039

Your Release Agent Specialist



Münch Chemie: Your specialist for release agents and processing aids

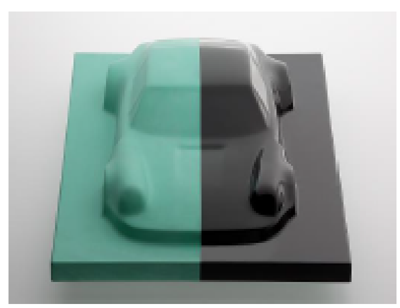
For over 70 years Münch Chemie International GmbH represents specialisation and broad know-how in release agent and auxiliary material solutions.

The continuous adaptation of our product portfolio to the ever-increasing market requirements is part of our company philosophy, with the aim of achieving the highest customer satisfaction.
In addition to a broad core product range we also offer innovative, customised solutions tailored to your individual requirements.

Sealers from the Mikon® 39x MC series *(Mikon® 397 MC, Mikon® 398 MC, Mikon® 399 MC)*

Best quality and high process reliability in model and mould construction are guaranteed by our innovative sealers from the Mikon® 39x MC series, which can be used for a variety of porous surfaces, especially block materials, MDF, plastic and metal moulds:

- Low material consumption
- Minimal effort (ready-to-use product; max. 2-3 coating layers; fast drying/curing time; no laborious after-treatment required after application of sealer)
- Both colourless and coloured mould sealer available
- High resistance against increased temperature and chemicals
- Significantly improved process reliability
- Enhanced overall quality of moulded parts
- Excellent value for money
- Increased overall efficiency



For further information, please visit our website www.muench-chemie.com or contact us personally.

Münch Chemie International GmbH	Phone: +49 (0)6201 - 99 83 0
Viernheimer Strasse 70-76	Fax: +49 (0)6201 - 99 83 66
69469 Weinheim - Germany	E-mail: info@muench-chemie.com