Process & Parameters of Friction Stir Welding

Prashant Pratap Mall[1],
[1]Research Scholar,
Modern Institute of Engineering & Technology,
Kurukshetra, Haryana (India)

Jitender Panchal[2]
[2]Assistant Professor,
Mechanical Engineering Department,
Modern Institute of Engineering & Technology,
Kurukshetra, Haryana (India)

***Abstract*-The tensile strength of Friction Stir Welded (FSW) joints was significantly affected by welding speed and shoulder diameter whereas welding speed strongly affected percentage elongation. If special focus on friction stir welding (FSW) modelling on the heat generation due to the contact conditions between the FSW tool and the work piece is consideredthenthermo-mechanical conditions during FSW are very different from that registered during welding of metals which leads to completely different material flow mechanisms and weld defect analysis.**

I. INTRODUCTION

In 1991, Friction Stir Welding (FSW) was invented by Wayne Thomas at The Welding Institute. In this process, a tool which is cylindrical shouldered with a profiled pin is rotated and goes into the joint area between two pieces of the material. The parts have to be clamped safely to prevent the joint from separation. Frictional heat between the wear resistant welding tool and the work pieces resultsthe latter to soften without attaining melting point, which allows the tool to traverse along the weld line. The plasticized material, transferred to the trailing edge of the tool pin, is counterfeit through thr contact with the tool shoulder and pin profile. When it is cooled, a solid phase is formed between the work pieces. Friction Stir Welding process can be used to join aluminium sheets and plates.

MATERIAL USED FOR FSW

There are some studies that have shown that cast to cast and cast to extruded (wrought) combinations in similar and dissimilar aluminium alloys are equally possible. The following aluminium alloys could be successfully welded to yield reproducible high integrity welds within defined parametric tolerances:

2000 series aluminium (Al-Cu),3000 series aluminium (Al-Mn),4000 series aluminium (Al-Si),5000 series aluminium (Al-Mg),6000 series aluminium (Al-Mg-Si),7000 series aluminium (Al-Zn),8000 series aluminium (Al-Li).

Other Materials

The technology of friction stir welding has been extended to other materials also, on which researches are going on. Some of them are as follows- Copper and its alloys, Lead, Titanium and its alloy, Magnesium and its alloys, Zinc, Plastics and Mild steel.

II LITERATURE SURVEY

Following literature survey has been summarized here under

Hwang et al. (2010) experimentally explore the thermal history of a work piece undergoing Friction Stir Welding (FSW) involving butt joining with pure copper C11000. In the FSW experiments, K-type thermocouples were used to record the temperature history at different locations on work piece. This data, combined with the preheating temperature, tool rotation speeds and tool moving speeds allowed parameters for a successful weld to be determined. Vickers hardness tests were conducted on the welds to evaluate the hardness distributions in the thermal–mechanical affected zone, heat affected zone and the base metal. Tensile tests were also carried out, and the tensile strength of the welded product was compared to that of the base metal. The appropriate temperatures for a successful FSW process were found to be between 460 ◦C and 530 ◦C. These experimental results and the process control of temperature histories can offer useful knowledge for a FSW based process of copper butt joining.

The thermal histories in a C11000 copper work piece were determined experimentally during a Friction Stir Welding (FSW) butt joining process. The appropriate temperatures for a successful FSW process were found to be between 460 ◦C and 530 ◦C. The temperature sonthe advancing side were slightly higher than those on the retreating side. The tensile strength and the hardness at the TMAZ were about 60% of the base metal, whereas, the elongation can reach three times that of the base metal, assuming appropriate temperature control. These experimental results, and the process control of temperature histories, can offer useful knowledge for a FSW process of copper butt joining.

Kanwer S. Arora et al. (2010) in this research, successful friction stir welding of aluminium alloy 2219 using an adapted milling machine is reported. The downward or forging force was found to be dependent upon shoulder diameter and rotational speed whereas longitudinal or welding force on welding speed and pin diameter. Tensile strength of welds was significantly affected by welding speed and shoulder diameter whereas welding speed strongly affected percentage elongation. Metallographic studies revealed fine equiaxed grains in weld nugget and micro structural changes in thermo-mechanically affected zone were found to be the result of combined and interactive influences of frictional heat and deformation. A maximum joining efficiency of 75% was obtained for welds with reasonably good percentage elongation. TEM studies indicated coarsening and/or dissolving of precipitates in nugget. For the gas metal arc weld, SEM investigations revealed segregation of copper at grain boundaries in partially melted zone.

Tozak et al. (2010) newly developed tool for friction stir spot welding (FSSW) has been proposed, which has no probe, but a scroll groove on its shoulder surface (scroll tool). By use of this tool, FSSW has been performed on aluminium alloy 6061-T4 sheets and the potential of the tool was discussed in terms of weld structure and static strength of welds. The experimental observations showed that the scroll tool had comparable or superior performance to a conventional probe tool. It was confirmed that sound welding could be achieved without a probe hole, in which the scroll groove played significant roles in the stirring of the material and the shoulder plunge depth was the important processing variable. The maximum tensile shear strength of the welds made by the scroll tool was found to be 4.6kN that was higher than that of the welds made by the probe tool and two different fracture modes, shear fracture and plug fracture, appeared depending on processing condition. The shear fracture took place at smaller shoulder plunge depths or at shorter tool holding times, while the plug fracture occurred at larger shoulder plunge depths or at longer tool holding times. It was indicated that the tensile-shear strength and associated fracture modes were determined by two geometrical parameters in the weld zone.

S. Rajakumar et al. (2011) observed that AA6061 aluminium alloy has gathered wide acceptance in the fabrication of light weight structures requiring high strength-to-weight ratio and good corrosion resistance. 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 FSW process and tool parameters play a major role in deciding the joint strength. Joint strength is influenced by grain size and hardness of the weld nugget region. Hence, in this investigation an attempt was made to develop empirical relationships to predict grain size and hardness of weld nugget of friction-stir-welded AA6061 aluminium alloy joints. The empirical relationships are developed by response surface methodology incorporating FSW tool and process parameters. A linear regression relationship was also established between grain size and hardness of the weld nugget of FSW joints.

Kumaran et al. (2011) In this research numerous advancements have been occurring in the field of materials processing. Friction welding is an important solid-state joining technique. In this research project, friction welding of tube-to-tube plate using an external tool (FWTPET) has been performed, and the process parameters have been prioritized using Taguchi’s L27 orthogonal array. Genetic algorithm (GA) is used to optimize the welding process parameters. The practical significance of applying GA to FWTPET process has been validated by means of computing the deviation between predicted and experimentally obtained welding process parameters.

*Elangovan et al. (2012)*The researchers in this paper focuses on the development of an effective methodology to determine the optimum welding conditions that maximize the strength of joints produced by ultrasonic welding using response surface methodology (RSM) coupled with genetic algorithm (GA). RSM is utilized to create an efficient analytical model for welding strength in terms of welding parameters namely pressure, weld time, and amplitude. Experiments were conducted as per central composite design of experiments for spot and seam welding of 0.3- and 0.4-mm-thick Al specimens. An effective second-order response surface model is developed utilizing experimental measurements. Response surface model is further interfaced with GA to optimize the welding conditions for desired weld strength. Optimum welding conditions produced from GA are verified with experimental results and are found to be in good agreement.

Mariano et al. (2012) presents a literature review on friction stir welding (FSW) modelling with a special focus on the heat generation due to the contact conditions between the FSW tool and the work piece. The physical process is described and the main process parameters that are relevant to its modelling are highlighted. The contact conditions (sliding/sticking) are presented as well as an analytical model that allows estimating the associated heat generation. The modelling of the FSW process requires the knowledge of the heat loss mechanisms, which are discussed mainly considering the more commonly adopted formulations. Different approaches that have been used to investigate the material flow are presented and their advantages/drawbacks are discussed. A reliable FSW process modelling depends on the fine tuning of some process and material parameters. Usually, these parameters are achieved with base on experimental data. The numerical modelling of the FSW process can help to achieve such parameters with less effort and with economic advantages.

ZHANG (2012) studied that, the thermal modelling of underwater friction stir welding (FSW) was conducted with a three-dimensional heat transfer model. The vaporizing characteristics of water were analyzed to illuminate the boundary conditions of underwater FSW. Temperature dependent properties of the material were considered for the modelling. FSW experiments were carried out to validate the calculated results, and the calculated results showed good agreement with the experimental results. The results indicate that the maximum peak temperature of underwater joint is significantly lower than that of normal joint, although the surface heat flux of shoulder during then underwater FSW is higher than that during normal FSW. For underwater joint, the high-temperature distributing area is dramatically narrowed and the welding thermal cycles in different zones are effectively controlled in contrast to the normal joint.

Guo (2013) Studied that the Dissimilar AA6061 and AA7075 alloy have been friction stir welded with a variety of different process parameters. In particular, the effects of materials position and welding speed on the material flow, microstructure, micro hardness distribution and tensile property of the joints were investigated. It was revealed that the material mixing is much more effective when AA6061 alloy was located on the advancing side and multiple vortexes centres formed vertically in the nugget. Three distinct zones with different extents of materials intercalations were identified and the formation mechanism of the three zones was then discussed. Grain refinement was observed in all three layers across the nugget zone with smaller grains in AA7075 Al layers. All the obtained joints fractured in the heat-affected zone on the AA6061 Al side during tensile testing, which corresponds very well to the minimum values in micro hardness profiles. It was found that the tensile strength of the dissimilar joints increases with decreasing heat input. The highest joint strength was obtained when welding was conducted with highest welding speed and AA6061 Al plates were fixed on the advancing side. To facilitate the interpretation, the temperature history profiles in the HAZ and at zones close to TMAZ were also measured using thermocouple and simulated using a three-dimensional computational model.

Liu a (2013) In their research, the 4 mm thick 6061-T6 aluminium alloy was self-reacting friction stir welded at a constant tool rotation speed of 600 r/min. The specially designed self-reacting tool was characterized by the two different shoulder diameters. The effect of welding speed on microstructure and mechanical properties of the joints was investigated. As the welding speed increased from 50 to 200 mm/min, the grain size of the stir nugget zone increased, but the grain size of the heat affected zone was almost not changed. So-called band patterns from the advancing side to the weld centre were detected in the stir nugget zone. The strengthening meta-stable precipitates were all diminished in the stir nugget zone and the thermal mechanically affected zone of the joints. However, considerable amount of b0 phases, tending to reduce with increasing welding speed, were retained in the heat affected zone. The results of transverse tensile test indicated that the elongation and tensile strength of joints increased with increasing welding speed. The defect-free joints were obtained at lower welding speeds and the tensile fracture was located at the heat affected zone adjacent to the thermal mechanically affected zone on the advancing side.

Simoes a, (2013) their work describes the thermo-mechanical conditions during Friction Stir Welding (FSW) of metals have already been subject of extensive analysis and thoroughly discussed in literature, in which concerns the FSW of polymers, the information regarding this subject is still very scarce. In this work, an analysis of the material flow and thermo-mechanical phenomena taking place during FSW of polymers is performed. The analysis is based on a literature review and on the examination of friction stir welds, produced under varied FSW conditions, on polymethyl methacrylate (PMMA). Due to the high transparency of this polymer, it was possible to analyse easily the morphological changes induced by the welding process on it. Results of the weld morphologic analysis, of the residual stress fields in the different weld zones and of temperature measurements during welding are shown, and its relation with welding conditions is discussed. From the study it was possible to conclude that, due to the polymers rheological and physical properties, the thermo-mechanical conditions during FSW are very different from that registered during welding of metals, leading to completely different material flow mechanisms and weld defect morphologies.

Ni (2014) observed that the Thin sheets of aluminium alloy 6061-T6 and one type of Advanced high strength steel, transformation induced plasticity (TRIP) steel have been successfully butt joined using friction stir welding (FSW) technique. The maximum ultimate tensile strength can reach 85% of the base aluminium alloy. Inter-metallic compound (IMC) layer of FeAl or Fe3Al with thickness of less than 1 lm was formed at the Al–Fe interface in the advancing side, which can actually contribute to the joint strength. Tensile tests and scanning electron microscopy (SEM) results indicate that the weld nugget can be considered as aluminium matrix composite,which is enhanced by dispersed sheared-off steel fragments encompassed by a thin inter-metallic layer or simply inter-metallic particles. Effects of process parameters on the joint microstructure evolution were analyzed based on mechanical welding force and temperature that have been measured during the welding process.

I. AIM OF THE OBJECTIVES

The objective of this research is to do thermal analysis of friction stir welding to optimize the chosen parameters of it by using RSM and to perform experimentation on Friction Stir Welding (FSW).This optimization will results in increase in quality of welding and decrease in defects.

II. METHODOLOGY

The response surface designsare types of designs for fitting response surface. Therefore, the objective of studying RSM can be accomplish by

1. Understanding the topography of the response surface (local maximum, local minimum, ridge lines), and
2. Finding the region where the optimal response occurs. The goal is to move rapidly and efficiently along a path to get to a maximum or a minimum response so that the response is optimized.

Introduction of Experimental Set-Up

The 21 experiments were carried out on a CNC vertical milling machine.

Fig. 1 CNC Machine

Fixture:-
The fixture is used for clamping the plates and we have fitted four nuts on each side for holding the plates

Length of the fixture =20cm

Width of the fixture=12.7cm

Distance between the upper and lower plates =3 cm

No. Of nuts used=4

Fig. 2 Fixture

Tool:-A tool is used for FSW welding on CNC vertical milling machine and the material of tool is high carbon steel.

Dimensions of tool:-

Total length of tool =19.63cm

Tool shoulder diameter =2cm

Tool pin diameter =0.6cm

Fig. 3Tool

Preparation of Specimens
Two aluminium alloy plates of size 100mm×63.5mm×6mm size plates are mounted on the fixture of vertical milling machine for making butt joint by using friction stir welding process as shown in figure 4.

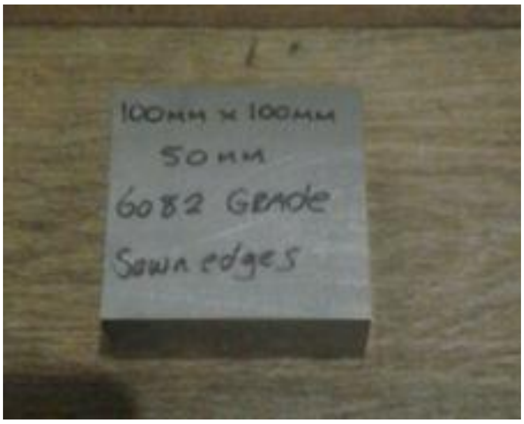

Fig.4 AA Plate before welding

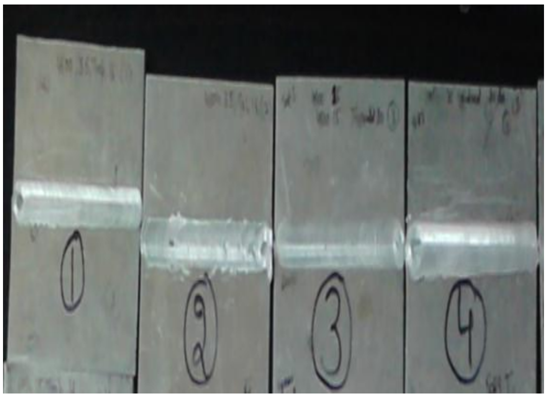

Fig.5 AA Plates after welding

Ultimate Tensile Strength:
Ultimate tensile strength (UTS) is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is not the same as compressive strength but the values can be quite different.

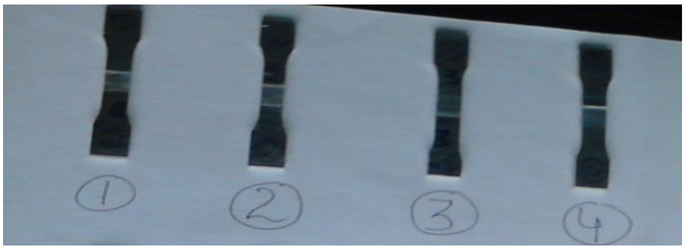

Fig. 6 specimen tested on UTM.

Response Surface Design
The FSW chosen for the optimizations of Ultimate tensile strength. The measuring devices attached to the machine are non-contact type digital thermometer for the measurement of temperature of weld.

Model Diagnostic Plots
Graphical summaries for case statistics can be seen by selecting the Diagnostics button. Most of the plots display residuals, which show you how well the model satisfies the assumptions of the analysis of variance. By default, the software shows the studentized form of residuals.

Normal Probability:The normal probability plot indicates whether the residuals follow a normal distribution, in which case the points will follow a straight line. Expect some scatter even with normal data. Look only for definite patterns, which indicates that a transformation of the response may provide a better analysis.

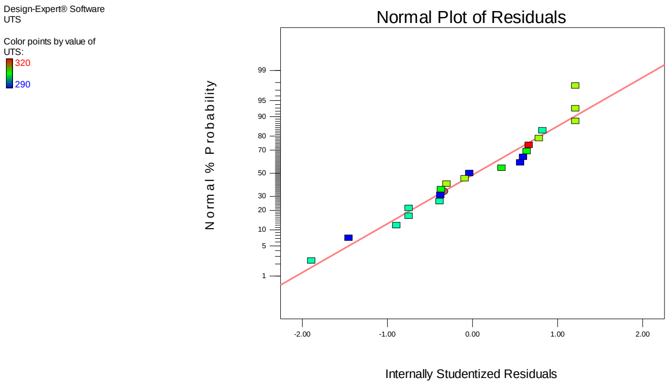

Fig 7Normal Probability

Residuals vs. Predicted:This is a plot of the residuals versus the ascending predicted response values. It tests the assumption of constant variance. The plot should be a random scatter (constant range of residuals across the graph.) Expanding variance ("megaphone pattern <") in this plot indicates the need for a transformation.

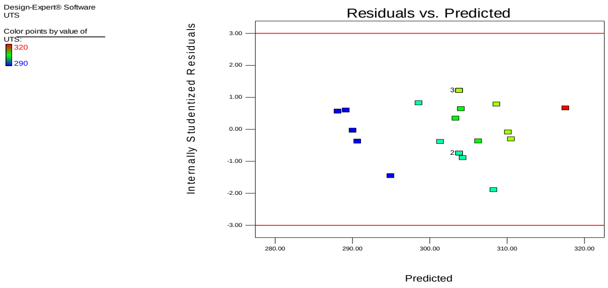

Fig 8Residuals vs. Predicted

Predicted vs. Actual: A graph of the predicted response values versus the actual response values. It helps you detect a value, or group of values, that are not easily predicted by the model.

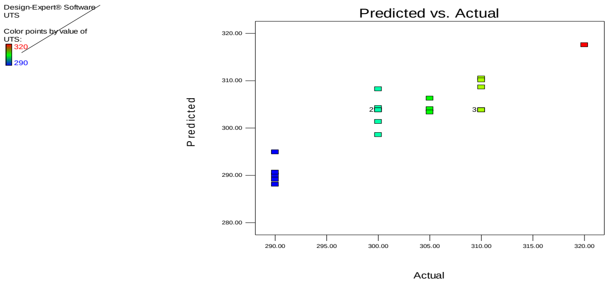

Fig 9Predicted vs. Actual

Box-Cox Plot for Power Transforms:

This plot provides a guideline for selecting the correct power law transformation. A recommended transformation is listed, based on the best lambda value, which is found at the minimum point of the curve generated by the natural log of the sum of squares of the residuals. If the 95% confidence interval around this lambda includes 1 then the software does not recommend a specific transformation.

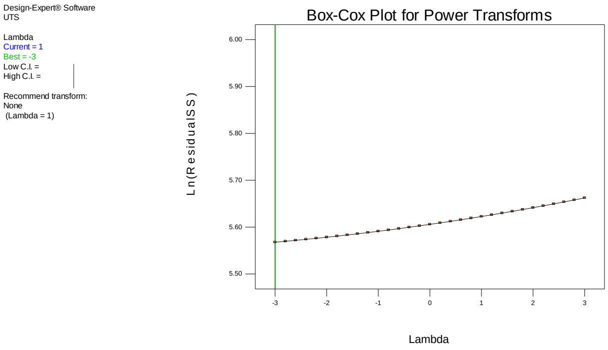

Fig 10Box-Cox Plot for Power Transforms

Contour Plot

The contour plot is a two-dimensional representation of the response across the select factors. The full range of two factors at a time can be displayed. If there are more than two factors the 2D surface can be thought of a slice through the factor space.

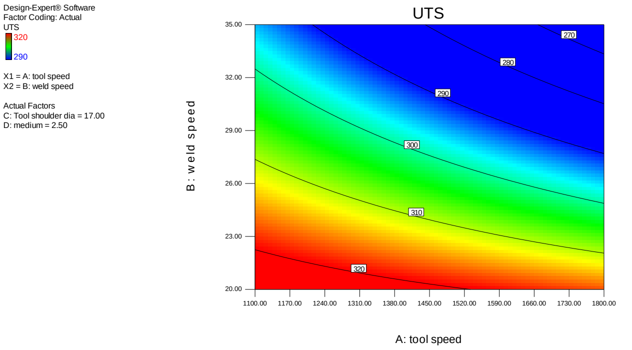

Fig 11 Tool Speed vs Weld Speed

This contour diagram is plotted between the tool shoulder dia. and tool speed. In this diagram tool speed is increase and the strength in decreased.

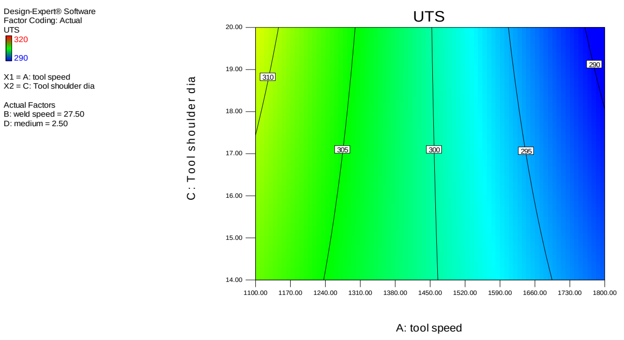

Fig 12 Tool Speed vs Tool Shoulder Dia

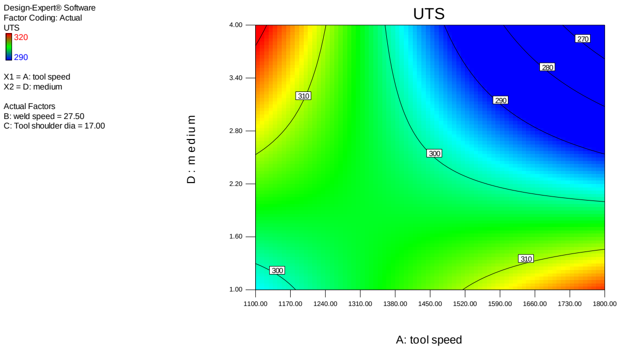

Fig 13 Tool Speed vs Medium

Interaction Graph

An interaction occurs when the response is different depending on the settings of two factors. Plots make it easy to interpret two factor interactions. They will appear with two non-parallel lines, indicating that the effect of one factor depends on the level of the other.

The "I beam" range symbols on the interaction plots are the result of least significant difference (LSD) calculations. If the plotted points fall outside the range, the differences are unlikely to be caused by error alone and can be attributed to the factor effects. If the I beam overlap there is not a significant difference (95% confidence is default) between the two points. You can then choose the most economical or convenient level for that factor.

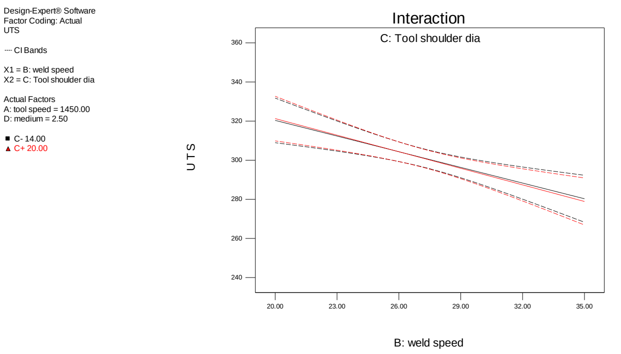

Fig 14 Weld Speed vs UTS

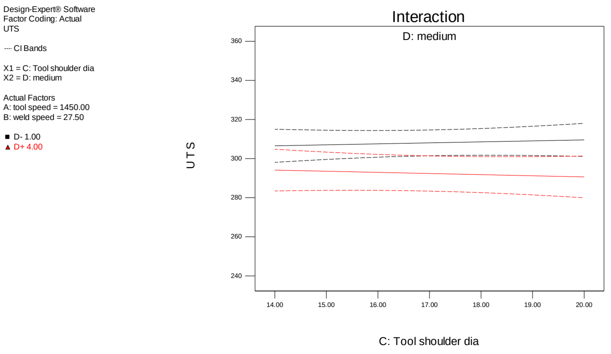

Fig 15 TSD vs UTS

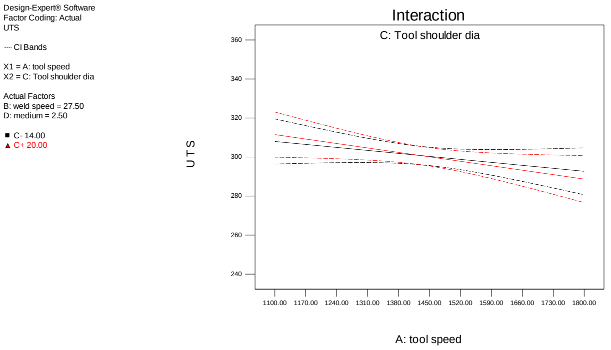

Fig 16 Tool Speed vs UTS

3D Surface

The 3D Surface plot is a projection of the contour plot giving shape to the colour. Except for zoom functions, the 3D surface has all the same options as the contour plot plus the ability to rotate the plot.

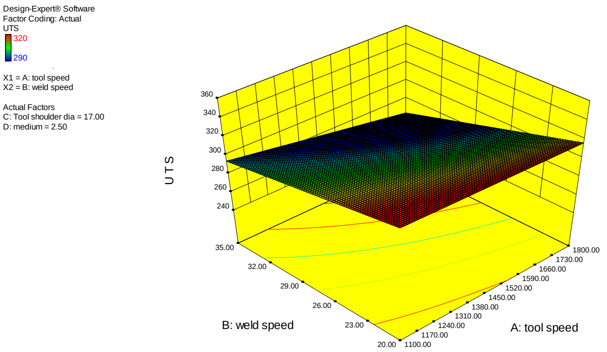

Fig 17 3D Surface

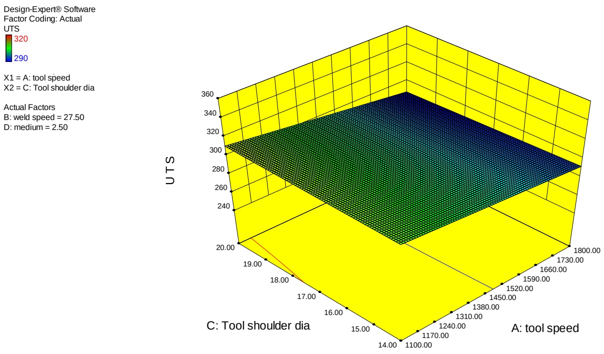

Fig 18 Tool Speed vs TSD

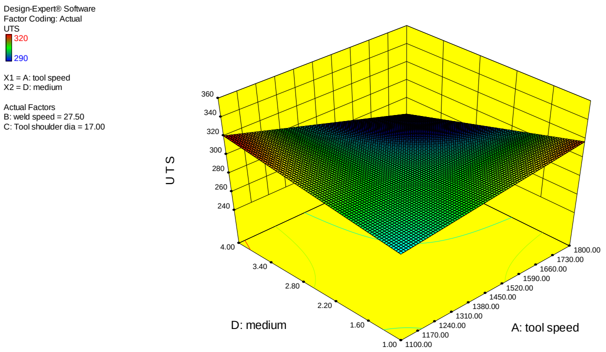

Fig 19 Tool Speed vs medium

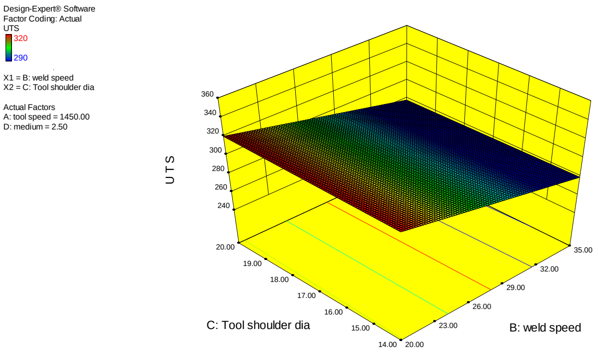

Fig 20 TSD vs weld Speed

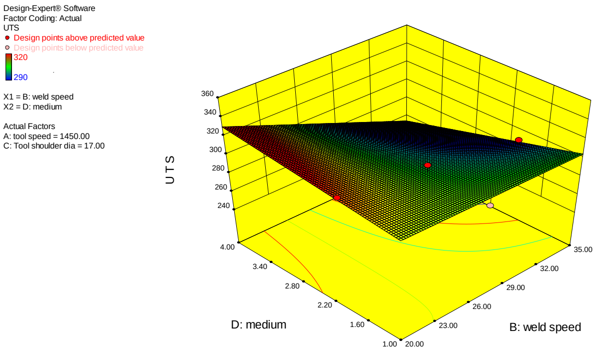

Fig. 21 Mediumvs Weld speed

Cube Plot

Cube plots are useful for representing the effects of three factors at a time. They show the predicted values from the coded model for the combinations of the –1 and +1 levels of any three factors that you select. Non-selected factors, numerical or categorical, can be set to a specific level via the Factors Tool palette. If you select a factor that is not in your model, the predicted values will not change when you move from the –1 to the +1 side of that factor's axis.

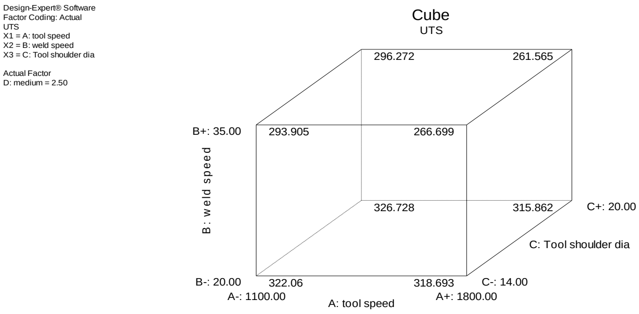

Fig 22 Cube plot

I. CONCLUSION

This research work leads to following conclusions:

- When the tool speed increase the UTS also increase.
- The upper and lower limit of weld speed is 20 mm/min to 35 mm/min. when the weld speed increases the UTS decreases.
- When the tool shoulder diameter is increased then the UTS is increased.
- The maximum UTS is obtain when natural convection heat transfer medium is used.

REFERNCES

[1] A. Górka1 and D. Kocańda1,2, MASS TRANSPORT IN A HIGH-GRADIENT THERMAL FIELD IN THE COURSE OF FRICTION STIR WELDING AND MODIFICATION OF THE UPPER LAYER, Materials Science, Vol. 47, No. 2, September, 2011 (Ukrainian Original Vol. 47, No. 2, March–April, 2011).

[2] Bo Li a, Zhenhua Zhang a, YifuShen a,⇑, Weiye Hub, Lei Luo a, Dissimilar friction stir welding of Ti–6Al–4V alloy and aluminum alloy employing a modified butt joint configuration: Influences of process variables on the weld interfaces and tensile properties, Materials and Design 53 (2014) 838–848, Received 26 May 2013,Received in revised form 5 July 2013,Accepted 7 July 2013,Available online 18 July 2013.

[3] F. Simoesa,b, D.M. Rodrigues b,⇑, Material flow and thermo-mechanical conditions during Friction Stir Welding of polymers: Literature review, experimental results and empirical analysis, Materials and Design 59 (2014) 344–351, Received 27 October 2013,Accepted 16 December 2013,Available online 18 February 2014.

[4] H. JamshidiAval& S. Serajzadeh& A. H. Kokabi, Experimental and theoretical evaluations of thermal histories and residual stresses in dissimilar friction stir welding of AA5086-AA6061, Int J AdvManufTechnol (2012) 61:149–160, Received: 7 April 2011 / Accepted: 24 October 2011 / Published online: 13 November 2011.

[5] Hui-jie ZHANG, Hui-jie LIU, Lei YU, Thermal modeling of underwater friction stir welding of high strength aluminum alloy, Trans. Nonferrous Met. Soc. China 23(2013) 1114_1122, Received 23 February 2012; accepted 26 June 2012.

[6] H.J. Liu a,⇑ , J.C. Houa,b, H. Guo a, Effect of welding speed on microstructure and mechanical properties of self-reacting friction stir welded 6061-T6 aluminum alloy, Materials and Design 50 (2013) 872–878, Received 22 January 2013,Accepted 30 March 2013,Available online 11 April 2013.

[7] H.J. Liu, H. Fujii, M. Maeda, K. Nogi. Tensile properties and fracture locations of friction-stir-welded joints of 2017-T351 aluminium alloy. Journal of Materials Processing Technology 142 (2003) 692–696.

[8] J.F. Guo ⇑, H.C. Chen, C.N. Sun, G. Bi, Z. Sun, J. Wei, Friction stir welding of dissimilar materials between AA6061 and AA7075 Al alloys effects of process parameters, Materials and Design 56 (2014) 185–192, Received 12 August 2013,Accepted 29 October 2013,Available online 9 November 2013.

[9] Kanwer S. Arora& Sunil Pandey& Michael Schaper&Rajneesh Kumar Effect of process parameters on friction stir welding of aluminium alloy 2219-T87, Springer-Verlag London Limited 2010, Received: 2 December 2009 / Accepted: 31 January 2010 / Published online: 20 February 2010.

[10] Mohammad Riahi&HamidrezaNazari, Analysis of transient temperature and residual thermal stresses in friction stir welding of aluminum alloy 6061-T6 via numerical simulation, Int J AdvManufTechnol (2011) 55:143–152, Received: 5 December 2009 / Accepted: 16 November 2010 / Published online: 1 December 2010

[11] M. GHOSH, R.K. GUPTA, and M.M. HUSAIN, Friction Stir Welding of Stainless Steel to Al Alloy: Effect of Thermal Condition on Weld Nugget Microstructure, The Minerals, Metals & Materials Society and ASM International 2013

[12] R. KEIVANI1, B. BAGHERI2, F. SHARIFI2, M. KETABCHI2, M. ABBASI3, Effects of pin angle and preheating on temperature distribution during friction stir welding operation, Trans. Nonferrous Met. Soc. China 23(2013) 2708−2713, Received 31 October 2012; accepted 14 January 2013.

[13] S. Rajakumar& C. Muralidharan& V. Balasubramanian. Statistical analysis to predict grain size and hardness of the weld nugget of friction-stir-welded AA6061-T6aluminium alloy joints, Springer-Verlag London Limited 2011Received: 29 October 2009 / Accepted: 17 March 2011 / Published online: 20 April 2011.

[14] S. SenthilKumaran& S. Muthukumaran& S. Vinodh. Optimization of friction welding of tube-to-tube plate using an external tool by Taguchi method and genetic algorithm.

[15] Xiaocong He, Fengshou Gu, Andrew Ball, A Review of Numerical Analysis of Friction Stir Welding, Progress in Materials Science (2014), Received Date: 2 September 2013,Revised Date: 29 November 2013,Accepted Date: 6 March 2014.

[16] Xingguo Zhou, Wenke Pan*, Donald MacKenzie, Identifying friction stir welding process parameters through coupled numerical and experimental analysis, International Journal of Pressure Vessels and Piping 108-109 (2013) 2e6,

[17] Y.M. Hwang⁎ , P.L. Fan, C.H. Lin, Experimental study on Friction Stir Welding of copper metals, Journal of Materials Processing Technology 210 (2010) 1667–1672, Received 15 January 2010,Received in revised form 8 April 2010,Accepted 31 May 2010.