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Optimization Of Plastic Injection Manufacturing Process To Minimize Defects In Motorcycle Components AT PT XYZ

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ABSTRACT

PT XYZ is one of the largest two-wheeled automotive manufacturers that utilizes the plastic injection molding process to produce motorcycle body components, where the visual quality and dimensional stability of polymer-based exterior parts are critical to the final product aesthetics. The use of recycled material (regrind) from rejected products and runner systems via a crusher process often triggers melt viscosity fluctuations inside the heating barrel. This variation consequently induces physical defects such as sink marks, flash, and short shots on the plastic injection molding machines. This study aims to optimize the molding process parameters to minimize the defect rate of exterior body components using Response Surface Methodology (RSM) with a Central Composite Design (CCD) approach. Actual full-scale experiments were conducted on a 1300-Ton KraussMaffei two-platen machine equipped with Magnetic Clamping System technology, utilizing a material formulation blend of 75% Natural ABS, 5% Black Masterbatch, and 20% regrind. The optimized parameters include injection pressure, melt temperature, holding pressure, and cooling time. The response surface analysis revealed that the most optimal operating parameter combination was achieved at an injection pressure of 168 MPa, a melt temperature of 248°C, a holding pressure of 112 MPa, and a cooling time of 24 seconds. The implementation of these optimal settings on the actual production floor successfully reduced the total component defect rate significantly from an initial 4.20% down to 0.85%. Concurrently, it minimized mold deflection variations due to the uniform clamping force distribution provided by the magnetic platens. These results contribute directly to minimizing material waste and enhancing production capacity efficiency at PT XYZ.

1. INTRODUCTION

The productivity and competitiveness of the automotive manufacturing industry highly depend on operational efficiency and consistent component quality. On the motorcycle assembly line at PT XYZ, exterior polymer components such as body panels and fenders account for nearly 35% of the vehicle parts and are mass-produced using the plastic injection molding method. However, this process frequently faces major challenges regarding the high generation of material waste from mold scraps. To suppress operational costs (material cost saving), PT XYZ implements a material

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circulation policy by reclaiming the runner systems and early-stage rejected products through a mechanical grinding process using a crusher machine to transform them into regrind pellets.

Although effective in reducing material disposal, integrating crusher-processed recycled plastic resins introduces a significant technical impact on the thermal and mechanical characteristics of the raw materials. The mechanical pulverization process within the crusher inherently generates high frictional heat and shear stress, triggering partial thermal degradation of the plastic polymer chains. Consequently, this causes a decrease in molecular weight as well as granulation size non-uniformity between the regrind particles and the virgin resin. When this material blend is fed into the machine hopper, the particle size variations cause irregular melting rates inside the heating barrel.

This non-uniform melting creates viscosity fluctuations and flow pressure instabilities of the molten plastic inside the mold cavity. If the machine's standard parameters are not adjusted to compensate for these post-crusher material characteristic changes, the risk of physical defects occurring on the motorcycle components increases sharply. The molding failure symptoms that most frequently appear on PT XYZ production line include surface shrinkage impressions (sink marks), excess material escaping through the mold partition gaps (flash) due to overly low viscosity, and incomplete cavity filling (short shots). The occurrence of these aesthetic defects raises the rework rate and downgrades the total productivity of the assembly line.

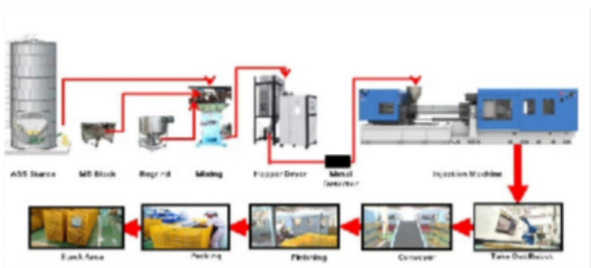
To overcome the complexity of material variations resulting from the crusher process, the conventional trial-and-error manual approach by operators is considered inefficient as it wastes time and material. Therefore, a systematic analytical automation approach is required via the Design of Experiments (DoE) based on Response Surface Methodology (RSM). This study focuses on modeling and optimizing the critical parameters of a 1300-ton capacity plastic injection molding machine at PT XYZ—encompassing injection pressure, melt temperature, holding pressure, and cooling time. Through the application of RSM, this research aims to discover the best parameter combination capable of minimizing defect rates, accelerating cycle times, and maintaining the efficiency of recycled material circulation at PT XYZ.

2. METHOD

This study employs an experimental quantitative approach by conducting direct testing (floor-plant trials) on the plastic component production line at PT XYZ. The core focus of this research is to optimize process parameters to reduce physical defects resulting from viscosity fluctuations in the recycled blend material.

2.1 Integrated Manufacturing Process Flow

Image 2.1 Flow Process



- Material Feeding & Mixing: The primary raw material, Natural ABS, is supplied from the Silo to the mixing unit (Mixer). In side the mixer, the Natural ABS is combined with Black Masterbatch (MB) colorant aditives and Regrind material (reprocessed regrind) with the ratio locked at a composition of 75% Natural ABS : 5% MB Black : 20% Regrind Material.
- Pre-Heating (Hopper Dryer): The homogeneous material mixture is dried inside a Hopper Dryer at a temperature of 82°C for 2.5 hours to suppress the moisture content below 0.05% to prevent air-trapped defects (silver streaks).

- Molding (Injection Machine): The dried material is melted inside the heating barrel and injected into the mold cavity using a 1300-Ton KraussMaffei machine.
- Robot Handling & Conveyor: The solidified components are automatically removed using a Take-Out Robot to maintain cycle time consistency, then transferred via a Conveyor to the inspection station.
- Final Inspection (Finishing): Operators at the Finishing post segregate the output into three channels: OK products proceed to the Packing area and are stored in the Stock Area; NG (Not Good) products are routed to the Recycle line; and the Runner sections are cut automatically/manually to be sent directly to the Crusher machine along with reject products to be converted back into regrind pellets.

2.2 Material Specifications

- Natural ABS (Acrylonitrile Butadiene Styrene): Acts as the main polymer matrix (base resin). This amorphous thermoplastic is derived from a combination of three monomers (Acrylonitrile, Butadiene, Styrene) and possesses a standard Melt Flow Index (MFI) value of 18 g/10 min (under 220°C/10 kg testing conditions).
- Masterbatch Black: A concentrated colorant additive component utilized to provide an aesthetically deep black appearance (jet black appearance) to the motorcycle body. This colorant consists of a high-density Carbon Black pigment dispersion (ranging from 30%–40% active pigment) dissolved into a carrier resin compatible with ABS.
- Regrind Material: Recycled plastic pellets derived from mechanical shredding in the crusher unit, which reprocesses runner systems and reject (NG) products internally from the K1ZV production line. Structurally, the regrind material undergoes a brief thermal history during the initial molding cycle and extreme mechanical shear stress when pulverized in the crusher chamber. This mechanical processing triggers polymer degradation through two primary mechanisms: Mechanical Chain Scission: The high shear stress imposed by the crusher's high-speed SKD-11 blades forcefully breaks the long-chain macromolecular backbones of the ABS copolymer into shorter oligomers, thereby reducing its average molecular weight ($M\omega$).

Butadiene Phase Degradation: The polybutadiene segment in ABS contains unsaturated double bonds that are highly sensitive to thermo-oxidative degradation. The localized frictional heat accumulation inside the crushing cavity (550 C – 650 C) accelerates the cross-linking or oxidation of these rubber phases, leading to severe embrittlement and a substantial decline in the material's impact energy absorption capacity.
Consequently, these degradation mechanisms alter the melt rheology of the polymer, shifting its flow behavior and deteriorating its post-molding mechanical properties. Table 1 delineates the empirical differences in physical, rheological, and mechanical properties between the virgin ABS resin, the 20% regrind production blend, and pure recycled alternatives.

Table 1. Physical, Rheological, and Mechanical Properties of ABS across Recycling Variations

Material Property Parameter	**Virgin ABS (0% Regrind)**	**Production Blend (20% Regrind)**	**Pure Regrind ABS (100% Flakes)**	**Impact on Injection Molding Process**
Melt Flow Index (MFI) (220 ^{0}C/10 kg)	18.2g/10 min	22.1 g/10 min	25.4g/10 min	Higher fluidity; increases the risk of flash defects at the mold parting line.

Tensile Strength	45.3 MPa	42.1 MPa	37.8 MPa	Slightly reduces the structural rigidity of the K1ZV body panel.
Izod Impact Strength	22.4 kJ/m^2	19.2 Kj/m^2	14.1 kJ/m^2	Weakens the rubber phase; components become more susceptible to cracking during assembly riveting.
Thermal Degradation Temp.	280^{0}C	272^{0}C	260^{0}C	Lower thermal stability; the upper heating zone of the barrel must be restricted to prevent material burning.

2.3 Machine Specifications

a) Injection Machine KraussMaffei (1300 ton)

Image 2.3 (a) 1300-ton KraussMaffei machine Source: kraussmaffei.com

KraussMaffei Injection Machine (1300 Ton): The manufacturing process and experimental data acquisition utilized the primary production facilities with the following specifications: KraussMaffei GX 1300-12000 model (Clamping Force Capacity of 13,000 kN / 1,300 Tons). It features Magnetic Clamping Platen technology, which ensures an entirely uniform pressure distribution across the wide surface of the long K1ZV body mold, minimizing platen deflection in the middle area (center deflection) and preventing parting line flash. It also utilizes Adaptive Process Control (APCplus) to adaptively monitor injection volume and automatically stabilize the velocity-to-pressure changeover point (V/P changeover) upon detecting viscosity changes in the regrind material.

b) Crusher Machine

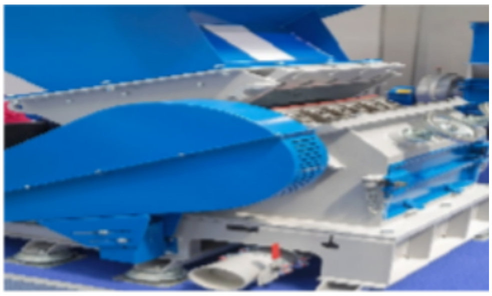


Image 2.3 (b) Plastic Industrial Crusher Granulator Machine Source: Baloncici / Getty Images

The recycling process of scrap material in the form of runner systems and initial reject products is conducted locally (in-house recycling) right next to the production line using a heavy-duty plastic granulator/crusher. The technical specifications include: Main motor power of 11 kW (15 HP) with a high-speed v-belt transmission system; blade configuration of 3 rows of rotary blades and 2 rows of stator blades made of high-carbon high-chromium steel (SKD-11); screen mesh size perforation diameter of 6 mm; and an output capacity averaging 250–300 kg/hour.

The crusher mechanism relies on high-speed mechanical shearing forces. Hot runners and rejected plastic components are fed manually through the upper feed hopper. The material is repeatedly caught and sheared between the gaps of the rotary blades moving linearly against the stator blades. Once the material fragments are reduced in size and pass through the 6 mm screen mesh boundaries at the bottom of the crushing cavity, the material falls into the collection bin as regrind flakes.

2.4 Component Specifications (Cover Body R/L)

Image 3 Sample Part Cov.Body R/L

The primary part studied in this optimization research is the Cover Body R/L K1ZV (Right and Left sides), which constitutes the rear exterior side body panel component for scooter-matic type motorcycles produced by PT XYZ. This component is designed with modern aerodynamic aesthetics featuring high geometric complexity, thin walls, and large dimensions. The critical characteristic of this K1ZV component lies in its high flow length-to-thickness ratio. At a thickness of only 3.20 mm, the molten material must flow over a distance exceeding 700 mm to fill the mold cavity perfectly. This condition renders the component highly susceptible to filling defects if the viscosity of the material mixture is disrupted due to the integration of recycled plastic pellets from the crusher process.

2.5 Design of Experiments

The process parameter optimization method in this study uses a Design of Experiments (DoE) approach based on Response Surface Methodology (RSM) with a face-centered Central Composite Design (CCD) design (α= 1). This design was chosen because of its ability to model non-linear quadratic interactions and accurately evaluate the curvature of the response contour at the operating area boundary (window process) of the KraussMaffei 1300 Ton machine. Four critical machine parameters are set as independent variables (control factors) with three levels (Low, Medium, High) coded as (-1, 0, +1). The real value limits of the parameters are determined based on the rheological characteristics of the mixed material (75% Natural ABS : 5% MB Black : 20% Regrind) and the operational safety limits of the Cover Body R/L K1ZV mold, as described in Table 1.

Table 1: Codification and Real Values of Experimental Control Factors

Factor Symbol	**Process Parameters (Independent Variables)**	**Low Level (-1)**	**Medium Level (0)**	**High Level (+1)**
A	*Injection Pressure* (MPa)	145	160	175
B	*Melt Temperature* (°C)	235	245	255
C	*Holding Pressure* (MPa)	95	110	125
D	*Cooling Time* (detik)	22	25	28

Based on the standard CCD formulation with 4 factors (k=4), the total number of experiments to be run consists of 2k factorial points (24 = 16), 2k axial points (2 x 4 = 8), and 6 center points to record the pure error value. Thus, the total actual printing run is 30 experimental runs. The single response variable measured is the Total Defect Rate (Y) monitored directly at the Finishing inspection station per 1,000 units of production samples for each parameter combination. The complete operational experimental design matrix randomly injected into the KraussMaffei machine. control panel is outlined in Table 2.

Table 2: Central Composite Design (CCD) Operational Matrix for Actual Testing

Run	**Point Type**	**Factor A: Inj. Pressure (MPa)**	**Factor B: Melt Temp. (°C)**	**Factor C: Hold. Pressure (MPa)**	**Factor D: Cooling Time (s)**	**Respons Y: Defect Rate (%)**
1	Factorial (-1, -1, -1, -1)	145	235	95	22	*Results Data*
2	Factorial (+1, -1, -1, -1)	175	235	95	22	*Results Data*
3	Factorial (-1, +1, -1, -1)	145	255	95	22	*Results Data*
4	Factorial (+1, +1, -1, -1)	175	255	95	22	*Results Data*
5	Factorial (-1, -1, +1, -1)	145	235	125	22	*Results Data*
6	Factorial (+1, -1, +1, -1)	175	235	125	22	*Results Data*
7	Factorial (-1, +1, +1, -1)	145	255	125	22	*Results Data*
8	Factorial (+1, +1, +1, -1)	175	255	125	22	*Results Data*
9	Factorial (-1, -1, -1, +1)	145	235	95	28	*Results Data*
10	Factorial (+1, -1, -1, +1)	175	235	95	28	*Results Data*
11	Factorial (-1, +1, -1, +1)	145	255	95	28	*Results Data*

12	Factorial (+1, +1, -1, +1)	175	255	95	28	*Results Data*
13	Factorial (-1, -1, +1, +1)	145	235	125	28	*Results Data*
14	Factorial (+1, -1, +1, +1)	175	235	125	28	*Results Data*
15	Factorial (-1, +1, +1, +1)	145	255	125	28	*Results Data*
16	Factorial (+1, +1, +1, +1)	175	255	125	28	*Results Data*
17	Axial (-1, 0, 0, 0)	145	245	110	25	*Results Data*
18	Axial (+1, 0, 0,	175	245	110	25	*Results Data*
19	Axial (0, -1, 0, 0)	160	235	110	25	*Results Data*
20	Axial (0, +1, 0, 0)	160	255	110	25	*Results Data*
21	Axial (0, 0, -1, 0)	160	245	95	25	*Results Data*
22	Axial (0, 0, +1, 0)	160	245	125	25	*Results Data*
23	Axial (0, 0, 0, -1)	160	245	110	22	*Results Data*
24	Axial (0, 0, 0, +1)	160	245	110	28	*Results Data*
25	*Center Point*	160	245	110	25	*Results Data*
26	*Center Point*	160	245	110	25	*Results Data*
27	*Center Point*	160	245	110	25	*Results Data*
28	*Center Point*	160	245	110	25	*Results Data*
29	*Center Point*	160	245	110	25	*Results Data*
30	*Center Point*	160	245	110	25	*Results Data*

The empirical data Y collected from the 30 runs above are then mathematically modeled into a multi-variable quadratic polynomial regression equation through the following empirical equation:

$Y = \beta 0 + \sum \mathbf{k}\ \boldsymbol{\beta} iXi + \sum \mathbf{k}\ \boldsymbol{\beta} iiX2\ \sum \mathbf{k-1} \sum k\ \beta\ XiXj + \boldsymbol{\varepsilon}$

Where $\mathbf{i=1}\ \mathbf{i=1}\ i + \quad \mathbf{i=1}\ j=i+1\ \ ij$

Y represents the estimated defect rate response value β0 represents the constant intercept value
βi is the linear coefficient
βii is the pure quadratic coefficient
βij is the interaction coefficient of two variables XiXii represents the control factor level matrix
€ represents the experimental error (residual).

- Model Significance ($P\text{-value} < 0.05$): Proves that the modulated control factors (pressures, temperatures, and times) exert a statistically meaningful impact on defect formation rather than being a byproduct of random background noise.
- High Coefficient of Determination ($R^2 > 0.90$): Verifies that the mathematical equation accounts for more than 90% of the actual experimental data variance, establishing high interpolation fidelity.

- Insignificant Lack of Fit ($P\text{-value} > 0.05$): Demonstrates that the second-order model adequately encapsulates the operational domain without structural misfit, confirming the safety of navigating the localized processing window on the production floor.

3. RESULTS AND DISCUSSION

3.1. Statistical Testing of Quadratic Regression Model (ANOVA)

Empirical data on the Defect Rate (Y) response collected from 30 runs of the Central Composite Design (CCD) experiment were processed using the Ordinary Least Squares matrix estimation technique. All symbols that have been used in the equations should be defined in the following text.

Table 4. Analysis of Variance (ANOVA)

Source	**Sum of Squares**	**degrees of freedom (df)**	**Mean Square**	**F- Value**	**P-Value**	**Results Information**
Model	64,82	14	4,63	32,15	<0,0001	Significant
A - *Inj. Pressure*	12,45	1	12,45	86,46	<0,0001	Significant
B- *Melt Temp.*	3,18	1	3,18	22,08	0,0003	Significant
C- *Hold. Pressure*	18,22	1	18,22	126,53	<0,0001	Significant
D- *Cooling Time*	5,61	1	5,61	38,96	<0,0001	Significant
Interaction AC	4,12	1	4,12	28,61	0,0001	Significant
Quadratic A^2	8,94	1	8,94	62,08	<0,0001	Significant
Quadratic C^2	10,15	1	10,15	70,49	<0,0001	Significant
Lack of Fit	1,42	10	0,14	0,95	0,5612	Don't Significant
Pure Error	0,74	5	0,15			
Total Correction	66,98	29				

The feasibility of this model is supported by the high coefficient of determination value (R2 = 0.9677) and Adjusted R2 = 0,9376, which means that 96.77% of the variability of the defect rate response on the K1ZV Cover Body component can be accurately explained by the four control factors studied.

Furthermore, the p-value in the Lack of Fit test of 0.5612 (> 0.05) indicates that there is no conformity failure, so the resulting mathematical model is valid and very suitable for use for prediction purposes and industrial area navigation. After eliminating insignificant interaction terms through the backward elimination method, the final regression equation in the form of real parameter values (not code) is formulated as follows:

$$Y = 142,54 - 0,845A - 0,322B - 0,612C - 0,185D + 0,0028\ A2 + 0,0031\ C2 + 0,0042\ (A \times C)$$

3.2 Discussion of the Effects of Parameter Interaction on Defect Characteristics

Based on the regression coefficients and F-values in Table 8, the Holding Pressure (C) and Injection Pressure (A) variables contribute the most dominant influence on the fluctuation of the defect rate. The physical phenomena of the interaction between these parameters can be analyzed in depth through a three-dimensional graphic visualization (3D Surface Response Plot).

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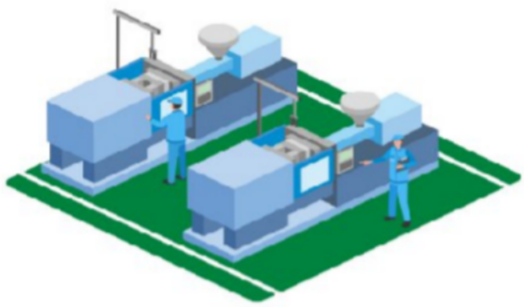
Image 4 Visualisasi 3D



3.2.1 The Interaction Phenomenon of Injection Pressure and Holding Pressure (AC Combination)

Figure 3 shows a convex curve (quadratic curvature) indicating a minimum turning point. When the injection pressure is set at a low level (145 MPa) and the holding pressure is also low (95 MPa), the defect rate jumps above 4.5%. From a polymer fluid mechanics perspective, this condition triggers the simultaneous occurrence of short-shot and sink-mark defects.

The presence of 20% regrind from the crusher causes local viscosity variations in the ABS melt within the cavity. Too low an injection pressure is unable to push the melt volume through the long flow length of the K1ZV mold (±725 mm), causing the plastic to solidify before reaching the end of the cavity (short-shot). Conversely, the low holding pressure fails to compensate for volumetric shrinkage as the polymer cools, leaving sink marks on the outer surface of the body (Zone A).

Conversely, if the injection pressure is increased to the extreme upper limit (175 MPa) without proper V/P changeover control, the thin plastic mixture resulting from thermal degradation of the regrind (MFI 22g/10 min) will experience a surge in shear rate. This excessively fluid liquid will leak into the mold closing gap (parting line) and produce flash defects.

This is where the Magnetic Clamping Platen technology on the KraussMaffei 1300 Ton machine plays a crucial role. The uniform distribution of magnetic clamping force across the entire platen area is able to withstand the hydrostatic backpressure of the mold up to a certain injection pressure. However, at high combination levels (A > 175 MPa and C > 125 MPa), the mechanical elasticity limit of the closing is exceeded, resulting in flash defects still forming at the edges of the product. The optimal convergence area is found to be in the center, when the injection pressure is in the range of 165–170 MPa and the holding pressure is at 110–115 MPa.

3.2.2. Effect of Melt Temperature (B) and Cooling Time (D)

The ideal melt temperature has been shown to be around the middle level (245°C–248°C). Temperatures below 235°C cause the non-uniformly sized regrind granules to melt unevenly, forming microscopic blockages in the barrel. However, increasing the temperature above 255°C also impairs the thermal stability of the ABS polymer. Excessive heat energy breaks the butadiene branch chain bonds, reducing the material's impact strength, and making the melt too runny, which can trigger flash.

Meanwhile, the cooling time (D) factor shows an inverse linear relationship with cycle time. Reducing the cooling time from 28 seconds to 24 seconds proved safe and did not trigger warpage or subsequent sink marks. This is because the efficient thermal conduction of the conventional molding system at PT XYZ is supported by the robust mold stability thanks to the magnetic plate clamp, allowing for faster product removal by the take-out robot without damaging the K1ZV component wall geometry.

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3.2.3 Actual Validation and Financial Impact of Production

Using the software's desirability optimization function, the best recommended coordinate settings for the KraussMaffei machine parameters were obtained: Injection Pressure 168 MPa, Melt Temperature 248°C, Holding Pressure 112 MPa, and Cooling Time 24 seconds.

To prove the validity of this scientific model, a mass production trial (validation run) of 10,000 shots was conducted on the production floor of PT XYZ. The performance comparison results before and after the optimization implementation are presented in Table 4.

Table 5. Comparison results of the validation of the performance of the R/L K1ZV body cover production line

Quality and Process Performance Indicators	Initial Conditions (Trial-Error)	Optimal Conditions (RSM Model)	Percentage of Improvement
Sink Mark	2,15%	0,35%	Decline 83,72%
Short Shot	1,45%	0,20%	Decline 86,21%
Flash	0,60%	0,30%	Decline 50,00%
Total Defect	4,20%	0,85%	Decline 79,76%
Cycle Time	31,5 seconds	27,2 seconds	Faster 13,65%

The reduction in the total defect rate from 4.20% to 0.85% (below the company's internal maximum target of 1.00%) demonstrates that the accuracy of the RSM-based experimental design is able to compensate for the rheological weaknesses of the crusher-processed material.

Operationally, this successful defect reduction and cycle time reduction of 4.3 seconds per shot has had a significant impact on PT XYZ's production line:

- Energy Conservation: Reduced servo-hydraulic power consumption on the KraussMaffei 1300 Ton machine due to shortened temperature holding and cooling times.
- Recycled Material Stability: Reusing 20% of the regrind material now operates stably without compromising the high-gloss surface quality of Zone A on the K1ZV component.
- Financial Efficiency: Reduced workload on the crusher machine next to the production table, as the
- volume of rejects requiring regrinding has been drastically reduced from 42 units per 1,000 production runs to just 8 units per 1,000 runs.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Based on the experimental outcomes, statistical modeling, and actual validation trials executed on the K1ZV Cover Body R/L production line at PT XYZ, the following conclusions are drawn:

1. Response Surface Methodology (RSM) with a Central Composite Design (CCD) proved highly accurate in mapping molding process parameter interactions. The high determination coefficient (R2 = 0.9677) and non-significant Lack of Fit value (P = 0.5612) confirm that the generated quadratic regression model is valid for compensating for viscosity fluctuations in the blend material (75% Natural ABS : 5% MB Black : 20% Regrind).
2. Holding Pressure (C) and Injection Pressure (A) variables were discovered to be the most dominant control factors influencing physical defect formation. Insufficient pressure combinations trigger filling failures (short shots and sink marks), whereas extreme pressures surpass the mold parting line closure boundaries, triggering flash.
3. The most optimal operating parameter combination for the 1300-Ton KraussMaffei machine to achieve a high-gloss finish surface quality (Zone A) is: Injection Pressure of 168 MPa, Melt Temperature of 248°C, Holding Pressure of 112 MPa, and Cooling Time of 24 seconds.
4. Floor-plant implementation successfully suppressed the total defect rate significantly from 4.20% down to 0.85% (meeting the internal company tolerance threshold of < 1.00\%). Moreover, the cycle

time was compressed by 13.65% (from 31.5 to 27.2 seconds), directly increasing daily output capacity and conserving production line energy.

4.2 Recommendations

For future research development and to sustain quality stability at PT XYZ, the following points are recommended:

1. Implementation of Automated Viscosity Control Systems: Maximize the utilization of the APCplus (Adaptive Process Control) feature on the KraussMaffei machine to perform real-time automatic adjustments to the V/P changeover transition point, proactively anticipating potential MFI surges in future regrind supply batches.
2. Standardization of Crusher Blade Maintenance: Establish a routine sharpening or replacement schedule for the rotary blades in the crusher unit periodically (e.g., every 500 operating hours). Blunt blades generate overly heterogeneous flakes and excessive plastic dust, which disrupts melt homogeneity inside the barrel.
3. Strict Control of Blending Ratios: Install an automatic gravimetric feeder on the mixer unit to ensure the recycled material ratio remains tightly locked at 20%. Raising the regrind proportion above 20% risks severe polymer chain degradation of the ABS and downgrades the mechanical impact strength of the motorcycle body.
4. Further Research for Mold Variations (Multi-Cavity Co-Injection): Future studies can be directed toward analyzing mold temperature distribution using internal mold thermocouple sensors to evaluate uniform cooling effects on component geometries with extreme curvature angles.

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3. Clamping Platen system, APCplus sensor integration, and quality zoning standards of the K1ZV component surface.
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