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Effect of Composition of Fluxes on Mechanical Properties of Mild Steel Welds by Submerged Arc Welding

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There is a plethora of experimental research available in the area of Submerged Arc Welding due to its novelty and benefits. However experimental techniques require a lot of time and cost which sometimes is not feasible. In case of less availability of time a quick response is desired that gives fast results shall be a boon to researchers. This problem has been solved with the advent of high computational methods that helps in predicting few parameters e.g. stress, strain, thermal effects, etc. related to SAW which otherwise would be extremely difficult to measure by conventional methods. The Finite Element Method has proved to be very efficient in the simulation of SAW and the accuracy of the model is also increasing day by day due to more advancement in technology. The market is flooded with simulation software and the suitability of each depends upon their applications. This paper summarizes scholarly work done in the area of Finite element modeling and simulation of friction stir welding. This will provide some insights into current research status as well as their benefits and limitations which will help to add some value to existing research by finding a gap in the literature. This paper provides a summary of work done by researchers in the field of finite element simulation of SAW for analysis of different parameters, their preference and suitability for a particular numerical approach as well as software.

Keywords: Finite Element, Simulation, Software, Numerical analysis

Introduction:

The popularity of SAW rose to great heights just after its invention in the year 1991 by The Welding Institution (TWI) due to its great advantages over existing welding processes [1]. It is a solid-state welding technique initially developed for welding of aluminum alloys because of other welding process being inefficient [2]. Existing welding techniques like TIG and MIG were not able to produce joints of sufficient strength. Joints produced by these welding techniques were having maximum strength in the range of 50-60% of base metal strength [3-5]. Now with more advancement in technology SAW is used to weld a huge category of materials including plastics. The strength of aluminum joints produced by SAW has reached weld efficiency up to 85%. There are so many advantages of using SAW over other fusion welding process e.g. no blowhole, porosity, extremely small or no heat-affected zone, no fume generation, low distortion, equiaxed grains, no requirement of filler material, energy-efficient, excellent ability to join dissimilar metals, etc. Fewer limitations are also there e.g. remaining exit holes at the end of welding leading to material loss, no mechanism to control flash, need for the robust machine to control highly reactive forces during the welding process [6]. Most of the application we find in automobile and aircraft industries where welding of dissimilar metals was very difficult by earlier processes [7]. Another area where it finds its applications are marine and electronics.
SAW uses no consumable tool that rotated and pushed against interfaces of two workpieces. The heat energy produced due to friction between tool and workpiece is utilized in softening the workpiece material. Mechanical mixing of material is done by a rotating tool to produce a solid-state bond. [8]
A lot of experimental research work has been done to have a greater understanding of the process and relationship among various process parameters. This may help in innovations and far large applications. However experimental work being extremely costly, time-consuming needs some prior predictions to avoid frame experiments more precisely. This can be done either by doing it analytically or numerically which gives the approximate solution. Both methods have their pros. and cons. One of the few options to predict relationship among parameters is analytical technique but

is mostly suitable for processes that are linear but for a complex process that involves several other factors then it will no longer remain linear. Analytical methods find very few or most of the time no application in case of highly nonlinear processes. Due to the nonlinearity of most of complex problem use of analytical methods is less desirable. Numerical analysis which gives better results in case of nonlinear problems has been preferred over analytical methods. Numerical analysis provides an approximate solution by solving differential equations.

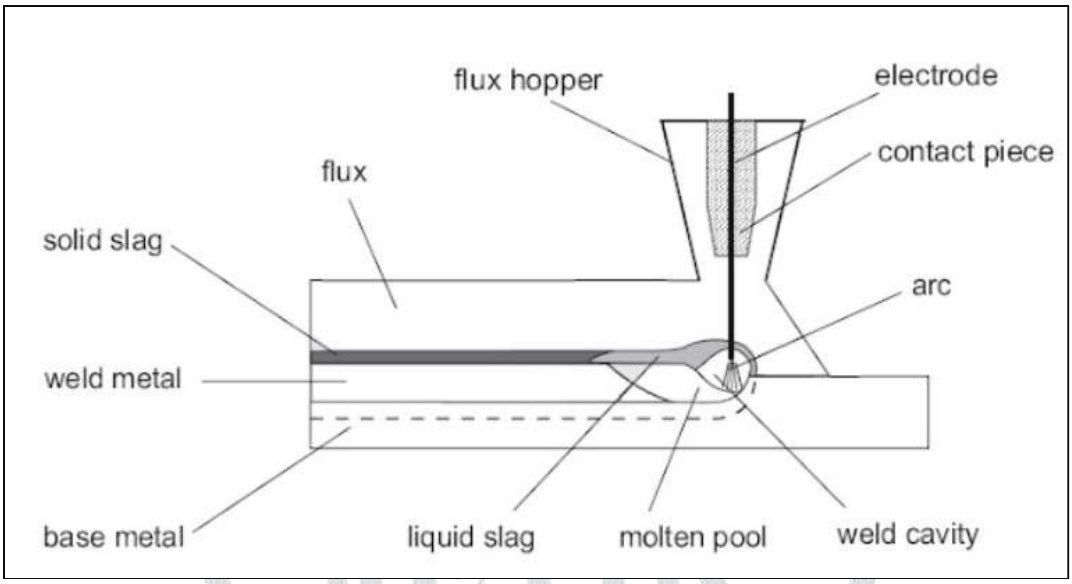

Fig 1: Principal of SAW [8]
("Courtesy of TWI Ltd")

Numerical Technique:

The application of numerical techniques in providing an approximate solution to real-life problems has been immense. Numerical methods have been applied in solution to partial differential equations hence it should have *consistency*, *stability*, and *convergence*. Methods e.g. finite difference method (FDM), finite volume method (FVM), finite element method (FEM), boundary element method (BEM), etc are commonly used in different problems. [9]

Finite Element Method

The finite element method is one of the numerical techniques which have used to solve complex problems of linear or nonlinear nature. It is a powerful tool that has revolutionized the field of simulation for it's near to actual results.
Simulation can be defined as a statistical technique for performing experiments on a digital computer, involving logical and mathematical relationships that interact to explain the behavior and structure of a complex real-world system over an extended period.

FE simulation

Simulation of the SAW process has been done by a no. of researchers due to the advent of high-speed powerful computers. Numerous FEM software packages have been available in the market some of mostly used are DEFORM 3D, ABAQUS/EXPLICIT, ANSYS, FLUENT, ALTAIR HYPER WELD, SIMUFACT WELDING, SYSWELD, MAXIM, VISUALWELD, VIRFAC etc. Each of them has its own characteristics which make them suitable for a particular type of welding or parameters.

The various aspects of SAW e.g. grain structure in nugget zone, temperature distribution, material flow analysis, strength of joints, tool velocity effects can be predicted with the help of this FEM software. However utmost care is required in proper selection of variables and boundary conditions also accuracy of solution depends on computational capacity of computer.

Approaches in numerical computation:

Table 1: Approaches in numerical computation [9]

Approach / Feature	Langragian	Eulerian	Arbitrary Lagrangian and Eulerian (ALE) approach
Nodes	Material attached to nodes and determination of properties e.g. temperature, displacement can be done by tracking the node.	Nodes are stationary and control volume is defined in a space.	Flexible grids which allow the influx of material.
Computational Time	More computational time	Less computational time	Intermediate
Interface	Defined interface makes it easier to apply boundary conditions.	Very difficult	Difficult
Mesh	Major issues in mesh distortion so preferable in case of small distortion otherwise remeshing is required which increases computation time.	No issue with mesh distortion due to fixed nodes.	Remeshing becomes extremely difficult.
Simulation	Steady state simulation is possible	Not possible	Combines feature of both Langragian and Eulrerian approach
Application	Prediction of temperature, force and strain. Covers from plunging to welding	Flow behaviour and temperature distribution	Not suitable for SAW simulation due to heavy mesh distortion

Software used:

Table 2: Software used

Sr. No.	Type of Investigation	Software
1	Thermo mechanical behaviour, strain, stress and friction simulation	ABAQUS, ANSYS
2	material flow and fluid dynamic behaviour modelling	FLUENT

Literature on FE Simulation of SAW

The work of researchers has been summarized in table 3.

Table 3: Literature Survey

Sr. No.	Author	FE Model	Key Findings	Year
1.	Ulysse P.	Three Dimensional Viscoplastic model To assess the effects of welding and tool rotational speeds on temperature, loads on the tool pin, and flow of particles near the rotating pin.	"There was increase in forces on pin with increasing welding speed, and decrease with increasing rotational speed. There was over prediction of temperature compared to experimental findings."	2002

2.	Seidel T.U. and Reynolds A.P.	"Two Dimensional thermal model Laminar, Viscous and Non-Newtonian fluid flow around a circular cylinder"	"Vertical mixing was prominent during SAW at low welding speed to rotational speed ratio".	2003
3.	Deng X. and Xu S.	"Two Dimensional finite element model to simulate the material flow around the tool pin in SAW using Abaqus Dynamic Explicit."	"Two models were compared where one was Modified Coulomb's frictional model and the other was a constant rate model. Both were found to be having no significant difference."	2004
4.	Colegrove P.A. and Shercliff H.R.	"Three Dimensional CFD model on FLUENT. To assess temperature distribution and material flow during SAW of Al7075."	"The model was inadequate to exactly predict the temperature and size of the deformation zone, the effect of rotational speed."	2004,2005
5.	Schmidt H. and Hattel J.	"Thermo-mechanical model to simulate the steady-state SAW of Aluminium alloy using coupled temperature-displacement dynamic explicit with ALE techniques.	"Simulation findings shown that the cooling rate plays an important role in defect formation, and a higher cooling rate leads to faulty deposition of material behind the tool pin."	2005
6.	Buffa G. et al.	"Three-dimensional thermo-mechanical coupled, rigid-visco-plastic, finite-element model"	"There is a significant reduction in distortion with an increase in pin angle which results in uniform temperature distribution. The result showed that the use of tapered tool should be preferred in case of thick sheets."	2006
7.	Zhang H.W. et al.	"3 Dimensional modeling of material flow in friction stir welding under different process parameters."	"Axial force was more pronounced in the nugget zone then TMZ and HAZ."	2007
8.	Guerdoux S. and Fourment L.	"Three dimensional FE software using Forge 3 adaptive ALE formulation to compute the material flow and the temperature evolution during the SAW process."	"The results concluded that this can be used for a nonsteady and steady welding phase with the right sensitivities."	2009
9.	Zhang Z. and Zhang H.W.	"Model for the thermomechanical conditions in SAW. "	"Simulation results predicted that weld quality can be improved by increasing tool rotational speed and decrease in welding speed. If the rotational speed is increased there will be obvious flash formation."	2009
10.	Assidi M. and Fourment L.	"SAW numerical simulation tool based on Forge FE software."	'It was found in comparing the two friction model Norton's and Coulomb for tool plate interface in Al6061 T6 that considering various tool speed friction calibration can be regarded as general. "	2009

11.	Li, H.; Mackenzie, D.	"Parametric finite-element studies on the effect of tool shape in friction stir welding."	"Results have shown that, with increase in pin radius, there was appreciable increase in force, torque and heat generation in plunge state. However there was almost no effect was found to be due to shoulder angle."	2010
12.	Riahi and Nazari	"Material characteristics were added to FE model."	"There is dependency of temperature on tool geometry, contact information between tool and workpiece."	2011
13.	Long T. and Reynolds A.P.	"CFD-based model to study the effect of material properties and process parameters on the x-axis force, material flow and potential defect formation."	"Pattern of material flow was predicted around the tool for different process parameters. Defect formation was also described by the model."	2013
14.	Carlone P. and Palazzo G.S.	"CFD model to simulate the SAW process of AA2024-T3 using the ANSYS CFX"	"Model was able to explain defects in welded zone. Others were grain size, microstructure and microhardness profiles."	2013
15.	Dialami N. et al.	"Fully coupled thermo-mechanical model for SAW simulation."	"The simulation results showed the material flow pattern near the tool pin. In this study particle tracing was done and different non circular pins were analysed."	2013
16.	Bussetta P. et al.	"Used solid model to compute position and temperature fields and fluid model to find velocity, pressure, and temperature."	"Fluid model was found to be more useful with regard to computational view point and solid model had benefits of prediction of accurate residual stresses."	2014
17.	Veljic´	"Three Dimensional finite element models is developed using the software package ABAQUS; arbitrary Lagrangian-Eulerian formulation is applied for thermo-mechanical analysis of SAW of high strength Al alloy."	"The temperature fields were found to be symmetrical along the welding line. The temperatures below the tool shoulder, i.e. in the welding zone, reached during the plunging stage, are approximately constant during the entire welding process."	2014
18.	Bussetta et al.	"Three-dimensional thermomechanical models with trigonal pin to simulate flat welding pin."	"The study found that both formulations lead to similar findings."	2016
19.	Jain et al.	"Three Dimensional coupled model based on a Lagrangian method using DEFORM 3 D Software in the assessment of temperature distribution, strain distribution of Al 2024 alloy. "	" The simulated resulted in the prediction of temperature distribution which revealed that maximum temperature is on the top surface of workpiece."	2016
20.	Luo et al.	"Three Dimensional finite element simulation to study heat transfer between the newly designed spindle system and AA2024-T4 workpiece."	"The simulated result confirmed that the newly developed spindle can be used for welding of complex aluminium structures."	2017

21.	Zhi Zhu	"3D coupled thermo-mechanical finite element model is developed to predict and analyze the defect formation during friction stir welding based on CEL method. "	"Simulation results show that voids produced in welding will be smaller in case of low welding speed and high tool rotational speed. A defect less weld can be obtained by using featured tool pin."	2017
22.	M.M.El-Sayed	"The temperature distribution and the residual thermal stresses generated from the friction stir welding process were predicted by using finite element analysis (FEA). "	"Defect-free welds were obtained by using a threaded pin at lower rotational speed (i.e.400 rpm)."	2018
23.	Kareem N.Salloomi	"Fully coupled thermomechanical simulation of the SAW process of Al 6061-T6 alloy T-joint type using the finite element method."	"The simulated result has confirmed that during plunging maximum stress is transferred to stringer part with advancement of tool. "	2019
24.	Meyghani et al	"FE model to simulate SAW process on a curved plate using Hyperworks and ABAQUS software."	"It was found from the results of the curved finite element model that, there is a marginal increment in the heat generation as the shear zone expands due to the viscous dissipation leading up to a total peak temperature value of 300 °C (ABAQUS) and 338 °C (Altair Hyperworks) happened at time, t = 3 s at the plunge stage."	2020

Conclusion:

From study of research papers pertaining to FE modelling and simulation of SAW following points are observed and are concluded here:

1. Most of the researchers in simulation of SAW have preferred ABAQUS, ANSYS and FLUENT software. Higher accuracy has been obtained when stress, strain and other thermo-mechanical behaviour is simulated with the help of ABAQUS and ANSYS whereas FLUENT is best suited to material flow simulation
2. Fluid model is found to be more efficient from point of view of computation while solid approach is better for residual stresses.
3. Three approaches for numerical simulation are used. They are Langragian, Eulerian and ALE. CFD utilizes Eulerian mesh whereas langragian approach is used in solid meshing and ALE combines the feature of both.
4. A constant value of friction coefficient is used in most of the cases which is usually 0.58.

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