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Research Article

Welding Parameter Optimization of Alloy Material by Friction Stir Welding using Taguchi Approach

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Abstract

Friction stir welding is used as a solid state joining process for soft materials such as aluminium alloys and also for hard materials like steels. It avoids many of the common problems obtained in fusion welding. In mechanical, civil, automobile, naval, and aeronautical engineering beams are widely used of the magnesium alloys for different applications and that are joined by conventional inert gas welding process. Magnesium has less density and low melting point so due to that large heat generation in the conventional welding process so adaptation of new welding process is essential. By using frictional stir welding process enhancement of weld is observed under different mechanical testing which improves weld quality. Also by using different tool size; we implement new techniques of weld.

Keywords: *Frictional stir welding, Magnesium alloy, Tool Siz, Taguchi Method*

1. Introduction

[1]Welding is a fabrication process used to join materials, usually metals or thermoplastics, together. During welding, the work pieces to be joined are melted at the joining interface and usually a filler material is added to form a weld pool of molten material that solidifies to become a strong joint. In contrast, Soldering and Brazing do not involve melting the work piece but rather a lower melting point material is melted between the work pieces to bond them together. Friction stir welding is one of the new entrants to the solid state joining techniques, which have made remarkable progress in welding technology. Friction stir welding was developed in 1991 and is essentially a solid state joining process. Recently, its applications have been extended to the welding of high melting point materials such as various types of steels, Ti alloys, Ni-based super alloys. With recent developments in technology of friction stir welding, it is now possible to carry out dissimilar welding of various types of steels with alloys of aluminum, magnesium, copper, titanium and also other alloy (N. T. Kumbhar, *et al.*,2011).

2. Friction Stir Welding

Friction stir welding (FSW) is a relatively new solid-state joining process. This joining technique is energy efficient, environment friendly, and versatile. The principal advantages are low distortion, absence of melt related defects and high joint strength. In FSW parameters play an important role like tool design and material, tool rotational speed, welding speed and axial force. Friction stir welding (FSW) is a solid state joining technique that was invented at The Welding Institute (TWI), United Kingdom in 1991 and has found applications in a wide variety of industries, including aerospace, automotive, railway and marine. It is an alternative welding technology process to fusion welding.

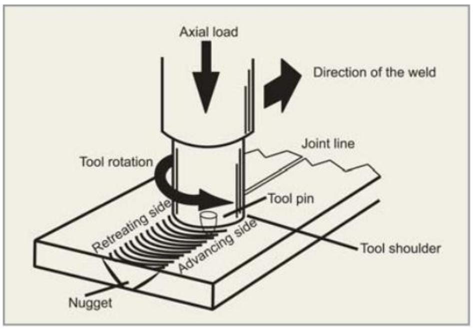

Fig. 1 Friction Stir Welding

A defining characteristic of FSW is that the joint is created by a cylindrical rotating tool, mechanically traversed through the materials. Frictional heat is generated between the wear-resistant welding tool shoulder and pin, and the material of the work-pieces.

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The frictional heat and surrounding temperature causes the stirred materials to best oftened and mixed. The principle of the friction stir welding (FSW) is the rotating pin (tool) is pushed into the material until shoulder meets the work piece surface this causes the material to plasticize due to heating by frictional contact of the tool shoulder and the work piece then tool moved forward and the joint is formed, the process is finished when the tool is retracted from the work piece. The FSW process is as shown in figure 1 (N.T.Kumbhar, *et al*., 2011).

3. Material Selection

Two of the largest challenges that the automotive industry has always faced are lightening the vehicles and at the same time improving the safety of passengers. The former aim is important to improve vehicle performance, i.e. acceleration, top speed and fuel consumption. The latter is vital to secure passengers in case of accidents. Considering both of these factors simultaneously is usually difficult to lead to a product. One of the materials that provides enough strength and is also lightweight is aluminium.In general, all aluminum components in a car can be welded by FSW: bumper beams, rear spoilers, crash boxes, suspension systems, rear axles, drive shafts, intake manifolds, stiffening frames, water coolers, engine blocks, cylinder heads, dash boards, rollover beams, pistons, engine and chassis cradles, wheel rims, attachments to hydro- formed tubes, tailor welded blanks (TWBs), etc. The application of FSW in large vehicles is even more interesting, as this process could be used in truck bodies, tail lifts for lorries, mobile cranes, armour plated vehicles, fuel tankers, caravans and buses. Motorcycle and bicycle frames are the other potential fields for applying FSW and also in BIW too. Body in white **or** BIW refers to the stage in automotive design or automobile manufacturing in which a car body's sheet metal components have been welded together — but before moving parts (doors, hoods, and deck lids as well as fenders) the motor, chassis sub-assemblies, or trim (glass, seats, upholstery, electronics, etc.) have been added and before painting. The name derives from manufacturing practices before steel unibody or monocoque bodies — when automobile bodies were made by outside firms on a separate chassis with an engine, suspension, and fenders attached. The composition of alloys of magnesium the AZ31 is 2.75% Al, 0.001% Fe, 0.91 % Zn, 0.01 % Mn and magnesium for balance and AZ91 having the composition as 8.67% Al, 0.002% Fe, 0.85% Zn, 0.03% Mn and magnesium for balance and mechanical properties of alloys as AZ31 having tensile strength of 272 N/mm2 and elongation is 7.2 %, and AZ91 having tensile strength of 240 N/mm2 and elongation is 16.8%. Alloys of magnesium plates (150mm X 50mm X 5mm) were used for this experiment. The material of the tool is H13 steel is used. The material is as shown in figure 2.

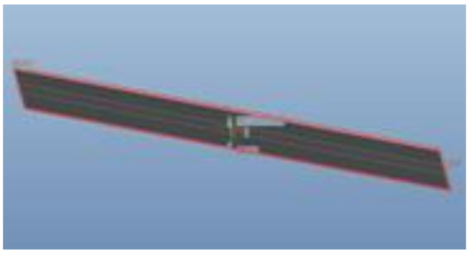

Fig. 2 Modelling of material using Pro-E

4. Tool used in FSW

The weld microstructure may also be affected as a result of interaction with eroded tool material. Apart from the potentially undesirable effects on the weld microstructure, significant tool wear increases the processing cost of FSW. Owing to the severe heating of the tool during FSW, significant wear may result if the tool material has low yield stress at high temperatures. Stresses experienced by the tool are dependent on the strength of the work piece at high temperatures common under the FSW conditions. Temperatures in the work piece depend on the material properties of tool, such as thermal conductivity, for a given work piece and processing parameters. The coefficient of thermal expansion may affect the thermal stresses in the tool. Other factors that may influence tool material selection are hardness, ductility and reactivity with the work piece material. The tool hardness is important in mitigating surface erosion due to interaction with particulate matter in the work piece Also in part of material selection one more selection is important for the process is the tool material selection. It is very important parameter for the process. While selection of the tool material we have to consider the effects observed on the tool during the process. Mainly we have to consider the effect of heat generation and dissipation on the tool material. The welding tool used along with the forging temperature as shown in table 1

Table 1 Tool material with their forging temperature

Sr. No.	Material Alloys	Tool Material	Forging Temperature in ^{0}c
1.	Aluminum Alloys	Tool steel, WC-Co	440-550
2.	Magnesium Alloys	Tool steel, WC	250-350
3.	Copper and copper alloys	Nickel alloys, PCBN(a), Tungsten alloys, Tool steel	600-900
4.	Titanium alloys	Tungsten alloys	700-950
5.	Stainless steels	PCBN, Tungsten Alloys	860-1020
6.	Low-alloy steel	WC, PCBN	650-800
7.	Nickel alloys	PCBN	600-800

5. Selection of tool

The recent study on FSW tool design that increases the tool travel speed, increase the volume of material swept by pin-to-pin volume ratio, and/or increases the weld symmetry. Many of these tool designs have focused on tool motion and not specifically on the tool pin design, although each type of complex motion can have an optimal tool design. Most complex motion tools require specialized machinery or specially machined tools, making these tools unsuitable for basic applications.

1. Skew-Stir Tool 2. Com-Stir tools 3. Dual-Rotation Tool 4. Re-Stir Tool

Weld quality and tool wear are two important considerations in the selection of tool material, the properties of which may affect the weld quality by influencing heat generation and dissipation. The material of the tool H13 steel was used. The Dimensions of the tool is as shown in figure 3.

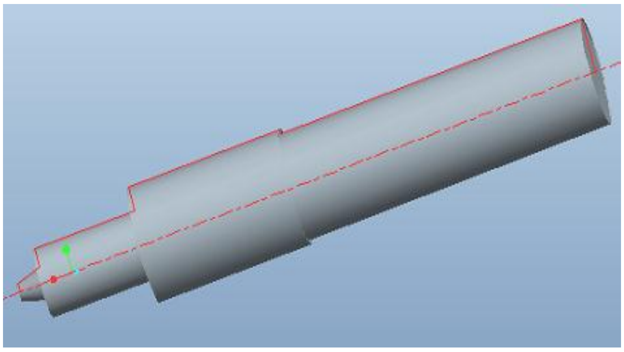

Fig. 3 Tool Used in Welding

6. Taguchi Approach

Optimization of process parameters is the key step in the Taguchi method to achieving high quality without increasing cost. This is because optimization of process parameters can improve quality and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically classical process parameter design is complex and not easy to use an advantage of the Taguchi method is that it emphasizes a mean performance characteristic value close to the target value rather than a value within certain specification limits, thus improving the product quality. A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way, while using a signal-to-noise ratio to analyze the experimental data could help the designers of the product or the manufacturer to easily find out the optimal parametric combinations A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments. Using an orthogonal array to design the experiment could help the designers to study the influence of multiple controllable factors on the average of quality characteristics and the variations in a fast and economic way (Ugur Esme, *et al*, 2009).

7. Design of Experiment

DOE (Design of Experiments) provides a powerful means to achieve breakthrough improvements in product quality and process efficiency. From the viewpoint of manufacturing fields, this can reduce the number of required experiments when taking into account the numerous factors affecting experimental results. DOE can show how to carry out the fewest number of experiments while maintaining the most important information. The most important process of the DOE is determining the independent variable values at which a limited number of experiments will be conducted. For this purpose, Taguchi proposed an improved DOE. This approach adopts the fundamental idea of DOE, but simplifies and standardizes the factorial and fractional factorial designs so that the conducted experiments can produce more consistent results. The major contribution of the work has been in developing and using a special set of orthogonal arrays for designing experiments. Through fractional experiments, optimal conditions can be determined by analyzing the S/N ratio (Signal-to-Noise ratio) as a performance measure, often referred to as ANOVA (Analysis of Variance)(Dong woo kim, *et al*, 2008).

If one of these steps or precautions is not well taken care of, a micro structural or mechanical property may be varied or one of the process equipment will be damaged. Mounting the work holding device is on the FSW machine table. The clamping plate should be strongly clamped to the table in order to withstand the forces exerted by the tool during the process. The clamping plate should be flat on the table by making sure the T bolts are fully screwed and that there are no objects under the plate. Otherwise, the tool may go deep or out of the work piece while passing between it. Before fully screwing the T bolts, the plate should be adjusted to make a 90° with the FSW machine table; so different specimen is selected for the testing in different size and shapes. Working parameters are Rotating speed (N), Transverse speed (S) and Material are selected as shown in the table 2.

Table 2 Working Parameters

Parameters Level	Rotating Speed (rpm)	Transverse Speed (mm/min.)	Materials
1	1000	60	AZ31
2	1200	75	AZ91
3	1400	80	AZ31 & AZ91

Orthogonal arrays are a set of tables of numbers, each of which can be used to lay out experiments for a number of experimental situations. The DOE technique based on this approach makes use of these arrays to design experiments. Through the orthogonal arrays, it is possible to carry out fewer fractional factorial experiments than full factorial experiments. Also, the relative influence of factors and interactions on the variation of results can be identified.

After selecting working parameters for the welding process: the L9 orthogonal arrays are selected. And according to this parameter welding operation is performed in friction stir welding and different weld is obtained.

Table 3 L9 orthogonal array with parameter (P) and response(R)

Sr. No.	P1	P2	P3	R1	R2	R3
1.	P11	P21	P31	R11	R21	R31
2.	P11	P22	P32	R12	R22	R32
3.	P11	P23	P33	R13	R23	R33
4.	P12	P21	P32	R14	R24	R34
5.	P12	P22	P33	R15	R25	R35
6.	P12	P23	P31	R16	R26	R36
7.	P13	P21	P33	R17	R27	R37
8.	P13	P22	P31	R18	R28	R38
9.	P13	P23	P32	R19	R29	R39

Experiments were conducted as per the design levels of DOE Taguchi method on vertical milling machine at kopargaon. A conventional Vertical Milling Machine can be used to carry out the FSW process. The machine must have the ability to apply significant pressure onto the work piece, should offer wide range of tool rotation and feed rate speeds, provides enough space for its working table to holding the welding assembly and rigidly during the welding operation.

8. Welding of Material

The FSW process was carried out with outmost care. There are many steps and precautions that should be taken care of mounting the work holding device on the FSW machine table. The clamping plate should be strongly clamped to the table in order to withstand the forces exerted by the tool during the process. After making sure the clamping system is safely and accurately mounted on the Work table, the tool rotation speed and welding speed of the experiment should be well adjusted. Good care of the readings and the axial force should be taken just before starting of the experiment. Next, the work pieces should be grounded in welding zone with a grinding paper of grade 400 (for aluminium), to remove any stains, oil, and the Al2O3 layer that is formed on the top of the aluminium sheets. Then, mount the two butt weld plates on the clamp plate and make sure that they are strongly fixed. While fixing them from the side, do not screw the Alan key screws so tight so that the weld plates will not form an angle with the plate. Move the tool towards the rigidly fixed weld plates in order to centre the tool so that it becomes just above the point of contact between the two weld plates joining line. Move the spindle in the downward direction and let the weld plate's just touch the bottom of the tool pin. Check if there is enough clearance between the tool pin and the steel plate by inserting a small piece of paper between the pin and the steel plate, sometimes the sheet thickness may not be uniform and can cause problems, and see if the paper will pass between them or not. Enter the corresponding tool offset position in the panel to set the tool pin penetration through the weld plates. Wear goggles for eye safety.Bring down the spindle towards the butt line of weld plates and turn on the spindle. Move the tool into the weld plates until the pin starts penetrating at the joint line. Then, move the spindle downward until the shoulder is just in contact with the sheet surface. Friction Stir welding method is adopted to carry out the experimental trials by which dissimilar materials of AZ31 and AZ91 welded at three different levels listed in table below. After conducting the experimental trials, it has been observed that input parameters like tool rotational speed, welding speed, tool angle and tool pin profiles have some significant effect on the tensile strength of dissimilar materials of AZ31 and AZ91 weld joint. The Taguchi Method is a multistage process, namely, systems design, parameter design, and tolerance design which used to improve the quality of products and processes. In Taguchi's approach, optimum design is determined by using design of experiment principles, and consistency of performance is achieved by carrying out the trial conditions under the influence of the noise factors

9. Result and Discussion

The experiments were being carried out as per Taguchi parametric design concepts and an L9 orthogonal array will be used to study the influence of various combination of process parameters. Statistical optimization technique, ANOVA, will be used to determine optimum levels and to find the significance of each process parameters. The different image of weld microstructures was taken with two different kinds of microscopes.

The compound microscope typically has three or four different magnifications - 40x, 100x, 400x and sometimes 1000x.

1. At 40x magnification will be able to see 5.1 mm.
2. At 100x magnification will be able to see 2 mm.
3. At 250x magnification will be able to see 0.82 mm
4. At 400x magnification will be able to see 0.45mm, or 450 microns.

At 1000x magnification will be able to see 0.180mm, or 180 microns.

Conclusions

The welding of magnesium alloy is possible by using friction stir welding process. The different mechanical properties of base material joint were found as per the experimentation. The maximum strength of joint is found at 1400rpm rotational speed and 70mm/min transverse speed of AZ31 alloy. From the microstructure analysis in the welded joint the materials is properly mixed and there is no pores and having good quality of welding. Further this structure can be test by UTM to determine different mechanical properties of weld .Also by using analysis software will comment on HAZ and temperature distribution within the material. Similarly, the same research methodology can be implementing to the different alloy materials.

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