EXTRUSION BLOW MOLDED BUMPER WITH TACKOFFS: ELIMINATING THE NEED FOR TWO COMPONENT BUMPERS

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Abstract

A bumper is an essential component to vehicles as its purpose is to absorb impact during low-speed collisions to lessen damage to other components of the vehicle. The functionality of this proposed design was validated through finite-element stress analysis (FEA) with ANSYS. The PP part is designed with tack-offs to meet the bumper standards provided by NHTSA, and it was determined that the design meets these standards through deflection and stress analysis.

Introduction

A bumper for passenger vehicles is a safety feature designed to absorb impact from low-speed collisions to prevent damage to the vehicle. When the first vehicles were invented, there were no safety requirements or considerations. In the early 1900’s, the first bumpers were invented but did not have a set of safety standards to go by. It was not until 1971 that National Highway Traffic Safety Administration (NHTSA) issued the first passenger vehicle bumper safety standard [1]. Today, car bumpers are designed based on a variety of considerations, such as safety, weight, functionality, and appearance.

In the past, car bumpers were made of metal, but due to the desire for lighter, faster cars and technological advancements in the plastics industry, they are nearly all made out of plastic. However, there is still typically a reinforcement bar, commonly known as a bumper beam, underneath the outer plastic part, or fascia. This is what actually absorbs the impact. Bumper beams are typically made out of steel, aluminum, and composites. If there were a way to eliminate the bumper beam, cars could potentially be much lighter and exhibit enhanced performance. Hence, the design of a blow molded bumper with tack-offs to absorb and distribute impact.

As previously mentioned, NHTSA has established standards for passenger vehicle bumpers. Briefly, there is a set of damage criteria that must be met when the bumper is subjected to impact at 2.5 mph. Some of these damage criteria include proper function of the doors, hood, and trunk after impact, as well as no leaks in fuel, cooling, and exhaust systems. Since the standard for bumpers deals with impact, a finite-element stress analysis will be done on the proposed design to validate its effectiveness.

The proposed material for this part design is an extrusion grade of polypropylene (PP). As mentioned, bumper beams are typically constructed from steel, aluminum, or composites. With this design, a bumper beam will not be used, so the bumper itself will have to perform similar to the beam. PP is a durable material and remains so in a wide range of application temperatures, and has exceptional environmental properties such as weathering and chemical resistance. The fascia that covers the beam is currently injection molded from materials such as PP and thermoplastic olefins (TPO). Bumpers have also been extrusion blow molded from acrylonitrile butadiene styrene (ABS) in the past. Because this design concept of an extrusion blow molded bumper included tack-offs, the need for a bumper beam will be eliminated and the bumper will consist of one component.

Statement of Theory and Definition

The Passenger Vehicle Bumper

Product Description

As explained previously, bumpers for passenger vehicles are designed to protect other components of the vehicle during a low-speed collision. It is important to note that the bumper is not responsible for absorbing high speed impacts to protect the passenger, but solely to lessen damage and ultimately repair costs due to low-speed collisions. Bumpers are used in the front and rear of the vehicle, and are designed to be the first component of the vehicle to come in contact with another object during a collision.

In the introduction, it was explained that bumpers are traditionally constructed of two components, a plastic fascia and an impact absorbing beam. There are no specifications of what materials to use for bumpers, nor how they should be constructed, but that they should withstand perpendicular impact up to 2.5 mph [2]. The
proposed product design introduces a new design element to eliminate the need for a heavier, undesirable second component.

Bumpers are essential to vehicles, but an increasing desire for lighter, faster, and greener vehicles necessitates a need for lighter or fewer components. If the need for a bumper beam with plastic bumpers is eliminated, then the weight of the vehicle will decrease significantly.

Brief History

Before the plastics industry began to take over the automotive industry, bumpers were made of metal. Because of this, they were much more durable than bumpers manufactured today. It is for this reason that metal components are still used in bumpers. In general, vehicles were much heavier and had very poor fuel efficiency. With more recent technology, bumpers can be made lighter, especially with composite bumper beam designs, without sacrificing significant structural stability.

The bumper is far from a new product design, in fact, they have even been extrusion blow molded. However, typically the bumper beam is the only component blow molded; there is still a second injection molded fascia component. There is always a window of opportunity to improve current designs and propose new methods of manufacturing existing products.

Anticipated Life

A bumper is a long-term application because it is expected to withstand environmental elements and last the entire lifespan of the vehicle to which it is attached. Passenger vehicles are not designed specifically for the environment they will be used in, because there is no way of knowing that type of information; cars are driven all over the country and passed from owner to owner. This means there is a wide range of conditions which vehicles, and ultimately bumpers, will have to withstand.

The performance of the bumper and its lifespan will depend mostly on material selection. The design of the bumper will determine the amount of damage done if it is ever exposed to impact. If it is designed properly, it should remain functional after small, low-speed bumps. Other factors to consider when designing a bumper include temperature, sun exposure, precipitation, and chemicals.

There is a wide range of temperatures vehicles are exposed to throughout their lifetime. Bumpers must be able to withstand and perform in temperatures as cold as Alaska and as hot as Texas. Also, no matter where a vehicle is used, it will be exposed to UV rays from the sun. Not all vehicles are put under a roof when not in use, so they are exposed to large amounts of UV radiation. UV radiation has one of the largest effects on outdoor plastic applications as it breaks down the polymer chains, significantly decreasing the mechanical and appearance properties of the product. Luckily, bumpers can be painted or coated to enhance their UV resistance. Bumpers are also exposed to a number of elements, such as rain, snow, hail, etc. Some rain has pollution in it, and chemicals are applied to roads to melt snow, so chemical resistance of the bumper is important.

Demand

Overall, there is a noticeable trend in making products more “green”. This trend does not fall short of the automotive industry, in fact it is one of the main factors consumers consider. According to “Automotive Resource Guide,” current market trends for passenger vehicles in Austria are centered around fuel savings, in which lightweight plastic car bumpers are an ideal prospect [3]. In Israel, importers are looking for quality products at competitive prices, of which bumpers are in the greatest demand [3]. In general, there is a global demand for lightweight plastic bumpers to enhance the fuel economy and efficiency of vehicles.

With the lightweight properties of the proposed design, it is anticipated that the demand will be significant. The concept of using tack-offs to add strength without added weight can be applied to various bumper designs to fit different vehicle models. Extrusion blow molded bumpers with tack-offs are anticipated to become very popular and desired by vehicle manufactures to improve their products, therefore increasing the demand.

Tack-off Design

One design detail that is commonly used in blow molding is tack-offs. This feature is typically used in flat panel structures to enhance required stiffness, strength, load type, support conditions, and aesthetics required. According to GE/SABIC’s “Engineered Blow Molding Part Design,” tack-offs enhance panels structurally by creating a compression weld between the opposite walls, allowing loads to transferred between them. As a load is applied, it is distributed by the tack-off to the opposite wall to increase its strength. This function can be seen in Figure 1. There are two types of tack-offs, conical and rib. Rib tack-offs were used in this design because conical tack-offs generally do not perform well under significant
bending stress [4], and in this case, structure enhancement is of prime importance.

![Figure 1: Tack-off Transferring Load; Source: GE/SABIC Plastics Engineering Blow Molding Part Design](image)

The design of the tack-off is based on the relationships between typical wall thickness and the size of the part. Figure 2 shows these relationships and how the dimensions are determined.

![Figure 2: Tack-off Design; Source: GE/SABIC Plastics Engineering Blow Molding](image)

The first important step to designing the tack-off is determining the x value. This is done by multiplying the y value by 1.2, with the y value being the width of the part. Typically, the angle of the four sides of the tack-off is 25°. Possibly the most important step is determining the thickness where the opposite walls come in contact. The recommended dimension is 1.5-2 times the nominal wall thickness. With this proposed part design, 1.5 was used to ensure a strong contact weld. The final dimension is the spacing between the tack-offs. Figure 2 is based on a 19.05mm thick panel, so a part with a thickness of 101.6mm would have a much larger x dimension. The recommendation for spacing is 50.8-76.2mm, so it requires alteration for a larger part. This was determined by doubling the maximum recommendation.

### Original Manufacturing of Bumpers

The most common method for manufacturing bumpers is injection molding an outer fascia and mounting it over a bumper beam made of metal or composite materials. Bumper systems also contain compressive materials such as PP foam or plastic honeycomb to absorb impact upon collision [6]. There have been studies on blow molded bumper beams, but traditionally they are formed from metal. Designs of some common bumper systems can be seen in Figure 3.

![Figure 3: Common Bumper Systems; Source: Development process of new bumper beam for passenger car: A review](image)

Bumper design number four in Figure 3 is more desirable because it not only serves the purpose of a bumper to the vehicle, but also reduces injury to an individual if struck by the vehicle [8].

The process used to manufacture the plastic fascia of the bumper is injection molding. Injection molding is one of the most common and most important processing methods of plastic parts. The injection molding process can be used to produce a high volume of parts in a relatively short period of time. The basic operation of injection molding includes the melting of a thermoplastic material with a screw and heater bands around a barrel. The screw advances material from a hopper forward, and gradually compresses it. This causes shear heating which melts the pellets in conjunction with heat from the heater bands. Once the polymer is melted, it is measured in the metering zone of the screw and forced into the mold cavity through a nozzle. A packing phase then continues...
to push material into the cavity as the part cools to compensate for volumetric shrinkage. Once the part is cooled, it is ejected. This process allows for tighter tolerances than most plastics processes.

There are several major advantages of the injection molding process, some of which have already been stated. Fast production and low production costs are arguably the biggest and most important advantages. Bumpers are mass produced due to the large volumes of vehicles being manufactured yearly. It is important that the cost of production remain minimal to optimize revenue. Also, there is very little post production operations with injection molding. The process yields high precision, ready to use parts. With injection molded bumper fascias, the only secondary operations required are painting and assembling. Precision molding is ideal for the fascia component of the bumper, because it is visible to the consumer.

Despite the many advantages of injection molding, there are also some disadvantages. A major disadvantage is the high initial tooling cost required to make a part. Before a part can be made, a tool must be designed, built, and conditioned before it is ready for production. This is especially undesirable when molding bumpers because they are so large. A part of this magnitude would yield an outrageous initial tooling cost. Also, injection molding machines are not capable of producing hollow parts. It is for this reason that an injection molded bumper needs a bumper bar to make it functional. Without it, the fascia would not be able to withstand the impact specified by NHTSA.

The metallic component of the bumper is typically made of steel or aluminum. These can be stamped to shape and may have ribs for added support. They are typically hollow and are fastened to the vehicle with brackets. The plastic fascia is then assembled on top of the beam to complete the bumper.

Proposed Manufacturing of Bumpers

The proposed method for manufacturing this bumper design is extrusion blow molding (EBM). EBM is a very common method of producing hollow, thermoplastic parts. It can be used for a wide variety of applications due to its ability to produce various part sizes. Compared to current methods of producing bumpers, EBM offers enhanced product capabilities and a significant cost and weight reduction. EBM is ideal for car bumpers because a hollow, light, cheap part can be mass produced.

The mold will be very large, so it would be more convenient if it were constructed of aluminum rather than steel. This aluminum alloy was chosen over other aluminum alloys used for extrusion blow molding molds because it is cheaper and still has enough strength. Aluminum also has a much higher thermal conductivity than steel, so it would aid in cooling the mold.

EBM is a commonly used process because of its many advantages. One benefit to EBM is lower tooling costs. With a part as large as a car bumper, the mold strength of an injection mold would have to be significant to withstand clamping forces required due to plastic pressure. EBM is a lower pressure process, so the mold can be much cheaper than an injection mold for the same part. Also, EBM can produce hollow parts without the use of cores. No cores allows for irregular shapes, such as a bumper with tack-offs. The hollow aspect of the part allows it to absorb more impact. Another advantage to EBM is one piece construction. EBM bumpers are produced as one piece, so there is no assembly required before installation. There will be some secondary operations, but the single component bumper will make installation easier. Impact strength will also be greater because there are no seams along the length of the part to act as stress concentrators.

Even though EBM is an ideal process for producing bumpers, there are some negatives. A major one is the longer cycle times when compared to injection molding. Because all sides of the part are in contact with the mold in injection molding, heat is conducted through the mold much faster. With EBM, only one side of the part wall is in contact with the mold, so it takes longer to cool. This can negatively impact production rates, which can become a problem with higher demand. It is also not possible to mold in holes with EBM. When molding a bumper, ideally holes would be molded in to aid in assembling to the vehicle. However, secondary drilling operations can be eliminated if fasteners are designed and molded into the part. Because the parison only comes in contact with the mold on the outer wall, there is wall thickness variation. This may create variations in load distribution for EBM bumpers, affecting its overall performance.

Extrusion blow molding is a common process that involves the extrusion of a hollow parison that gets closed in a mold and blown to shape. It begins with the melting of a polymer in the extruder by means of a screw in a barrel. As the screw rotates, material is conveyed through the barrel and gradually compressed, creating shear heat. This causes the polymer to melt, where it then enters the extrusion head from the side port. Here the melt comes in contact with the mandrel and divides to flow around it. The melt then welds together on the other side and turns 90° to go downwards. A hollow parison is formed when it is pushed through the die and mandrel, which are sized to achieve a more even wall thickness distribution [7]. There are two type of mandrels, converging and diverging. For the bumper design, a
50.8mm diameter converging die is used. A shaping is calculated to make certain areas of the parison thicker to reduce wall thickness variation; this is known as parison programing. As previously mentioned, a weld line is formed during the extrusion of the parison. This can be eliminated with the use of a die that turns 90°, eliminating the need for the melt to flow around the mandrel. Overall extrusion blow molding is a very popular process and would be an ideal way to manufacture bumpers.

**Design Specifications**

As one can imagine, there is a set of specifications that a passenger vehicle must meet. There are three tests used to determine the effectiveness of a bumper. The bumper is installed on the vehicle as it would during consumer use. The vehicle must be at its unloaded weight, front wheels facing straight ahead, tires inflated to manufacturers specifications, brakes disengaged, transmission in neutral, and trailer hitches, license plate brackets, and headlamp washers are removed. A pendulum-type test is used, one at 1.5 mph on the sides and another at 2.5 mph on the front. The third test consists of impact into a fixed collision barrier perpendicular to the vehicle at 2.5 mph [2].

After the execution of each test, a list of items must be examined to validate bumper effectiveness. Each lamp and reflective device shall remain un-cracked and be adjustable to within the beam aim specifications. Also, the hood, trunk, and doors shall maintain normal operation. There should be no leaks in the fuel, cooling, and exhaust systems [2].

Unfortunately due to time and resource limitations, design validation cannot be done with these tests. Instead, design validation will be done through FEA simulation where von Mises stress and total deformation will be evaluated.

**Original Materials**

The majority of fascia components of bumpers are molded from flexible materials. Out of the various bumper styles including metal, flexible fascia, hard chrome steel, and rigid plastic, approximately 60% of the market share is comprised of flexible fascia [9]. Materials used for these types of bumpers include RIM Urethane (RIM), Thermoplastic Olefin (TPO), and Thermoplastic Polyester Elastomer (TPPE). Out of these materials, RIM makes up about 70-80% of the bumper fascia market [9]. Flexible materials such as these are commonly used for bumper fascias to prevent cracking during impact. Rigid materials are more likely to crack if involved in a collision and will need to be replaced. However, fascias made of these materials are not capable of meeting the specifications of a bumper.

With the use of a flexible fascia, a metal or composite component is needed to absorb impact. Steel, aluminum, and rigid thermoset materials are used to create bumper beams because they can withstand much greater impacts than the plastic fascia alone. These materials are able to meet the specifications of a bumper, but they add weight and an extra component to the design which is undesirable.

**Proposed Materials**

With the use of tack-offs and a durable thermoplastic material in an EBM bumper design, the need for a heavy bumper beam can be eliminated. The proposed material for this design is an extrusion grade of PP, specifically Hostacom BE17FC BLK from LyondellBasell. This material is UV stabilized, precolored, 40% calcium carbonate filled, and has an excellent balance of properties [10]. It is commonly used in extrusion and blow molding processes and is used for exterior and underhood automotive applications. This grade of PP is ideal for extrusion blow molded bumpers because it can be easily extrusion blow molded and will provide optimum environmental and mechanical properties for an automotive bumper exposed to various outdoor elements.

PP is a commodity material that is widely used in plastics products due to its outstanding properties. It is one of the cheapest resins and can be processed with all thermoplastic equipment. One major advantage of using PP for a bumper is its good impact strength. Since the main purpose of a bumper is to absorb impact to protect other vehicle components, it is important that the material it is composed of has considerable impact strength. PP has a relatively low Tg of 15°C when compared to other thermoplastic resins. This means that PP will maintain its impact strength at lower temperature than other materials, which is beneficial when the bumper is exposed to freezing temperatures. Also, PP has very good chemical and corrosion resistance, which is necessary for bumpers due to exposure to chemicals such as oils, soaps, and cleaners. Another advantage to using PP for bumper applications is its moisture resistance. Bumpers are exposed to moisture from precipitation, humidity, and washing throughout their lifespan, so it is important that they do not absorb moisture. This means that the part will have good dimensional stability, so it will maintain its specified dimensions.

Despite all of the benefits to using PP, there are some disadvantages to consider. A major disadvantage when using PP for a bumper is its inability to bond well
with paint. In the automotive industry, color of vehicles is very important. If PP is unable to be painted to match the rest of the vehicle, it may be undesirable to consumers. However, methods have been developed to allow the decoration of PP surfaces. PP is also very susceptible to UV degradation. The grade of PP used in this contains a UV-absorbing additive, which eliminates the need for a coating to protect the product from degradation due to UV radiation. Another disadvantage when using PP is its high thermal expansion coefficient. This means that as the temperature of the product increases, it will expand. This can make it difficult to attach the bumper to the vehicle properly, but fastening methods can be designed to eliminate this problem.

Design Validation

With the time and resources available for this part design, the proper tests were not able to be conducted. Instead, FEA simulation was used to determine proper wall thickness and analyze the stress and deformation of the design.

The bumper design was analyzed with ANSYS Workbench 16.1. This simulation software allows the simplification of model analysis through the use of symmetry and mid-surface extraction. Because the bumper is not being produced, there cannot be a physical test. Previous studies have been done to simulate the NHTSA test specifications. One particular study modeled the low-speed impact scenario and determined how it should be analyzed with finite element modeling. Figure 4 shows how the loadings will be applied in the simulation.

![Figure 4: Impact Layout; Source: Thin-Walled Structures](image)

Analysis of the proposed bumper design in ANSYS will be done in a similar manner, with the loading on the front of the bumper and fixed supports on the back. A load of 136.08kg will be used based on requirements for low-speed impact. The performance of the bumper will be evaluated based on von Mises stress plot and total deformation. Von Mises is important to evaluate to ensure the material did not yield. If the material yields, it fails and does not meet its requirements. Total deformation is also important because E.C.E says, “all structures located before the bumper should remain undamaged after the impact” [5]. The article shows that deflection less than 40mm is sufficient to achieve this. Essentially, if the material does not exceed its yield stress and the bumper does not deflect more than 40mm, then the design is probable.

Design Procedure

The initial redesign of the bumper began with a basic rectangular extrusion in PTC Creo Parametric 3.0. Angled sections were added to either end of the rectangle, similar to the shape of Figure 5.

![Figure 5: Generic Bumper Shape; Source: BenzWorld.org, 411 Bumper Forum](image)

This figure is a very basic design of a metal bumper, and was used to establish a generic shape for the redesign. The dimensions were based on a relatively smaller vehicular width, similar to that of a jeep. Rough dimensions can be seen in Figure 6.

![Figure 6: Generic Bumper Shape; Source: Thin-Walled Structures](image)
The overall length, width, and height were based off of this bumper design.

Once the general shape of the bumper was modeled, chamfers were added to the sharp corners. GE/SABIC’s design guide states that rounds cause the parison to stretch more than a chamfer of the same dimension [4], so there will be greater wall thickness variation.

After the basic design and chamfers were modeled, attempts to create a successful, rigid design began. Initially, ribs were modeled in the back of the bumper to add strength, which can be seen in Figure 7.

The design of these ribs were based roughly on working relationships provided by GE/SABIC’s design guide [4]. Before an analysis was run, tack-offs were considered. After consideration, it was decided that tack-offs would provide higher strength properties and distribute loads more efficiently than ribs. So, the part was redesigned with tack-offs. The specifications for this feature can be seen in the “Statement of Theory and Definition”, subsection “Tack-off Design.”

The final features added to the model were draft and rounds. Draft is a necessary feature to aid in ejection of the part. Also, increasing draft angles reduces parison stretching to yield more even wall thickness. The recommended draft angle is 2° per side [4], but 4° was used. Then, rounds were added to reduce polymer stretching. Even though this part design is not a flat panel, recommendations for a flat panel with the same cross sectional width were used. GE/SABIC’s design guide has specifications for a panel with a sectional thickness of 127mm, which is very close to the 101.6mm sectional thickness of the bumper. Here it recommends a nominal wall thickness of 2.5-3.8mm, 2.5mm was used until the model was analyzed in ANSYS. It also recommends an edge radius of 8.128mm and a minimum corner radius of 12.7mm. Because of the chamfers, there were no 90°corners, so the 12.7mm radius was only used on the outer edge of the angled ends. The 8.128mm radius was applied to all remaining edges [4]. A detailed drawing of the part design can be found in the appendix.

The Creo part was then saved as a Parasolid file format to be imported into ANSYS. Once in ANSYS, quarter symmetry was applied and the mid-surface was extracted to use Shell181 element type. In engineering data, a new linear elastic material was created for 40% calcium carbonate with a Young’s Modulus of 3500MPa and a Poisson’s Ratio of 0.4. In the design modeler, the material was set to the newly created material. Then, in mesh settings, the relevance was set to 100, a medium relevance center was used, and an element size of 2.54mm was used. Also, a face sizing of 1.27mm was applied to the three flat surfaces of the tack-offs to reduce mesh error. These mesh settings produce mesh statistics seen in Table 1.

Table 1: Mesh Statistics

<table>
<thead>
<tr>
<th>Mesh Statistics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes</td>
<td>35527</td>
</tr>
<tr>
<td>Elements</td>
<td>35213</td>
</tr>
</tbody>
</table>

Because the model was being analyzed in quarter symmetry, displacement constraints were put on the exposed edges in the x and y directions. Also, a fixed support was placed on the center tack-off. Finally, a load of 1334.5N was applied to the front face of the bumper. These conditions are summarized in Table 2.

Table 2: Boundary Conditions

<table>
<thead>
<tr>
<th>Displacement</th>
<th>X=0mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>Y=0mm</td>
</tr>
<tr>
<td>Fixed Support</td>
<td>Center tack-off face</td>
</tr>
<tr>
<td>Force</td>
<td>1334.5</td>
</tr>
</tbody>
</table>

Finally, the thickness was defined as 2.54mm and the model was solved. The von Mises and total deformation plots were analyzed to validate the thickness of the part. The simulation was re-run, this time with a
thickness of 3.81mm. It is in this way that the optimal thickness of the part can be determined.

Once the part design was finalized, a mold was constructed. To do this, a new mold assembly was created in Creo based on the geometry of the bumper part, with the parting line being the greatest perimeter around the part. A shrinkage value of 0.7% was applied to the mold for the proposed 40% calcium carbonate filled PP material. The mold should be constructed of 6061-T6 Aluminum.

After the mold halves were created, additional features needed to be added such as vents, pinch off, air inlets, and cooling circuits. Each of these features was dimensioned according to Advanced Elastomer Systems’ guide for extrusion blow molding [10].

Presentation of Design

With the increasing desire for green vehicles, the need to reduce weight without sacrificing performance is a necessity. The goal of this design is to do just that. Currently, bumpers are made of two or more components, including a heavy bumper beam, an impact absorbing material, and a plastic fascia. The proposed design of an extrusion blow molded bumper with tack-offs will eliminate the need for multiple components.

Even though it is not the most common method, bumper beams have been extrusion blow molded, and are typically covered with a fascia. The beam is designed to absorb the impact of a low-speed collision, while the fascia is for aesthetics. The proposed EBM bumper with tack-offs was shown to meet the requirements of low-speed collisions, and the design can be altered to enhance aesthetics if desired. The basic design of the bumper remained similar to those of bumper beams, but the most important differences are the tack-offs, material selection, and wall thickness.

FEA simulation was used to evaluate the effectiveness of the tack-off design and to determine the proper wall thickness. It is an important tool in the redesign of the bumper because it will make the design comparable to previous designs. This can be done with FEA by analyzing the total deformation plot to establish an optimum part thickness and evaluate the effectiveness of the tack-offs. The von Mises stress plot will show whether or not the material yielded, which will also aid in the validation of tack-off design.

The major feature modification in this bumper design is the use of tack-offs. Bumper beams typically have ribs on the back to increase strength, but it was decided that tack-offs would add more support to the weaker plastic material beam by distributing the load more evenly. The tack-offs were designed based on recommendations from GE/SABIC’s design guide.

Material selection and wall thickness are both required to design a functional part. The wall thickness of the bumper was determined through the use of FEA simulation. For this to be done, the modulus of the material needs to be known. Once the material was selected, an FEA simulation was run on the part. The results of the initial analysis can be seen in Figure 8 and 9.

The total deformation plot in ANSYS shows the total distance the part travels after a force or load is applied. In Figure 8, a light outline can be seen where the part was originally. ANSYS exaggerates the deflection to make it more apparent where the most deflection occurs and how the object behaves under load. The results from ANSYS can be found in the appendix to better show the details of the images. The scale on the left shows a color-coded range of deflections which can be used as a reference when examining the plot. A red tag can be seen on the plot that says “max”. This is where the maximum deflection occurs.

It can be seen in Figure 8 that the total deflection of 13.579mm is well within the requirement of less than 40mm. From this it can be determined that the wall thickness and tack-off design meet the requirements specified.
The equivalent von Mises stress plot shows the stress throughout the part while it is under load. Similar to the total deformation plot, the color-coded scale on the left can be used to determine where the higher and lower stresses occur on the model. Again, the red tag that says “max” points to the maximum stress on the model. Von Mises stress plots are useful when determining whether or not a design will yield under the specified loads. The max value can be compared to the yield stress of the material used, and if the von Mises stress exceeds the material yield stress, the model failed.

When comparing the max von Mises stress of 245.15MPa to the yield stress of 27MPa of the material, it is obvious that the model failed in the simulation. So, this means that the wall thickness of the part is not large enough.

The initial wall thickness used was recommended in GE/SABIC’s design guide for a 127mm cross sectional panel, which was 2.5-3.8mm. Initially, 2.5mm was used, but after seeing the failed results of the von Mises plot, a second analysis was run with a thickness of 3.8mm. These results can be seen in Figure 10 and Figure 11.

If there were more time, the model could be redesigned to eliminate this problem. Ideally, a fastener would be designed and molded into the part, so the fixed support would be more consistent. Despite that single high stress point, it is obvious that the material selection, wall thickness, and tack-off design were effective in the bumper design. The concepts are solid enough to move forward with, and it is clear that the need for multiple component bumpers can be eliminated. It is important that the high stress point in the part became apparent through simulation, so design modifications can be made to the mold before it would be constructed.

When modeling the mold, there are several features that need to be added such as shrinkage, vents, ejector pins, pinch offs, and air inlets, and cooling circuits. Mold shrinkage was applied to the mold once it was made to compensate for the volumetric shrinkage of the material. This makes the mold slightly larger, so the final product is ejected at its correct dimensions. Vents are also added to allow air to escape the mold during blowing. This is critical to the process to ensure optimal contact between the parison and the mold. It is also important to add an ejection system to the mold to prevent parts from
getting stuck. Perhaps one of the most important features is pinch off. The dimension for the pinch relief depth is 80% of the wall thickness. This will cause some material to be squeezed back into the mold to prevent weak welds. With this bumper design, four blow needles were used to fill the part because a blow pin was not feasible. Finally, a cooling circuit was designed to remove heat from the mold to allow faster cycle times.

For the extrusion blow molded bumper design, a diverging die and mandrel design should be used. The smallest diameter of the part design is 101.6mm, so with a blow ratio of 2:1, the outer diameter of the parison should be 50.8mm. This is also the diameter of the die. To accommodate for material stretching and thinning the corners of the part, a die shaping should be applied. Essentially, this programs the parison by making sections that stretch the farthest thicker. This will produce a more even wall thickness. A drawing of the specified die with the calculated shaping can be located in the appendix.

Another very important consideration when designing a bumper is the recyclability of the material. Old and broken down vehicles sit in junk yards and rust overtime. Plastic components that are not recyclable sit there and clutter up the environment. In recent years, there has been an emphasis on making the majority of vehicle components recyclable. With this design, the completely plastic bumper would serve its purpose, and when the vehicle is no longer functioning or the bumper needs replaced due to damage, it can be recycled and potentially used in the manufacturing of other vehicle components.

**Conclusion**

Through finite element analysis, it was determined that, with the right material, wall thickness, and tack-off design, bumpers can successfully be extrusion blow molded to eliminate the need for multiple component bumpers. Multiple component bumpers are heavy and require extra cost for assembly, but with a lightweight, recyclable, single component bumper, vehicles have potential to be greener, and ultimately more appealing to consumers. The basic design concept has been modeled and analyzed, and is now ready for the next step. With a redesign of the fixed support location and a more detailed, aesthetically pleasing front, the product would be very desirable.

The purpose of this redesign was to optimize the design of the passenger vehicle bumper while still meeting the requirements of a bumper. Wall thickness was determined through the use of FEA simulation, and the design of the tack-offs was validated. With the second wall thickness of 3.8mm, the bumper only deflected 5mm, which is ideal. This would ensure the protection of the specified doors, hood, fuel systems, exhaust systems, etc. and the safety the pedestrian in low-speed collisions.

**Future Work**

As mentioned earlier, time and resource restrictions limited the evaluation of this bumper design. To improve testing in the future, more time could be spent on the design of the FEA simulation to closer replicate real life tests. Load steps could be applied to simulate the swinging pendulum impact at the specified speeds. As seen in the analysis of this design, there was a singularity where the bumper was attached to the vehicle. More time could be spent on the part design to create a more effective means of assembly. Also, a mold filling simulation for blow molding would be beneficial. If time and resources permitted, ideally a mold would be built so parts could be run and physically tested. It would also be beneficial to test the vehicles fuel efficiency before and after the bumper redesign to validate its effectiveness in that aspect.

**Acknowledgements**

I would like to thank Mr. Jason Williams for taking the time to help me with questions and difficulties while modeling my mold. I would also like to thank Mr. David Johnson for tailoring his course schedule to help us with analyzing thin walled parts in ANSYS. He was also very helpful with questions and did everything he could to help. Finally, I would like to thank Mr. Jonathan Meckley for answering questions about my mold and part design. He also helped me calculate my parison thickness when I ran into problems. Equivalent

**References**


Appendix

Figure

As Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
2/10/2016 6:14 AM

12.579 Max
12.17
10.161
9.9375
7.540
6.036
4.5363
3.0125
1.5128
0 Min

Figure

As Static Structural
Equivalen t Stress
Type: Equivalent (von-Mises) Stress - Top/Bottom
Unit: MPa
Time: 1
2/10/2016 6:15 AM

245.15 Max
217.51
196.62
165.01
136.19
126.85
114.96
74.477
27.229
0 Min
**Hostacom BE17FC**

**Compounded Polyolefin**

**Product Description**

*Hostacom BE17FC* fractional melt flow, 1,800 MPa flexural modulus, UV stabilized, precolored, 40% calcium carbonate filled polypropylene copolymer is designed for a variety of extrusion and blow molding applications. It is characterized by an excellent overall balance of properties.

**Product Characteristics**

<table>
<thead>
<tr>
<th>Status</th>
<th>Commercial: Active</th>
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<tbody>
<tr>
<td>Test Method used</td>
<td>ASTM</td>
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<tr>
<td>Availability</td>
<td>North America, Asia-Pacific, Australia/NZ, Africa-Middle East, Latin America</td>
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<tr>
<td>Processing Methods</td>
<td>Extrusion Blow Molding, Extrusion Pipe Sheet and Semi Finished Products</td>
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<tr>
<td>Features</td>
<td>Copolymer, Low Flow, Good Impact Resistance, Good Melt Strength, Good Processability, Good Stiffness, Good UV Resistance, Good Weather Resistance</td>
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**Typical Customer Applications**

Interior Applications, Panels & Profiles

<table>
<thead>
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<th>Typical Properties</th>
<th>Method</th>
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<tr>
<td>Density -Specific Gravity</td>
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<tr>
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<td>MPA</td>
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<tr>
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<td>ASTM D 638</td>
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<td>MPA</td>
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<tr>
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<td>MPA</td>
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<td>Durometer Hardness (D Scale)</td>
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<td>°C</td>
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</table>

**Notes**

Typical properties; not to be construed as specifications.

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