Thermo-Mechanical Characterization of Aluminium Alloy 7075 and Tool Wear Parameters at Heat Affected Zone by Friction Stir Processing

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ABSTRACT: *Friction stir processing is an adoptive method of changing the material properties through intense evolution of frictional heat and localized plastic stage deformation. This deformation is produced by means of forcible insertion of non-consumable tool (h13 steel) introduced into the surface/subsurface of the workpiece Aluminium Alloy 7075 (AA7075) and directing the tool both in rotational and translational motion[6] so as to push laterally through the leading edge of the workpiece. This procedure stirs up the material without altering the metallurgical phase change but creates a fine microstructure with equi-axed grains. The factors influences the temperature rise amidst Stirred Zone (SZ) and Heat Affected Zone (HAZ) since the temperature distribution closer to SZ had directly shown impact over the microstructure viz., size of grain, behavior of grain boundary character, coarsening stage followed by dissolution of precipitates and finally resultant temperature, thermal and mechanical properties of AA7075. It is quite important to determine information regarding temperature distribution during FSP. Also HAZ purely experiences a thermal cycle, which do not undergo plastic deformation but it retains the similar grain structure because AA 7075 subjected to unknown temperature rise. In this research, the project mainly deals with thermal exposure which exerts correlation effect of AA 7075 and Tool Wear Rate (TWR) of h13 steel and the real time temperatures are found with the help of J-type thermocouples that helps in determination of thermal characteristics and heat transfer parameters such natural convection heat transfer, Nusselt number and heat transfer coefficient corresponding to TWR. ANOVA and Regression analysis was applied and proved that the TWR is directly affected by thermal properties.*

KEYWORDS: FSP, AA7075, HAZ, THERMAL ANALYSIS

LITERATURE SURVEY

FSP is a solid-state process [3] that has been drawn much attention in manufacturing industry and research areas as well. It is used in modern technology applications especially aerospace industry [3] at which the aircraft body is exposed to space atmosphere & higher altitudes and also automotive industry [3] where high precision applications such as micro processing. The primary feature of this process is the non-melting stage of AA7075 [7][10] which permits optimum temperature and heat input[4] which in inline to the melting point of base materials that are about to processed. This method is beneficial as compared to conventional fusion type of processing where high amount of heat input is essential to melt the base material. The optimal quantity of heat input is required in FSP which accelerates economic benefits, safest & few complicated processing techniques.

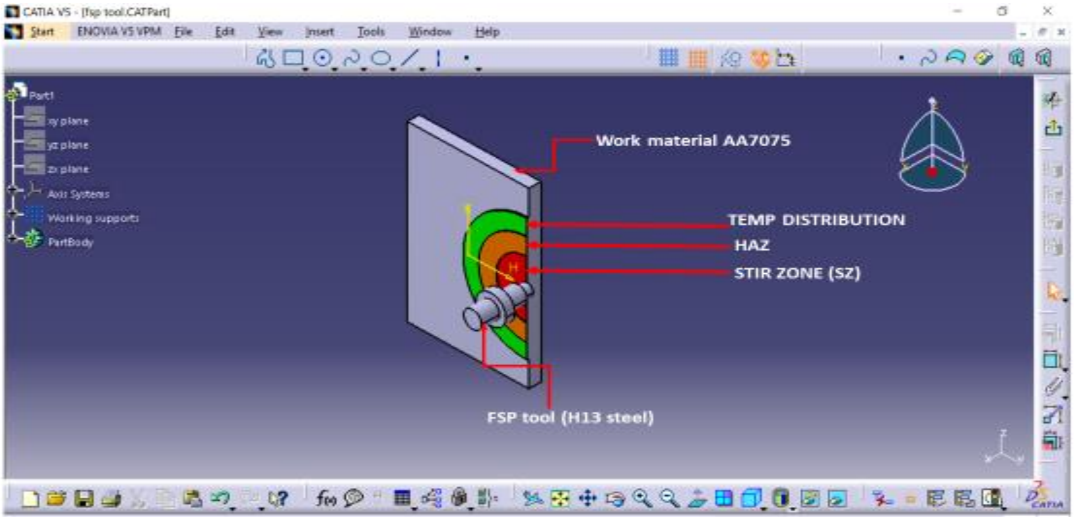

Fig 1: Working Procedure of FSP

However, FSP is premier method that improves light weight & low density such AA, magnesium alloys [8], titanium and copper alloys [8] which are complicated by conventional methods. In addition to this, FSP also helps to yield sound area in case of 5000 & 7000 series AA [8] which would prone to be processed using traditional methods. FSP has proved good & proper quality and sturdy structure with less expensive and number of equipment. The need to show progressive understanding and improve FSP methods by continuous procedures in many applications. Many researchers have done various methodologies including mathematical modelling to put forth more work on this system to measure quantitatively regarding heat transfer parameters such as convective and transient type processes. Nusselt number, heat transfer coefficient, Tool wear [9] etc., in FSP. This thesis focused exclusively upon the process parameters [2] [6] such as rotational and translational speed [6], that vary temperatures [4] and a thermomechanical model [7] was employed and how the thermal properties [5] would have shown the greater influence upon the tribological property [4] [5] (tool wear) [9]. Also, Electro-thermal devices such as J-type thermocouple [1] was used for determining temperatures during FSP.

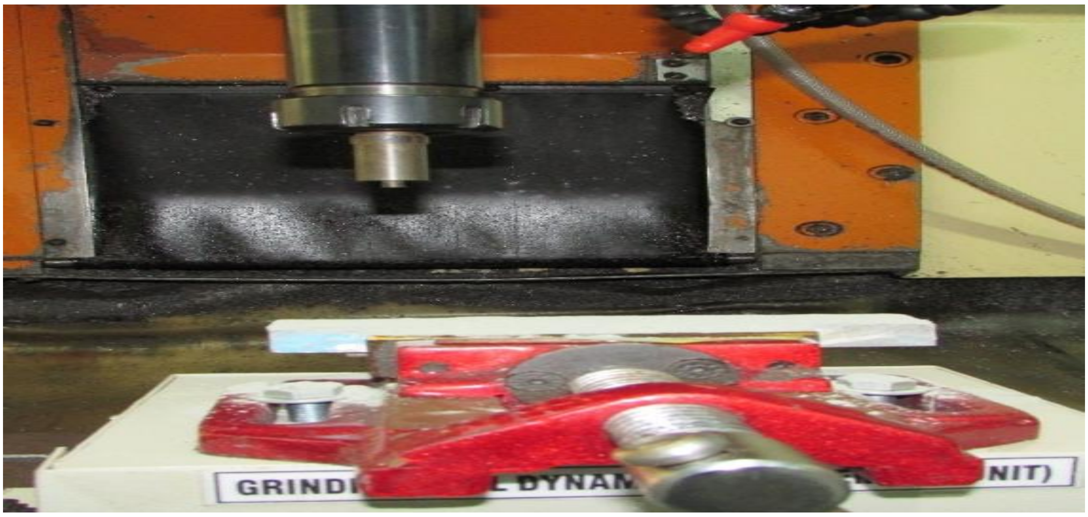

Fig 2: Experimental set up of FSP

EXPERIMENTATION:

FSP experimental set up[6] comprises of (1) Cylindrical[2] rotational tool H13 steel (2) Work material AA 7075 with 80 x 20 x 7 mm dimensions[6] [7] (3) J-type thermocouple [1] with 6 channel selector multimeter & (4) Clamping or holding fixture as shown in fig (1). The tool design having a combination of two cylinders of a specific ratio known as shoulder-pin[2] ratio where the pin height is more than half of the AA 7075 plate thickness. The more materials to be processed are arranged in surface level configuration. The versatility of FSP having the capability to process various types, for any configuration of plate thickness without the essence of special preparation before processing. The vital part of the AA 7075 set up lies in the clamping fixture, because inappropriate clamping may fail the mating surface to be Friction Stir Processed (FSPed)[6] and will headed to gap formation which results in order to procure worm holes over the surface of AA 7075[10].

HEAT TRANSFER METHODOLOGY:

Fig 3: Real time temperatures Measurement

The state of convective heat transfer was generated on constantly transferred from the system to the tool as boundary condition. Also, optimal quantity of heat is thoroughly distributed within the surface and/or subsurface AA 7075[7] [10] and finally to the ambience. In microscopial approach, convective heat generation[5] depends upon the principle of three dimensional way (3D) heat that escalates away from the rotating tool which acts as heat source under boundary conditions at which the corresponding heat transfer at the rotating tool pin in compliance with AA 7075[10] interface along with convective heat transfer effected around the pin in the Heat Affected Zone (HAZ) [1][3].Both convective & radiative modes of heat transfer are taking into account at the top position of work material surface, pass through the shoulder portion[2] peripheral but at the same instance only natural convection heat transfer is considered at the boundary surface of work material. At last the total heat energy generated by mechanical actions of tool throughout the FSP is converted to convective heat transfer and physical deformation. However, 80% of heat is transferred and distributed uniformly to the AA 7075[10] and to the rotating tool. The thermal energy [5] place a prominent role not only in case of physical process but also framing the temperature profile [4], heat transfer and the tool wear [9]. It simulates directly on the tool wear [4] [9], heat transfer coefficient, thermal and mechanical characteristics [5] which are correlated to the process parameters [2] [6] and temperature dependent material and tool properties.

Table 1: Experimental data

Speed RPM	Translational Speed, mm/min	T_{Amb} °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_5 °C	T_6 °C	Avg. Temp °c	Bulk temp °C
500	20	28	215	245	289	315	347	422	305.5	166.75
700	20	28	232	260	278	303	365	434	312	170
900	30	32	258	277	296	338	374	466	335	183.5
1000	30	35	269	284	322	359	393	492	353	194
1200	35	35	278	290	316	347	386	448	344	189.5
1500	40	37	294	305	329	337	375	394	339	188

Table 2: Calculated values

Experimental convective heat transfer watts	Heat transfer coefficient, W/m^2 K	Nusselt number	Tool Wear Rate, mm^3/N-m
42.46416	1501864.237	69.316	0
43.45881	1537042.827	70.94	0.002587
46.36627	1639873.313	75.686	0.004679
48.66163	1721055.163	79.433	0.005982
47.28441	1672345.911	77.185	0.007756
46.21324	1634460.977	75.436	0.008549

TOOL WEAR RATE (TWR) [9]

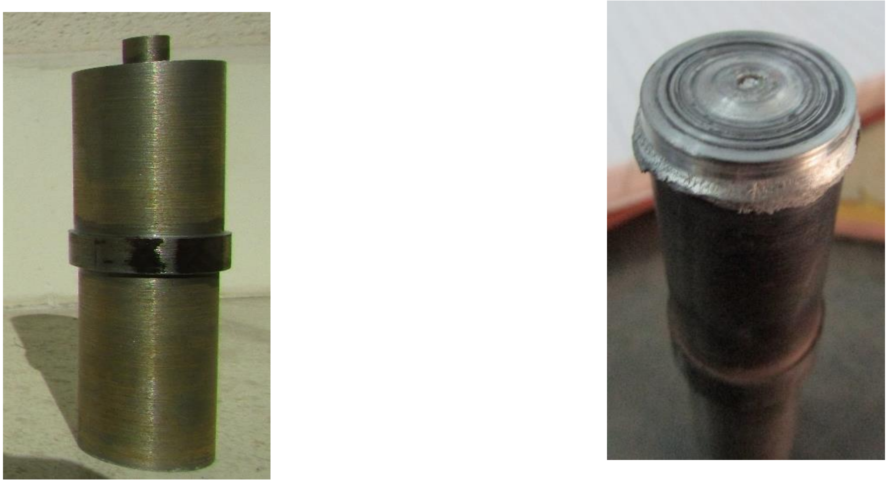

Fig 4: Tool wear before and after FSP

FEATURES OF THERMO-MECHANICAL PROCESS IN FSP: The basic principle of FSP depends upon the generation of heat by the mechanical action of a special tool (h13 steel) in direct contact with the base/parent material. The first step of initiation of FSP is characterized by conversion of the mechanical work of friction and stirring that are going through hand in hand simultaneously between the rotating tool and AA 7075[7][10] to be processed into thermal energy[5]. The obtained thermal energy lowers the material resistance in order to avoid plastic deformation.

During this process additional heat is generated as a result of materials plastic dissipation. The relationship between heat generation [5] and material plastic deformation is affected directly by the pin diameter with the increase of diameter of pin/probe. The amount of plastic dissipation is also increases and reduction of the heat generated in the area of shoulder plate contact leads to increase of contact portions. Surface and subsurface layers of the base material were directly affected by the tool surface that are rotating through its length while the remaining portion of the material restricts the dynamic process [1]. The cohesive type of bond between the surface and subsurface of material in the SZ [3] [8] at different rotational speed results in the formation of intensive local heat. It indicates that the mechanism of FSP formation is related to combination of both thermal and mechanical processes [5] [7]. The mechanical actions of the tool is uniformly distributed into initial heat while the rest is changed into convective heat transfer type.

RESULTS & DISCUSSION:

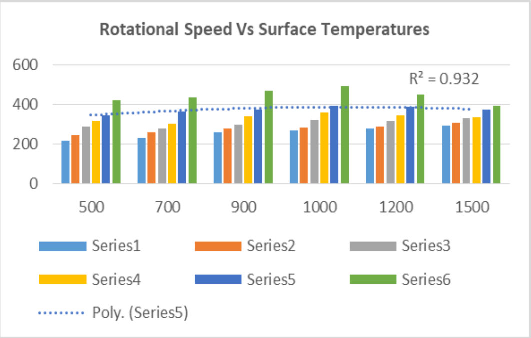

Fig 5: Graph of Rot. Speed Vs Surf Temp

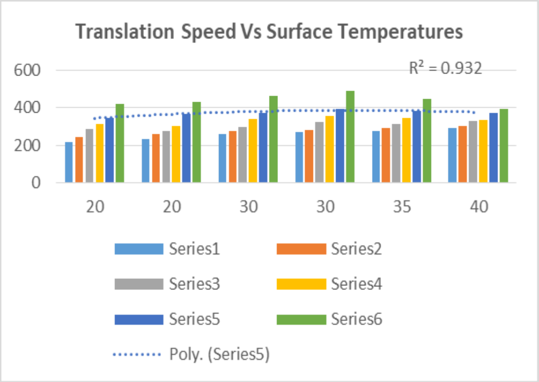

Fig 6: Graph of Trans Speed Vs Temperature

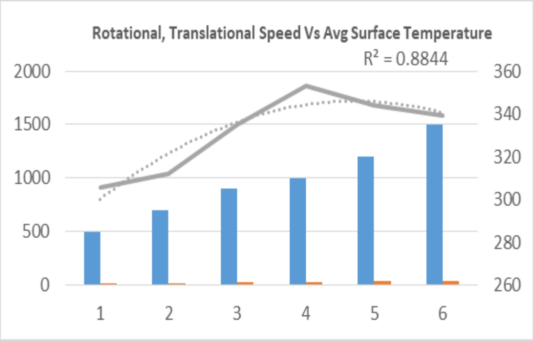

Fig 7: Graph of Speeds Vs Avg Surf Temp

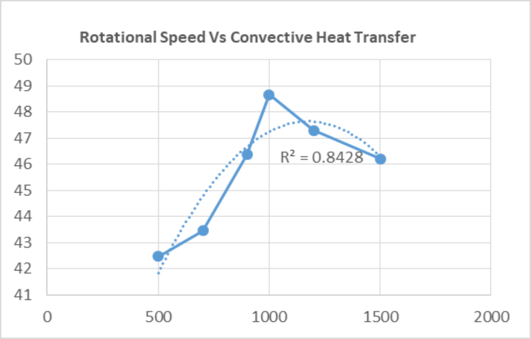

Fig 8: Graph of Rot. Speed vs heat transfer

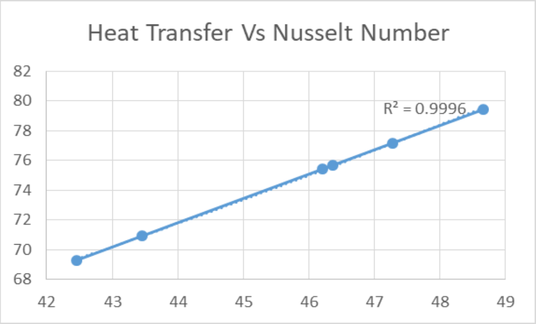

Fig 9: Convective Heat Transfer Vs Nu

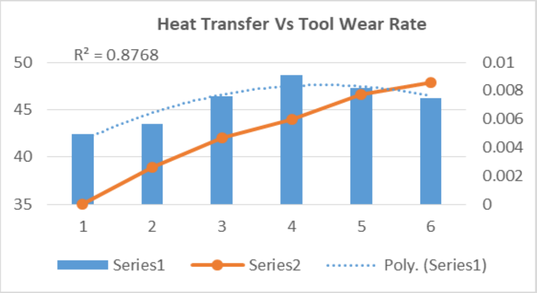

Fig 10: Convective Heat Transfer Vs TWR

ANALYSIS OF VARIANCE (ANOVA)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	32.7832	6.5566	*	*
TWR	1	0.2930	0.2930	*	*
AVG	4	25.3143	6.3286	*	*
Error	0	0.0000	*		
Total	5	32.7832			

Model Summary

S	R-sq.	R-sq.(adj)	R-sq.(pred)
*	100.00%	*	*

Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	41.56	*	*	*	
TWR	-0.3827	*	*	*	1.87
AVG					
312	1.684	*	*	*	1.67
335	4.746	*	*	*	2.67
344	5.913	*	*	*	2.54
352	7.357	*	*	*	1.95

Regression Equation in Uncoded Units

AVG			
301	conv heat transfer	=	41.95 - 1501 TWR
312	conv heat transfer	=	43.63 - 1501 TWR
335	conv heat transfer	=	46.69 - 1501 TWR
344	conv heat transfer	=	47.86 - 1501 TWR
352	conv heat transfer	=	49.30 - 1501 TWR

Fits and Diagnostics for All Observations

Obs	conv heat transfer	Fit	Resid	Std Resid
1	41.95	41.95	0.00	*
2	43.63	43.63	-0.00	*
3	46.69	46.69	-0.00	*
4	48.99	48.99	-0.00	*
5	47.30	47.30	-0.00	*
6	45.93	45.93	-0.00	*

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Regression Analysis: conv heat transfer versus TWR, AVG Temp
Method
Categorical predictor coding    (1, 0)
Continuous predictor standardization
Levels coded to -1 and +1
Predictor   Low   High
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TWR         0     0.00051
Stepwise Selection of Terms
Candidate terms: TWR, AVG
                  -----Step 1-----
                  Coef        P
--------------------------------------
Constant          41.56
TWR               -0.3827     *
AVG               7.357       *


S                             *
R-sq.                         100.00%
R-sq.(adj)                    *
R-sq.(pred)                   *
α to enter = 0.15, α to remove = 0.15
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- If translational speed is low, evolution of heat and convective heat transfer are being generated with a higher rate and vice-versa.
- Whenever convective heat transfer rate from workpiece to tool is low, the TWR is high.
- At Stir zone (SZ)[3][8], the conductive mode of heat transfer is existed, by the stirring action of the h13 steel tool followed by convective type of heat transfer from work piece to ambience and shoulder portion of tool.
- At HAZ [3], higher quantities of local heat is generated as per tool directions (translation) i.e. from trailing to leading edge (as shown in fig 3 colour deformations).
- TWR is independent of SZ [3] [8] and HAZ [3] but it is directly correlated to the amount of convective heat transfer, heat transfer coefficient and temperature distribution.

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