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A New Approach of Aluminum Oxide Addition for Friction Stir Welding

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ABSTRACT

This work presents a systematic approach to addition welded joints of 6061 aluminum pipe fabricated by friction stir welding of pipes has been investigated. 5%, 10%, 15% and 20% Aluminum Oxide (Al_2O_3) powder was added to weld interface. Welding was performed on the pipe with different material thickness 2 to 4mm, rotational speeds 1800 RPM and a traverse speed 4 mm/min was applied. The Mechanical properties of welded joints were investigated using different mechanical tests, including nondestructive test (visual inspection) and destructive test (tensile strength and hardness). This paper presents indicated that the addition percentage of added material has a major effect on the mechanical properties of friction stir welding of pipes joint. The results have been obtained at 20% Aluminum Oxide (Al_2O_3) powder at the weld interface.

Key words: FSW, Aluminium pipes, Aluminium Oxide powder, Mechanical properties

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INTRODUCTION

Aluminum can't successfully be arc welded in an air environment, due to the affinity for oxygen. If fusion welded in normal atmosphere oxidizes readily happens and this outcome in both slag inclusion and porosity in the weld, greatly reducing its mechanical properties. In modern years, there has been a potential demand for lightweight transport equipment. The use of aluminum alloys to substitution ferrous alloys in transport equipment is most effective in reducing the weight of automobiles and aerospace vehicles. Considerable tonnages of aluminum alloys are used in the transport manufacture. In that esteem, the strength to weight ratios of aluminum alloys has thus been a predominant design consideration. Several strengthening mechanisms have been used in the else 30 years to incubate new aluminum alloys with high strength to weight ratios. Stampede hardening, precipitation hardening, and improvement of grain structure provide active strengthening mechanisms [1-2].

Fusion welding of mercantile aluminum alloys is mostly hard and not bespoke for some aluminum alloy groups. The existence of protective tenacious oxide film on aluminum alloys is accountable for such difficulties. Extensive surface planning to take off the oxide film is needful before welding of some aluminum alloys. Fusion welding of Al-alloys, whilst, faces some other problems, such as, generation of welding defects such as blowholes, cracks, welding distortion, and angular distortion, which reduced the mechanical properties of weldments. Fusion welding of high strength Al-alloys caused significant changes in the microstructure of cold worked and age hardened alloys, which drastically decrease the mechanical properties of welded alloys [3-4]. The advantage of hydroforming of FSW tubes is the tailoring of the starting materials that can vary in thickness and/or composition to optimize weight or performance. This tailoring is typically carried out in stamping by welding sheets of different thickness together. The blank is then stretched, formed and drawn, resulting in a part with optimized weight [3-7]. more recently, attempts have been made to weld dissimilar aluminum alloys, which ultimately could provide flexibility in design as well as optimize strength, weight, and corrosion resistance [7-13]. To date, no work has been reported on the welding of tailor welded tubes for hydroforming. The study shows the preliminary results on Friction Stir Welding (FSW) of 2024-T3 aluminum alloy tubes and the impact of the welding process on weld quality. Welding was performed on tubes with similar thickness. The mechanical properties of the welds were assessed by hardness and tensile measurements on as-welded and heat treated tubes [14]. So in recent years have spread the use of friction stir welding alloys, aluminium has been used successfully in welding plate. In 2013 appeared to use this method in the pipe welding aluminium has been successfully stunning and we began to develop and improve the mechanical properties of the pipes, welded by the addition Aluminium Oxide (Al2O3) powder during the welding process.

In this work study effective material thickness and addition Aluminium Oxide powder on mechanical properties of friction stir welding pipes.

EXPERMINTAL WORK

Material

The chemical composition and mechanical properties of Al 6061 aluminum pipe parts used in the present study as delivered by the Miser Aluminum company. The chemical composition and mechanical properties of Al 6061 aluminum pipe showing in the table (1-2). To progress the mechanical properties at friction stir welding of pipes joining, the addition Aluminum Oxide (Al2O3) powder [21] at weld interface with different proportions such as 5%, 10%, 15% and 20% by creating at weld interface. After inserting addition, aluminum Oxide (Al_2O_3) powder which was created, processing the tool rotation at 1800 R.P.M, travel speed 4mm/min and different material thickness 2 to 4mm.

Table -1 Chemical Composition (Weight %) of Al 6061 Aluminum Pipe

Weight %	Al	Si	Fe	Cu	Min	Mg	Cr	Zn	Ti
6061	Ball	0.6	0.70	0.2	0.15	0.80	0.33	0.23	0.12

Table -2 The Mechanical Properties of Al 6061 Aluminum Pipe

Alloy	Ultimate Tensile Strength σ UTS M pa	Elongation EL%	Hardness VHD
6061	252.690	8	86

Design and Construction

Setup friction stir welding: constructed apparatus is mounted on the friction stir welding machine bed to the two workpieces of the studied materials which will be welded by friction stir welding technique, Showing Illustration, Drawing, and Construction Setup friction stir welding for pipe parts show Fig. (1).

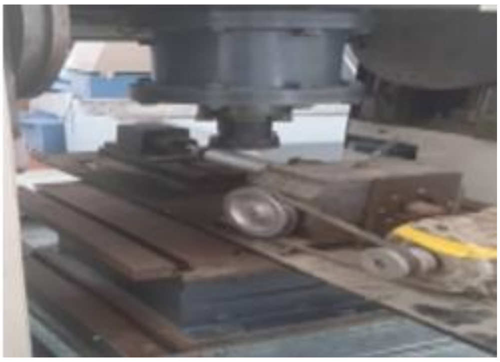

Fig. 1 Friction stir welding machine

Fig. 2 Finished pipe

RESULT AND DISCUSSION

The Visual Testing is very significant, nevertheless neglected by many non-destructive testing personnel. The Visual Inspection is a non-destructive testing style that furnishes a wherewithal of detecting and examining an assortment of surface flaws surface discontinuities on joints. The Visual inspection is also the most exceedingly used methods for detecting and check surface cracks, which are predominately substantial because of their relevance to structural failure mechanisms. Even when other NTD styles are used to detect surface cracks, visual inspection often provides a useful supplement [15-17]. Visual inspection of the external surface of welded specimens showed uniform semi-circular surface undulation, caused by the final sweep of the trailing edge of the rotating tool shoulder over weld nugget, under the effect of probe overhead pressure. It can be seen the finished pipe in Fig. (2).

Tensile Test Results

The outcomes of transverse tensile tests for the weld are summed up in Fig. 3 and Fig. 4. The outcomes of transverse tensile tests for the friction stir welding addition, aluminum oxide powder was added to weld interface and friction stir welding without addition joint that produced welding. The outcomes compared with the tensile properties of friction stir welding with addition and friction stir welding without addition the welding efficiency for friction stir welding have been calculated for friction stir welding experiment (with and without addition). Fig. 5 shows the tensile test results for each different welding thickness with and without addition.

It can be seen from Fig. 3, Fig. 4 Fig. 5 reveals that the ultimate tensile strength each welding thickness of friction stir welded for pipes joint with the addition of weld interface decreases about 42% over the without addition. When the aluminum oxide powder was added to weld interface as an addition, Ultimate was enhanced. By 5% of addition, ultimate was increased by 3.6% for welding thickness compare to without adding. By 10% of addition ultimate were increased by 10.6% for welding thickness incomparable to without adding. By 15% of addition, ultimately were increased by 19.5% for welding thickness in comparing to without adding. By 20% of addition ultimate were increased by 25% for welding thickness in comparing to without adding. By increasing the percentage of addition, aluminum oxide powder as an addition at the weld interface the ultimate tensile strength was increased.

Elongation%

The effect of adding content on the percentage of elongation of Friction stir welded for pipes Joint of Al 6061is shown in from Figs. (6 -8).

Hardness

The hardness value of friction stirs welded for pipes joint increase as the volume percentage of Al_2O_3 at weld interface increases from 5% to 25% in the joint as shown in from Figs. (9-11). The hardness of friction stirs welded joint increased about 19% at weld portion without adding addition Al_2O_3. As the addition at weld interface from 5% to 25% hardness increases about 35%.

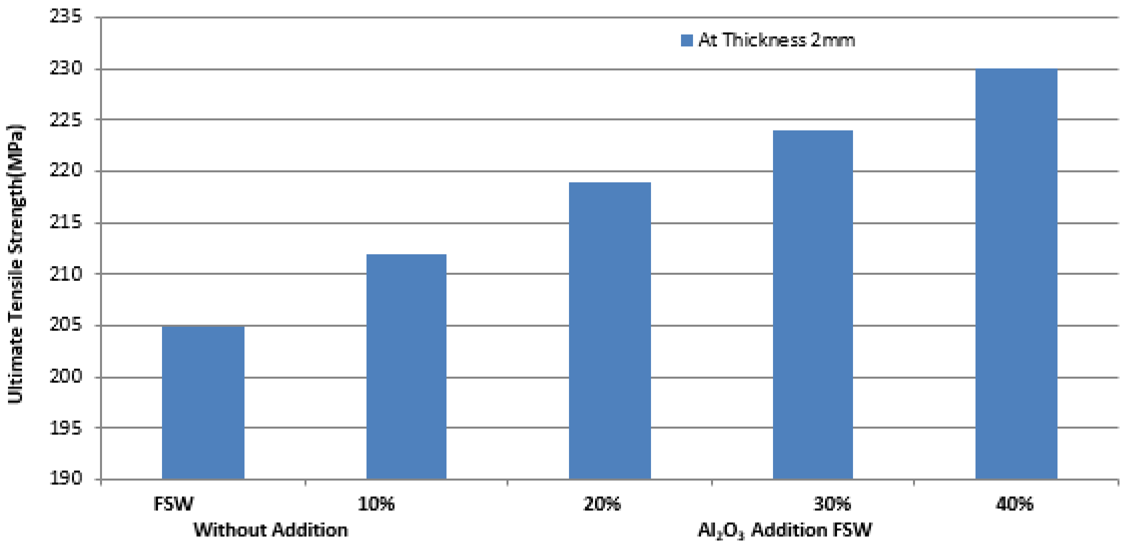

Fig. 3 Relation between ultimate tensile strength and FSW with and without addition of Al6061 (at thickness 2mm)

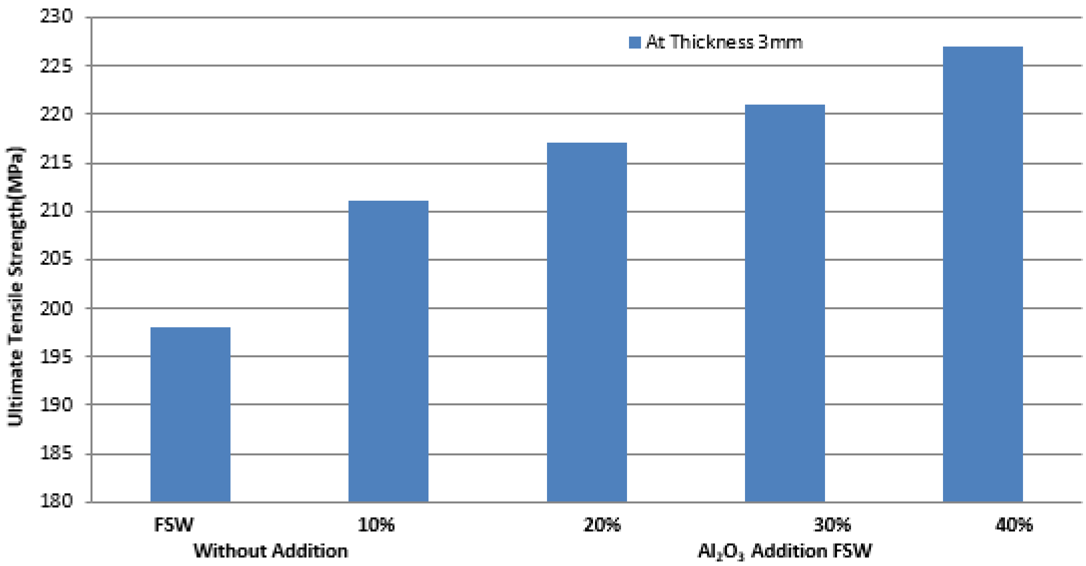

Fig. 4 Relation between ultimate tensile strength and FSW with and without addition of Al6061 (at thickness 3mm)

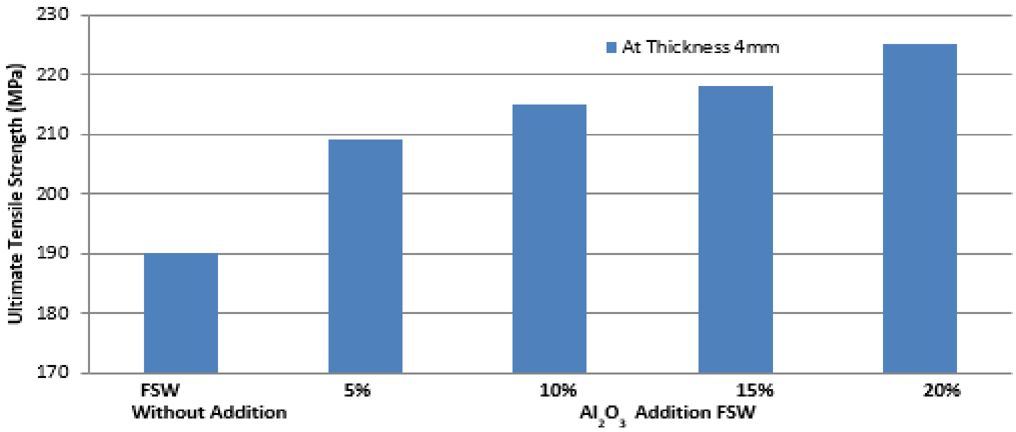

Fig. 5 Relation between ultimate tensile strength and FSW with and without addition of Al6061 (at thickness 4mm)

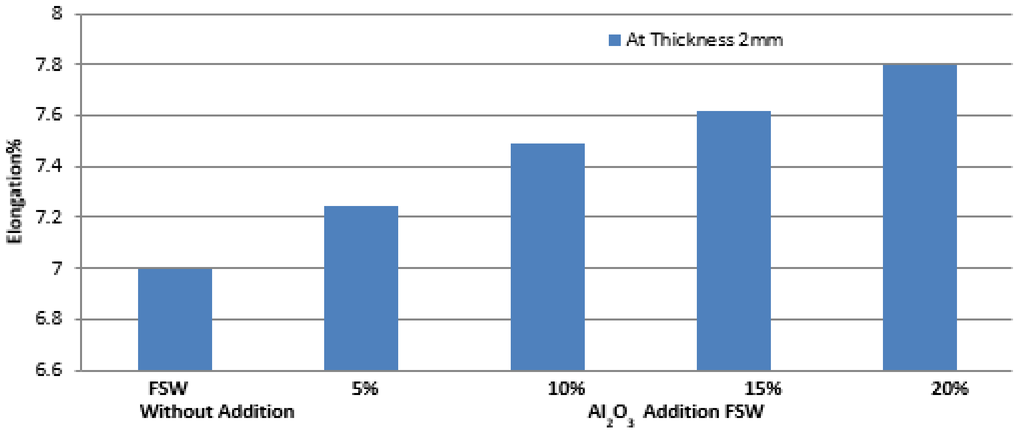

Fig. (6) Relation between elongation and FSW with and without addition of Al6061 (at thickness 2mm)

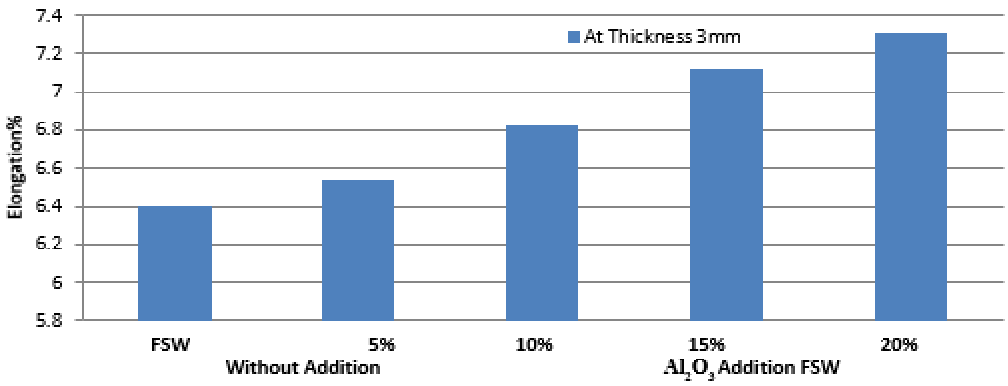

Fig. (7) Relation between elongation and FSW with and without addition of Al6061 (at thickness 2mm)

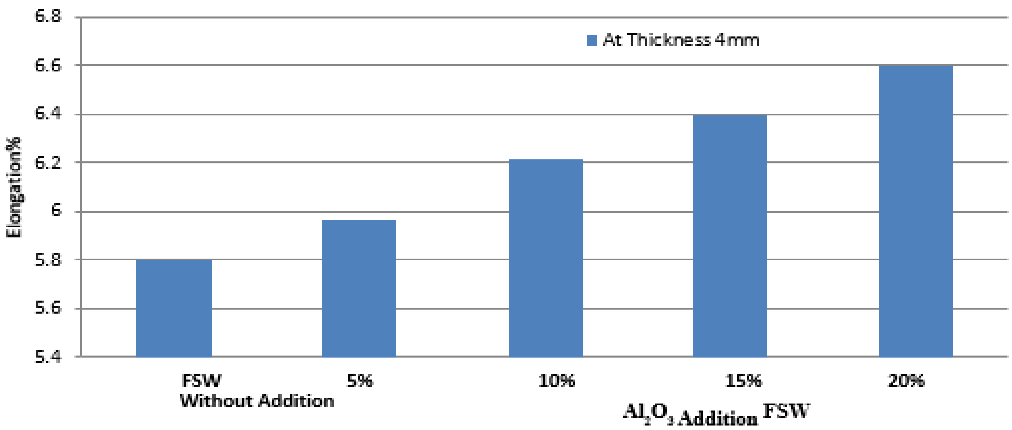

Fig. (8) Relation between elongation and FSW with and without addition of Al6061 (at thickness 2mm)

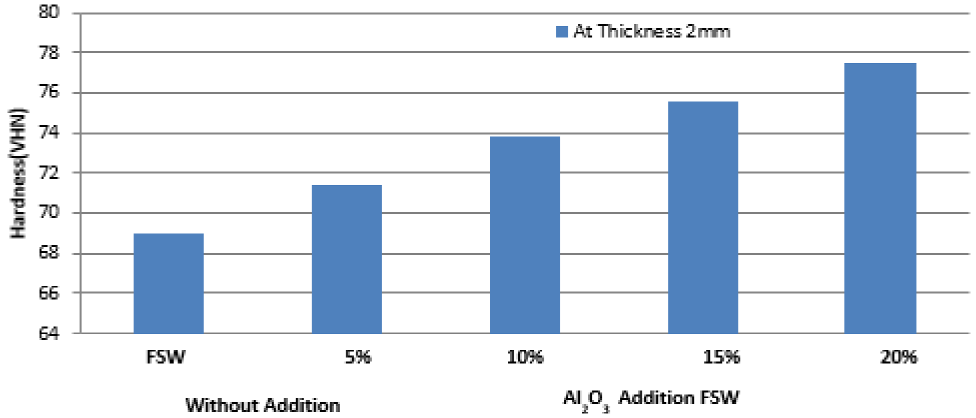

Fig. (9) Relation between hardness and FSW with and without addition of Al6061 (at thickness 2mm)

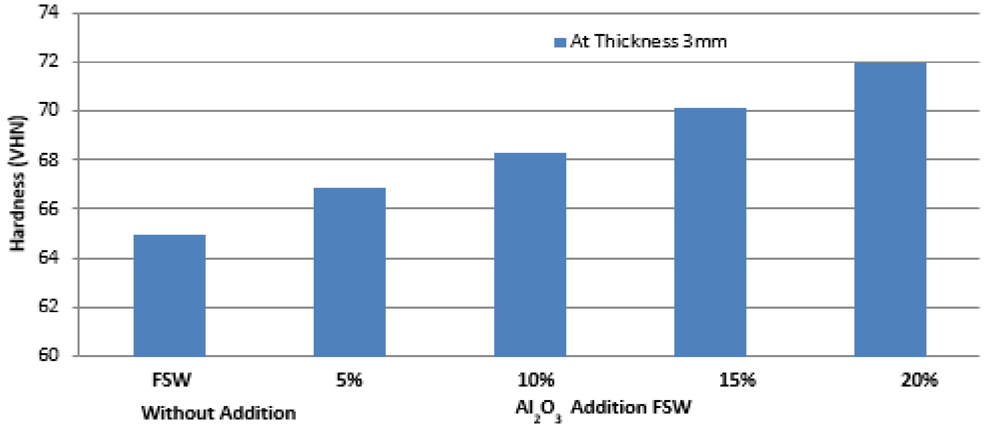

Fig. (10) Relation between hardness and FSW with and without addition of Al6061 (at thickness 3mm)

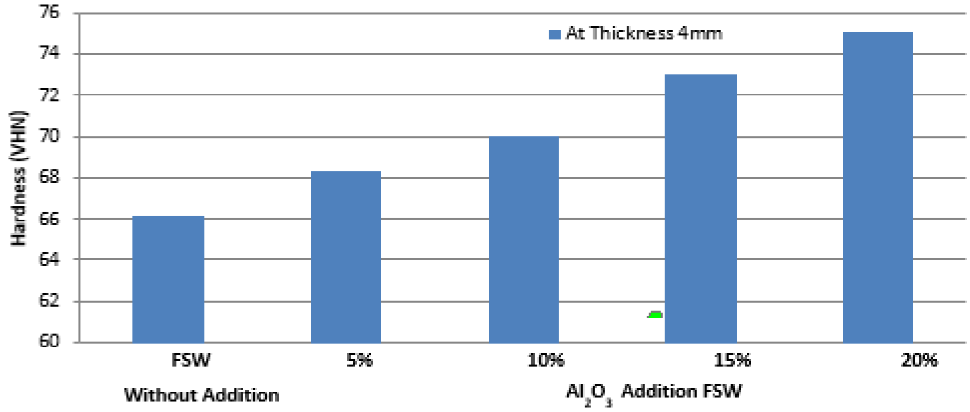

Fig. (11) Relation between hardness and FSW with and without addition of Al6061 (at thickness 4mm)

MATHEMATICAL MODELING

Response Surface Methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for analyzing the problems in which several independent variables influence [18-19]. The objective of the response surface methodology is to find those settings of process parameters that give an optimum value of the response. In addition, it provides a regression model that establishes a relationship between the process parameters and response. This relationship can be used to predict the response when the process parameters are varied within the selected ranges. The regression model geometrically represents the surface, when plotted as response versus any two process parameters. Such plots make it possible to visualize the relation between the response and process parameters. Contour plots for corresponding response surface facilitate visually to locating the process parameter values that give an optimum response [18-20]. The tensile strength, elongation% and hardness of the joints is the function material thickness and addition Aluminum Oxide (Al_2O_3) powder% it can be expressed as (Eq. 1)

$$Y = f\,(T, A) \qquad (1)$$

Where Y-The response. A- Addition of aluminum Oxide (Al_2O_3) powder. T- Material thickness

For the two factors, the selected polynomial (regression) could be expressed as (Eq. 2)

$$y = \frac{1}{\sqrt{K+aM+bA+cM^2+dA^2+eMA}} \quad (2)$$

Where k is the free term of the regression equation, the coefficients a, b,c,d, and e are linear terms showing table 3.

Design-Expert 6.0.8 Software Packages is used to calculate the values of these coefficients for different responses. After determining the coefficients, the mathematical models are developed see (Eq. 3), (Eq. 4) And (Eq. 5). The developed final mathematical model equations in the coded form are given below [11-13]:

$$Tensile\ strength(MPa) = \frac{1}{\sqrt{0.06+7.2E004M-2.9E004A+2.9E005M^2+8.6E006A^2-3.2E005AM}} \quad (3)$$

$$Elongation\% = \frac{1}{\sqrt{0.35+7.2E003M-1.7E003A+1.9E003M^2+7.4E005A^2-1.55E004AM}} \quad (4)$$

$$Hardness\ (VHN) = \frac{1}{\sqrt{0.093+0.019M-3.09E004A-2.9E003M^2+1.4E006A^2-2E005AM}} \quad (5)$$

Table -3 D Estimated Regression Coefficients of Mathematical Models (RSM) (Al 6061 Pipes)

Regression Coefficients	Tensile Strength	Elongation%	Hardness
K	+0.0685	+0.354	+0.093542
a	+7.28E-004	+7.2E-003	+0.019153
b	-2.92E-004	-1.76E-003	-3.092E-004
c	+2.96E-005	+1.9E-003	-2.956E-003
d	+8.61E-006	+7.4E-005	+1.49E-006
e	-3.52E-005	-1.55E-004	-2.0084E-005

Checking for Adequacy of Model

The experimental work value and predicted value of the responses from regression equations are approaching in It seen from Figs. (12-14), which detects that there is a perfect correlation between the experimental value and predicted value of the responses. Which it has been introduced considerations signalize a very good sufficiency of the suggestion regression models. It can be seen from Figs. (15-17) The relation between total error and tensile strength, elongation, and hardness. All the coefficients were evaluated and tested by applying 'F-test' using Design-Expert software for their significance at a 95% confidence level. After locating the significant coefficients, the final suggestion model was developed to predict the ultimate tensile strength, elongation, and hardness of FSW joints of 6061 aluminum pipe as given below in Figs. (12-14).

Optimization of parameters of FSW on responses

One of the most substantial objectives of this realization was to maximize the tensile strength, elongation % and hardness of friction stir welded joints, pipes of Al 6061 and also, find the optimum process parameters from the suggested model developed. We feel that numerical optimization Such describes multiple response methods called desirability this method used to solve multiple response optimization problems, combines multiple responses into a dimensionless measure of performance called the overall desirability function.the desirability ranges between 0 and1.The suggestion model predicted optimal results from above technique are a tensile strength, elongation % and hardness that can be obtained, are 230 Mpa, 7.8% and 77.8 respectively. The acquired desirability value of 0.477. It can be seen from Fig. (18.a-b)

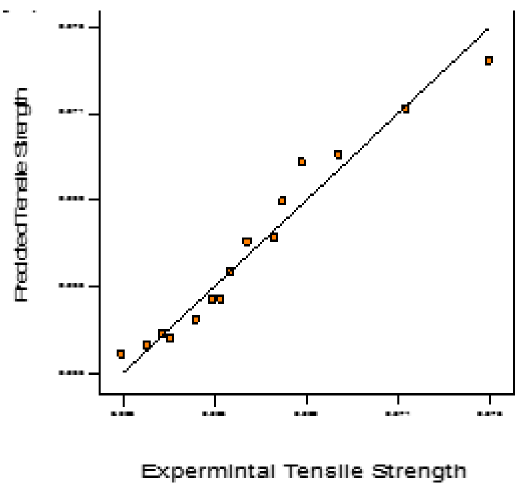

Fig. (12) Relation between experimental tensile strength and predicted tensile strength

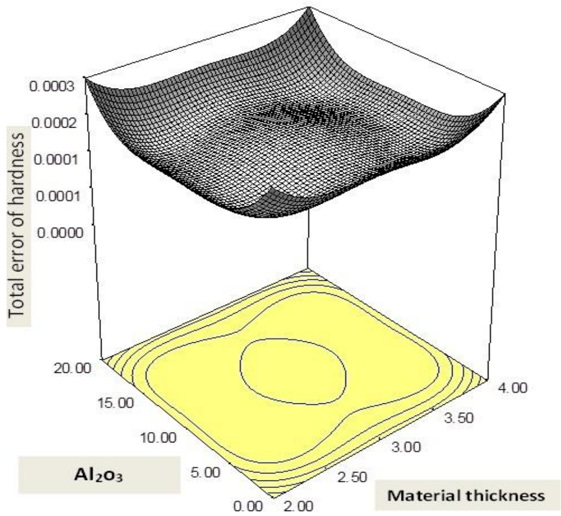

Fig. (15) Relation between total errors of tensile strength, Aluminium Oxide (Al_2O_3) powder %, and material thickness

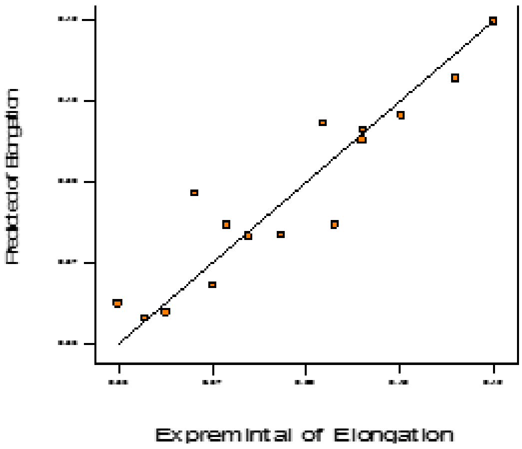

Fig. (13) Relation between experimental elongation% and predicted elongation%

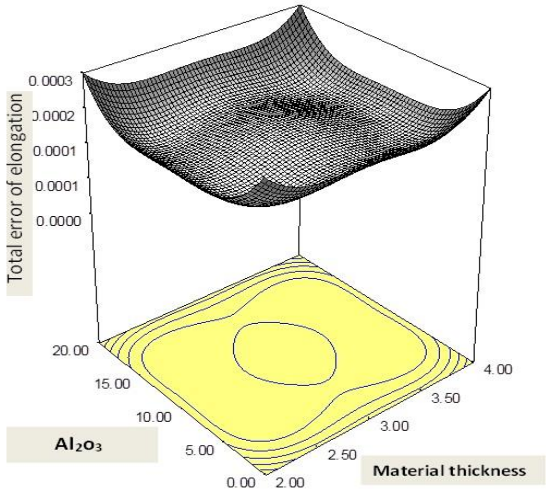

Fig. (16)Relation between total errors of elongation, Aluminium Oxide (Al_2O_3) powder %and material thickness

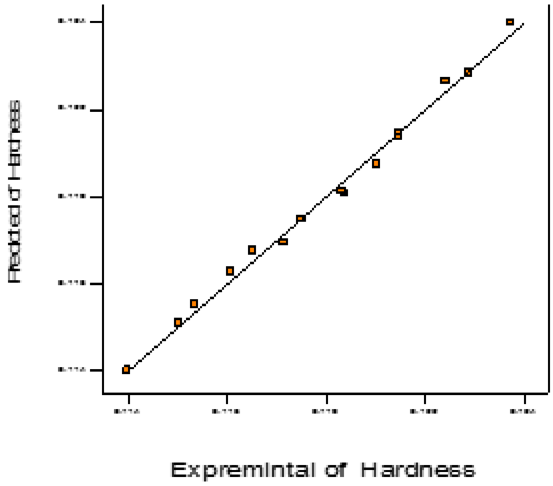

Fig. (14) Relation between experimental hardness and predicted hardness

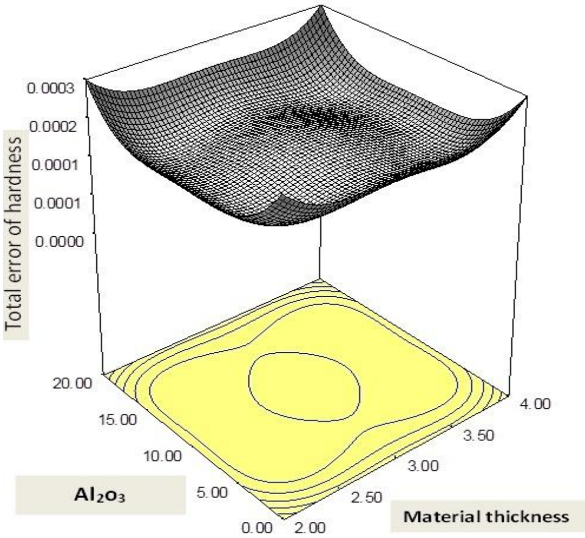

Fig. (17)Relation between total errors of hardness, Aluminium Oxide (Al_2O_3) powder%, and material thickness

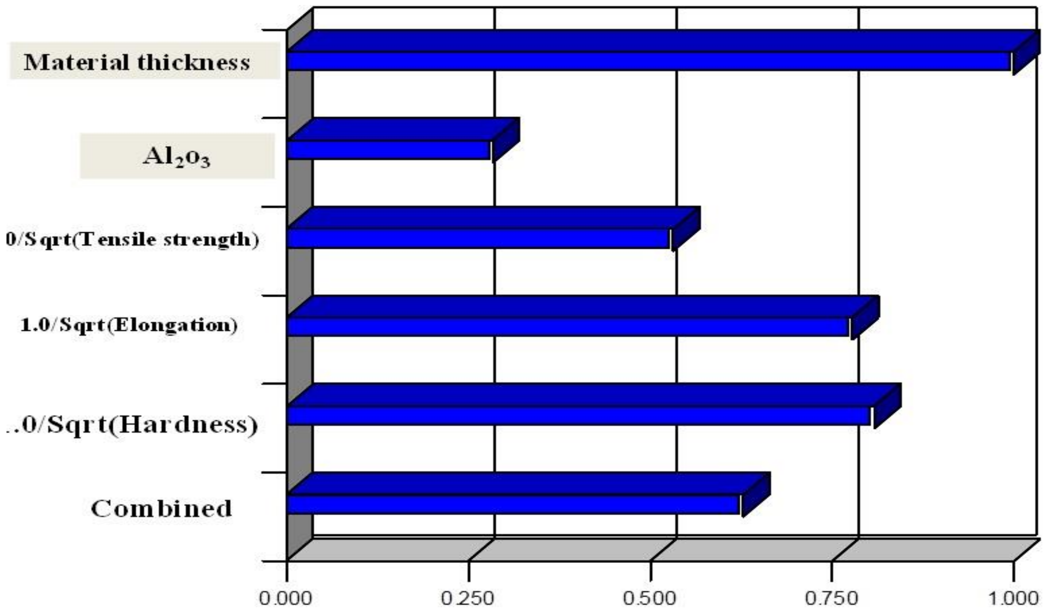

Fig. 18 (a) Bar graph showing the maximum desirability of 0.641 for the combined objective

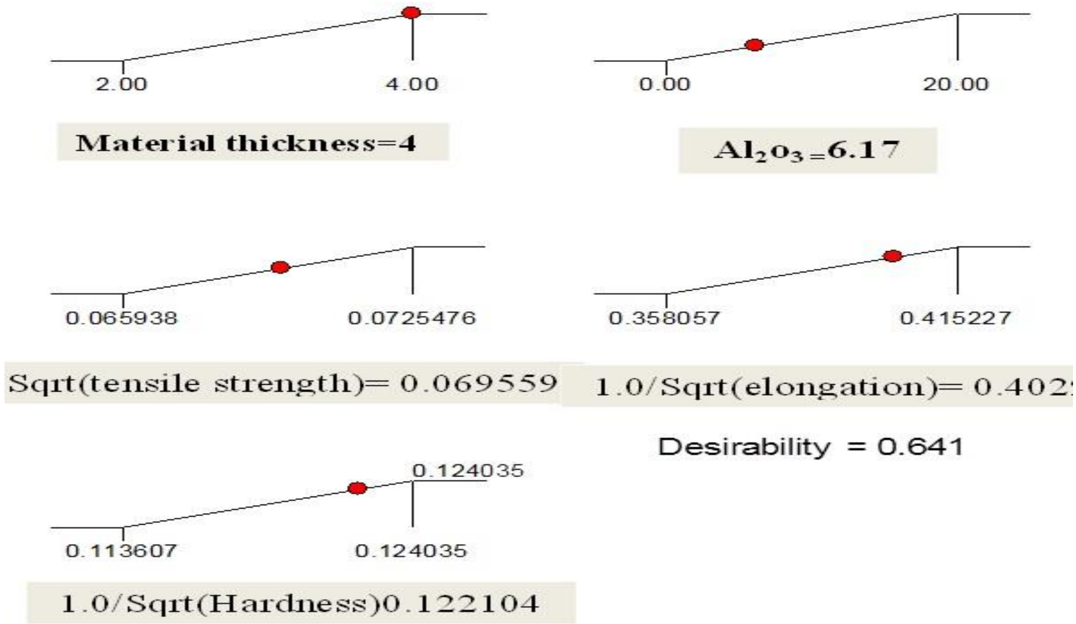

Fig. 18 (b) Bar graph showing the maximum desirability of 0.477 for the combined objective

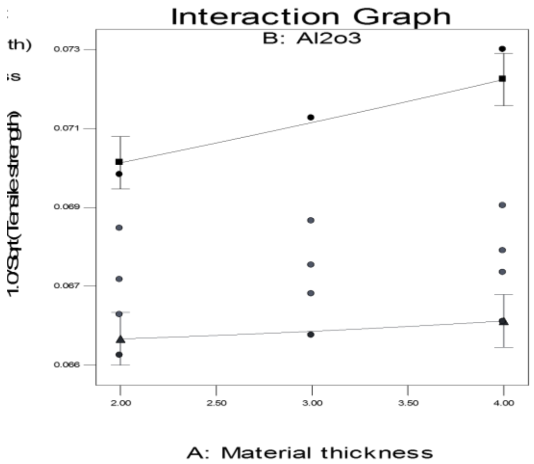

Fig. 19 Interactive effects of material thickness and Aluminum Oxide (Al_2O_3) powder% on tensile strength

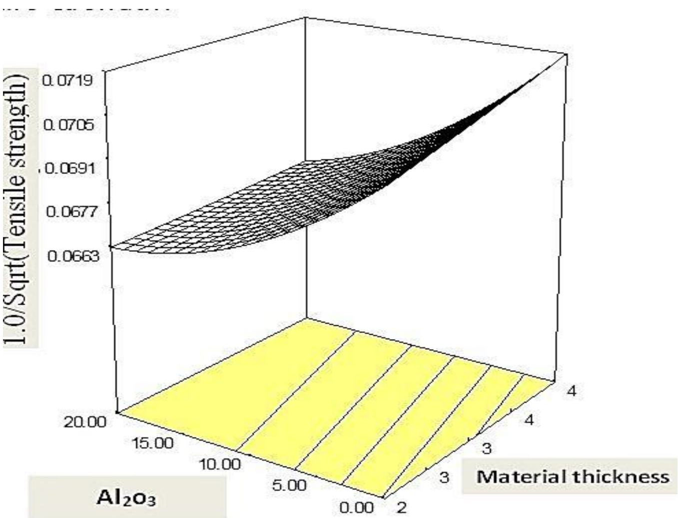

Fig. 22 Surface plot for Interactive effect of material thickness and (Al_2O_3) powder% on tensile strength

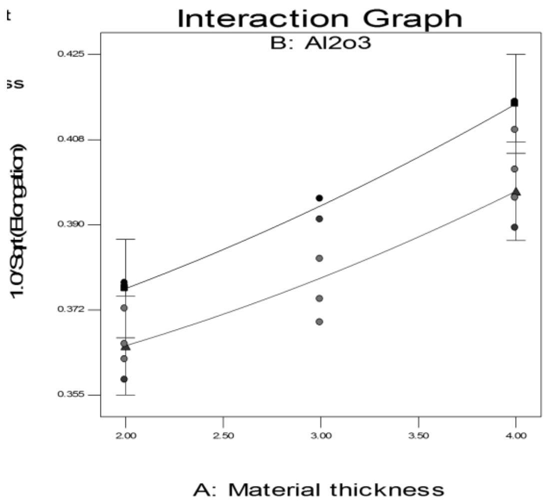

Fig. 20 Interactive effects of material thickness and Aluminum Oxide (Al_2O_3) powder% on elongation

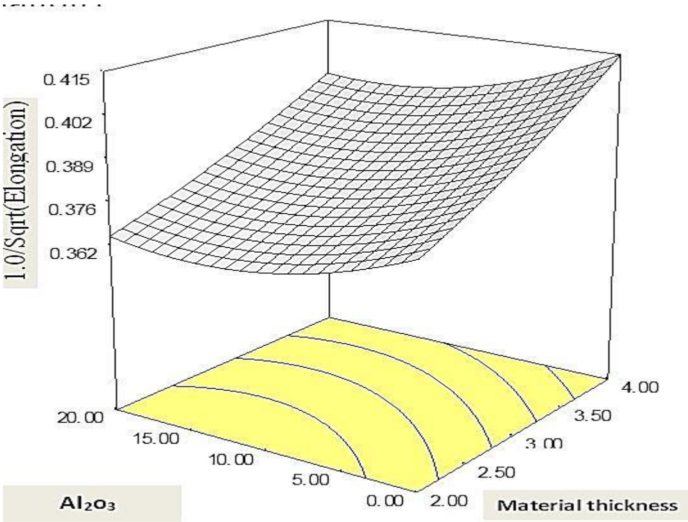

Fig. 23 Surface plot for Interactive effect of material thickness and (Al_2O_3) powder% on elongation

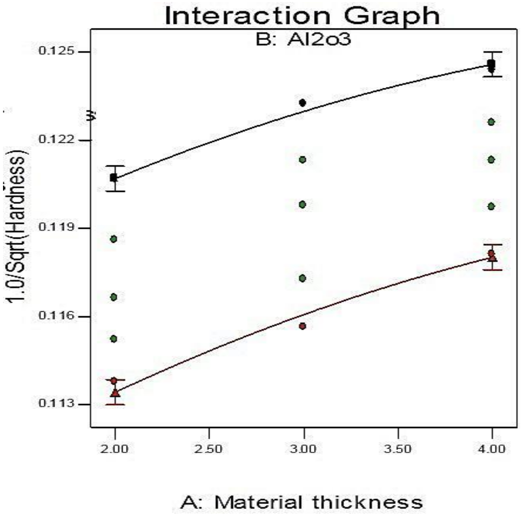

Fig. 21 Interactive effects of material thickness and Aluminum Oxide (Al_2O_3) powder% on hardness

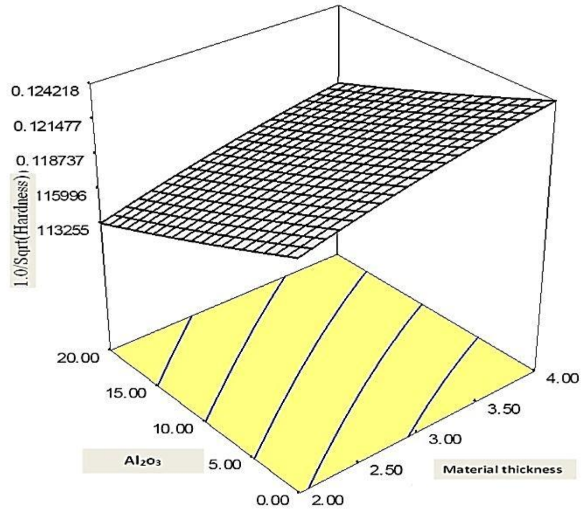

Fig. 24 Surface plot for Interactive effect of material thickness and (Al_2O_3) powder% on hardness

Influence of Material Thickness and Aluminum Oxide (Al2O3) Powder % on Tensile Strength, Elongation, and Hardness

It can be seen from Fig. (19), Fig. (20) and Fig. (21) The interaction effect of material thickness and Aluminum Oxide (Al_2O_3) powder% on the tensile strength, elongation, and hardness. The tensile strength increases from 205 to 230 (Mpa) with increase Aluminum Oxide (Al_2O_3) from 5% to 20%. However, the elongation increases from 7% to 7.8% with increase Aluminum Oxide (Al_2O_3) from 5% to 20%. The hardness increases from 69 to 77.48 (VHN) with increase Aluminum Oxide (Al_2O_3) from 5% to 20%. It can be seen from Fig. (22), Fig. (23) and Fig. (24) Surface plot for tensile strength, elongation% and hardness due to interaction effect on the material thickness and Aluminum Oxide (Al_2O_3) powder%

Tensile Strength Calculator

To estimate the tensile strength, elongation, and hardness of friction stir welded for pipe joints for different combinations of process parameters, a program to calculate the mechanical properties of the design of friction stir welding aluminum pipes using the programming language c ++.

Graphical Results for Tensile Strength, Elongation%, and Hardness

The Aluminum Oxide (Al2O3) is directly proportional to the tensile strength, elongation and hardness of the weld. The maximum tensile strength of the weld is also seen when the process parameter rotational speed and set at a higher level in the process window. Thus the Aluminum Oxide (Al2O3) at 20% level is the best possible level for the desired responses considered. It can be seen from Fig. (24) Main effects plot for actual experimental tensile strength and Aluminum Oxide (Al2O3) and material thickness. The material thickness plays a major role in affecting the tensile strength of the welded joints. The material thick-ness with flat surfaces is associated with eccentricity, which allows the material to flow around the pin. The tapered pin profile produces the pulsating action as the ratio between the static volumes to the dynamic volume is more than one.

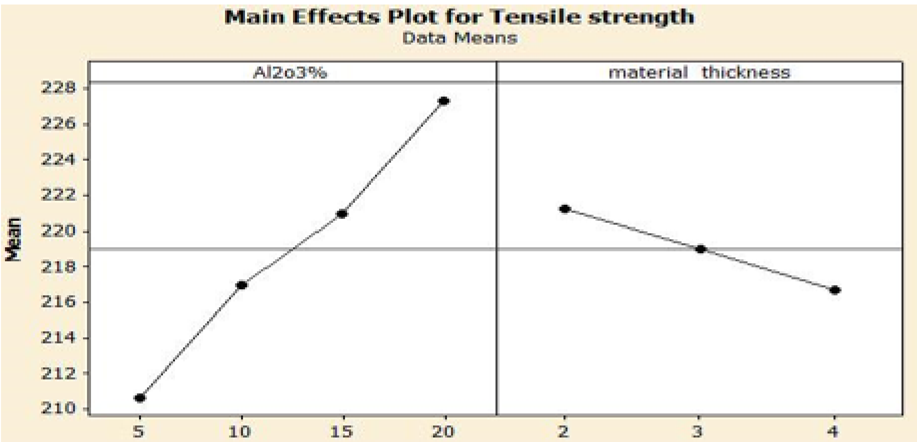

Fig. 25 Main effects plot for experimental tensile strength (T.S) values

CONCLUSIONS

The effect of added aluminum Oxide (Al2O3) to weld interface on friction stir welding of aluminum pipes have been investigated. The results obtained from this study can be summarized as follows:

- The Mechanical properties of friction stir welding aluminum pipes 6061 increases with increase addition aluminum Oxide (Al_2O_3) powder.
- The Proposed model is adequate at 96% confidence level, thus justifying the use of assumed polynomials.
- The RSM suggestion model has been developed for the prediction of tensile strength, elongation, and hardness as a function aluminum Oxide (Al_2O_3) powder and material thickness. The models have been proved to be successful in terms of the agreement with experimental results ratio 96.6%.

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