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Optimization of Double Pan Design for Household Use Based on Weight Reduction Using Taguchi Method

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Abstract

Double pans are widely used in household kitchens due to their convenience and cooking efficiency. However, many users report discomfort caused by the excessive weight, particularly when flipping the pan during cooking. This study aimed to optimize the double pan design by focusing on reducing its weight using the Taguchi method. Three controllable factors were selected: pan material, handle material, and shaft material. An L9 orthogonal array was employed to efficiently design the experiments. The measured responses included total pan weight score assessed through the CAD simulation. Signal-to-noise ratio analysis was also conducted to identify the most influential factors and determine the optimal design combination. The findings indicate that material significantly affect user comfort, while pan weight is primarily influenced by material choice. This study demonstrates the applicability of the Taguchi method in consumer product design and provides a reference for developing lightweight and user-friendly kitchenware.

Keywords: double pan; weight reduction; Taguchi method; optimization; household kitchenware

INTRODUCTION

The double pan, a common household cooking utensil, is widely used due to its convenience and cooking efficiency. At least 3,5 million people in Indonesia have already used the double pan since 2008 – 2022 (Cahyadi, 2022). Unlike single pans or other conventional cookware, a double pan incorporates two hinged compartments that allow users to flip food without the risk of spillage, enhancing cooking efficiency and versatility. However, this dual-structure design also results in a significantly heavier product compared to standard pans, creating usability concerns, particularly for individuals with limited upper body strength, such as elderly users or those with reduced hand grip capability. The average weight of the double pan can reach 5 kg, with the main material of stainless steel coated with Titanium material and ABS Plastic for the handle (Yusnita, 2019). Furthermore, many users report discomfort caused by the excessive weight of the pan, especially when flipping it during cooking—a task that can be particularly challenging for elderly individuals or those with limited upper body strength. While heavier pans typically offer better heat distribution and retention, lighter pans improve maneuverability, which directly impacts user comfort during dynamic cooking activities like flipping food (Blacksmith Skillet, 2020). Carter (2025) Explain that the recommendation for the pan ranges from 1 to 4 pounds (0.45–1.8 kg), where these weights are ideal because they balance heat retention and ease of use handling. This trade-off highlights the importance of carefully selecting materials, as the choice of construction material strongly influences pan weight. Accordingly, the current study aims to optimize the double pan design by striking a balance between structural integrity and user-friendly handling. By applying the Taguchi method, which enables efficient experimentation with multiple design variables, the study seeks to identify the most suitable combination of pan material, handle material, and shaft material to reduce pan weight.

The Taguchi method is a robust design approach that offers a systematic way to optimize product parameters by minimizing the impact of uncontrollable factors, leading to enhanced quality and performance (Nur Permadi & Basiratun Nisa, 2023). This methodology emphasizes designing products and processes that are insensitive to variations in manufacturing and usage conditions(Kaziz et al., 2023). The Taguchi method utilizes orthogonal arrays to efficiently explore the design space, reducing the number of experiments required to identify the optimal combination of design parameters and material choices(Logothetis & Haigh, 1988a). The application of the Taguchi method proves particularly advantageous in scenarios where multiple design parameters interact in complex ways, making it challenging to determine the optimal settings through traditional trial-and-error approaches. Optimizing kitchen tools, such as double pans, involves addressing various ergonomic considerations to ensure they are user-friendly and efficient. Ergonomics focuses on designing products that accommodate the physical capabilities and limitations of users, thereby preventing strain and discomfort (Gu & Gu, 2013; Ritzel & Donelson, 2001).

This study proposes an optimization of double pan design, focusing on one key performance indicators: weight reduction. Leveraging the Taguchi method, a robust design of experiments approach, the research systematically evaluates the influence of design factors such as pan material, handle material, and shaft material on the product's usability. Through controlled experiments based on orthogonal arrays and signal-to-noise ratio analysis, the study aims to determine the optimal combination of design parameters that enhances comfort without compromising essential cooking functionality.

RESEARCH METHOD

This study focuses on optimizing the total weight of a household double pan by evaluating three key design parameters: pan material, handle material, and shaft material. These components were selected as controllable factors due to their direct impact on the product’s mass. The aim is to identify a configuration that minimizes weight without compromising durability or usability. Although handle shape is a critical factor for user comfort, it is not treated as a variable in the optimization process. Instead, the handle shape was pre-designed using ergonomic principles derived from existing human factors studies, ensuring that the final product maintains comfort during repetitive tasks such as flipping. The optimization process prioritizes weight reduction, particularly to benefit users such as the elderly or individuals with limited upper body strength, while maintaining essential product functionality.

Taguchi Method. The experimental design leveraged the Taguchi method for efficient exploration of the design space. This methodology employs orthogonal arrays to reduce the number of experiments needed to determine the optimal combination of parameters (Agarwal & Mthembu, 2022). By strategically selecting a subset of all possible combinations, the Taguchi method facilitates a comprehensive understanding of each factor's influence on the overall response. The Taguchi method was selected due to its demonstrated capability in optimizing processes with multiple variables, ensuring dependable and conclusive results with minimal experimentation. The typical procedure involves identifying control factors and their respective levels; choosing an appropriate orthogonal array based on the number of factors and levels; executing experiments based on the array; analyzing the results using the Signal-to-Noise ratio to evaluate performance consistency; and performing an Analysis of Variance to ascertain the relative contribution of each factor to the variability in the response.

Analysis of Variance (ANOVA). The percentage contribution of each parameter on the desired outputs is investigated through analysis of variance(Logothetis & Haigh, 1988b). ANOVA is essential for determining the statistical significance of individual factors and their interactions. The statistical significance of each factor is rigorously evaluated through the computation of p-values, derived from the F-statistic in the ANOVA table, and these p-values are meticulously compared against a pre-defined significance level, typically set at 0.05, to ascertain whether the observed effects are statistically meaningful or merely due to random variation. The primary goal of employing ANOVA in this study is to decompose the total variation in the measured responses into components attributable to each control factor, thereby facilitating a comprehensive understanding of their relative importance.

RESULT AND DISCUSSION

The study employed the five-stage Taguchi methodology, which involved defining control factors (pan material, handle material, and shaft material), selecting an appropriate orthogonal array (L9), performing experiments based on the array, calculating the Signal-to-Noise ratio to evaluate performance consistency, and subsequently, conducting an Analysis of Variance to determine the statistical significance of each factor. The Taguchi method was chosen due to its efficiency in optimizing processes with multiple variables, ensuring dependable and conclusive results with minimal experimentation. This approach allowed for a systematic investigation of how different material combinations and design parameters impacted the pan's weight and overall usability.

The Control Factor. To systematically evaluate the impact on the weight of the double pan, the study identified and defined three primary control factors: the material composition of the pan body, the handle material, and the shaft material. These factors were selected because they directly influence the product's mass. The optimization process focused on minimizing weight while maintaining durability and usability. Based on a comprehensive review of materials commonly used in kitchenware manufacturing, several candidate materials were selected for each control factor.

For the pan body, the options were aluminium 6061, stainless steel, and a mixed steel alloy. For the pan body, materials were selected based on their varying densities, with an emphasis on those commonly used by pan manufacturers. For the pan body, the materials selected were aluminum 6061, stainless steel, and a mixed steel alloy, each chosen for their distinct properties and suitability in cookware. These materials were selected based on their varying densities, which directly impact the overall weight of the pan. Aluminum 6061 is widely used in cookware due to its lightweight nature and excellent thermal properties, making it a great choice for those seeking efficient heat conduction and easy handling (Guma & Sukuntuni, 2019). Stainless steel, known for its durability and resistance to corrosion, offers a sturdier option but at a heavier weight compared to aluminum. The selection of Aluminum 6061 aligns with broader engineering practices where lightweight materials are crucial, with aluminum alloys like AA2024, AA6061, and AA7075 frequently utilized in industries such as aerospace to reduce weight without compromising structural integrity (Bosneag et al., 2018). The mixed steel alloy, offering a balance of strength and weight, was selected to explore how different alloy compositions affect the performance and feel of the pan.

For the handle material options, ABS plastic, wood, and PET plastic were selected, each chosen for their unique properties and relevance in cookware design. These materials were carefully considered based on their durability, weight, and the comfort they provide during use. ABS plastic is a commonly used material for handles due to its strength, impact resistance, and ability to withstand high temperatures, making it a practical choice for cookware. Wood, on the other hand, is often selected for its aesthetic appeal and its natural heat insulation properties, which prevent the handle from becoming too hot to touch. PET plastic, known for its strength and lightweight nature, was also considered as a handle material due to its ability to resist wear and tear while offering a lighter alternative to both ABS plastic and wood.

The same materials used for the pan body were also considered for the shaft, ensuring consistency in weight, strength, and overall performance across all components. By selecting these materials, the aim was to provide a well-rounded set of handle options that cater to different preferences in terms of comfort, durability, and aesthetics.

Selecting an appropriate orthogonal array. This study utilized an L9 orthogonal array, which is particularly effective for analyzing three control factors, each at three levels. An L9 orthogonal array is a specific experimental design that enables the efficient evaluation of multiple factors and their effects on a given process or outcome. The primary advantage of using an L9 array lies in its ability to reduce the number of experimental trials required to gather meaningful data.

The L9 orthogonal array, critical to this study, systematically examined the impact of three key factors—Pan, Handle, and Shaft—each evaluated at three distinct material levels as shown in Table 1 L9 orthogonal array of double pan factors and levels. This design allowed for an efficient and comprehensive assessment. At Level 1, the Pan utilized Mixed Steel Alloy, the Handle employed ABS Plastic, and the Shaft was constructed from Stainless Steel. Level 2 featured Aluminum 6061 for the Pan, Wood for the Handle, and Mixed Steel Alloy for the Shaft. Finally, Level 3 incorporated Stainless Steel for the Pan, PET Plastic for the Handle, and Aluminum 6061 for the Shaft, completing the material combinations evaluated.

Conducting the experiments. The model design of the double pan, as simulated in CAD software, features a rectangular body measuring 320 mm in width, 260 mm in height, and 40 mm in thickness, as shown in Figure 1. It includes two side-mounted handles, each projecting 45 mm and spaced 186 mm apart, and rounded corners with a radius of R11.67 for enhanced safety and grip. The design also specifies a 17 mm spacing between component edges, ensuring overall accuracy and stability. Based on the L9 orthogonal array, nine experiments were conducted, each using a unique combination of materials for the pan body, handle, and shaft, as detailed in the table. The weight of each pan was measured using the CAD simulation based on the double pan model.

Based on the L9 orthogonal array design, experiments were performed to assess the weight of the double pan across various material configurations. Nine distinct double pans were manufactured, each reflecting a unique combination of pan body, handle, and shaft materials, along with the corresponding weight measurements, as shown in Table 2. Weight measurements were obtained through CAD software simulations, ensuring data accuracy and consistency. The results revealed that material combinations incorporating Aluminum 6061 generally exhibited significantly reduced weights, reflecting the inherent lightweight properties of aluminum. Conversely, configurations utilizing Stainless Steel or Mixed Steel Alloy, particularly in multiple components, yielded elevated weight measurements, as seen in experiments 1, 2, 7, 8, and 9. For instance, experiment 9, which employed Stainless Steel for both the pan and shaft, recorded the highest weight at 4.096352 kg, while experiment 5, using Aluminum 6061 for both components, registered the lowest weight at 1.403352 kg. This data-driven methodology facilitated the identification of optimal material combinations aimed at minimizing product weight while adhering to performance standards. The application of the L9 orthogonal array effectively reduced the number of required experiments from 27 to 9, maintaining the comprehensive nature of the analysis.

Table 1 L9 orthogonal array of double pan factors and levels

Factors	Level 1	Level 2	Level 3
Pan	Mixed Steel Alloy	Aluminum 6061	Stainless Steel
Handle	ABS Plastic	Wood (Maple)	PET Plastic
Shaft	Stainless Steel	Mixed Steel, Alloy	Aluminum 6061

Table 2 Taguchi experimental design of double pan optimization.

Experimental Run	Pan	Handle	Shaft	Measured Weight [kg]
	(A)	(B)	(C)	
1	Steel, Alloy	ABS Plastic	Stainless Steel	3,921
2	Steel, Alloy	Wood (Maple)	Steel, Alloy	3,880
3	Steel, Alloy	PET Plastic	Aluminum 6061	3,915
4	Aluminum 6061	ABS Plastic	Steel, Alloy	1,492
5	Aluminum 6061	Wood (Maple)	Aluminum 6061	1,403
6	Aluminum 6061	PET Plastic	Stainless Steel	1,543
7	Stainless Steel	ABS Plastic	Aluminum 6061	3,997
8	Stainless Steel	Wood (Maple)	Stainless Steel	4,013
9	Stainless Steel	PET Plastic	Steel, Alloy	4,096

Signal-to-noise ratio calculation. The signal-to-noise ratio (S/N), a cornerstone of the Taguchi method, is essential for process optimization, enabling the reduction of variability around a target value(Nweze Stephanie & Achebo J, 2021). By aggregating data from multiple experimental runs into a single metric, the S/N ratio facilitates a streamlined identification of the most effective parameter settings. This is crucial for achieving the project goals of reducing weight. The application of the S/N ratio is adapted based on the experimental objective, categorized into three types: Smaller the Better is applied when aiming to minimize a specific characteristic; Larger the Better is used when aiming to maximize a characteristic, and Nominal the Better is for optimizing performance around a specific target value (Nweze Stephanie & Achebo J, 2021). In this research, the Smaller the Better S/N ratio was chosen due to the objective of minimizing the weight of the double pan. The formula for calculating the Smaller the Better S/N ratio is

$$S/N = -10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right), \tag{1}$$

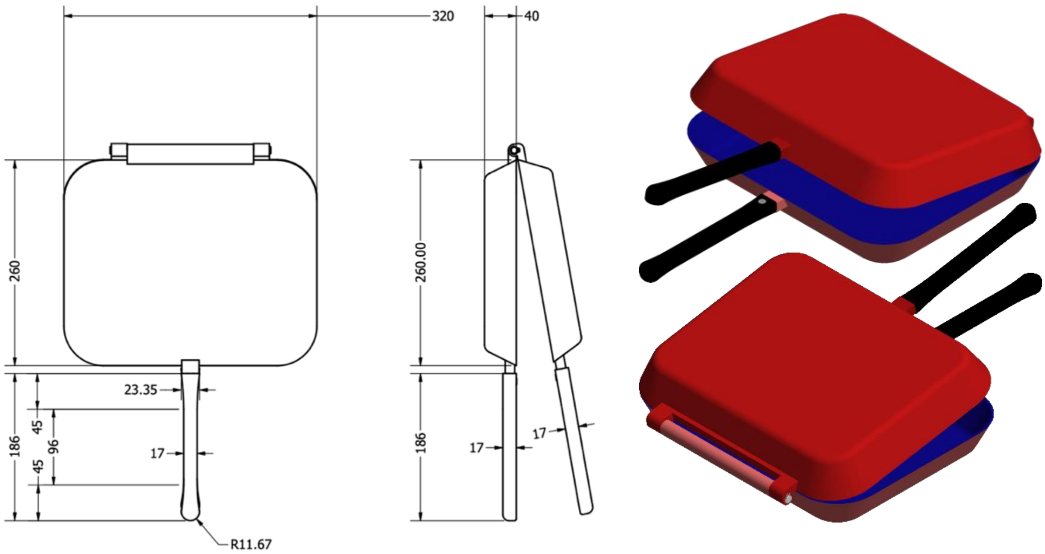

Figure 1 Proposed design of double-pan CAD model.

where *n* represents the number of repetitions in each experimental run, y_i denotes the measured value of the response variable for the repetition. Table 3shows the calculated signal-to-noise (S/N) ratios for each experimental run, providing crucial information regarding how different material configurations influence the double pan's weight. A lower S/N ratio signifies a more favorable result, indicating a reduction in weight.

Figure 2 shows the influence of each control factor—Pan, Handle, and Shaft—on the double pan's weight, as assessed through signal-to-noise ratio analysis, utilizing the Taguchi method. The SNR, calculated using the "smaller-is-better" criterion, aligns with the study's objective of minimizing product weight. Pan material exhibits the most substantial impact, with Aluminum 6061 producing the highest SNR, thereby indicating lower variability

Table 3 Calculated S/N ratio of double pan optimization experimental run.

Experimental Run	Weight (Kg)	SNR
1	3,921	-11,869
2	3,880	-11,777
3	3,915	-11,855
4	1,492	-3,477
5	1,403	-2,943
6	1,543	-3,769
7	3,997	-12,035
8	4,013	-12,070
9	4,096	-12,248

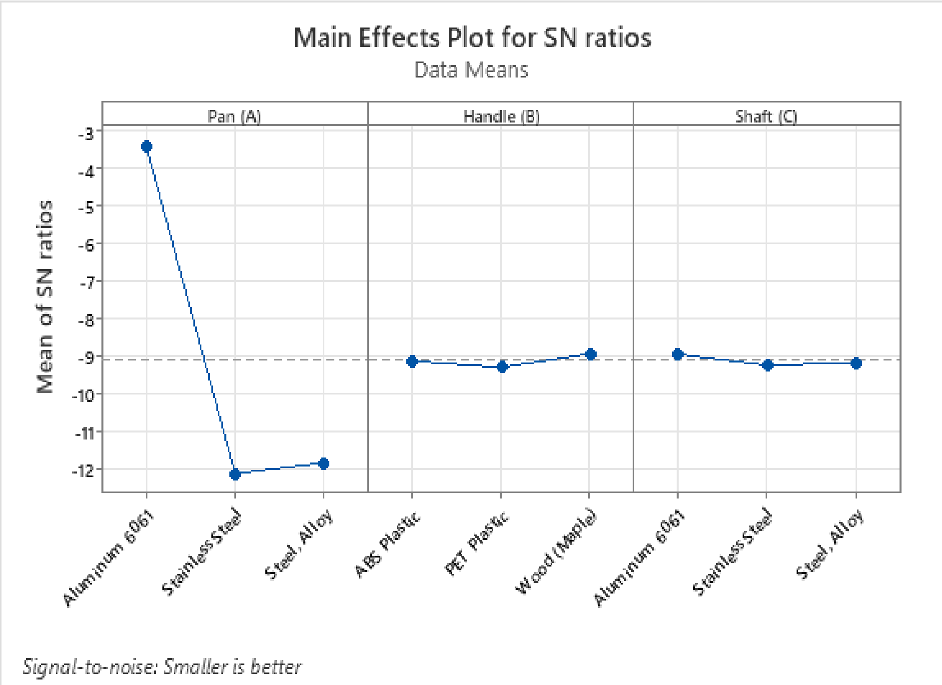

Figure 2 Main effects plot for S/N ratios.

and a significant weight reduction compared to Stainless Steel and Mixed Steel Alloy, which demonstrate considerably lower SNRs. This dramatic difference strongly suggests that the selection of the pan material is the primary determinant of the product's overall weight. Conversely, the effects of Handle and Shaft materials on the SNR are considerably less significant. SNRs for handle materials—ABS Plastic, PET Plastic, and Wood—are relatively consistent, with Wood showing a slight advantage in weight reduction. Similarly, while Aluminum 6061 shows a marginal improvement as a shaft material compared to Stainless Steel and Steel Alloy, the differences are minimal. These findings suggest that although the handle and shaft materials contribute to the total weight, their influence is secondary to that of the pan material. Consequently, optimizing the pan component—specifically through the choice of Aluminum 6061—represents the most effective strategy for achieving substantial weight reduction in the double pan design

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Pan (A)	2	12,4355	99,87%	12,4355	6,21776	*	*
Handle (B)	2	0,0111	0,09%	0,0111	0,00557	*	*
Shaft (C)	2	0,0055	0,04%	0,0055	0,00276	*	*
Error	2	0,0000	0,00%	0,0000	0,00000		
Total	8	12,4522	100,00%				

Figure 4 Analysis of variance (ANOVA) of the double pan optimization.

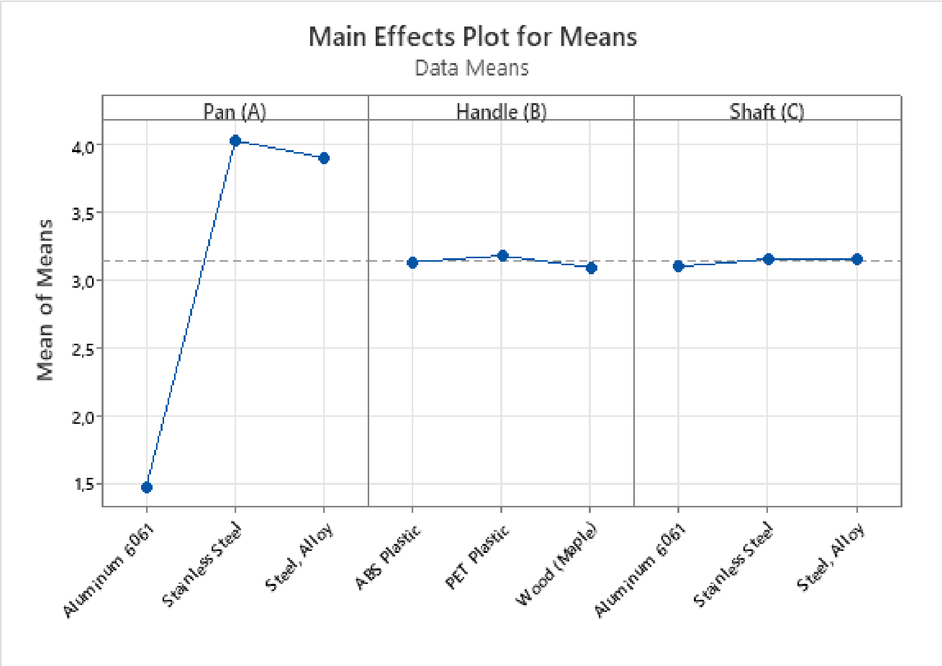

Figure 3 Main effects plot for means.

Analyze of Variance (ANOVA). ANOVA was employed to quantitatively assess the impact of each control factor on the double pan's weight. Prior to conducting the ANOVA, a thorough examination was performed to validate the assumptions underlying the analysis, with particular attention to the normality and independence of residuals; graphical methods, including normal probability plots and residual plots, were employed to assess these assumptions, ensuring the reliability of the ANOVA results.

The analysis of variance results is shown in Figure 4, provide additional statistical evidence of the influence of each factor on the double pan's weight. The ANOVA results provide a detailed assessment of the impact of various design parameters on the weight of the double pan. The analysis reveals that the pan material is the most significant factor, contributing 99.87% to the total variance in weight, with an extremely low P-value of 0.000, thus underscoring its statistical significance. This highlights that the choice of material for the pan is critical in determining the overall weight of the product. The handle material accounts for approximately 0,09% of the variance, and the shaft material accounts for about 0,04%. Figure 4 shows that the pan material is the most influential factor in the variation of the measured weight, with an adjusted sum of squares of 12,4355, representing nearly the entire total variation. In comparison, the contributions of the handle and shaft materials are minor, with adjusted sum of squares values of 0,0111 and 0,0055, respectively. The F-values and P-values for all three factors indicate statistical significance, confirming that alterations in these factors significantly affect the response variable. However, the substantial difference in adjusted sum of squares confirms that the pan material is the primary determinant of the product's weight.

Figure 3 shows the main effects plot for means that influence of three different factors, which are Pan (A), Handle (B), and Shaft (C), based on a Taguchi method experimental design. Each point on the graph represents the average performance result for each material used in the respective component. The y-axis shows the Mean of Means, which indicates the average output performance value, allowing us to compare the effectiveness of different materials. Based on those three factors, the Pan (A) shows the most significant impact on performance. The mean value for Aluminum 6061 is notably low, around 1,5, while Stainless Steel yields the highest mean (over 4,0), and Steel Alloy follows closely behind. This indicates that the choice of pan material greatly influences the final outcome, and using stainless steel significantly enhances performance. In contrast, the Handle (B) and Shaft (C) factors exhibit relatively flat lines in the plots. This means that changing the handle material (ABS Plastic, PET Plastic, or Maple Wood) or shaft material (Aluminum 6061, Stainless Steel, or Steel Alloy) has little effect on the overall performance. All these combinations produce nearly the same average results, hovering around 3,1.

Conclusion

The study successfully employed the Taguchi method to optimize the design and material selection for a double pan, aiming to reduce its weight while maintaining functionality, particularly for ease of use by female or elderly users. The findings indicate that the pan material is the most critical factor influencing the overall weight of the double pan. Specifically, using Aluminum 6061 for the pan resulted in the most substantial weight reduction, making it the optimal choice compared to Stainless Steel and Mixed Steel Alloy. While handle and shaft materials also contribute to the weight, their impact is significantly less pronounced. Specifically, the optimum material for handle and shaft is with the material of Wood (Maple) and Aluminum 606, respectively. The optimization achieved through the Taguchi method not only addresses the primary concern of excessive weight but also ensures that the double pan remains functional. Further research could explore the integration of composite materials or advanced polymer blends to achieve even greater weight reduction without sacrificing durability. Additionally, design modifications, such as incorporating lattice structures, could be explored to further reduce weight while maintaining structural integrity.

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