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Abstract:
Numerical simulation is regarded as a powerful tool to understand the physical mechanisms taking place during friction welding, provided that the numerical approach accurately models the complex interface phenomena and as long as the related model parameters are identified from experimental data acutely measured close to the interface. After describing the utilized finite element formulation, the friction and heat and friction interface models are calibrated from thermal measurements, both for the FSW welding of aluminum under a lap joint configuration and for the LFW of titanium alloys.

Keywords: FSW, LFW, Numerical Simulation, Thermal Measurements, Calibration.

Numerical Simulation of Friction Welding processes

Numerical simulation provides essential information for understanding complex bonding mechanisms occurring in friction welding processes like FSW (Friction Stir Welding) and LFW (Linear Friction Welding). Obtaining sufficiently accurate 3D results requires developing specific numerical methods such as adaptive mesh refinement, treatment of unilateral contact conditions, and formulations dedicated to very large material deformations like the ALE (Arbitrary Lagrangian or Eulerian) [1] or Updated Lagrangian (including automatic 3D remeshing) [4] formulations. Such specific model allows predicting the actual tool print formed during FSW, which has significant influence on material local temperature [2].

A main difficulty is however encountered to model material and interface behaviors under widely ranging thermo-mechanical conditions. An inverse approach is consequently necessary to assess the selected JMatPro material model and to calibrate the still unknown friction parameters [2], based on instrumented experiments providing displacements, forces and especially temperature measurements. A special attention is paid to acutely monitor data as close as possible to the welding interface.

Application to FSW

This approach is first applied to FSW welding of aluminum under a lap joint configuration of 7175 on 2024 using a scrolled tool [3] (see Figure 1(a)), which shows quite difficult to model. Tool temperature is consequently measured close to the surface (using an embarked recording system) under different welding configurations. Calibration of the physical coefficients of the numerical model, which is based on an ALE formulation with unilateral contact conditions [1][3], allows obtaining a rather adequate agreement with experimental measures. On the other hand, the sensitivity of worm hole formation to the advancing and rotating velocities is very satisfactorily simulated as presented in Figure 1(b).

Application to LFW

This approach is extended to the LFW of titanium alloys, a process presenting same numerical and modeling difficulties along with similar bonding mechanisms. The numerical simulation is based on an Updated Lagrangian formulation with frequent adaptive remeshing [4]. It allows properly predicting the material consumption rate (downhill velocity of the upper tool under a constant forging force). As shown in Figure 2(a), temperatures are recorded at different locations of the Ti6242 sample, as close as possible to the welding interface. Although in good agreement, numerical results (see Figure 2(b)) obtained before calibration of the friction coefficient do not properly follow the experimental curves. It shows the necessity of both enhancing the accuracy of the numerical model through mesh adaption based on error estimation, and of precisely identifying the friction coefficient, a very sensitive model parameter.

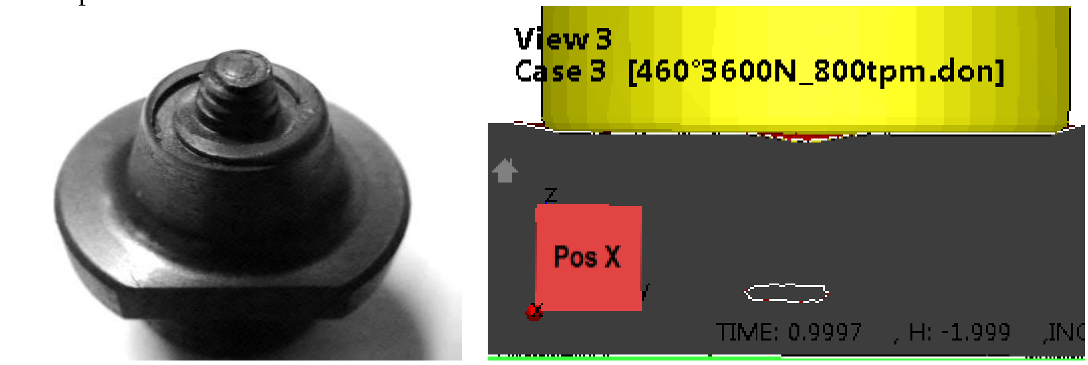

Figure 1: (a) Conical tool with threaded pin and scrolled shoulder (b) Development of worn hole defect in the simulation that perfectly corresponds with macrographs from FSW trials [3].

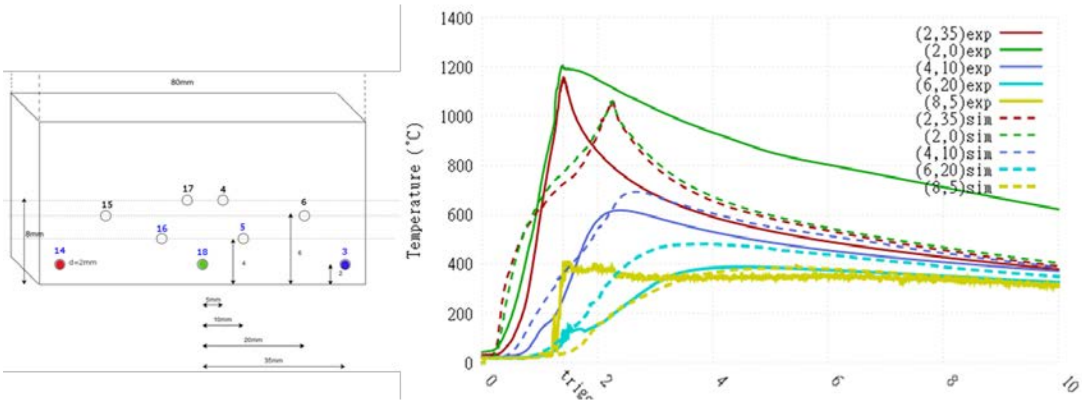

Figure 2: (a) Location of thermocouples on the sample (b) Time evolution of measured and computed thermocouples temperatures, using a symmetrized numerical model [4]

Conclusions

Accurate numerical simulation of temperature evolution close to the friction welding interface shows delicate. It raises experimental and especially numerical difficulties, which are though essential to be tackled and solved, following the proposed approach based on adaptive meshing, unilateral contact and friction calibration. This approach aims at acutely understanding the metallurgical evolutions within the welded join.

Acknowledgements

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