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DETERMINATION OF CASTING RESIDUAL STRESSES

Ioan Aurel CHERECHEŞ, Mircea BEJAN

Abstract*: In this paper, the authors study the residual stresses that arise in a stress lattice during casting. The residual stresses are firstly determined experimentally and secondly simulated using a numerical method (control volume) for method validation.* ***Key words:*** *residual stresses, stress lattice, casting, and numerical simulation.*

1. Introduction

The presence of residual stresses in castings is independent of our will; they appear as a result of laws regarding slowing down thermal contraction on cooling, the constituents specific volume changes etc.

Generally, residual stresses in castings have negative consequences for them. Thus, residual stresses can cause deformation in service parts, which have very serious consequences for the smooth operation of machinery or equipment.

Residual stresses in castings can summarize as value, stresses that occur during mechanical processing or service operation, which may cause their rupture [4].

If stresses do not exceed the material limit of elasticity in castings, elastic deformations appear, if exceeded, plastic deformations are forming. in the second case the part remains distorted when stress exceeds the material tensile strength, cracks are starting to form in the part. Hence, responsible for the appearance of deformation, hot tears, cold cracks; internal cracks or breaks are stresses in these castings. This is because stresses caused by loads applied σ_s overlap the residual stresses existing in the part from the manufacturing process σ_{rem}, obtaining the resulting stress σ_{rez} (Fig. 1.1) [1].

$$\sigma_{rez} = \sigma_{rem} + \sigma_s \qquad (1)$$

For these reasons the problem of appearance and manifestation of stress in castings is yet preoccupying many manufacturers of castings and many researchers in this field.

Given the many factors that influence the size, direction and distribution of stresses in castings, the problem is still far from being resolved in all its complexity. Experimental analysis of moulding and determination of residual stresses in castings is difficult and expensive. For these reasons in many laboratories and production facilities, numerical modelling is deployed, using a variety of calculation methods based on finite volume method, the finite element or finite difference [3].

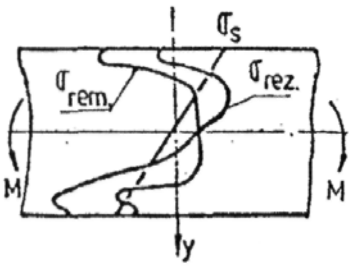


Fig. 1.1 Resulting stresses in exploitation

2. Determination of residual stresses in a batch of castings

To determine the stresses that occur in iron castings, O. Bauer and K. Sipp, since 1936 have designed and used a stress lattice with different thickness, shown in Figure 2.1. They have adopted a way of assessing stress in iron castings by moulding these sample, which were implanted parts of stainless steel wire and measuring the distance between them and then immediately after cooling the sample after annealing for stress relief heat treatment [4].

A similar experiment was conducted by the authors (Fig. 2.2), using cast iron EN-GJL-150 to determine the residual stresses in the part. The specimen, symmetric about a vertical axis, has two sidebars, of sections A1 and a central bar that is considerably larger in diameter, A2, and two beams, upper and lower that are rigid enough, to be considered in deformable.

Let σ_1 and σ_2 be the unknown residual stresses considered to be uniformly distributed over the three bar sections. In the central bar, thicker and thus cooling last, stresses are of stretching and in the lateral bars stresses are of compression.

It marks two benchmarks on the central bar at a measured distance. Central bar is then cut between benchmarks, which releases the residual stresses. Because the bar is not stretched anymore, the distance between benchmarks

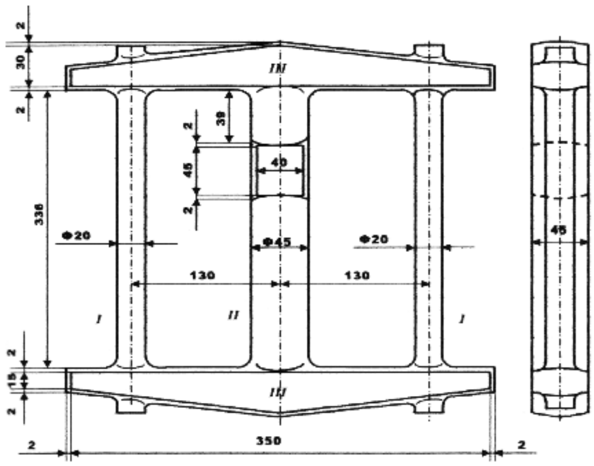


Fig. 2.1 Stress lattice, used by O. Bauer and K. Sipp

decreases with $\Delta l = \delta$. Meanwhile, after cutting the central bar, the lateral bars are relieved of compressive stresses, so are prolonged, which results in benchmarks spread out in the central bar.

Fig. 2.2 Stress lattice, cast and sectioned

Reducing the distance between benchmarks is the outcome of the overlapping effect of shortenings due to σ_2 stress release and a stretching due to release of σ_1

$$-\frac{\delta}{l}=-\varepsilon_2+\varepsilon_1=-\frac{\sigma_2}{E}+\frac{\sigma_1}{E} \qquad (2)$$

The second equation is obtained from the equilibrium condition of the forces produced by residual stresses

$$A_2\sigma_2+2A_1\sigma_1=0 \qquad (3)$$

Solving the system gives the value of residual stresses

$$\sigma_1=-E\frac{\delta}{l}\cdot\frac{A_2}{2A_1+A_2}$$
$$\sigma_2=E\frac{\delta}{l}\cdot\frac{2A_1}{2A_1+A_2} \qquad (4)$$

Deformation $\varepsilon=\frac{\delta}{l}$ is read directly on the measuring device [2].

According to [6], cubic test sample, Figure 2.3, is simpler and allows a simplified calculation of residual stresses. This test sample can be more accurately applied of the case of parts with flat wall. The test sample has three walls 10 mm thick and the fourth wall thickness can vary between 10 and 60 mm. Providing identical contraction in the three walls, which have the same thickness, was made by filling the form under identical conditions.

The formulas for calculating the stresses are:

- for thin wall:

$$\sigma_1=-\frac{\Delta l}{l}\cdot E\cdot\frac{A_2}{A_1+A_2} \qquad (5)$$

- for thick wall:

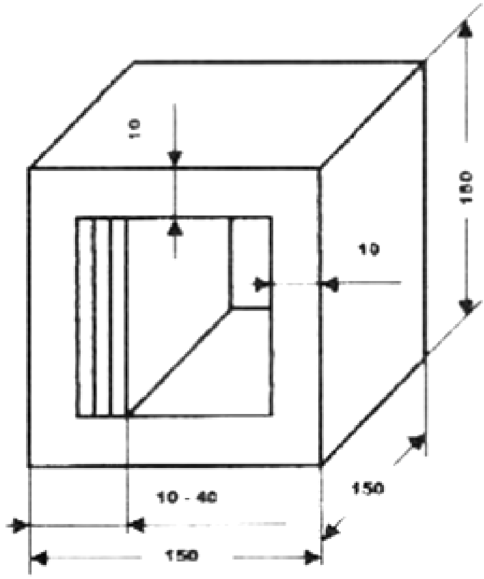


Fig. 2.3 Cubical test sample

$$\sigma_2=\frac{\Delta l}{l}\cdot E\cdot\frac{A_1}{A_1+A_2} \qquad (6)$$

3. Numerical simulations

From the multitude of software's based on different numerical methods in this paper we used the software NovaFlow & Solid CV.

NovaFlow & Solid CV is a mould filling and solidification simulation package based on advanced fluid flow and heat transfer theories.

CVM (control volume meshing) technology allows the surface of the 3D model to control the shape of the mesh elements on the border of the casting. This creates cubic elements inside the casting and border cells on the boundary of the casting.

The quasi-equilibrium theory lies in the basis of alloy crystallization model for NovaFlow & Solid CV. It is the macroscopic phenomenological theory. The main assumption of the two-phase zone theory is that state of the two-phase (mushy) zone may be described with the help of macroscopic functions, analogously to the temperature fields, velocity fields and so on.

High fidelity simulations using mesh-based computational technologies such as computational fluid dynamics and heat transfer are very important in providing valuable performance information of a design. These simulations, however, require accurate geometry representation as well as high quality meshes about the design in order to obtain accurate data. Therefore the equations of solidification theory of multicomponent alloys are solved on the mesh of Control volumes imposed on the casting layout in this version of NovaFlow & Solid CV [5].

For meshing (Figure 3.1) we have chosen 4 mm cells, resulting in a total of 271200 cells, in which 31250 cells belong to castings. Mould minimum thickness is 25 mm. The mould material is green sand and the poured material is EN-GJL-150. In order to calculate the residual stresses, were taken into account both the liquid phase and the maximum temperature in the part. 50 ^{0}C temperature steps were chosen from the casting temperature (1250 ^{0}C) to a temperature of 20 ^{0}C.

Figure 3.2 presents the evolution of the maximal principal stresses in the time immediately following complete solidification (about 1100 ^{0}C) and at room temperature.

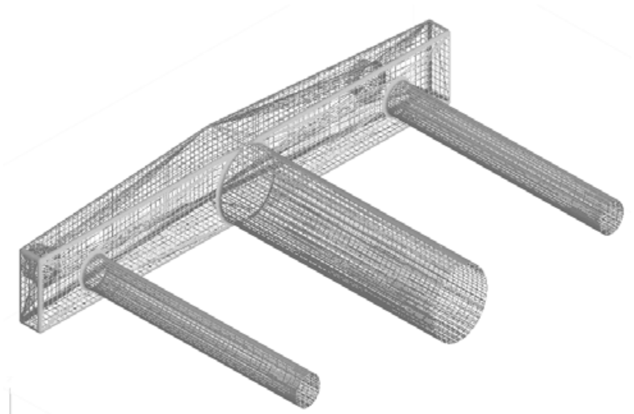
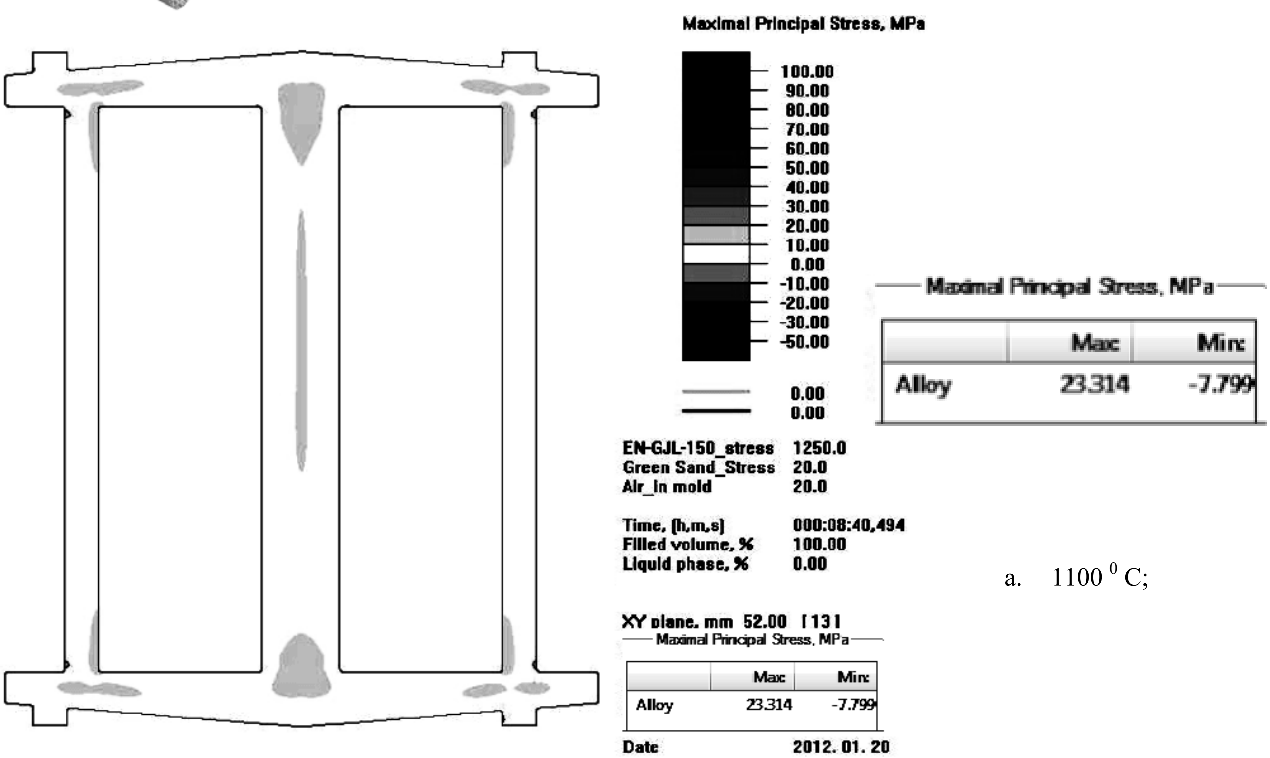
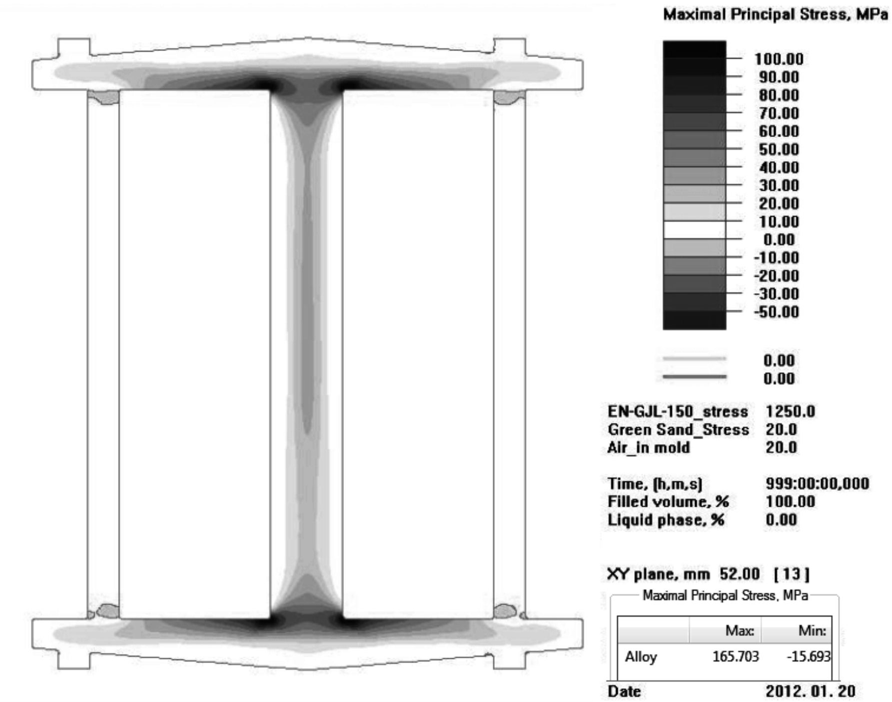
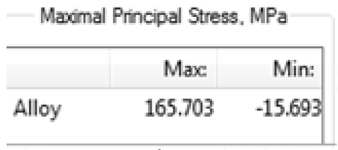


Fig. 3.1 Castings mesh



a. 1100 ^{0} C;





Maximal Principal Stress, MPa

	Max:	Min:
Alloy	165.703	-15.693

b. $20\ ^0C$

Fig. 3.2 Maximal principal stresses at different temperatures:

a. $1100\ ^0$ C;

b. $20\ ^0C$

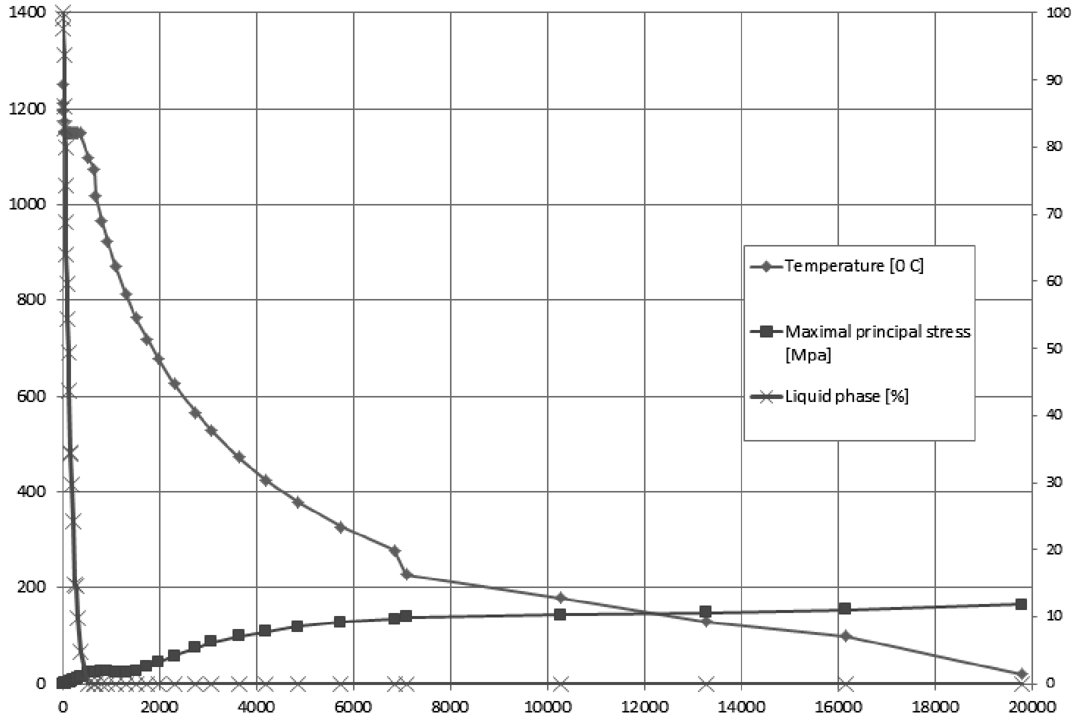


Fig. 3.3 Evolution of maximal temperature, principal maximal stresses and liquid phase as a function of time

Figure 3.3 presents the evolution of temperature [^{0}C], the maximum principal stress [MPa] and the evolution of the liquid phase depending on the time [s], thus being able to easily see the interdependence of these parameters. Because of relatively small thickness of the mould (minimum 25 mm), the temperature has decreased quite suddenly, in about 7200 seconds about 1000 ^{0}C. Complete solidification time is about 500 seconds.

4. Conclusions

Generally, the factors influencing thermal stresses in castings are: modulus of elasticity, thermal conductivity respectively the temperature difference between different parts of the piece and its geometrical shape. So, the elements that increase the modulus of elasticity are also increasing stresses in castings. The elements that decrease thermal conductivity are increasing stresses due to reduction of the equalization speed in the castings. Sections large differences are leading to increased stresses. Knowing the causes that generate stresses in castings measures can be taken to reduce them by removing the causes. Complete removal of the causes is not always possible, but an improvement - larger or smaller - is feasible [6]. Because similar values were obtained both experimentally and numerically, we consider numerical approach the problem of residual stresses induced by casting cast iron parts is possible and recommended.

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DETERMINAREA TENSIUNILOR REMANENTE DIN TURNARE

Rezumat: În această lucrare, autorii studiază tensiunile remanente care apar în timpul turnării într-o probă de tip rețea de contracție. Tensiunile remanente sunt determinate mai întâi pe cale experimentală apoi sunt simulate folosind o metoda numerică (volume de control), pentru validarea metodei.

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Chereches Ioan Aurel, Drd. Ing., Technical University of Cluj Napoca - Romania, Faculty of Mechanical Engineering, Mechanical Engineering Dept., E-mail: relu_chereches@yahoo.com;
Bejan Mircea, Prof.Dr.Ing., Technical University of Cluj Napoca - Romania, Faculty of Mechanical Engineering, Mechanical Engineering Department, E-mail: Mircea.Bejan@rezi.utcluj.ro.