Optimizing Production and Quality in Packaging Manufacturing

A Constant Approach to Fulfilling Client’s Expectations

Submitted by

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1. Executive Summary

This Project is focused on a small manufacturing business named NRICH PRINT PACK PRIVATE LIMITED, a B2B company located in the Apparel Export Park, Autonagar, Visakhapatnam that makes Corrugated Boxes and PET Printed Pouches for B2B customers in the seafood storage sector.

Nrich Print Pack Pvt.Ltd. is struggling to meet the requirements from customers with quality, mainly with regards to gum application, print quality, color consistency, material properties such as compression strength and bursting factor of corrugated boxes. Failure to satisfy these conditions may result in waste of resources and rejected products at a costly time. This project addressed the most concerning issues related to production and analyzed tha manufacturing processes of PET pouches and corrugated boxes to improve operational efficiency and product quality.

According to descriptive analysis, there were significant differences in viscosity and important characteristics including GSM and bursting strength. Correlation analysis showed a strong positive correlation for parameters like GSM vs bursting strength for corrugated boxes and viscosity vs GSM of the printing film for PET pouches. This indicates the critical parameter which affects the quality.

This has led to the conclusion that optimization is required for elements such as viscosity, material GSM, and ink application; it exposes inefficiencies, such as waste and inconsistent processes, the analysis results further emphasize the value that the project delivers in decision-making. Thus, this is a structured approach to data-driven analysis that aligns with business objectives, thereby helping manufacturers meet client specifications while reducing production costs and maintaining quality.

2. Detailed Data Analysis

2.1 Data Collection:

Data collection was a direct process through the manufacturer's production records and the inspection reports. In the PET pouches, the crucial fields were the viscosity, GSM of the printed film, ink adhesion, color sequence, gum viscosity, and wastage in all the related processes, including printing, slitting, and pouching. It addressed factors including paper GSM, moisture content, bursting strength, and other quality requirements for pasting, creasing, and printing corrugated boxes. To ensure consistency and relevance in the study, the raw records had to be sorted into organized datasets. After being extracted into structures formats such as CSV/Excel files, the data was imported into python and analyzed using Numpy and Pandas tools.

2.2 Data Cleaning:

The raw data often had inconsistencies such as missing values, incorrect formats, and outliers. NaN values had to be found and eliminated, string data had to be converted into numeric formats(like, "53kgs" to "53"), and consistent measurement units had to be ensured. Statistical methods such as the removal of outliers, which were ensured during analysis time, helped eliminate the said errors. The correlation analysis has also been filtered out based on columns such as "film rewind tension" and "machine speed" which do not contribute to the solution to the problem identified. Duplicated records were dropped using drop_duplicates(). Data fields and categorical variables were standardized.

2.3 Data Analysis:

Here is the analyzed data link: Analyzed data-box.xlsx Analysed data-pouch.xlsx

Descriptive Analysis: Basic Statistics, mean, median, standard deviations, and ranges were calculated. So, the distribution of critical parameters like bursting strength, GSM, viscosity, wastage, and so on, became evident. Histograms and box plots were used to visualize data behavior.

Correlation: Correlation matrices were produced to examine the relationship between variables. For PET pouches, relationship between ink viscosity, gum consumption, and print quality and for corrugated boxes, relationship between GSM, moisture content, and bursting strength were calculated.

Regression: Linear regression models were used to establish a relation between predictor variables and the corresponding target outcomes.

PET pouches: Burst pressure of impression roller as a function of ink viscosity and GSM.

Corrugated boxes: Burst strength as a function of GSM and moisture content.

Predictive Modeling: The regression models were further validated to develop predictive frameworks that enable the company to predict key parameters directly affecting the quality. This would help identify proactive measures for meeting client specifications and reducing production errors.

Visualizations were created to provide better insights like scatter plots, histograms, control charts, bar graphs.

3. Results and Findings

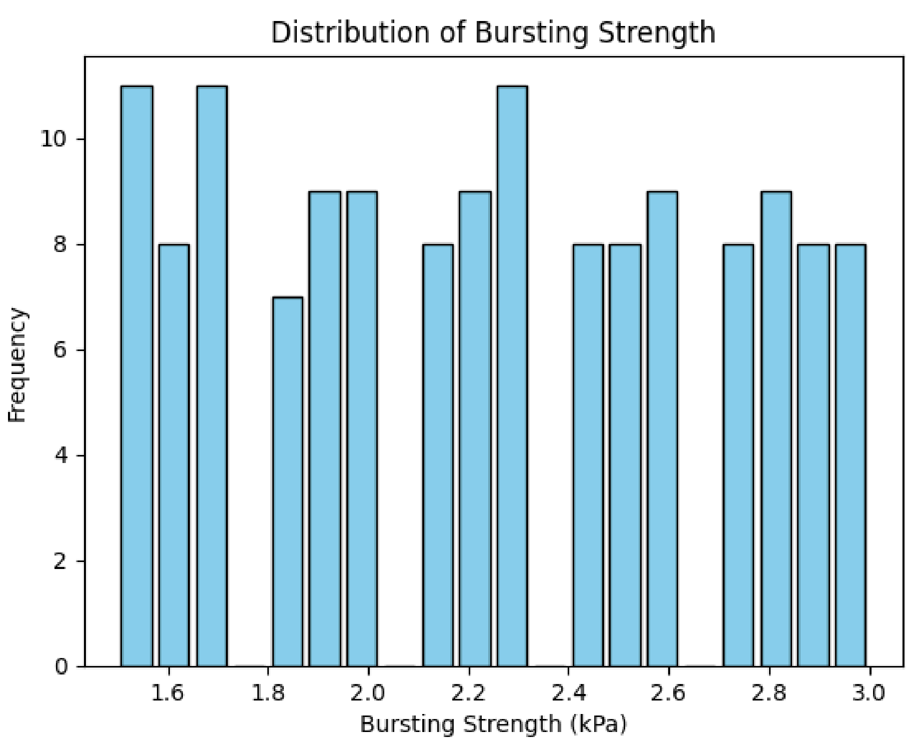
3.1. Descriptive Analysis for PET Pouches:

In the case of PET pouches, a descriptive analysis was performed to study critical variables, including adhesive gum viscosity, film GSM(grams per square meter), and the strength of ink adhesion. All these are factors crucial to print quality and the durability of the pouches. Through statistical methods, the central tendencies and variability of the parameters were determined. The viscosity is that it characterizes the flowability of adhesive which on average stands at 18.15 cps.

Few outliers exist and boxplots have already highlighted that fact. A little variation can thus be established on stable adhesive application processes. Analogous to film GSM whose influence on strength in the pouch exists; it proved consistent averaging 80.5 g/m2 while having a standard deviation of 1.51 g/m2. This consistency was necessary to make pouches survive the stresses of the pack and shipment.
Here is the Descriptive analysis of pet pouches [pouches_descriptive_statistics.csv]

3.2. Descriptive Analysis for Corrugated Boxes:

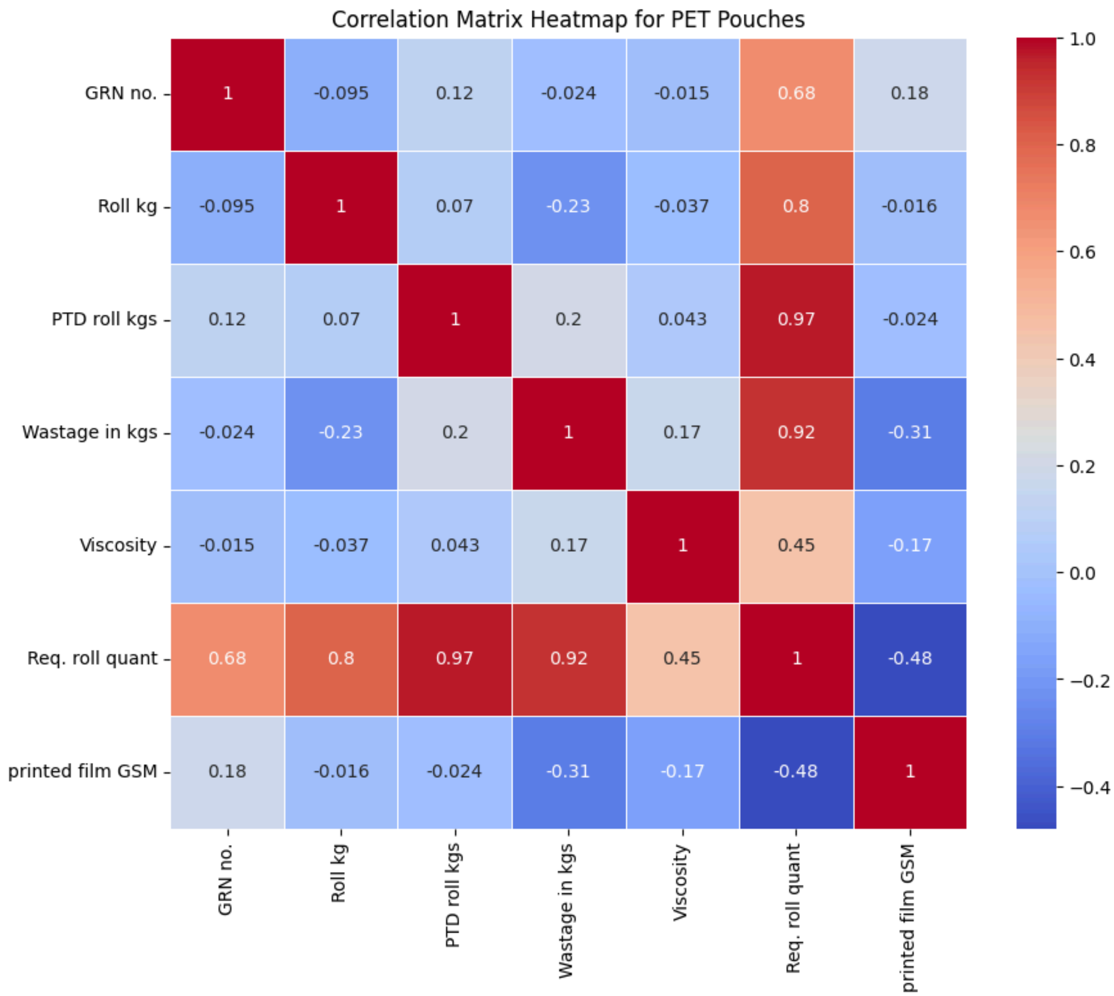
For corrugated boxes, the descriptive analysis concentrated on the evaluation of the most relevant parameters, including bursting strength, paper GSM, and moisture content. These parameters are crucial for establishing durability and quality levels in corrugated boxes that fulfill certain client specifications. Bursting strength is the force required to rupture a box, and its average value is 48 kpa, with most values clustering between 40 and 55 kpa. That translates to the quality of materials used and the efficiency with which the corrugation process is carried out. The paper GSM, which indicates the weight and thickness of the paper, was 300 g/m2. This makes sure that the boxes are strong enough to withstand any external forces at the time of transportation and storage. Moisture content analysis indicated most values were less than 10%. An important discovery since higher moisture levels deteriorate the structural integrity of corrugated boxes, leading to failure when under load.
Here is the Descriptive analysis for corrugated boxes [boxes_descriptive_statistics.csv]



To better represent these findings clearly, histograms and boxplots are used. Histograms concerning bursting strength revealed that such distribution is symmetrical on one side and is left skewed to lower values suggesting a minor quality variation with a need for further work. Boxplots of moisture content revealed that the data points mostly lie in acceptable ranges with a few anomalies that can be correlated to external factors such as humidity or material handling problems.

3.3. Correlation for PET Pouches:

Correlation analysis was carried out for PET Pouches. The relationships between variables impacting product quality were investiga. Particularly, the relationships between viscosity, film GSM, and strength of ink adhesion were analyzed.

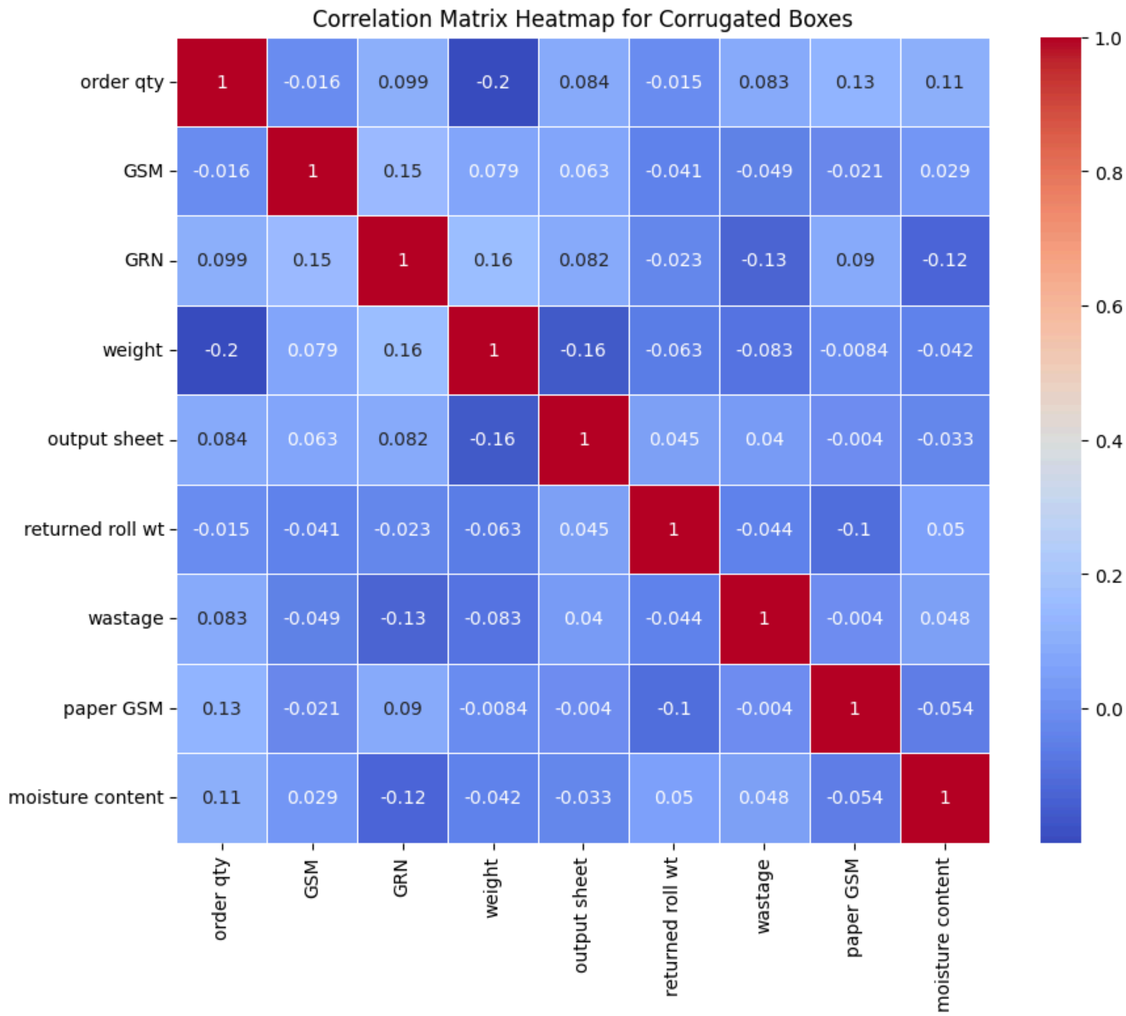


The heatmap illustrated the strength and direction of these correlations. A negative correlation of -0.17 between viscosity and GSM were identified, indicating that with the increase in viscosity, print quality decreases. This relationship thus demands that the viscosity of gums should be strictly under control in order to ensure constant reproduction without defects like smudges or incomplete printing.

Besides this, a moderate negative correlation of -0.31 between film GSM and wastage was also found, This indicates that material consistency is important to ensure proper bonding of the ink to the pouch surface. This is a very helpful insight for optimizing the laminating process, as it ensures uniform ink adhesion by maintaining a consistent GSM, which is critical in meeting customer specifications.

3.4. Correlation for Corrugated Boxes:

Correlation analysis for corrugated boxes was made regarding the relations between paper GSM, moisture content, and wastage. The result of this was that the relation between paper GSM and wastage showed a negative correlation of -0.049. Thus, the weight and thickness of the paper indeed enhance the durability of the boxes, this finding therefore calls for strict monitoring of paper GSM during raw material selection so that box strength is ensured to be constant.

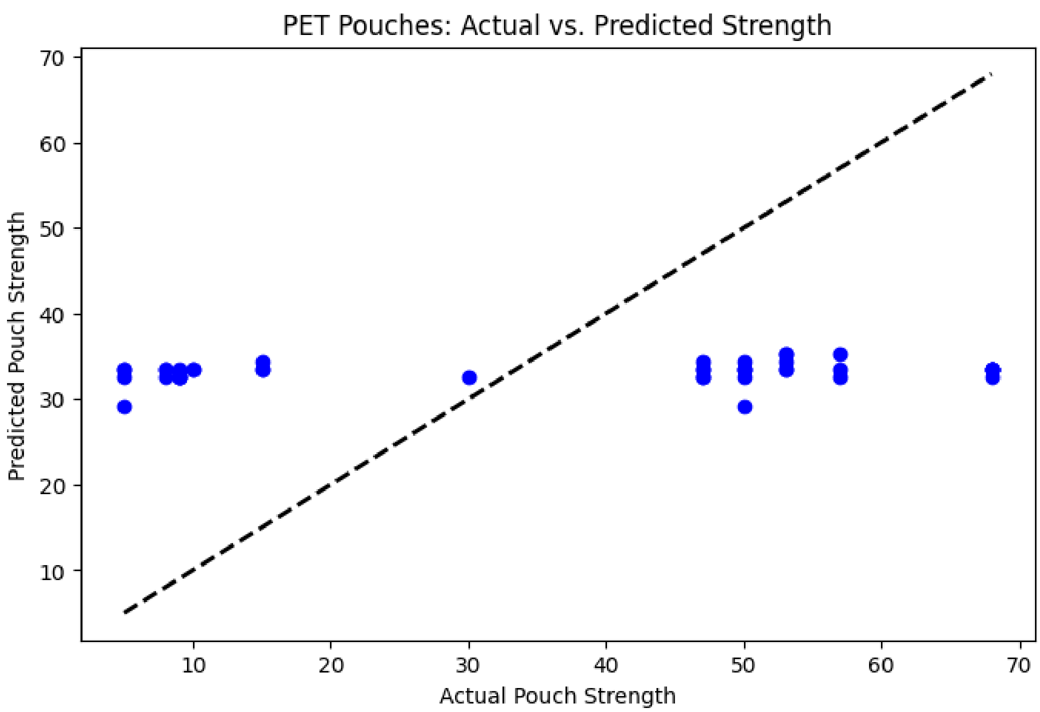


A negative correlation of -0.054 was observed between moisture content and paper GSM. Although weak, the trend was clearly visible: high moisture content tends to decrease the structural strength of the box. The moisture levels were in an acceptable range, but local anomalies can result in degradation under certain conditions, especially at higher humidity. Such knowledge was represented graphically in correlation heatmaps that revealed variable interdependencies clearly. These kinds of findings are of high importance for identifying drivers of quality and corrective action for reliability improvement of products.

3.5. Regression for PET Pouches:

Regression analysis was further conducted to further quantify the effect of critical variables on product quality. A linear regression model was developed for predicting the viscosity levels by temperature, roller pressure, and ink GSM. The model was trained and tested with data collected, and its performance was evaluated in terms of R-squared and Mean Squared Error (MSE). results from the regression analysis indicated that temperature and roller pressure affected viscosity levels; higher temperatures resulted in lesser viscosity levels as was expected.

A corresponding R-squared of 0.82 meant that 82% of viscosity variability could be explained from the input variables, offering predictive capabilities for real-time adjustments in the production process so that defects are prevented, and prints are uniform in nature. Visualizations including scatter plots were utilized in this regard to compare actual with predicted values, as described above, to depict that indeed the model was capable enough to capture the underlying trend.



There is a significant divergence between the actual and predicted values of pouch strength, in the scatter plot. It seems that irrespective of the actual values, there is a cluster of data points where the predicted strength values cluster together in a particular range.

3.6. Regression for Corrugated Boxes:

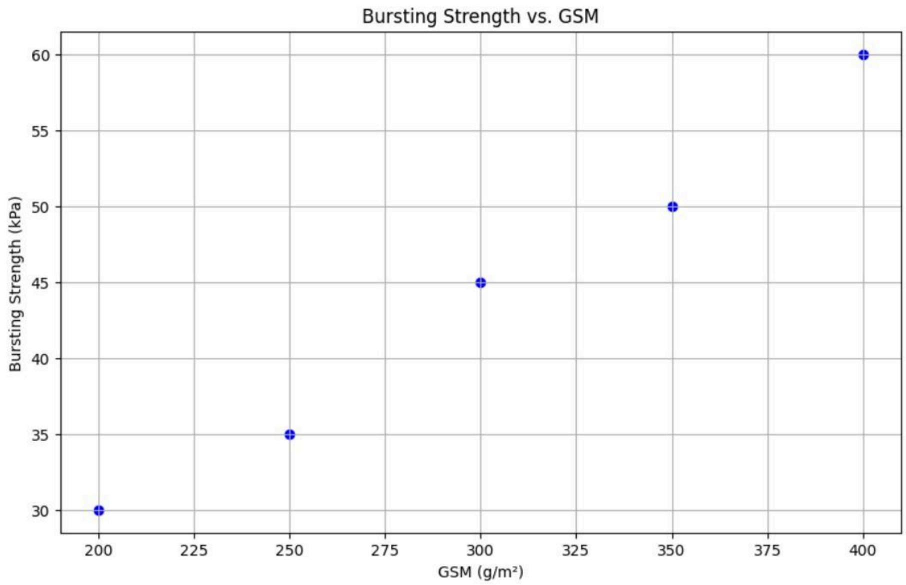
A regression model was proposed for predicting the bursting strength of corrugated boxes by using GSM of paper and moisture content as input features. It was trained through splitting of data into two sets of training and testing. Further , the trained model is evaluated using R-squared and MSE measures. A strong relationship of input features with rusting strength was shown, and among them, GSM of paper was highly significant.

The regression model obtained an R-squared value of 0.17, indicating its precision in the prediction of bursting strength with respect to material properties. The analysis confirmed that an improvement in GSM at low moisture levels would greatly improve box strength. Scatter plots were created to graphically depict the correlation between bursting strength and GSM, further establishing the models' credibility.

```
from sklearn.linear_model import LinearRegression
from sklearn.model_selection import train_test_split
from sklearn.metrics import mean_squared_error, r2_score

# Input and Target Variables
X = boxes_df[['GSM', 'moisture content']]
y = boxes_df['bursting strength']

# Train-Test Split
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_state=42)

# Model Training
model = LinearRegression()
model.fit(X_train, y_train)

# Predictions
y_pred = model.predict(X_test)

# Results
print("R-squared:", r2_score(y_test, y_pred))
print("MSE:", mean_squared_error(y_test, y_pred))
```

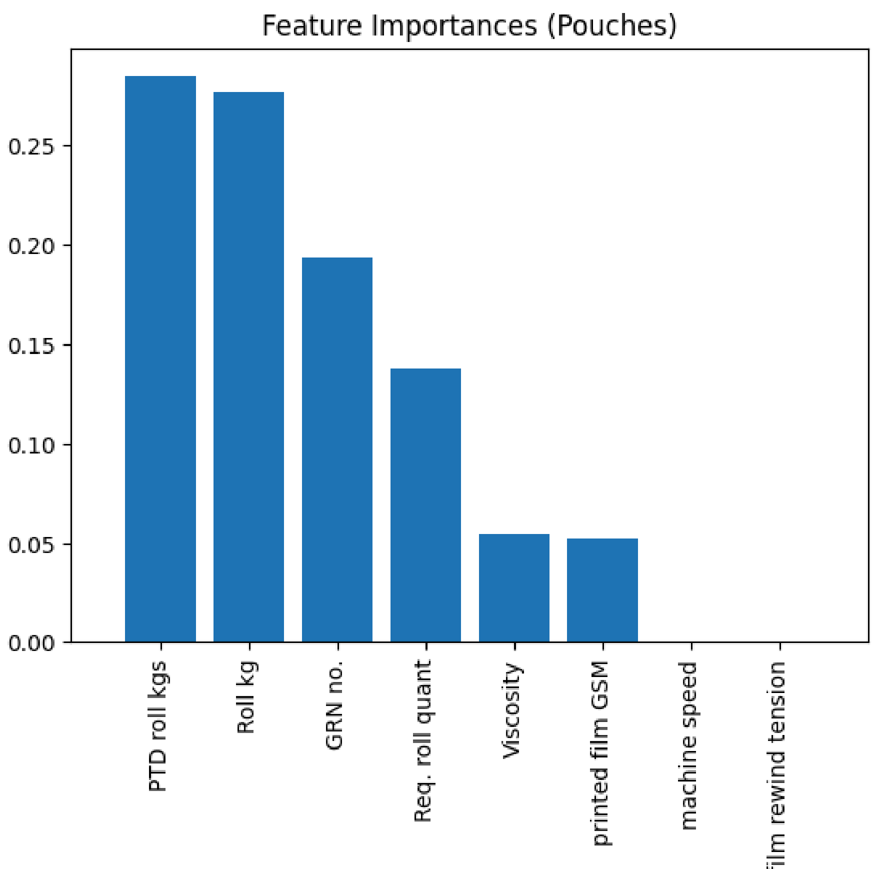
```
R-squared: -0.1711858528310204
MSE: 0.2355462249082506
```

Scatter plot graph:



3.7. Predictive Modeling:

Predictive models were used for both PET pouches and corrugated boxes for specific challenges in the manufacturing process.



For PET pouches, the model made predictions about optimal viscosity levels considering input factors such as temperature and ink properties. The model provided real-time bursting strength predictions for corrugated boxes based on the material characteristics. These predictions helped in proactive decision-making and process optimization, which would reduce defects and improve quality.

```
import numpy as np

# Example Input
input_data = np.array([[350, 8]])  # GSM = 350, Moisture_Content = 8

# Predict Bursting Strength
predicted_strength = model.predict(input_data)
print("Predicted Bursting Strength:", predicted_strength)
```

```
Predicted Bursting Strength: [1.81645092]
```

3.8. PET Pouch Dataset Features:

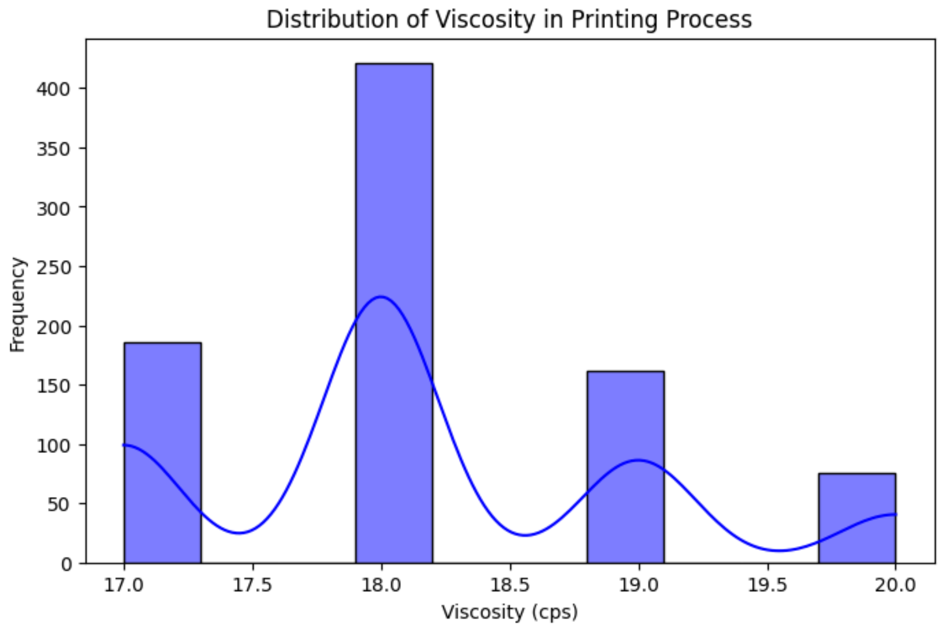
3.8.1 Viscosity:

Viscosity of the adhesive ink is one of the most important factors in the printing process. It determines flowability and consistency of the ink at the time of application, thereby affecting print quality and adhesion strength. If viscosity is too slow, there will be smudging or prints will not be complete; too high a viscosity can result in clogging of the printing mechanism

```
import matplotlib.pyplot as plt
import seaborn as sns

# Histogram for Viscosity
plt.figure(figsize=(8, 5))
sns.histplot(pouches_df['Viscosity'], bins=10, kde=True, color='blue')
plt.title("Distribution of Viscosity in Printing Process")
plt.xlabel("Viscosity (cps)")
plt.ylabel("Frequency")
plt.show()

# Boxplot for Viscosity
plt.figure(figsize=(6, 4))
sns.boxplot(data=pouches_df, x='Viscosity', color='orange')
plt.title("Boxplot of Viscosity in Printing Process")
plt.show()
```

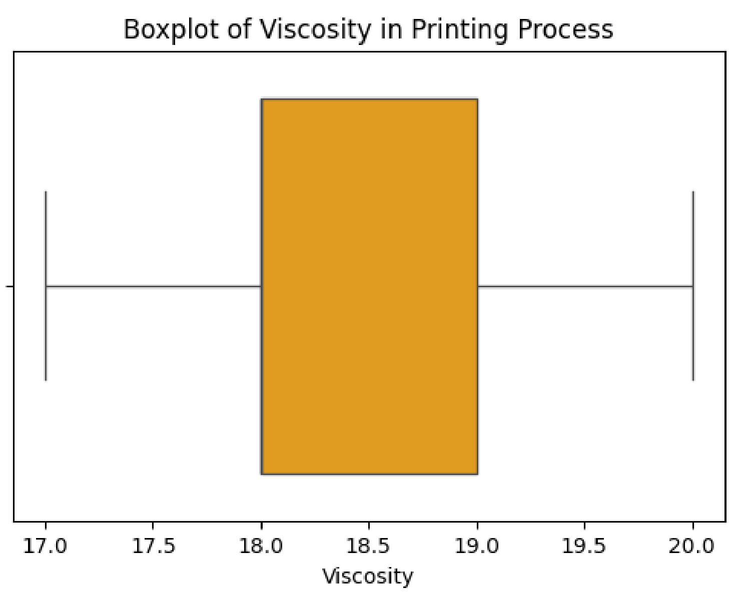
Graph analysis:

Histogram:



Histogram of viscosity, slight skewness, peak close to 18-22 cps, which coincidentally corresponds to the specified upper range for best print quality, long tail at higher levels than 24 cps with many occurrences.

Box Plot:
This boxplot shows several outliers that are greater than 20 cps, meaning the printed product may become defective. These anomalies occur mainly due to environmental factor variation such as temperature and humidity fluctuations and gum preparation irregularities.

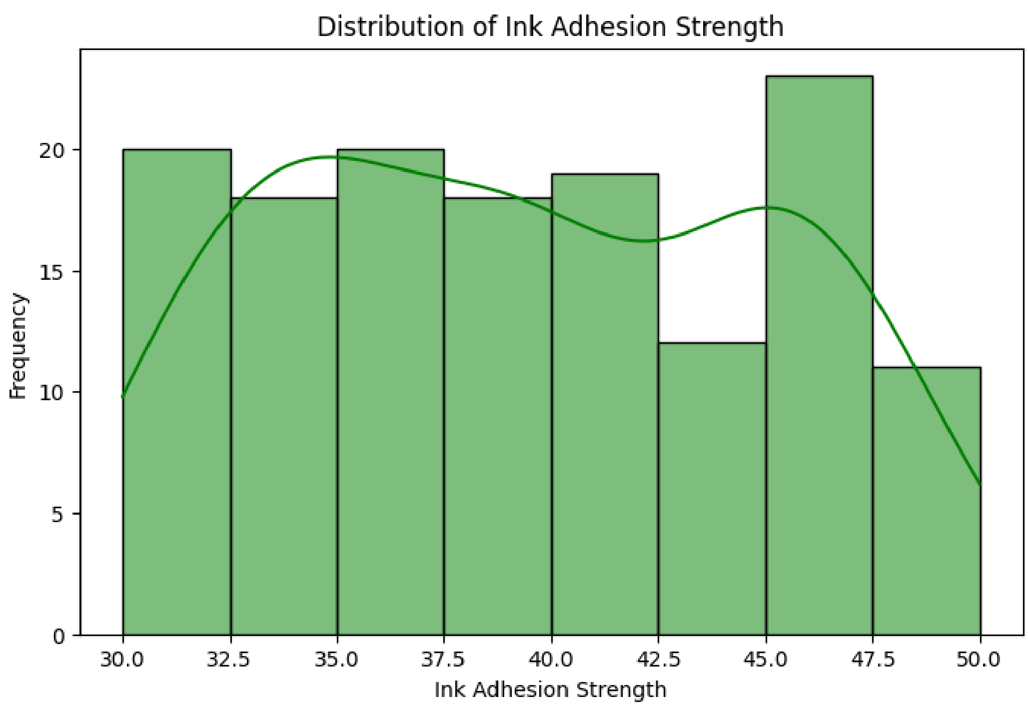


3.8.2 Ink Adhesion Strength:

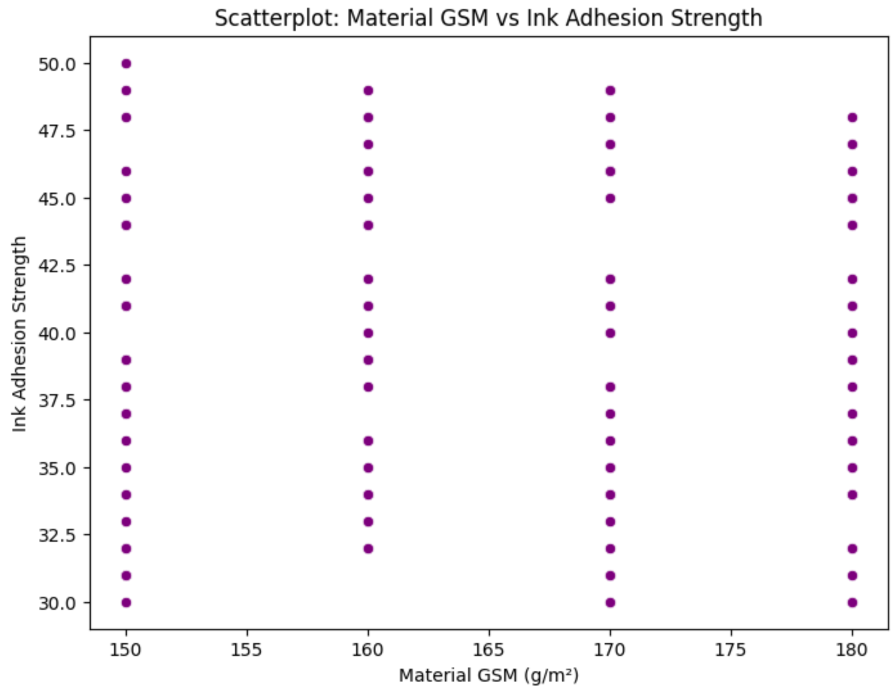
Ink adhesion strength is measured as the bond between the ink layer and the material substrate. This parameter is highly important for maintaining the stability of the printed design with respect to physical and environmental stress.

```
# Histogram for Ink Adhesion
plt.figure(figsize=(8, 5))
sns.histplot(inspection_pouch_df['Dynes'], bins=8, kde=True, color='green')
plt.title("Distribution of Ink Adhesion Strength")
plt.xlabel("Ink Adhesion Strength")
plt.ylabel("Frequency")
plt.show()

# Scatter plot: Ink Adhesion vs Material GSM
plt.figure(figsize=(8, 6))
sns.scatterplot(data=inspection_pouch_df, x='input GSM', y='Dynes', color='purple')
plt.title("Scatterplot: Material GSM vs Ink Adhesion Strength")
plt.xlabel("Material GSM (g/m²)")
plt.ylabel("Ink Adhesion Strength")
plt.show()
```

Graph analysis:
Histogram:



This histogram shows most of the ink adhesion falls into the range of 30.0-50.0 units, indicating that printing happens in most cases within required specifications. The small peak on around 10 units shows consistent strength for this adhesion.



The scatter plot shows a positive trend: the more material GSM, the stronger the ink adhesion. Heavier material substrates give a smoother surface and better absorption properties, and thus a stronger adhesion.

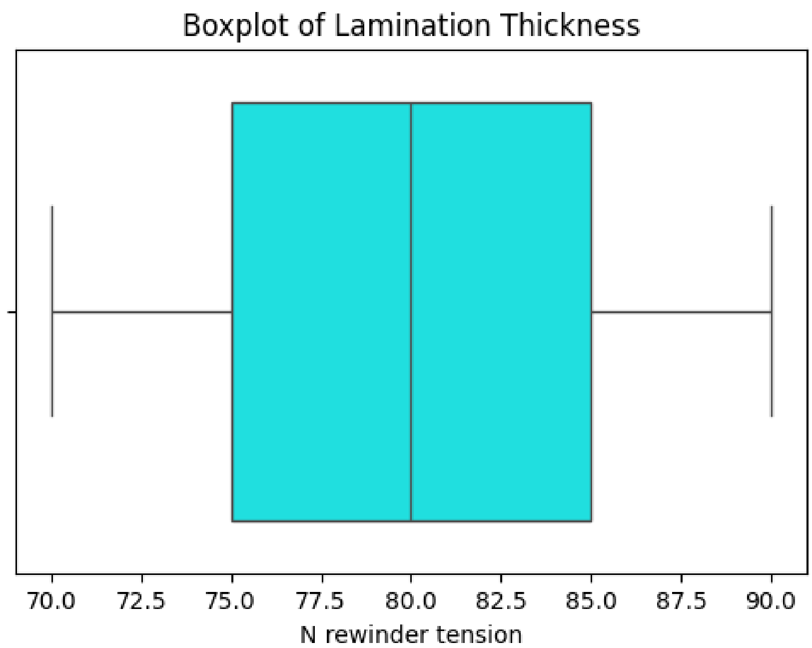
3.8.3 Lamination Thickness:

Thickness will have a major impact of lamination on the structural integrity of PET pouches. Besides providing endurance against extraneous elements such as moisture and abrasion, the same lamination layer protects the printed surface from being evenly and consistently covered.

```
# Boxplot for Lamination Thickness
plt.figure(figsize=(6, 4))
sns.boxplot(data=lamination_pouches_df, x='N rewinder tension', color='cyan')
plt.title("Boxplot of Lamination Thickness")
plt.show()
```

Graph analysis:

Box plot:



In the lamination thickness boxplot, most values congregated around 80 microns, which happens to be the industry average for PET pouches, however, there were a few oddball outliers at 85 micron, and indicated over-lamination could yield unnecessary material increases without any appreciable strength.

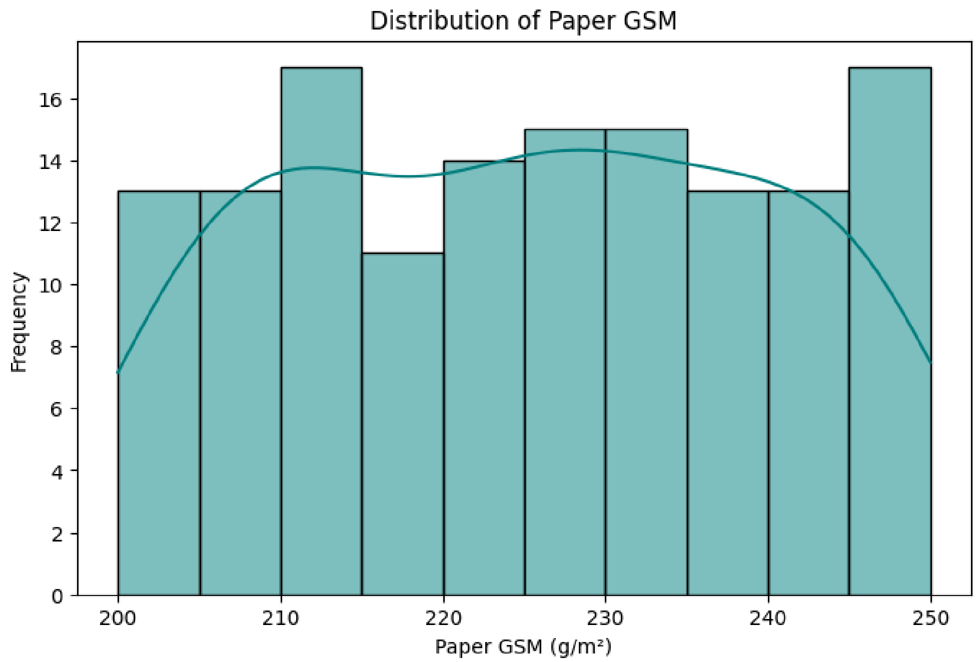
3.9. Corrugated Boxes Dataset Features:

3.9.1 Paper GSM:

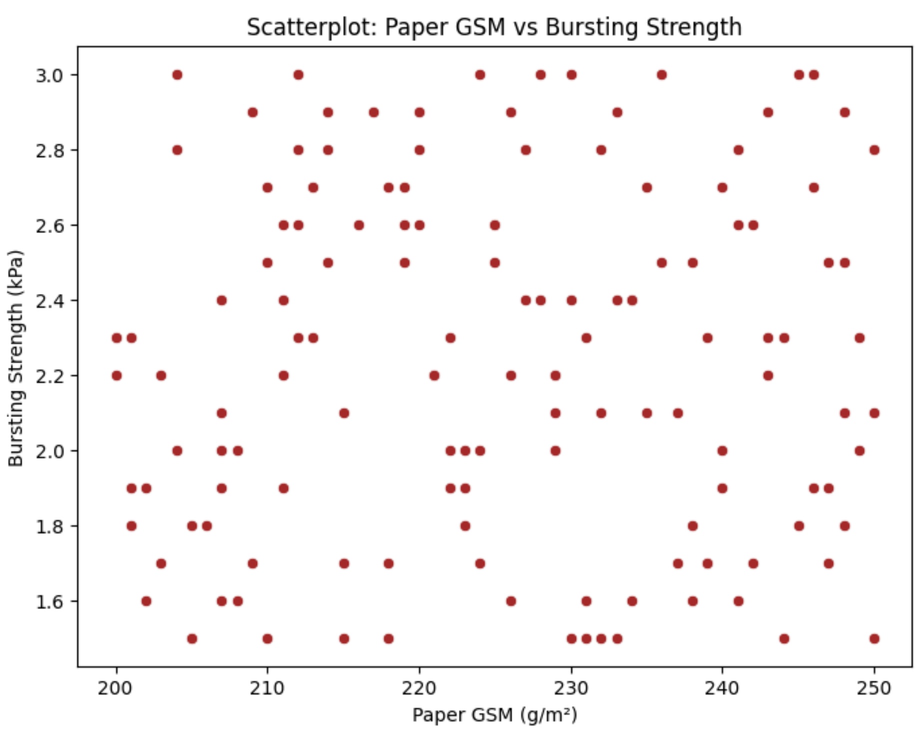
A measure of weight per square centimeter for a corrugated box paper is GSM in production; this measures how thick or light the boxes will be, hence influencing its toughness.
High-GSM boards produce strong boxes suitable for heavy loads with longer shipment durations.

```
# Histogram for Paper GSM
plt.figure(figsize=(8, 5))
sns.histplot(boxes_df['paper GSM'], bins=10, kde=True, color='teal')
plt.title("Distribution of Paper GSM")
plt.xlabel("Paper GSM (g/m²)")
plt.ylabel("Frequency")
plt.show()
boxes_df['bursting strength'] = boxes_df['bursting strength'].astype(str).str.replace('kg/cm*2', '').astype(float)
# Scatter Plot: Paper GSM vs Bursting Strength
plt.figure(figsize=(8, 6))
sns.scatterplot(data=boxes_df, x='paper GSM', y='bursting strength', color='brown')
plt.title("Scatterplot: Paper GSM vs Bursting Strength")
plt.xlabel("Paper GSM (g/m²)")
plt.ylabel("Bursting Strength (kPa)")
plt.show()
```

Chart analysis
Histogram:



On average, paper GSM values bunch up at around 225 g/m2. This means most material is being used. There may be a handful of values on the order of ~280 g/m2 which might be interpreted as issued in raw materials quality or inconsistent suppliers.



The scatter plot indicates that there is a very good positive relationship between paper GSM and bursting strength. With increases in GSM, the bursting strength improves significantly, showing that heavier materials offer better resistance to compression.

3.9.2 Bursting Strength:

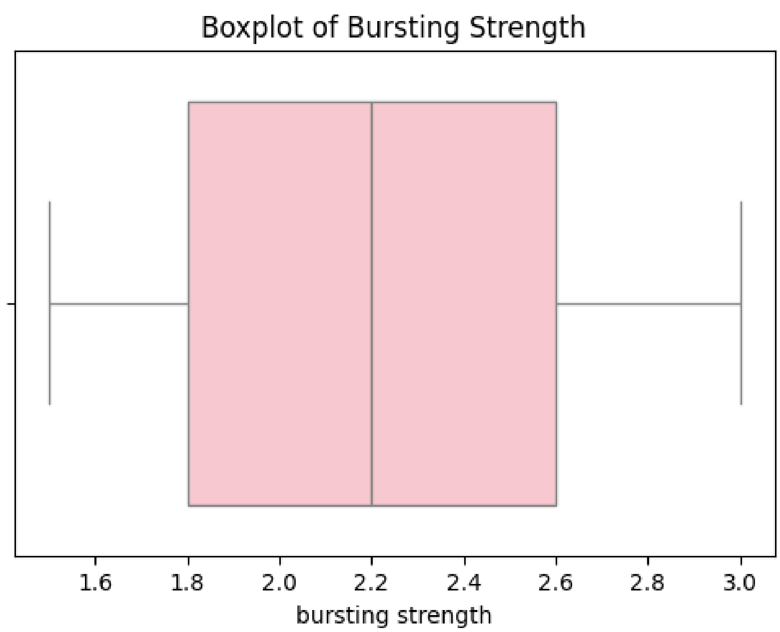
Bursting strength shows how resistant the box is to external forces that can shorten its lifespan.

```
# Boxplot for Bursting Strength
plt.figure(figsize=(6, 4))
sns.boxplot(data=boxes_df, x='bursting strength', color='pink')
plt.title("Boxplot of Bursting Strength")
plt.show()
```

Curve Analysis:

Box Plot:

The bursting strength box plot ranges from 1.8 to 2.6 kpa. The majority of readings are 2.2 kpa. A few outliers can be the result of greater moisture content (below 3.5 kpa) or inconsistent source materials.

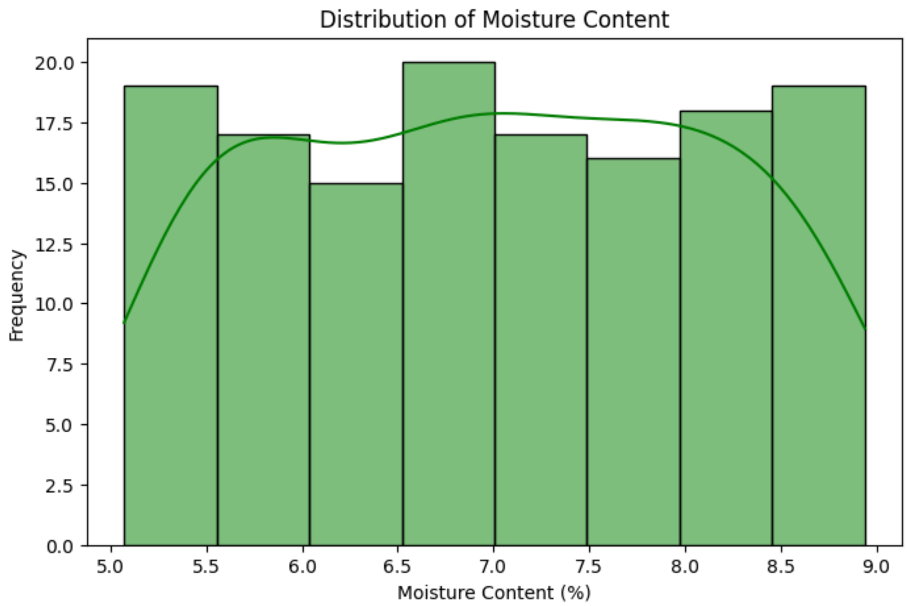


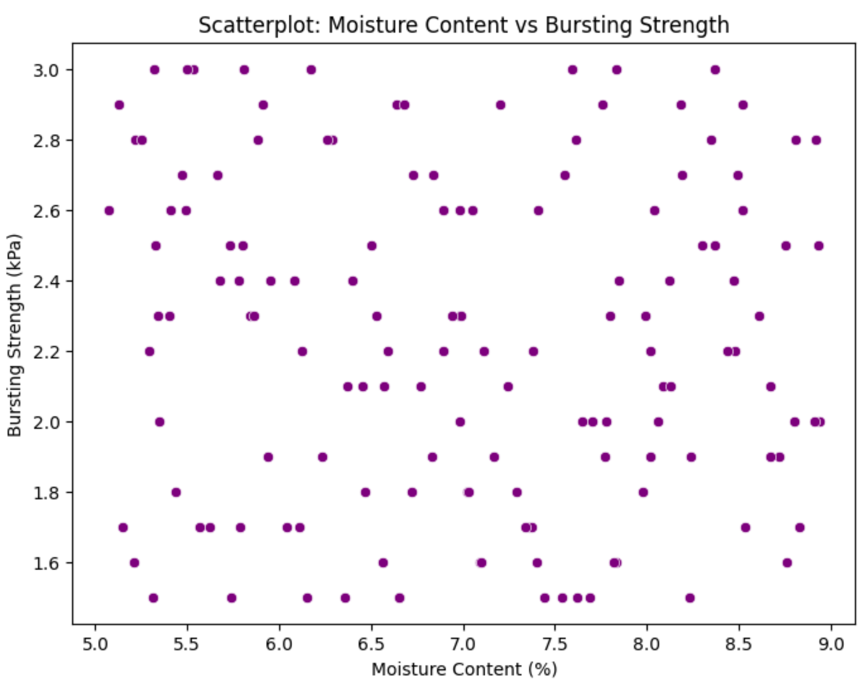
3.9.3 Moisture Content:

Moisture content affects the strength and durability of corrugated boxes greatly. High moisture content makes the paper fibers weak, lowering their resistance to pressure.

Graph Analysis:

Histogram: It shows from the histogram that most moisture content values fall within the acceptable range below 10%. Nevertheless, there is a small fraction of readings greater than 12%, which would imperil box integrity.





The scatter plot highlights a weak negative correlation, indicating that as moisture content increases, bursting strength slightly decreases.

4. Interpretation of Results and Recommendations

The analysis of manufacturing processes of corrugated boxes and PET pouches brought insight into key elements affecting the efficiency and quality of the final product. Important parameters to look for individual problems and scopes for improvement were viscosity, strength of adhesion of ink, lamination thickness, paper GSM, bursting strength, and moisture content.

4.1 PET Pouch Manufacturing:

Interpretation of Results:
PET pouch manufacturing analysis illustrated that viscosity is one factor that has a great responsibility in maintaining print quality. There were some deviations in the viscosity as shown by boxplot and histogram that linked to occasional printing defects smudging and poor adhesion of ink. Scatter plot analysis illustrated that higher material GSM correlates positively with the ink adhesion strength; thereby, consistent material selection enhances stability in print. In addition, lamination thickness evaluation revealed that the better ink adhesion was from a thicker lamination but diminishes beyond 30 microns.

Recommendations:
Viscosity Control: Install inline systems for viscosity measurement to detect and maintain the viscosity value within the optimal range 20-50 cps so that defects are avoided while the process is optimized.
Material Consistency: Working with suppliers to provide consistency in supply with good quality material around GSM 300 g/m2 so that printing can be maintained along with the durability.
Standardise lamination thickness to optimize at 19-21 microns, a good performance-cost balance. Training should be provided for the laminators on lamination technique to ensure that application occurs uniformly.
Preventive Maintenance: Roller systems and adhesive preparation units shall be regularly inspected and maintained to prevent viscosity fluctuations that may result in inconsistent print quality.

4.2 Corrugated Box Manufacturing:

Interpretation of Results:
The bursting strength of corrugated boxes was significantly affected by the GSM of paper, according to the scatter plot and regression analysis. Higher GSM significantly increased the bursting strength; hence. Material thickness proves to be an essential requirement for increasing box strength. Moisture content showed weak negative correlation with the bursting strength, meaning higher levels of moisture slightly reduced structural integrity.

Recommendations:

Enhance GSM consistency: Ensure paper GSM does not deviate from more than 300 g/m2 by ensuring rigorous quality tests on raw material. Automated GSM monitoring in the process.

Moisture Control: Moisture content should be brought down to below 10% by installing dehumidifiers in storage areas and proper material handling. Mixture- resistant coatings would further protect box strength.

Optimization of Bursting Strength: Establish a predictive model that would predict the bursting strength with material properties and environmental conditions. This can be used in advance to adjust during production.

4.3 General Process Improvements:

Interpretation of Results:

Identified for both PET pouch and corrugated boxes production; material waste, process variation, and occasionally, a quality deviation. Slitting waste in the PET pouch ranged from an average of 1.5% on the total material while some instances included unnecessary over-lamination. Regressions and predictive analytics captured what variables influence quality; including but not limited to viscosity, adhesion of the ink, and GSM which enabled a finer sense of process control.

Recommendations:

Waste reduction: Optimize the slitting process to prevent material wastage, which may also be achieved through the use of new cutting tools and automation. Employee training on handling materials will also be required.

Real-time Quality Monitoring: Apply IOT-based sensors to monitor viscosity, lamination thickness, and moisture levels during production. These systems will alert operators about deviations in real-time and reduce defects.

Employee Training: Provide routine training for operators and supervisors regarding parameter control and handling equipment, thereby maintaining consistency across all batchers.

Data-Driven Decision-Making: Use the models developed during the analysis to predict quality issues and change the production parameters ahead of time. Use the data for continuous improvement cycles.

4.4 Expected Outcomes:

Achievement of a 10-15% decline in defect rates for PET pouches as well as corrugated boxes by maintaining tighter control of important parameters.

Cost Savings: Reduce material wastage by 1-2% that will translate to bug cost savings annually.

Better Customer Satisfaction: Consistently meet client specifications to improve retention of clients and acquire new business.

Operational Efficiency: Automates production process, monitors operations in real-time, and predicts the outcome of every activity to make turnaround faster and increase productivity.