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Assessment of effectiveness of water mist cooling of casting die

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Abstract

At work research findings of the process of cooling the research casting die in the range of the 600-100°C temperature were presented and of the research-production casting die while pouring the cycle out cooled with compressed air about the pressure 0.6 MPa and the water mist about the pressure of air and water appropriately 0.3/0.35 MPa. The character and the speed of the temperature changes in the die and being formed of gradient of the temperature on the thickness partition walls were shown the die with the help of thermal and derivative curves. A course of changes was presented to the density of the thermal stream during cooling and in function of the temperature as well as results were shown a computer simulation of the process of pouring the production casting die. A scheme of the device for generating the water mist cooling the die and an image of spraying water were shown with the help of the designed rotary sprayer. They showed that applying the water mist for cooling dies is increasing the intensity of casting process and is accelerating it.

Keywords: Innovative materials and casting technologies, Heat transfer, Cooling, Water mist, Low-pressure casting, Die, Silumin .

1. Introduction

Presented results are the continuation of examinations of die castings concerning increasing the quality, shortening of the casting cycle and increasing the effectiveness of the production as a result of the substitution of the way and the speed of cooling the casting die [1-4].
Analysis of the heat transfer process and the assessment of steering possibility with it were an aim of examinations carried out in the range of the temperature appearing in the production casting die while casting car wheels under the low pressure. At present universally used cooling of dies consists in aiding convection giving back the heat with stream of compressed air pointed to appropriately prepared places of the outside surface of die.
The realization of the work purpose consisted on examining of the process of being getting cold of the research die on the laboratory position. Limiting direction and surface size of the heat transfer were basic establishing the studied cooling system with the cooling medium and appropriate selection of parameters of the water mist in order to led the drops of water to the hot surface of the die and evaporate them completely.
The increase in intensity of heat transfer from chosen die areas will let better steer with course of setting of the cast and will shorten its crystallization influencing reducing porosities of castings, size reduction the microstructure and the improvement in the Rm, $Rp_{0.2}$, A_5 and HB properties [5, 6].

2. Experimental

Examinations were carried out on the laboratory position and on the research-production, industrial post of casting of car wheels under the low pressure.

In picture 1 a scheme of the position for examinations of cooling intensity was shown. Cooling of the research die (1) heated to temperature 620°C was a essence of examinations. The cuboid-shaped die was made from EN–GJL-200 grey cast iron. The die was being put on the stand (4) in heat-insulating shield (2) with the possibility of the directional heat transfer with the surrounding only by the bare surface of the bottom partition wall. This surface was being cooled with stream of air or the water mist pointed with the nozzle (3) placed at right angles to the surface. The temperature of the die was being measured at the same time with 6 K - type thermocouples (5) put in her vertical axis of symmetry in distance 8, 16, 24, 32, 40 and 48 mm from the cooled surface. The recording of the temperature was being kept with automatic KD7 recorder of the Lumel company with the frequency 2 per second and the accuracy 0.1°C.

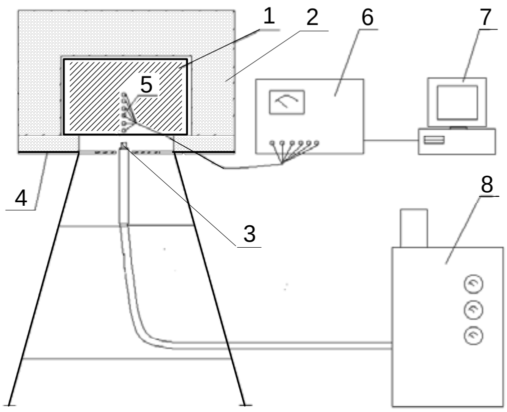

Fig. 1. Position for intensity research of cooling with water mist: 1 - research die, 2 – heat-insulating shield, 3 – nozzle of cooling system, 4 – stand, 5 – thermocouples, 6 – recorder of the temperature, 7 – PC, 8 – automatic cooling servo device

The water mist was being generated in multichannel Automatic Cooling Servo (8), of which the scheme was presented in picture 2. He lets to simultaneous dosing and spraying water in channel of the cooling system. Controlling cooling circumferences consisted in the change of the pressure of compressed air in the 0.25 to 0.65 MPa range and of water from 0.05 to 0.6 MPa. Demonstration streams of sprayed water and the starting cooling mist were shown in pictures 3 and 4.

During the completion of examinations on the industrial position casts of car wheels were being produced from AlSi7Mg silumin modified with Ti, B and Sr and refined with Ar. The research-production die installed on the position of the casting machine consisted of 4 side jaws, the bottom and upper core in which were located the thermocouples by using the scheme presented in picture 5. The temperature of its preheating was included in a 350 to 460°C range.

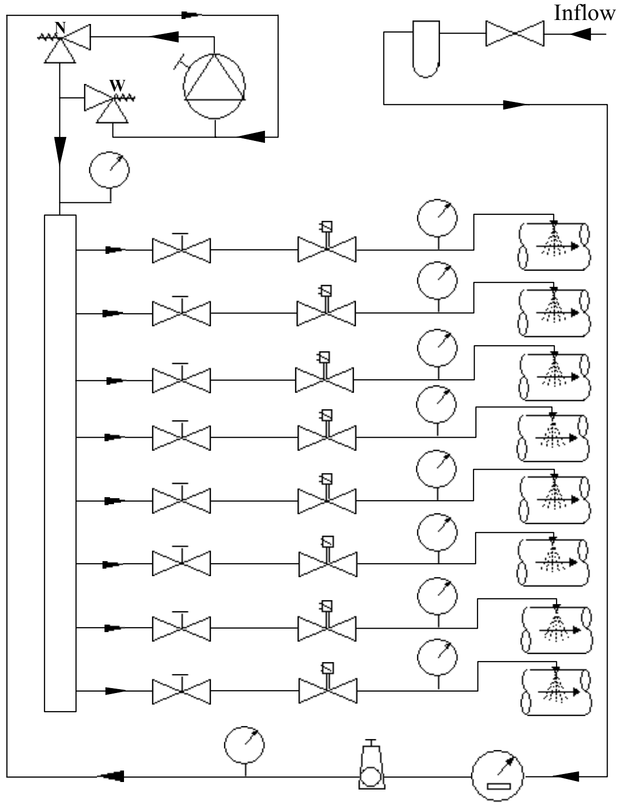

Fig. 2. Scheme of Automatic Cooling Servo device

Fig. 3. Streams of sprayed water with use of designed rotary sprayer, magnification 3 times

Fig. 4. Stream of water mist cooling the die surface

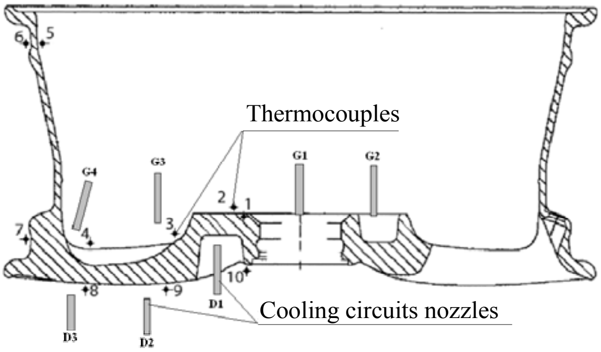

Fig. 5. Layout scheme of thermocouples and cooling circuits nozzles

Filling the die cavity followed under the influence of the pressure in the 0.01 to 0.09 MPa range exerted on the surface of molten metal in the holding furnace.

Cooling the die was carried out with the help of Automatic of Cooling Servo and multichannel air installation, of which nozzles were put in prepared holes on the outside surface of die (fig. 5).

The registration of the temperature of this chill was being kept with device JUMO Logoscreen with the automatic record of 10 measuring channels in 1 second time intervals. The registration of the process of being getting cold of the die and the cast was fundamental to a computer simulation of the casting process carried out with use of Magma computer system.

3. Results and discussion

At work a disitribution of the temperature was examined in chosen points of the research die and the production die for cooling: with air about the 0.60 MPa pressure and with the mixture of 0.30 MPa air pressure and water which pressure was appropriately 0.35 MPa.

In picture 6 a change of the temperature and a speed were presented of being getting cold of the research die (fig. 1) cooled with air compressed to 0.60 MPa. It results from presented data, that before beginning cooling, the die had the identical temperature in the checked section. Beginning cooling caused the uppearing of the gradient temperatures in direction perpendicular to the chilled surface what on the graph it shows with increasing distances between thermal curves of individual points. As a result the time of being getting cold of the die in the checked denotation from 600 to 100°C achived a value 1009 s. Maximum speed of the temperature change was registered at the initial stage of cooling for point 8 mm, that was put the closest from the cooled surface. From derivative curve of this point it results that the cooling rate at first is highest and is equel 13 °C/s and next it intensively is decreasing and then asymptotic it is approaching the nought.

In picture 7 were presented a change of the temperature and a speed of being getting cold of the research die cooled with water mist under pressure of air 0.3 MPa and with water under pressure 0.35 MPa. It appears from presented data that the highest speed of being getting cold is appearing of mm in the initial stage of cooling and for the point put in distance 8 is 18 °C/s. The time of cooling of the all die from temperature 600 °C for achieving 100 °C in the point put farthest from the cooled surface is taking 596 s It's mean a 59% in comparing to the higher presented time at cooling with air under the pressure 0.6 MPa. Appearing of the bigger gradient of the temperature also results from this data. It is caused by the much higher initial speed (18-13 = 6 °C/s) changes of the temperature of the layer of the surface die as a result of cooling her with water mist. In pictures 8 and 9 a change of the gradient of the temperature was presented in the wall of the die in direction perpendicular to the surface cooled with air under the pressure 0.6 MPa (fig. 8) and cooled water mist under the pressure appropriately 0.3/0.35 MPa. These examinations are confirming distinct increasing the gradient by chilling with water mist and his dependence on the time of cooling and the current temperature of the system.

In picture 10 and 11 a change of the stream density of heat transferred from surface of research die was presented appropriately die cooled with the air under the pressure 0.6 MPa (fig. 10) the density of the thermal stream get back from surface layer of research chilled appropriately chill with air and with water mist under the pressure 0.3/0.35 MPa (fig. 11). It appears from graphs that the maximum of the stream density of the heat is appearing in the initial stage of cooling the die. Its value for the die cooled with water mist is $9.2*10^3$ kW/m^2 and it is much bigger in comparing to the die cooled with air, that amount to $7.5*10^3$ kW/m^2. It also appears from data that changes of the heat stream in the time have the very intense character in the first short stage and completely different, smooth in the more distant part of the course of being getting cold

Describing the stream density of heat in the function of the research die temperature is delivering the additional information, introduced in pictures 12 and 13 with air appropriately for cooling with air compressed to 0.6 MPa and the with water under the pessure 0.3/0.35 MPa.
These distributions were described with mathematical models with applying of polynomial 6 the step getting correlation above R^2 = 0.87. From comparing both distributions he results, that chilling with water mist is giving the greater temperature range to the high density of the heat stream. Its characteristics are beginning the decided increase in temperature 150 °C . It's mean about 200 °C of the difference in comparing to cooling with compressed air. It is indicating, that cooling with water mist also has the greater effectiveness in the lower temperature what can successfully be applied for cooling casts after taking them out of the die.
Examinations carried out on the industrial research-production position are confirming get earlier results. For example in picture 13 a change of the temperature and the speed of being getting cold of the wheel cast was described in the „1" point (fig. 5) during the casting cycle in the die cooled with air under the pressure 0.60 MPa.

It appears from presented data that for the cast in the „1" point the highest temperature was registered at the beginning stage of the filling cycle and it amounted 572°C, however the minimum 423°C temperature appeared after removing the cast from the die. A legitimacy of selection of the 600 to 100 °C range of checking the temperature of being getting cold of the research die is confirming .
It results from derivative curve that while filling the speed of the changes of the temperature of the cast is achieving values from –4 to 10 °C/s which is also close for values get for the research die. High temperatures in this point result from putting it close the gate in the casting die. How it was shown in a picture a computer simulation (fig. 16) of the process of filling and the distribution of the temperature in the cast, the rosette of the wheel from the beginning is fed with hot metal and till the end of its solidification it determines feeding area for spokes and the ones in turn for the wheel ring.
The distribution of the temperature of the wheel cast during more further filling was shown in picture 17. It results that the area of the bottom edge of the ring on the connection with spokes should to be subordinate to a special attention on account of appearing thermal centers and big gradients of the temperature.
The discussed area of the production die was being analyzed with use the thermocouple in the point „4". Pictures 18 and 19 are presenting curves: thermal and derivative of the casting cycle for the „4" point (fig. 5) of research-production cooled appropriately die with air about the pressure 0.6 MPa (fig. 18) and with water mist under the pressure 0.3/0.35 MPa (fig. 19).

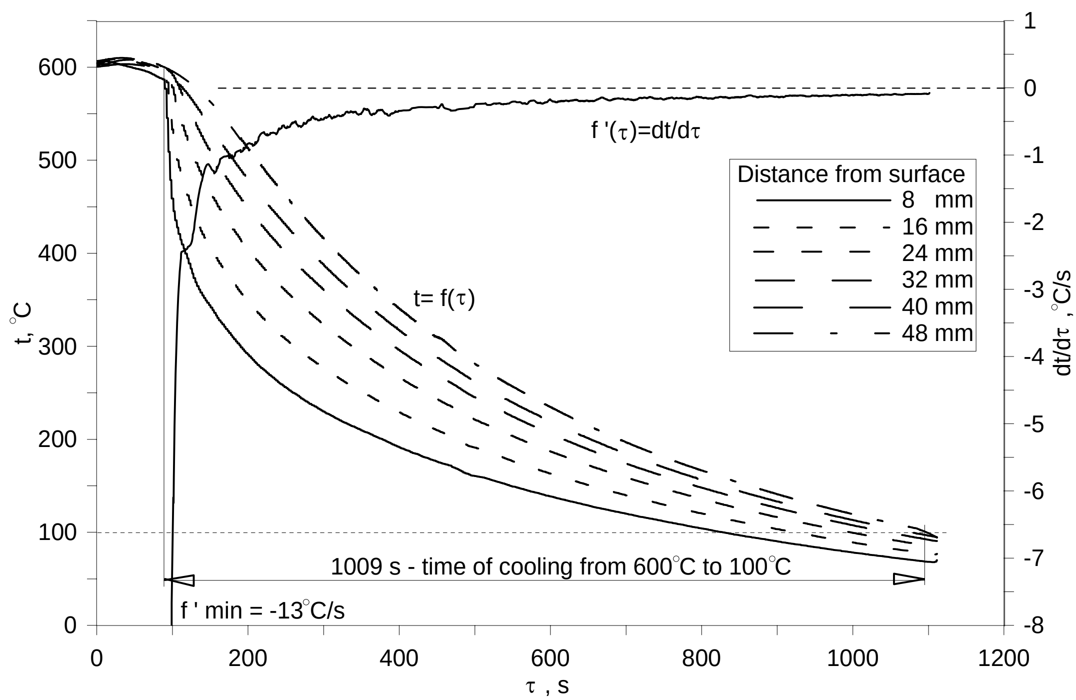

Fig. 6. Thermal and derivative curves for research die cooled with air compressed to 0.6 MPa

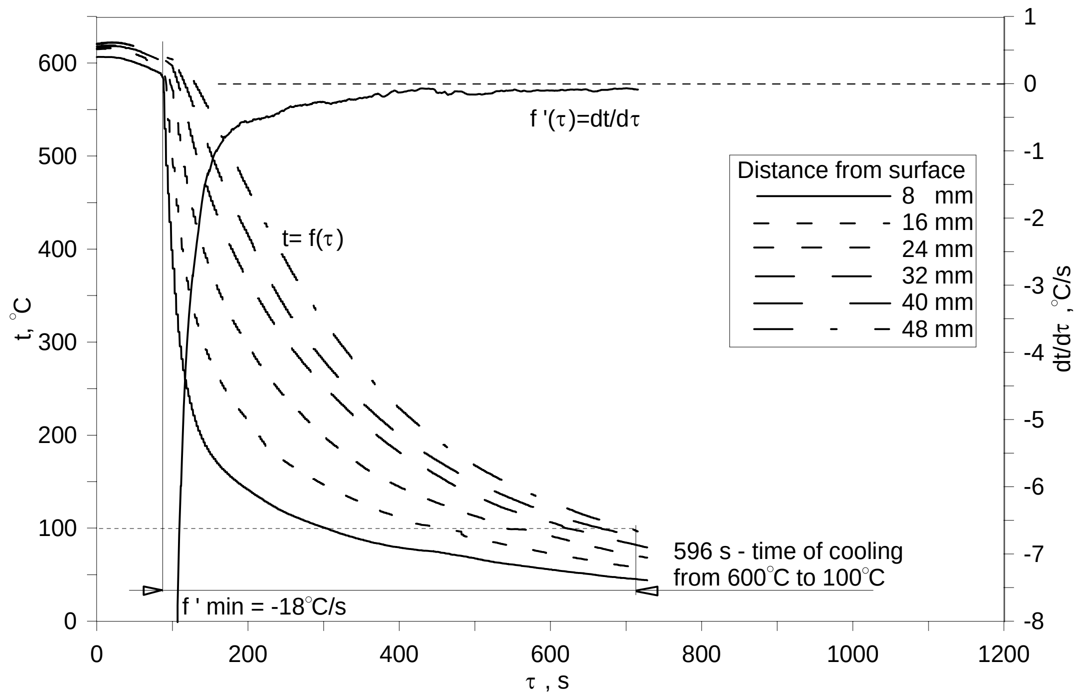

Fig. 6. Thermal and derivative curves for research die cooled with water mist under pressure 0.3/0.35 MPa

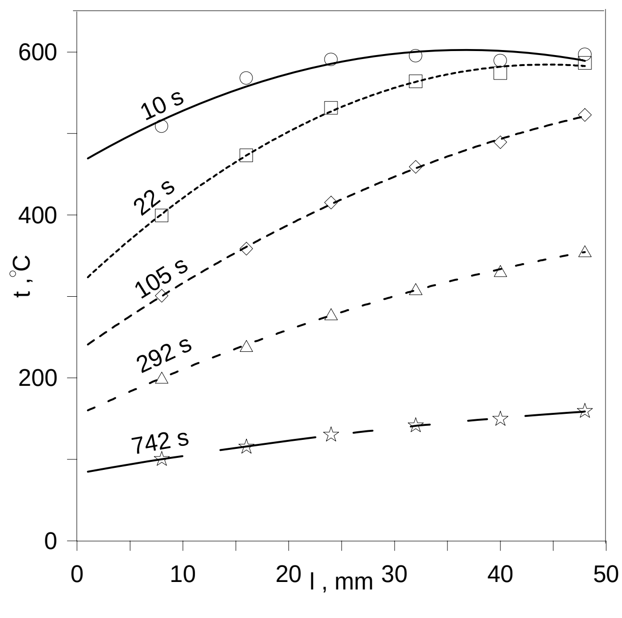

Fig. 8. Curves of temperature gradient in wall of die in direction perpendicular to surface cooled with air compressed to 0.6 MPa for different moments of cooling time

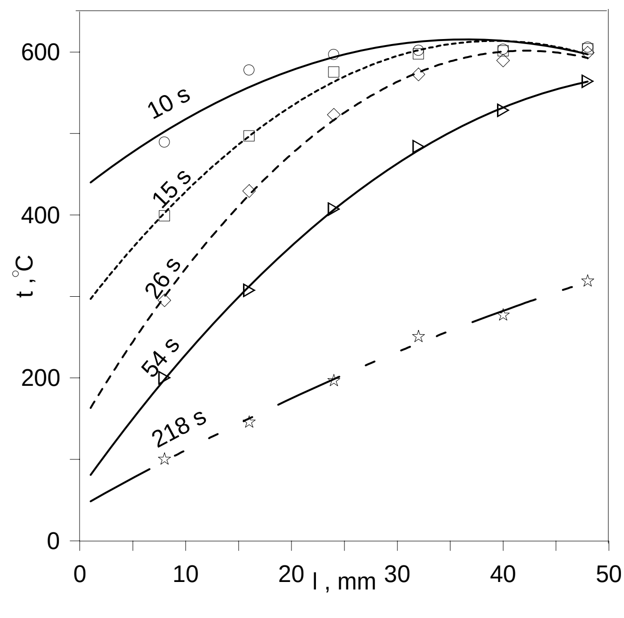

Fig. 9. Curves of temperature gradient in the wall of the die in direction perpendicular to the surface cooled with water mist under pressure 0.3/0.35 MPa for different moments of cooling time

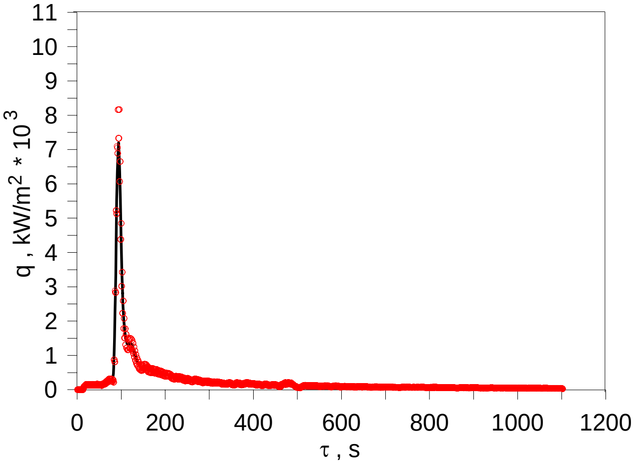

Fig. 10. Stream density of heat transfered from surface of research die cooled with air compressed to 0.6 MPa

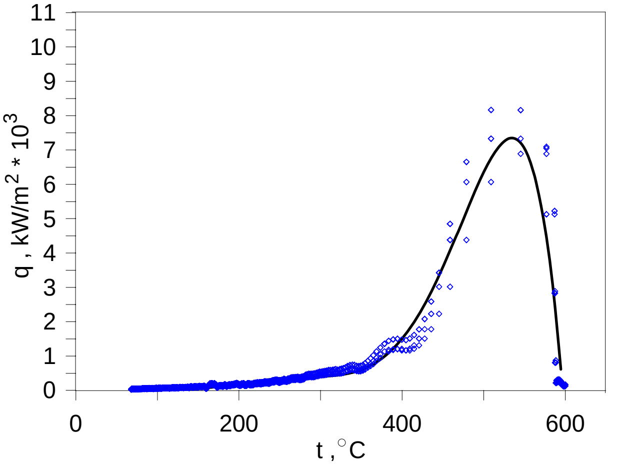

Fig. 12. Stream density of heat transfered from surface of research die cooled with air compressed to 0.6 MPa in temperature function

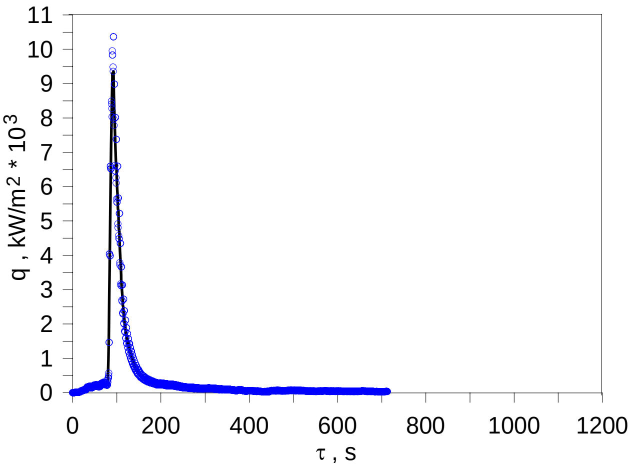

Fig. 11. Stream density of heat transfered from surface of research die cooled with water mist under pressure 0.3/0.35 MPa

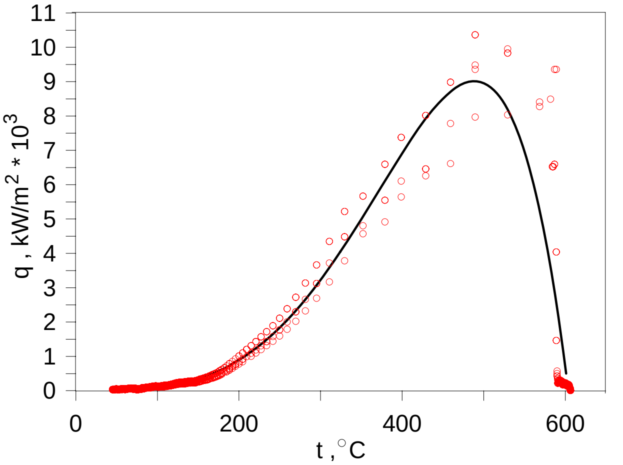

Fig. 13. Stream density of heat transfered from surface of research die cooled with under pressure 0.3/0.35 MPa water mist in temperature function

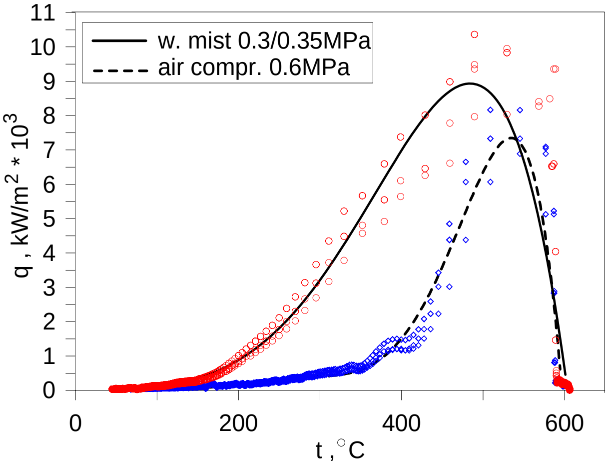

Fig. 14. Comparing of stream density of heat transfered from surface of research die cooled with air compressed to 0.6 MPa and with water mist under pressure 0.3/0.35 MPa in temperature function

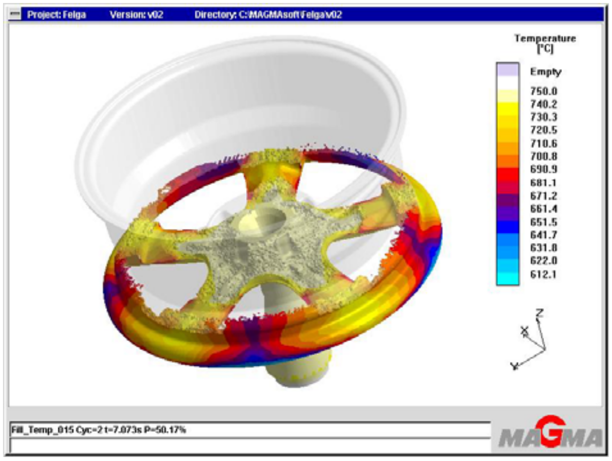

Fig. 16. Simulation of wheel casting process in casting die cooled with air; the temperature during filling up the rosette and spokes of the wheel

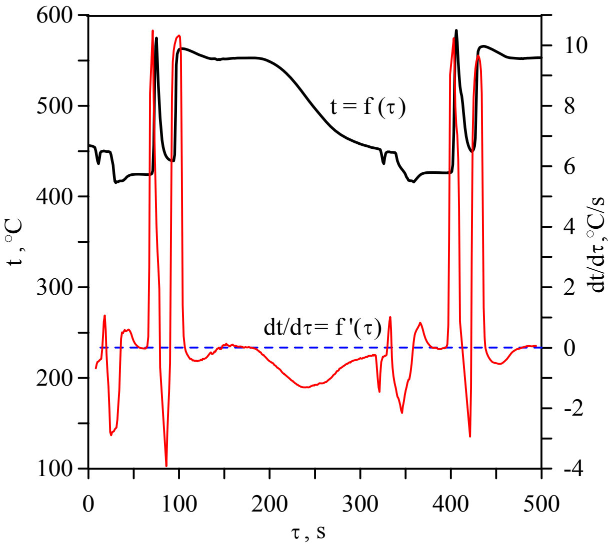

Fig. 15. Thermal and derivative curves of research casting at “1” point for research-production die cooled with air compressed to 0.6 MPa

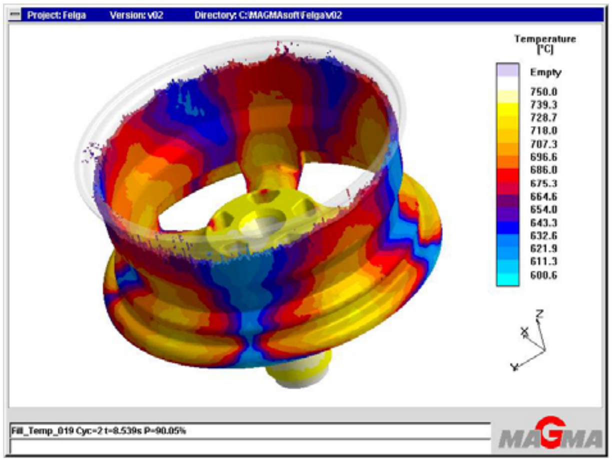

Fig. 17. Simulation of wheel casting process in casting die cooled with air; temperature during filling wheel ring up

From characteristics for the casting die cooled with air it results that the temperature is changing smoothly in a narrow range values from 462 to 543°C. However the velocity of being getting cold as it results from the dt/dt curve, is smaller than of „1” point and is taking turns in the –0.5 to 2.5 °C/s range.

Applying cooling with the water mist (fig. 19) caused the increase in the range of the temperature changing from 300 to 470 °C as well as the increase in the velocity range of the temperature changes from -4 to 5 °C/s. Also, from comparing the time of cycles (fig. 18 and 19) distinct shortening the cycle of wheel's casting results with use of water mist. The time of cycle is reducing from 340 to 230 s.

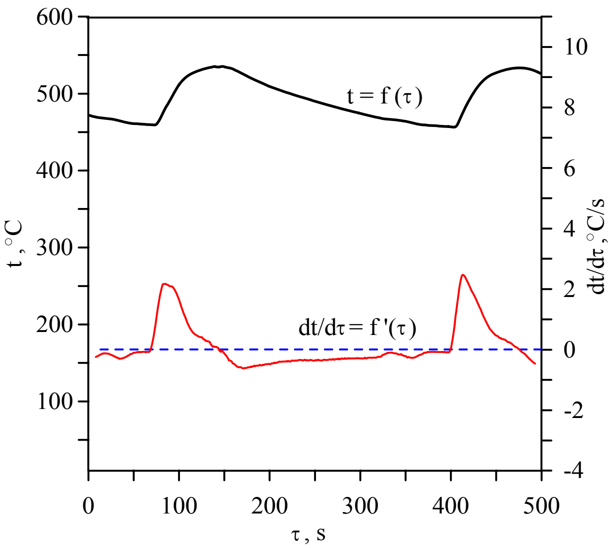

Fig. 18. Thermal and derivative curves of research-production die in “4” point cooled air compressed to 0.6 MPa during casting cycle

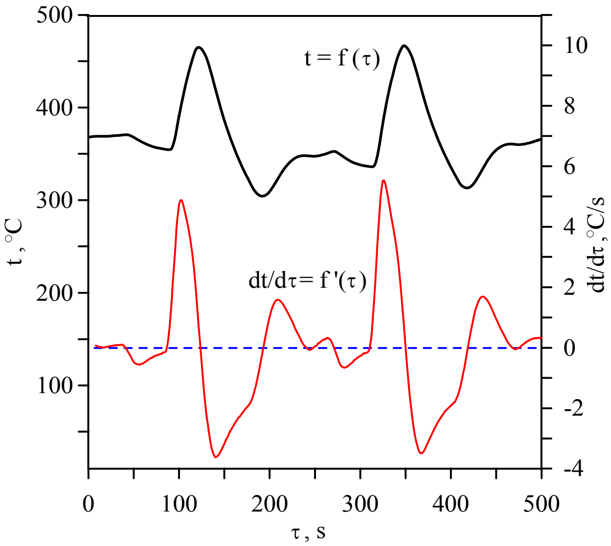

Fig. 19. Thermal and derivative curves of research-production die at “4” point cooled with water mist under pressure 0.3/0.35 MPa during casting cycle

4. Conclusions

It results from described at work examinations, that cooling of casting dies with the water mist under the pressure 0.3/0.35 MPa in comparing to cooling with the air compressed to 0.6 MPa couses :

- for the die cooled in the range from 600 to 100 °C:
    - increasing the maximum velocity of being getting cold from 13 to 18 °C/s,
    - 41% shortening the time of being getting cold and lowering the temperature of the die while casting cycle,
    - increasing the maximum gradient of the temperature on the thickness of the die wall,
    - increasing the maximum density of the heat stream from $7{,}5*10^3$ to $9{,}2*10^3$ kW/m^2,
- for the research-production die:
    - increase of the temperature range in the „4” point - from 300 to 470 °C,
    - increase the range of the temperature changes velocity from -4 to 5 °C/s,
    - shortening the cycle of casting of car wheels from 340 to 230 second.

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