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Publication date:
2015

Document Version
Peer reviewed version

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Citation (APA):
Sonne, M. R., & Hattel, J. H. (2015). Modelling the residual stresses and microstructural evolution in Friction Stir Welding of AA2024-T3 including the Wagner-Kampmann precipitation model. Poster session presented at 14th International Conference on Modelling of Casting, Welding and Advanced Solidification Processes, Awaji island, Hyogo, Japan.

DTU Mechanical Engineering
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Modelling the residual stresses and microstructural evolution in Friction Stir Welding of AA2024-T3 including the Wagner-Kampmann precipitation model

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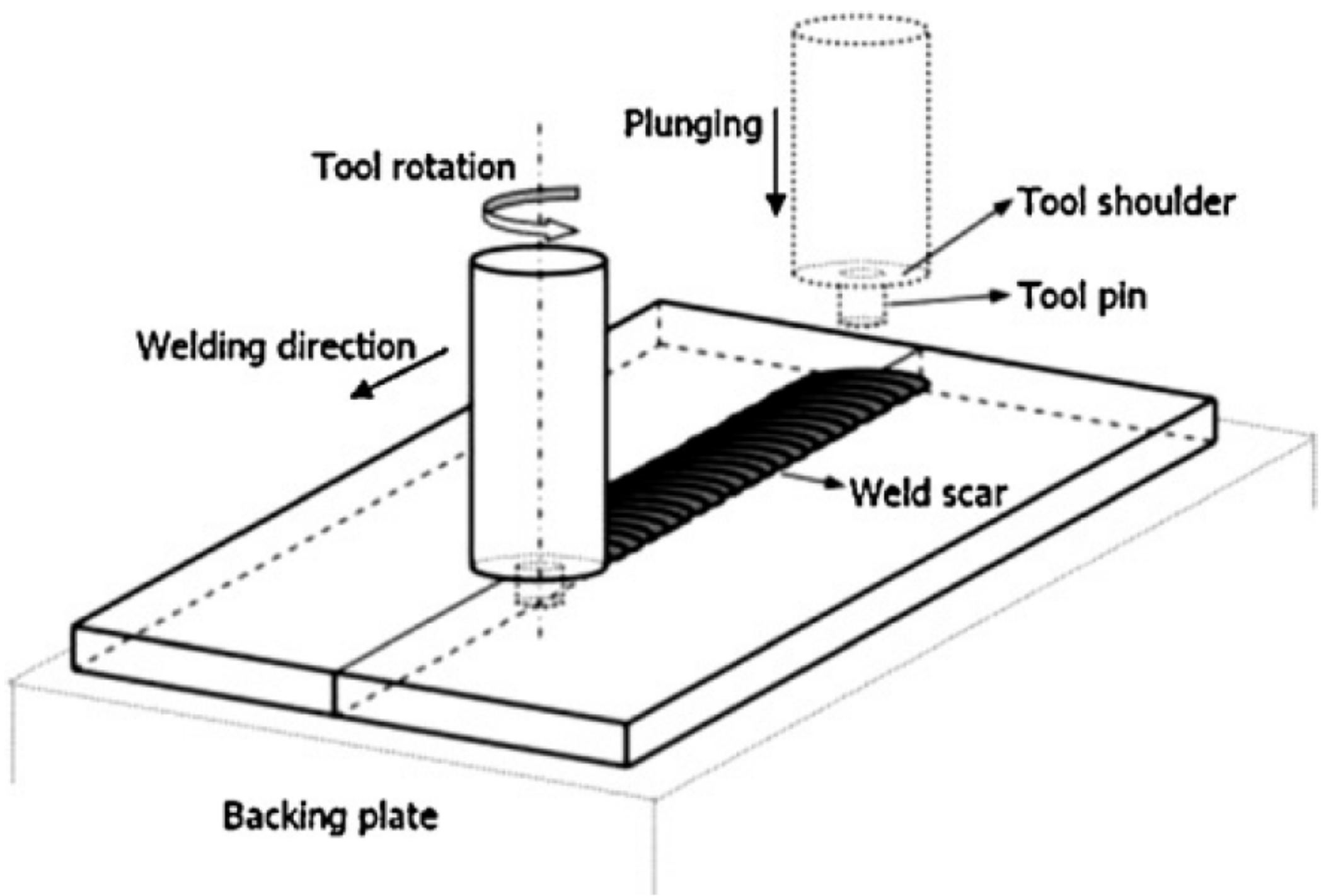
Introduction

Friction stir welding (FSW) is an efficient solid state joining technique that without melting is intended to be used for joining of for example high strength aluminum alloys. In this process, heat is generated by the friction and plastic deformation between tool shoulder and the work piece.



Schematic view of the FSW process [5].

Thermal model (TPM)

The model for the heat generation proposed by Schmidt and Hattel [2] is applied in this study. This is a function of the tool shoulder radius and the temperature dependent yield stress as follows

$$\frac{\dot{q}_{surface}}{A}(r,T) = \omega r \tau(T) \quad = \left(\frac{2\pi n}{60}\right) r \frac{\sigma_{yield}(T)}{\sqrt{3}},$$

$$\text{for} \quad 0 \le r \le R_{shoulder}$$

The heat source is used as a boundary condition at the interface between the tool shoulder and the work piece for the heat conduction equation

$$\rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + \dot{q}_{vol}$$

Mechanical model

For calculation of the transient as well as the residual stress field, a standart mechanical model based on the solution of the three static force equilibrium equations is used

$$\sigma_{ij,i} + p_j = 0$$

Hooke's law and linear strain decomposition as well as small strain theory are applied together with the expression for the thermal strain.

In this work, a numerical finite element model for friction stir welding of 2024-T3 aluminum alloy, consisting of a heat transfer analysis and a sequentially coupled quasi-static stress analysis is proposed. Metallurgical softening of the material is properly considered and included in the calculations by means of the Wagner-Kampmann precipitation model.

Precipitation model

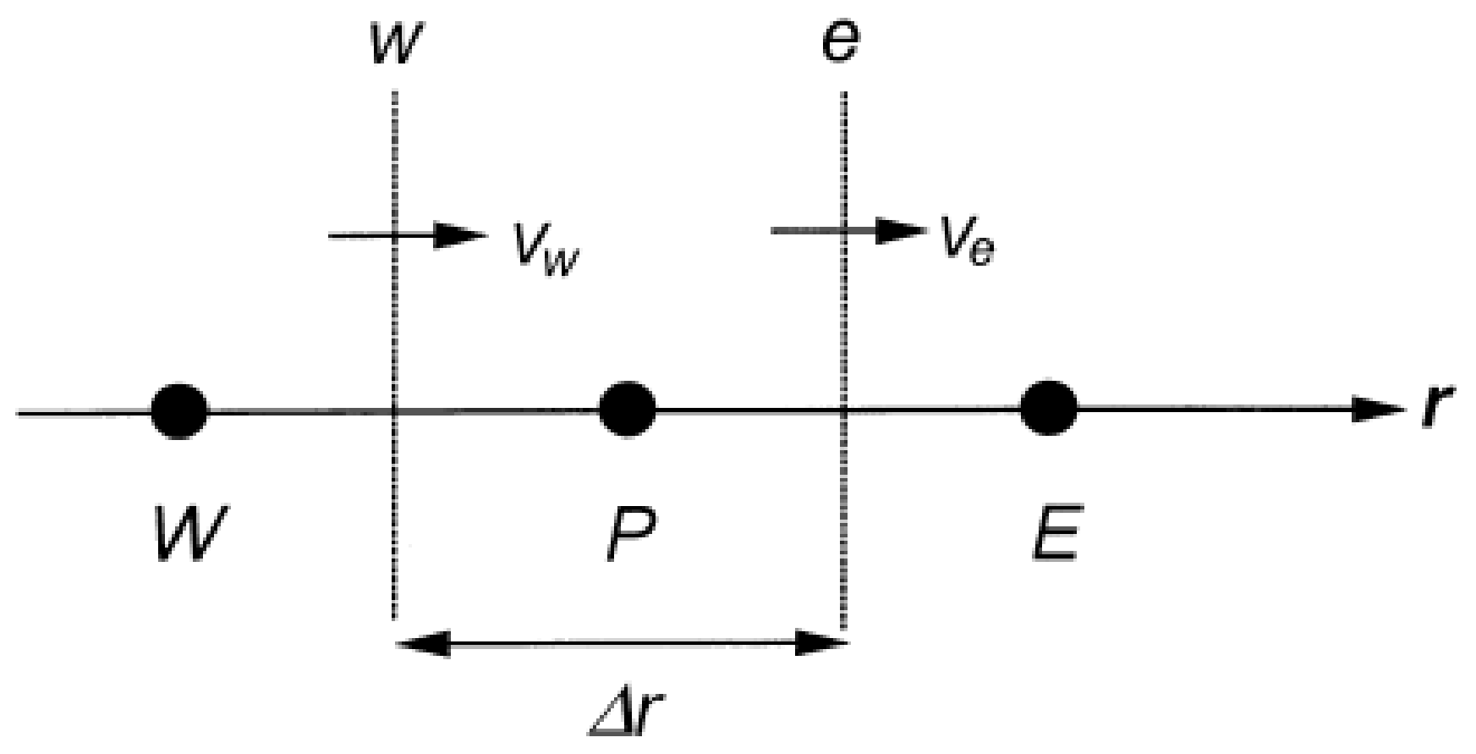
In the present work, the simplified precipitation sequences observed in Al-Cu-Mg alloys is used

a_{ss}->Cu-Mg coclusters->S phase precipitates

where a_{ss} is the super saturated solid solution, Cu-Mg coclusters are formed by initial ageing in these alloys and the S phase is the equilibrium phase precipitates [3]. In this model the precipitate aging of the S phase precipitate is simulated based on the Wagner-Kampmann numerical model. This model takes nucleation, growth and dissolution into account. The governing evolution equation is written as

$$\frac{\partial N}{\partial t} = -\frac{\partial (Nv)}{\partial r} + S.$$

Where N is the number density of precipitates, r is the precipitate radius, v is the growth or dissolution rate and S is equal to the nucleation rate. This differential equation can be solved with a standard finite difference procedure, in this case with explicit time integration.

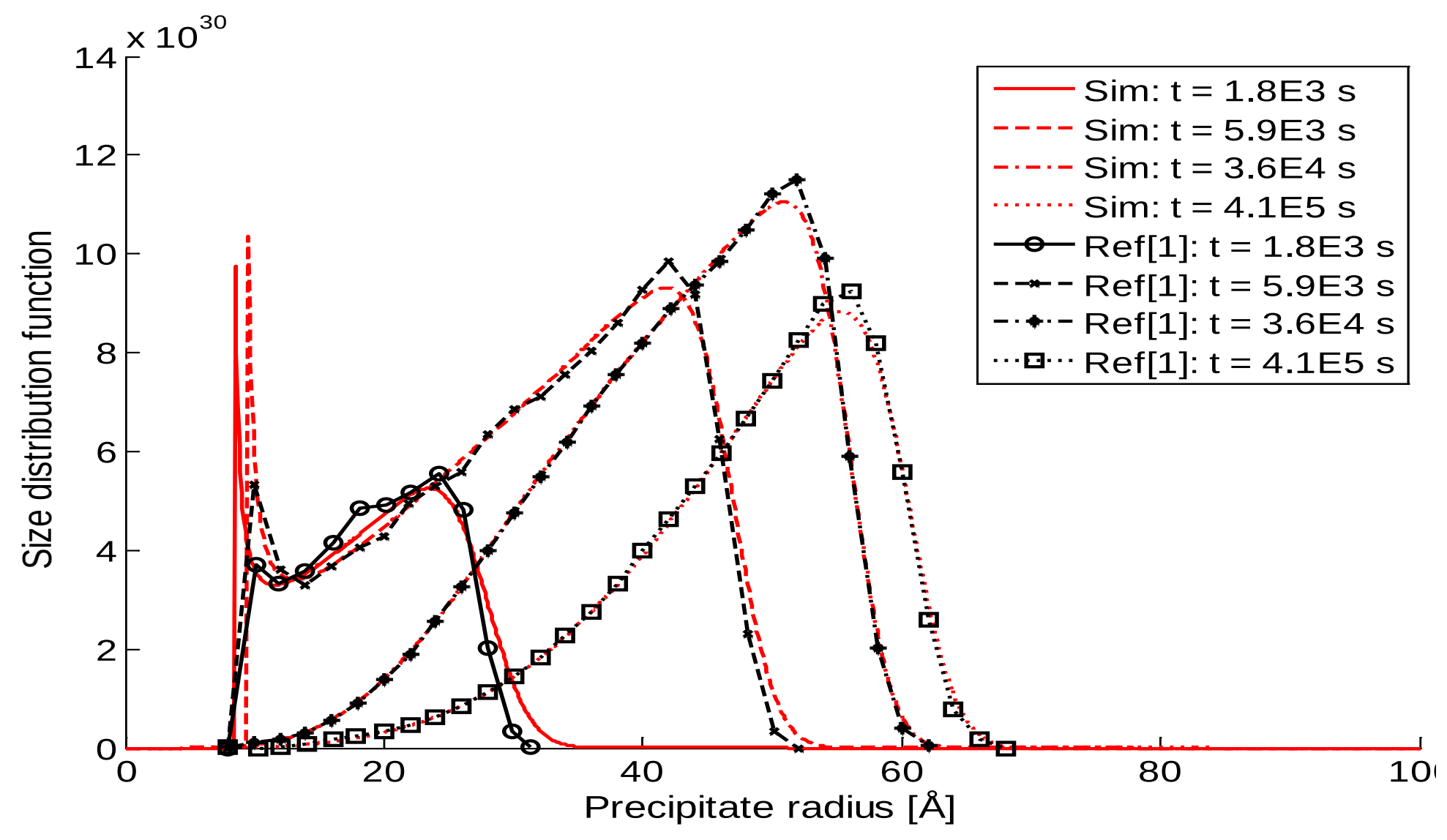


Grid points in the finite difference model and definition of the interface velocities [1].

From the mean radius and volume fraction of the Cu-Mg coclusters and S phase precipitates, the yield strength (and hardness) can be predicted by critical resolved shear stress (CRSS) models.

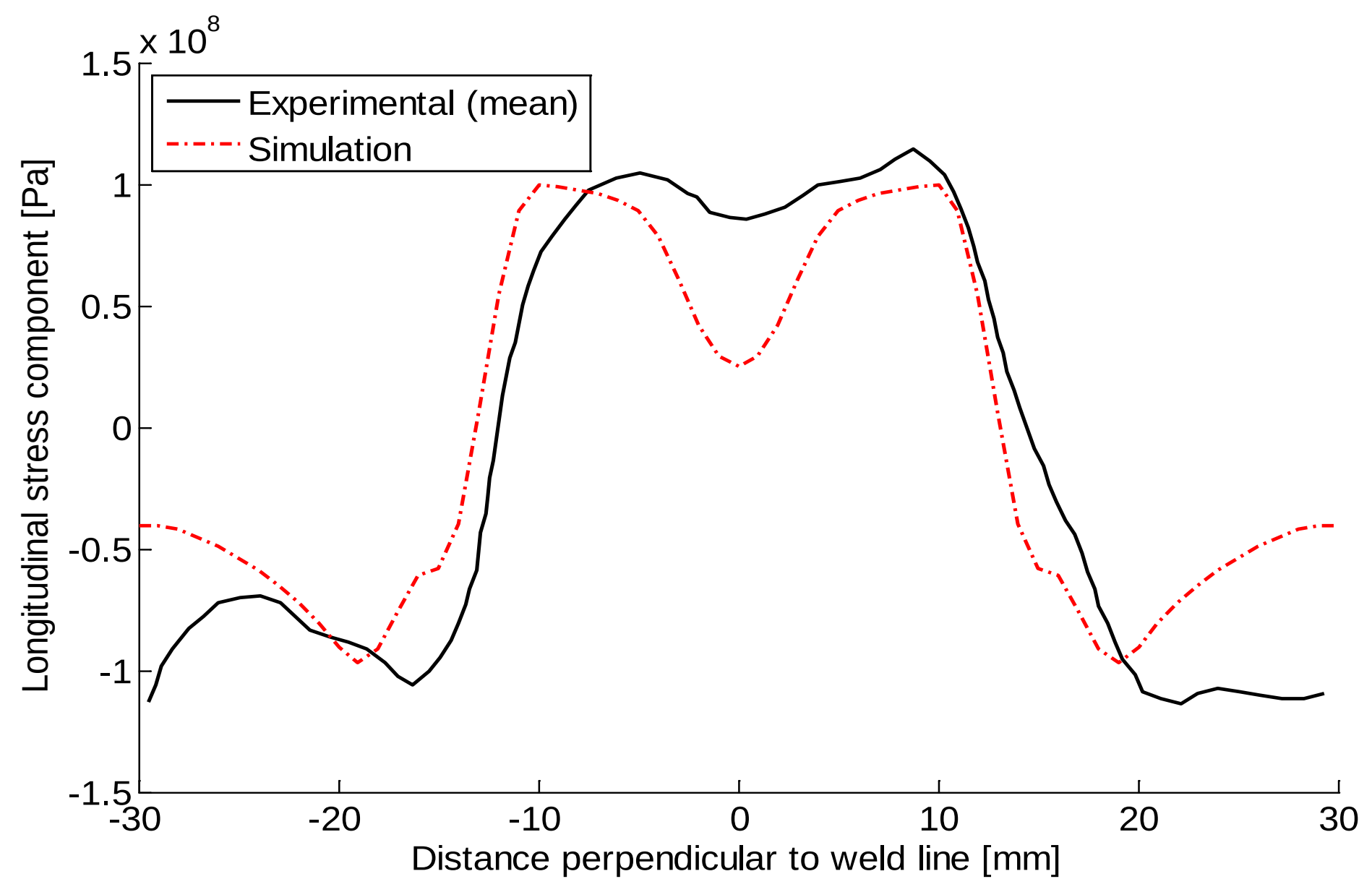
Results

Verification of the precipitation model was performed by comparison with particle size distributions at different ageing times from Myhr and Grong [1].

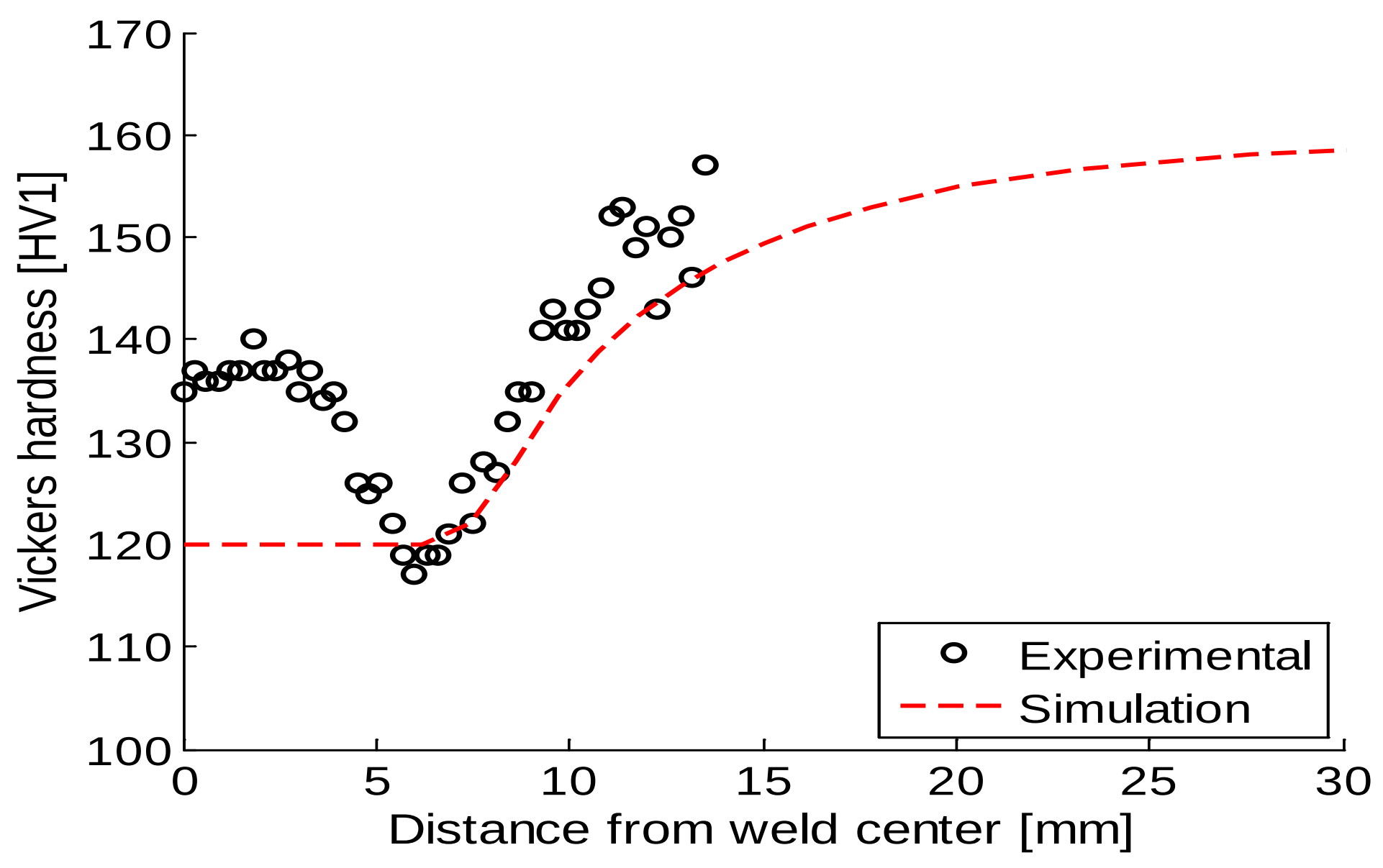


Verification of precipitation model during artificial ageing at 180 °C.

Preliminary residual stresses and hardness predictions are compared by experimental results obtained in previous work.



Comparison of longitudinal residual stresses from simulation and experiment [4].



Comparison of predicted and experimentally obtained Vickers hardness [5].

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[1] O. R. Myhr and Ø. Grong, Acta. Mater. 48 (2000) 1605 – 1615), [2] H. Schmidt and J. Hattel, Scripta Mater. 58, 332 – 337 [3] I. N. Khan and M. J. Starink, Mat. Sci. and Tech. (2008) vol. 24 no. 12, [4] M. R. Sonne, P. Carlone, P. Palazzo and J. H. Hattel, Key Eng. Mat. 611-612, pp. 1675-1682, [5] M. R. Sonne, C. C. Tutum, J. H,. Hattel, A. Simar and B. de Meester, J. Mat. Pro Tech (2013) 213 477-486