COST 526

“Automatic Process Optimization in Materials Technology”

(APOMAT)

Half-Yearly Report

To be sent to **V.Tesch@access.rwth-aachen.de** until **February 28, 2003**

1. Reporting Period	**1.1.2002 – 30.6.2002**
Project title	A Numerically Based Optimization of a Near-Gamma TiAl Precision Casting Process
Project leader Organization	Dr. Antonín Dlouhý Institute of Physics of Materials, Academy of Sciences of the Czech Republic
Main collaborators involved	Department of Casting, Institute of Materials Engineering, BUT

2. Funding Situation

Amount of money received specifically for COST	**0** kEuros
Other resources partially used for the project	**7** kEuros

3. International Collaboration

(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Saint-Die + project progress report

☐ YES

☐

NO

4. Industry participation

(mention name of companies and work done in collaboration during the whole project)

NO

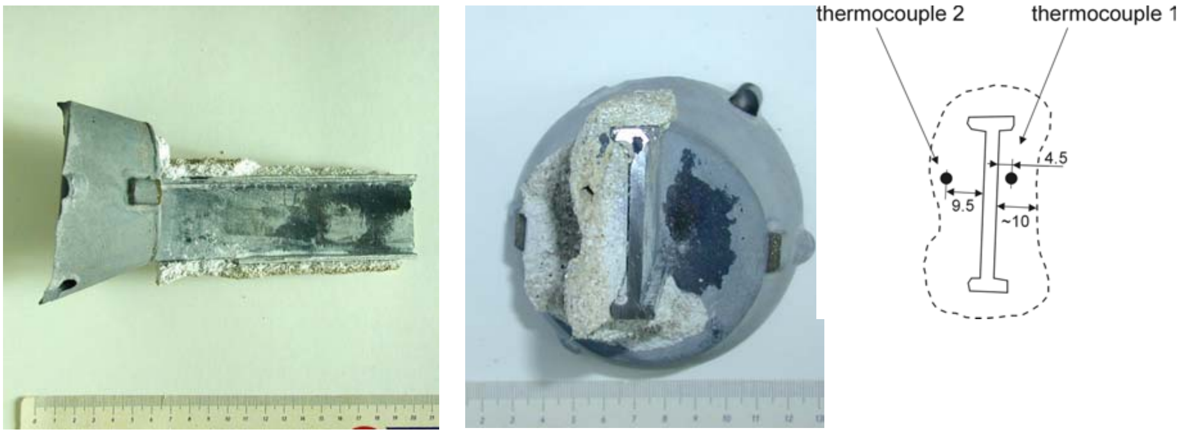
5. Meetings, visits, exchange of scientists, short-term scientific missions	**Location, date**
NO	

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

Experimental casts

A girder-shape plate was designed to assess the magnitude of the tensile stress induced into the cast during solidification and cooling. The plate shape and its cross-section are shown in Figs. 1a and 1b, respectively. The upper and lower crossbeams anchor the plate in the ceramic shell. This configuration schematically illustrated in Fig. 1c (the original ceramic shell has already been partially removed in Figs. 1a and 1b), gives rise to the tensile stress in the plate plane perpendicular to the anchoring crossbeams. The tensile stress state builds up since the intermetallic cast (without the anchors) would shrink faster during cooling as compared to the surrounding ceramic shell. Therefore, the stress state induced into the plate during cooling can be represented by one-dimensional (1D) tensile stress the magnitude of which is expected to change with relative area fractions of the plate and corresponding mould parts in the cross-section of Figs. 1b and 1c. This experimental design offers another simplification associated with the transfer of heat during cooling. Regarding that the plate area is large as compared to the area of anchoring crossbeams, the relevant heat flow is oriented perpendicular to the plane of the plate and thus can also be treated as 1D process. Two thermocouples situated in the ceramic shell, one closer and one farther out of the cast plate surface, as depicted in Fig. 1c, recorded temperatures in the system during pouring, cast solidification and cooling.



(a) (b) (c)

Figure 1: Planar (a) and cross-section (b and c) view of the investment cast experimental plate with two perpendicular crossbeams which anchor the plate in the ceramic shell mould and contribute to the build up of the tensile stress in the cast. Temperature changes in the mould during cast solidification and cooling are recorded by two thermocouples highlighted in (c). Dimensions are given in millimetres.

Model of heat flow, thermal strains and stresses

The two coupled 1D processes of heat flow and the thermal strain in the investment cast plate and the ceramic shell mould (shown in Fig. 1) were studied numerically using the software Mathematica 4.2 by

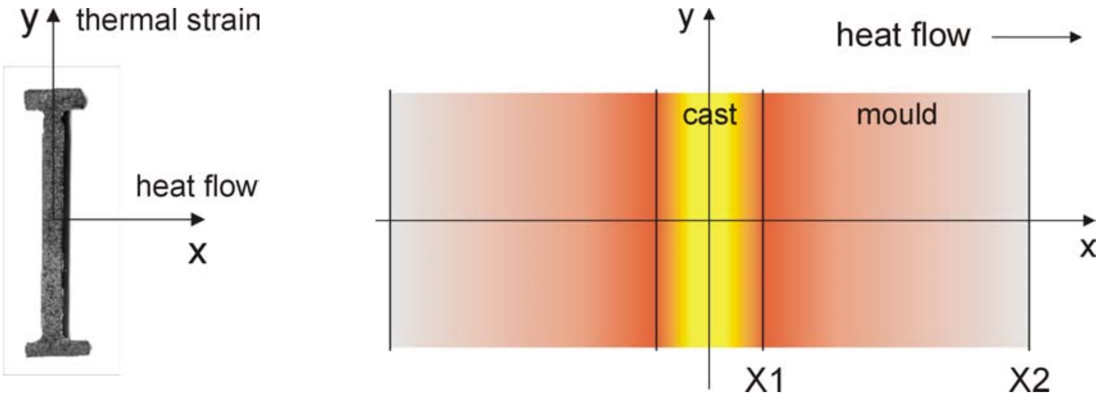
Wolfram Research. The solution of the coupled system during cooling to room temperature was divided into two parts. In the first step, the equation

$$a^2 \cdot \frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial x^2} + q \; ; \quad a = \sqrt{\frac{\rho \cdot c_p}{\lambda}} \tag{1}$$

governing the heat flow in the x-direction (perpendicular to the cast plate, see Figs. 2a and 2b) was solved. Parameters ρ, c_p and λ represent respectively, the density, thermal capacity and thermal conductivity of the TiAl cast or the ceramic shell mould. The quantity q describes a normalized rate of heat production or sink in the unite volume. Two boundary conditions were considered at the outer shell wall (in the point X2 shown in Fig. 2b). Either the outer shell wall temperature was prescribed as $T(X2,t) = T_E(t)$ or the radiation looses to the external environment controlled the heat flow

$$-\frac{\partial T(X2,t)}{\partial x} = c \cdot (T(X2,t)^4 - T_E(t)^4) \qquad (2).$$

In both cases, T_E represents the external temperature and the parameter c characterizes the geometry of the system and its radiation efficiency.



(a) (b)

Figure 2: (a) Cross-section of the girder-shape cast plate oriented in the x-y coordinate system. (b) Schematic representation of the heat transfer along x-direction from the TiAl cast (region 0-X1) through the ceramic shell (region X1-X2) into the external environment (region x > X2).

Model of heat flow and its validation

The 1D approximation of the heat flow, as described in the present study for the constrained geometry of the girder-shape plate, might be regarded as an oversimplification. Therefore, mould temperatures recorded by thermocouples 1 and 2 during the casting experiment (Fig. 1) and their comparison to the temperatures predicted by the 1D model for the same experiment and the same positions inside the ceramic shell are critically important. Figure 3 presents cooling curves recorded in both positions inside the ceramic shell during the casting experiment (Fig. 1) and also curves predicted by the 1D model (Eq. 1). It is evident that the agreement is quite satisfactory. The 1D model reflects correctly the increase in mould temperatures during initial 150 seconds after pouring and also the long-term behaviour for times exceeding 2000 s. The only apparent difference in simulated and measured mould temperatures occurs in the range between 500 and 2000 s where model predicts slightly lower temperatures than those observed in the experiment. A tentative explanation of the observed difference relates to the latent heat of the α -> $\alpha + \gamma$ transformation which is released in the experiment and which was not incorporated into the 1D model. Nevertheless, this moderate discrepancy is not important for the main objective of the present study since it has only negligible effect on the tensile stresses created in the experimental cast. A reasonably good agreement between experimental and modelling mould temperatures justifies the adopted 1D approximation of the heat flow. This agreement

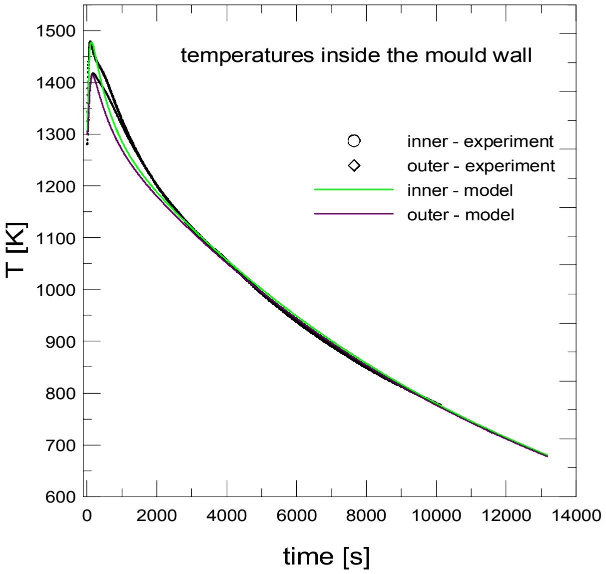


Figure 3: Comparison of cooling curves as measured in two positions inside the ceramic shell mould during pouring, solidification and cooling of the investment cast plate (Fig. 1) and as predicted by the 1D model of the heat flow (Eq. 1).

also implies that the temperature of the TiAl cast and its changes during solidification and cooling, which were only obtained as a result of calculations, are close enough to the real situation in the experiment.

7. List of publications

a) Published

b) Submitted for publications

c) In preparation

Near-gamma TiAl Investment Casting and Its Optimization