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Original Research Article

Experimental Investigation of Friction Stir Welding of Aluminium Alloys Using Response Surface Methodology

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Abstract: Friction stir welding (FSW) uses a non-consumable tool to produce frictional heat in the adjoining surfaces. The welding parameters like rotational speed, welding speed, tool pin length, and tool shoulder diameter play a major role in deciding the joint properties. In this work, an attempt has been made to analyse the effect of various tool profiles have been used to fabricate joints by using constant thickness (3mm) work piece of aluminium alloy. The mechanical properties of welded materials are measured in terms of tensile strength. With the help of vertical milling machine create the specimen by friction stir welding (FSW). Now using universal testing machine on which tensile testing of the welded specimen was carried out. After that by using design of experiment (DOE)concept. Experimentally were carried out to predict tensile strength of the welded joint. After comparison of predicted and practical values of tensile strength conclude that with increase in pin length tensile strength increase contently and tool geometry with a large shoulder diameter together with high welding speed leads to decrease in welds speed leads to decrees' in tensile strength of the welds work pieces.
Keywords: aluminium alloy 6063-TS, friction stir welding, RSM.

INTRODUCTION

Friction stir welding (FSW), a solid-state welding process has gained much popularity in research areas as well as manufacturing industries since its inception in 1991. For nearly two decades, FSW has found its applications in aerospace and marine industries as well as in high precision applications such as micro welding. The basic physics behind a solid state welding process is the joining of work pieces without arriving at the melting point of the work pieces, thereby requiring lower heat input for welding process. This is a major advantage of FSW over conventional fusion welding processes where high heat input is required to melt the work material. The FSW makes it possible to join lightweight materials like aluminium alloy, magnesium alloy, etc. which are difficult to weld using conventional welding processes. These advantages have appreciably increased the usage of these materials in structural applications. In addition, FSW also makes possible to produce sound welds in 5000 and 7000 series aluminium alloys which cannot be welded by conventional welding processes. In FSW, no sparks or flames are produced. Therefore, safety and environmental issues are not a major concern. FSW process provides good quality and strong weld joints with less number of equipment and eliminates the use of filler metal. Due to these factors, FSW has been successfully utilized in aerospace and ship building industries. The need to understand and improve FSW process continues to promulgate in many applications.

From much literature we select the metal aluminium alloy 6063-TS which has good weld ability for FSW aluminium plate of 3mm thickness were cut to 50mm*70mm rectangle for suitability for conventional milling machine. Tool dimension and material play very important role of FSW. The tool is made of mild steel. From the literature we come to know that tool rpm, welding speed, shoulder diameter and pin length play very important role of the tool design so we taking 4 input parameters. After that with the conversional milling machine we prepare the specimen with FSW after that universal testing machine is used for tensile strength. Total number of 30 experiment ware performed experimentally including all the combination of the four independent parameter experimental runs generated through design expert stactical software with response surface methodology after finding the 30 experiment we will compare the both values.

LITERATURE REVIEW

The friction stir welding makes it possible to join light weight material like aluminium alloy, magnesium alloy, etc. which are difficult to weld using conventional welding process. These advantages have appreciable increased the uses of these materials in structural application and many researchers have been to focus on FSW[1]. In this study, Al 1080 alloy materials were welded using friction stir welding process. The influence of stirrer design on the welding process was investigated. For this purpose, five different stirrers, one of them square cross-sectioned and the rest were cylindrical with 0.85, 1.10, 1.40 and 2.1 mm screw pitched were used to carry out welding process. Bonding could be affected with the square, 0.85 and 1.10 mm screw pitched stirrers. Microscopic examination of the weld zone and the tension test results showed that the best bonding was obtained with 0.85 mm screw pitched stirrer. In addition, temperature distribution within the weld zone was also determined [2]. Friction stir welding (FSW) is a new and promising welding process that can produce low-cost and high-quality joints of heat-treatable aluminum alloys because it does not need consumable filler materials and can eliminate some welding defects such as crack and porosity. In order to demonstrate the friction stir weldability of the 2017-T351 aluminum alloy and determine optimum welding parameters, the relations between welding parameters and tensile properties of the joints have been studied in this paper. The experimental results showed that the tensile properties and fracture locations of the joints are significantly affected by the welding process parameters. When the optimum revolutionary pitch is 0.07 mm/rev corresponding to the rotation speed of 1500 rpm and the welding speed of 100 mm/min, the maximum ultimate strength of the joints is equivalent to 82% that of the base material. Though the voids-free joints are fractured near or at the interface between the weld nugget and the thermo-mechanically affected zone (TMAZ) on the advancing side, the fracture occurs at the weld center when the void defects exist in the joints[3]. The effect of different shoulder geometries on the mechanical and microstructural properties of a friction stir welded joints have been studied in the present paper. The process was used on 6082 T6 aluminium alloy in the thickness of 1.5 mm. The three studied tools differed from shoulders with scroll and fillet, cavity and fillet, and only fillet. The effect of the three shoulder geometries has been analysed by visual inspection, macrograph, HV microhardness, bending test and transverse and longitudinal room temperature tensile test. The investigation results showed that, for thin sheets, the best joint has been welded by a shoulder with fillet and cavity[4]. AA6061 aluminium alloy (Al-Mg-Si alloy) has gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to-weight ratio and good corrosion resistance. Compared to the fusion welding processes that are routinely used for joining structural aluminium alloys, the friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. This process uses a non-consumable tool to generate frictional heat in the abutting surfaces. The welding parameters such as tool rotational speed, welding speed, axial force etc., and the tool pin profile plays a major role in deciding the weld quality. In this investigation an attempt has been made to understand the effect of axial force and tool pin profiles on FSP zone formation in AA6061 aluminium alloy. Five different tool pin profiles (straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square) have been used to fabricate the joints at three different axial force levels. The formation of FSP zone has been analysed macroscopically. Tensile properties of the joints have been evaluated and correlated with the FSP zone formation. From this investigation it is found that the square tool pin profile produces mechanically sound and metallurgically defect free welds compared to other tool pin profiles [5]. AA2219 aluminium alloy has gathered wide acceptance in the fabrication of light weight structures requiring a high strength to weight ratio. Compared to the fusion welding processes that are routinely used for joining structural aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. This process uses a non-consumable tool to generate frictional heat in the abutting surfaces. The welding parameters and tool pin profile play major roles in deciding the weld quality. In this investigation, an attempt has been made to understand the effect of welding speed and tool pin profile on FSP zone formation in AA2219 aluminium alloy. Five different tool pin profiles (straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square) have been used to fabricate the joints at three different welding speeds. The formation of FSP zone has been analysed macroscopically. Tensile properties of the joints have been evaluated and correlated with the FSP zone formation. From this investigation it is found that the square pin profiled tool produces mechanically sound and metallurgically defect free welds compared to other tool pin profiles[6]. In this study, the different heat-treated-state 2024 Al-alloys were friction stir welded. The tensile properties of the joints have a tendency to increase with the precipitation hardening of the base material. The peak tensile properties have been obtained in the T6 (100 _C – 10 h) joint. It is observed that the weld zone is strengthened by the friction stir welding process for the 2024-O joint. The fracture regions are detected near the nugget for W joint, the interface between the nugget and the thermo mechanically affected zone for T4 and T6 joints and base material for O joint[7]. Friction stir welding (FSW) is a novel solid state welding process for joining metallic alloys and has emerged as an alternative technology used in high strength alloys that are difficult to join with conventional techniques. The applications of FSW process are found in several industries such as aerospace, rail, automotive and marine industries for joining aluminium, magnesium and copper alloys. The

FSW process parameters such as rotational speed, welding speed, axial force and attack angle play vital roles in the analysis of weld quality. The aim of this research study is to investigate the effects of different welding speeds and tool pin profiles on the weld quality of AA6082-O aluminium. This material has gathered wide acceptance in the fabrication of lightweight structures requiring a high strength-to-weight ratio. Tri-flutes and taper screw thread pin are used as tool pin profiles in this research. The appearance of the weld is well and no obvious defect is found using these tools. Consequently, the obtained results explain the variation of stress as a function of strain and the effect of different welding speed and pin profiles on yield strength ultimate tensile strength and elongation. The friction stir welded plates of AA6082-O by using the taper screw thread pin profile reaches the ultimate tensile strength of 92.30% of the base metal ultimate strength and % elongation of 27.58% [8]. The aircraft aluminium alloys generally present low weld ability by traditional fusion welding process. The development of the friction stir welding has provided an alternative improved way of satisfactorily producing aluminium joints, in a faster and reliable manner. In this present work, the influence of process and tool parameters on tensile strength properties of AA7075-T6 joints produced by friction stir welding was analysed. Square butt joints were fabricated by varying process parameters and tool parameters. Strength properties of the joints were evaluated and correlated with the microstructure, microhardness of weld nugget. From this investigation it is found that the joint fabricated at a tool rotational speed of 1400 rpm, welding speed of 60 mm/min, axial force of 8 kN, using the tool with 15 mm shoulder diameter, 5 mm pin diameter, 45 HRc tool hardness yielded higher strength properties compared to other joints [9]. Currently friction stir welding tools are designed by trial and error. Here we propose and test a criterion for the design of a tool shoulder diameter based on the principle of maximum utilization of supplied torque for traction. The optimum tool shoulder diameter computed from this principle using a numerical heat transfer and material flow model resulted in best weld metal strength in independent tests and peak temperatures that are well within the commonly encountered range [10]. Friction stir welded joints of Al–Zn–Mg aluminium alloy AA7039 were given five different post weld heat treatments in order to investigate their effect on microstructure and mechanical properties. In general, all the applied post weld heat treatments increased the size of an aluminum grains in all zones of friction stir weld joints. Abnormal grain growth was observed in entire zone modified by friction stir welding in case of solution treated joints with and without artificial aging. The naturally aged joints offered the highest mechanical properties while solution treated joints offered lowest mechanical properties of the joints. Naturally aged joints yielded highest tensile strength (94.9%) and elongation (174.2%) efficiencies while artificially aged joints yielded highest yield strength efficiency (96.7%). Further, post weld heat treatment also affected fracture location and mode of fracture [11]. Friction stir linear welding (FSLW) uses a non consumable tool to generate frictional heat in the abutting surfaces. The welding parameters such as rotational speed, welding speed, axial force, tool tilt angle, etc., and tool pin profiles play a major role in deciding the joint properties. In this paper, an attempt has been made to study the effect of four different tool pin profiles on mechanical properties of AA 6061 aluminum alloy. Four different profiles have been used to fabricate the butt joints by keeping constant process parameters of tool rotational speed 1200RPM, welding speed 14mm/min and an axial force 7kN. Different heat treatment methods like annealing, normalizing and quenching have been applied on the joints and evaluation of the mechanical properties like tensile strength, percentage of elongation, hardness and microstructure in the friction stirring formation zone are evaluated. From this investigation, it is found that the hexagonal tool profile produces good tensile strength, percent of elongation in annealing and hardness in quenching process[12]. The joining of dissimilar AA2024 and AA6061 aluminium plates of 5mm thickness was carried out by friction stir welding (FSW) technique. Optimum process parameters were obtained for joints using statistical approach. Five different tool designs have been employed to analyse the influence of rotation speed and traverse speed over the microstructural and tensile properties. In FSW technique, the process of welding of the base material, well below its melting temperature, has opened up new trends in producing efficient dissimilar joints. Effect of welding speed on microstructures, hardness distribution and tensile properties of the welded joints were investigated. By varying the process parameters, defect free and high efficiency welded joints were produced. The ratio between tool shoulder diameter and pin diameter is the most dominant factor. From micro structural analysis it is evident that the material placed on the advancing side dominates the nugget region. The hardness in the HAZ of 6061 was found to be minimum, where the welded joints failed during the tensile studies [13]. Friction stir welding (FSW) uses a non consumable tool to produce frictional heat in the adjoining surfaces. Then welding parameters like rotational speed, welding speed, tool pin length, and tool shoulder diameter play a major role in deciding the joint properties. In this work, an attempt has been made to analyze the effect of various tool profiles on mechanical properties of aluminum alloy. Various tool profiles have been used to fabricate joints by using constant thickness (3mm) work piece of aluminum alloy. The mechanical properties of welded materials are measured in-terms of tensile strength and Brinell hardness number (BHN). By using Design of Experiment (DOE) concept, experiments were carried out to predict tensile strength and BHN of the welded joint. In this work, heat generated during the process is utilized to improve the quality of welded joint by using backing plate (low thermal conductivity or insulating material) between workpiece and fixture. By varying the welding parameters, effect on joining efficiency in terms of gap between two mating surfaces on the back side of the welded plate has been analyzed. From this investigation, it has been found that tool profile (shoulder dia. 18 mm, pin length 2.8 mm) produces good tensile strength.

From the literature review, the following areas are identified in which future work is needed to be carried out. Limited study has been done in the pin length variation with shoulder diameter variation of tool for same thickness of work piece in FSW. Various tools have been used for the process parameters but use of different tool length. Limited study has been done to relate pin length variation with indentation quality.

METHODOLOGY

On the basis of literature review, still there is a need to strengthen friction stir welding for light weight and low melting temperature materials. Implementation of such a strengthened friction stir welding requires proper instrumentation to analyse the welded specimen. To increase the strength of the friction stir welding, it is important to control parameters used during the friction stir welding process. The motive of this work is to achieve high quality strength of the welded joint by controlling the parameters when welding is taking place. There for eat tempt has been made to improve the strength of the welded specimen by applying statistical analysis

Materials

Aluminum alloy 6063-T6, which has good weldability for FSW, was used. Aluminum plate of 3mm thickness was cut to 50mmx70mm rectangle whose chemical composition is listed inTable1.

Table 1: chemical composition

Component	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Wt.%	Max. 97.5	Max. 0.1	Max. 0.1	Max. 0.35	0.45-0.9	Max. 0.1	0.2-0.6	Max. 0.1	Max. 0.1

Experimental setup

Experimental setup was established using a conventional vertical milling machine Figure 1. No extra setup is required for friction stirwelding except tool and fixture, so as to place piece in proper position during welding.

The specimen is fixed in the machine between the grips and machine the displacement between its cross heads on which the specimen is fixed. The objective of tensile testing was to determine the tensile yield strength and percentage of yield elongation of friction stir welds of aluminium alloys.

Fig.1: Experimental Setup

Design of Experiment

Response surface methodology is concerned with a set of statistical and mathematical techniques that are useful for designing, developing, improving and optimizing the process under study. RSM has widely been used in the field of industry and chemical engineering to study the yield or output of a system as it varies in response to the changing levels of one or more applied factors [2]. The main emphasis was on the use of designs of experiments and regression analysis to investigate a particular response produced by a given set of input variables over a specified region of interest; to explore the level of input variables that give a specified response and to model the information in adequate functional form, so that the shape of response surfaces at its optimum point is identified. The role of RSM is to work as a set of techniques that consists of the following steps:

i. Determination of a sequence of experiments that provide adequate and reliable values of the response variables under study.
ii. Finding the relationship between response and a suitable independent factor (variables).
iii. Locating optimum response of the process by changing the levels of the input variables ξ_, ξ_ ……. ξ_ that can be viewed as design variables.

Factors are the processing conditions or input variables whose values (or levels) can be controlled for performing the experiments e.g. diameter, bend and speed etc. The word level means the value of input variables or factors examined in the experiment.

Experiments, which are particularly designed to explore response surfaces, are called response surface designs. They are particularly used to predict the model. The form and order of approximating polynomial depends on the postulated model. Usually first and second order models are used.

There are many different second order design e.g. Central composite cuboidal design, central composite orthogonal design, central composite rotatable design, central composite minimum variance design, central composite mini-max loss3 design and Box-Behukent design.

The suitability of the second order model is based upon the following:

i. It is a flexible model which can be used to generate the curvilinear response surface and to draw contour plots. The estimation of parameters is simple which is obtained through ordinary least squares method.
ii. The second model is very useful in solving real response surface problems.
iii. In the case of missing observations, it is used to measure the losses in central composite designs.

The statistical experimental designs extensively used in optimization of experiments are referred as "response surface designs." In addition to the trials at extreme level settings of the variables, response surface designs also contain trials in which one or more variables is/are set at the midpoint of the study range. Thus, these designs provide information on direct effects, on pair wise interaction effects and on curvilinear variable effects. Response surface methodology, an approach to product and process optimization, derives its name from the extensively used optimization experiment designs. Most of the practitioners of RSM now obtain their experimental designs and analyse the data using statistical software running on a personal computer. Many of this software can generate various classes of RSM designs and, in some cases, can also offer several varieties of each class. However, the central composite design is the most popular of all the RSM

A design which consists of two levels factorial or fractional factorial is chosen so as to allow the estimation of all first order and two factor interaction terms augmented with further points which allow pure quadratic effects to be estimated is called central composite design (CCD). Three types of central composite design (CCD), depending on the location of star points are:

1. Central Composite Circumscribed (CCC) Design
2. Central Composite Inscribed (CCI) Design
3. Central Composite Face (CCF) Centred Design

In this thesis, a face centred design is used because it requires only three levels of the factor sand in practice; it is frequently difficult to change factor level. However, a Face centred central composite design is not rotatable. CCF designs provide relatively high quality predictions over the entire design space and do not require using points outside the original Factor range [2].

The choice of the distance of axial points (ζ) from the centre of the design is important to make a central composite design (CCD) rotatable. The value of ζ for rotatability of the design scheme is estimated as $\zeta = (2)^{f*1/4}$But in (CCF) face centred ζ =1. The number of experiments is estimated as

$$N = 2^{f} + 2 * f + n_c$$

Where,
N=number of the experiment
f= number of the factor
n_c= number of centre point

In the experiment where f=4, nc=6 . The number of experiments in a CCD matrix corresponding to three process variables is calculated as $2^{4} + (2 * 4) + 6 = 30$.

Table 2

Input Parameter	Level		
	-1	0	1
Shoulder dia. (mm)	20	18	16
Pin length (mm)	2.8	1.9	1
Tool RPM	1600	1200	800
Welding speed (mm/min)	100	80	60

Level of Independent variables

Response Surface Methodology (RSM)

Response surface methodology has been used to develop the regression model. Regression models have been developed using 30 experimental runs as per desired central composite rotatable experimental design shown in Table 2. In central composite face centred design, the response of the system and the input parameters are taken to have the following relationships:

$$Y = \beta_0 + \sum_{i=1}^{K} \beta i\, Xi + \sum_{i=1}^{K} \beta ii\, Xi^2 + \sum\sum_{i<j} \beta ij\, XiXj \dots \dots \dots \dots$$

Above equation expanded to:
Y=β0+β1X1+β2X2+β3X3+β4X4+β5 X12+ β6X13+β7X14+β8X23+β9X24+β10X34+β11X1 2+ β12 X22+ β13 X32 + β14 X42 ……………………..…….Eq. (1)

Where:
β0= constant X1 = Shoulder dia.
β1, β2, β3,β4 = linear coefficients X2 = Pin length
β11, β12, β13, β14= quadratic coefficients X3 = Tool RPM
β5, β6, β7, β8, β9, β10= cross product coefficients X4= Welding speed

Regression equation has been developed using equation 1 to predict the response.
1. Regression equation for tensile strength:
Ts=(-275.458) + (14.657*S) + (77.622*P) + (0.079*T) + (2.976*F) - (0.748*S*P) + (0.003*S*T) - (0.0218*S*F) -(0.007*P*T) - (0.098*P*F) + (0.002*T*F) - (0.303*S2)-(6.437*P2)-(0.003*T2)-(0.016*F2) ………………..…Eq. (2)

Table 2 shows the predicted response using regression Eq. (2) from the Response surface methodology (RSM) designing a set of experiments which are analysed to identify the optimal conditions, the factors that influence the results, selecting the number of experiments to be performed under controlled conditions. Develop the regression model. Regression models have been developed using 30 experimental runs as per desired central composite rotatable experimental design. Table shows the predicted values.

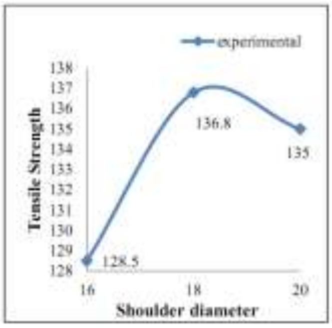
A total number of 30 experiments were performed to include all combinations of the four independent parameters (table1). Table shows list of experimental runs generated through Design expert statistical software. These are the friction stir welding conditions in sequence for friction welding.

Table 3

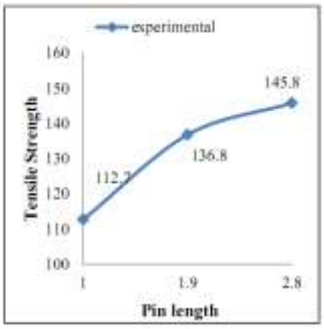
Experiment no.	Input parameter				Predicted values of specimen	Experimental values of specimen
	Shoulder dia.	Pin length	Tool RPM	Welding speed		
1	20	2.8	800	60	139.87	138.6
2	16	1	1600	60	92.229	90.5
3	20	1	1600	60	100.992	100.6
4	18	1.9	1200	80	135.007	136.4
5	18	1.9	1200	80	135.007	132.8
6	18	1.9	1200	80	137.7	136.8
7	20	2.8	1600	100	139.3	128
8	16	2.8	1600	100	139.442	141.4
9	20	2.8	1600	60	137.371	139.4
10	16	2.8	800	100	134.514	135.2
11	18	1.9	1600	80	132.975	132.1
12	16	2.8	1600	60	134.761	136.8
13	18	1.9	1200	60	128.5	129.11
14	16	1	800	60	84.606	86.2
15	16	1	800	100	88.467	88.5
16	18	1	1200	80	108.795	112.7
17	18	1.9	1200	80	135.007	136.6
18	16	1	1600	100	104.236	105.8
19	18	2.8	1200	80	144.008	145.8
20	20	1.9	1200	80	135.77	135
21	18	1.9	1200	100	130.005	129.3
22	20	1	800	60	92.63	91.7
23	20	2.8	800	100	133.653	136.43
24	20	1	800	100	93.759	91
25	18	1.9	800	80	126.34	125.9
26	18	1.9	1200	80	135.007	136
27	18	1.9	1200	80	136.007	136.4
28	16	1.9	1200	80	128.932	128.5
29	16	2.8	800	60	137.999	137.8
30	20	1	1600	100	110.267	110.5

After performing experiments tensile strength is measured with the help of universal testing machine (UTM). With the help of response surface methodology, results relating input parameters and output are shown graphically. Design expert statistical software is used which defines input factors (such as shoulder diameter, pin length, tool RPM and welding speed)with their values and tensile strength as a response. Results have been plotted as shown in graph 1 to 4.

In graph1, Effect of shoulder diameter on tensile strength is shown where tensile strength increases with increase in shoulder diameter up to 18mm due to large surface area but in case of 20mm shoulder diameter more heat generation results in coarse structure hence, tensile strength decreases.



Graph 1

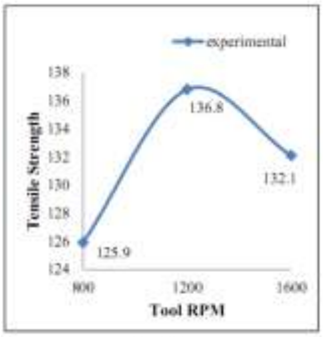


Graph 2

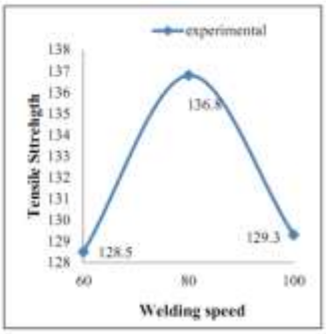
Effect of pin length on tensile strength is shown in graph 2, where tensile strength is continually increasing with increasing pin length due to more penetration of pin in the work pieces and produces more frictional heat throughout the thickness of work piece and plasticizes the material.

Effect of tool RPM on the tensile strength is shown in graph 3 where tensile strength increases up to a certain level then decreases due to more heat generation, which causes grains to become coarse.

Effect of welding speed on tensile strength is shown in graph.4, where tensile strength is lower at initial level due to more heat generation which results in coarse grain structure and at high welding speed lower frictional heat is generated resulting in poor plastic flow and defect generation.



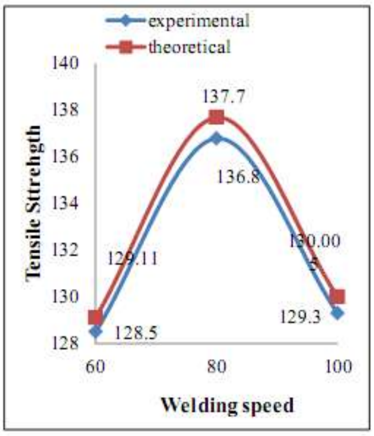
Graph 3



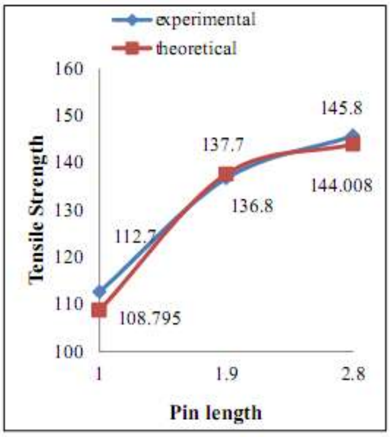
Graph4

Comparison of experimental and model value for various responses- now after got all the practical and experimental values we will compared the all values and plot the curves.

Experimental and theoretical values of tensile strength with variation in welding speed. (Graph 5)



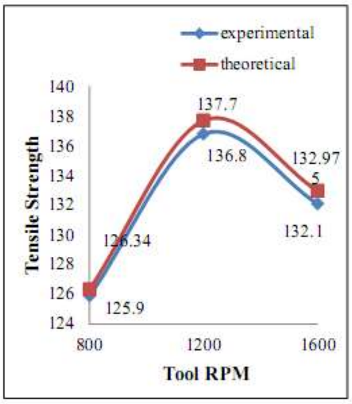
Graph 5



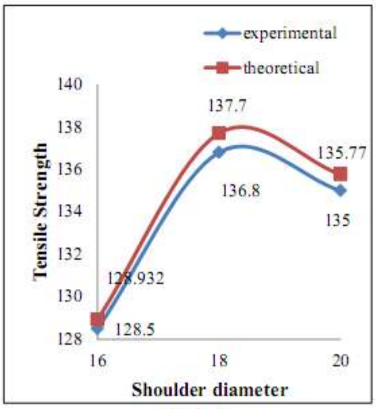
Graph 6

Experimental and theoretical values of tensile strength with variation in pin length. (Graph 6)

Experimental and theoretical values of tensile strength with variation in tool RPM. (graph7)



Graph 7



Graph 8

Experimental and theoretical values of tensile strength with variation in shoulder Diameter.(graph8)

RESULTS AND DISCUSSION

The error rate of this model is calculated. Maximum error in case of tensile strength has been reported at medium level for shoulder diameter, welding speed and tool RPM and at lower level for pin length. The calculated value of error is 0.26% for the tensile strength. The error is within 5% which is acceptable for regression model.

CONCLUSION

Tensile strength response is investigated by varying input parameters such as shoulder diameter (mm), length of pin (mm), tool speed (RPM) welding speed (mm/min) which affect the performance of friction stir welding under normal running condition. Experiments were conducted according to Central Composite Face Cantered Design with various combinations of parameters, so as to determine the combination which produces sound weld quality in friction stir welding. Regression model was developed to predict the tensile strength. The experimental values were used to develop the regression modal. The experimentally determined tensile strength values were compared with values predicted by the regression model and the model is proved to be capable of predicting tensile strength within the acceptable margin of error. The following conclusions have been made out.

1. Regression analysis has been successfully used to develop the relation between input parameters and tensile strength.
2. The dominant factor affecting tensile strength is pin length (mm) with increase in pin length tensile strength increases constantly.
3. A tool geometry with a large shoulder diameter together with a high welding speed leads to decrease in tensile strength of the welded work pieces.

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