Analysis of core stress during casting

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Abstract

This article is focused on analysis of stress inside the piston casting molding core, which is the result of interaction between the core and the liquid. The mold and core are both metal and their surfaces are nitrated. The mold is water cooled. The core cooling is ensured by drilled hole on the bottom side, into which is injected water. As a result of uneven stress in the core, cracks begin to appear which have a negative influence on the longevity (to 15% of predicted duration).

Keywords: mold core, core stress, heat transfer, FEM analysis, ANSYS Polyflow;

1. Introduction

After the heat and mechanical stress testing of the core, the aim of the analysis was to perform a spatial analysis of the core stress. The solution was done using ANSYS Workbench – Polyflow. Geometry of the mold and core was simplified for the minimization of errors during calculation (Fig. 2) [1, 4].

There were two methods used for the stress calculation. First used the results of the 2D temperature simulation (Fig. 1) [2].
The second method used the temperature on the core surface, with the liquid meeting it. The temperature was constant. The core is symmetrical towards the inner plane (Fig.3); therefore, the stress analysis was done for only a half of the core [3].

2. Progress and discussion of results

Solution was performed using two methods, which were subsequently compared. The first method was time independent, second dependent. Geometry of the mold and core was created using the 3D CAD and meshing was created only for one-half of the model. There were 201 581 elements in the mesh and 37 773 knots. Elements were tetrahedron shaped with the biggest being 2 mm and the smallest being 0.5 mm (Fig. 4)

Peripheral conditions for the first method were determined from the 2D simulation with time steps $t = 0.8$ s, $t = 1.2$ s, $t = 1.6$ s and $t = 2$ s. Core surface meeting the liquid was divided into three parts depending on the liquid placement at chosen time step. Surface division is in fig. 5. They are marked in the text as P1, P2, and P3.
First time independent simulation used the $t = 0.8$ s time step values. On P1, 550 °C temperature was measured. Surfaces P2 and P3 were not in contact with the liquid at the time. Other core surfaces were named BS (boundary surface) and are pictured in Fig. 6. On surfaces BS1, BS2 and BS 4 temperature of 160 °C was assigned, which is the temperature to which the core is pre-heated before casting.

On surface BS3 temperature of 433 °C was assigned, which was taken from the time step $t = 0.8$ s in cut B. Surface BS5 was at the time $t = 0.8$ s not in contact with the liquid and was marked as “Insulated”. To surface BS6 was assigned 25 °C temperature. (Fig. 5, 6).

For the second time independent simulation, $t = 1.2$ s time step values were used. P1 was assigned with 566 °C and P2 with 470 °C. P3 was marked as “Insulated“ as it wasn’t in contact with the liquid at the time. P3 surface was assigned with 436 °C temperature taken in the $t = 1.2$ s in cut B. Surface BS5 was at that particular time not in contact with the liquid and was marked “Insulated“. Other surfaces were assigned in the same manner as in the previous paragraph.

In the third time independent simulation, $t = 1.6$ s values were used. P1 was assigned with 605 °C, P2 with 536 °C and P3 with 456 °C temperatures. Surface BS3 was assigned with 560 °C temperature taken from the $t = 1.6$ s time step in cut B. Surface BS5 was at the time not in contact with the liquid and was marked as “Insulated“. Other surfaces were assigned in the same manner as in the previous paragraph.

In the fourth time independent simulation, $t = 2.0$ s values were used. P1 was assigned with 646 °C, P2 with 590 °C and P3 with 516 °C temperatures. Surfaces BS3 and BS5 were in cut B assigned with 520 °C and 436 °C respectively. Other surfaces were assigned in the same manner as in the previous paragraph.

Second stress measurement method was time independent. Surface marking is visible in Fig. 7.

For the second stress measurement method, $t = 2.0$ s time step values were used. P1 was assigned with 750 °C and P2 with 470 °C. P3 was marked as “Insulated“ as it wasn’t in contact with the liquid at the time. P3 surface was assigned with 436 °C temperature taken in the $t = 1.2$ s in cut B. Surface BS5 was at that particular time not in contact with the liquid and was marked “Insulated“. Other surfaces were assigned in the same manner as in the previous paragraph.

In the third time independent simulation, $t = 1.6$ s values were used. P1 was assigned with 605 °C, P2 with 536 °C and P3 with 456 °C temperatures. Surface BS3 was assigned with 560 °C temperature taken from the $t = 1.6$ s time step in cut B. Surface BS5 was at the time not in contact with the liquid and was marked as “Insulated“. Other surfaces were assigned in the same manner as in the previous paragraph.

In the fourth time independent simulation, $t = 2.0$ s values were used. P1 was assigned with 646 °C, P2 with 590 °C and P3 with 516 °C temperatures. Surfaces BS3 and BS5 were in cut B assigned with 520 °C and 436 °C respectively. Other surfaces were assigned in the same manner as in the previous paragraph.

Second stress measurement method was time independent. Surface marking is visible in Fig. 7.

On surfaces P1, BS5 and BS3 temperature of 750 °C was assigned. BS4 and BS1 surfaces were defined by 160 °C temperature. Core cooling is in the surface BS2. Time of the heat penetration was set to 2.0 s so we could compare the results with the fourth time independent simulation $t = 2.0$ s.

3. Results

The results are visible in the following figures.
Fig. 8 Plane tension in time $t = 0.8$ s with detailed view

a) tension in the direction of axis x
b) tension in the direction of axis y
a) tension in the direction of axis z
a) tension in the direction of axis x
b) tension in the direction of axis y
c) tension in the direction of axis z
d) tension in the direction of axis z

Fig. 9 Plane tension in time $t = 1.2 \text{s}$ with detailed view
a) tension in the direction of axis x
f) tension in the direction of axis y
ea) tension in the direction of axis z

Fig. 10 Plane tension in time $t = 1.6$ s with detailed view
g) tension in the direction of axis x
h) tension in the direction of axis y
i) tension in the direction of axis z

Fig. 11 Plane tension in time $t = 2.0 \text{ s}$ with detailed view
In Fig. 8, 9, 10, 11 there are marked the tension processes inside the mould during piston casting. As was stated above, the core was preheated to 160 °C, the mould was then closed and the alloy had 750 °C during casting. The core is heated by the liquid, which then cools down in the mould. Thanks to the core heating (and its inner cooling) there are evident inner stresses. The tension progress at times \( t = 0.8 \, \text{s}, \, t = 1.2 \, \text{s}, \, t = 1.6 \, \text{s} \, \text{a} \, t = 2.0 \, \text{s} \) is apparent from Fig. 8-11. The maximal and minimal tension values in each axis are organized in Tab. 1.

### Tab. 1 Spatial core tension overview

<table>
<thead>
<tr>
<th>Tension in [MPa]</th>
<th>Time ( t = 0.8 , \text{s} )</th>
<th>Time ( t = 1.2 , \text{s} )</th>
<th>Time ( t = 1.6 , \text{s} )</th>
<th>Time ( t = 2.0 , \text{s} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Max} )</td>
<td>( \text{Min} )</td>
<td>( \text{Max} )</td>
<td>( \text{Min} )</td>
<td>( \text{Max} )</td>
</tr>
<tr>
<td>Direction ( x )</td>
<td>215</td>
<td>-831</td>
<td>250</td>
<td>-1500</td>
</tr>
<tr>
<td>Direction ( y )</td>
<td>220</td>
<td>-901</td>
<td>300</td>
<td>-1030</td>
</tr>
<tr>
<td>Direction ( z )</td>
<td>320</td>
<td>-900</td>
<td>387</td>
<td>-1130</td>
</tr>
</tbody>
</table>

Based on the FEM analysis results it was discovered, that at points where the core cracks, the tension exceeds the solidity of H13 steel.

### 4. Conclusion

ANSYS Workbench – Polyflow program confirmed the assumption that the highest temperatures of the core are measured at the point of its longest contact with the liquid; despite the cooling. The core surface temperatures are after 2.0 seconds considerably uneven and these differences are the cause of inner stress in the metal core (Fig. 8-11) (second method shows higher stress values, but not considerable).

These readings are going to be specified and compared with the experimental measurements in the next article. On the basis of heat stress, stress was determined including the speed of its changes. Given these changes, critical points were marked. In the next steps, core adjustments are going to be suggested with possible technologies of casting and cooling adjustments resulting in increased longevity. The current method of core heating before casting and after technological breaks with cooling solutions included will be assessed as well as this process may considerably influence longevity of the cores.

In the next step, further core adjustments are going to be specified. These should lead to lowering of the number of core cracks. The newly designed shape is going to be analyzed with FEM and then tested in real operation.

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### References


