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ORBITAL FRICTION WELDING OF RAILS

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Summary. In the European project WRIST, two new innovative rail welding processes are being developed. One of these and the focus of this contribution is orbital friction welding. Here we present the initial work of developing a finite element model of the orbital friction welding process allowing the study of process parameters. Initial results from thermal and mechanical results are presented.

1 INTRODUCTION

The welding processes currently used to weld rails typically leads to large heat-affected zones (HAZ), with changes in the mechanical properties compared to the parent rail. These changes, notably the surface hardness, lead to increased wear and as a consequence amplified dynamic forces. In fact, welds are one of the primary reasons for rail degradation and rolling contact fatigue (RCF) of rails.

The European project WRIST addresses these issues by focusing on developing two innovative welding methods that will increase the weld quality, primarily by reducing the width of the HAZ. The two methods in development are *automatic forged aluminothermic welding* and *orbital friction welding* (OFW), where the latter is the focus of this contribution.

Orbital friction welding is a welding process where heat is generated by “rubbing” two bodies against each other in an orbital motion while applying a high pressure. The benefit of this process is that a uniform relative velocity, between the bodies, can be achieved compared to other friction welding methods such as linear and rotary welding. In addition, friction welding usually leads to a small HAZ. Since OFW cannot directly be applied to rails (in the way described above), the welding process being developed utilizes an intermediate component – an eccentrically rotating disk – which the two rails pieces are pressed against. In effect, this setup causes the rail ends to experience an orbital motion relative to the rotating disk and will produce a uniform heat input.

This contribution presents a first attempt at modelling the new OFW procedure and in this initial step we limit ourselves to using a square bar instead of an actual rail cross section. The aim of this exploratory study is to investigate the cooling rate at the weld interface and the buildup of residual deformations after cooling.

2 MODELLING OF FRICTION WELDING

Modelling welding (typically) involves solving a coupled thermomechanical problem governed by:

$$\begin{cases} \rho C_\mathrm{p}\dot{T} = \dot{Q} + \nabla \boldsymbol{q} & (1) \\ \nabla \boldsymbol{\sigma}^\mathrm{T} + \boldsymbol{b} = \boldsymbol{0} & (2) \end{cases}$$

containing the temperature T, heat capacity C_p, density ρ, heat flux $\boldsymbol{q}$, heat source Q, stress $\boldsymbol{\sigma}$, and body forces $\boldsymbol{b}$. However, in this paper this coupled problem is not solved in a monolithic fashion but rather as a sequentially coupled problem. Here the temperature evolution is first simulated from Eq. (1) and then used as a prescribed field to solve for the stresses from Eq. (2). This procedure, introduces an approximation where the heat generated from plastic deformations is neglected, which otherwise would contribute to the heat input Q. This approximation is in many cases sound since the heat energy input from frictional welding is much larger than that of plastic deformation[1].

2.1 Heat generation model

The heat flux $\boldsymbol{q}$, produced by the orbital motion of the disk is modelled by

$$|\boldsymbol{q}| = \mu \cdot p \cdot v_t. \tag{3}$$

where μ, p and v_t correspond respectively to the coefficient of friction, the axial pressure and the relative tangential velocity of the orbiting disk. The friction coefficient is computed using a temperature dependent trilinear model resembling that presented in a review paper on friction welding[2]. It is illustrated in Figure 1. The trilinear model is motivated by physical phenomena, i.e. partial slip (at $T \approx 720°C$) and full slip (at $T \approx 1500°C$).

3 FE-MODELLING AND RESULTS

3.1 Process steps

The OFW process consist of three phases, namely welding, forging and cooling. In this analysis, the three phases have a duration of 5, 3.5 and 1200 seconds respectively. During the welding phase the disk orbits with a uniform relative velocity of 2 m/s while an axial pressure of 60 MPa is applied to the end of the rail. This generates heat flux according

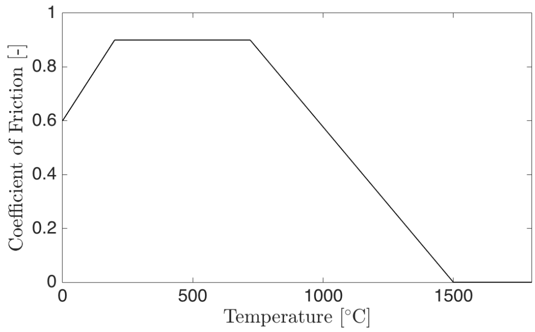

Figure 1: Behaviour of coefficient of friction with respect to temperature.

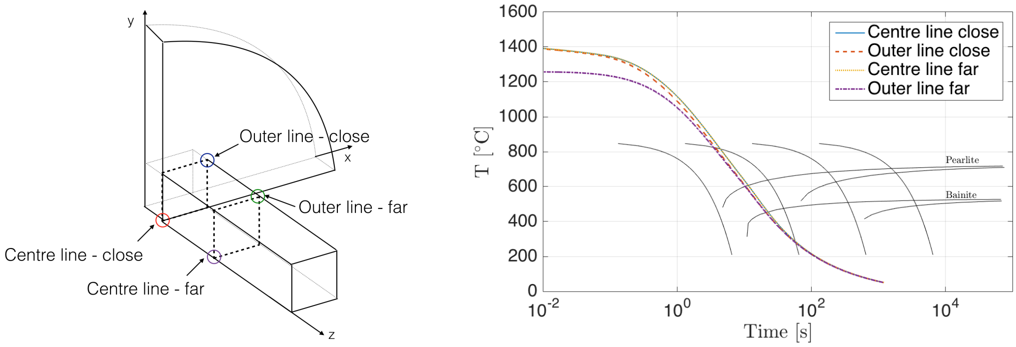

Figure 2: Sampling points (L) and their cooling rates (R).

to Eq. (3). During the forging phase heat is no longer generated and the pressure is increased to 200 MPa over the first 1.5 seconds. Finally, during the cooling phase the pressure is removed and the pieces are left to cool.

3.2 Thermal results

Preliminary results from the thermal analysis show favourable cooling rates, as martensite formation appears unlikely. See Figure 2. The cooling rates are measured at two locations at the bar-disk interface and two points 1.6 mm from the disk, illustrated in Figure 2. It is noted that due to symmetry, only one quarter of the geometry is considered.

3.3 Mechanical results

Figure 3 presents the deformation fields and minimum/maximum values obtained at different phases in the welding process. The largest deformation is found at approximately 6.5 seconds, when the pressure reaches its maximum of 200 MPa.

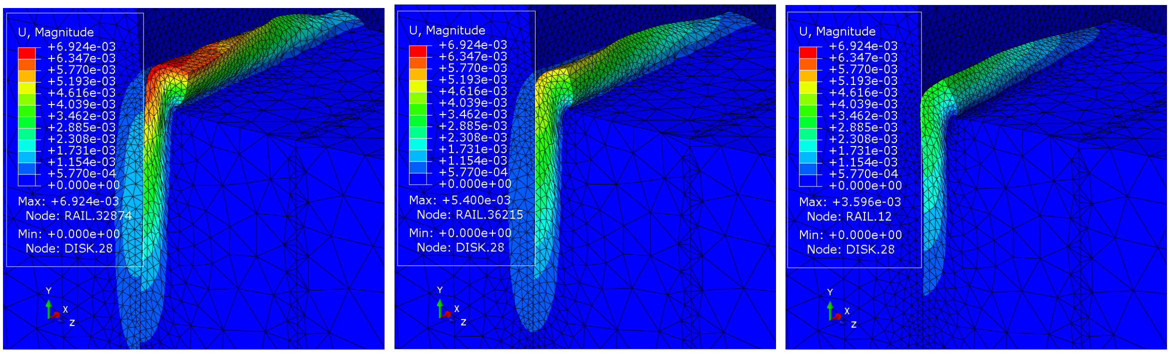

Figure 3: Maximum deformation during forging (L), deformation at the end of forging (M) and deformation at the end of cooling (R).

4 CONCLUSION AND DISCUSSION

In this contribution, we have presented the initial attempts at modelling a new rail welding procedure – orbital friction welding of rails. From the thermal analysis of the process, results indicated that martensite formation was unlikely and consequently a high quality weld may be achievable with the proposed method.

From the mechanical analysis, a mesh dependency in terms of size of flash formation was observed. This clearly needs to be studied further in future work. Furthermore, the time with which the pressure is ramped in the forging stage greatly effects the deformation field (not shown here). In fact, this process parameter determined whether or not a flash formation was obtained in the disk. What impact the flash formation will have on the final weld quality will be the topic of future investigations.

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