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Thermal Stress Analysis and Optimization of FSW Process on UHMWPE by Using Triangular Tool Profile

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Abstract: The use of polymeric materials has grown widely in various sectors such as packaging, building, electronic, automotive, and aerospace industries. Particularly, Ultra-High Molecular Weight Polyethylene has wide engineering applications and is used in large quantities in automotive oil pans, gears, slides, cams, bearings, fluid reservoirs, and the sports industry. Friction Stir Welding (FSW) is a solid-state process in joining thermoplastic materials. In this investigation, FSW process must be applied to join a UHMWPE plate of 10 mm thickness with specially designed triangular tool pin profile. The aim of this study is to examine the effect of main friction stir welding (FSW) parameters on the quality of UHMWPE plate welds. FSW machine, using a tool with a stationary shoulder and no external heating system. The welding parameters studied were the tool rotational speed which varied between 1300 and 1500 (rpm); the traverse speed which varied between 15 and 25 (mm/min), and the axial force ranging from 8 to 10 (KN). Good quality welds are achieved without using external heating, when the tool rotational speed and axial force are above a certain threshold. For high rotational speed and axial force welds have poor material mixing at the retreating side and mild voids at the nugget, tensile strength also obtained very poor. The hardness angle distortion and bead geometry also evaluated. Taguchi design optimum parameters and ANNOVA were found.
Keywords: FSW, Tool Profile, Taguchi, HRM, Polyethylene

Abbreviation

1. UHMWPE - *Ultra-High Molecular Weight Polyethylene*
2. *Tool TR – Tool Traverse*
3. *AX-FC – Axial Force*
4. *Temp – Temperature*
5. *TL – Tensile Load*
6. *TS – Tensile Strength*
7. *SN-Ratio – Signal to Noise Ratio*
8. *HRM – Hardness Rockwell "M" Scale*

I. INTRODUCTION

FSW creates a weld joint without bulk melting. Compared to the widely used fusion welding processes (e.g., arc welding, laser welding), an inherent advantage of FSW is that it is immune to the defects and property deteriorations associated with solidification. Solidification cracking, porosity, and melting and coarsening of strengthening phases are eliminated in FSW. In addition, the extensive thermo mechanical deformation of FSW refines the microstructure of the weld region. Hence, whereas fusion welding generally results in weld property degradation, FSW can produce a weld with mechanical properties like or even better than those of the base metal.

A. Objectives

For this research, the objectives that are tried to achieve by the researcher are:

1) To get optimum parameters for the materials under considerations i.e., UHMWPE
2) To investigate the Various Mechanical behaviors
3) Defects occurring during the welding process

B. Scope of Study

The focus of the research work will be concentrated in the mechanical performance and the stir zone microstructure by FSW butt welded part having 100mm × 100mm × 8 mm thick sheet UHMWPE using constant pin diameters. All the testing of welded part will be tested by ASTM standard. Triangular pin tool will used to conduct experiments.

In this research, Universal Testing Machine (UTM), Hardness testing machine IMAGE-J (Bead Geometry Analysis) will also be used to measure the. Friction stir processing is a method of changing the properties of a metal through intense, localized plastic deformation.

C. Friction Stir Welding (FSW)Process Principle

Friction stir welding (FSW) produces welds by using a rotating, non-consumable welding tool to locally soften a work piece, through heat produced by friction and plastic work, thereby allowing the tool to “stir” the joint surfaces. The dependence on friction and plastic work for the heat source precludes significant melting in the work piece, avoiding many of the difficulties arising from a change in state, such as changes in gas solubility and volumetric changes, which often plague fusion welding processes.

Further, the reduced welding temperature makes possible dramatically lower distortion and residual stresses, enabling improved fatigue performance, new construction techniques, and making possible the welding of very thin and very thick materials.

II. MATERIALS AND METHODS

A. Polymers And Its Significance in Industries

The automobile industry has inclined its focus towards the reduction of vehicle weight leading to control of energy consumption and CO2 emission. To reduce the vehicle weight, automobile industries are looking for thermoplastics instead of conventional engineering materials. The choice of thermoplastic materials is its high stiffness-to-weight ratio and easy production of complex design. The reinforced fiber thermosets consume long production cycle times due to curing of the materials. Thermoplastics deform when subjected to heat beyond the melting temperature. The material typically regains original stiffness when the temperature is subsequently reduced below melting point.

The recent developments in the thermoplastic technology are listed as follows:

1) Reduction in material cost
2) Industrialization and integration of composite manufacturing processes
3) Improvement in recyclability of composites and waste management
4) The enhancement of repair methods and damage detection
5) Development of hybridization and joining technology.

B. Choices of Welding

Plastic joining fulfils the difficulties in an effective means by considering different aspects.

1) In adhesive bonding, the final strength cannot be achieved instantly, and it depends on the type of adhesive used. To minimize the time consumed for adhesive joining, chemicals are used to increase the curing time.
2) In a long curing time, the material is vulnerable to different environmental conditions. It will react with environmental moisture, chemical compounds, and ultraviolet light.
3) Material surface preparation consumes more time, depending on the materials and type of adhesives used.
4) It needs proper safety while bonding. It possesses problem during disposal and recycling.

III.EXPERIMENTAL DETAILS

A. Work Description

The main objective of this work is to study the mechanical properties of friction stir welded aluminum alloy plates with various tool profile analyzed. The study includes the mechanical property will be -weld condition. For this, a series of experiments were conducted based on constant parameter with various tool profiles.

Using the recommended parameter orthogonal array, the first set of experiments was conducted on the UHMWPE plates. The UHMWPE plates were cut into required dimension of 100x100x8 mm for friction stir welding.

Fig. 1 Vertical Milling Machine

B. Selection of tool shoulder diameter

UHMWPE was used as base metal to perform friction stir welding in this study. The prepared samples to be welded using triangular profile tools with 6mm with shoulder diameters 18mm.

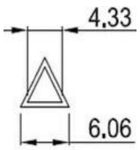

Fig. 2 Triangular tool pin profile

IV. TAGUCHI METHOD

A. An Orthogonal Array L_9 Formation

Table I
L9 Array Formation

Sl. No	Speed RPM	Tool-TR Mm/Min	AX-FC KN
1	1300	15	8
2	1300	20	9
3	1300	25	10
4	1400	15	9
5	1400	20	10
6	1400	25	8
7	1500	15	10
8	1500	20	8
9	1500	25	9

V. FEA ANALYSIS

A. Introduction

In recent years, some software's are developed for simulation of cutting process such as ANSYS, DEFORM, ABAQUS, etc. DEFORM-3D is finite element simulation software based on process simulation system that synthesizes functions for modeling, shaping, and heat conducting, and forming equipment and so on. DEFORM-3D has some features such as good robustness, easy to use, powerful simulation engine, etc. In this experimental DEFORM-3D is used to research simulation of friction stir welding for UHMWPE.

B. Geometry

The gear geometry generated from Auto Cad is imported in to DEFORM Workbench through Design Modeller.

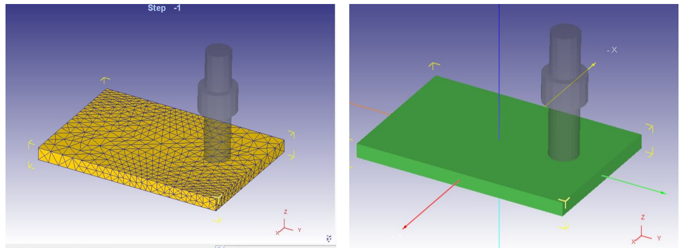

Fig: 3 FSW Tool & Plate Mesh & Model of Triangular Pin

C. Damage, Tool Strain Rate & Temperature Analysis of Triangular Pin

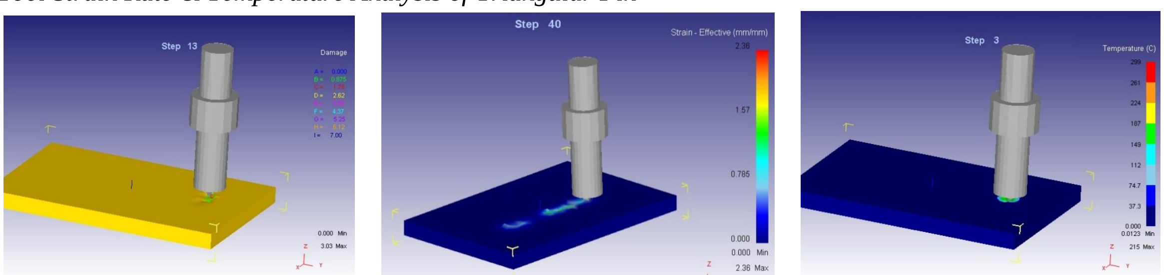

Fig: 4 Damage, Tool Strain Rate & Temperature Analysis of Triangular Pin

Table III

Experimental Input and Deform Results Output of FSW Process

S.NO	Speed RPM	Tool-TR mm/min	AXFC KN	TEMP (^{0}C)	STRAIN	DAMAGE %
1	1300	15	8	215	2.36	3.03
2	1300	20	9	206	1.27	2.23
3	1300	25	10	203	1.54	1.81
4	1400	15	9	221	2.36	3.07
5	1400	20	10	210	2.07	2.62
6	1400	25	8	187	1.03	1.74
7	1500	15	10	193	1.83	2.22
8	1500	20	8	191	1.80	2.20
9	1500	25	9	180	0.848	0.791

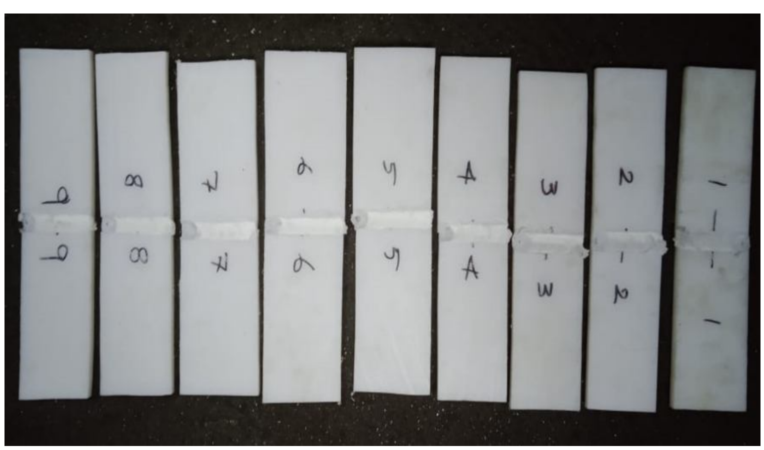

Fig: 4 FSW UHMWPE Welded Plate Images

VI. EXPERIMENTAL RESULT

A. Rockwell Hardness Test

Using the "M" Scale.

1) Use a ¼" indenter
2) Major load: 160 Kg, Minor load: 10 Kg
3) Use for Case hardened fiber material
4) Do not use on hardened steel

Table IIIII
Hardness Value –HRM Value

SL.NO	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Hardness Value	72	66	68	67	74	71	87	77	71

T_2 test plate only found lower hardness compare than others.

B. Tensile Test & Elongation

Friction processed joints are evaluated for their mechanical characteristics through tensile testing. A tensile test helps determining tensile properties such as tensile strength, yield strength, percentage of elongation, and percentage of reduction in area and modulus of elasticity. The welding parameters were randomly chosen within the range available in the machine.

Table IVV
Taguchi Analysis Result for Tensile Strength-SN Ratio

S.NO	Speed RPM	Tool-TR mm/min	AXFC KN	TL KN	TS N/mm^2	SN-RATIO
T_1	1300	15	8	2.25	9.00	19.0849
T_2	1300	20	9	3.36	13.44	22.5680
T_3	1300	25	10	2.65	10.60	20.5061
T_4	1400	15	9	2.93	11.72	21.3786
T_5	1400	20	10	3.11	12.44	21.8964
T_6	1400	25	8	2.01	8.04	18.1051
T_7	1500	15	10	2.39	9.56	19.6092
T_8	1500	20	8	2.76	11.04	20.8594
T_9	1500	25	9	1.77	7.08	17.0007

Table V
Response Table for Signal to Noise Ratios- Larger IS Better

Level	Speed RPM	Tool-TR mm/min	AXFC KN
1	20.72	20.02	19.35
2	20.46	21.77	20.32
3	19.16	18.54	20.67
Delta	1.56	3.24	1.32
Rank	2	1	3

Table VI
Analysis of Variance Tensile

Source	DF	SEQ SS	ADJ MS	F	P	% Of Contribution
SPEED	2	5.541	2.770	1.42	0.414	16
TOOL TRAVERSE	2	21.147	10.574	5.41	0.156	61
AX FC	2	4.207	2.104	1.08	0.481	12
Error	2	3.906	1.953			11
Total	8	34.801				100

C. Angle Distortion

Table VII
Angle Distortion

No of Plates	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
Angle Distortion	2^o	1^o	2^o	0^o	0^o	0^o	0^o	0^o	2^o

Angle distortion analyzed through AUTOCAD software. During the inspection plate 4, 5, 6, 7 & 8 found no deviation from the axis.

D. Conclusion of Bead Geometry & Weld Bead Appearance Analysis

1) Through IMAGE-J software depth of penetration and bead width evaluation found during this investigation nominal bead width and depth obtained sample no 2. (L-18.022mm & H-1.648mm). This sample shows higher tensile strength also.

2) No of 4th, 7th & 8th specimen is found smooth bead appearance it has no crack, porosity.

VII. RESULT & CONCLUSION

3D–Deformation analysis satisfied result obtained during maximum speed (1500RPM), maximum Tool Traverse (25mm/min) and medium level of Axial Force (9KN).

The UHMWPE material could be welded by the Triangular pin profile in the friction stir welding process. UHMWPE tensile specimen test executed FIE-600KN machine. During this tensile evaluation 2nd sample show has more tensile strength 13.44 N/mm^2. Hardness value found through hardness "M" - Scale tester (Model: sivaganga) major load applied 160kgf and ¼" ball indenter was used. Normal UHMWPE hardness was 90HRM.

Based on the Taguchi design optimized parameter was UHMWPE for 10mm with executed triangular profile A_2, B_1, & C_3 – (Speed 1400 RPM, TR 15mm/min & AF 10KN) and tensile strength majorly infused with tool Traverse 61%.

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