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Thermomechanical modeling and characterization of the semi-solid state of A356 alloys during solidification

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ABSTRACT

After liquid metal pouring, the solidification in casting processes starts below the liquidus temperature by local undercooling and the nucleation of solid germs takes place. In the slurry at low solid fractions the solid germs grow independently and form with the continuous liquid a suspension. After further temperature decrease, the dendrites agglomerate and form a continuous skeleton, which behaves like a fluid saturated mush. Below a specific temperature, defined as coherency temperature, the semi-solid is able to sustain low strains. Liquid feeding still occur to accommodate possible externally applied or thermally induced strains. The notion of coherency temperature (T_C) allows the separation of the semi-solid state into two distinct regimes: one more fluid-like and one more solid-like. The aim of this contribution is to give an overview over our collaborative research activities in order to characterize and model thermomechanically the whole semi-solid regime during equiaxed solidification of the industrial aluminium alloy A356.

The flow behaviour above the coherency temperature is analysed in a Searle rheometer with concentric cylinders of graphite to avoid chemical interactions with the liquid or semi-solid aluminum. Creep tests have been performed to analyse the deformation behaviour at different stress levels. Figure 1.a shows exemplarily deformation-time curves for different stress levels applied to the semi-solid A356 alloy (f_S = 33%) during 30min. After a non-linear increase with time during 5 minutes, the deformations growth with a constant rate. The fluctuations (exemplarily shown at 600Pa) of the measured values indicate that the semi-solid aluminium already tends to behave like a solid [1].

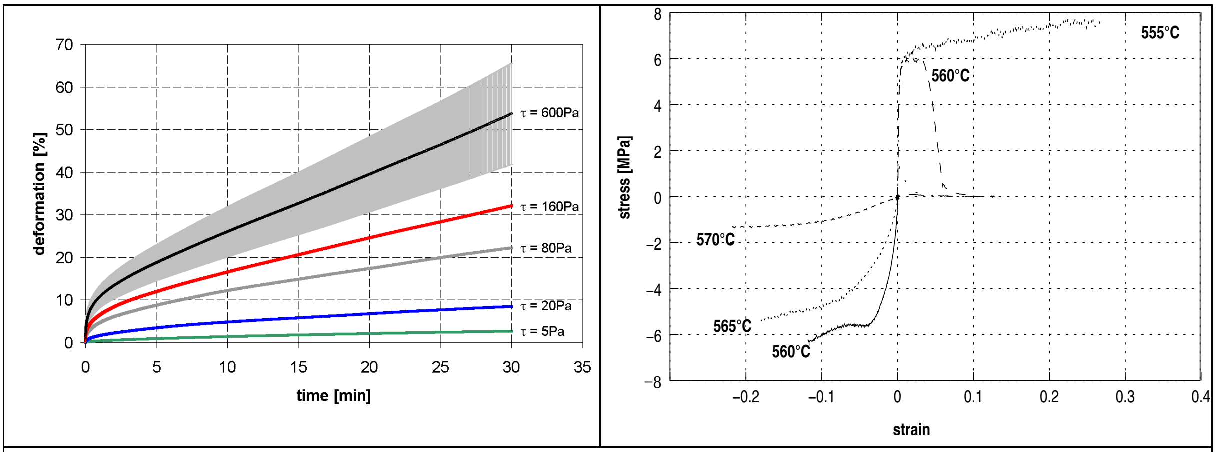

Figure 1: left: creep tests for different stress levels (A356, f_s = 33%)
right: stress-strain curves in uniaxial tension and compression at different f_S

These experimental curves are the basis for modelling the semi-solid state above T_C in casting processes. In order to describe its elastic, plastic and viscous behaviour a 1-D rheological model is used. The corresponding constitutive equations of Perzyna type, enables the simulation of primary and secondary creep. Based on the experimental data, the material parameters are identified with the least-square method, see e.g. [2].

Hot tensile tests have been performed at different temperatures using a hot forming simulator in order to identify the coherency temperature. At various temperatures below T_C, tensile and compression tests are achieved under varying strain rates and the local deformation in the partially solidified region of the specimen was measured by a laser speckle extensometer. The corresponding nonlinear stress/strain curves show a different yield behaviour in tension and compression (see Fig.1.b).

The developed 2-phase mechanical model for the coherent mush below T_C is based on the theory of porous media and distinguishes two constituents, namely the elasto-viscoplastic solid skeleton and the viscous fluid metal, and takes their interaction in terms of mass, momentum, species and energy exchange into account [3]. The behaviour of the solid phase on the macro-scale is described by an original single surface viscoplastic flow potential which includes micro-structural parameters (e.g. a back-stress tensor). These parameters allow the accurate description of the anisotropic response of the coherent metallic mush in different loading scenarios. The temperature dependence of these micro-structural parameters reflects the change of the morphology of the solid constituent due to the ongoing material solidification. After parameter identification for the A356 aluminium alloy, both developed models are used to analyze the deformation behaviour of the semi-solid mush of this technical alloy during the gravity sand casting of a stress frame.

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