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Study of Plastic Injection Molding Process and its Optimization using IoT; And a Case Study on Development of Polypropylene (PP) Shells using the same.

Sarvesh.U.Yeole[1] and Asst. Prof. Mangesh.R.Saraf[2].

[1,2]Mechanical Engineering Department, Savitribai Phule Pune University, MAEER'S MIT-COE, Kothrud, Pune, India.

Abstract

Plastic Injection molding has been a both challenging and provocative process for many manufacturers and researchers to produce products meeting the requirements and achieve customer satisfaction at the lowest cost. With the increase in the global competition and demand in injection molding industry, using the conventional injection molding techniques without optimization and a trial and error approach to determine the process parameters for injection molding is no longer a good idea. Four major factors which affect the quality of a molded part are: part design, mold design, machine performance and processing conditions. Looking at the need of the time one needs to evolve from the traditional techniques and look forward towards the next generation technology and advances in this process which will bring in optimization in this field.

The aim of this paper is to give a glimpse of the latest trends in Plastic Injection Molding industry from mechanical as well as software point of view. In the mechanical domain a brief about the Reaction Injection Molding (RIM), Gas Injection Molding (GIM), Water Assisted Injection Molding (WAIM), Multi-Shot Molding (MSM) and Over-Molding (OM) is given; whereas in the software domain a brief about the use of Internet of Things (IoT), Genetic Algorithm (GA) and Taguchi Method is given.

Further the paper also gives a comparison between Injection Molding and 3-D Printing and suggests which method is best applicable in which situation. Finally a case study on the development of Polypropylene (PP) shells used for the manufacturing of hard-sided luggage bags is presented which gives a real time idea about the Injection Molding process. So in this way the paper flows from the Injection Molding process, advances in it, its optimization and finally into a case study.

Keywords: *Reaction Injection Molding (RIM), Gas Injection Molding (GIM), Water Assisted Injection Molding (WAIM), Internet of Things (IoT), Genetic Algorithm (GA), Taguchi Method, 3-D Printing, Polypropylene (PP) shells .*

1. Introduction:

Injection molding is a method of forming a plastic product from powdered thermoplastics by feeding the material which is generally available as grains or powder through the machine component called the hopper to a heated chamber in order to make it soft and force the material into the clamped mold under high pressure (500-1500 bar) by use of the screw. In this whole process pressure should be constant till the material is hardened and is ready to be removed from the mold. This is the most common and preferable way of producing a plastic product with any complexity and size. The main advantage of injection molding is that it is a very fast and economical method of mass production. In general after-processing is not necessary. [1], [2].

The main components/parts of an Injection Molding machine are as follows: Hopper, the Barrel. the Screw and the Nozzle. Figure showing conventional Injection Molding machine:-

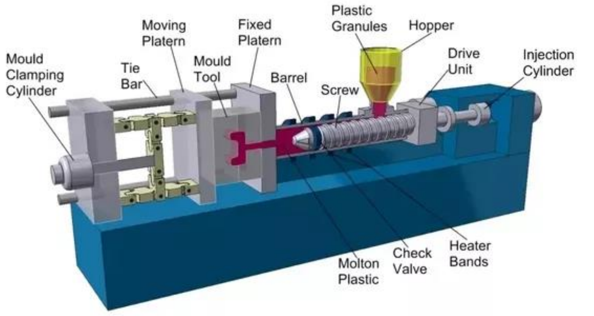

Fig.1: Conventional Plastic Injection Molding (PIM) machine. [3].

Raw material used in Plastic Injection Molding process is Plastic which may be: low density polyethylene (LDPE), high density polyethylene (HDPE), Acrylonitrile Butadiene Styrene (ABS), nylon, polycarbonate, polypropylene, flexible PVC, polystyrene, polyamide, etc.

Some of the drawbacks and limitations of Conventional Plastic Injection Molding are:

1. High initial cost compared to RIM.
2. Low durability and persistency.
3. Less flexibility of production.

4. Thermoset materials cannot be manufactured.
5. Large parts (like: truck fenders, tower caps, etc.) cannot be manufactured.

These drawbacks can be covered by using other techniques instead of conventional PIM. Some of these techniques are being discussed below.

2. Advances in Plastic Injection Molding Technique:

A. Reaction Injection Molding (RIM):

Reaction Injection Molding (RIM) is similar to injection molding except thermosetting polymers (or thermosets) are used, which require a curing reaction to occur within the mold. But "Reaction" here signals a big difference between conventional PIM and RIM. RIM technique utilizes low-viscosity liquid polymers which are thermosets and not thermoplasts in this process. Since these liquid polymers require less pressures of around 7bar and low temperatures of around 90°C compared to 1000bar and 400°C required in PIM, they can be injected into cost-efficient aluminum molds, which eventually lowers the tooling costs. The molds are moderately heated at about 190°C, but the resulting exothermic reaction quickly brings the materials to a high temperature of around 325°C and quickly cures the part inside the mold. Curing time varies from less than a minute to several minutes depending on the shape, size, complexity, geometry, and wall thickness of the molded part. Figure showing Reaction Injection Molding process setup:-

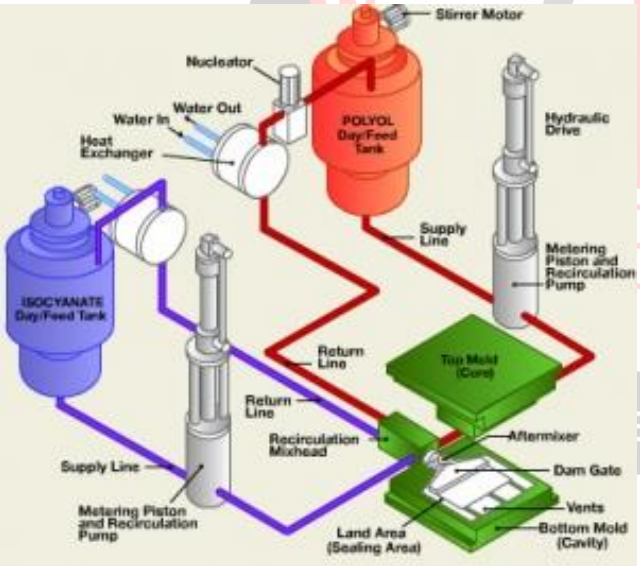

Fig.2: Reaction Injection Molding process setup.

B. Gas Injection Molding (GIM):

The prime feature of gas injection molding technology is the filling of a form with two different materials. Plastic materials make up the first component while gases, generally (N_2) form the second component.

The process begins with the injection of the first component – the plastic. A dose of approximately 70% ±20% of the volume of the cavity is proportioned and injected. [4].

Just before the completion of the injection phase of plastic, injection of the gas starts. The short-period overlapping of plastic injection and gas injection phases is intended to avoid a speed break of the melt front and the switch over marking which is related to this. The best location for introduction of the gas is in areas which are having large melt accumulations. The gas fills the cavity and simultaneously forces the melt forward. Molded parts with design specific cavities are the result.

When the cavity is filled completely, then the gas-holding pressure phase begins. This pressure phase is applied until the part is dimensionally steady and stable (maximum gas pressure is about 400 bar). Gas pressure during this period is constant throughout the entire canal. Because of the relatively low gas pressure, there are correspondingly low interior pressures in the mold, which lead to low clamping forces in the injection molding machine.

Once the initial solidification of the melt takes place, the gas pressure is reduced. This is done either by allowing the gas to escape into the ambient atmosphere, or by recovering a certain proportion (up to 90%) through the machine nozzle or the mold nozzle. Figure showing Gas Injection Molding process:-

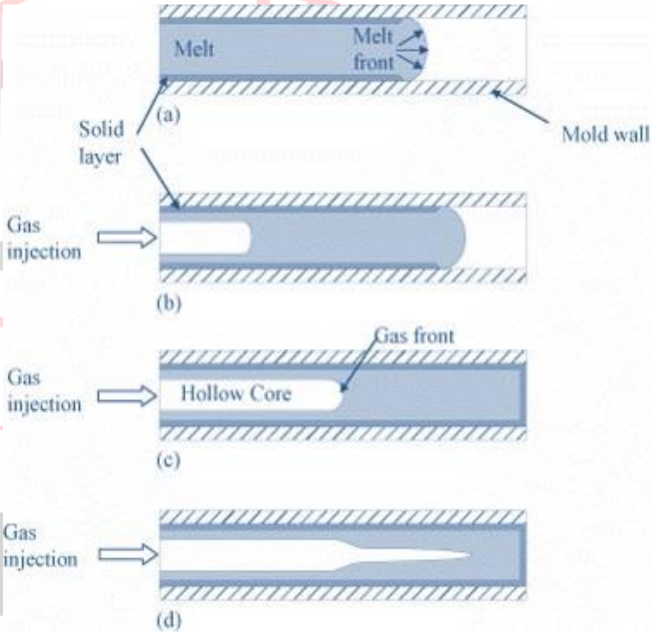

Fig.3: Gas Injection Molding process. [5].

C. Water Assisted Injection Molding (WAIM):

Water Assisted Injection Molding (WAIM) or Water Injection Technology (WIT) is a very similar technique to GIM only difference is it uses water instead of gases. Although this was not the first research work in this field, significant barriers to success in previous work were overcome. The aim was to replace the nitrogen gas with water in order to reduce cooling times. The use of water injection presented technical challenges: to generate both high pressures and high flow rates as well as defining a single hollow section. With these problems now overcome WAIM has become a viable fluid injection technique of increasing commercial interest.

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The process itself is very similar to GIT except that during the water injection one or more hydro-pumps are used to inject the water at temperatures between 10 °C and 80 °C, and up to 350 bar, into the polymer pre-injected into the cavity. The water flows through the hollow body to provide cooling until the part has sufficiently solidified for ejection. Finally, the water is removed either by gravity-induced draining or by feeding compressed air through one of the nozzles. [6]. Figure showing Water Assisted Injection Molding process:-

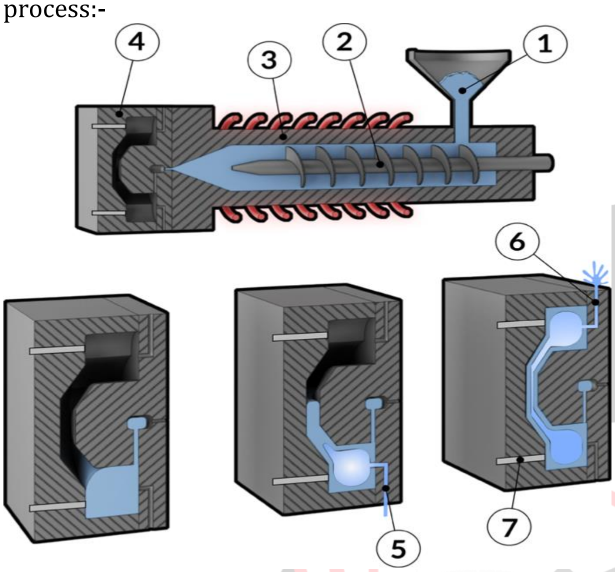

Fig.4: Water Assisted Injection Molding process. [7].

3. Optimization of Plastic Injection Molding Technique:

A. <u>Use of Internet of Things (IoT):</u>

During the third wave of industrial evolution, we had automation that produced a large amount of data. This data had high potential for analytic applications, but it was not easy to analyze this data because it was isolated in the machines where it was generated, but it's not that complex to send the data to the cloud using secure and reliable services that allow us to analyze the data in near-real time and build matching learning models to extract knowledge from it. The basis of this discussion is the molding machine that takes measurements each millisecond during its process. The data captured during the molding process is useful to build a machine learning model that will warn us when the quality of the product may be lower than the defined standard and we need to take action to improve the quality of the product as is the requirement. [8].Figure showing the schematic of Plastic Injection Molding using IoT:-

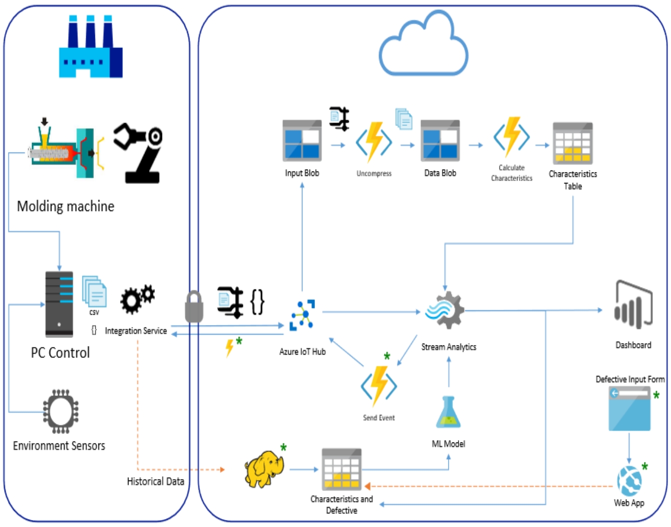

Fig.5: Schematic of PIM using IoT. [9].

To minimize the impact we have on the machine, a lightweight software service was developed that detected new *CSV* files in a folder and sent them zipped to IoT Hub. All the rest of the process is executed on the cloud side and automatically.

Some of the major advantages of using IoT in optimization of Plastic Injection molding process are:

1. Increased efficiency in production.

2. Improved quality of production.

3. Reduce the time of marketing.

4. Improvements in predictive and preventative maintenance.

5. Ability to predict and prevent failure.

6. Recommendation of necessary corrective action.

7. Troubleshooting is more easy and efficient.

8. Ultimate benefit of both customers and manufacturers.

In this way by the use of IoT in any of the injection molding processes let it be PIM,GIM,RIM or WAIM the process can be optimized efficiently which would ultimately lead to gain in the cost benefits, lead time reduction, less scrap, more profits and benefit of the customers at the user end. So the use of IoT is the need of the time for injection molding industry to convert them into Smart Manufacturing Industries.

B. <u>Taguchi Method:</u>

Orthogonal Arrays (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, which help in data analysis and prediction of optimum results; thus increasing the outcome of the process and making it more beneficial.

Taguchi method can be applied to any of the injection molding processes with these few simple steps:

1. Identify the main function (molded part), side effects and failure mode (malfunctioning of any part).

2. Identify the noise factors, testing conditions and quality characteristics.

3. Identify the objective function to be optimized (molded part).

4. Identify the control factors and their levels (pressure and temperature limits).

5. Select the orthogonal array matrix experiment.

6. Perform the matrix experiment.

7. Analyze the data, predict the optimum levels and performance.

8. Perform the verification experiment and plan the future course of action.

There are 3 Signal-to-Noise ratios (S/N) of common interest for optimization of Static Problems these are:

Smaller-the-better, Larger-the-better and Nominal-the-best. Any one can be selected from these three depending upon the required conditions and level of optimization required.

In this way the use of Taguchi method can be done for optimization of injection molding process which would in turn lead to gain in the cost benefits, lead time reduction, less scrap, more profits and benefit of the customers at the user end and benefiting the manufacturers on a large scale.

C. <u>Genetic Algorithm (GA):</u>

Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on bio-inspired operators such as mutation, crossover and selection. The GA process can be deployed to find out the most suitable and efficient technique (from PIM, GIM, RIM and WAIM) for the production of a particular part.

The GA process can be applied with the help of these few simple steps:

1. Import feature data (part to be molded, time and cost constraint, quality constraint, etc.).

2. Initialization (select any method at random).

3. Evaluation of models (analyze the solutions).

4. Selection of best model (from the results).

5. Reproduction (possibility of a combined solution).

6. Mutation (implementing the best possible solution).

7. Population replacement (going forward with the best possible method).

In this way the use of Genetic Algorithm (GA) method can be done for optimization of injection molding process which would ultimately lead to cost reduction, tooling cost minimization, lead time reduction, less scrap, more profits and benefit of the customers at the user end and benefiting the manufacturers on a large scale.

4. Plastic Injection Molding v/s 3-D Printing:

Here a brief comparison between the PIM and 3-D printing is given considering factors like: cost, quality, etc.

1. <u>Cost (for 1 and 10 parts):</u> If only one part or ten parts are to be produced then 3-D printing is the method to be deployed as molds of Injection Molding are quite costly to make.

2. <u>Cost (for 100+ parts):</u> If you are going for mass production then Injection Molding is more efficient than 3-D printing as it saves both time and money.

3. <u>High Quality:</u> If high quality is the priority then Injection Molding is the method to be used as parts produced by injection molding do not require much finishing and are having tight tolerances compared to 3-D printing.

4. <u>Time (for 1 and 10 parts):</u> If only one part or ten parts are to be produced then 3-D printing is the method to be deployed as molds of Injection Molding are quite time consuming to make and increase the lead time.

5. <u>Time (for 100+ parts):</u> If you are going for mass production then Injection Molding is more efficient than 3-D printing as it saves both time and money. As once the mold is designed it is used continuously for mass production. [10].

From the above discussion we come to the conclusion that 3-D Printing is the technology used for 'Batch-production' while Injection Molding is the technology used for 'Mass-production'.

So depending on the type of production one can go for 3-D Printing or Injection Molding (PIM, RIM, GIM or WAIM) and have the maximum outcome from the selected process.

5. Case Study on Development of Polypropylene (PP) shells using the conventional Plastic Injection Molding (PIM) process:

Here we present a real life case study on the development of Polypropylene (PP) shells for the manufacturing of hard-sided luggage bags.

1. Firstly the PP granules along with LDPE, HDPE granules (which impart colour) are loaded in the hopper loader.
2. These granules are further extracted and passed on through a tapered rotating screw around which heaters are fitted.
3. Temperature of around 200˚C-250˚C is maintained in the heaters around the rotating screw due to which the granules get melted and form a molten state which is further compressed as it advances over the screw due to its increasing taper.
4. At the extreme end the material is fully compressed at around 500-1500bar and injected into the mold

through the nozzle which takes up the desired shape as it is in molten state.

5. After the process of injection is complete the shell is cooled and taken out.

6. Finally these shells are sent to the assembly lines where they get assembled and product is ready.

The PP shell development stages are shown with the help of a flow chart:-

.PP shell development stages.

Design – In **D&D** Department.

↓

Design verification – In CAD-CAM center **(TR Dept.).**

↓

Sketching/Styling – In CAD-CAM center **(TR dept.).**

↓

Software used **Pro-E - 3-D Modeling** – In CAD-CAM center **(TR Dept.).**

↓

Software used **Pro-E – Prototyping** – In CAD-CAM center **(TR Dept.).**

↓

Software used **UG-NX – Mold design** – In CAD center **(TR Dept.).**

↓

Software used **Power-mill – Mold manufacturing** – In CAM center **(TR Dept.).**

↓

Mold assembly – In assembly section **(TR Dept.).**

↓

Spotting process – In large mold section **(TR Dept.).**

↓

Trial production – In production line **(PP Dept.).**

↓

Pilot lot – In production line **(PP Dept.).**

↓

Verification/Check – In **QE Dept.**

↓ (After **OK** from **QE Dept.**).

Mass production – In production line (PP Dept.).

Note: D&D Dept.-Design and Development department, TR Dept.-Tool Room department, QE Dept.-Quality Engineering department, PP Dept. - Polypropylene department.

In this way the Polypropylene (PP) shells are made with the conventional Plastic Injection Molding (PIM) process in the industry which here are used for production of hard-sided luggage bags or trolley bags.

6. Conclusion

From the above paper we can conclude the following points:

1. Conventional Plastic Injection Molding (PIM) process is a quite good and efficient process, but its drawbacks can be covered by using latest technologies like: Reaction Injection Molding (RIM), Gas Injection Molding (GIM), Water Assisted Injection Molding (WAIM), etc.

2. Further the optimization of any one of these processes PIM, RIM, GIM, WAIM, etc. can be done by use of Internet of Things (IoT), Genetic Algorithm (GA), Taguchi method, etc.

3. Comparing the two processes Injection Molding and 3-D Printing we conclude that both processes have their own advantages and limitations depending on the type of production whether batch or mass-production.

4. Finally we see a case study on development of PP shells using the conventional PIM process for the production of hard-sided luggage bags or trolley bags.

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