PLET 323

EXTRUSION BLOW MOLDED MANHOLE COVER WITH TACK-OFFS TO REPLACE CURRENT PROBLEMATIC COVERS

Kevin Cummings & Hunter Fantechi

April 19, 2019
Introduction

The part would be similar to a standard manhole cover. The cover would be intended for use in areas of pedestrian traffic rather than vehicular traffic, mostly in areas like sidewalks. The diameter will remain the same as a standard manhole cover so the cast iron ones can be easily replaced. Currently in New York City, according to engineering drawings, a common manhole cover is 38 inches in diameter, sitting on a 36-inch frame. Also, the thickness of the cover is 1 and ½ inches (1, SE41). An image of the current cover can be viewed in Figure 1 and the dimensions can be viewed in Figure 2. Maintaining these crucial dimensions will ensure it will fit in place of the old cover.

![Image of Current Cover](image1.png)

![Cover Dimensions](image2.png)

To enhance the design, the bottom will have tack-offs to provide structural support. The tack-offs will span across the bottom reaching almost to the outer edge. These tack-offs will provide the strength needed to support pedestrians, bikers, and other possible other sidewalk traffic.

The top of the manhole cover will have a textured surface similar to current covers. Small grooves will be on the top to provide traction, mainly to prevent someone from slipping on it. Small vent / drainage through holes will be added to the part too. The top will also feature decals/writing to fit current standards and provide necessary information.
Drawings of the proposed part can be viewed in Figures 3 and 4.
Most manhole covers are made from cast iron through the process of casting. There are some plastic covers made from injection molding and through the use of thermosets. This part relies heavily on its ability to support large amounts of force, making cast iron a suitable material for the job. The part has yet to be extrusion blow molded due the simplicity of manhole covers today and the desire for a uniform manhole cover for all applications.

The basic use of manhole covers has evidence dating back to the 4th century when manhole covers used by the Roman Empire were discovered that were made of stone and located in current Vienna, Austria. The design and materials, like stone and wood, used to make makeshift manhole covers did not change much leading up to the 19th century [2]. Once sewer systems became more common in cities, engineers realized they needed a way to access the sewers to perform maintenance or clean them. Typical manholes are 4-5 feet deep under the surface. In order to protect pedestrians from falling in theses engineers designed uniform size manhole covers. Some of the first records indicating the use of cast-iron to make manhole covers date back to 1860. Manhole covers have not changed much since the 1870’s. The most recent design change is making more manhole covers circular rather than rectangular. The circular design makes it impossible for a manhole cover to fall down the manhole not matter what way it is turned, unlike a rectangular design [3].

Sewers are an underground network for waste collection and transportation. They are located almost everywhere that people are. Therefore, access to sewer systems is necessary to perform maintenance and resolve problems. The manhole provides means without needing to dig up the ground to reach the sewer. These manholes need a cover that is able to support passing pedestrians and prevent unwanted items from falling into the sewer systems. They also act as an exhaust for the sewers, without them the unpleasant odor would be forced back into homes [3].

The manhole cover is meant to blend in with the surface of where it is located whether that be a road, sidewalk, or other various places they are used. The cover should not protrude outward or inward into the surface it is installed on, that could be problematic for obvious reasons. The cover should also fit into the frame so that there is a minimal gap between the outer diameter of the cover and inner diameter of the frame.

Currently manhole covers are being made with cast iron utilizing the casting process. Cast-iron is one of the first materials used to mass produce manhole covers and is still a relatively cheap material at around $0.10 per pound [4]. The casting process is also relatively old and has been mastered to achieve tolerances as low as 1/32 inch [5]. It also provides great strength especially in tension, with a tensile strength of up to 60000 psi. [6]. Specifications for cast-iron covers are also readily available since they have been made out of the same material for years. Most specifications and codes from agencies like the American Association of State Highway and Transportation Officials (AASHTO), are defined for loads on cast-iron and steel manholes rather than plastic.
Application

Blow molding would be the best process for manufacturing the manhole cover because it will be less expensive and quicker than the standard casting process. The blow molded part will also be designed with the replacement of cast iron covers and frames in mind so that they can be easily replaced. They will serve as a perfect mate for the current cast iron frame, whereas injection molded ones are made from their own plastic frame.

Making the manhole cover from extrusion blow molding would be the most ideal process for the application. The part would be lightweight, strong, and inexpensive. Plastic is known for being lightweight and since the part is hollow it helps keep the part light. If the cover were thermoformed it might not provide the necessary strength for the application. Rotational molding could form the part successfully but with such long cycle times it would not be an a preferred process. When comparing blow molding and injection molding the mold costs for blow molding are typically less expensive. Also, since the part is going to be hollow it will potentially use less material and be lighter than an injection molded cover.

Replacing cast iron covers with plastic blow molded ones in pedestrian areas would be beneficial for several reasons. Using the same type of cover for a 2-ton truck and a 180 pound person is unnecessary and wastes raw material. The blow molded cover would be much lighter than the cast iron one, making routine maintenance much quicker, safer, and easier. The current cover needs special tools to lift it because it is very heavy so the cover can be dangerous when handling it and dropping it onto concrete sidewalks can cause damage to them. Also, a plastic cover is not susceptible to rust and could provide better chemical resistance and weatherability than the cast iron covers. The part could also be easily colored which could be for aesthetically pleasing reasons or to blend in with the ground around it. Lastly, plastic manhole covers are inherently theft resistant due to the low scrap price of plastic as compared to plastics, making it less enticing for criminals.
Specifications

Meeting the specifications for a manhole cover is crucial for maintaining the safety and well-being of the people and vehicles that travel over the covers. There are different classes of manhole covers which have different specifications. The specifications depend on what type of traffic will be passing over them. The American Association of State Highway and Transportation Officials (AASHTO) has set specifications for ways to test manhole covers and what constitutes a failure. The testing must be done with the cover in the “frame” that it will be used in. The necessary load should be applied to a 9-inch by 9-inch area in the center of the cover. The load then is applied from 100 lb/seconds up to 1000 lb/seconds. For a 1.5-inch thick cover, a permanent deformation of more than 0.125 inches will constitute a “failure”. Any visible cracks would also be considered a failure. These cracks will not be detected by ANSYS though [7]. Since the proposed manhole cover will be used in areas of pedestrian traffic only it is classified as an A15 and will need to sustain a load of 1.5 metric tons = 3306 pounds [8].

<table>
<thead>
<tr>
<th>Class</th>
<th>Max. weight load (tonnes)</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>A15</td>
<td>1.5</td>
<td>Very light duty for pedestrian areas like gardens, patios and driveways</td>
</tr>
<tr>
<td>B125</td>
<td>12.5</td>
<td>Domestic driveway thresholds for family cars, vans and 4x4s</td>
</tr>
<tr>
<td>C250</td>
<td>25</td>
<td>Lightly trafficked roads and small private car parks</td>
</tr>
<tr>
<td>D400</td>
<td>40</td>
<td>Main roads, highways and high traffic areas like public car parks</td>
</tr>
<tr>
<td>E600</td>
<td>60</td>
<td>Industrial estates, loading bays and cargo handling yards</td>
</tr>
<tr>
<td>F900</td>
<td>90</td>
<td>Docks and airports, extreme heavy duty applications</td>
</tr>
</tbody>
</table>

Figure 5: Different class descriptions and load specifications [8].

The UV resistance of the manhole cover will need to be relatively high due to the environment the part will be subject to. During the day, the sun’s ultraviolet radiation will be shining on some or all of the cover for a portion or the entire day. This will depend on where the cover is being used though. So, the design must be able to withstand the harshest possible conditions, which is, constant sunlight from dawn until dusk. This means the design and material will need to be able to resist less than 10% degradation over the course of 5 years. The part may require the use of a UV stabilizer in the material to help prevent the adverse effects of the sunlight. Testing the cover’s UV resistance would be a requirement before the product could actually be used in the field. Possible testing methods include, xenon lamp, fluorescent lamp, and / or a QUV which are all accelerated weathering testing machines.

Another aspect that the cover would require is chemical resistance. The part will be subject to detrimental chemicals during its service life, so, it is important that the cover maintains mechanical properties while being used. It is essential that a material with a high degree of chemical resistance is used to prevent degradation from things like, water, oils, acids, salt, and various by-products produced by the sewer systems below the covers. Similar to UV resistance, the cover will need to withstand less than 10% degradation over 5 years of exposure. The ASTM D543 test would be used to determine the chemical compatibility of a material and a substance [9]. After exposure, tensile testing will be utilized to measure the strength of the material. This would need to pass a less than 10% loss in mechanical properties to ensure the part will perform as expected.
Material Selection

Manufacturing a manhole cover from plastic will require the part to withstand extremely heavy loads. For one in a pedestrian area it would specifically need to support at least 1.5 metric tons = 3306 pounds [10]. Temperature could also present a problem for the cover. The material should have a glass transition temperature (Tg) above the highest temperature ever recorded, which is, 134°F (56.7°C) [11]. Low temperatures are just as important though, some materials become very brittle at low temperatures, a small impact could break the cover. Temperature will contribute to the possibility of bearing a massive load or resistant an impact, so the material should be able to withstand high and low temperatures with or with a load or impact.

The part will also be subject to ultraviolet (UV) light from the sun for part or all of the day. Depending on where the cover is placed the UV light may be stronger and shine for more hours than it would in other places, so the part will be designed to handle harsh conditions. Using the U.S. National Weather Service UV Index the product should be able to withstand an 11+ UV Index. This would encompass harsh UVB and UVA radiation with no cloud cover and at an elevation of over 1 kilometer [12]. Another aspect the cover should possess is resistance to substances such as, water, oils, acids, salt, dirt, and various by-products produced by the sewer systems below the covers. Ideally the cover will withstand less than 10% UV and chemical degradation over 5 years of exposure.

Since one of the top requirements of our product is high mechanical strength it makes sense to look at a rigid PVC material. Geon™ Vinyl Packaging 161J-1 by PolyOne is a blow molding grade PVC and is a great candidate material for the product. Its tensile modulus is 334,000 psi which is much higher than most thermoplastic materials. This is paired with a high flexural modulus of 384,000 psi. It also has 80.5% transmittance making it great against the UV radiation it will face as it is in the sun all day. The 1.8MPa heat deflection temperature of the material is also 157°F, which it is unlikely to face in its use [13]. Although it is an amorphous material, PVC has typically good chemical resistance, especially against alcohols, ammonium and acids.

Polypropylene (PP) was a candidate for a potential material due to its excellent chemical resistance and low cost. Maxxam™ PP7005 from PolyOne has a tensile stress (yield) of 3770 psi and a tensile strain (yield) of 13%. Also, the flexural modulus is 157,000 psi [14]. This is not the ideal strength or stiffness the cover needs to have and since polypropylene has a low Tg it would allow the cover to be ductile during some or all of the day / year depending on where it is. The UV resistance of PP is poor when exposed for a long time too.

Stanyl® Diablo OCD2305 BM is a high performance, 25% glass-filled, blow molding grade PA 4,6 developed by DSM engineering plastics that is used often in the automotive and outdoor power equipment products. This material has a tensile modulus that is significantly lower than that of the rigid PVC discussed above of 123,2821 psi. Its flexural modulus is also lower than that of the PVC at 130,5340 psi. One advantage the nylon has is a higher 1.8MPa heat deflection at temperature at 240°C which is much higher than any possible condition it may experience [15]. With nylon being a semi-crystalline material, the chemical resistance is inherently great due
to its crystalline structure. The semi-crystalline structure also makes the material more susceptible to sensitivity to UV radiation.

Sabic’s Lexan™ polycarbonate line is well known and used often in the plastics industry. The PK2870 is a blow molding grade with great mechanical properties. It is transparent and typically used in manufacturing reusable water bottles. Its tensile modulus is 340,838 psi which is just below the value for our rigid PVC selection. The flexural modulus is also just below the PVC at 333,586 psi as well. This polycarbonate material has a great 1.8 MPa heat deflection temperature at 130°C making it the second best, just behind the nylon material. This polycarbonate also has the highest transmittance value at 88% making it the best for UV resistance [16]. The downfall of polycarbonate is the chemical resistance of the material. The amorphous nature that allows the material to be transparent also hurt it in resistance chemical. Of our material options polycarbonate has the lowest degree of chemical resistance.

After weighing all of the options against our requirements we determined the unplasticized rigid PVC was our best overall option, beating out the nylon by 1 point. This material had both the highest tensile and flexural modulus which will help us meet our load requirements as well as good UV resistance to prevent degradation. The project will move forward with test and using Geon™ Vinyl Packaging 161J-1 by PolyOne.

<table>
<thead>
<tr>
<th>Material</th>
<th>Strength</th>
<th>UV Resistance</th>
<th>Chemical Resistance</th>
<th>Tg</th>
<th>Stiffness</th>
<th>Cost</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPVC</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>PP</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Nylon 4,6</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>PC</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>

Highest Ranking = 4  Lowest Ranking = 1

Table 1: Material Rankings
These drawings are the final product idea that were then used to define the part specifications and create the CAD model. The 38-inch diameter was determined by current specifications used by the manhole that this one will be attempting to replace. The tack-off design was not determined yet so rough preliminary sketches were drawn to represent the use of tack-offs. Vent holes were also pictured in the drawing, these would allow for gases to escape out of the sewer system.
To start the CAD model, a circular plate like shape was revolved. The shape had a 38-inch diameter and 1.5-inch thickness. The feature was then shelled leaving a 0.125-inch wall thickness.

Next to simplify the modeling process, one fourth of the outer hollow edge and tack-off design was modelled. The width of the outer edge was 2 inches. This was used to ensure a good contact
area for the cover to rest on once in place. Then there were 6 tack-offs that spanned across the part one way and then 2 tack-offs perpendicular to those. Each tack-off had a width of 3.125 inches. This width was determined by using the 2.5 times the height of the tack-off; which was 3.75 inches. This was the maximum recommended width, so a slightly smaller width was used to maintain the desired design. This was the width for all the tack-offs used.

When the tack-offs were modelled they all were designed with a 5° draft to allow for easy ejection. The wall thickness remained nominal (0.125 inches).
Isometric View: Bottom of the Cover (Before Rounds were Added)

Isometric View: Top of the Cover (Before Rounds were Added)
Isometric View: Bottom of the Cover (with Rounds)

Front View: Top of the Cover (Section View to Show Detail)

Right View: Top of the Cover (Section View to Show Detail)
Views Shown: Top View (With Hidden Lines), Front View (With Hidden Lines), Right View (With Hidden Lines), and Isometric View (Without Hidden Lines).

Part has a Nominal Wall Thickness of 0.125 Inches.
Manufacturing Details

Extruder Type

Many factors need to be taken into account to determine the optimal extrusion blow molding process. One of the main factors is part size, which contributes to determining the machine size. For large parts the mold and shot size will be larger, requiring a large press. Another major factor is extruder type. There are three different types of extruders; continuous, intermittent, and 3D.

For a continuous process, the extruder is continuously running, so a parison is always being produced. The extruder is mainly stationary, some move vertically to prevent the parison from building up on top of itself when the mold closes though. This process is ideal for lightweight / smaller parts. It does not allow for excessive parison sag / stretch since the parison does not become too long or heavy between cycles [17].

The next process is intermittent extrusion blow molding. An intermittent process uses an accumulator or reciprocating screw to first allow the polymer melt to build up. This melt “build up” is similar to how a reciprocating screw injection molding machine builds up a shot. Once the shot is built up is then begins to extrude the melt through the die, forming a parison. Since this part for this process are normally large this prevents the parison from stretching because the heavy parison is not hanging for an extended amount of time [18].

The last process to analyze is the 3D extrusion blow molding. The 3D process is similar to an intermittent process except it utilizes a manipulator to properly direct the parison into place. This process has the ability to manufacture parts that are curved or have complex shapes with minimal flash. It either requires the mold or extruder to move so place the parison in the mold [18].

The Manhole Cover will utilize an intermittent process. With the part’s circular shape and 38-inch diameter, it will require the mold and in turn, the parison to be relatively large. To drop a parison large enough for the diameter while still providing the desired wall thickness of 0.125 inches will cause the parison to be relatively heavy as well. The intermittent process could use an accumulator or reciprocating screw to produce the Manhole Cover. The accumulator / reciprocating screw size will be determined by taking into account of the part using between 1.3 to 4 times of the shot size [18]. The intermittent process should allow for the part to be easily produced without much worry to the parison stretching because of weight. The continuous process could potentially allow the parison to stretch an excessive amount which would cause thin wall sections; weak spots on the cover. The 3D process is not necessary since the part does not have complex curves. The 3D process would also add cost and since a manipulator is not required to effectively manufacture the part so it would not make sense to use this process. It has not yet been determined on how many / if any layers will be used since the part needs further testing at the current stage of the development process. Also, the part is expected to be pre-blown so it can form to such a thin and wide shape.
Based on preliminary calculations, the optimal extrusion blow molding machine for producing the Manhole Cover will be the Milacron UA1200 Series with the 15-FS-25 fixed spiral accumulator head. This machine provides an adequate amount of clamp tonnage, space for mold and daylight. The accumulator head provides the necessary amount of space to build up the shot size for the process as well [18]. The data sheet for this machine can be found in the Appendix.

Using simple equations, the volume of the part was calculated to be approximately 294 inches cubed. According to an article by Robert Slawska in Plastics Technology, it is advised that an additional 30% should be added to this volume to account for the flash produced [20]. According to the data sheet for Milacron machine specifications, 0.026 lb./inches cubed is used as the density of for HDPE to calculate the shot weight available in the accumulator. With this the shot weight for the volume was calculated as 9.932 lbs. of HDPE. Based on the recommendations outlined in the Elastomer blow molding guide, the shot weight of the machine should be between 1.3 and 4 times the calculated shot weight [18]. This makes the machine range between a 12.9 lb. minimum and a 39.72 lb. maximum accumulator head size. Calculations and reference equations for this can be found below in the Appendix.

The next aspect evaluated for finding a suitable machine was finding the necessary pinch-off and blow pressure clamp force. Using the equation for circumference around a 38-inch circle and 700 lb./linear inch as a close estimate from Plastics Technology it was calculated that the necessary pinch off tonnage would be 41 tons [20]. The blow clamp force was then calculated with the projected area of the part and an estimate of blow pressure being 100 psi from a Plastics Technology article [20]. This calculation gave an estimated necessary clamp force of 113 tons. This gives a machine specification of a minimum of 113 tons of clamp force. The UA 1200 Series provides 140 tons of clamp force meeting this requirement. Calculations and reference equations can be found in the Appendix.

The overall mold size was then determined by using the overall geometry of the part. Using roughly 2 inches on each side of the 38-inch Manhole Cover, the mold block will be 42 in. X 42 in. giving an area of 1764 inches squared. The UA 1200 Series machines has 62 in. X 62 in. providing plenty of room to fit the mold on the platen by utilizing around half of the available room on the plate [19]. Due to the thin nature of the Manhole Cover, the maximum daylight should not be an issue being that the thickness of the part is 1.5 inches and the maximum daylight it 66 inches on the UA 1200 giving a large amount of room for tooling. In fact, it may be harder to meet the minimum die height of the machine of 14 inches. This can be easily accomplished though with the addition of spacer plates in the tooling. These calculations can be found in the Appendix.

The last aspect of machine requirements needed was the extruder output. The extruder needs to fill the accumulator head in a reasonable amount of time so that parison can drop from the accumulator as soon as the mold is open and ready to accept it. The 120S 120mm single extruder provides a 900 lb./hr melt output which would fill the accumulator head with the desired shot size of 9.9 lbs in 39.6 seconds [19]. This is well below the cycle time estimation for a 0.125-inch thick part cycle time estimation from Plastics Technology of 180 seconds and meets the requirement. Calculations for this can be found in the Appendix.
Head Type

Before the melt is extruded into a parison it must be forced through the head. The head should be designed to balance material flow and maximize parison strength. The head is very important when trying to produce good parts since it is essentially the first step in the parison formation process [18].

There are several different types of heads which are typically designed specifically for a certain process, some types include; the spider / axial flow head, the side feed / radial flow head, and the accumulator. The exact heads that will be discussed are; the Axial Flow Head with Uninterrupted Spider Legs, the Axial Flow Head with Interrupted Spider Legs, a Conventional Radial Flow Head, a Modified Mandrel with Heart-Shaped Channel, a Typical Accumulator Head, and a Multilayer / Sequential Extrusion with Ram Accumulators [18].

The spider / axial flow head is used for continuous extrusion methods and can be divided into two different types; the Axial Flow Head with Uninterrupted Spider Legs and the Axial Flow Head with Interrupted Spider Legs. The Axial Flow Head with Uninterrupted Spider Legs is a very simple design used for thermally sensitive materials with low elastic memory. The torpedo inside the head is place in the center of the flow path cause this type to undesirable for materials with high elastic memory because it can produce dramatic weld lines. The Axial Flow Head with Interrupted Spider Legs is similar to the uninterrupted flow head except the spider legs break the flow of the resin, which allows this head to be used for materials with high elastic memory since the parison can be produced weld line free [18].

Like the axial flow head, the side feed / radial flow head is used for continuous extrusion and can be broken down into two different types such as; the Conventional Radial Flow Head and the Modified Mandrel with a Heart-Shaped Channel. These heads allow the melt to enter from the side and is then divided by a mandrel. After dividing the melt, the Conventional Radial Flow Head rewelds the melt when it enters the area where it is put under higher pressure, this causing the weld to be stronger. Following this step, the melt is then extruded. The Conventional Radial Flow Head is not recommended for material with high elastic memory. The Modified Mandrel with a Heart-Shaped Channel is similar to the Conventional Radial Flow Head except it uses additional techniques to strengthen the weld line. This allows the heart-shaped mandrel to process material with high elastic memory [18].

The next type of head is the Accumulator Head. This is used for intermittent extrusion blow molding. This provides a combination of an extrusion head with a “first-in / first-out tubular ram-melt accumulator.” This means the melt must first enter the accumulator and once the desired shot size is achieved the ram forces the melt through the die. This head is used for larger parts where the parison becomes longer and heavier. The design of this head prevents excessive parison sag. The Multilayer / Sequential Extrusion with Ram Accumulators use the same method as the Accumulator Head [18].

Since the Manhole Cover will be utilizing an intermittent extrusion process it would be necessary to use an Accumulator Head. This is because the Accumulator Head is designed specifically for an intermittent extrusion process. The axial and side feed heads would not be able to produce the cover since they are designed for continuous extrusion methods.
Advantages and Disadvantages of the Selected Process

The largest advantage of intermittent extrusion is the reduction in parison stretching during extrusion [18]. The accumulator head can quickly push out the parison and gravity has less time to act on the parison. This is especially important for the manhole cover as thin spots and wall thickness variation can cause changes in mechanical strength of the part which is the device’s main requirement. The Manhole Cover is also a relatively large part at 38-inches in diameter making parison stretch even more of a factor that is reduced by intermittent extrusion.

Another advantage of intermittent extrusion is the ability to reduce the amount of shrinkage and oxidation during the parison extrusion process. This is especially important in semi-crystalline materials including the nylon material chosen for the Manhole Cover. Excessive shrinkage of the parison during extrusion will result in differences in wall thickness and as stated earlier, affect the overall critical mechanical properties of the part. Rapid shrinkage and oxidation can also potentially cause surface finish problems with the part [18].

The Manhole Cover may also have a long cycle time as a relatively thick part (0.125-inch wall thickness) will take a long time to cool, especially to allow the nylon to crystallize as much as possible. An article from Plastics Technology states that with a wall thickness between .120-.180 inch could result in a cycle time of 180 seconds [20]. The problems stated above with parison stretching, oxidation and excessive shrinkage would all be compounded and become even worse with a longer cycle time.

The main disadvantage of intermittent extrusion blow molding is the cycle time needed to produce parts. During continuous extrusion the parison is continuously being extruded and there is essentially no wait time for the parison to fall unlike intermittent blow molding, where the parison starts to drop when the mold is open and ready to accept it [18]. Intermittent extrusion also requires that the machinery has an accumulator head that is largest to hold an entire shot. This can be limiting and expensive, especially with very large parts.
Preliminary Calculations

According to the National Precast Concrete Association (NPCA), there are a variety of loading rating on manhole covers. The specification that best fits the manhole cover being tested is the non-traffic specification. These covers are ones that will only encounter foot traffic and no vehicular traffic. The load specification for these is a load between 0 and 2500 pounds (1). This specification is different from a previous determination of 3300 lbs (2) that was found to be much too large for the product’s use. This was determined from the hand calculations shown below. Despite the load the test and analysis procedure is to apply this load to a 81in^2 area in the center of the cover. The final loading specification determined from the calculations was a maximum load of 1000 pounds (1).

The first step in the calculations was to find the equivalent thickness of a plate by find the moment of inertia of the shape with tack offs. This was found so that a load case for Roarks’s equations for a flat solid plate. The relative shape of the cross-section of the manhole is shown below.

![Diagram of manhole cross-section](image)

After dividing the complex shape into simple rectangular areas, Mr. Meckley’s Excel spreadsheet for calculating the moment of inertia for complex shapes was utilized to find the moment of inertia for the shape. This calculation can be seen in Figure 2.
After the moment of inertia for the shape was calculated, that value was able to be used in order to find a plate thickness that would have the same moment of inertia. This was accomplished by setting the 1.0119 in\(^4\) value for moment of inertia of the complex shape to the equation for moment of inertia for a rectangular cross section of \(I = \frac{1}{12}bh^3\). This calculation came to an equivalent plate thickness of 1.104 inches using Excel. Both the Excel spreadsheet and the hand calculation used to verify it can be seen in the next two pictures.
Using the equivalent plate thickness a load case from Roark’s equation for a flat disk simply supported around the diameter with a central load was used to find the deflection. The equation can be seen circled in red in the figure below (3).

The initial load used for the calculation was the initial load specification of 3,306 lbs. I was found that the deflection of the plate was -0.374 inches. This would be considered a failure with the maximum allowable deflection value of on -0.125 inches (2) the spreadsheet calculation and the hand calculation to verify the spreadsheet can be seen in Figures 6 and 7.
Once confirming that the spreadsheet was applicable and the specification for the load was much too high for the application, the load was lowered to approximately 1,000 pounds in the spreadsheet it was determined that the manhole cover could hold the load with a deflection of -0.01128 inches, which is within the -0.125 specification. This calculation in the spreadsheet can be seen in Figure 8.
In conclusion, it was determined that the initial load specifications were far too high for the use of the manhole cover along with the capabilities of the design. The new specification of a 1,000-pound load was confirmed to be an applicable specification and also proven to be supported with in the specification of a maximum deflection of -0.125 inches.

\[
\begin{align*}
\text{ymax} &= \frac{-W\alpha^2 (3 + \nu)}{16\pi D (1 + \nu)} \\
W &= q \pi r^2 \\
E &= 1233821 \text{ psi} \\
t &= 1.10498 \text{ inch} \\
q &= 12.34 \text{ psi} \\
r &= 5.08 \text{ inch} \\
\alpha &= 19 \text{ inch} \\
\nu &= 0.35 \\
D &= \frac{E t^3}{12 (1 - \nu^2)} \\
D &= 157955.31 \text{ lb*in} \\
\text{ymax} &= -0.112877299 \text{ inches}
\end{align*}
\]
To start the CAD model, a circular plate like shape was revolved. The shape had a 38-inch diameter and 1.5-inch thickness. The feature was then shelled leaving a 0.125-inch wall thickness. The 0.125-inch wall thickness is towards the upper limit of the recommended wall thickness for extrusion blow molded parts. This was assigned to the part since it will potentially have to withstand very large loads (initially around 3,300 lbs.).
Next to simplify the modeling process, one fourth of the outer hollow edge and tack-off design were modelled. The width of the outer edge was 2 inches. This was used to ensure a good contact area for the cover to rest on once in place. There were 6 tack-offs that spanned across the part in one direction with equal distance from one another. Then 2 tack-offs perpendicular to the other 6 were added. While these 2 tack-offs will help with structural support they will also provide the necessary air ways to properly inflate the part. Each tack-off had a width of 3.125 inches. This width was determined by using the 2.5 times the height of the tack-off; which was 3.75 inches. This was the maximum recommended width, so a slightly smaller width was used to maintain the desired design. This width was used for all the tack-offs.
When the tack-offs were modelled they all were designed with a 5° draft. The wall thickness remained nominal (0.125 inches). 4° is the minimum recommended draft for a part with such a thick nominal wall so, 5° was used since the design had the ability to utilize this amount of draft and it should ensure easy ejection.
The one fourth design of the outer edge and tack-offs were then mirrored across the frontal and right planes to complete the major design features of the bottom of the part.
A draft of 1° was added to each side of the parting line. This is because the walls do not remain parallel and there is not a to steel shut off, so a minimal of 1° of draft was recommended and added to aid with ejection. This prevents the draft from alter the part dimensions by too much as well. The horizontal plane (parting line) was used as the draft hinge.
Rounds were added to all concave and convex corners. Following typically part design standards
the concave corners were rounded at 50% of the wall thickness and convex corners were rounded
at 150% of the wall thickness. So, concave corners received a 0.0625-inch round and convex
corners received a 0.1875-inch radius. These rounds were used since the worked with the design
and maintained the nominal wall thickness.
Views Shown: Top View (With Hidden Lines), Front View (With Hidden Lines), Right View (With Hidden Lines), and Isometric View (Without Hidden Lines).

Overall Dimensions are shown and the Nominal Wall Thickness is 0.125 Inches.

These final part drawing models show the dimensions of the tack-offs, draft, and rounds that were previously described.
Part Revision

Isometric View of the Bottom of the Cover

Right Sectioned View with Updated Equal Spacing

After analyzing the first revision of the part it was noticed the 2 tack-offs (pictured more horizontally) were not evenly placed apart. The 2 tack-offs were then adjusted so the space from edge to tack-off to tack-off to edge are all roughly 10 inches apart.
Mold and Tooling Details

The mold will be manufactured using a CNC machine. This is the will be quick and require minimal labor. The part is fairly simple so the CNC could be easily programmed to mill the plate into shape.

Design Drawings

Die and Mandrel Hand Sketch
Pictured above is the two mold plates with water lines, pinch-off, venting, and blow needle holes included. A shrink factor of 2% was included to account for the shrinkage of the material. The technical data sheet reported a 0.5% shrink factor [21]. Since the part needs to fit securely into the manhole opening a higher shrink factor was used because the part wall is extremely thick and nylon is a highly crystalline material. The cover is much more lightweight than the previous cast iron one so it is best if the cover fits into the opening without being able to slide around or move to maintain safety.
Using Creo Parametric with the appropriate Pull Direction the bottom of the mold is shown as the Front View. In this view the 6 holes on each plate are for the water line circuit. Plugs are intended to be added to shut off openings and route the water through the mold properly. Intended inlets, outlets, and plugs are shown. Water lines are placed approximately 2.56 inches from the center of the cooling line to the edge of the mold cavity. This should allow for sufficient cooling while being well over steel safe and being able to withstand the high clamp tonnage. The water lines were also slightly over drilled to prevent blockage of a channel. Each circuit is in series.
Mold: Right View

The Right View of the mold follows the same concept of the Front View. Two gun drilled holes will be drilled into each plate and plugged to route the cooling channels.
Core Half: Overall Dimensions

The overall dimensions of the Core Half are approximately 44” x 44” x 3.75”. As shown in two pictures after this the core is 38.820” in diameter and the outer diameter of the flash pocket is 40.500”. The mold plate is about a 44” square to allow for enough area for the part to be comfortably molded while not having an oversized mold. To help with venting a relief cut was added in an area of minimal concern. To do this, a 7” x 7” contact area was left in each corn of the plate and are at the same height as the Pinch-off area. These areas help resist wear on the Pinch-off area while providing an ideal area for clamp force to be exerted. Tack-offs are also shown in the image.
The cavity half of the mold follows the same concept as the core half. The only difference is that the cavity half does not have any tack-offs. The molding surface is flat.
As discussed earlier the outer diameter of the mold core is 38.820” and the outer diameter of the flash pocket is 40.050”. The mold core diameter was determined using the shrink factor parameter in Creo Parametric set at 2%. 

Core Half
Cavity Half

The cavity half follows the same concept as the core half on the previous page.
One crucial area when attempting to extrusion blow mold a part is the Pinch-off. As discussed in class there are a few different types of Pinch-offs. The one used for this mold was a Single Angle Pinch-off. This was because the part has very simple geometry; a single circular feature with a constant parting line. The recommended dimensions as discussed in class for a Single Angle Pinch-off are recognized to be concerned with, Land Length, Flash Angle, and Flash Pocket Depth. The Land Length is recommended to be between 0.015” – 0.045”, for this mold the length used was 0.030”. This was due to the size yet simplicity of the part. For the Flash Angle it is recommended to be between 30° and 45°. For this mold a 30° angle was used to provide an appropriate Pinch-off design. The lower end of the range for the Flash Angle was used in hopes a less steep angle would allow for plastic to push up into the parting line easier causing a better seal. Lastly the Flash Pocket Depth was dimensioned. The Flash Pocket Depth has the largest effect on the Pinch-off strength and is recommended to be 80% of the wall thickness. Since the wall thickness of the part is 0.125” the Flash Pocket Depth was dimensioned to be 0.100”. This should be the optimum size and provide the best Pinch-off strength. The Cavity half of the mold is pictured on the next page and follows the same exact dimensioning scheme for the Pinch-off area.
Cavity Half: Pinch-Off Detail Dimensions

The Pinch-off for the cavity half is the same as the Pinch-off for the core half.
For this part the perimeter is crucial and is unable to be interrupted by a large blow pin that can be a stress concentration area. Since the part must support a load of 1,000 pounds it would be ideal for there to be zero weak spots on the part. So, to combat this, blow needles are being used to hopefully minimize this effect. The part is very large and has several tack-offs which will require multiple evenly placed blow needles to properly blow the parison into shape. Four blow needles are intended to be used, each placed at a major intersection to provide even inflation of the parison. When searching for typical hypodermic needles the Birmingham Gauge was found and for this part it was decided to use an 8 Gauge Needle. The sizing followed the Birmingham Gauge, so the outside diameter of the hypodermic needles is 0.165” (radius = 0.0825”) [22]. The holes were dimensioned to this size but will need to be a few thousandths of an inch larger to allow for the needle to be inserted and retracted from the hole.
Shown is the entry hole of where the needle will come through the core plate of the mold and pierce the parison.
The Draft Analysis for the core and cavity halves show no undercuts so the part should eject with ease.
The website was not able to account for such a large mold. So, the highest values for size were inputted and the cost was calculated. The Envelope X-Y-Z dimensions and Projected Area were obtained from the part size.

The tolerance is also not critical since the part is so large and the clearance for the hole should allow extra room. The part is also fairly simple even with the tack-off design used. The surface finish of the mold is not critical and is not fine. Also, the material is glass fiber filled which will be hard to obtain a good surface finish with. Plus, a high polish finish would be quickly worn by the material.

The estimated cost is $83,193, but since the mold is larger than the input values it is expected that the mold cost will be more than the estimate. It is unknown how much more the mold will cost though [23].
Design Details 2

Design Drawings

Die and Mandrel Hand Sketch
Parison thickness not changed by die or mold.
Thickness changed by pre-temper thickness expansion.
Views Shown: Top View (With Hidden Lines), Front View (With Hidden Lines), Right View (With Hidden Lines), and Isometric View (Without Hidden Lines).

Overall Dimensions are shown and the Nominal Wall Thickness is 0.125 Inches.
Right Sectioned View with Updated Equal Spacing

Draft Analysis

Draft Analysis
Mold: Front View
Mold: Right View

<table>
<thead>
<tr>
<th>Title</th>
<th>MANHOLE COVER MOLD</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
<td>KEVIN CUMMINGS &amp; HUNTER FANTECHI</td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>17-MAR-19</td>
<td></td>
</tr>
</tbody>
</table>

Penn State Behrend School of Engineering
Core Half: Overall Dimensions
Cavity Half: Overall Dimensions
Core Half
Core Half: Pinch-Off Detail Dimensions

This line is part of the relief cut for venting.

DETAIL A
SCALE 4:000

8 x Ø0.875
For All Water Lines

SECTION A-A
This line is part of the relief cut for venting.

 SCALE 4.000

SECTION A-A

8X Ø0.875 For All Water Lines

SEE DETAIL B

Cavity Half: Pinch-Off Detail Dimensions
Core Half: Blow Needle Detail Dimensions

SAME SIZE FOR ALL FOUR BLOW NEEDLE HOLES
SAME SIZE FOR ALL FOUR BLOW NEEDLE HOLES

Core Half: Blow Needle Detail Dimensions
Core Half: Draft Analysis

Cavity Half: Draft Analysis
Estimated Mold Cost [23]
ANSYS Analysis

Using ANSYS software can help to accurately predict the mechanical properties of a part by meshing a model with nodes and elements that calculate the stresses and deflections at the node. The load case associated with the manhole cover involves adding a load of 1,000 pounds to the top surface of the cover. The specification for this was that the maximum deflection must stay below 0.125 inches.

Since the particular grade of material that is being used on the manhole cover is not within the Workbench database a custom material had to be made with the material values from the material data sheet. The data used for the modulus and Poisson’s ratio can be seen in Figure 6.

The next step of the process is to establish a mesh on the part that is being analyzed. Tighter meshes with smaller element sizes typically yield more accurate results. Too many nodes or elements can lead to much longer solve times with not much of higher degree of accuracy. Our model was meshed using global sizing and contained 76,116 nodes and 39,255 elements. The mesh pattern can be seen in Figure 7.

![Figure 6: Material Data](image-url)
Once the mesh is developed the next step to completing the analysis is to add conditions for the load applied. Constraints must be added to simulate what will occur as the manhole cover is sitting within the ground and the outside is unable to deflect due to the edge that surrounds the cover. A fixed support was then added to both the bottom edge of the cover as well as around the edges of the part since the edges around the manhole cover also prevent it from moving. These constraints can be seen in Figure 8.
Once the supports on the areas that stay fixed were added to the part, the next step was to add the load that would be tested on the part. In order to do this a 1,000 pound component force was added in the negative Y direction across the top face of the manhole cover. Both the fixed support constraint and the load condition can be seen in Figure 9.

Figure 9: Loading conditions

The deformation can be seen in the plot below for the initial loading conditions. With the 1,000 pound force a maximum deformation was found in the negative Y direction of 0.0425 inches. This can be seen in Figure 10.

Figure 10: Deformation Plot at 1,000 pounds
After observing the deformation was well below the limit of 0.125” the load was increased all the way to 3,000 pounds which would equate to a pressure of 2.64 psi. The deformation from this load was 0.127” which put the model over the allowable limit. The can be seen in the figure below.

After looking at ways the model could be fine tuned it was determined that the support conditions could be changed to be more accurate to the real world application and have better performance of the part as well. Since the manole cover actually sits on a lip within the hole, the width of this lip is essentially 1-inch. With this the model had to be moved in to design modeler to create a split body around a 36” diameter edge boundary. This split can be seen in Figure 12.

Figure 11: Deformation Plot at 3,000 pounds

Figure 12: Split-face sketch
Once the split face was created, a fixed support could be added to the 1” width around the lip of the cover. The fixed support could then be added the lip and the outer edge. The new constraints can be seen in Figure 13.

With the new fixed supports, the deformation was tested in a similar way starting with the 1,000-pound load force. With this force the deformation was only 0.03394” compared to the 0.0452” deformation that was seen with the old constraints which is an improvement. The plot can be seen in Figure 14.
The applied force was then increased incrementally by 1,000 pounds all the way to 5,000 pounds. These increases can be seen in Figures 15 and 16.
At even the 4000-pound load the deformation was still within the maximum deflection of 0.125" with the deflection of only .10125". Using the 1” lip around the outside helped to give more accurate results and also show that our design is more robust than was thought. One possible reason for this is that the hand calculations used only accounted for the tack-offs in one direction rather than the transverse tack-offs which would have raised the momement of inertia as well as increase the equivalent thickness that was calculated using the moment of interia.

POLYFLOW

Geometry showing the surfaces used to develop the PolyFlow in SpaceClaim.

The mesh for the PolyFlow analysis was created with 81502 nodes and 82196 elements.
This plot shows the constant thickness of the parison because there is no parison programming to alter the thickness of the parison as it drops before the mold closes and is blown. There is very little variation in thickness throughout the parison.
Upon running the solution for the mold closing the solution failed after the 30 minute run time.
References


17. GE Design Guide

18. Elastomer Part and Mold Design Guide

19. Milacron UA 1200 Data Sheet


