EXPERIMENTAL ANALYSIS ON POLYPROPYLENE MOULDED PART FOR PERFORMANCE OF LASER PRINTING

Ajay L. Dumanwad

PG Student, Department of Mechanical Engineering, JSPM Narhe Technical Campus, Savitribai Phule Pune University, Pune – 411041, India

ajaydumanwad143@gmail.com

Manoj A. Kumbhalkar

Associate Professor, Department of Mechanical Engineering, JSPM Narhe Technical Campus, Pune, India

manoj.kumbhalkar@rediffmail.com - https://orcid.org/0000-0003-2289-6373

Jaswindar Singh

Director, Ecorea & Kuroda Electric India Pvt. Ltd., Ranjangaon, Pune, India

Reception: 04/12/2022 **Acceptance**: 20/01/2023 **Publication**: 16/02/2023

Suggested citation:

L. D., Jay, A. K., Manoj and S. Jaswindar (2023). **Experimental Analysis on Polypropylene Moulded Part for Performance of Laser Printing**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(01)*, 366-384. https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

ABSTRACT

Now a day plastic injection molding is widely used process to manufacture engineering product and consumer goods typically thermoplastic is combined with rubber or another thermoplastic like RM master batch is used to add color to the Molded part also the laser marking on plastic part and their printing cut, faint issue observed. The aim of the study was to Optimize the injection parameters and processing condition for the laser performance on polypropylene part. To achieve enhanced dark laser marking on polypropylene, the process parameter of plastic injection molding and the Raw material master batch mixing parameter successfully prepared this laser–sensitive composite consisted of a high Laser induced carbonization rate.in plastic injection molding use of raw material and mixing of master batch is considerable factor for faint laser marking. Because of laser does not respond well on carbonization added material, it was evident that master batch having the carbon properties is much more responsible for faint laser marking issue on polypropylene material part.

The effect of laser beam interaction (Nd: YVO4) with selected operational parameters on the Quality of graphical features obtained on the surface of polypropylene-molded pieces with different surface Textures (variable parameters of the surface layer). Polypropylene test specimens were injection molded using original injection molds Products with variable end parameters determined by the position of the cavity circle can be identified. The layout of the laser function, the beneficiary texture of the molded piece, the molded color and the support of the marking piece allow the evaluation of the graphic symbol performance by means of laser marking of the type of master back in their rendering relationship. Marked evaluation criteria were adopted for the project.

KEYWORDS

Laser marking, injection moulding, master batch, printing, polypropylene

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

PAPER INDEX

ABSTRACT

KEYWORDS

1. INTRODUCTION

 1.1. INJECTION MOULDING MACHINE TYPE

 1.2. LASER PRINTERS

 1.3. PROBLEM IDENTIFICATION

 1.4. DATA COLLECTION

2. EXPERIMENTAL TRIAL WITH MASTER BATCH MIXING

 2.1. EXPERIMENTAL TRIALS ON EXISTING MATERIAL (340 MASTER BATCH)

 2.2. COMPARISON STUDY OF EXISTING MASTER BATCH AND SUGGESTED MASTER BATCH

 2.2.1. GRADE 340 MASTER BATCH TRIALS

 2.2.2. GRADE 394 MASTER BATCH TRIAL

3. EXPERIMENTAL TRIALS WITH SUGGESTED MATERIAL (394 MB)

 3.1.1. CALCULATION OF NEW RPN

 3.1.2. IMPROVED CALCULATION TRIAL

4. RESULT AND DISCUSSION

5. CONCLUSION

REFERENCES

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

1. INTRODUCTION

Plastic injection moulding is the process of heating raw material to its melting point (plastic resin in pellet form in our case), forcing the viscous material into a mould, and allowing it to cool into a hardened shape. In almost every product you encounter, injection moulded parts are used, from electronics to housewares to automotive to food packaging. At its most basic, it's a very simple process, but there's a lot more to it than that—from creating the mould to understanding the chemical and physical properties of the material. Plastic injection moulding arose from metal pressure die casting processes in the late 1800s. Plastics were introduced in the 1920s, but the process was still very crude, with simple two-piece moulds manually clamped together. Since then, the art and science of plastic injection moulding have advanced significantly [1-5].

1.1. INJECTION MOULDING MACHINE TYPE

Injection moulding is a method of transforming thermoplastics or thermosetting materials into a wide range of products. Plasticizing and injection units, clamping and opening units, ejecting or knockout units, and an electric and hydraulic control system comprise an injection machine or injector.

There are four basic types of injection moulding equipment according to the type of screw or plunger. [6]

Four types of injection moulding machines.[6]

1. Conventional injection moulding machine.
2. Piston-type preplastifying machine.
3. Screw-type preplastifying machine.
4. Reciprocating-screw injection machine.

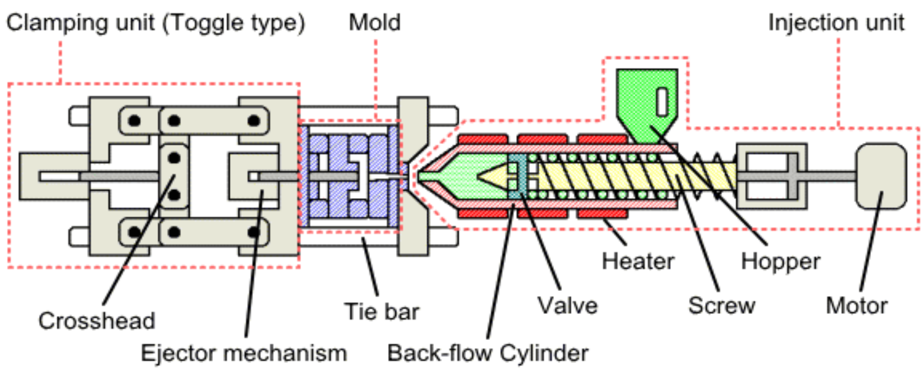

Figure 1. Plastic Injection Moulding machine. [4] (Courtesy: Polypastics Co., Ltd.)

In Conventional injection moulding machine, Plastic granules or pellets are poured into a hopper and fed into the chamber of the heating cylinder in this process. A plunger then compresses the material, forcing it through the heating cylinder's increasingly hotter zones, where it is spread thin by a torpedo. The torpedo is placed in the centre of the cylinder to accelerate the heating of the plastic mass's centre. The

 https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

torpedo can also be heated from the inside as well as from the outside. The material flows into the mould from the heating cylinder via a nozzle. The nozzle seals the cylinder and the mould, preventing molten material from leaking. The clamp end of the machine holds the mould closed. Two to three tonnes of pressure are typically applied to polystyrene for each inch of projected area of the work-piece and runner system.[6]

To preplastify the plastic granules, Piston-type preplastifying machine uses a torpedo ram heater. The fluid plastic is pushed into a holding chamber after the melt stage until it is ready to be forced into the mould. Because the moulding chamber is filled to shot capacity during the cooling time of the work-piece, this type of machine produces work-pieces faster than a conventional machine. Because the injection plunger is acting on fluid material, there is no pressure loss when compacting the granules. This enables a larger work-piece with a larger projected area.[6]

Screw- Type preplastifying machine is an extruder that is used to plasticize plastic material. The pellets are fed forward by the turning screw to the heated interior surface of the extruder barrel. The molten, plasticized material exits the extruder and enters a holding chamber before being forced into the mould or die by the injection plunger. The use of a screw provides the following benefits: improved plastic melt mixing and shear action, the ability to run a wider range of stiffer flow heat sensitive materials, colour changes can be handled in less time, and fewer stresses are obtained in the moulded part [6].

A horizontal extruder replaces the heating chamber in a reciprocating-screw injection moulding machine. The rotation of a screw propels the plastic material forward through the extruder barrel. The material changes from granular to plastic molten as it moves through the heated barrel with the screw. As the material advances, the screw returns to a limit switch, which determines the volume of material in front of the extruder barrel. During the shot, the screw advances to displace the material in the barrel. The screw acts as a ram or plunger in this machine.There are several benefits to using reciprocating-screw injection moulding. Because of the screw's mixing cation, it plasticizes heat-sensitive materials more efficiently and blends colours more quickly [6].

The main component of injection moulding machine are clamping unit and injection unit. Clamping unit consist of three main components such as mould, clamping motor drive and Tier bars, the sender is clamped onto the edge of a workbench. Injection Unit consist of three main components viz. Screw motor drive, reciprocating screw & barrel and heaters, thermocouple, ring plunger.

1.2. LASER PRINTERS

Laser printers are another well-known laser-based consumer product, frequently used in conjunction with personal computers. Their operating principle is based on electro photography, also known as xerography, which is the same process used in photocopiers. Figure 2 depicts the electro photographic process. Ions from a corona discharge charge uniformly a photoreceptive surface with a layer of photoconductive material. The surface is frequently that of a rotating drum. The surface is exposed

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

after charging by scanning the laser beam across it. The intensity of the beam is varied to create a replica of the desired image. The pattern of light intensity replicates the pattern of the to-be-printed text or graphics. In laser-illuminated regions, the photoconductive layer conducts. This allows the electrostatic charge to move and creates an electric charge pattern on the surface [7-12].

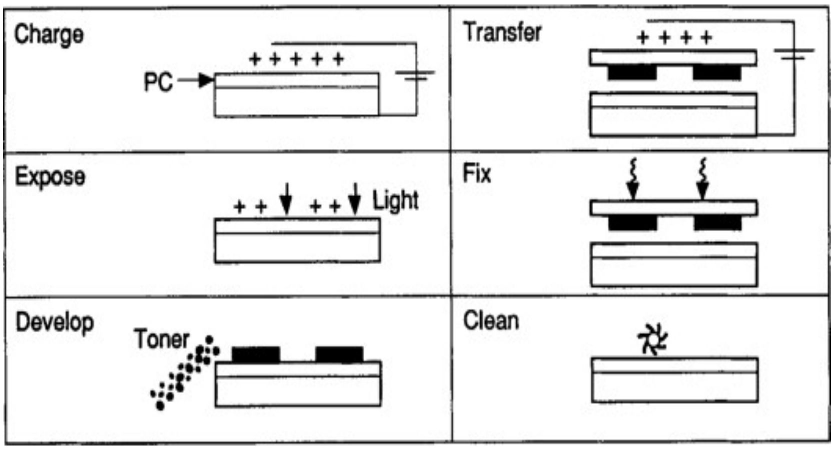

Figure 2. Basic working principle dia. [7]

This sequence is similar to that used in photocopiers, except that the pattern in the exposure step is obtained from projection of an image of the text or graphics to be copied in photocopiers. A computer generates the material and sends it to the laser printer, which stores the data in its memory, composes one page of material at a time, and controls the scanning of the laser beam to produce the desired image. Laser printers produce high-quality prints with sharp images and consistent black levels. [7]

The various type of Lasers is green laser, UV laser, CO2 laser and MOPA laser.

1.3. PROBLEM IDENTIFICATION

As shown in the figure 3, the Engine Room RB Upper Cover has the good laser marking as well as the defective information for the part. In the first stage, the parts are kept in their respective jigs for further laser marking purposes. The part should be properly held and jigged before beginning the laser marking. After that, the inspector should check the part as per inspection and visually check for defects.

As shown in the defect information image below, some alphabetical letters, numeric numbers, or any specific symbol are found cut or faintly printed; because of this, the production team faced too many rejections. The faint marking refers to the cutting or invisible letter found on a part after the laser marking process.

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

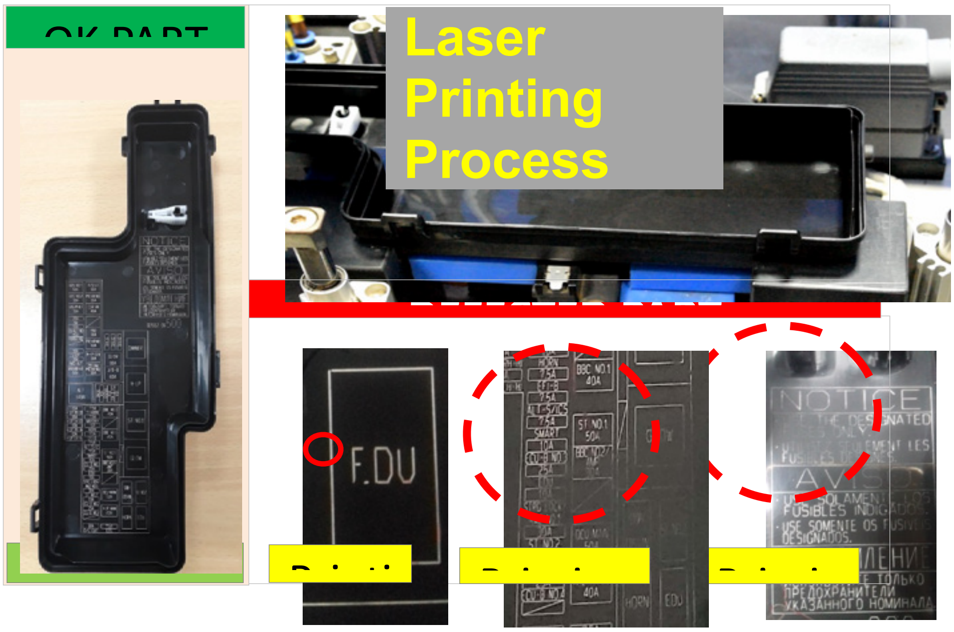

Figure 3. Laser Printing Process on Upper Cover of the moulded part

1.4. DATA COLLECTION

Before experimentation, to investigate the process parameters of the printing problem, it is necessary to have a thorough understanding of the process, which is studied using a process flow chart. The first stage of the work was to collect the rejection data due to faint laser marking. Performance information and performance issues for the evaluation of three steps is done on a numerical scale. They are based on the needs of the high-pressure moulding line of the company or the final product. Priority is given to the cause with the highest rejection part number. After collecting three months of production data from various parts in order to identify the part with the highest rejection ratio. Table 1 displays rejection data for various moulding parts. PPM stands for parts per million. According to the data presented, the highest rejection was observed in the ENG ROOM R/B upper cover.

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

Table 1. Theme Data (Part wise defect data)

Part name	Feb-22	Mar-22	Apr-22	Prod. Qty.	Rej. Qty	PPM
ENG ROOM R/B UPPER	5,762	8,752	74,58	21,972	1,456	**66,266**
ASSY R/B FRAME	12,432	14,235	9,663	36,330	498	**13,708**
COVER FUSE RB NO 2	3,456	2,564	2,657	8,677	250	**28,812**
UPPER RHD PROTECTOR BASE	4,562	4,578	5,060	14,200	39	**2,746**
L TYPE 2P HOUSING FEMALE Grey	6,532	12,452	4,591	23,575	15	636
PROTECTOR COVER L74.4 W269.2 H34 PA66B	7,562	6,423	5,903	19,888	6	302
CONN COWL SIDE RH C/B 2 PP N	6,452	5,423	5,855	17,730	5	282
TOTAL	46,758	54,427	41,187	1,42,372	2,269	15937

By combining the three-month production rejection rate of various moulded parts in a part-by-part pareto chart, it was discovered that the Engine Room RB Assembly upper cover has the highest value as shown in pareto chart (figure 4), indicating the highest total process rejection. Hence, the upper cover was chosen for further drill-down analysis after studying the selected moulded part of the engine room RB assembly.

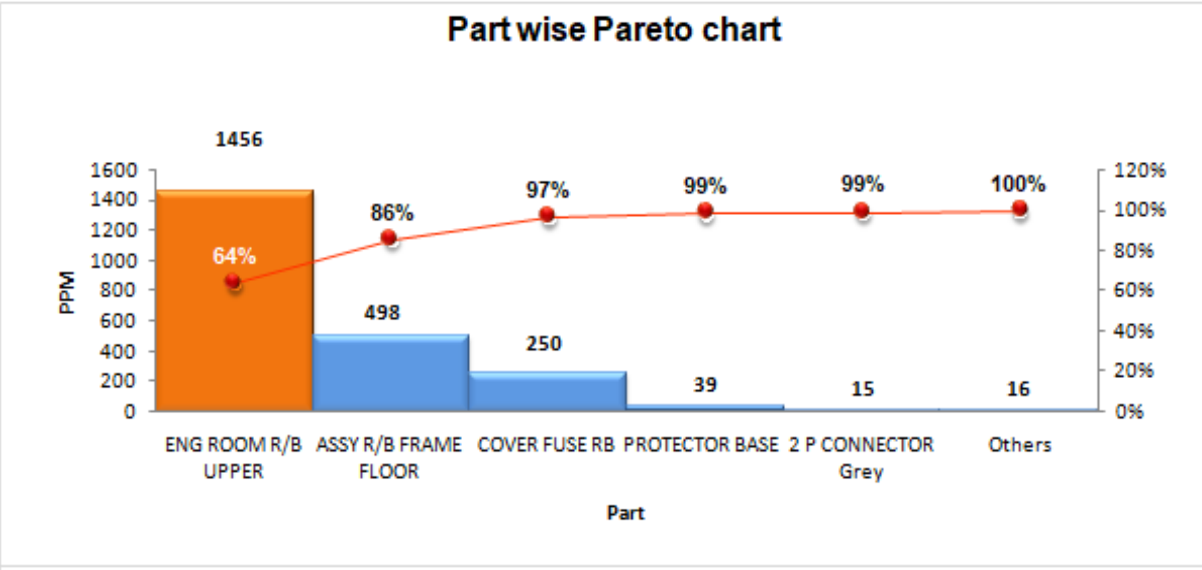

Figure 4. Partwise rejection of the component (Pareto chart)

After selecting the moulded part with the highest rejection ratio for drill-down analysis, it is necessary to investigate which type of rejection occurred as a result of which part was rejected the most frequently. Printing cut issues, printing faint issues,

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

and other process defects such as short mold, sink mark, flash, flow mark issue, and so on are commonly found in laser-printed parts. Based on the detailed examination of the collected rejection details, it was determined that the majority of the major rejections occurred as a result of the Faint Laser Issue in Engine Room RB Upper Cover, as shown in figure 5.

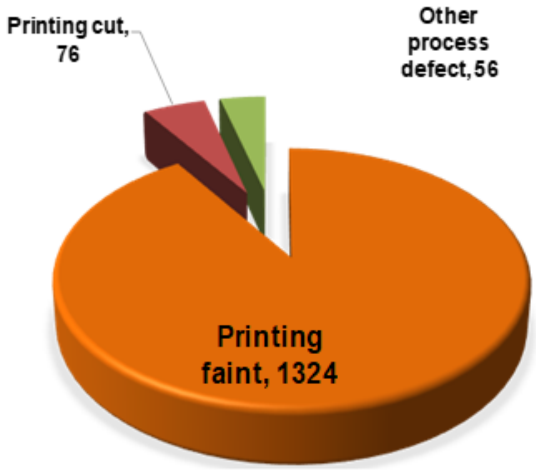

Figure 5. Rejection Detail Analysis (Pie Chart)

After studying part-wise defect data, a part-wise pareto chart, and pie chart data, the part with the highest rejection ratio in three months is chosen for the part-wise pareto chart. And, based on the large number of rejections, it has been determined that the laser faint printing issue in Engine Room RB Upper Cover is a significant factor. So, selecting the above parts and causes for project theme improvement and experiment investigation of process parameters.

The 4M method analysis is a method for evaluating which of the 4M conditions is responsible for a defect mode. The 4M is a method for identifying and grouping causes that have an impact on a specific effect. The 4M categories of man, machine, method, and material are often used in the cause-effect diagram, which is also called a fishbone diagram. We discovered the following significant factors for the same issue shown in Figure 6. In this method, raw material and master batch mixing are considerable factors. In material, the master batch is not suitable for the laser printing issue, and the raw material to master batch ratio is not optimized.

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

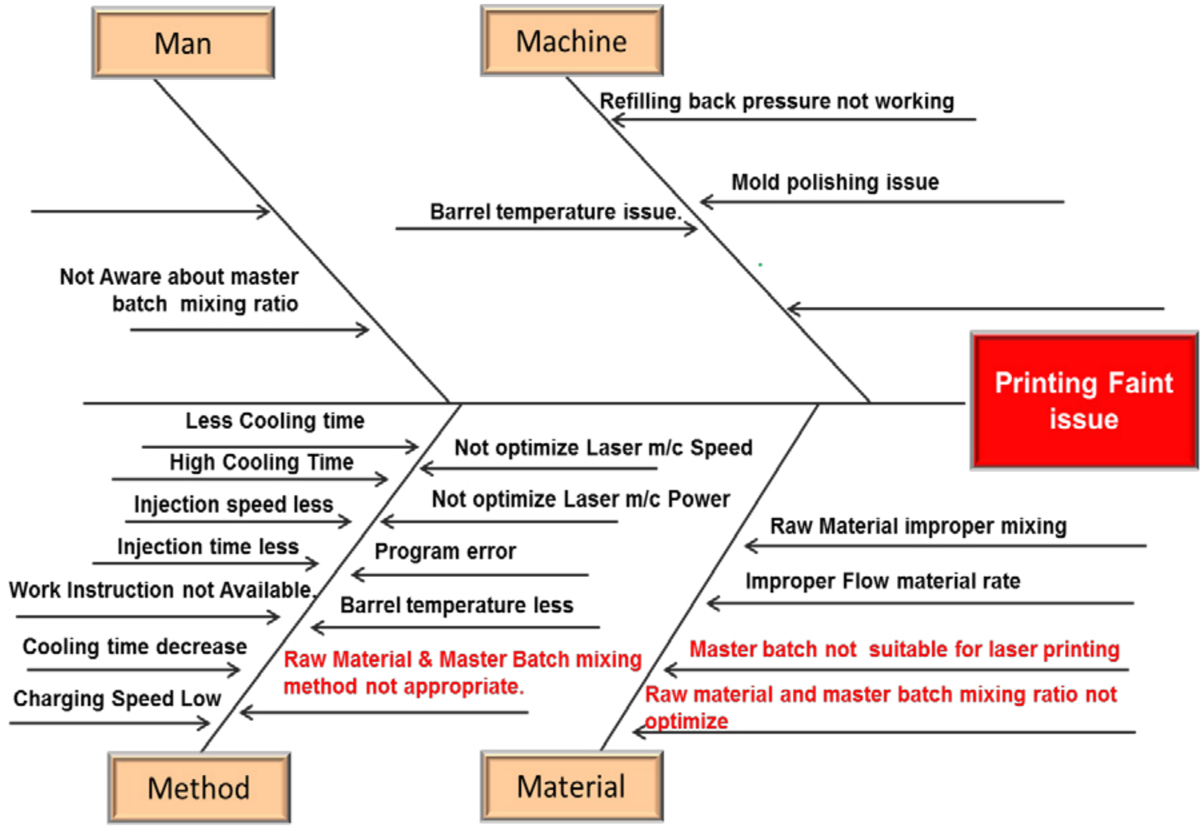

Figure 6. Fish bone dia.

The major problem of printing on the company's moulded part is discussed and resolved with many trials and experiments by changing the different process parameters in this project. The main objective of the work is to find the cause of faint printing. Also, to investigate the problem, an experiment with the existing material using a different batch mixing percentage and time is needed. It is necessary to finalise the percentage of the master batch and the time for mixing MB. The experiments have to be carried out with different batch mixing percentages and times for the suggested material. The final objective of the work is to reduce or eliminate the rejection rate of the laser printing process in Part Engine Room RB Assembly Upper by 100%.

A process flow chart is a diagram that represents the decision-making procedures and the sequential steps of a process. Every step in the chart or visual representation is denoted by a shape. To depict the movement and direction of the process, these forms are joined by an arrow or line. From the initial receipt of raw materials to the final dispatch stage, the following process flow chart is included. Here, the raw material mixing and raw material loading on the hopper are very important stages.

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

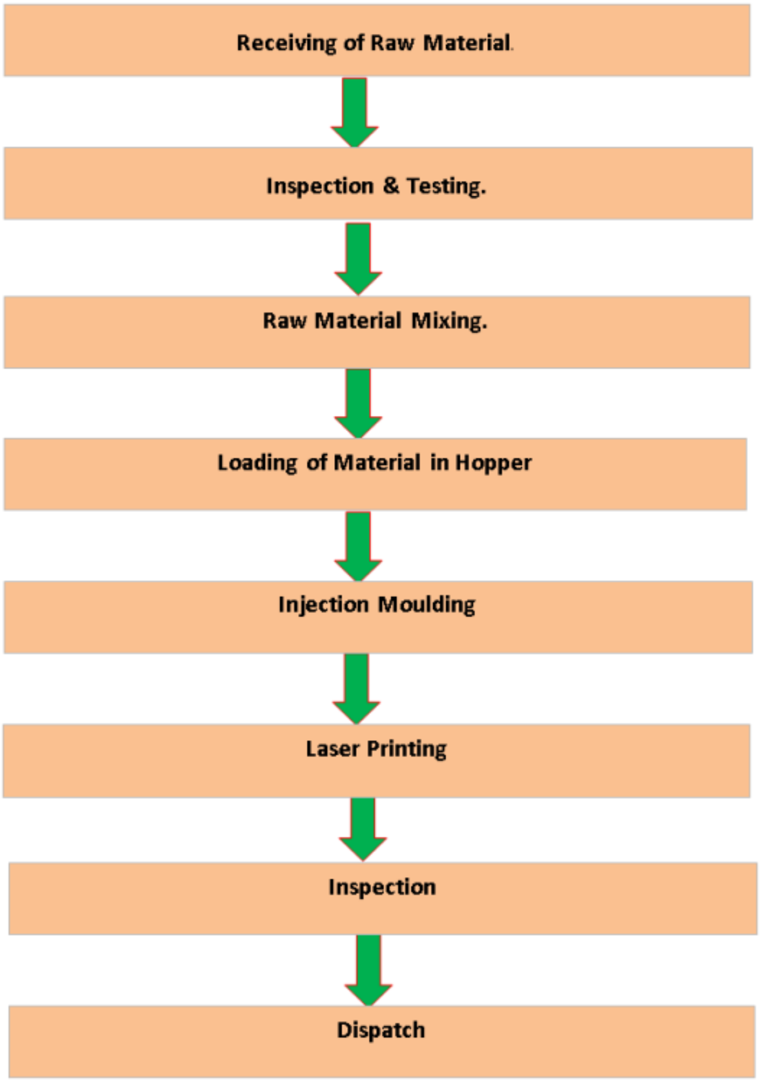

Figure 7. Process Flow chart

2. EXPERIMENTAL TRIAL WITH MASTER BATCH MIXING

2.1. EXPERIMENTAL TRIALS ON EXISTING MATERIAL (340 MASTER BATCH)

To find the exact cause of printing failure on the part, various trials need to be taken with reference to the rejection rate as discussed above. To determine the precise cause of printing on the top cover, various trials for master batch mixing, ranging from 8% to 3%, are considered, and the rejection ratio is calculated. A sample image of raw material with the master batch is given in Figure 8. The existing master batch 340 has a melting point of 1240 °C and a heat stability of 2800C. The upper cover is subjected to five trials with existing material, namely master batch 340, with a MB mixing time of 10 minutes. The total lot for each trial is taken as 50, and it has been observed that the percentage of rejection is reduced with a reduction in the percentage of master

 https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

batch mixing. The results obtained on the injection moulding machine for five different trials are given in table 2.

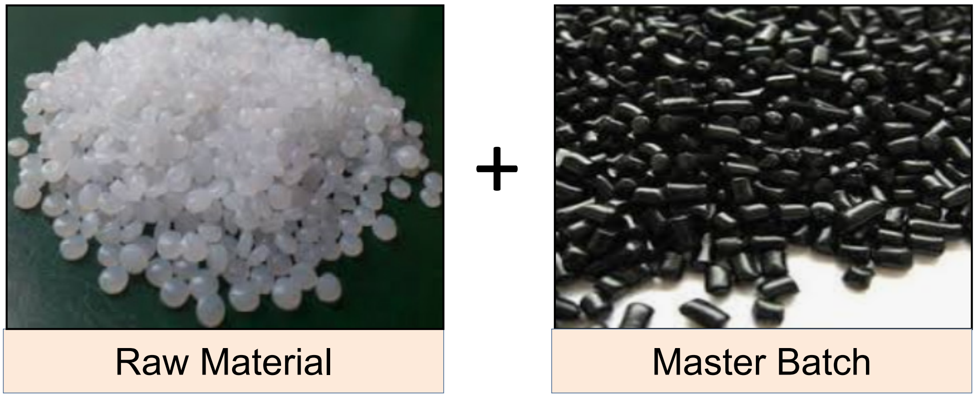

Figure 8. Raw material and master batch mixing

From the above-mentioned analysis, it is evident that master batch percentage and master batch Mixing time is a considerable factor for printing faint lines. Hence, there is a need to improve the master batch mixing as well as change the master batch and check the issue of mixing at the same percentage level. For this purpose, Master Batch 394 is suggested for mixing with a mixing ratio of 2% and a MB mixing time of 10 minutes. The comparison study of the existing master batch and the suggested master batch is given in table 2.

Table 2. Trail on Upper Cover with Existing Material (Master Batch Grade & MB Mixing ratio

Trial	Raw Material PP	% of Master Batch 340	MB Mixing time. In min.	Trial Lot	NG	Rejection %
T1	100%	8%	10	50	7	14%
T2	100%	7%	10	50	7	14%
T3	100%	6%	10	50	6	12%
T4	100%	5%	10	50	5	10%
T5	100%	4%	10	50	5	10%
T6	100%	3%	10	50	2	10%
T7	100%	2%	10	50	1	8%

2.2. COMPARISON STUDY OF EXISTING MASTER BATCH AND SUGGESTED MASTER BATCH

Based on the number of trials taken, the 2% master batch mixing has been finalized for further trials for existing as well as suggested materials for Batch 394. By operating the injection moulding machine for different operating variables and process parameters of the raw material mixing method, we took the rejection of no. part reading from the mixing of RM with master batch.

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

Existing Master Batch	Suggested Master Batch
Master Batch 340 /TP/P	**Master Batch 394 /TP/P**
MFI :- **0.29** Gram per 10 min) by ASTM D1238 Melting point (°c) :-124 Heat Stability (°c) :280 Carbon used:- **Black (WN-96)**	MFI :- **25.1** Gram per 10 min) by ASTM D1238 Melting point (°c) :-126 Heat Stability (°c) :280 Carbon used :- **Laser Black**
Existing Use :Master Batch 340 Grade	**Suggested :Master Batch 394 Grade**

Following an examination of both the 340 master bath and the 394 master batch, it was determined that the value of the multi-flow index for the 340 master bath is less than required, while the value for the 394 master batch is in the middle of the specifications. As shown in the comparative study above, the carbon used in both master batches is different. It has been concluded that the 394 master batch is a suitable factor; further, there is a need to conduct a trial in an optimized percentage of the master batch with new laser carbon with proper mixing time. Furthermore, a trial in an optimized percentage of the master batch with new laser carbon and proper mixing time is required.

2.2.1. GRADE 340 MASTER BATCH TRIALS

The carbon used in both master batches is different, as shown in the comparative study above.It has been concluded that the 394 master batch is a suitable factor; further, there is a need to conduct a trial in an optimized percentage of the master batch with new laser carbon with proper mixing time. Furthermore, a trial in an optimized percentage of the master batch with the new laser carbon with proper mixing time is required. So, for the next trial, the master batch mixing ratio is set to 2% and the mixing time is set to 10 minutes.

Table 3. Grade 340 Master batch trial Table

Sr/no	Trial	Raw Material PP	% of Master Batch 340	Trial Lot	NG	Rejection %
1	T1	100%	2%	50	3	6%
2	T2	100%	2%	50	4	8%
3	T3	100%	2%	50	3	6%
4	T4	100%	2%	50	3	6%
5	T5	100%	2%	50	4	8%
6	T6	100%	2%	50	4	8%

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

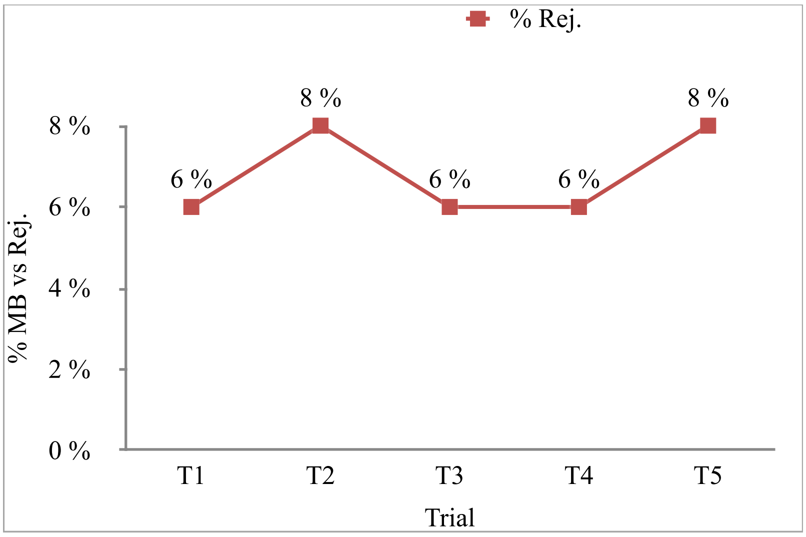

Figure 9. Grade 340 Master batch trial Graph

2.2.2. GRADE 394 MASTER BATCH TRIAL

As per the comparative study, the carbon used in both master batches is different, as shown in the comparative study. It has been concluded that the 394 master batch is a suitable factor; further, there is a need to conduct a trial in an optimized percentage of the master batch with new laser carbon with proper mixing time. Furthermore, a trial in an optimized percentage of the master batch with the new laser carbon with proper mixing time is required. So, for the next trial, the two percentages of the master batch mixing ratio and the mixing time of 10 minutes are fixed.

Table 4. Grade 394 Master batch trial Table

Sr/no	Trial	Raw Material PP	% of Master Batch 394	Trial Lot	NG	% Rej
1	T1	100%	2%	50	2	4%
2	T2	100%	2%	50	2	4%
3	T3	100%	2%	50	1	2%
4	T4	100%	2%	50	2	4%
5	T5	100%	2%	50	1	2%
6	T6	100%	2%	50	1	2%

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

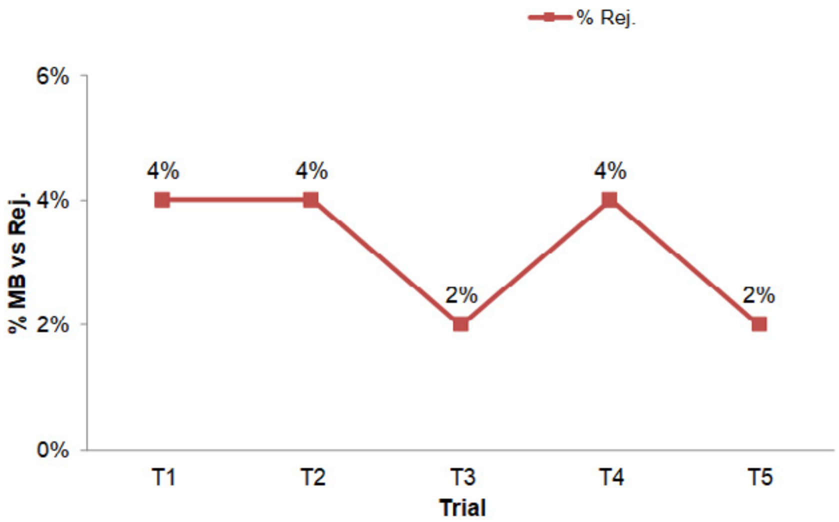

Figure 10. Grade 394 Master batch trial Graph

After taking a constant value of the percentage of master batch mixing and the master batch mixing time mentioned above, it was discovered that the laser printing rejection is lower in the 394 master batch than in the 340 master batch, though the difference is not significant. It has been concluded that the master batch grade change has a positive impact on reducing laser printing rejection.

3. EXPERIMENTAL TRIALS WITH SUGGESTED MATERIAL (394 MB)

3.1.1. CALCULATION OF NEW RPN

After finding the solution for cause, it has been concluded that the main causes, like the first percentage of master batch mixing, the second master batch mixing time, and the third master batch change (394), are now finalized for the further trial calculation as shown in table 5. solution for the causes, let's head towards calculating a new RPN after taking action and a percentage decrease in rejection data.

Table 5. Trial with 394 MB with 2% RM mixing

Sr/no	Trial	Raw Material PP	% of Master Batch 394	Trial Lot	NG	Rejection %
1	T1	100%	2%	50	2	4%
2	T2	100%	2%	50	2	4%
3	T3	100%	2%	50	1	2%
4	T4	100%	2%	50	2	4%
5	T5	100%	2%	50	1	2%
6	T6	100%	2%	50	1	1%

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

3.1.2. IMPROVED CALCULATION TRIAL

After taking actions, there is a change in the rejection number of the part value that is reduced by almost 50%. It is time to collect data after implementing the RM mixing process parameter and the percentage of RM mixing as shown in the table 6.

Table 6. Trial with 394 MB with 1% RM mixing

Trial	Raw Material PP	% Of Master Batch 394	Trial Lot	NG	% Rejection
T1	100%	3%	50	3	6%
T2	100%	2.5%	50	2	3%
T3	100%	1%	50	1	1%
T4	100%	1%	50	0	0%
T5	100%	1%	50	0	0%

Table 6 shows how lowering the percentage of master batch mixing affects the rejection part number ratio in the laser printing issue. Based on the above-mentioned trials, it has been determined that tumbler mixing for 30 minutes of a new master batch in a 1 percent ratio produces the best laser printing results with the least rejection.

4. RESULT AND DISCUSSION

As per the experimentation carried out to resolve the issue of faint printing on upper cover of the moulded part in the industry, it has been observed that there are no any problems in the process parameters set for moulding and the moulded part in injection moulding is perfect. It means, the faint printing on the moulded upper cover is not an issue of injection moulding and it was the problem due to master batch mixing in the raw material. Based on the several trials by reducing percentage of master batch 394, it has been observed that the 1% mixing of master batch 394 is improved the printing quality and the reduces rejection rate. Based on the analysis carried out the net cost saving of the printing on the moulded part is INR 2,70,812 as shown in table 7 and the reduction in rejection quantity is shown in figure 11.

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

Table 7. Net cost saving due to reducing rejection quantity

Cost Saving

- Part Cost INR - 45.95 INR
- Rejection Qty (Nov.2018-Jan.2019) -1456 nos.
- Rejection amount Saving Quarterly -66903 INR
- Rejection amount Saving Annually -2,67,612 INR
- Inspection man power saved -14000 INR

- **Net Cost Saving Per Annum - 2,70,812 INR**

Other Benefits

- Laser Printing machine capacity increased by 8%
- Material Mixing operator fatigue improved

Extra Cost

- Old master batch Cost per KG - 150 INR
- New master batch Cost per KG -200 INR
- Annual Master batch Consumption- 216 Kgs
- Extra Cost incurred - 10800 INR

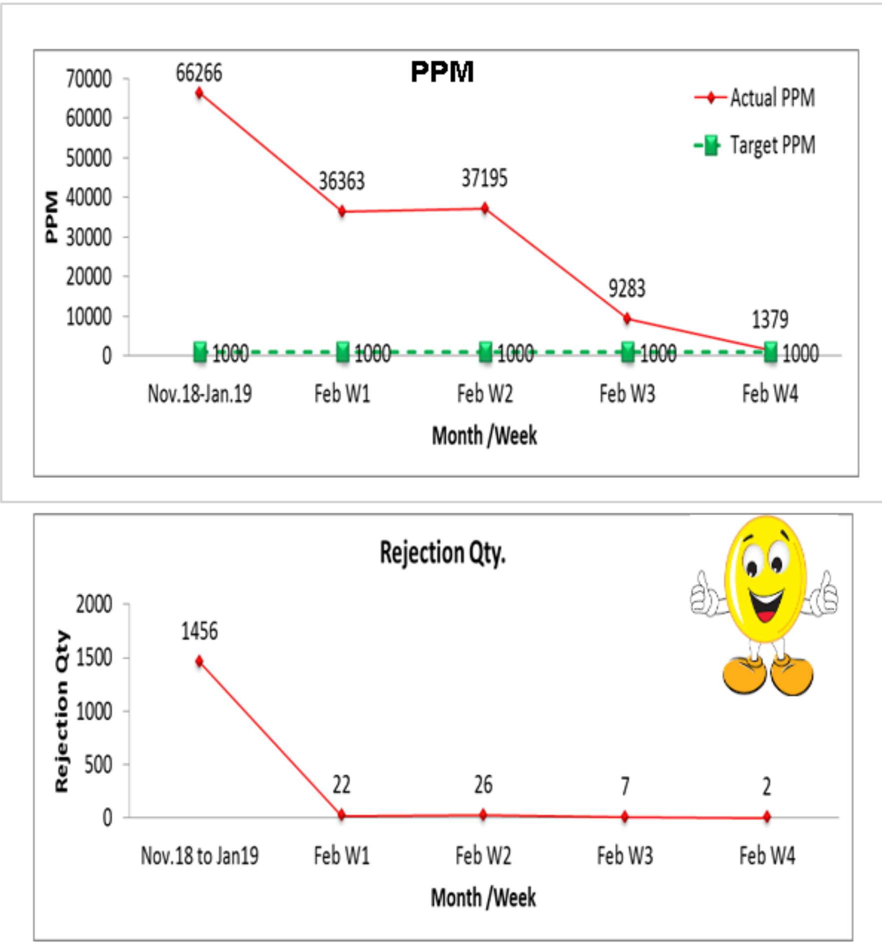

Figure 11. statistics of rejection and reduction in rejection

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

To reduce the further rejection of printing on any moulded part the standardization in process is very important. The process can be standardized with five quality steps as shown in figure 12. This is the future scope of this research work.

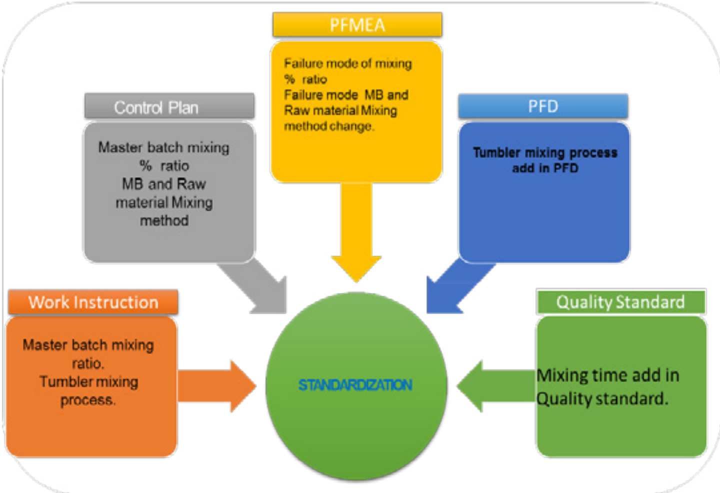

Figure 12. Standardization in process

5. CONCLUSION

- The analysis, investigation methodology is allowed to study and analyze every step of perform making process and to achieve the improvement in product and process quality. The improvements obtained by the implementation of the recommended actions thus reduce the individual rejection of part and risk level associated with each defect is reduced.
- By using 4M methodology it is help to easy recognize the main root cause and improvement.
- After implementation of action the rejection value of faint laser marking is reduced for each of the part, and the total cost saving Detail is as follow.

Cost INR	45.95 INR part
Rejection Qty. (Feb.2022-APR-2022)	456 no's
Rejection amount Saving Annually	2,67,612.0 INR
Inspection man power saved	14000 INR
Net Cost Saving (Per Annum)	2,70,812.0 INR

- By this way laser faint issue, Development time, and cost has been reduced and also there is less chance of occurring same kind of failure in future.

REFERENCES

(1) Gaikwad, M. U., Krishnamoorthy, A., & Jatti, V. S. (2019). **Investigation and optimization of process parameters in electrical discharge machining (EDM) process for NiTi 60**. *Materials Research Express*, 6(6), 065707.

(2) Ravikiran, B., Pradhan, D. K., Jeet, S., Bagal, D. K., Barua, A., & Nayak, S. (2022). **Parametric optimization of plastic injection moulding for FMCG**

https://doi.org/10.17993/3ctecno.2023.v12n1e43.366-384

polymer moulding (PMMA) using hybrid Taguchi-WASPAS-Ant Lion optimization algorithm. *Materials Today: Proceedings*, 56, 2411-2420.

(3) Huang, C. (2008). **Investigation of injection molding process for high precision polymer lens manufacturing** *(Doctoral dissertation, The Ohio State University)*.

(4) Czyżewski, P., Sykutera, D., Bieliński, M., & Troszyński, A. (2019). The impact of laser radiation on polypropylene molded pieces depending on their surface conditions. *Polymers*, *11*(10), 1660. https://doi.org/10.3390/polym11101660

(5) Cheng, J., Zhou, J., Zhang, C., Cao, Z., Wu, D., Liu, C., & Zou, H. (2019). **Enhanced laser marking of polypropylene induced by "core-shell" ATO@ PI laser-sensitive composite**. *Polymer Degradation and Stability,* 167, 77-85.

(6) Cheng, J., You, X., Li, H., Zhou, J., Lin, Z., Wu, D., ... & Pu, H. (2021). **Laser irradiation method to prepare polyethylene porous fiber membrane with ultrahigh xylene gas filtration capacity**. *Journal of Hazardous Materials*, 407, 124395.

(7) Yang, J., Xiang, M., Zhu, Y., Yang, Z., & Ou, J. (2022). **Influences of carbon nanotubes/polycarbonate composite on enhanced local laser marking properties of polypropylene**. *Polymer Bulletin*, 1-13.

(8) Cao, Z., Lu, G., Gao, H., Xue, Z., Luo, K., Wang, K., ... & Luo, M. (2021). **Preparation and laser marking properties of poly (propylene)/molybdenum sulfide composite materials**. *ACS omega*, 6(13), 9129-9140. https://doi.org/10.1021/acsomega.1c00255

(9) **Injection moulding machine,** *DAICEL Group.*

(10) AIM processing

(11) **China plastic moulding**, *Jmoulding*

(12) Ready, J. F. (1997). **Industrial applications of lasers**. *Elsevier*.

(13) Kumbhalkar, M. A., Bhope, D. V., & Vanalkar, A. V. (2015). **Material and stress analysis of railroad vehicle suspension: a failure investigation**. *Procedia Materials Science*, 10, 331-343.