Management and Production Engineering Review
Volume 11 • Number 1 • March 2020 • pp. 73–78
DOI: 10.24425/mper.2020.132945

SIX SIGMA METHODOLOGY USED TO IMPROVE THE MECHANICAL PROPERTIES FOR FRICTION STIR WELDING OF ALUMINUM PIPES

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Received: 8 August 2018
Accepted: 12 September 2019

Abstract
This paper presents a new welding quality evaluation approach depending on the analysis by the fuzzy logic and controlling the process capability of the friction stir welding of pipes (FSWoP). This technique has been applied in an experimental work developed by alternating the FSW of pipes process major parameters: rotation speed, pipe wall thickness and travel speed. variable samples were friction stir welded of pipes using from 485 to 1800 rpm, 4–10 mm/min and 2–4 mm for the rotation speed, the travel speed, and the pipe wall thickness respectively. DMAIC methodology (Defining, Measuring, Analyzing, Improving, Control) has been used as an approach to analyze the FSW of pipes, it depends on the attachment potency and technical commonplace demand of the FSW of pipes process. The analysis controlled the Al 6061 friction stir welded joints' tensile strength. To obtain the best tensile strength, the study determined the optimum values for the parameters from the corresponding range.

Keywords
Six Sigma, DMAIC, pipe welding, tensile strength, hardness.

Introduction

Six Sigma is a well-structured methodology that concentrates on decreasing variation, measuring defects and beneficent the quality of products, processes, and services. Six Sigma methodology was primarily progressing by Motorola in the 1980s and it targeted a difficult aim of 3.4 parts per million defects [1, 2]. Six Sigma has been on an unbelievable run, manufacture important savings to the under the most line of many large and small organizations [3]. Enforcement of quality initiatives in any manufacturer leads to improvements in the performance of the product through the generation of high-quality properties, and improved efficiency.

The DMAIC (Define, Measure, Analyze, Improve, Control) approach has been followed here to control the defects of under accepted level for the mechanical properties of the friction stir welded joints. Six Sigma is a registration of variation in the sense of standard deviation. For a stable process parameter should be in appropriate limits. Six Sigma, a statistically based quality improvement program, helps to improve welding processes by reducing the leak, welding undercut, blowholes and incomplete weld related to poor quality, and by benefiting the efficiency and effectiveness of welding processes. Tungsten inert gas (TIG) welding operation variables were optimized by Six Sigma DMAIC [4]. Six Sigma succeeded in improving the process performance leading to more utilization of resources, minimizing defects and variations by maintain a non-alternating level of quality. Whilst in [5] the oxidation defect reduction was considered in a nuclear plant application. DMAIC technology under Six Sigma is used for considering the tube welding parameters for controlling the mechanical properties of the joint produced [3]. The welding pressure, welding speed and strip thickness were varied to control the yield and tensile strength for the steel tube welding process. Also, for the welding assembly process of automotive exhaust system, Six Sigma DMAIC has been applied [6]. The results were minimizing the defects of biting edge and stomata by controlling the process parameters of welding torch angle, welding speed and argon flow. The level of quality was raised by near 130% based on the standard deviation measure. For submerged arc welding process, Six Sigma controlled the shear strength of welded joint by solving the variation problem arises during the process [7]. Based on literature, the work on an implementation of Six Sigma for the process of frication stir welding (FSW) does not exist to the best of our knowledge. The aim of this paper is the application of the Six Sigma approach to eliminate defect concerning the tensile strength, and hardness of an aluminum pipe friction stir welded.

Research methodology

The methodology adopted for this case study is explained by this department. Any scientific implementation of a process technology needs to begin with a certain structure and outline. This framework and outline of implementing were imaginary to procure answers to research questions in the research design [8] as DMAIC (Define, Measure, Analyze, Improve, Control) method was implemented. This case study is conducted to determine the values of the FSW of pipes parameters leading to an optimal joint made.

Case study

The FSW of pipes is a joining process, a solid-state process, carried out by plastic deformation using a special geometry method that cannot be used (Fig. 1).

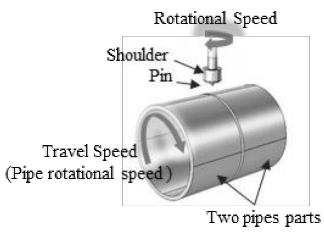

Fig. 1. The FSWoP process.

The friction between the tool and the two base metal to be welded is the source of welding heat. A several of parameters define and affect the FSW process. Tool rotation speed, shape of tool and travel speed are such examples. For further information about the FSW process [cf. 9]. Three parameters only are considered in this paper, the tool rotation speed (n), the travel speed (s) and the pipe wall thickness (t).

Measure

There are many measures of the mechanical properties that can be used for evaluating the FS welded joints. In this paper, Tensile Test was used for measuring the tensile strength of the FS welded joint. As, the tensile strength is a major key performance for the FS welded joints [10]. Producing FSW joints for pipes rather than welding plates is considered. All the pipes were made of Al 6061 material that were welded by the FSW process at different values of the considered parameters. The rotation speed (n), the travel speed (s) and the pipe wall thickness (t) associated with their corresponding levels are indicated in Table 1. General full factorial design was established for designing the experiments. For each pipe wall thickness, a group of 18 joints were FS welded and used as instances for measure and further analysis.

Table 1
Levels of the FSW process parameters.

	Levels					
	1	2	3	4	5	6
n [rpm]	485	710	910	1120	1400	1800
s [mm/min]	4	8	10	–	–	–
t [mm]	2	3	4	–	–	–

Analyze

The output of the measure process was three groups of date, each group represented the tensile strength of each thickness pipe joint at different values of tool rotation speed (t) and travel speed (s). Whether the parameters considered has a relative effect on the tensile strength (σ) and hardness (HV) of the FS welded joint or not is needed to be resolved. This can be performed by applying the analysis of variance (ANOVA) [11]. ANOVA is based on calculating the F value for each parameter (based on the F-test). When the parameter's F value is high, it means it has a significant effect of the response considered (the response here is the tensile strength and hardness) [12].

Table 2 shows the results of ANOVA on the tensile strength (σ) and hardness (HV) of the FS welded joints. From the results of the ANOVA, All the three parameters have a high value of F-value and also, their corresponding P-values are < 0.0001 (not included in Table 2). So, the tool rotation speed (n), travel speed (s) and the pipe wall thickness (t) have significant effects on the tensile strength (σ) and hardness (HV) of the welded joints.

Table 2
Results of ANOVA on σ and HV.

Parameter	DF	Adj SS	Adj MS	F-Value
Tensile Strength (σ)				
n	5	14174.1	2834.82	849.81
s	2	644.6	322.32	96.62
t	2	1692	846.01	253.61
Error	44	146.8	3.34	
Total	53	16657.6		
Hardness (HV)				
n	5	1594.35	318.87	114.92
s	2	185.88	365.02	33.50
t	2	730.04	92.94	131.55
Error	44	122.09	2.77	
Total	53	2632.36		

Improve

Fuzzy logic is one of the most multivariate techniques for optimization. It simply relates the experimental work to optimize the levels of the parameters to obtain the optimal objective performance [13]. As three parameters of the FSW process (n, s, t) were considered for optimizing the tensile strength (σ) of the FS pipe welded joints, fuzzy logic were used as an analysis approach.

However, the pipe wall thickness (t) can't be considered as a process parameter. Figure 2 to Fig. 7 represents the influence of the interaction between the rotation speed (n) in rpm and the travel speed (s) in mm/min at each pipe wall thickness (t) in mm on the tensile strength (σ) in MPa and hardness (VH).

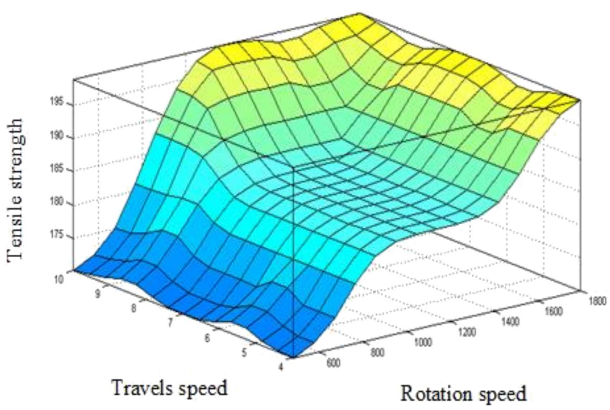

Fig. 2. Influence of the interaction between n and s at t_1 on the tensile strength σ.

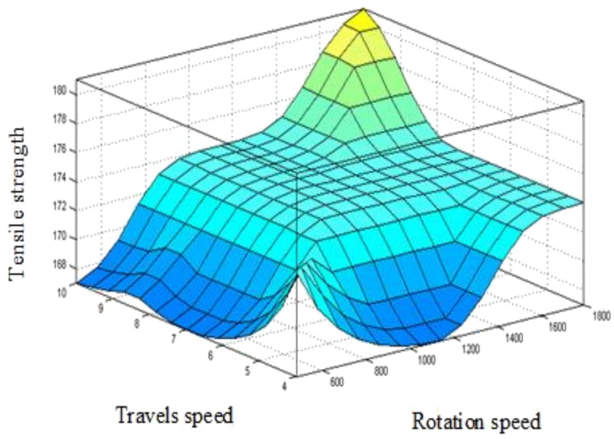

Fig. 3. Influence of the interaction between s and n at t_2 on the tensile strength σ.

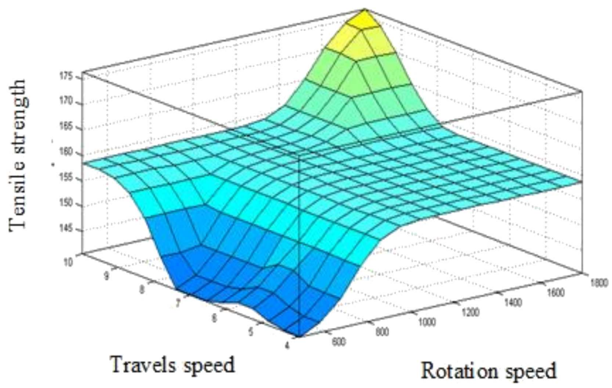

Fig. 4. Influence of the interaction between s and n at t_3 on the tensile strength σ.

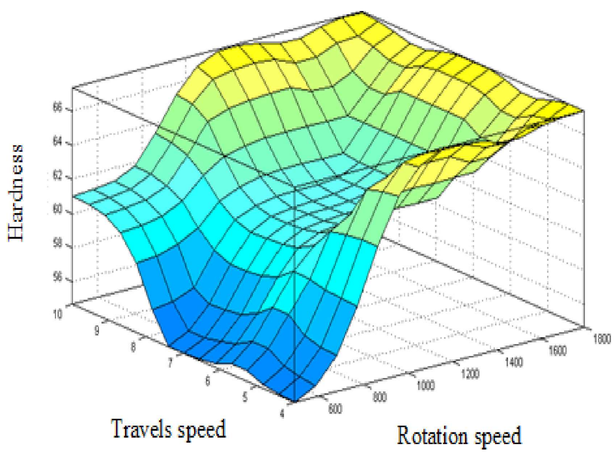

Fig. 5. Influence of the interaction between n and s at t_1 on the VH.

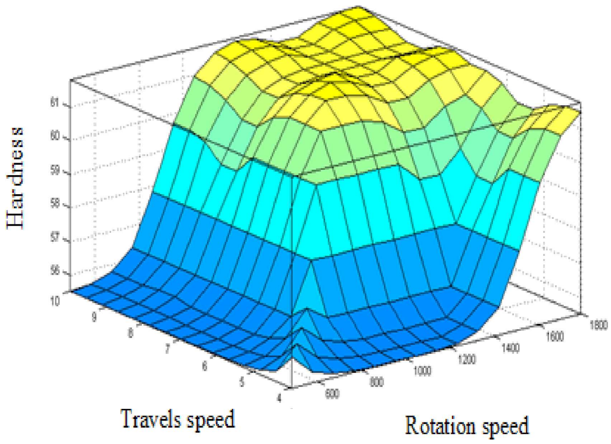

Fig. 6. Influence of the interaction between n and s at t_2 on the VH.

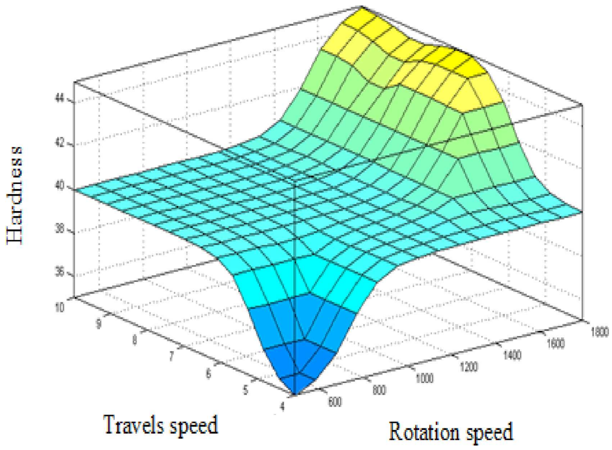

Fig. 7. Influence of the interaction between n and s at t_3 on the VH.

Control

By deducing that the highest values of tensile strength (σ) and hardness (VH), in all experiments performed, were at the maximum n of value 1800 rpm and minimum s of value 4 mm/min. So, using these values of the FSW parameters n and s respectively should led to the maximum tensile strength of the welded joint.

Although the FSW process under these parameters' values need to be controlled. Further experiments have been conducted with FSW process parameters values at $n = 1800$ rpm and $s = 4$ mm/min for the three pipe wall thickness values t_1, t_2 and t_3.

Table 3 summarize the statistical measures of the two group of experiments performed. The measured values are the tensile strength (σ) and hardness (VH) for each instance. Initial experiments refer to different n and s as stated earlier where fixing the values of n and s to be 1800 rpm and 4 mm/min is the characteristic of the further experiments.

Table 3
Statistical measures of FSW experiments.

Measure	Initial experiments			Further experiments		
	t_1	t_2	t_3	t_1	t_2	t_3
Tensile strength (σ)						
Mean	200.6	168	161	205	197	192.7
SD	17.1	17.3	16.8	2.78	4.19	2.14
Hardness (VH)						
Mean	61.2	56.6	52.2	70	66	65
SD	4.39	5.51	7.89	2.04	2.14	2.34

Table 3 demonstrates obviously the effect of using the optimum value of $n = 1800$ rpm and $s = 4$ mm/min that yield the highest values of σ and HV for the welded pipe joint. However, controlling the FSW of pipes process is needed to be confident about this demonstration. Controlling are graphical tools that helps determine if a process is "in control or not". There are a wide range of control charts that can't be applied for controlling such a process [14, 15]. A statistical process control (SPC) chart: graphical summary for tensile strength and hardness was used for the control phase. graphical summary measure the variability of the given output attribute.

Figures 8–10 are the graphical summary of the joint tensile strength (σ) and hardness (VH) for these further experiments. Figures 8 and 13 refers to thicknesses t_1, t_2 and t_3 respectively. The variations through the FSW process have been decreased obviously with high values of the tensile strength for the produced pipe welded joints.

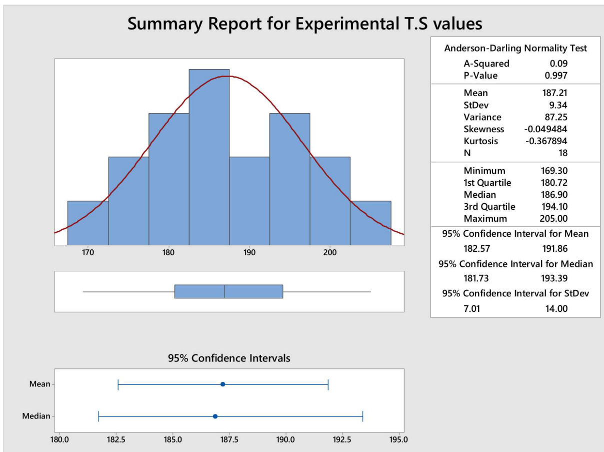

Fig. 8. Summary report of tensile strength chart for the output σ ($n = 1800$ rpm, $s = 4$ mm/min and t_1).

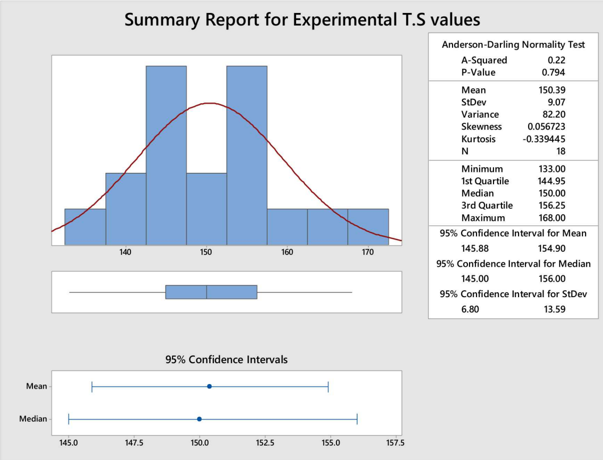

Fig. 9. Summary report of tensile strength chart for the output σ ($n = 1800$ rpm, $s = 8$ mm/min and t_2).

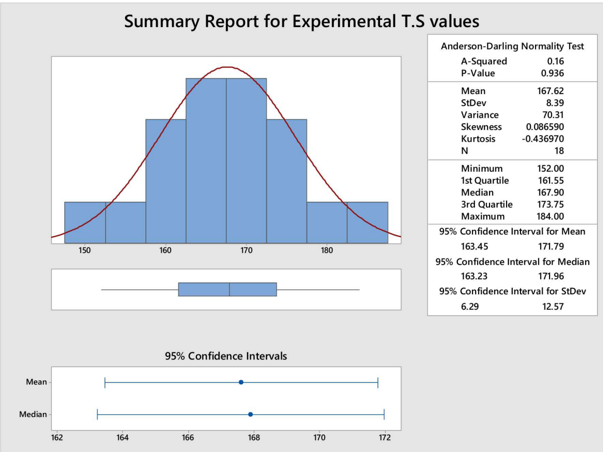

Fig. 10. Summary report of tensile strength chart for the output σ ($n = 1800$ rpm, $s = 10$ mm/min and t_3).

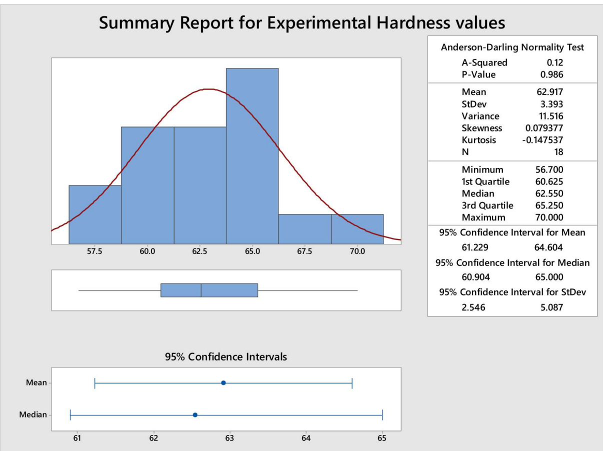

Fig. 11. Summary report of hardness chart for the output HV ($n = 1800$ rpm, $s = 4$ mm/min and t_1).

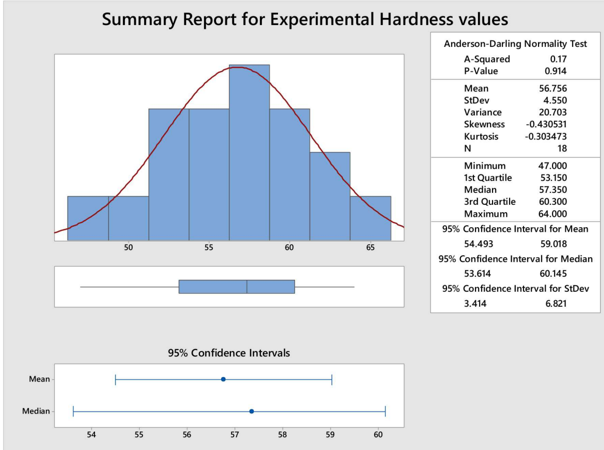

Fig. 12. Summary report of hardness chart for the output HV ($n = 1800$ rpm, $s = 8$ mm/min and t_2).

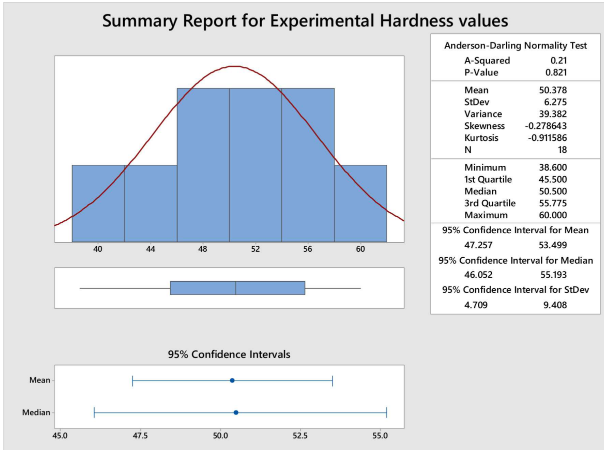

Fig. 13. Summary report of hardness chart for the output HV ($n = 1800$ rpm, $s = 8$ mm/min and t_3).

Conclusions

From the present theoretical result of aluminum pipes welding with Six-Sigma technique, and use of friction stir welding and changes the wall thickness then increase rotation speed, and reduce travel speed to increased tensile strength and hardness check the mechanical properties pipes strength (tensile stress) but maximum optimization result show in thickness σ/VH tensile strength and hardness ($t = 205$ Mpa and hardness 70 VH) in graph to solve the aluminum pipes welding leakage problem at the flow of fluid in the aluminum pipes, improve customer satisfaction.

This analysis will be extremely useful as a reference guide of friction stir welding in aluminum 6061 pipe material for this range of process parameters. The tool rotation speed is directly proportional to the tensile strength and hardness of the produced welded pipe joints, for the FSW of pipes parameters ranges considered.

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