

A Study on the Relationship Between Process Parameters and Strip Hardness Based on Correlation Analysis

Yiliang Huang, Yang Liu, Wenjian Wei

School of Information Science and Engineering, Dalian Polytechnic University, Dalian 116034, China

Abstract: Optimizing process parameters to control and improve steel strip hardness has become a critical concern for ensuring product quality and process stability in modern industrial production. This study firstly confirms the absence of missing values and performs descriptive statistical analysis. It is found that the strip thickness and width fluctuate between 8020 to 9570 and 180 to 234, respectively, while carbon and silicon contents show greater variability, ranging from 42 to 615 and 0 to 22. Among process parameters, leveler tension shows relatively minor fluctuations, while hardness ranges from 490 to 600, concentrated above 595. Through Pearson correlation analysis, carbon content, quench furnace temperature, strip speed, and thickness exhibit a strong positive correlation with hardness. In contrast, block cooler temperature, homogenizing furnace temperature, and heating furnace temperature show a significant negative correlation. Based on the results, this study suggests further process optimization to enhance the mechanical properties of the strip.

Keywords: Strip hardness, Process parameters, Correlation analysis, Pearson coefficient, Carbon content.

1. Introduction

In modern industrial production, the mechanical properties of steel strips, particularly hardness, are critical factors influencing product quality and process stability[1]. The hardness of the steel strip not only determines its application and workability but also affects the durability and reliability of the final product[2]. Thus, optimizing process parameters to control and improve strip hardness has become a key concern in manufacturing processes[3].

The challenge in optimizing steel strip hardness lies in the complex interaction of numerous process parameters, such as carbon content, quench furnace temperature, cooling rate, and strip speed. These parameters not only affect hardness individually but also interact in intricate ways, often leading to unpredictable results if not carefully controlled. Traditional methods of process control, while effective to some extent, often fail to capture the subtle interdependencies among variables, especially when the number of influencing factors grows. Moreover, manual adjustments and experience-based decision-making are prone to errors and inefficiencies, which may result in suboptimal product quality and increased production costs.

In recent years, with the rapid development of automation and data-driven technologies, leveraging big data and statistical analysis to explore the relationship between process parameters and strip performance has become an essential approach to enhancing product quality[4]. Correlation analysis, in particular, as a commonly used statistical method, can effectively evaluate the impact of various process parameters on strip hardness, providing valuable data support for process optimization[5].

This study addresses the influence of different process parameters on steel strip hardness through data preprocessing, statistical descriptions, and correlation analysis. It examines the positive and negative correlations of key factors such as carbon content, quench furnace temperature, and strip speed, to offer theoretical insights and practical recommendations

for further process optimization and product quality control.

2. Data Sources and Preliminary Analysis

The data in this paper originates from <https://cxcy.upln.cn/>. Firstly, it is confirmed that there are no missing values in the data, which is handled here using Python.

Table 1: Missing value finding results

Column	NaN Count	Inf Count
Strip		
Thickness	0	0
Strip		
Width	0	0
Carbon		
Content	0	0
Silicon		
Content	0	0
Strip Speed	0	0
Heating		
Furnace Temperature	0	0
Homogenization		
Furnace Temperature	0	0
Slow Cooling		
Furnace Temperature	0	0
Over-aging		
Furnace Temperature	0	0
Quick Cooling		
Furnace Temperature	0	0
Quenching		
Furnace Temperature	0	0
Leveling		
Machine Tension	0	0
Hardness	0	0

As shown in Table 1, it can be seen that the number of

missing values in this dataset is 0, i.e., there are no missing values. Meanwhile, descriptive statistical treatment as shown

in Table 2 was carried out to describe the data better:

Table 2: Statistical metrics

	mean	std	min	25%	50%	75%	max
Strip Thickness	8600.59	341.4383	8020	8360	8470	8720	9570
Strip Width	204.039	12.84245	180	201	202	203	234
Carbon Content	382.058	55.86137	42	355	387	418	615
Silicon Content	9.057	2.672994	0	7	9	10	22
Strip Speed	613.29	44.57401	451	586.75	629	649	679
Heating Furnace Temperature	717.176	48.99581	81.2	708.35	718.7	730	812.6
Homogenization Furnace Temperature	647.552	30.57564	319.5	636.5	643.5	652	725
Slow Cooling Furnace Temperature	621.885	40.07173	232	602.375	618.5	638	720.5
Over-aging Furnace Temperature	353.212	24.18906	99.5	344.5	352	359.5	416.5
Quick Cooling Furnace Temperature	59.783	9.603652	28	51	57	70	72
Quenching Furnace Temperature	41.659	5.16521	7	38	42	45	60
Leveling Machine Tension	2365.42	170.6408	1962.36	2255.880863	2339.957164	2438.663827	3064.760135
Hardness	595.35	23.72848	490	580	600	610	660

Based on the above, we can derive several insights from various aspects of the data.

The strip thickness ranges from 8020 to 9570, with a standard deviation of 314.44, indicating that while the thickness is relatively centralized, it still exhibits some fluctuation. The strip width varies between 180 and 234, with a standard deviation of 12.84, suggesting it is more concentrated than the strip thickness, fluctuating around the 200 mark.

The carbon content spans from 42 to 615, with a higher standard deviation of 55.86, reflecting greater variability. In contrast, the silicon content ranges from 0 to 22, with a standard deviation of 2.67, showing less fluctuation. The silicon content is generally centered around 10.

The process parameters (strip speed, heating furnace speed, equalizing furnace speed, slow cooling furnace speed, over-aging furnace speed, fast cooling furnace speed, quenching furnace speed, and leveler tension) exhibit more variation overall. However, leveler tension specifically ranges from 1962.36 to 3064.76, with a standard deviation of 170.64, indicating less fluctuation compared to other factors.

The hardness values range from 490 to 600, with a standard deviation of 23.73. While fluctuations are present, they remain relatively concentrated, particularly around values

above 595.

In conclusion, this analysis identifies which parameters display significant variability. Moreover, a preliminary assessment suggests that these parameters may influence the mechanical properties of the strip. Further analysis will focus on identifying which factors have a significant impact on strip hardness.

3. Correlation Analysis of Process Parameters and Strip Hardness

To solve the correlation coefficients of all process parameters related to hardness only, we first carried out the correlation coefficients between all process parameters, the process and results are as follows:

$$r = \frac{m(\sum ab) - (\sum a) \times (\sum b)}{\sqrt{[m\sum a^2 - (\sum a)^2][m\sum b^2 - (\sum b)^2]}} \quad (1)$$

Where a, and b are the values of the variables in the current data

Obtain correlation between all process parameters plus hardness and plot heat map

After calculation and plotting, the following results were obtained as shown in and Figure 1:

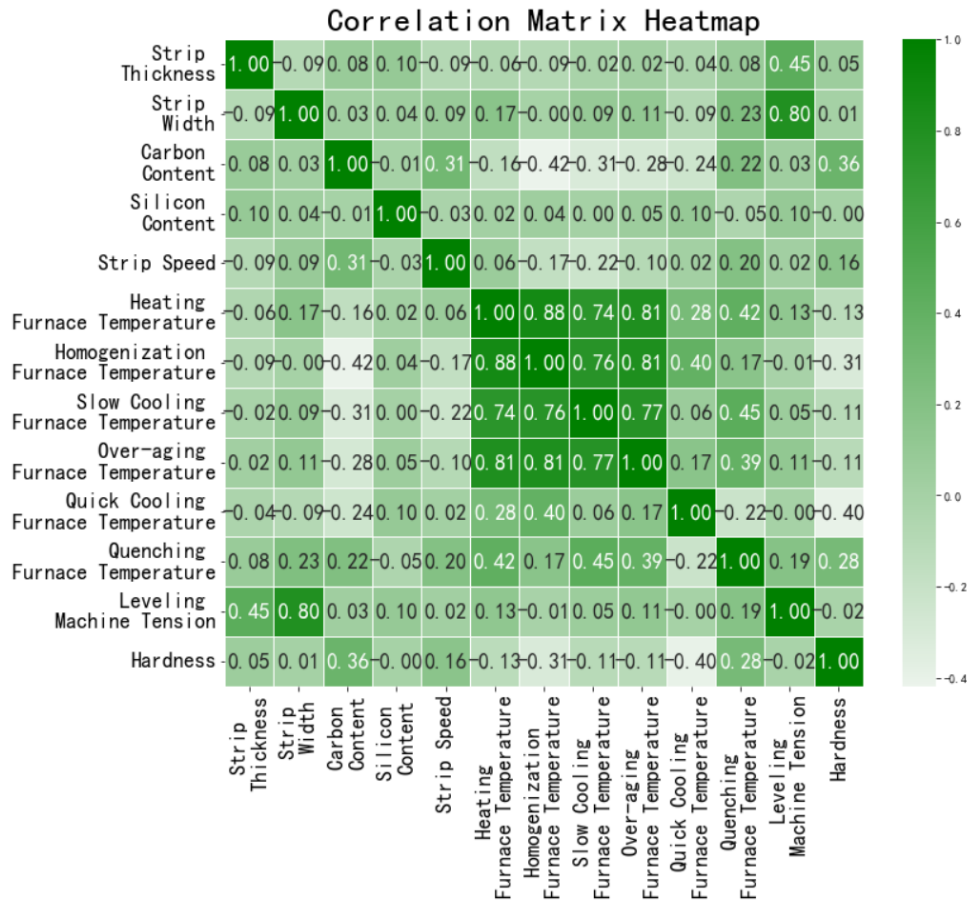


Figure 1: Pearson correlation coefficient heat map mapping

From the results of Figure 1, the Pearson's correlation coefficient between only and hardness will be solved for all the process parameters, the procedure and results are as follows:

According to equation (2), this study get

$$r_y = \frac{m(\sum x_t y) - (\sum x_t) \times (\sum y)}{\sqrt{[m\sum x_t^2 - (\sum x_t)^2][m\sum y^2 - (\sum y)^2]}} \quad (2)$$

where x_t is the set of 1 of the 12 eigenvalues. y for the hardness (this formula is rounded later)

After calculation, the coefficients were obtained and plotted on a histogram, with negative numbers being negative correlations and positive numbers being positive correlations, with r -values between -1 and 1.

Finally, the correlation is known based on the order in which the histograms are arranged.

Table 3 Pearson's coefficients of parameters concerning hardness

Influencing Factors	Correlation Coefficient (Hardness)
Strip Thickness	0.049760066
Strip Width	0.005457303
Carbon Content	0.355306525
Silicon Content	-0.003550199
Strip Speed	0.160936939
Heating Furnace Temperature	-0.127604851
Homogenization Furnace Temperature	-0.312226847
Slow Cooling Furnace Temperature	-0.111541404
Over-aging Furnace Temperature	-0.112442795
Quick Cooling Furnace Temperature	-0.398454614
Quenching Furnace Temperature	0.281479489
Leveling Machine Tension	-0.020577007

In summary, based on the results presented in Table 3 and Figure 2, this study can draw the following conclusions: the carbon content, quench furnace temperature, strip speed, and

and heating furnace temperature show a significant negative correlation with hardness, suggesting the need for careful control of these parameters. All other factors appear to have a relatively minor impact on hardness.

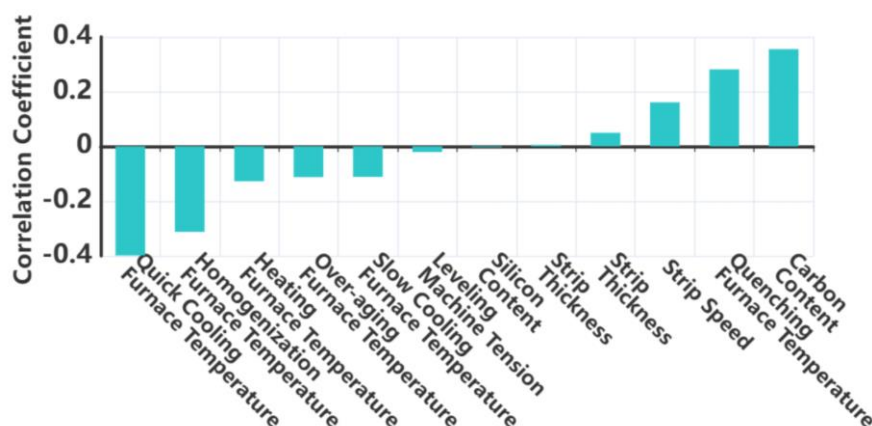


Figure. 2 Comparison of strip hardness correlation coefficients

4. Conclusion

This study confirms data integrity and performs descriptive statistical analysis to reveal the relationship between process parameters and the mechanical properties of the strip. The analysis shows that while strip thickness and width exhibit limited fluctuation, process parameters such as strip speed and furnace temperature settings display significant variability, with carbon content showing particularly notable changes, suggesting its important influence on mechanical properties like hardness. Through Pearson correlation analysis, it was found that carbon content, strip speed, quenching furnace temperature, and strip thickness have a significant positive correlation with hardness, while block cooler temperature, homogenizing furnace temperature, and heating furnace temperature are negatively correlated with hardness. These findings provide a strong basis for process optimization, recommending a focus on factors such as carbon content and strip speed to enhance hardness, and careful control of furnace temperatures to achieve product quality improvement and optimization.

References

- [1] RALLS A M, KASAR A K, MENEZES P L. Friction strip processing on the tribological, corrosion, and erosion properties of steel: a review[J]. Journal of Manufacturing and Materials Processing, 2021,5(3): 97.
- [2] RAO V D. Metallurgical integrity for economic production of quality steel forgings for advanced applications[J]. Materials Today: Proceedings, 2021,39: 1434-1439.
- [3] WANG X, WANG Y, TANG L. Strip hardness prediction in continuous annealing using multiobjective sparse nonlinear ensemble learning with evolutionary feature selection[J]. IEEE Transactions on Automation Science and Engineering, 2021,19(3): 2397-2411.
- [4] VERMA P, KUMAR V, MITTAL A, et al. The role of 3S in big data quality: a perspective on operational performance indicators using an integrated approach[J]. The TQM Journal, 2023,35(1): 153-182.
- [5] XIANG M, LI Y, YANG J, et al. Heavy metal contamination risk assessment and correlation analysis of heavy metal contents in soil and crops[J]. Environmental Pollution, 2021,278: 116911.