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Influence of pouring temperature on a thermal gradient

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Abstract

In the thesis there are presented results of computer simulation of casting solidification process, characteristics of solidification rate in several points as well as course of gradient change between these points. Based on the obtained results, an influence of initial conditions on temperature gradient during the solidification process was determined.

Keywords: Solidification, Thermal derivative analysis (TDA), Gradient analysis

1. Introduction

The purpose of this thesis is to define influence of moulding materials and pouring temperature on temperature gradient during solidification of casting with different walls thickness. It is critical, because the temperature gradient, besides the solidification rate, is the factor deciding about structure and future properties of a casting [1-5].

2. Research method

Simulation of analysis of initial conditions influence on temperature gradient during solidification will be carried out on 3D model performed in the CAD graphic software (Fig. 7). In order to obtain high differentiation of solidification conditions within one casting, a cone was selected as a tested geometrical shape. The casting dimensions are presented in fig. 1.

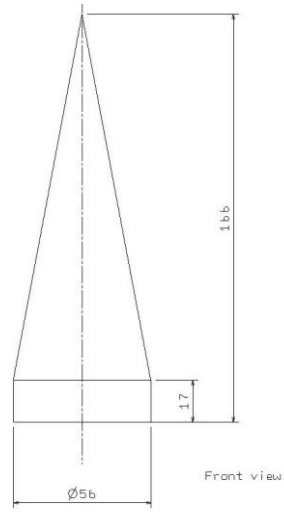

Fig. 1. Geometrical dimensions of cone casting model

Measuring points had been distributed spirally on surface created by revolution of vertical angle bisector of the cone around Z axis (Fig. 2). The points had been laid every 15 [*mm*] at Z axis counting from cone vertex and every next point is located at 90° angle with regard to the previous one (Fig. 3).

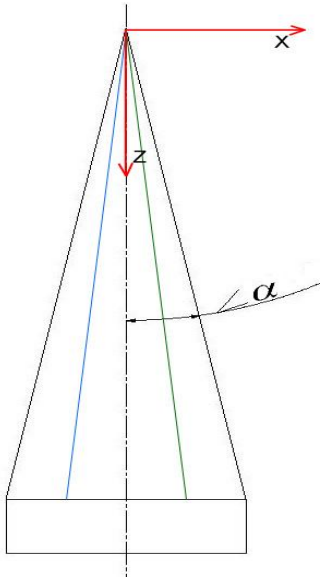

Fig. 2. Determination of a surface where measuring points will be located

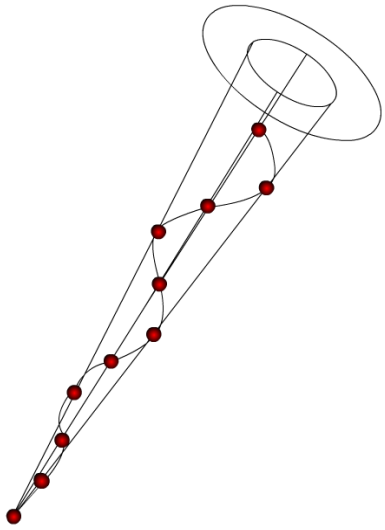

Fig. 3. Distribution of the measuring points

The casting material chosen for numerical test from the NovaFlow&Solid program database there is the grey cast iron with liquidus temperature T_L=1231 [ºC].

Pouring temperatures: 50 and 150 ^{o}C above T_L liquidus temperature of the alloy chosen for numerical calculations.

3. Test results

Below there are presented simulation results, TDA graphs of respective points and graph of gradient value changes between these points, calculated by formula (1). This section presents measuring results for points 1 and 2, 7 and 8, 8 and 9, 9 and 10, 10 and 11 - for the lowest and the highest pouring temperatures, in order to explicitly show the analysis of influence of casting wall thickness and pouring temperature on temperature gradient during solidification.

In the thesis the gradient is determined as a relation of temperatures difference in measuring points and distance between these points (1) [5].

$$\blacktriangledown = \frac{T_{n+1} - T_n}{l} \left[\frac{K}{cm} \right] \tag{1}$$

Where:

$\blacktriangledown$ – temperature gradient $\left[\frac{K}{cm} \right]$,

T_{n+1}-T_n – temperature difference [K],

L – distance between measuring point n and n+1 [cm].

Below there are graphic presentations of numerical tests in time function and summary gradient of heat transfer, determined by numerical trapezoid integration (Fig. 14).

4. Analysis of the test results

Analysing graphs of temperature gradient determined based on numerical test results, one may notice two characteristic time ranges, when the gradient obtains a certain peak value. These ranges are explicitly visible in gradient graphs at thicker wall, e.g. Fig. 6 - T8-T7/L Gradient, the first range is within 0÷148 [s], and the second one within 148÷500 [s].

In order to widen possibilities of test result analysis, the test results include graphs presenting summary heat transfer gradient, total for the whole gradient (Fig. 14)

For better imaging of gradient changes the graphs are compared in sets of three: TDA graph of n+1 point, T_{n+1}-T_n temperature gradient graph and TDA graph of n point. Because of extensiveness of obtained results the thesis presents only the selected graphs.

4.1 Analysis of wall thickness influence

Analyzing the course of temperature gradient during solidification of the moulding quartz-clay mixture, one may notice the characteristic peak values of which the maximum gradient value decreases at wall thickness increase. At the lowest wall thickness the first characteristic value is invisible, being melted into ascending slope of the second peak value (Fig. 4 and 5, T2-T1/L Gradient). At more thicker wall, a minimum value occurs between these characteristic maximum values – Fig. 6 and 7, T8-T7/L gradient, time from 135 [s] to 215 [s] - duration of

this minimum value – nearly zero – increases with wall getting thicker, i.e. the distance between peak values increases.

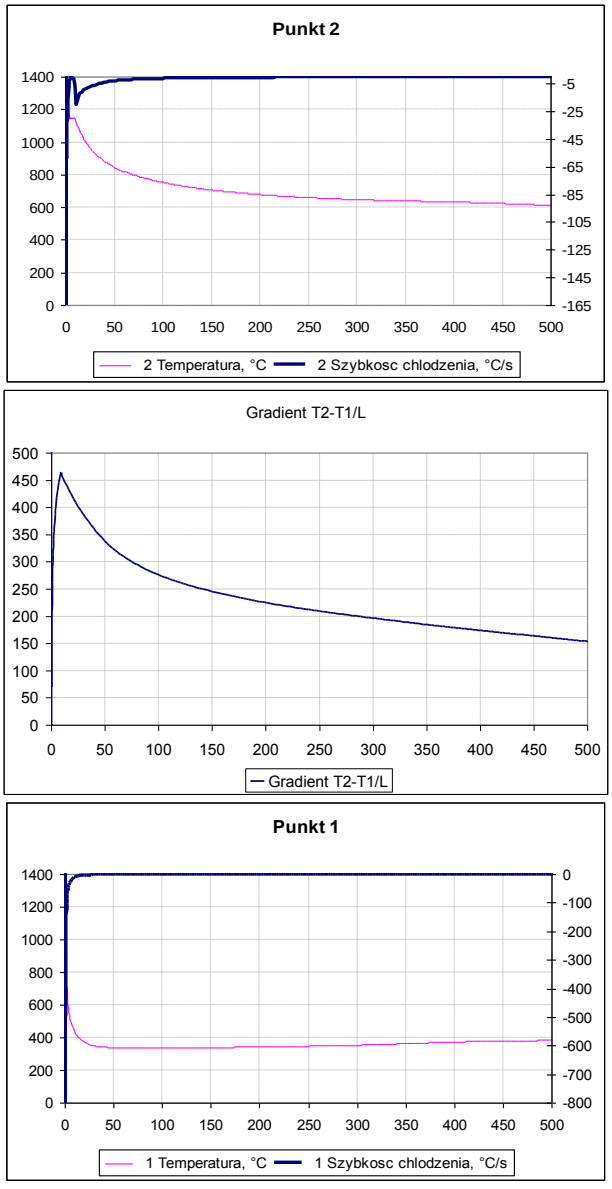

Fig. 4. Graph of gradient changes within time and TDA graphs of points 1 and 2, version 1

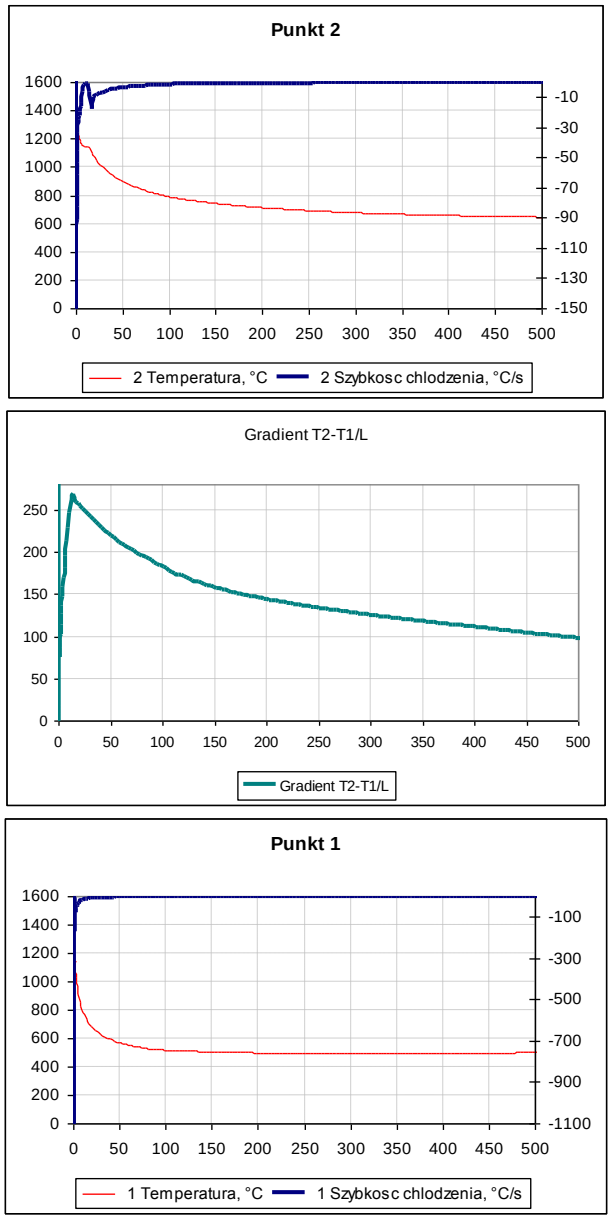

Fig. 5. Graph of gradient changes within time and TDA graphs of points 1 and 2, version 2

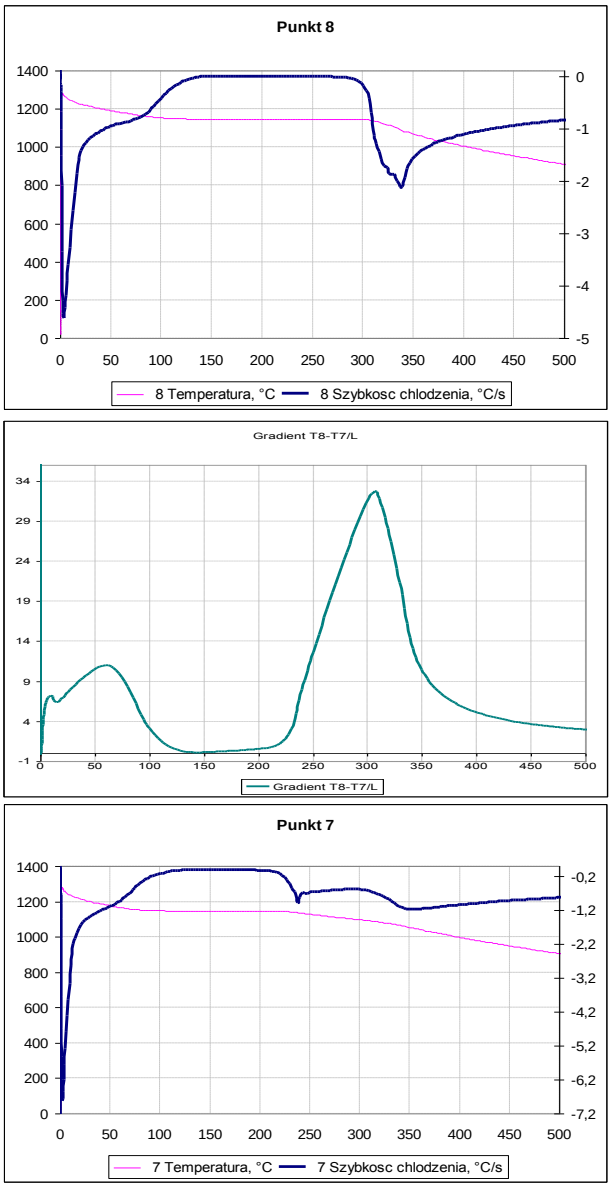

Fig. 6. Graph of gradient changes within time and TDA graphs of points 7 and 8, version 1

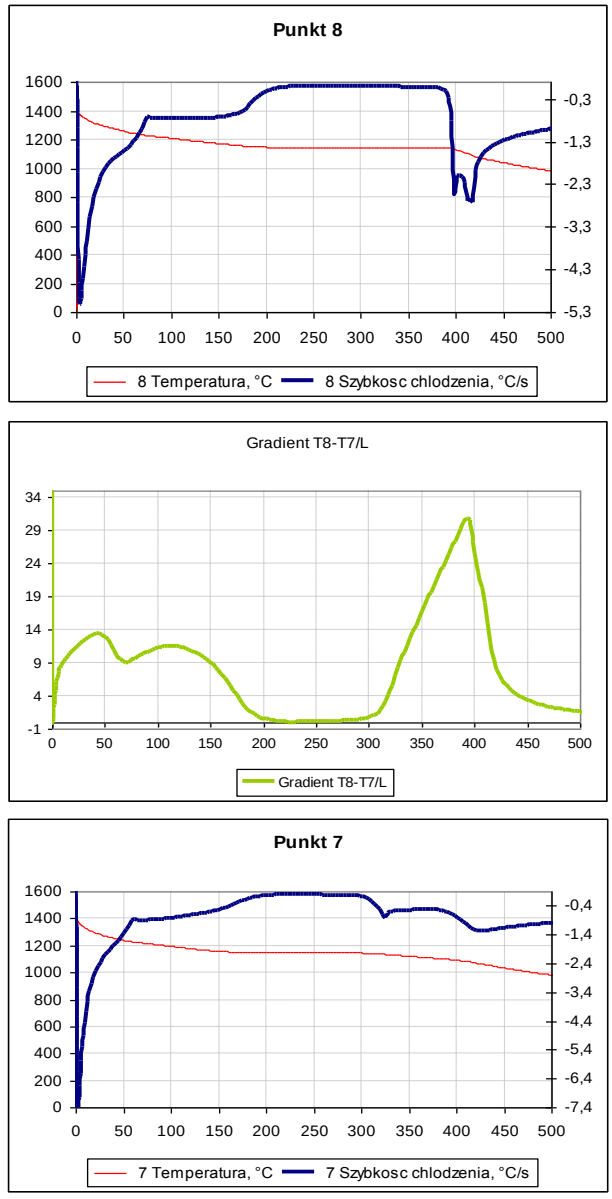

Fig. **7**. Graph of gradient changes within time and TDA graphs of points 7 and 8, version 2

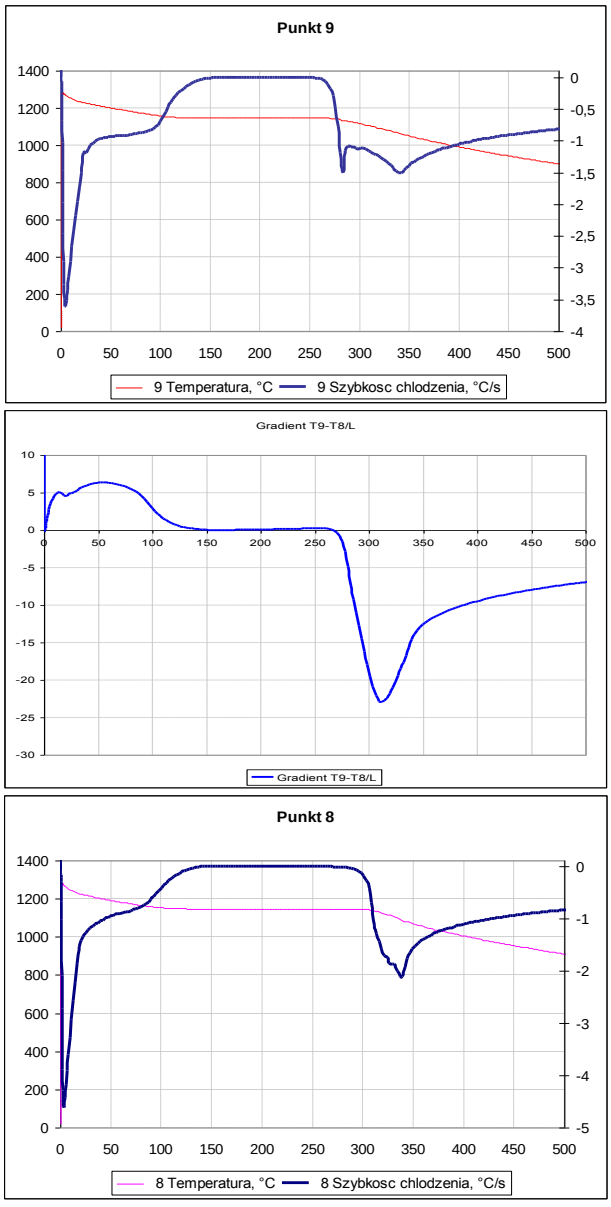

Fig. 8. Graph of gradient changes within time and TDA graphs of points 8 and 9, version 1

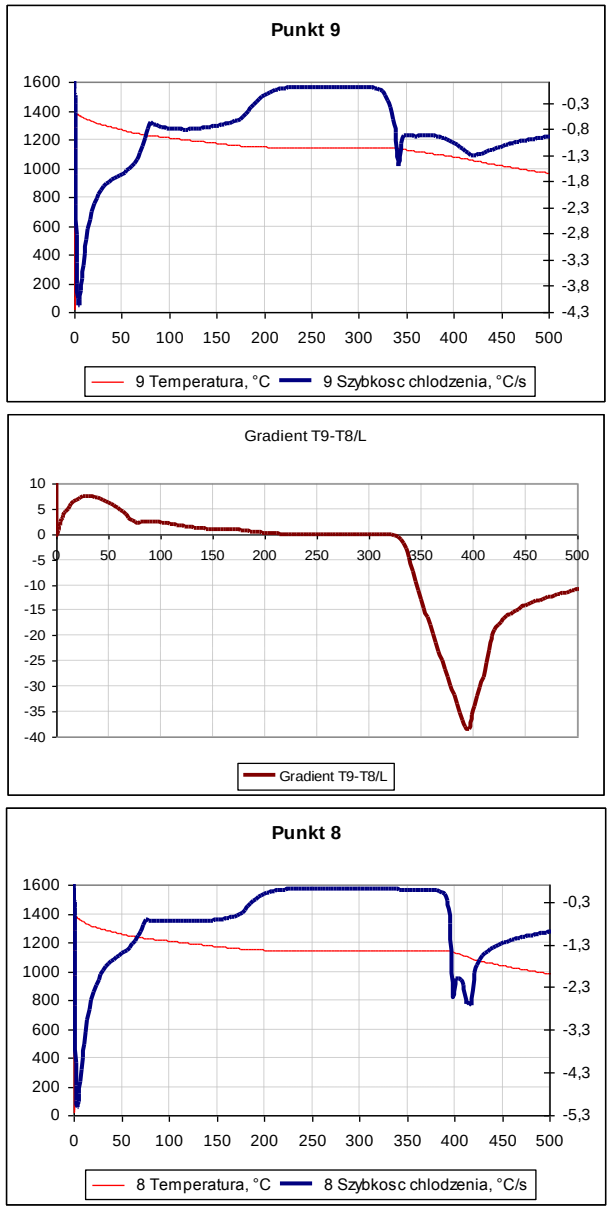

Fig. 9. Graph of gradient changes within time and TDA graphs of points 8 and 9, version 2

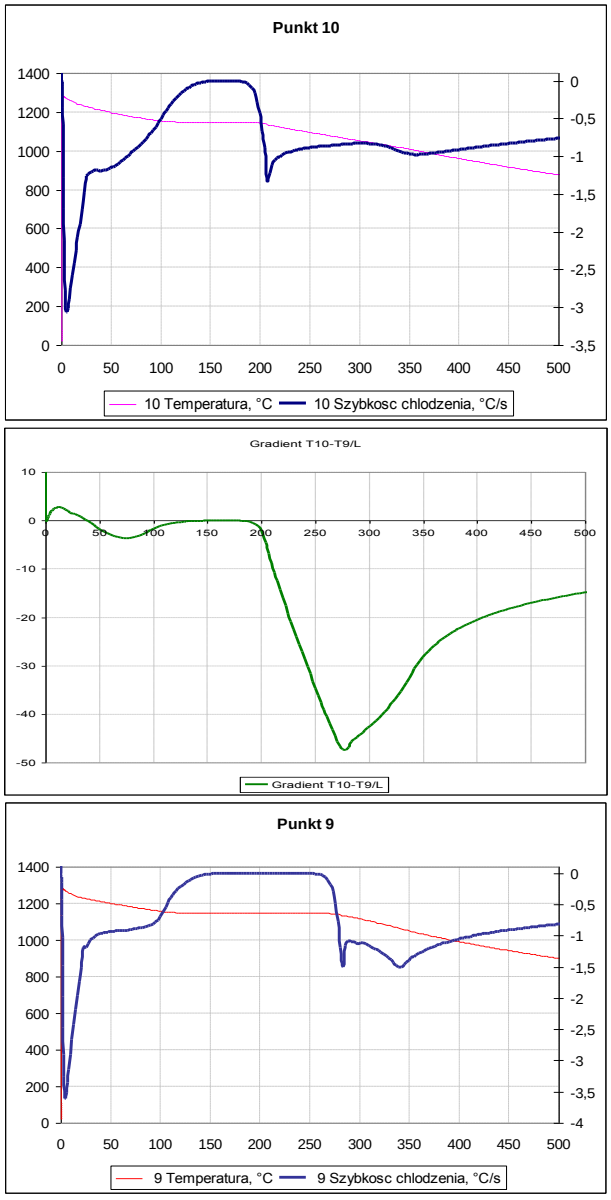

Fig. 10. Graph of gradient changes within time and TDA graphs of points 9 and 10, version 1

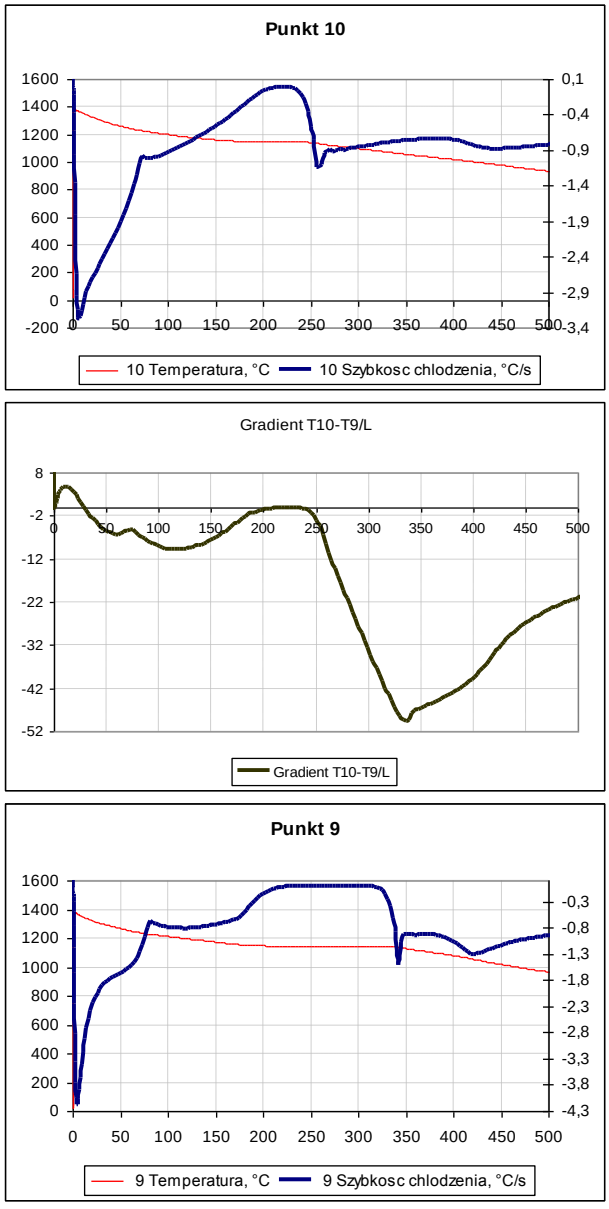

Fig. 11. Graph of gradient changes within time and TDA graphs of points 9 and 10, version 2

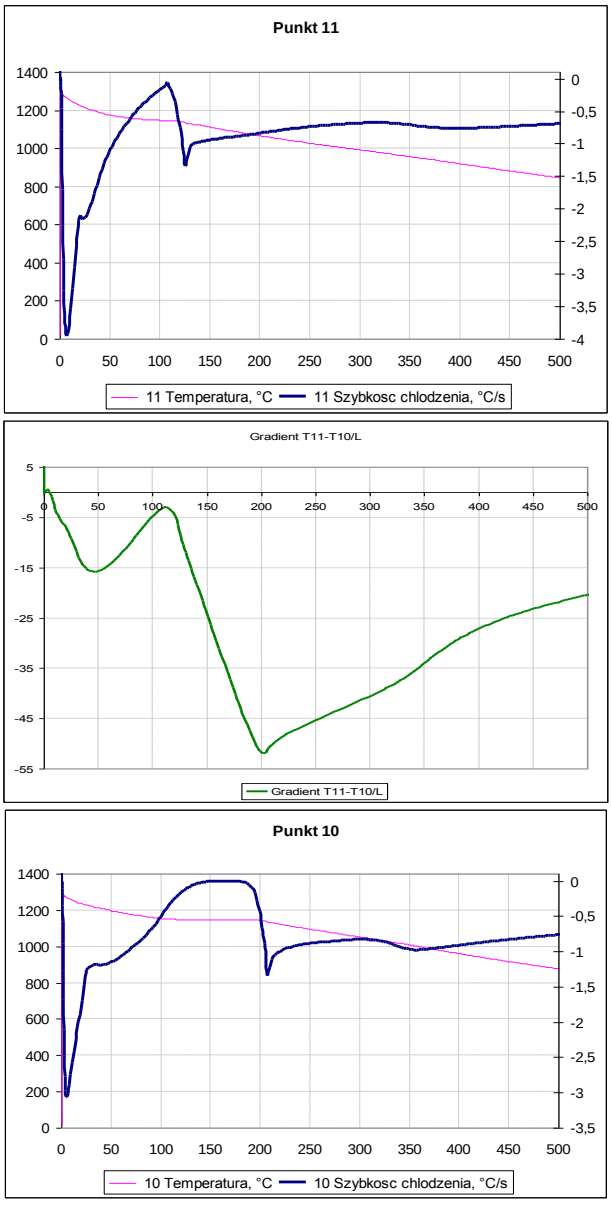

Fig. 12. Graph of gradient changes within time and TDA graphs of points 10 and 11, version 1

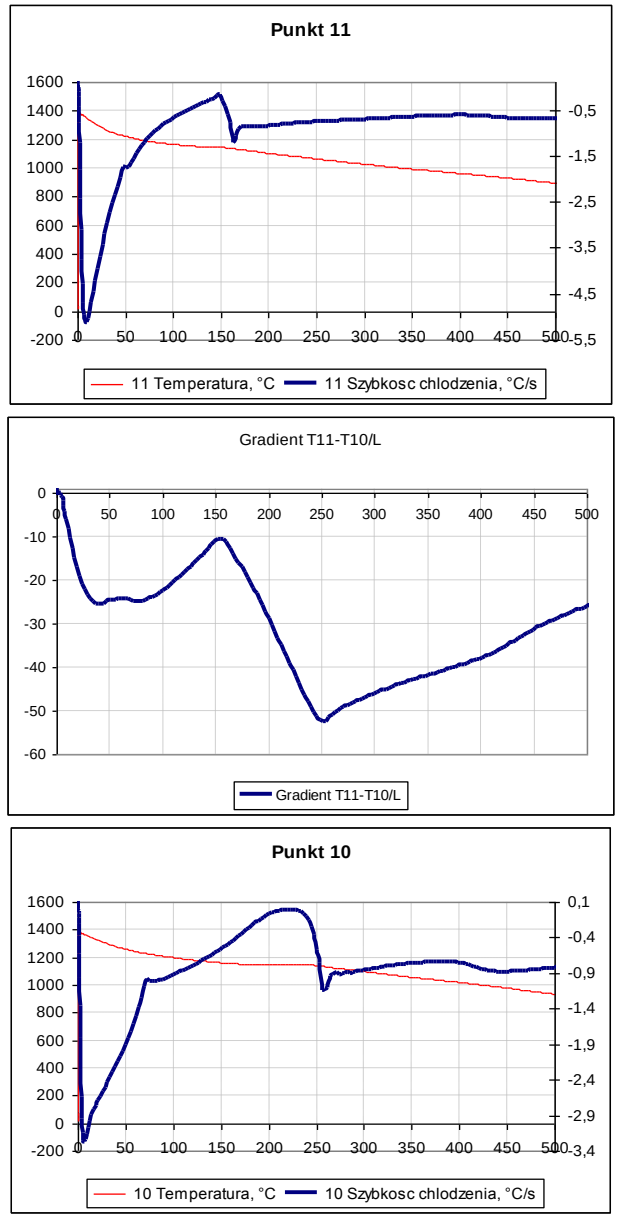

Fig. 13. Graph of gradient changes within time and TDA graphs of points 10 and 11, version 2

Duration of the first maximum value – the first peak, increases with increase of wall thickness.

Change of sign occurs between points 8 and 9 (Fig. 8 and 9, T9-T8/L Gradient), then the second extreme value – local minimum has negative value and the first extremum – the maximum has still positive value. Between points 9 and 10 (Fig. 10 and 11, T10-T9/L Gradient) in gradient graphs one may notice that the first local extremum is still of positive value and the second one is of negative value, then the descending slope of the first peak point obtains value nearly zero – but the negative value, then the minimum occurs which is of negative value.

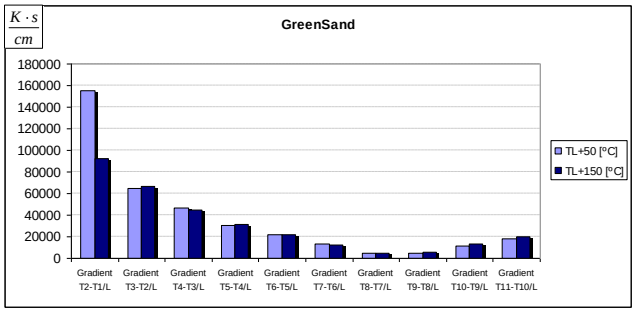

Fig. 14. Distribution of summary gradient value for individual measuring points in tested pouring temperatures

Between points 7 and 8 (Fig. 6 and 7, T8-T7/L Gradient) the gradient is of positive value, and between points 8 and 9 (Fig. 8 and 9, T9-T8/L Gradient) the gradient – the second peak value – is of negative value, what indicates that at the height of point 8 the liquid metal will solidify at the end, indicating this is the heat centre.

4. 2 Analysis of pouring temperature influence

With increasing pouring temperature the maximum gradient value decreases, it is most explicitly noticeable in gradient graphs between points 1 and 2 for both pouring temperatures (Fig. 4 and 5, T2-T1/L Gradient).

The local extremum which occurred in the first peak value is already much better noticeable at higher temperature (Fig. 7, T8-T7/L Gradient). One may note that the minimum value of the local extremum occurs in time between obtaining liquidus temperature of point n and n+1. And the maximum value of the second peak value occurs within time between obtaining solidus temperature of point n and n+1.

Duration of the first peak value at increasing of pouring temperature expands, hence the time during which the second peak value (the second extremum) begins to ascend, delays. The pouring temperature does not change the duration of the gradient minimum value occurring between the peaks.

4.3 Summary

The maximum gradient value is dependant on pouring temperature.

Reversing of gradient direction occurred between points 8 and 9 (Fig. 8, 9, T9-T8/L Gradient) – for all the pouring temperatures – what indicates the heat centre location.

The gradient between points 9 and 10, where division occurred of the first peak value into positive and negative part, the gradient after obtaining the negative value (Fig. 10 and 11, T10-T9/L Gradient) all the time further on remains at negative value.

Time gap in characteristics of cooling rate – between liquidus and solidus points expands at increase of wall thickness (see enclosure Fig. 1÷10). After reversion of the gradient direction – what is influenced by environment – the time gap between obtaining liquidus and solidus temperature begins to decrease.

On the first peak the local extrema occurred – it is noticeable most explicitly for the highest temperature of 150 [ºC] over the liquidus temperature. Also in all the trials the maximum value of the first "projection" decreased at thickening of wall, but as may be noticed, the summary gradient value decreased (Fig. 14) at average up to point 7 and then started to increase.

One may also note that temperature influences the summary gradient value in the respective ranges.

5. Conclusions

1st The maximum gradient value is inversely proportional to increase of casting wall thickness,

2nd Time after which the gradient reaches the highest value expands at thickening of wall,

3rd Wall thickness and temperature influence the duration of the first peak value,

4th The wall thickness influences also the time gap between liquidus and solidus temperature in TDA graphs – temperature derivative, for the respective points,

5th The summary gradient value is directly proportional to the pouring temperature.

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