INFLUENCE OF PARAMETERS IN FRICTION STIR WELDING (FSW) PROCESS: A REVIEW

A. Chauhan* and T. Soota**

*M.Tech scholar, Department of Mechanical Engineering, Bundelkhand Institute of Engineering & Technology, Jhansi (U.P.), India.
**Associate Professor, Department of Mechanical Engineering, Bundelkhand Institute of Engineering & Technology, Jhansi (U.P.), India

ABSTRACT: In this paper an attempt has been made to envelop the parameters of FSW in framework of input-output model, governed by the general peculiarities of solid state joining process. Reported work on FSW has been reviewed in a manner that how the independent process parameters like tool rotation rate, tool traverse speed, tool geometry, tool tilt angle, plunge depth, axial force for plunging etc. may be made to address the process requirements in most favourable way. The focus of the work is to look for the critical parameters and analyze them so that one can get optimum match between the expectations regarding the soundness of joint made and actual behaviour of joint in real working environment. The aim of this work is to make an attempt to draw some general inferences about input parameters to the FSW process and their effects with respect to joint characteristics in general.

INTRODUCTION

FSW was developed by W. Thomas at The Welding Institute (TWI), UK, in 1991.FSW was initially applied to aluminium alloys but the recent developments and successful implementation have motivated its application to other non-ferrous materials and metals. Recently, it has been applied to the welding of high melting point materials such as various types of steels, Ti alloys, super alloys, metal matrix composites and polythene (Mishra and Ma, 2005). FSW is considered as a green technology because no gases are evolved during the process. Also, there are no toxic fumes or smoke produced during or after the welding process.
Literature has been studied with respect to tool rotation rate, tool traverse (welding) speed, tool (pin and shoulder) geometry, tool plunge depth, tool tilt angle only and their effect on effect on joint (mechanical and micro-structural) characteristics. Basic theme of this work i.e. input-output type interaction has been illustrated through figure 1. In recent literature there are numerous attempts to explore and apply FSW process by experimentation for concluding the results qualitatively and quantitatively. Researchers had proposed mathematical models about characteristic behaviour like material flow of plastically stirred substrate material, torque, force, mechanical properties etc. pertaining to the process. This is a very basic idea that, like any other mathematical model, here also, for the models which had been proposed in literature, these also require inputs. So aim is to understand enough about them so that they can be used efficiently and accurately in mathematical models and simulations to serve the purpose. Environment plays an important role in governing the outcome of an experiment so whatever the concluding remarks made in this work through literature are general inferences so variations in outcome of similar experiments are highly probable.

PERFORMANCE OF PROCESS PARAMETERS

Tool rotational speed and traverse speed are two main welding parameters which can be controlled in FSW for a given tool. Tool rotation results in stirring and mixing of material around the rotating pin. Rotating pin moves the stirred material from front to back of pin. These two parameters must be selected with care to ensure a successful and efficient FSW cycle.

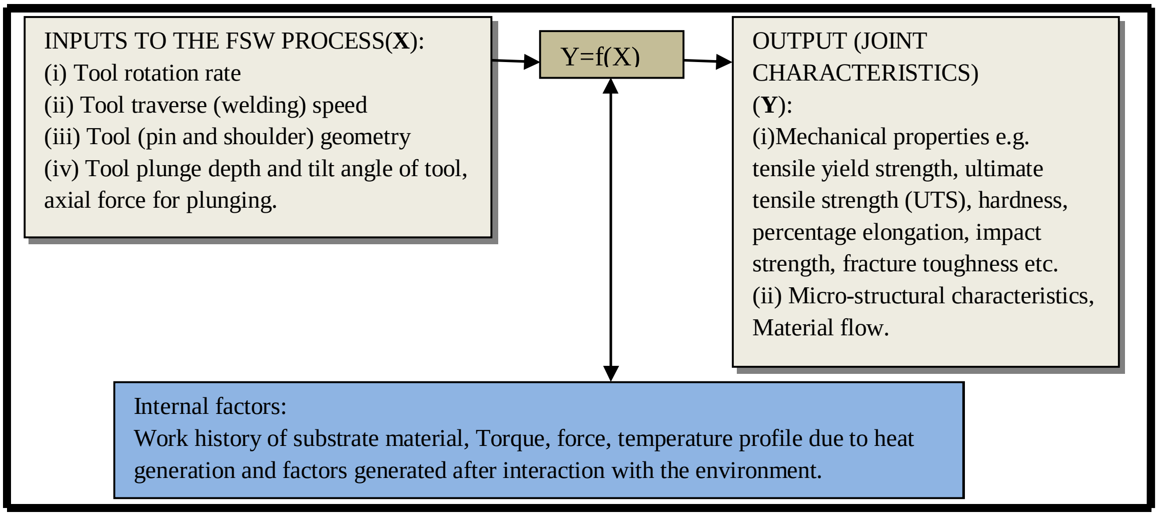

Figure. 1. Input-output tyion between parameters of the FSW process

Tool geometry plays critical role in material flow and in turn governs the traverse rate at which FSW can be conducted. It is only due to geometry of tool, which leads to easier plasticization of specimen material, facilitating the downward augering effect and sufficient interfacing between pin and plasticised material, thereby increasing the heat generation. Ratio of dynamic volume to static volume is very critical to give adequate flow path to plasticised material. More is the ratio, easier will be the flow underneath the pin. Tool geometry directly affects the tool traverse speed and axial force. Among the various types of pin profiles selection of a particular pin is also guided by the type of joint i.e. butt, lap t-type etc. apart from the pin, there are tool shoulder profiles, which improve the coupling between tool shoulder and specimen by entrapping plasticized material with in re-entrant features of the tool. Fundamental correlation between material flow and resultant microstructure of welds varies with each tool. Critical need is to develop systematic framework for tool design (Mishra and Ma, 2005). Fact that most of initial thermo-mechanical conditions are generated during the plunging phase of process, that means pertaining variables like plunge depth, tool tilt, dwell time etc. are in close coherence with tool geometry, tool rotational and traverse speed.

From literature survey which has been summarised in table 1 it can be observed that most of the work is related to tool rotational speed, traverse speed, and tool design features. There are few experimental studies that focus on plunge stage and not many numerical models that focus on thermo-mechanical environment developed during plunging phase. Formation of FSW weld seems to be governed by thermal and mechanical loads of FSW tool, but in literature definitive functions of mechanical loads are not described. Literature of FSW does not have well established analytical information about the mechanical loading of tool, hence not covered in most mathematical models as per the references made in this work related to review of process parameters.

REMARKS ABOUT PARAMETRS ON THE BASIS OF EXPERMENTAL WORK

Solid phase joining process is known for its perfectness of joint at least purely theoretically, but what appears to view is, significant low values of joint efficiency usually less than 1 (Prakash et al. 2008 and Cam et al. 2008). TS, H_B, H_R and IE values are better for similar alloy configuration than dissimilar ones. Both H_B and H_R increase with increase in N up to their maximum and then falls in magnitude. YS, TS, and EL decreases with increase in N, IE increases with N, up to optimum value of N (Krishna et al. 2014). Increase in magnitude of N,V and F leads to increase in UTS up to its maximum and then falls. Same is true for YS and EL (Palanivel et al. 2011). Tool rotational speed 9N) appears to be most dominant factor contributing to TS followed by tool traverse speed (V). F affects the TS least significantly but has its contribution.

Surface response methodology (Palanivel et al. 2011) and optimization approaches like Taguchi design (3^3factorial) of experiment (jayaraman et al. 2009), Neldermead algorithm (Reddy et al. 2013) are few among the wide range available methodologies for establishing correlation among input and output parameters of process. Use of software packages like ABAQUS (Zhang et al. 2008), MINITAB (Jayaraman et al. 2009), and many others like MATLAB, SOLIDWORKS, ANSYS etc. improves the efficiency and scope of mathematical approaches to judge dependent parameters in tems of independent parameters without actually conducting the costly FSW experiments.

Contribution of non-linear terms in mathematical models appears to be insignificant as compared to linear (Jayaraman et al. 2009).

Table. 1. Summary of literature review

Refrence	Specimen material	Independent parameters	Dependent parameters	Tool material/shoulder dia/pin dia/pin length (mm)
Prakash et al. (2013)	AA6061	N,V,L, F=constant	TS	H13 steel/18/6/-
Krishna et al. (2014)	AA6351+AA6351; AA6351+AA5083	N	TS,YS, H_B, ,H_R,IE	-
Palanivel et al. (2011)	AA6351	N,V,F	UTS,YS,E	HCHCr steel/-/-/-
Jayaraman et al. (2009)	A319	N,V,F	TS	Carbon steel/-/-/
Raguraman et al. (2014)	AA6061+AZ61	PP	Q	-
Doos and Mahmood (2011)	AA2218-T72	PP, d	E,TS,EL	-/18/-/-
Zhang et al. (2008)	AA6061-T6	N, PP	T,EL,N,V	-
Narimanii et al. (2015)	Al-B_4C	D, d, N	MS,MH	-
Wang et al. (2014)	AA7022	N,V	GS, MS	Tool steel/-/-/-
Chandrasahekar et al.(2016)	AA5083-H111	PP,N, F=constant.	TS,MS	HSS/-/-/-
Thube and Pal (2014)	AA5083	PP,N,V	TS	SS316/-/-/-
Reddy et al. (2013)	AA2024+AA7075	N,V	TS	-/17.5/5/4.65
Padmanaban et al. (2015)	AA2024+AA7075	N,V	TS	HSS/17.5/5/4.65
Cam et al. (2008)	AA5086-H32	N,V,L	TS,MS,E,EL	HSS/-/(3-4)/2.8
Rodrigues et al.(2010)	AA5083-H111; AA6082-T6	TA,F,N,V	MS,EL,E	-
Venkateswarlu et al. (2013)	AA7039	D, d, SCV, N=constant, V=constant,	TS, EL, WC	SS310/-/-/-
Kumar and Kailas (2008)	AA7020-T6	L,F	MFL	-/20/(6-4)/4.2

Note: N=tool rotational speed, V=tool traverse speed, L=plunge depth, F=axial force on tool, PP=pin profile, d=pin cylinder diameter, D=shoulder cylinder diameter, TA=tilt angle, TS=tensile strength, YS=yield strength, H_B=Brinell hardness, H_R=Rockwell hardness, Q=heat generation rate, T=temperature, EL=% elongation or ductility, E=efficiency of joint, IE=impact energy, MS=micro-structure, SCV=Surface concavity, WC=weld cross-section, MFL=Material flow, GS=grain size, MH=micr-harness, UTS=Ultimate tensile strength.

Concave fluted tools yield least value of heat flux. Internal taper profiles get more heat than threaded tool. Non-uniform heat flux appears in threaded geometry of tools (Raguraman et al. 2014). Joint efficiency is a composite function of tool geometrical features. Max. TS and EL are obtained with threaded cylindrical flat pin.

Increase in pin diameter leads to increase in mechanical efficiency of joint (Doos and Mahmood, 2011). Temperature gradient in advancing side is more than retreating side. Max. T and plastic strain can be increased with increase in N. Effect of shoulder diameter (D) on material deformation can be increased by N↑ and V↓ (Zhang et al. 2008). Increasing the tool size i.e. D/d ratio and N results in increase of nugget zone and volume fraction of reinforcing particle decreases. Smaller tool size leads to more volume fraction of reinforcing particles in composite layers and higher hardness (Narimanii et al. 2015). Grain size changed from coarse to fine from top to bottom of nugget. If N=constant then higher V produces finer grains. If V=constant then higher N produces coarse grain. MS appears to be function of N (Wang et al. 2014). Most contributing factor to affect TS is pin diameter followed by shoulder diameter and shoulder surface concavity. Same is true for weld cross-section. D and SCV have similar affects on weld cross-section. Pin diameter most significantly affects the EL (Venkateswarlu et al. 2013).

For different N there is different optimum profile with respect to dependent parameters. TS vary significantly with tool profiles (Chandrashekar et al. 2016). But according to some experiments (Thube and Pal 2014), tool pin design affects the heat input insignificantly. Same is true for TS and power consumption. Irrespective of tool PP there is an optimum combination which results in best TS. Increase in N cause TS to increase and Increase in V cause TS to decrease (Reddy et al. 2013). With similar trend it is again observed that TS increases with N and than falls. Same is true for TS with V (Padmanaban et al. 2015). There is marked low values of joint efficiency (75%) and ductility (20%), loss of cold work due to heat input. Higher joint performance can be achieved by increasing penetration depth of tool (Cam et al. 2008).

For very low tilt angle it is not possible to achieve defects free weld whatever be the process parameters in use (Rodrigues et al. 2010). So, intermediate values for tilt angle are preferred for the process.
Behind the typical characteristics of joint properties it is the material flow which is in play to govern all these. Defect size reduces and axial load increases as tool interface with specimen material increases. F and D are locked together regarding heat generation during the process. Defects in welds at initial stages are accounted for insufficient value of axial load and consequently less shoulder contact. When F increases above critical value the sub- surface material flow become intense. For the given set of input parameters there is an optimum F to give best material flow aspects regarding the joint characteristics. Friction stir welds are asymmetric about weld line when F increases above critical value. Pin deforms the material layer by layer and shoulder in bulk. Onion ring formation in friction stir weld is due to combined effect of geometric nature of pin pin-driven material flow and vertical movement of material due to shoulder interaction (Kumar and Kailas 2008).

CONCLUSIONS

FSW can be used to join many types of materials and material combinations. Tool and traverse rate coupled with geometrical features of tool govern the final micro-structure and consequently mechanical properties. Due to contribution of many contributing factors, optimization plays an important role to have a balance between desired characteristics of joint and feasible limits to independent inputs to the process, guided by environment and intrinsic factors and at last but not least it is typical material flow pattern which is in play behind all those characteristics of FSW joint.

REFERENCES

[1] Cam G.; Gucler S.; Cakan A.; Serindag H.T.; (2008); *Mechanical properties of friction stir welded Al 5086-H32 plates;* JAMME; 30(2); 151-156.
[2] Chandrashekar A.; Reddappa H.N.; Ajaykumar B.S.; (2016); *Influence of tool profile on mechanical properties of friction stir welded aluminium alloy 5083;* IJCMNMME; 10(1); 8-14.
[3] Doos Q.M.; Mahmood S.J.; (2011); *The influence of tool geometry of friction stir welds on mechanical properties and micro-structure of 2218-T72 aluminium alloy ;*JE; 17(5); 1-18.
[4] Jayaraman M.; Sivasubramanian R.; Balasubramanian V.; Lakshminarayan A.K.; (2009); *Optimization of process parameters for friction stir welding of cast aluminium alloy A319 by Taguchi method;* JSIR; 68; 36-43.
[5] Krishna G.G.; Reddy P.R.; Hussain M.M.; (2014); *Mechanical behaviour of friction stir welding joints of aluminium alloy of AA6351 with AA6351 and AA6351 with AA5083;* IJETT; 10(4); 161-165.
[6] Kumar K.; Kailas S.V.; (2008); *The role of friction stir welding tool on material flow and weld formation;* MSE(A); 485; 367-374.
[7] Mishra, R. S.; Ma, Z. Y.; (2005); *Friction stir welding and processing*; MSE(R); 50;1–78.
[8] Narimanii M.; Lotfi B.; Sadeghian Z.; (2015); *Investigating the effect of tool dimension and rotational speed on micro-structure of Al-B_4C surface composite layer produced by friction stir processing (FSP);* JAMP; 3(2); 61-70.
[9] Padmanaban R.; Balusamy V.; Nouranga K.N.; (2015); *Effect of process parameters on the tensile strength of friction stir welded dissimilar aluminium joints;* JEST; 10(60); 790-801.
[10] Palanivel R.; Mathews P.K.; Murugan N.; (2011); *Development of mathematical model to predict the mechanical properties of friction stir welded AA6351 aluminium alloy;* JESTR; 4(1); 25-31.
[11] Prakash p.; Jha S.K.; Lal S.P.; (2013); *A study of process parameters of friction stir welded AA6061 aluminium alloy;* IJIRSET; 2(6); 2304-2309.
[12] Raguraman D.; Murugandam D.; Kumarswamidhas L.A.; (2014); *Study of tool geometry in friction stir welding of AA6061 and AZ61;* IOSR-JMCE; 63-69.
[13] Reddy A.G. Saketh Ch.; Padmanaban R.; Balusamy V.; (2013); *Process parameter optimization for friction stir welding of dissimilar aluminium alloys;* IJERT; 2(10);3281-3288.
[14] Rodrigues D.M.; Leitao C.; Louro R.; Gouveia H.; Loureiro A.; (2010); *High speed friction stir welding of aluminium alloys;* STWJ; 000; 1-6.
[15] Thube R.S.; Pal S.K.; (2014); *Influnces of tool pin profile and welding parameters on friction stir weld formation and joint efficiency of AA5083 joints produced by friction stir welding;* IJIRAE; 1(4); 1-8.
[16] Venkateswarlu D.; Mandal N.R.; Mahapatra M.M.; Harsh P.P.; (2013); *Tool design effects of FSW of AA7039;* WJ; 92; 41-47.
[17] Wang H.F.; Wang J.L. ; Zuo D.W.; Somg W.W.; Duan X.; (2014); *Effect of friction stir welding on micro-structucture and wear properties of 7022 aluminium alloy;* IJEMS; 21; 557-562.
[18] Zhang Z.; Bie J.; Liu Y.; Zhang H.; (2008); *Effect of traverse/rotational speed on material deformation and temperature distributions in friction stir welding;* J. Mater. Sci. Technol.; 24(6); 907-914.