OPTIMIZATION OF FRICTION STIR SPOT WELDING PARAMETERS FOR 7075 AND 6061 ALUMINUM ALLOYS USING TAGUCHI METHOD

By

Mohamed Mohamed Azzam Abdallah

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
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Title of Thesis:

Optimization of Friction Stir Spot Welding Parameters for 7075 and 6061 Aluminum alloys Using Taguchi Method

Key Words:
FSSW, 7075-T6, 6061-T6, Anvil, Taguchi method

Summary:

Friction stir welding is a solid-state welding process, where there is no melting taking place. In this study, a friction stir spot welding process was developed. The aim of this work was to optimize the process parameters of welding AA7075-T6 and AA6061-T6, separately. Rotational speed, pin profile, plunge depth, and shape of anvil were the main parameters studied. The experimental results showed that the optimal levels found to be 800 rpm, triangular pin, 1 mm, and convex anvil for AA7075-T6; and were 500 rpm, square pin, 1 mm, and convex anvil for AA6061-T6, respectively. The worst joint properties were observed for a rotational speed of 1250 rpm, and rounded pin profile and 1.5 mm plunge depth, with flat anvil for both alloys. ANOVA results revealed that the pin profile is the dominant parameter in the process, followed by the plunge depth, then the anvil shape and the last parameter was the rotational speed. The percentages of contribution were 54%, 21%, 14, and 11%, respectively, for the AA7075-T6 alloy. For the 6061-T6 alloy, it was found that the pin profile was most effective FSSW process parameter, followed by anvil shape, plunge depth and the rotational speed. The percentages of contribution were 51%, 35%, 8, and 6%, respectively.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

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Nomenclature

ANOVA	Analysis of variance
BM	Base material
DOE	Design of experiment
DT	Dwell time
FSSW	Friction Stir Spot Welding
FSW	Friction Stir Welding
HAZ	Heat affected zone
LSS	Lap shear strength
OM	Optical microscope
PD	Plunge depth
RS	Rotational speed
RSW	Resistance Spot Welding
SEM	Scanning electron microscope
SPR	Self-Piercing riveting
SCC	Stress corrosion cracking
SZ	Stir zone
Tm	Melting point
TMAZ	Thermo- mechanically affected zone
TWI	The welding institute
TIG	Tungsten Inert Gas
MIG	Metal Inert Gas
W_{eff}	Effective weld width
T_{eff}	Effective sheet thickness

Abstract

Friction stir welding is a solid-state welding process, where there is no melting taking place. In this study, a friction stir spot welding process was developed. The aim of this work was to optimize the process parameters of welding AA7075-T6 and AA6061-T6, separately. Rotational speed, pin profile, plunge depth, and shape of anvil were the main parameters studied. The experimental results showed that the optimal levels found to be 800 rpm, triangular pin, 1 mm plunge depth, and convex anvil for AA7075-T6; and were 500 rpm, square pin, 1 mm plunge depth, and convex anvil for AA6061-T6, respectively. The worst joint properties were observed for a rotational speed of 1250 rpm, and round pin profile and 1.5 mm plunge depth, with flat anvil for both alloys. ANOVA results revealed that the pin profile is the dominant parameter in the process, followed by the plunge depth, then the anvil shape and the last parameter was the rotational speed. The percentages of contribution were 54%, 21%, 14, and 11%, respectively, for the AA7075-T6 alloy. For the AA6061-T6 alloy, it was found that the pin profile was most effective FSSW process parameter, followed by anvil shape, plunge depth and the rotational speed. The percentages of contribution were 51%, 35%, 8, and 6%, respectively.

Keywords: FSSW, 7075-T6, 6061-T6, Anvil, Taguchi method

Chapter 1: Introduction

Nowadays, there is a great challenge for developing and improving advanced welding techniques, to reduce the weight, increase the strength, and enhance the performance especially in automotive industries, ship building, and aerospace. Friction stir is one of these welding techniques that solves the problem of joining high strength aluminum alloys. These aluminum alloys are difficult to weld by traditional fusion welding such as TIG and MIG, especially in 2xxx and 7xxx series of aluminum alloys. FSW gave great results in improving of the mechanical properties and microstructure. It has been reported that fuel consumption can be decreased by 5.5% for each 10% reduction in weight of the vehicle and a one-pound reduction in the weight of a car would decrease carbon dioxide emissions by 20 pounds over the life of the vehicle [1].

FSSW has been developed by Mazda Motor Corp and Kawasaki Heavy Industries [2]. FSSW technique was first used in the Mazda RX-8 rear door panel spot welding in 2003 [3]. Mazda claimed that the reduction in consumption of the energy by 99% compared with the traditional technique such as resistance spot welding (RSW), due to the disadvantages of RSW, such as consuming electrode due to wear, high power consumption and high cost.

Friction stir spot welding (FSSW) is one of the advanced welding techniques which is derivative of friction stir welding (FSW). FSSW can be classified as a transient process due to its short cycle period. Both of FSW and FSSW use the same rotating tool [4]. The difference only between FSW and FSSW is that FSW has traverse movement, unlike FSSW. Unlike the fusion welding like TIG and MIG, the temperature during FSSW welding technique does not reach to the melting point of the parent metal, FSW run in the solid phase below the melting temperature of joining materials. The maximum temperature which was observed during FSW process between 0.6 T_m and 0.9 T_m [5]. Consequently, FSSW is classified as a solid-state welding technique, therefore hot cracking is excluded. FSSW is considered a “green technology”, because of absence of consumable filler rods, shielding gas, environmental friendliness and energy efficiency [3]. The process of FSSW is mainly applied for lap joint as aluminum with aluminum, aluminum with steel or aluminum with magnesium.

There are many process parameters that determine the strength and the quality of the surface finish of the welded joint in FSSW such as rotational speed, geometry of the tool, dwell time, plunge depth, and the dimensions of the rotating tool [4].

High strength aluminum alloys such as 2xxx and 7xxx series have a critical problem where these alloys are difficult to be welded by conventional fusion welding such as TIG and MIG, therefore FSW is one of the successful welding processes which is used to weld these alloys with each other, and gives great results whether in mechanical properties or microstructure, due to many advantages such as: low distortion and residual stresses, no loss of alloying elements, no arc, no spattering, low noise, no fumes and free from porosity [6]. The improvements in the mechanical properties (i.e. yield strength and strain hardening rate) of the high strength aluminum alloys are produced because of the existence of the nanosized precipitates, which hinder the movement of dislocations.

The heat treatable aluminum 6xxx alloys have moderately high strength levels, better corrosion resistance than the 2xxx and 7xxx alloys, good weldability and higher extrudability [7]. The 6xxx series aluminum alloys are most commonly used for extrusion purpose and are widely used as vehicle body sheets. The 6xxx series alloys are heat-treatable and have the following advantages: good corrosion resistance, good surface finish, good formability, and medium strength. All these advantages make the 6xxx are suitable for structural applications. Magnesium and silicon are the main alloying elements in 6xxx aluminum alloys. These alloying elements are combined to form Mg_2Si compound, which makes the 6xxx alloys are heat treatable, and producing the medium strength. Although the AA6061 alloy can be joined by traditional fusion welding such as: TIG and MIG, the excess heat which occurred during these processes causing dissolution of its Mg_2Si compound which causing severe softening in the material and reduce the mechanical properties of the alloy [8].

Taguchi technique of Design of Experiments (DOE) is defined as an influential statistical method that permits optimizing the performance of a product, process, design and system with a significant reduction in the number of the experiments, time and costs [9]. Taguchi method is considered a special type of fractional factorial design. Taguchi determines the optimum conditions of parameters, which are unresponsive to the variation in environmental condition and other noise effects. There are three classes of quality characteristics defined in the analysis of signal to noise (S/N) ratio as the following: lower-the-better larger-the-better and nominal-the-best. The S/N ratio for each process parameter is calculated depending on S/N analysis function. A Larger S/N ratio is normally agreement with better quality characteristics regardless of the category. The level of larger S/N ratio is the optimal process parameter one. Analysis of variance (ANOVA) is performed to investigate which parameters have a significant effect on the quality characteristic [9].

From the previous studies, there are found many published studies on Friction Stir Welding and processing [10-13]. There are a few or absent information about using FSSW to weld similar aluminum alloys, especially using different designs for the anvil. The aim of this work is to study the effect of rotational speed, pin profile, penetration depth, design of the anvil on microstructure, and mechanical properties of these similar alloys joint, to achieve optimized properties, as much as possible.