A Linked Processing & Microstructural Model for Weld Pool Analysis

The University of Birmingham benefits from ESI's Virtual Prototyping solutions

The PRISM^2 Research Group, part of the **School of Metallurgy & Materials at the University of Birmingham**, has been working on the development of a multi-physics modelling approach to predict the formation and properties of a titanium alloy fusion weld joint. Welding applications are critical to a wide range of industry sectors, from aerospace to automotive. Computer simulations of welding processes have been widely used throughout academia and industrial companies for several years. Improvements in computing power, and recent software developments, have further allowed a more detailed modelling methodology to be adopted.

Researchers at the PRISM^2 Research Group have successfully simulated the stresses and distortions arising from a welding process for several years, thanks to **ESI SYSWELD**, the specialist Finite Element (FE) welding software, from **ESI Group**. SYSWELD is the most accurate multi-physics software on the market to simulate thermal joining (arc, electron beam, laser, friction stir, spot welding) and heat treatment (carburizing, carbonitriding, quenching). By accounting for all relevant manufacturing effects and enabling the transport of simulation results from one manufacturing step to the next, SYSWELD delivers a truly predictive end-to-end solution for the manufacturing of welded and assembled industrial parts.

A challenge industrials face in conducting FE welding simulation is the need for a-priori knowledge of the weld pool shape, usually gained from sectioning physical weld samples at the specified welding parameter set (speed, power, joint thickness, material). Additionally, the complex nature of a weld, whereby the material ranges across solid, liquid – and even vapour phases too, when a keyhole phase is present within high power density beam welds – means that in order to accurately predict material flow and joint integrity properties for such a complex arrangement, an FE-based approach falls slightly short. To address this, the PRISM^2 Research Group has explored **Computational Fluid Dynamics (CFD)** methods to accurately predict the shape and size of the molten and vapour weld bead region as it is traversing through the solid surroundings.

A third challenge is in achieving fully coupled microstructural predictions. Researchers would benefit from the ability to accurately model the microstructural evolution, along with grain sizes and distributions within the solidified weld pool. This also was investigated using CFD codes.

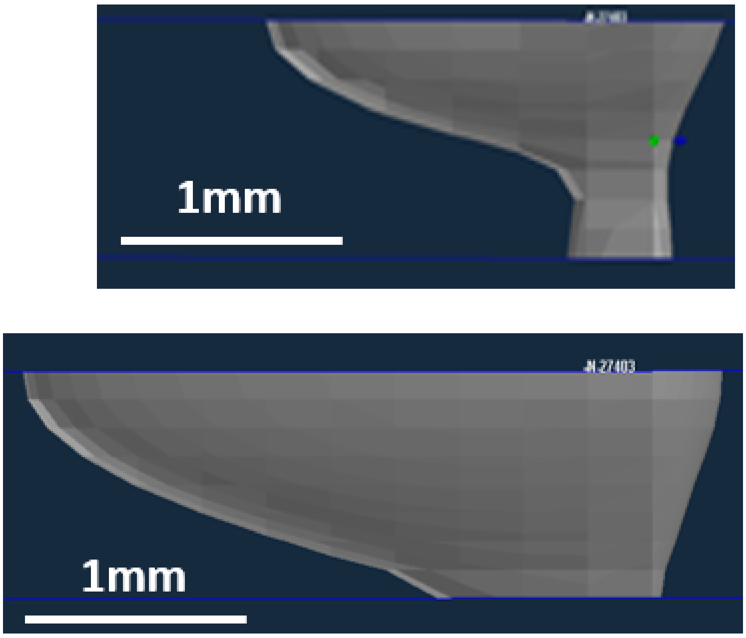

Figure 1: Weld pools produced in ESI SYSWELD using a Cartesian co-ordinate data entry measured from OpenFOAM

Construction of the model

PRISM[2] researchers have developed CFD models within **OpenFOAM**, a free, open source CFD software package developed by **ESI OpenCFD** and other participants in the global OpenFOAM community. These models take into account vaporisation, thermo-capillary force, surface tension, buoyancy and complicated heat radiation, conduction, and convection, together with parameters of the power and speed of the external heat source. The engineers established a solver for two compressible, non-isothermal immiscible fluids using a volume of fluid (VOF) phase-fraction based interface capturing approach. This solver integrates the momentum and other fluid properties; while a single momentum equation coupled with equations of energy and continuity is solved to rationalise the evolution of metallic and gaseous phases.

To predict the associated weld microstructure, engineers assigned the 3D weld pool geometry and nodal temperature history from OpenFOAM as dynamic temperature boundary conditions for a coupled Cellular Automata / Finite Element (CAFE) model in **ESI ProCAST,** advanced casting simulation software. This creates a fully coupled model from liquid to solid phases with the capability to predict the microstructure in the welding zone for a given set of process conditions, and subsequently enables the prediction of its mechanical behaviour.

The Outcome

A CFD-based OpenFOAM model is now used to offer predictions of weld pool geometry as it traverses through a titanium alloy plate, of specified thickness, with specified welding parameters. This has removed the need for experimental cut-ups to understand weld pool shape, to feed in to an FE model, significantly reducing experimental costs. This modelling approach also markedly improves the predictive capabilities of the combined OpenFOAM/ SYSWELD modelling technique.

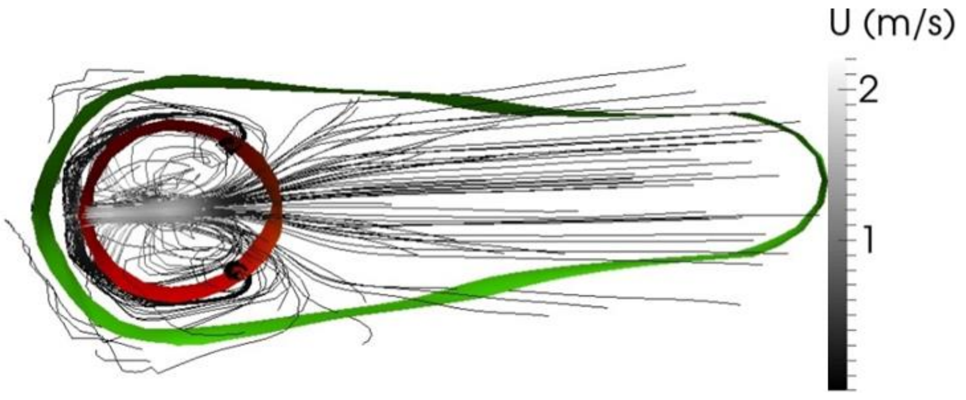

Figure 2: OpenFOAM CFD model showing weld pool (green) and key hole (red) boundaries from top down.

Figure 3: OpenFOAM CFD model showing flow of material within the molten weld pool, and notably the flow around the key hole formation (red), viewed from the side.

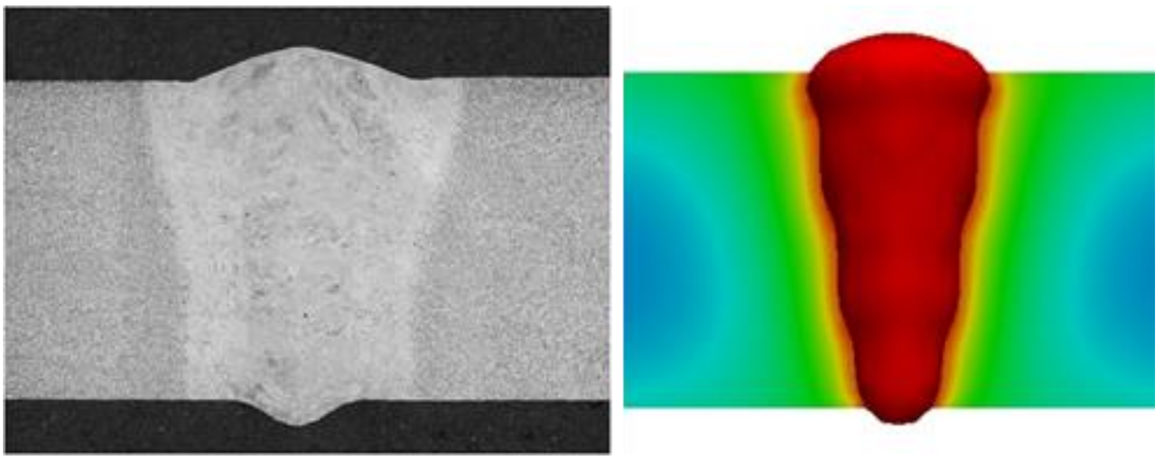

Figure 4: Weld pool cross-section from experiment, and compared to CFD modelling.

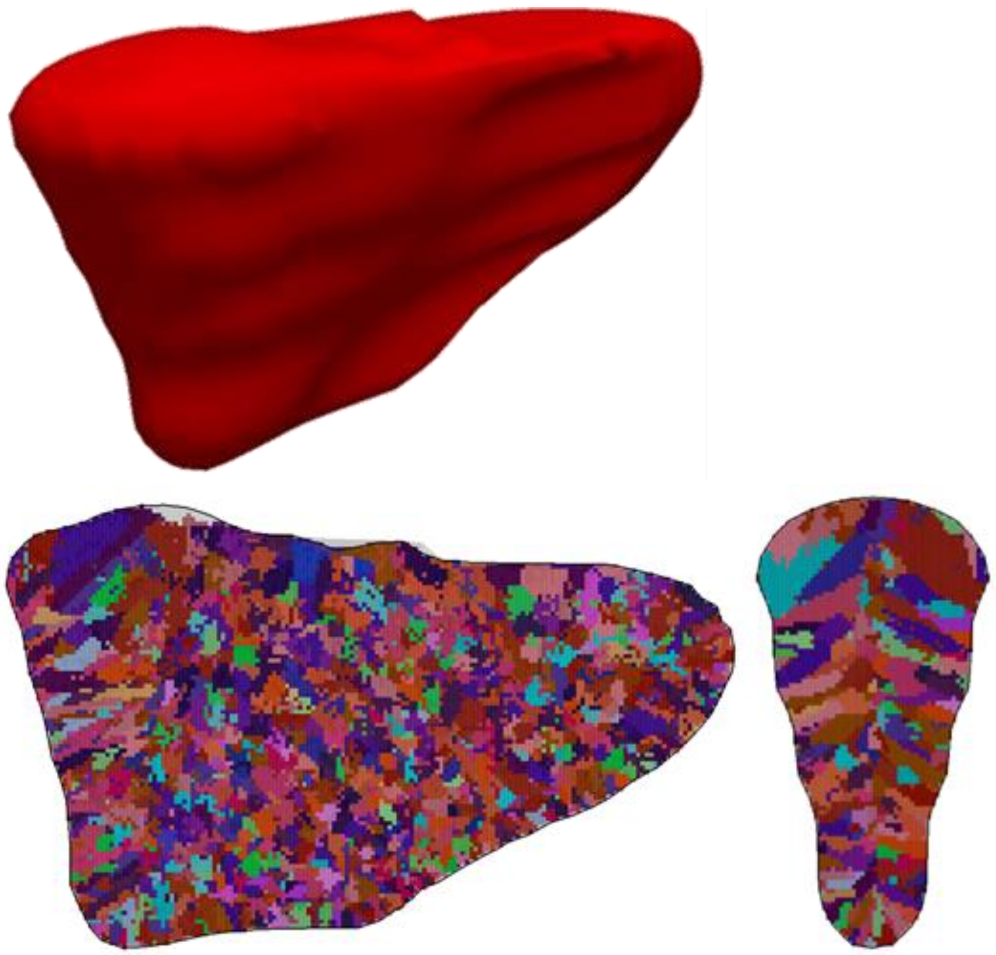

Figure 5: (top) An Extracted weld pool geometry, which can be fed in to the CAFE model in ESI ProCAST (bottom) to predict grain growth and microstructure within the solidified pool – viewed from the side, and from the front.

Alternatively, the weld pool geometry, and associated thermal histories, can be loaded into the ProCAST software, to perform Cellular Automata calculations to understand grain formation within the solidified weld pool. Thus, a multi-scale modelling methodology, linking the three **ESI Group** software packages OpenFOAM, SYSWELD and ProCAST, has been established.

According to researchers at the PRISM^2 Group, School of Metallurgy & Materials, University of Birmingham: “Multi-scale materials engineering is vital in order to accurately represent all physical phenomena involved within a complex manufacturing process, and provide industry with a reliable option for accurate predictions. Thanks to ESI’s wide portfolio, and highly specialised software packages, the research group was able to find all essential models needed and build the entire methodology with great level of confidence.”

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About ESI Group

ESI Group is a leading innovator in Virtual Prototyping software and services. Specialist in material physics, ESI has developed a unique proficiency in helping industrial manufacturers replace physical prototypes by virtual prototypes, allowing them to virtually manufacture, assemble, test and pre-certify their future products. Coupled with the latest technologies, Virtual Prototyping is now anchored in the wider concept of the Product Performance

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About PRISM^2:

PRISM^2 is a research centre at the University of Birmingham, with expertise in the modelling of materials, manufacturing and design for high technology applications in the aerospace and power generation sectors. It is located in the Interdisciplinary Research Centre (IRC) on the University of Birmingham's Edgbaston campus.
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