Experimental Report

02/04/2014

Proposal: 1-02-118 **Council:** 4/2012

Title: Residual stresses in as-cast aluminium AA7050 rolling sheet ingots: influence of using a wiper

This proposal is continuation of: 1-02-66

Researh Area: Engineering

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Samples: aluminium

Instrument	Req. Days	All. Days	From	To
SALSA	8	7	02/04/2013	09/04/2013

Abstract:

The present work is the continuation and conclusion of the neutron diffraction measurement campaign carried out in July 2011 at SALSA (ILL-Grenoble) on as-cast rolling sheet ingots, 300 mm in thickness, 600 mm in width, 1000 mm in length and 500 Kg in weight. Residual strains and stresses were measured along the three directions, x, y and z, and along five scan lines.

Only the ingot (labelled HS) cast without wiper (wipers are aimed at reducing as-cast stresses) was measured as the neutron beam
path length was maximum, around 300 mm, at all locations.

Following the measurements on this ingot at SALSA (July 2011), we would like to resume the work by measuring the d0 reference values on ingot HS over the five scan lines as macrosegregation is known to be important in rolling sheet ingot casting and certainly induces d0 variations, and the residual stresses on ingot HSW cast with the help of a wiper along the same five scan lines.

Both ingots, HS and HSW, were cast at Constellium-Voreppe with the same casting speed (90 mm/min), mould and casting recipe, meaning that only the use of a wiper will result in different stress levels.

Experimental report: experiment 1-02-118 (April 2013)
Residual stresses in as-cast rolling sheet ingots: influence of using a wiper.

During casting, thermally induced deformations give birth to ingot distortions and residual stresses. For some high strength alloys, ingot cracking can happen during casting per se or during cooling down. Ingot distortions such as rolling face pull-in, but curl and but swell are rather easy to quantify as opposed to internal stresses. As aluminium is rather transparent to neutrons, residual stress measurements using neutron diffraction appeared to be a good way to validate the thermomechanical models aimed at simulating the stress build-up during casting. This technique has been applied to DC cast AA7050 rolling plate ingots with special attention to the stress generation in the transient start-up phase, i.e. in the foot of the ingot. The measured stress distributions are compared with the results of a numerical model of DC casting for ingots cast with and without a wiper.

Residual strain measurements have been undertaken on two rectangular AA7050 rolling plate ingots 300 mm in thickness, 600 mm in width and 1 m in length cast at 90 mm/min. One ingot is cast with the use of a wiper, the second without it. Residual stress measurements have been carried out at the neutron diffractometer SALSA at ILL-Grenoble, France in July 2011 and in April 2013 in order to

- to quantify the level of as-cast residual stresses in the foot of the slab,
- to compare the measured residual stresses with those predicted by the DC casting finite element (FE) model developed by Drezet et al. [1, 2]
- and to quantify the reduction of internal stresses when using a wiper.

The AA7050 alloy is a heat treatable alloy from the 7xxx series alloy containing Zn, Mg, Cu and Zr. Its temperature of end of solidification, rigidity (corresponding to the onset of thermal contraction) and liquidus temperatures were calculated using the software ProPHASE proposed by Sigli et al. In order to reduce possible cracking during and after casting, high strength aluminum alloys are usually cast with a wiper placed on its surface as schematically shown in fig. 1. The wiper ejects the running water from the ingot surface and thus reduces the efficiency of cooling. The ingot being hotter, internal stresses are partially relaxed during casting.

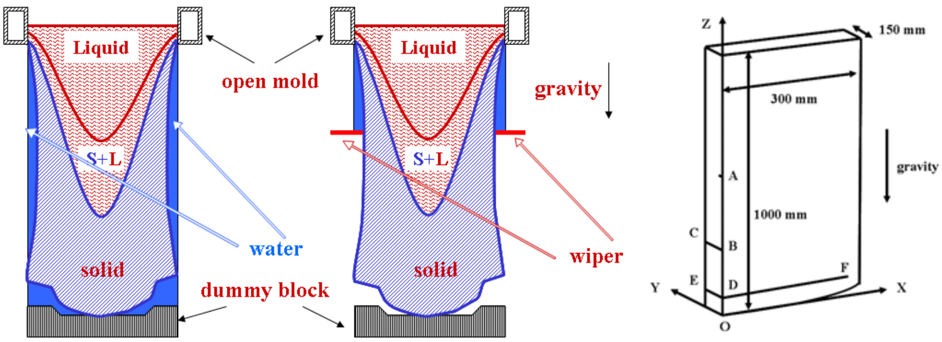

Figure 1: schematics of the use of a wiper for casting high strength aluminum alloys (left) and reference frame (xyz) with the 4 scan lines, OA, DE, BC and DF along which xx, yy and zz strain components have been measured. Point O is the centre lower point of the slab.

Two 1 meter long rolling plate ingots were cast semi-continuously at the experimental cast house at Constellium CRV, Voreppe, France. After the transient start-up phase, the casting speed was set to a steady state speed of 90 mm/min. The first ingot was cast with a wiper. Keeping all casting parameters constant as much as possible, the casting team managed to cast the second ingot without a wiper. Both ingots were wrapped in security nets in case of erratic explosion and transported to Institut Laue Langevin, Grenoble, for neutron diffraction residual stress measurements. The weight of each sample was slightly lower than 500 kg. Typical grain size in this casting was 100 +/- 30 microns with a globular microstructure due to the use of grain refiner.

In the case of monochromatic neutron source where only one diffraction peak is recorded, for fcc metals such as aluminum, the (311) diffracting planes are commonly used to measure the strain since they do not accumulate significant intergranular stresses and hence exhibit similar behavior as that of the bulk. The (311) is also recommended for use in the measurement of residual strains by neutrons in aluminum alloys by the ISO VAMAS standard. A series of stress free reference samples, for measurement of the reference lattice constant d_0, were also acquired. These samples were electro-discharge machined along the casting direction at the symmetry plane of the slab every 20 mm in order to account for any variation in d_0 that may be present due to long range chemical inhomogeneities, i.e. macrosegregation. For the measurements at SALSA, 2 mm radial focusing collimators were used to reduce experimental errors introduced by the optics. The instrumental gauge volume was set to 2x2x4 mm3 as strains may vary in all directions during the transient start up phase.

The strain measurements were carried out in the orthogonal (x,y,z) reference frame (axis z is along casting direction and gravity, axis x is along the width of the ingot and axis y along its thickness) along four scan lines, OA, DE, DF and BC. The location of these scan lines are depicted in figure 1 where only one quarter of the slab is represented owing to the presence of the tow symmetry planes. Points D and B are located 85 mm and 250 mm above point O, respectively.
Applying Hooke's law with a Young's modulus E (71.3 GPa) and a Poisson's ratio ν (0.3), the stress components along each axis write:

$$\begin{aligned}\sigma_{xx} &= 2\mu\varepsilon_{xx} + \lambda(\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}) \\ \sigma_{yy} &= 2\mu\varepsilon_{yy} + \lambda(\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}) \\ \sigma_{zz} &= 2\mu\varepsilon_{zz} + \lambda(\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz})\end{aligned} \quad \text{with} \quad \lambda = \frac{\nu E}{(1+\nu)(1-2\nu)} \quad \text{and} \quad \mu = \frac{E}{2(1+\nu)} \qquad (1)$$

where λ and μ are the Lamé's coefficients:

For each of the three measured strain components, both the beam orientation and the position of the ingot within the neutron chamber must be varied. The length of the beam path varies from almost zero at the ingot surface to values of the order of the ingot thickness i.e. 300 mm. In that case, time measurements are greatly longer.

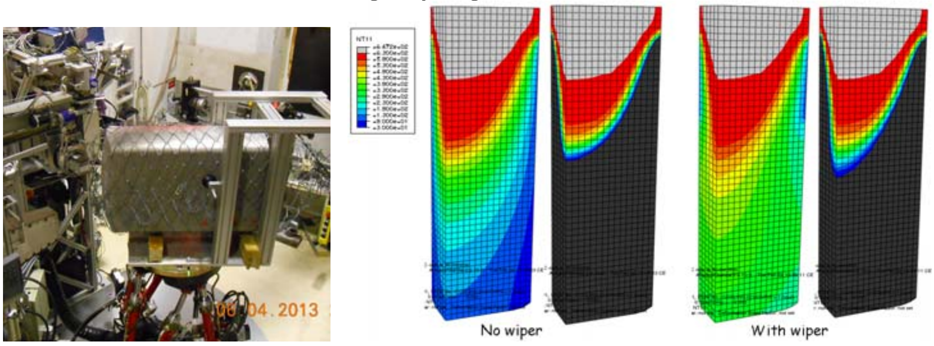

Figure 2: ingot positioning for measuring residual stresses at SALSA (left) and influence of a wiper on temperature distribution and mushy zone extension during casting. Grey regions correspond to the liquid phase (right).

Measured as-cast residual stress profiles are compared with the computed ones along the four scan lines OA, DE, DF and BC. Fig. 3 shows the xx, yy and zz stress component distribution along the axis OA, i.e. along the axis of symmetry of the ingot (cf. fig. 2) when casting was performed without a wiper and with a wiper. A similar scale is used to better see the differences in terms of stress level. Both distributions exhibit the same trends and are rather well reproduced by the FE model: a bi-axial compression stress state at the very bottom of the ingot and a transition to a tri-axial stress state after a cast length of 50 mm. As expected, the stress level is much lower when a wiper is used, roughly 35% lower. In the absence of a wiper, the xx stress component goes through a maximum at a cast length of 120 mm before reaching a plateau. This effect is less pronounced with the presence of a wiper.

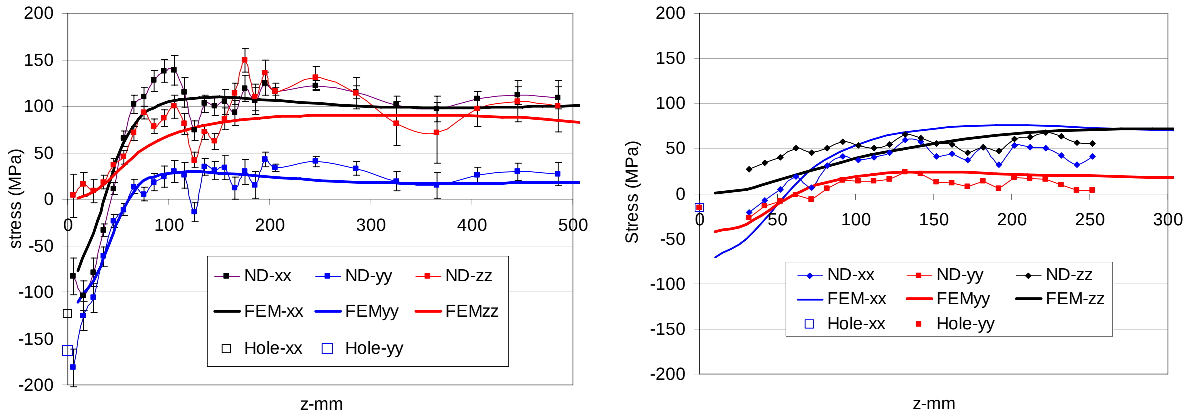

Figure 3: computed and measured stress profiles along OA for the ingot cast without a wiper (left) and with a wiper (right). ND stands for neutron diffraction and FEM for finite element modeling.

The results using the hole drilling method are also reported at the bottom of the ingot (x = 0) and agree well with the overall distributions, especially in the ingot cast without a wiper.

Fig. 4 shows the stress distribution along the scan line DE, i.e. along a short side close to the foot of the ingot (cf. fig. 2) cast without a wiper and with a wiper. The surface is in bi-axial compression stress state whereas the center is in tri-axial tension. Again, stresses are much lower when a wiper is used during casting. The FE model underestimates the xx stress component at the surface whereas both hole drilling and neutron diffraction techniques give comparable results.

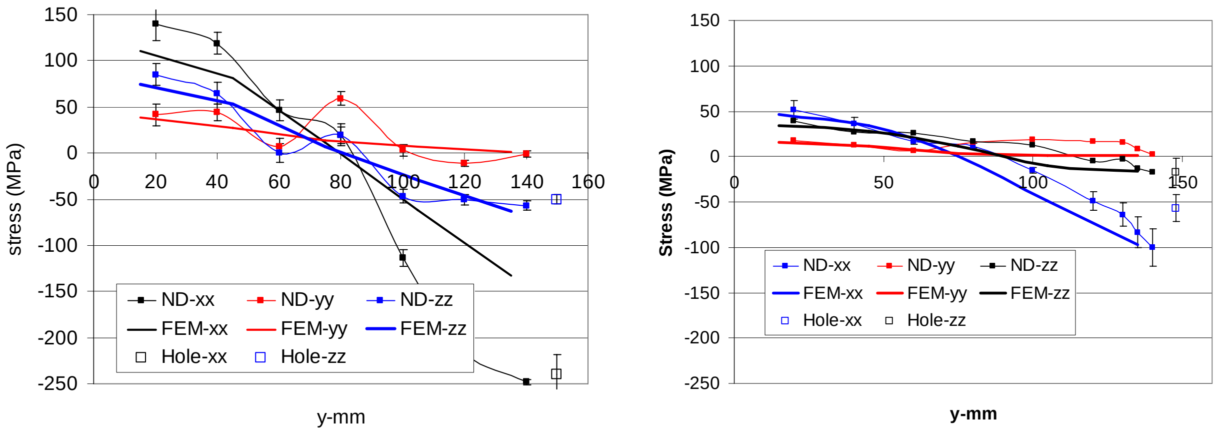

Figure 4: computed and measured stress profiles along DE f or the ingot cast without a wiper (left) and with a wiper (right).

The overall agreement between FE results and measured values induces confidence in the casting numerical model. This allows us to be more quantitative in the stress reduction owing to the use of a wiper during casting. Fig. 5 shows the computed distribution of the Von Mises equivalent stress along the symmetry axis (cf. fig. 2). High values are found at the very bottom of the ingot owing to the high cooling through the dummy block. Then values exhibit a minimum before reaching a plateau in the steady state regime of casting, i.e. when heat transfer operates through the lateral surfaces of the slab. The mean reduction of 33 % in the stress level is explained by the fact that the ingot remains hot during casting with a wiper, typically above 200°C (cf. fig.2). At these temperatures, the strain rate sensitivity of the AA7050 alloy is not nil and stresses are relaxed by visco-plastic deformation.

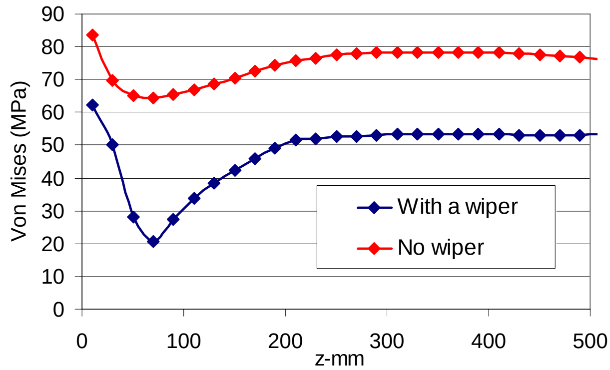

Figure 5: influence of using a wiper on the Von Mises equivalent stress along the symmetry axis.

The present results were published in one scientific journal [3] and presented at TMS 2014 [4].

Acknowledgements

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