International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Artificial Intelligence and Predictive Analytics: A Novel Approach for Molded Product Quality Improvement

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Submitted: 20/10/2023 **Revised**: 24/12/2023 **Accepted**: 30/12/2023

Abstract: In the manufacturing process, injection molding is one of the most widely used plastic materials manufacturing technology where Artificial Intelligence (AI) plays an important role, which is particularly popular in the automobile industry. This paper aims to establish consistency in mold, short size, and run-to-run. The molded part should meet all quality requirements, and its injection process should run efficiently. Hence, injection molding cannot be completed and imagined without the help of a sensor. There are many sensors available in the market, but some of them are the most important sensors; like first one is a temperature sensor, which senses the temperature of the material in the hopper, barrel, nozzle, and cavity.

The paper presented here gives a comprehensive overview of five elements that help accelerate successful injection molding to manufacture quality molded products. During the manufacturing process, obtained data with the help of sensors are sent to the PLC (Programmable logic control unit) to monitor and control with the help of Artificial Intelligence (AI) in the injection molding process. The second one is the pressure sensor, which senses pressure in the mold cavity. This paper also studies different processing parameter conditions like mold temperature, melt temperature, injection time, injection speed, injection pressure, screw rotation speed, shot size, holding time, cooling time, and so many parameters. Here discussed their effect on molded products and their ignorance of the risk or defects in the developed products.

Keywords: *Artificial Intelligence, Predictive Analytics, Injection Molding, Quality Products, Molding Machine and Design, Sensors*

1. Introduction

Product quality depends on successful injection molding, which depends on five elements: part design, mold design, material, molding machine, and injection process life cycle [3]. There are two sections to the injection molding machine: an injection unit and a clamping unit. The role of the injection unit is to dry, heat, and mix materials in the hopper and barrel after injecting them into the mold cavity [1]. In contrast, the roles of the clamping unit are mold closing, holding, cooling, mold opening, and so on.

The mold design also plays a vital role in manufacturing molded items. The mold has two parts: the punch part and the cavity part. The punch part is the male portion of the mold, responsible for developing the mold's outer part, and the cavity part is the female portion of the mold, which is responsible for developing the inner part of the set item.

The paper describes the various molding parameters, their importance, and their effect on the injection molding life cycle. Successful plastic production requires a team effort and a well-developed strategy. If each parameter individually plays a role seriously with conciseness, then the quality of molded items is automatically achieved. It is like a relay raise where every player should give their best so that the team automatically goes in wins condition.

The successful injection molding process is uncompleted without discussing the importance and the role of sensors in this process. The process parameters are monitored and controlled with the help of different sensors like temperature, pressure, proximity, and so on [4]. The sensor senses the real-time data and sends it to the PLC (programmable logic control unit). The developed Artificial Intelligence (AI) machine learning model monitors the PLC data [14]. If the transmitted data is abnormal, then an alarm goes run and is immediately controlled automatically or by the control team members. This paper describes the polypropylene (pp) plastic material used in the bumper manufacturing automotive industry. Due to its lightweight, heat resistance, high chemical resistance, and low cost, it is favourable to use in industry.

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2. Literature Review

The literature review helps to identify existing knowledge and gaps in the research topic. It also helps to select the framework, tools, and technology that will be used in the research paper. It also helps to identify the main cause of defects and send the recommendation to the respective teams. The below section describes some literature review papers, that are referred to in this research paper.

E. Hotz and G.Nakhaeizadeh and B. Petzsche and H. Spiegelberger(1999), proposed a This article attempts to conduct a reliability analysis of vehicle parts with high warranty and goodwill costs using Data Mining Support Environment for the Planning of Warranty and Goodwill Costs in the Automobile Industry. Regression analysis, model trees, SMART, and Naive Bayes are used to do this.

Dr. M.Hanumanthappa Sarakutty.T.K(2011), employing data mining techniques to forecast the future of the auto industry and using data mining technologies in the automobile manufacturing unit to determine how many cars a company will produce based on data from the previous year. This is achieved through linear regression analysis.

Jay Lee, Hung-An Kao, Shanhu Yang (2014), proposed Service innovation and smart analytics for Industry 4.0 and big data environment and The major goal is to achieve the production target with effective and efficient production planning and maintenance scheduling. The essential innovation of such a CPS framework is that it realises a self-aware and self-maintenance system by combining both sensor data as well as fleet-wide information.

Foggy K-Means Clustering Algorithm Has Excellent Results on Real Datasets as Compared to Simple K-Means Clustering Algorithm and Provides an Improved Solution for the Real World Problem, according to Akhilesh Kumar Yadav, Divya Tomar, and Sonali Agarwal's (2013) proposal to cluster lung cancer data.

A principal component analysis model-based predictive controller for regulating part warpage in plastic injection moulding was developed by Songtao Zhang, Rickey Dubay, and Meaghan Charest in 2015. This paper describes how the injection moulding technique affects the moulded pieces.

In May 2022, Marko Vukovic, Sebastian Stemmler, Katharina Hornberg, Dirk Abel, and Christian Hopmann developed a cross-phase cavity pressure control adaptive model-based predictive control. The time-variant model for Model-based Predictive Controller was applied in this research to track a specific cavity pressure reference.

For the goal of machine learning in injection moulding, Hasan Tercan, Alexandro Guajardo, Julian Heinisch, Thomas Thiele, Christian Hopmann, and Tobias Meisen (2018) developed Transfer-Learning: Bridging the Gap between Real and Simulation Data. The use of machine learning to forecast process characteristics based on machine parameters is described in this research paper.

An explanatory study on flaws in plastic moulding parts induced by machine parameters in the injection moulding process was the goal of Ankush Mourya, Arshit Nanda, Kartik Parashar, Sushant, and Rajender Kumar (2023). The purpose of this study is to investigate moulding faults as well as the contributing factors.

This paper by Hong He, Yu Xing, Runguo Wang, Yonglai Lu, Liqun Zhang, and Fanzhu Li (2023) is titled Optimisation design of cooling system for injection moulding mould of non-pneumatic tyre. Its goal is to serve as a reference for professionals in automobile tyre manufacturing and mould design in the mould cooling system design method to enhance tyre quality and shorten the moulding cycle.

Lih-Sheng Turng and Jinsu Gim's intended Measurement, influencing factors, prediction, and control are discussed in relation to recent developments in high-surface-quality injection moulding. Predicting the quality of injection-molded goods, which may be affected by a number of circumstances, is the goal of this research.

Based on a comparison of injection moulded parts, Julia Volke, Margarita Reit, and Hans-Peter Heim (2023) intended to establish parameters for injection moulding. This paper differs from the studies in that it solely uses the CAD models of the relevant parts rather than simulations Motivation

In Today's Competitive market, where customers demand quality products, high response time is more important than cost. The second motivation point is wasting raw materials and time by producing defective products. It puts an unnecessary burden the on company account. So we should try to minimize it as early as possible to prevent taking care during production. We know, we cannot completely stop it but minimise it as much possible as. These are the motivation points for working on quality improvement parameters and giving recommendations to the respective team members in the Injection Molding process [3][13]. The product quality issue dominates the supply chain market in every country [25]. The customers do not accept if product quality is degraded / low, and as a result, demand goes down, as does the revenue of the company.

We must first determine the metrics that are impacted before we can discuss product quality. Once these factors have been identified, the corresponding team members should take care of them or modify them to enhance the quality of the final output.

3. Aim of the Molding Operation

The aim of the molding operation is to create a three-dimensional object with a desired shape and size by pouring molten material into a mold and allowing it to cool and solidify to get consistent molded items [7]. Several industries, like the automotive industry, use molding as a manufacturing method to create a wide variety of molded items using consistency like:

3.1. Consistency in Mold Part

Consistency in mold parts is critical for ensuring the quality of the final product and the efficiency of the manufacturing process [5]. Mold parts must be consistent in terms of size, shape, and surface finish to ensure that the molten material can flow uniformly and fill the mold completely. Any inconsistency in the mold parts can lead to defects in the final product, such as warping, cracking, or shrinkage.

The consistency of mold parts can be affected by a number of variables, such as the mold design, which affects consistency from cavity to cavity, the material used and its consistency in shot size, and the consistency of the manufacturing process (refer to Table 1), which affects consistency from run to run Regular maintenance of the mold parts is also important to ensure consistency. Mold parts can wear over time, leading to changes in dimensions or surface finish, which can impact the quality of the final product. Regular inspection and maintenance can help to identify correctly any issues before they lead to defects in the final product. Overall, consistency in mold parts is critical for regular maintenance of the mold parts is also important to ensure consistency. Mold parts can wear over time, leading to changes in dimensions or surface finish, which can impact the quality of the final product [14].

Table 1. Consistency in the mold part

Consistency	Descriptions
Cavity To Cavity Consistency	Dimensions of each cavity should be identical in the mold for similarity in quality.

Shot Size Consistency	Every melted mixed material should be identical in quantity for quality.
Run To Run Consistency	To attain comparability in quality, each process' life cycle time should be the same.

Regular inspection and maintenance can help to identify and correct any issues before they lead to defects in the final product. Overall, consistency in mold parts is critical for ensuring the quality and efficiency of the manufacturing process. Ensuring the quality and efficiency of the manufacturing process.

3.2. The Molded Items Should Meet All Quality Requirements

The manufacturing company should give their best effort to satisfy their customer's requirements in terms of quality, service, value and delivery time. Here, quality is a very critical thing to achieve, and quality requires making routine inspections in all shifts on all necessary stuff in production [20]. Some points that should be kept in mind by the plastic manufacturing company for quality practices are:

- The capability of manufacturing testing, control & master plan validation.
- In the first article, in-process and final inspections
- Raw material inspection
- ISO certified, FDA, FFL & ITAR registered
- Product failure chance and effect analysis
- Risk mitigation process
- Manage client audit and internal investigation
- Follow validation protocols requirements

3.3. The Injection Process Should Run Efficiently

Successful plastic production requires a team effort and a well-developed strategy [20]. During the injection process, all parameters give their best, like relay raise player to archive the best quality.

4. Successful Injection Molding to Achieve Quality Product

When we are talking about the quality molded product, five elements help to produce a successful injection molding. They are shown below in Fig. 1:

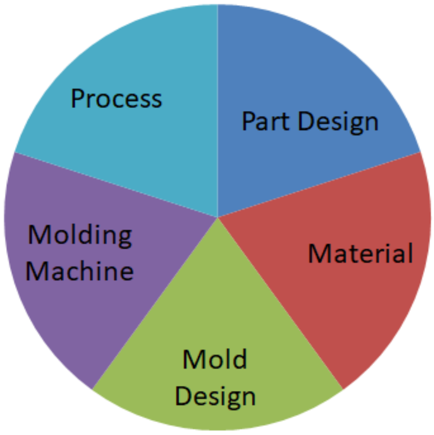
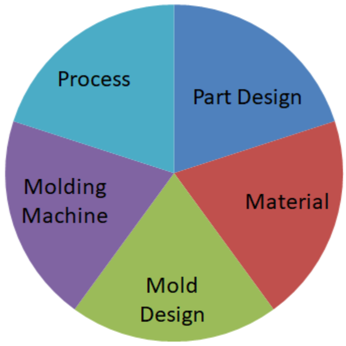
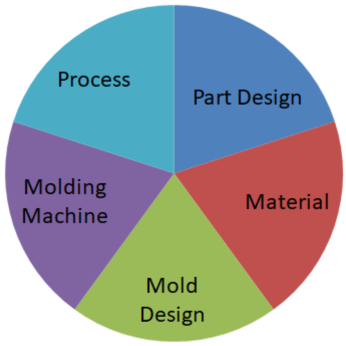


Fig. 1. Quality Dependency Elements





4.1. Molding Machine

Injection molding is a very common and significant material processing process that produces many plastic products [24]. An injection molding machine does this with the help of, and the molding machine size depends on the molded item and material [6]. For instance, if the clamping unit or moulding machine is 120 tons, it means 120 T/inch2 pressure on the mold during plastification. Fig. 2 illustrates the injection unit and clamping unit of an injection machine.

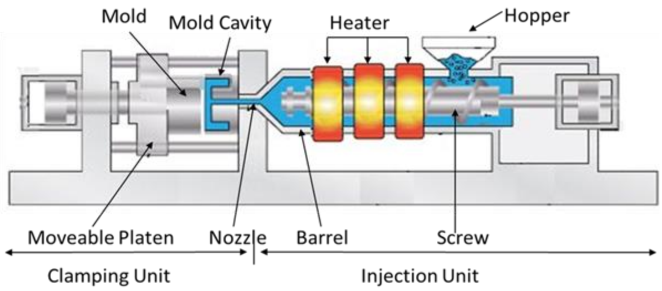


Fig. 2. Injection molding Machine main parts

4.1.1. The Injection Unit

This is responsible for drying (in the hopper), heating, and mixing material in the screw barrel [24]. After that, it injected material into the cavity of the molds as depicted in figure2.
Here are a few injection unit specifications

- Type of screw
- Shot size
- Injection speed
- Injection pressure
- Back pressure
- Screw rotation speed
- Thermocouples
- Heater
- Delay time
- Cushion
- Suck back
- Alarm
- Alignment of unit etc

4.1.2. The Clamping Unit

This is responsible for closing the mold during injecting material into the mold. During that time, the clamping forces are required to control because of too high clamping force. High pressure might damage the mold & machine part, and if it is a too common cause for defective molded items.
Here are few clamping unit specification

- Clamping method-Toggle type or Ramp type
- Mold clamping force
- Mold height
- Mold size
- Mold platen size
- Mold opening size
- Ejector force
- Ejector points etc

4.2. Mold Design

Mold design is an essential part of the development process [11]. The finishing of molded items also depends on mold design complexity, and if mold design is more complex, it requires more time to fill with pressure. Mold has two parts punch and cavity as described in Table 2 and Fig. 3:

Table 2. Mold parts descriptions

Mold Parts	Descriptions
Punch part	It is a male portion of the mold responsible for creating the internal surface of the component.
Cavity part	It is a female portion of the mold responsible for creating the component's external surface. The cavity part holds three components:- • Locating ring • Sprue bush • Back

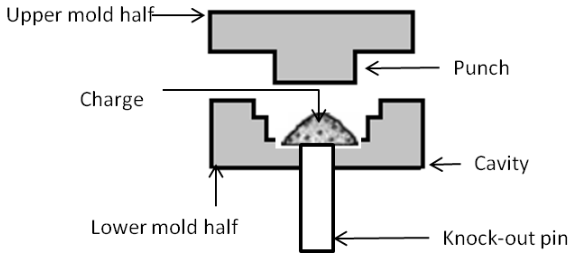


Fig. 3. The punch part and cavity part of Mold Design

4.3. Material

After the Second World War and towards the end of the 18th century plastic was invented. It has become very popular in the human life and automotive industry. The Automotive industry uses Polypropylene (PP) to develop the auto motives molded items, due to its semi-crystalline nature, lightweight, heat resistance, low chemical resistance and low electrical conductivity [6]. The PP has excellent chemical, and moisture resistance, a natural waxy appearance, low cost and the ability of transparent and colorful so used in nearly all industries. Table 3 describes the properties of polypropylene.

Table 3. Polypropylene property

Polypropylene Properties	Descriptions
Martial Name	Polypropylene
Abbreviation	PP
Material Structure	Crystalline
Absolute Max Temperature	320 °C
Ejection Temperature	93 °C
Max Shear rate	24000 1/s
Max Shear Stress	0.26MPa
Melt Density	0.7751 g/cm3
Solid Density	0.92889 g/cm3
Elastic Modulus	1340 MPa
Trade Names	Novolen, Appryl, Escorene

"Due to its lightweight, heat resistance, high chemical resistance, and low cost, the industry uses it frequently".

4.4. Process

Injection molding is when the malted plastic substance is inserted into the mold cavity at the desired temperature. After maintaining the pressure and cooling, we get the aimed product. This process continuously runs back to back by following specific steps as mentioned in Fig. 4 to get the product, called the injection molding life cycle.

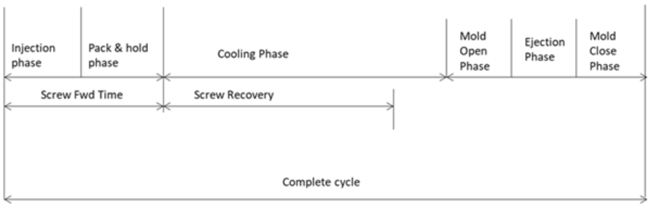


Fig. 4. Injection molding complete Cycle

There are many parameters in the injection and the clamping unit, but some essential parameters that leave an impact on the molded item's quality are mentioned in Table 4:

Table 4. List of parameters during injection molding

PARAMETERS IN THE INJECTION MOLDING
Mold Temperature
Melt Temperature
Injection Time & Speed
Injection Pressure
Screw Rotation Speed
Back Pressure
Shot Size
Cushion
Pack Time & Holding Time
Cooling Time
Material Charging
Eject Speed

4.4.1. Mold Temperature

The temperature in a different area in a mold, like in a complex mold heated by the heater on the mold, and the temperature sensor (thermocouple) senses temperature, and send it to the plc to the control team [14]. Table 5 discuss issues related to the mold temperature.

Table 5. Mold Temperature

Low mold temperature can cause issues	High mold temperature can cause issues
Jetting problem/Flow mark	Degrade material
Cold slung	Burn marks
Silver	Black sports
Brush mark	Runner sticking

4.4.2. Melt Temperature

The temperature of melted material in the hopper, barrel, nozzle, and mold directly impacts molded items. The hopper shape is like a keep structure following FIFO (first in, first out principle) means the firstly melted material first in and first out from the hopper. The reason to apply this principle is that materials don't get a chance to degrade and mix dirt in them. If the hopper shape is too large, fix a triangle shape object in it so that the FIFO principle follows. Some heaters and sensors are set on the hopper to melt the material, and sensors sense the temperature. When the material goes from hopper to barrel in the feed zone (50%), the material mixing process is done in the transition zone (25%). Here, heat the material with a heater fitted on a barrel, and the sensor senses the temperature. Some heat is also generated at the mixing time by screw rotation speed so the sensor sends it to the PLC to control it after sensing the temperature. The melted material fluidity mainly depends on barrel temperature [19]. If the barrel temperature is high, then the material fluidity is automatically increased. Suppose it is low, then material fluidity is also low [24]. So in the case of melt temperature, barrel temperature plays a vital role and its related issues as mentioned in the Table 6.

Table 6. Melt Temperature

Low melt temperature can cause issues	High melt temperature can cause issues
Jetting problem/Flow mark	Burn mark
Warpage	Black sport
Haze	Drooling
Cold slug	Runner sticking
Silver	Air trap
Weld line	Require long cooling time
	Brittleness
	Yellow mark
	Flash
	Eject mark

4.4.3. Injection Time & Speed

At the time of cavity filling in the mold, the injection time & speed are both required. The injection time & speed are both universal propositions to each other. If the injection speed is high, then the injection time needs to be low [24]. The Injection Time and speed-related issues are discussed in Table 7.

Injection time $\propto$ 1/Injection speed

Table 7. Injection Time & Speed

Low injection speed can cause issues	High injection speed can cause issues
Shot size	Shrinkage
Warpage	Flow mark
Jetting	Air trap
Dimensional issue	Drooling

4.4.4. Injection Pressure

The injection pressure is given by the injection unit during the mold cavity filling time. If the injection pressure is low, it requires more time to fill the cavity, so the machine should give a higher Injection pressure and its related issues are mentioned in Table 8.

Table 8. Injection Pressure

Low Back Pressure can cause issues	High Back Pressure can cause issues
Shot molding Wild line Bubble(in mold and barrel) Shrink mark, Flow mark Warpage Silver	Runner sticking problem Drooling Component sticking problem Material charging issue

4.4.5. Screw Rotation Speed

The speed at which the screw is rotating (issues mentioned in Table 9) in the feed zone (50%), transition zone (25%) & mixing zone (25%) during the injection process [24]. The rotation speed is measured in RPM. The material passes through the three-zone of the screw as mentioned in Fig. 5. They are

1) *Feed zone (50%):* Place where materials come from the hopper.
2) *Transition zone/Compression zone (25%):* A large amount of heat is generated here due to compression or screw rotation, slowly transferring the material to the mixing zone. Due to contraction, the poisonous gases, so it does not hold for long.
3) *Mixing zone (25%):* The material mixing has improved in this zone and has become ready for the injection process.

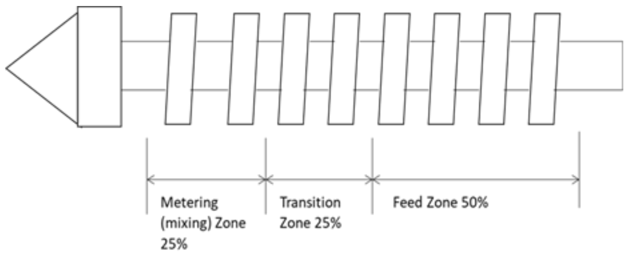


Fig. 5. Injection Molding Different Screw Zone

Table 9. Screw Rotation Speed

Low screw rotation speed can cause issues	High screw rotation speed can cause issues
Warpage Short shot Shrink mark (near the gate) Dimensional issue	Material degradation Drooling Runner sticking Yellow mark, Eject mark Brittleness, Flash Shrink spot (far from the gate)

4.4.6. Back Pressure

The force is required to flow forward the melted material during the injection process, which is required while filling the cavity. The related issues of back pressure are discussed in Table 10.

4.4.7. Shot Size

The shot size is the amount of malted material required to fill the area of the cavity. For example, if 100mm malted material needs to be loaded, then 95% or 98% is filled at one time in injection, and the remaining material is filled after holding that remaining cushion filling. If the cavity does not load properly, then shrinkage problems occur. We should take care of these parameters to solve this problem:

- Increase injection pressure
- Increase barrel temperature
- Increase holding pressure & time
- Increase the nozzle temperature
- Increase injection speed
- Increase back pressure
- Increase mold temperature
- Check material leakage
- Check the Air venting system
- Check material hopper
- Increase shot size
- Increase screw rotation speed(RPM)
- Check injection time
- Decrease switch over the position

4.4.8. Cushion

The last forward position the screw reaches during the injection process is the position of the cushion. The cushion position decided to fill some extra material in the mold, so from the switch-over position to till the end is the cushion time as mentioned in Fig. 6.

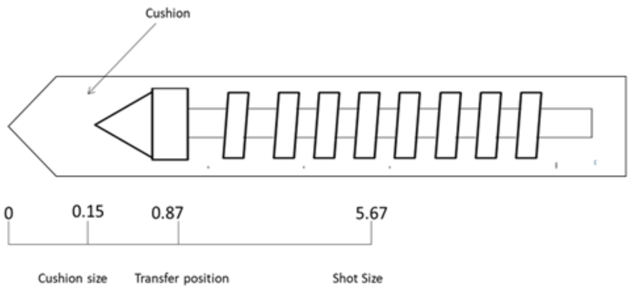


Fig. 6. Cushion in Injection molding

If cushion=0, it means injection holding pressure is more than many problems might occur, such as

Short shot

- Component sticking
- Runner sticking
- Flash
- Broken the pin
- Shrinkage
- Air trap

4.4.9. Pack Time & Holding Time

The time taken by malted material to be injected the remaining cushion in the mold and solidify before cooling down the molded parts. This time starts from the switch-over position to make space available in a mold to fill it with the remaining cushion. If cushion time is zero means holding time and pressure are more and its related issues are mentioned in Table 11.

Table 11. Pack time & holding time

Low pack and holding time can cause issues	High pack and holding time can cause issues
Short shot(due to cushion zero)	Short shot
Pin broken	Air trap
Zero cushion	Shrink mark
The material stuck in a mold	
Mold broken	
Dimensional issue	

4.4.10. Cooling Time

The mold takes time after injecting material into it for the cooling process [19]. At that time, the mold temperature has maintained so that the material inside the mold cools down quickly.
Problems if the cooling time is low:

- Molded part stick in the mold
- Not easily remove a product from the mold
- Dimensional issue
- Broken pins
- Broken some other parts of the machine

4.4.11. Material Charging

The material charging process is parallel to the cooling process so that the shot for the next injection process is ready. The material charging time depends on the screw rotation speed. If the screw rotation speed is high, material charging time will be reduced. If material residence time & sharing energy increase, then fluidity will increase. Sometimes material charging fault is not done correctly means the screw is not moving properly and needs to retreat.

To increase the material charging, there is a need to make these changes:

- Increase the heating temperature of the barrel
- Decrease feed zone temperature
- Increase screw rotation speed(for Crystalline material)
- Decrease screw rotation speed(for Amorphase material)
- Decrease back pressure
- Check hopper throat
- Check the bridge inside the hopper

4.4.12. Eject Speed

This speed is required by the ejection assembly when it pushes the molded product out from the cavity. Similarly, ejector stroke requires a position that is the distance between molds during ejection to allow the product to eject. Sometimes during the ejecting process, products remain inside the mold or are broken by ejector pins.
Some of the reasons for this problem are:

- If cooling time is not enough
- High eject speed
- Ejector stock is not enough
- The packing of material is too high
- Component catching

5. Sensors

The above processing parameters work without interruption with the help of sensors and a control circuit [18]. That monitors the molding operation and sends input to the PLC to control this parameter as required. There are many sensors used in molding operations, but some are mold sensors, temperature sensors, and pressure sensors.
The mold sensor detects the condition within the inserted mold, such as the insertion location. The insert sensor might be a micro-switch, proximity sensor, or ultrasonic sensor. The insert shields the micro-switch sensor during the molding process and the proximity sensor senses the insert's density to know the insert is in the proper position.

The thermocouple temperature sensor is inserted inside or outside of the mold. It is also inserted into the barrel in a group to sense the temperature. After sensing, it is sent to PLC for control. The cavity pressure sensor senses the pressure in the cavity during the injection process [24]. The cavity pressure sensor uses piezoelectric effort to transform the cavity pressure into a measurable unit. Hence, without the help of sensors, a successful injection molding process cannot be completed.

6. Conclusion

The above processing parameters work without interruption with the help of sensors and a control circuit. That monitors the molding operation and sends input to the PLC to control this parameter as required. There are many sensors used in molding operations, but some are mold sensors, temperature sensors, and pressure sensors [16].The mold sensor detects the condition within the inserted mold, such as the insertion location. The insert sensor might be a micro-switch, proximity sensor, or ultrasonic sensor. The insert shields the micro-switch sensor during the molding process and the proximity sensor senses the insert's density to know the insert is in the proper position.

The thermocouple temperature sensor is inserted inside or outside of the mold. It is also inserted into the barrel in a group to sense the temperature. After sensing, it is sent to PLC for control. During the injection procedure, the cavity pressure sensor measures the pressure in the cavity. The cavity pressure sensor converts the pressure of the cavity to a measurable unit using piezoelectric effort. Hence, without the help of sensors, a successful injection molding process cannot be completed.

Future Scope

This study aims to pinpoint the variables that affect product quality in order to enhance it. However other molding-related aspects like energy use and polymer recycling are not addressed in this work. The following list contains the paper's future objectives and constraints. One of the sectors that uses the most energy is the polymer sector. Making moulds requires a lot of energy. Another limitation or restriction of this article relates to the polymer recycling process, where energy conservation is the primary objective in the automotive industry. The amount of plastic waste also grows as more plastic components are regularly used. Brushes, non-food containers, and oil funnels are just a few of the products that use recycled plastic. Nevertheless, recycling needs to be both.

Acknowledgements

First, I would like to express my gratitude to God for guiding me through all of the challenges then express my gratitude and acknowledgement to my supervisor Prof. (Dr.) Kavita, who made this work possible. I was able to complete all of my paper writing thanks to her direction and suggestion.

Additionally, I want to express my gratitude to my husband (Mr Rajaram Prashad Kushwaha) and my entire family for their unwavering support and tolerance as I conducted my research and wrote my paper. Your supplication for me has kept me going so far.

Author Contributions

Rani Kumari: Conceptualization, Methodology, Data curation, Analysis and Visualization, Validation, Writing-Original draft preparation **Kavita Saini:** Investigation, Writing-Reviewing and Editing.

Conflicts of Interest

The authors declare no conflicts of interest.

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