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Multiphysics Coupling Method to Simulate the Friction Stir Welding Process

Método De Acoplamiento por Multifísica Para Simular El Proceso De Soldadura Por Fricción - Agitación

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***Abstract*— In In this work the methods are developed to perform simulations of the friction stir welding process using the ANSYS software working scheme, developing multiphysics couplings between computational fluid dynamics tools to Model the viscoplastic effect of the fluidity of the material when it is stirred by means of a solid tool modeled in the Transient Structure application that allows calculating the thermo-mechanical effects of the study process. The results show the validations corresponding to the modeled and experimentally performed analysis showing a lot of reliability in the proposed method. The torque reached in the process is maintained in the ranges of 14 Nm, the maximum temperature reached in the process was 540°C, this being 78.3% of the melting temperature of the material studied, having an adequate range for these studies.**

***Index Terms*— Computational Fluid Dynamics; Friction Stir Welding; Multiphysics Coupling; Remesh; Transient Structure.**

***Resumen*— En este trabajo, los métodos se desarrollan para realizar simulaciones del proceso de soldadura por fricción y agitación utilizando el esquema de trabajo del software ANSYS, desarrollando acoplamientos multifísicos entre herramientas de dinámica de fluidos computacionales para modelar el efecto viscoplástico de la fluidez del material cuando se agita por medio de un herramienta sólida modelada en la aplicación Estructura transitoria que permite calcular los efectos termomecánicos del proceso de estudio. Los resultados muestran las validaciones correspondientes al análisis modelado y realizado experimentalmente que muestra mucha confiabilidad en el método propuesto. El torque alcanzado en el proceso se mantiene en los rangos de 14 Nm, la temperatura máxima alcanzada en el proceso fue de 540°C, siendo esta el 78.3% de la temperatura de fusión del material estudiado, teniendo un rango adecuado para estos estudios.**

***Palabras claves*— Acoplamiento multifísico, Dinámica de fluidos computacional; Estructura transitoria; Remallado; Soldadura por fricción agitación.**

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I. Introduction

CURRENTLY, there are numerous computer programs focused on solving physical phenomena such as finite element tools, which allow modeling cases in specific sciences according to the program used. So, its learning and programming are of great importance since they allow validating processes without spending excessive physical resources and, in certain cases, pollutants. On the other hand, there is a bonding process called friction stir welding (FSW) that was developed and patented by W. Thomas at the Welding Institute (TWI) in 1991 Thomas [1]. FSW has advantages for joining materials compared to traditional fusion welding. FSW is made in a solid-state using a non-consumable tool that penetrates and friction the joint, generating temperature increase and stirring the material in a viscoplastic state. FSW resembles forging and extrusion. The maximum temperature of FSW is 90% of the melting material Mohan et al [2]. Subrata Pal et al [3]. They performed computational modeling using FLUENT, developing an FSW model for SS304 steel with a high hardness tool, predicting that for low flow velocity defects occur. Other authors Gaoqiang Chen et al [4]. they developed simulations with FSW computational fluid dynamics (CFD) in AA204 aluminum alloy, evaluating friction at the contact interface and comparing with experimental tests, obtaining good approximations. Other authors E. Sharghi et al [5]. Simulations were developed by

CFD to study the viscoplastic effect of FSW on AA6061 aluminum alloy using models for fluid volume (VOF). Other authors have carried out the FSW process through computational tools and experimental validations, obtaining results with little margin of error, giving greater reliability to the use of this practice through software to reduce costs in materials and associated costs [6-10]. Due to the importance of the computational tools to simulate FSW at present, the present study shows the methods for coupling multiphysics models to simulate the FSW process. For which multiphysics models will be appropriated that allow interaction between specific computer tools such as structural analysis and computational fluid dynamics, using laws for non-Newtonian fluids as an association to a material with visco-plastic behavior, to make a validation with experimental results.

II. METHODS

For the development of the simulation of the FSW process by means of computational tools, the physical phenomena that compose it must be understood such as heat transfer, fluid dynamics due to the viscoplastic effect of the solid material, mechanical materials due to stress normal and sharp present in the process, among others. So, to develop the simulation, the computer program to be used must have an interconnection between tools, which is known as multiphase coupling (MC). Figure 1 describes the physical parameters of the FSW process.

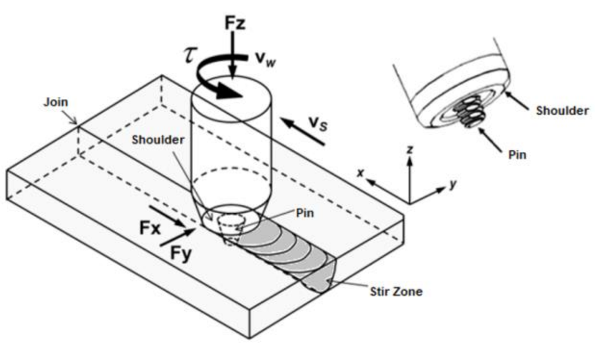

Fig. 1. FSW process parameters

Considering the associated phenomena, in this work the ANSYS software has been used for the development of the simulation with MC for presenting the capacity of the interconnection of sub-tools to model specific operations through the Workbench work scheme.

A. Heat Transfer Generated by Contact

The heat transfer generated by friction between the contact of the shoulder surface and the pin of the tool with the plates or joints is structured with respect to the geometric conditions of the tool mentioned in Figure 1 which has characteristics of conicity and threaded pin, as shown in figure 2 below, and by equation (1) [11].

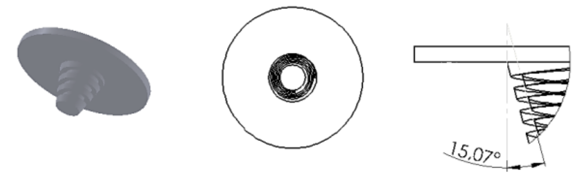

Fig. 2. A conical tool with threaded pin and flat shoulder

Whose total heat generated for this tool with conical pin is:

$$\dot{Q}_{total} = \frac{2}{3}\pi.\omega.\tau_{contact}\left(R_s^3 - R_{bp}^3 + \frac{3}{4}\frac{H}{\cos\alpha}\left(2 * R_{bp} - H * \tan\alpha\right)^2 + \left(R_{bp} - H * \tan\alpha\right)^3\right) \quad (1)$$

Where ω is the angular velocity, H is the pin height, Rs is the radius of the shoulder, R_{bp} is the radius of the pin base, R_p is the radius of the pin, α is the angle of inclination of the pin cone, $\tau_{contact}$ is the shear stress.

B. Viscoplastic Effect in Stir Zone

To perform the simulation of the process of stir and flattening of the joints, it is required to use a CFD tool that allows the fluid to be modeled as non-Newtonian, applying models that correspond to the viscoplastic effect of the material when heated, so the carreau model is used which is expressed in equation (2) below.

Carreau expressions for the viscoplastic model, which is shown in equation (2).

$$\mu(\gamma) = \mu_\infty + (\mu_0 - \mu_\infty)[1 + (\gamma\lambda)^2]^{\frac{n-1}{2}} \quad (2)$$

where λ is the time constant, γ is the shear rate, μ is the viscosity shear rate dependent. The variables for specifics of material, as is the n for non-Newtonians flow, defines the type material, as shown below.

n=1 is Newtonian fluid; n>1 is Dilatant fluids; n<1 is Pseudo-plastics.

C. Mechanical Power

To model the FSW process, the element that generates the movement is needed, which in this case is the tool, which has an angular velocity input and a forward movement once it has managed to preheat the joints by means of the friction when turning on these. Which allows calculating the mechanical power using the following equation (3).

$$P = (T * \omega) + (v_s * F_x) \quad (3)$$

Where T is the product torque of the pin and shoulder contact of the tool with the joints, ω is the angular velocity of the tool, v_s is the linear speed in the direction of tool travel, F_x is the reactive force of the joints to the impediment of the movement of the tool.

D. Simulation Conditions

Once the boundaries of each solid have been identified, the interface boundaries for the simultaneous solution are linked through the MC solution mechanism by coupling iterations. The volumetric meshing of both the plates and the tool is generated, the first in the TE design tool for structural behavior and the second in the CFD tool.

Choosing cells or elements in a tetrahedron way that allows to save computational resources by presenting fewer nodes than hexagonal cells, but which allows better assimilation when using re-molding techniques for the reconstruction of volumetric meshing and the interpolation of the solution variables for a better approach to the movement of the tool that causes the plastic deformation of the plates. You get the following cell organizations.

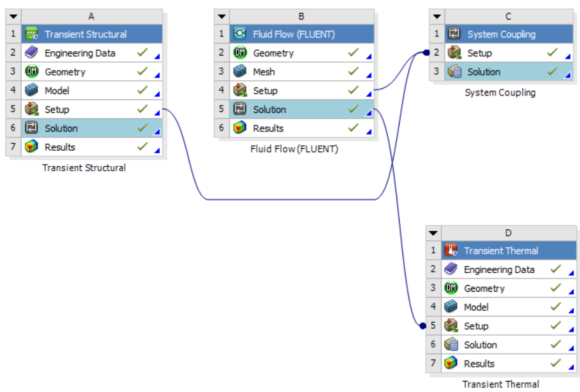

Fig. 3. Multiphysics coupling in ANSYS Workbench

E. Volumetric Remeshing Method

It became necessary to configure mesh reconstruction techniques or remeshing due to excessive deformation in the volumetric cells (elements) that are present when activating the rotation and displacement of the tool on the joints to be welded, which generates discontinuities in the solution of the variables until the error occurs.

Due to the above, methods of smoothing with mesh diffusion were implemented, which consists of allowing the contraction and stretching of the elements in the movement zone, establishing an acceptance criterion of 1E-3 to the error caused by the deformation of the elements, making 20 iterations for each time jump for verification, with detection patterns by means of maximum angle of cell deformation as well as the minimum reduction in size of 4E-4 m and maximum amplitude of 2E-3 m to prevent mesh dislocations. If the proposed conditions are not met, the overrun process is executed, which would start at the time jump where the conditions are not met, reconfiguring an element size between 4E-4 m and 1E-3 m, prioritizing the areas of interest and borders affected by deformation.

III. RESULTS

Solving simultaneously through MC the thermal profiles, shear forces, torque, among other variables of interest for all regions of the FSW process are obtained. Figure 4 shows the thermal profiles obtained for joining an AA1100 aluminum using H13 steel as the tool material.

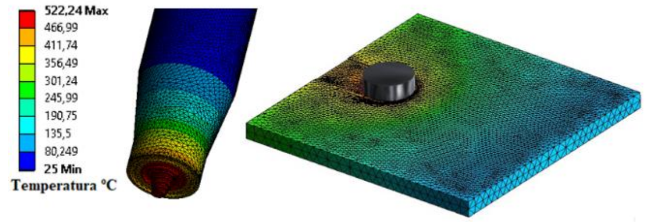

Fig. 4. Thermal profiles when applying the FSW process

From the results obtained, the measurement of the torque generated in the FSW process was performed for each moment of time, in addition to the measurement of the forces both for the X-axis and for the Z-axis reactive in the tool due to the advance of this in the joins while performing the FSW process for each instant of time, figure 5 representing this behavior as shown in the following.

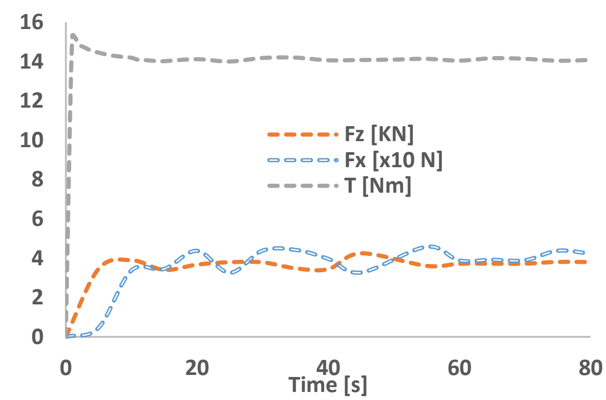

Fig. 5. Torque and forces in the joints

From the previous figure, it can be seen that the torque reached in the process is sustained in the ranges of 14 Nm.

Using the models described in the equations, the thermal profiles associated with the effects of heat generation and the volumetric deformation due to mechanical power are obtained, with the viscoplastic effects product of the above equations the torque is obtained of interactive form with the shear stress of the friction zone. Then the temperature profiles are shown in the toolpath.

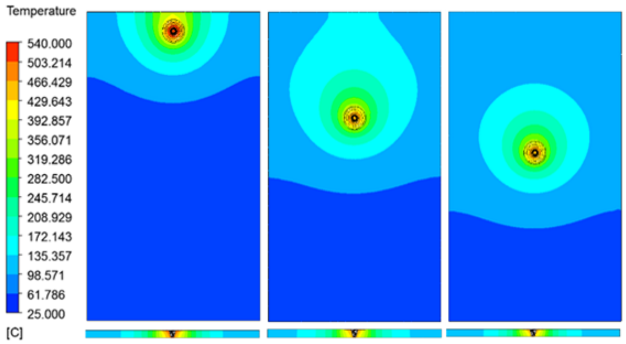

Fig. 6. Temperature profiles on plates

As well as the thermal profiles in the tool contact as shown in figure 7.

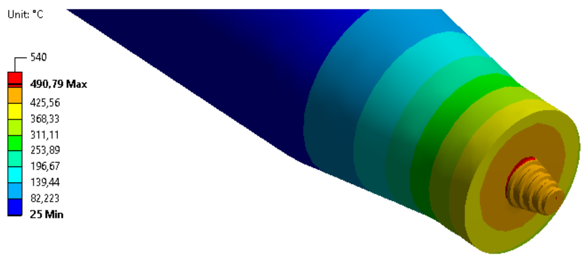

Fig. 7. Temperature profiles in the tool

Validating the final modeling with the experimental results for an AA1100 aluminum and tool material Steel H13, the following thermal cycles are presented in two measurement points immediately next to the center of the joints as shown in figure 8. It can be analyzed that the results obtained have a high degree of reliability with a deviation of 2,935°C for measurements closer to the joint junction and a deviation of 5,263°C.

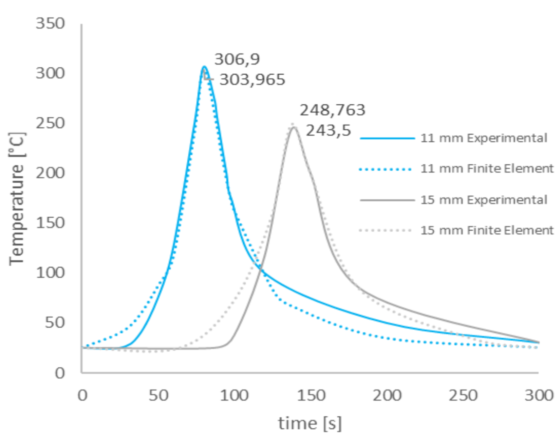

Fig. 8. Thermal cycles in the FSW process

IV. Conclusions

The FSW process developed by means of modeling programs provides a great advantage, in addition to saving resources, it provides the obtaining of variables that in the experimentation present great inconveniences to be able to analyze these readings.

The multiphysics coupling is presented as an ideal option for the modeling of the FSW process since the effects of computational fluid dynamics are involved, as well as transient structure analysis, in addition to thermal study.

The deviations found when experimentally validating the simulated process, have a high degree of reliability for this type of processes, in which usually because they are thermal studies, and with variable properties such as thermal conductivity and specific heats, they have to present large losses in experimental models energy, which were taken into account when activating the energy models associated with heat loss with the environment in the simulation.

For future processes, the validation of the FSW process for dissimilar joints, and validation for other types of materials can be planned, based on the technique presented in this work.

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