Friction Stir Welding: A Review of Optimization by Taguchi Approach

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Abstract: ***The optimization of Friction Stir Welding (FSW) processes has garnered significant interest, driven by the synergy of advanced simulation software and computational power. This review encompasses recent studies that have delved into autonomous optimization methodologies, including Taguchi - based Grey relational analysis coupled with principal component integration, learning - based algorithms such as reinforcement learning and Bayesian optimization. These approaches aim to enhance FSW weld quality by determining optimal parameters, such as rotational speed, plunge depth, dwell time, and welding velocity, with a twofold objective of minimizing defects and maximizing critical factors like failure load and bonded size. Notably, the Taguchi optimization technique has been extensively employed to optimize parameters like rotational and travel speeds, alongside pin shape, showcasing its effectiveness. The interplay of factors like material composition and feed rate further influences the optimization of hardness and tensile strength in the welded joint. Collectively, these endeavors augment joint strength and operational efficiency, underscoring FSW's potential as a pioneering welding technology.***

Keywords: Friction Stir Welding, FSW optimization, Taguchi analysis, Weld quality, Process parameters

1. Introduction

Optimization of friction stir welding (FSW) has been a topic of interest in recent years. The combination of advanced numerical simulation software and high computational power has led to improved understanding of the FSW process and the ability to optimize process parameters. Several studies have focused on autonomous optimization of FSW, using techniques such as Taguchi - based Grey relational analysis with integrated principal component analysis [1], optimization strategies coupled with 3D transient heat transfer computation [2], and learning - based algorithms like reinforcement learning and Bayesian optimization [3]. These approaches aim to improve the quality of FSW welds by determining optimal parameters such as tool rotational speed, plunge depth, dwell time, and welding velocity. The goal is to minimize defects like expelled flash volume and maximize critical factors like failure load and effective bonded size. The use of optimization techniques in FSW has shown promising results in terms of weld quality and process efficiency.

Friction stir welding (FSW) is an innovative method for welding technology that provides several benefits over traditional welding techniques. The optimization of FSW parameters is crucial for achieving desired joint strength and other operational parameters. The Taguchi optimization technique has been widely used for this purpose. Several studies have utilized Taguchi - based approaches to optimize FSW parameters such as rotational speed, travel speed, and pin shape [4] [5]. The findings have shown that the choice of pin shape has a significant influence on the performance and reliability of the joint [6]. Additionally, factors such as feed rate and material composition also play a role in optimizing the hardness and tensile strength of the welded joint [7] [1]. Overall, the Taguchi optimization technique has proven to be effective in determining the optimal parameter values for FSW, leading to improved joint strength and operational performance.

2. Taguchi optimization technique

Taguchi optimization is used in several papers to optimize the process parameters for friction stir welding. Shunmugasundaram et al. conducted experiments to determine the impact of process parameters on the mechanical characteristics of friction stir welded joints between AA5383 and AA7075 alloys. They used the Taguchi approach to identify the most significant parameter, which was rotational speed, and proposed a prediction equation for mechanical characteristics [8]. Sefene and Tsegaw also used the Taguchi method to optimize the process parameters for friction stir welding of a 6061 Al alloy. They found that higher rotational speed and minimum welding speed with a taper threaded tool pin were the optimum parameter settings [9]. Shaik et al. used Taguchi design of experiments to investigate the mechanical properties of friction stir processed aluminum alloys. They determined the optimized process parameters for welding speed, rotational speed, tilt angle, and axial force [10].

3. Implications

Based on the compilation of research papers on Friction Stir Welding (FSW) optimization techniques and parameter influences, several key conclusions can be drawn:

3.1 Optimal Rotational Speed

Across multiple studies, rotational speed consistently emerges as a critical parameter affecting various aspects of FSW, including tensile strength, hardness, and joint properties. An optimal rotational speed of around 1400 rpm appears to be a recurring value for achieving desirable weld characteristics. [4]

3.2 Feed Rate Importance

The feed rate is another vital parameter influencing FSW outcomes. It is the most influential factor for improving hardness and also significantly impacts joint strength. Optimization of the feed rate is crucial for achieving desired material properties. [6]

3.3 Shoulder Diameter Significance

The shoulder diameter of the tool is a key determinant of weld tensile strength and other properties. Studies highlight that an appropriate shoulder diameter, such as 20 mm, is crucial for obtaining high - quality welds with superior tensile strength. [10]

3.4 Effect of Material and Preheating

While rotational speed and feed rate are dominant parameters, the type of material and preheating also play roles in influencing joint strength and overall weld quality. These factors need careful consideration in FSW process planning. [9] [8] [12]

3.5 Tool Geometry Impact

Tool geometry, particularly the pin shape and taper, significantly affects weld properties. A convex pin shape and tapered tool pin profile have been found to contribute positively to tensile strength and overall weld performance. [4]

3.6 Multi - Response Optimization

Hybrid approaches, such as the Taguchi - Grey Relationship Analysis – ANN approach, offer effective methods for optimizing multiple response parameters simultaneously. These techniques can help identify optimal parameter combinations for achieving desired weld characteristics. [4]

3.7 Dissimilar Material Welding

Friction stir spot welding of dissimilar materials, such as aluminum and copper, also benefits from careful parameter optimization. Rotational speed is a key factor, and increasing it can lead to substantial improvements in maximum tensile force. [12]

4. Conclusion

The optimization of FSW parameters is a complex yet crucial endeavor for achieving desired weld properties. Rotational speed, feed rate, shoulder diameter, and tool geometry are among the key factors that warrant meticulous consideration. Utilizing hybrid optimization approaches and tailoring parameters to specific material combinations can lead to significant enhancements in weld strength, hardness, and overall quality.

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