COSTS OF TPC MOLDING: ECONOMICAL PRODUCTION TECHNOLOGY FOR LOW & HIGH VOLUME 3-D TPC PARTS

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Abstract

When thermoplastic composite materials first appeared, a great effort was made to allow the materials to be 3 dimensionally formed by existing molding processes, such as compression molding and thermoforming. As those materials have matured and new materials have become available, the demand for more flexible and economical molding technology has arisen.

By exploring the use of diaphragms in the molding process, technology has been implemented to form 3-D thermoplastic composite parts on an industrial level.

Evaluating the costs of current molding processes, such as compression molding or thermoforming, reveals an economical deficiency for thermoplastic composite parts with annual volumes from 1,000 up to 100,000. With a significant number of potential product applications increasing proportionate to a decrease in annual volumes, diaphragm molding technology can generate a competitive market for thermoplastic composite materials for low and high volume production applications.

Throughput, tooling costs, capital costs for molding equipment, and what the market will bear, all generate the viability of materials and manufacturing. Diaphragm molding assists in creating new economic targets for the market for a given application.

This paper will overview the diaphragm molding process, analyze and compare the economics of traditional molding processes for thermoplastic composites, and discuss how this new technology can be applied to automotive applications.

Introduction

As the world becomes a smaller place, and international trade grows, many manufacturers are looking for better and cheaper ways to produce and sell their products. Rapid growth in importing manufactured goods from Asia and Mexico are testament to the competitive shortcomings the U.S. industrial arena has, particularly in the plastics industry.

Despite the added cost and time of shipping goods from overseas, the upfront costs, such as tooling or labor, make foreign suppliers very attractive to U.S. manufacturers. With labor rates and raw goods costs at unachievable levels in the U.S., a manufacturer has the option of buying goods from overseas, paying higher prices from U.S. suppliers, or looking for technology that will help cut costs.

If we consider a market such as the automotive market where a significant portion of manufacturing and supplier base is in the U.S., the need for new technology to cut costs is essential.

When considering tooling, for example, we have all heard the stories about toolmakers who can't even buy raw materials for less than what a Chinese molder can build a complete tool for. The alternative for U.S. manufacturers is to seek cost savings by evaluating materials used in finished goods, such as steel versus plastics, injection molding versus roll forming, etc.

This is where the economics of manufacturing meets performance. Assuming that a roll formed steel part and an injection molded part both meet the performance requirements for an application, the decision on whether to use plastic or steel for the part will largely depend on part cost.

The part cost will encompass many factors, including tooling costs, material cost per pound, production throughput, quality, etc. Another significant factor is the number of units produced per year. For example, roll forming steel, which is widely available and relatively inexpensive on a per pound basis, allows an application to be produced in very high annual volumes, which reduces the process cost per unit. Conversely, the tooling to roll form a steel part is complicated, expensive, and requires a long set-up time. Due to the high capacity of roll forming equipment and high tooling costs, significant annual volumes are needed to support a competitive price structure.

Injection molding, on the other hand, offers lower cost tooling and reduced weight, but the resins are typically more expensive than steel. In addition, injection grade resins are inherently structurally inferior to steel, and require more design elements and a carefully planned design envelope. The capital costs of injection molding machinery that is dissolved into a production application is less than roll forming steel, but the annual capacity or throughput is less. For very high volume applications, multiple machines may be needed to meet production requirements. Again, the annual volumes are critical to defining the most economical process and material for a given application.

Discerning the most economical process and material for a given application by analyzing process costs does not necessarily create a more competitive environment. It simply maximizes the existing competitive environment by choosing the lesser of the two evils. As stated previously, the proliferation of new technology has the potential to drive costs down beyond what is achievable using existing processes and materials.

Processes like roll forming, injection molding, stamping, and compression molding are extremely mature, and with the exception of occasional advances, have remained the same for many decades. What have been moving forward technology-wise are materials. New explorations and developments in resins have cut costs and weight for many automotive applications. Similarly, steel has made progress with high-strength and ultra-high-strength grades, allowing for lighter and stronger parts. Despite the advances in materials, capital costs in equipment and tooling are still huge economical factors.

Ideally, a significant cost reduction in manufacturing parts would occur not only by employing new material technology, but new process technology as well. The introduction of thermoplastic composite materials over a decade ago quickly solved one side of the equation: new material technology that allowed costs to be cut. However, the materials, mostly Glass Mat Thermoplastics (GMT), still relied on traditional manufacturing techniques, primarily compression molding.

Initially, this was a positive attribute because it allowed new materials to be molded by established suppliers and equipment, quickly integrating into the marketplace. Since the initial appearance of thermoplastic composite materials, GMT has lost some volume to steel, while new woven thermoplastic composite materials have come to market. These new materials are struggling with applications growth because they too are commonly processed with compression molding, which was proved by the early GMT molders to offer limited cost benefits, especially compared to steel.

By looking at the capital investment into production equipment, such as a compression molding machine, compared to the number of pounds of throughput that investment can yield, versus the tooling costs, one can define the economical value of a process for a given material. Many GMT automotive applications require large, expensive tools that run on large, expensive compression machines. Without significant annual volumes to absorb the tooling and equipment costs, compression molding will remain a limited process, thus limiting potential thermoplastic composite applications.

By defining the potential limitations of compression molding thermoplastic composite materials, new woven materials face the same growth-prohibiting factors.

Now that a plethora of structural thermoplastic composite materials are available, many new applications can utilize them. The second part of the cost reduction equation is now needed: reduced processing costs.

Diaphragm Molding

The inherent form of thermoplastic composites as consolidated sheets or woven fabrics limits the manor in which they can be molded into 3 dimensional shapes.

Essentially, thermoplastic composite sheets or fabrics must be pre-heated and placed or suspended so as to form on a vertical mold. Traditional compression molding forces the material under high tonnage into shape using a matched die. This process can result in quick cycle times, but requires well built, two-sided molds. There are many applications where this is an economical solution to producing products, and annual volumes are high enough to justify the tooling costs.

However, applications where tooling costs or cycle times are not economical to the annual volumes desired, means a new process must be employed.

Using a process that requires low tooling cost, and low capital equipment cost can principally do this. Diaphragm molding offers such cost reductions.

Eliminating the need for high pressures eliminates the need for complex and expensive molding equipment, and allows less expensive tooling materials to be used, such as aluminum. In addition, the use of a flexible diaphragm in the molding process means only one side of the mold is necessary.

The diaphragm molding process in essence uses a flexible diaphragm to stretch a melted thermoplastic composite sheet or fabric over a single-sided mold. Pressure is applied to the diaphragm to insure that the diaphragm and thermoplastic composite material has conformed to the shape of the tool. Once the material has formed to the tool, it is cooled, and then ejected.

The simplicity of the process and low tooling costs gives way to the economical production of thermoplastic composite parts for many applications. However, not all applications are best suited for diaphragm molding, the size of a specific part and annual volume greatly impact production viability.

Diaphragm vs. Compression Molding

There are many sizes of compression machines that can process a wide range of material poundage. Just the same, a diaphragm machine can be configured to accommodate different sizes as well. However, the size of the part and annual volumes play a large role in the size of compression machine used for a specific application.

If a 50,000 piece per year part has a shot size that weighs 2 pounds, and the tooling is $40,000 for a two cavity compression mold, and it will fit onto 350 ton compression machine, then adding additional cavities, increasing the tool cost to $80,000, and running it on an 800 ton compression machine would probably not be the most economical solution. With diaphragm molding, the same two cavity mold would only cost $3,000. If the molding platform was 4 feet by 8 feet, a 16 cavity mold only costs $13,000, easily justifying the increase in mold cavities to reduce the piece price. In addition, the 4-foot by 8-foot molding platform of a diaphragm machine is easily equivalent to a 2,000 ton compression machine, but has the capital cost less than a 350 ton compression machine.

Since there are more potential applications that require lower annual volumes than high volume, we can clearly see the significance in a technology that can address those lower volume applications, while offering competitive costs for high volume applications as well.

Although cycle times are longer with diaphragm molding, the low cost for large molding platforms and low cost for multiple cavity tooling may allow the molder to produce more pieces per hour than what is achievable on a compression machine.

Figure 1 illustrates a projected price comparison between compression and diaphragm molding a Twintex woven thermoplastic composite material for a pressure vessel end cap. The projected annual volume for this project is 50,000 pieces, and the tooling has been amortized into the piece price over a 3 year period.

The diaphragm molding system used in these projections is an automated heating / forming system. The material is automatically transported to a heating station and then automatically transported to the forming station. The compression machines assume that the material is preheated independently from the molding press, and then transported to the molding press. The cycle times in these two different processes can vary significantly. By heating the material independently as in the compression molding scenario, the molding press is capable of producing parts very quickly. In fact, the cycle time is determined by how long it takes to cool the part. With an automated diaphragm process, the molding sequence is dependent on how long the material takes to reach melting temperature because the material cannot be transported to the forming station until it is heated, and only one cycle's worth of material can be heated at a time.

	DIAPHRAGM	350 TON COMPRESSION
Part Weight	0.5	0.5
Cycle Time	5 min.	45 sec.
No. of Cavities	10	2
Pieces / Hr.	120	160
Machine $/Hr.	$25.00	$35.00
Direct Piece Cost	$0.20	$0.22
Tooling	$20,000	$70,000
Amortized 3 yr.	$0.13	$0.47
Total Piece Cost	**$ 0.33**	**$ 0.69**

Figure 1. Cost comparison of diaphragm and compression molding pressure vessel end caps. Annual volume: 50,000.

The application described by Figure 1 demonstrates only one potential comparison between diaphragm and compression molding. To better understand how the two compare to each other, a much broader comparison must be taken into account. In addition, by comparing a multitude of cost scenarios, we can also determine where each process offers cost savings and where they do not.

Because the diaphragm molding system modeled here is capable of molding large parts as well as many small parts, it must be compared to 350 ton, 500 ton, 1,000 ton, and 2,000 ton compression machines as shown in Figure 2.

Each set of comparisons evaluates the projected piece prices for 2,000 potential pieces based on pounds of throughput. For example, a 500 ton compression machine is certainly capable of molding a wide variety of part weights and sizes. Assuming that you would not run a part size better suited for a smaller machine, this 500 ton machine was calculated to run 3 pounds, 3.5 pounds, 4 pounds, 4.5 pounds, and 5 pounds of material. An increased poundage increment applies to the other machine sizes, reaching a maximum of 12 pounds per cycle.

With the goal to determine the most economical solution to producing a thermoplastic composite part based upon machine cost, tooling cost, and cycle time, we can

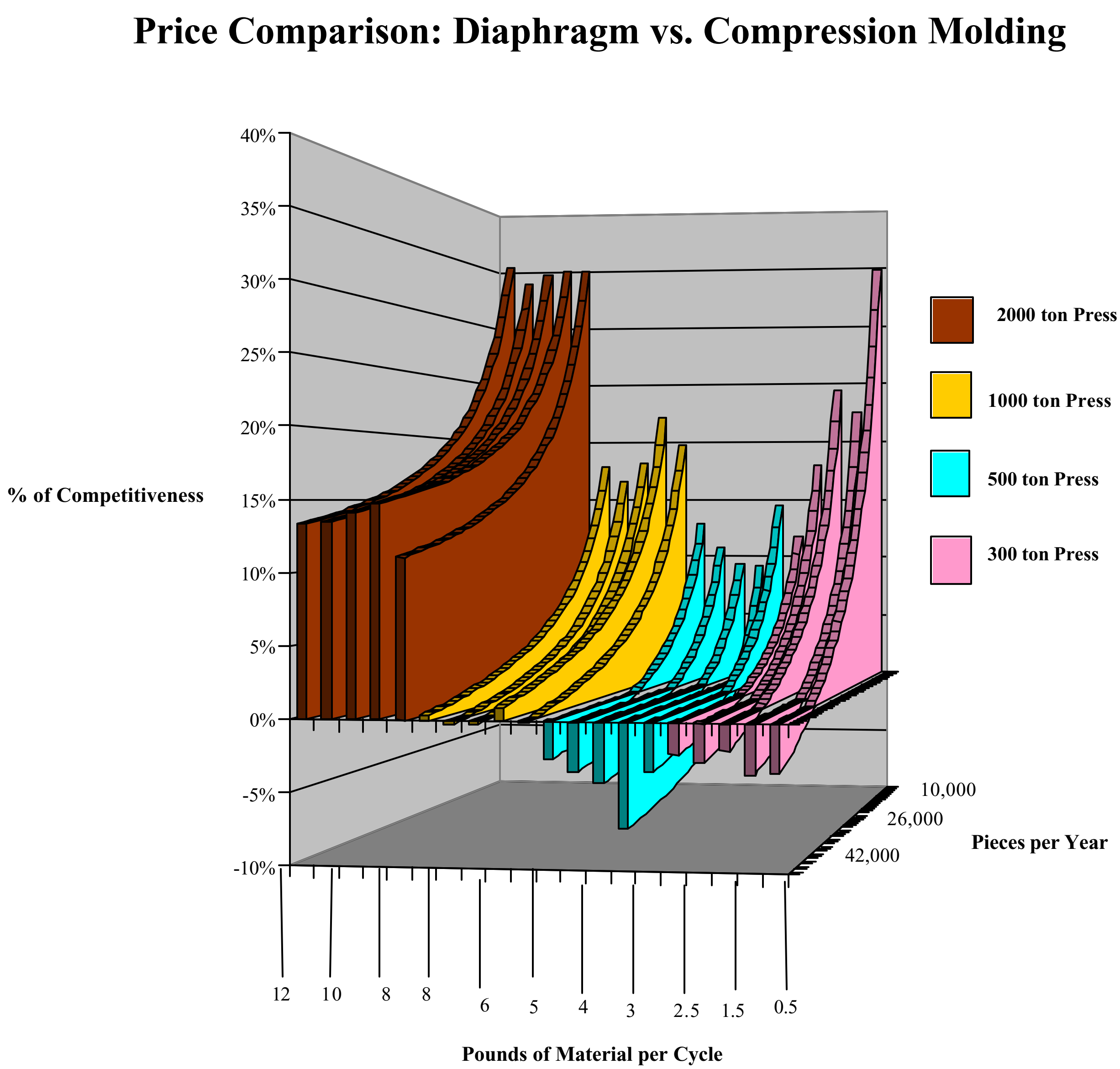

Figure 2. Price comparison for diaphragm & compression molded parts.

see where diaphragm molding can fill in the low to high annual volume gaps. The initial price projection model determined piece prices for part volumes up to 100,000 pieces per year; the selected data is a portion of that model.

Figure 2 demonstrates where diaphragm molding is competitive by percentage per part volume. For example, diaphragm molding is 14% more competitive than a 2,000 ton compression machine for an 11.5 pound part with an annual volume of 50,000. Or, diaphragm molding is approximately 5% less competitive than molding a 3.5 pound part on a 500 ton compression machine for volumes of 35,000 per year.

Clearly, the diaphragm process is more economical for larger parts. This is a direct result of the tooling costs for large compression molded parts. To compression mold a bumper beam or windshield wiper housing, the tooling can run into the hundreds of thousands of dollars, not to mention the capital costs to purchase and operate a 1,000 or 2,000 ton compression machine. The break-even point for compression molding those kinds of large parts is several hundred thousand pieces per year.

Almost any part size with annual volumes less than 25,000 would be more economically molded using a diaphragm molding process. Which again, opens up many new applications, especially with volumes that are 10,000 or less per year.

Automotive Applications

With the strong drive to reduce costs and compete on an international level, automakers and suppliers are increasingly searching for new materials and processes to become more competitive.

With the advent of diaphragm molding, highly structural materials can be economically employed. With such potential applications as bumper beams, woven thermoplastic composite materials can be used to replace existing steel reinforcement beams through meeting structural requirements, reducing weight, and adhering to current cost structures.

With the current reinforcement beam costs ranging from just under $6.00 for roll formed steel, to over $15.00 for a injection molded PC/PBT (1), diaphragm molding could produce a woven glass and PP beam for less than $10.00.

There are many automotive applications where thermoplastic composite materials would meet performance requirements, but need to be evaluated more closely for cost savings. And diaphragm molding certainly has the potential to bring costs down.

Conclusions

Recognizing the need to compete globally in the industrial manufacturing arena, U.S. manufacturers need to look at new plastics technologies to reduce costs, and improve product performance. Thermoplastic composites hold great potential for improving structural performance, reducing weight, and speeding up the manufacturing process. However, this cannot happen alone, suitable processes need to be available to fill in the gaps of non-economical production.

We have seen how compression molding has contributed to the thermoplastic composite market over the past decade, and the shortcomings that have been revealed. To move forward, processes like diaphragm molding must become industrialized to not only support the thermoplastic composite industry, but to find better, faster, and cheaper ways to manufacture goods in the U.S.

The automotive market provides an excellent industry to explore the uses of thermoplastic composite materials and diaphragm molding due to relatively high annual volumes and large part sizes. In addition, high tooling cost processes such as roll forming steel or injection molding may be replaced with lower upfront tooling costs with such processes as diaphragm molding.

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