ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 8
Issue 3/2008

227 – 236

42/3

Water mist effect on heat transfer coefficient in cooling of casting die

R. Władysiak*
Department of Materials Engineering and Production Systems, Technical University of Łódź
Stefanowskiego 1/15 Street, 90-924 Łódź, Poland
* Corresponding author: E-mail address: ryszard.wladysiak@p.lodz.pl

Received 29.04.2008; accepted in revised form 05.05.2008

Abstract

This project is showing investigation results of heat transfer process between cast iron die and environment during cooling of die in the temperature range 600÷100 °C with compressed air, spray water and water mist streamed under pressure 0.35÷0.45 MPa in air jet 0.3÷0.4 MPa .
At the paper are shown results of cooling die's flat wall using open cooling system. The temperature gradient was presented at die's wall thickness and calculated thermal curve for cooling surface. The calculation results of heat transfer coefficient α were presented between die and researched cooling factors and also mathematical models of α coefficient depending on surface temperature. Revealed that coefficient α has the biggest value's range for die cooling with water mist under pressure 0.3/0.35 MPa.

Keywords: Innovative materials and casting technologies; Heat transfer coefficient; Cooling; Water mist; Casting die

1. Introduction

In Department of Material Technologies and Production Systems of Technical University in Lodz the investigation are being made on intensification process of heat receiving from die and control of crystallizations process and cast self-cooling.
Main element of investigated technology is application of water mist as a cooling factor in die's opened cooling system.

The base assumption of managing of cooling process is the fixing of air and water pressure and amount that let's to evaporate all water which is deliver to the hot surface of mold. It's mean that providing the die with the water is allowed over casting furnace. This process doesn't couse additional menace to safety of people and casting machines at the work stations. Besides the heat flux taking over is more efficient than the heat transfer coused by separately compressed air or airless water spray.

The essence of achiving fo high effectiveness with use of the water mist is taking the heat away as a result of droplets water evaporation on the cooling surface well ahead of convection and radiation heat transport methods.

Rightness of the thesis comes from comparing of the fizycal properties of air and water:

- specific heat of air: 2 020 J/(kg *K),
- specific heat of water: 4 190 J/(kg*K),
- heat of vaporization of water 2 257 000 J/kg.

It's mean that 1 kg of evaporated water on the cooled die's surface takes away the heat flux which is more about 50 times than flux cosed by 1 kg of air and 25 times in relation to the liquid water, on the assumption that the temeperature of cooling factors increases by 20°C. Besides it let to get cool the 25 kg of the casting die (ΔT=200 K).

The analyse of the subject [1] is showing following values of cooling performance in dependence of factor's kind:

– do 0.5 W/cm^2 with blow-in of air,
– do 100 W/cm^2 with water chanels.

Recent publications [2-5] describing heat transfer processes deliver following informations:

- heat transfer coefficient α of green mould – casting interface is at the beginning reaches the maksimum in 570 W/m^2K and next gradually falls to value 60 W/m^2K in time [2],
- heat transfer coefficient α in system: Al-Si alloy casting – casting die during cooling down naturally reaches the top in value 2.8 kW/m^2K and next decreases to 1 kW/m^2K in the first stage and after that is following down to zero [3],
- in high pressure casting of silumins between the casting steel die and silumin casting the α heat transfer coefficient takes the values from range form 50 to 65 kW/m^2K [4],
- heat transfer coefficient α between the surface of steel cartridge heater at temperature 250°C and spray water is equal from 87.2 to 97.6 kW/m^2K in dependance on spraying pressure of water and the temperature difference of spray water and cooled surface. [5].

At the work research findings were presented about the intensification of metal moulds cooling with using the water mist sprayed in stream of air compressed. Applied device producing and controlling the stream of the water mist they verified in production conditions during manufacturing of the wheels from Al-Si alloys [6-8].

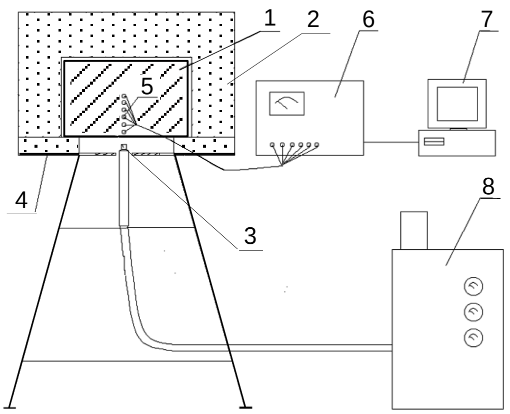


Fig. 1. Position for intensity research of cooling with water mist: 1 - research die, 2 – heat-insulating shield, 3 – nozzle of cooling system, 4 – stand, 5 – thermocouples, 6 – recorder of the temperature, 7 – PC, 8 – automatic cooling servo device

2. Experimental

Examinations were carried out on the laboratory position. 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.

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 stream of sprayed water and the starting cooling mist were shown in figure 3.

It follows from research of spraying water efficiency that the sprayer generate drops in a wide range from 28 to 438 μm of the Feret's diameter. Mean value is equal to 142 μm but its 95% confidence interval is +/- 18, 25μm. Histogram its structure is presented in figure 4.

It results from the tests presented in figure 5 that the increase of the water pressure causes reducing generated sizes of drops. Additionally, the pressure 0.08 MPa is appearing the maximum of the size of generated drops of the water mist is equal 177 μm.

On base of the mechanism analysis of drops and surface interaction [8] for farther research it’s used the water mist with pressure of water 0.05÷0.1 Mpa that let’s to get a lot of drops at the big size.

The stream of air compressed under 0.2÷0.6 MPa was used a medium transporting the drops and making them adequate kinetics. In figure 6 was presented the view of water mist stream flowing out from cylindrical nozzle under pressure 0.3/0.38 MPa.

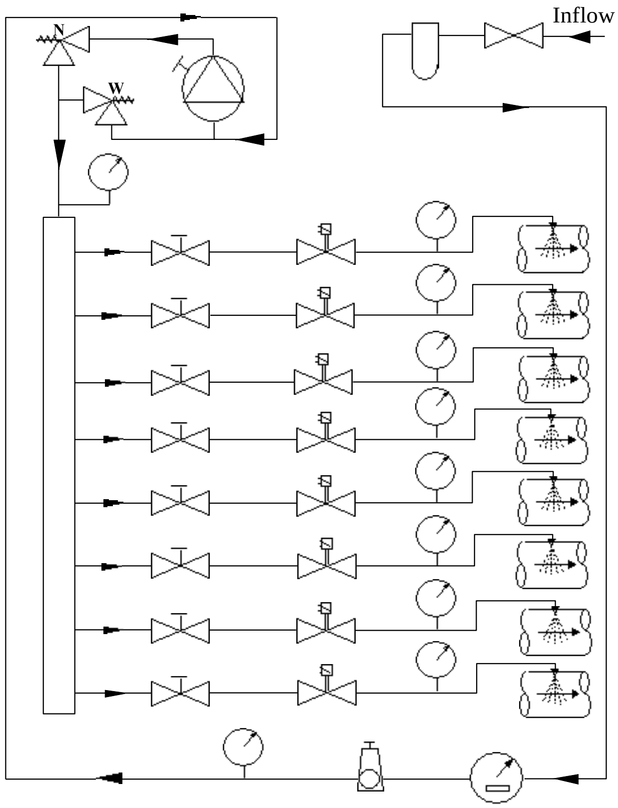


Fig. 2. Scheme of Automatic Cooling Servo device

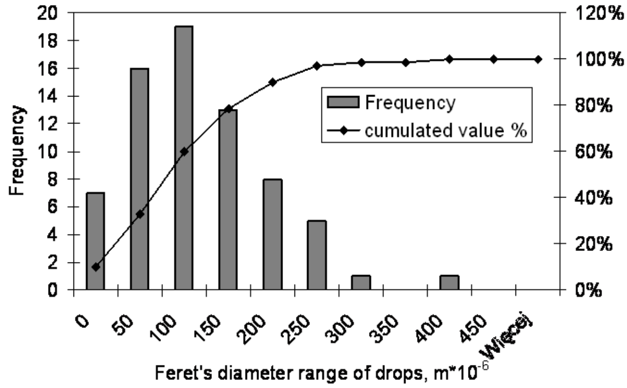


Fig. 4. Histogram of water mist stream image obtained for 0.25 MPa pressure

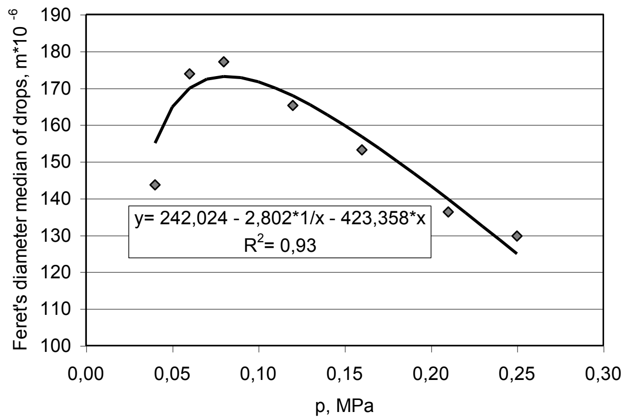


Fig. 5. Pressure effect on dimension water mist's drops

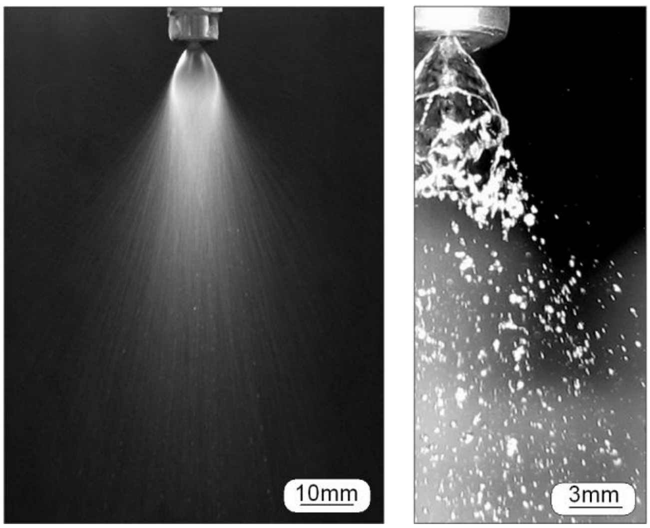


Fig. 3. Stream of sprayed water with use of designed rotary sprayer

Fig. 6. Stream of water mist under pressure 0.3/0.38 MPa cooling the die surface

3. Results

In this work there was examinated the distribution of temperature in selected points of probe mold when cooled by: air at 0.6 MPa pressure, water at 0.05 MPa pressure and a mixture of air at pressure between 0.3 and 0.4 MPa and water at 0.35-0.45 MPa.

In figures 7 to 10 there were presented the examination's results of temperature gradient at the surface and up to 48mm into the mold's structure in a temperature range of 100 degrees to 600.

The examination of die's cooling process with the use of compressed to 0.6 MPa air (fig.7) shows that in its early stage, between the 0.5 second and the 5th second, the total gradient approximates 10 °C, then increases and reaches a peak at 285 °C in the time between the 45th second and the 80th second. Finally the gradient gradually falls and in the 223rd second of cooling process amounts about 230 °C and in the 785th second - 80 °C.

The figure 8 presents the variation of the temperature gradient during cooling down with a water mist at 0.05 MPa pressure. Within cooling of the die's surface the temperature gradient rises up to 310 °C after 150 to 200 seconds. Then bottoms out and in the 270th second of cooling approximates 240 °C, while after 1052 seconds it is only 72 °C.

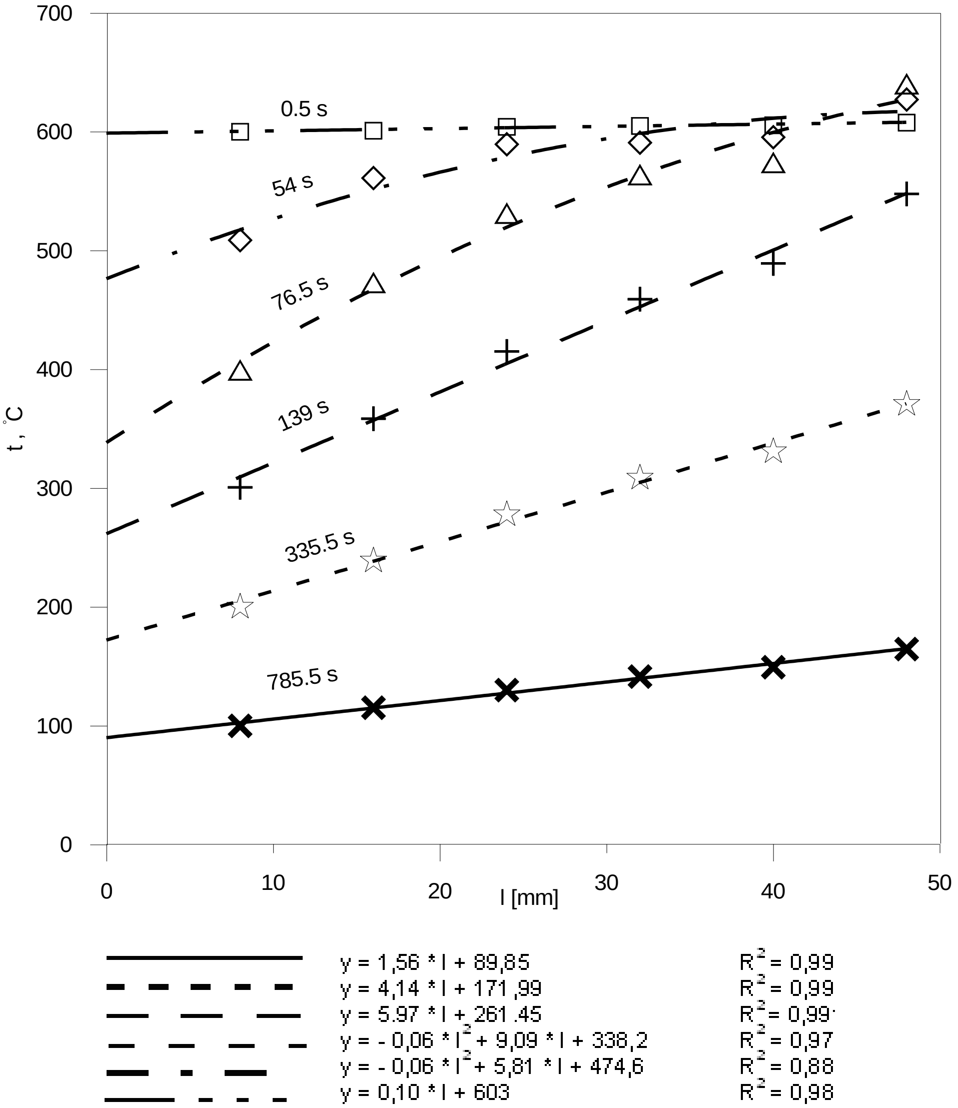


Fig. 7. Curves of temperature gradient in wall of die in direction perpendicular to surface cooled with air compressed to 0.6 MPa for different moments of cooling time

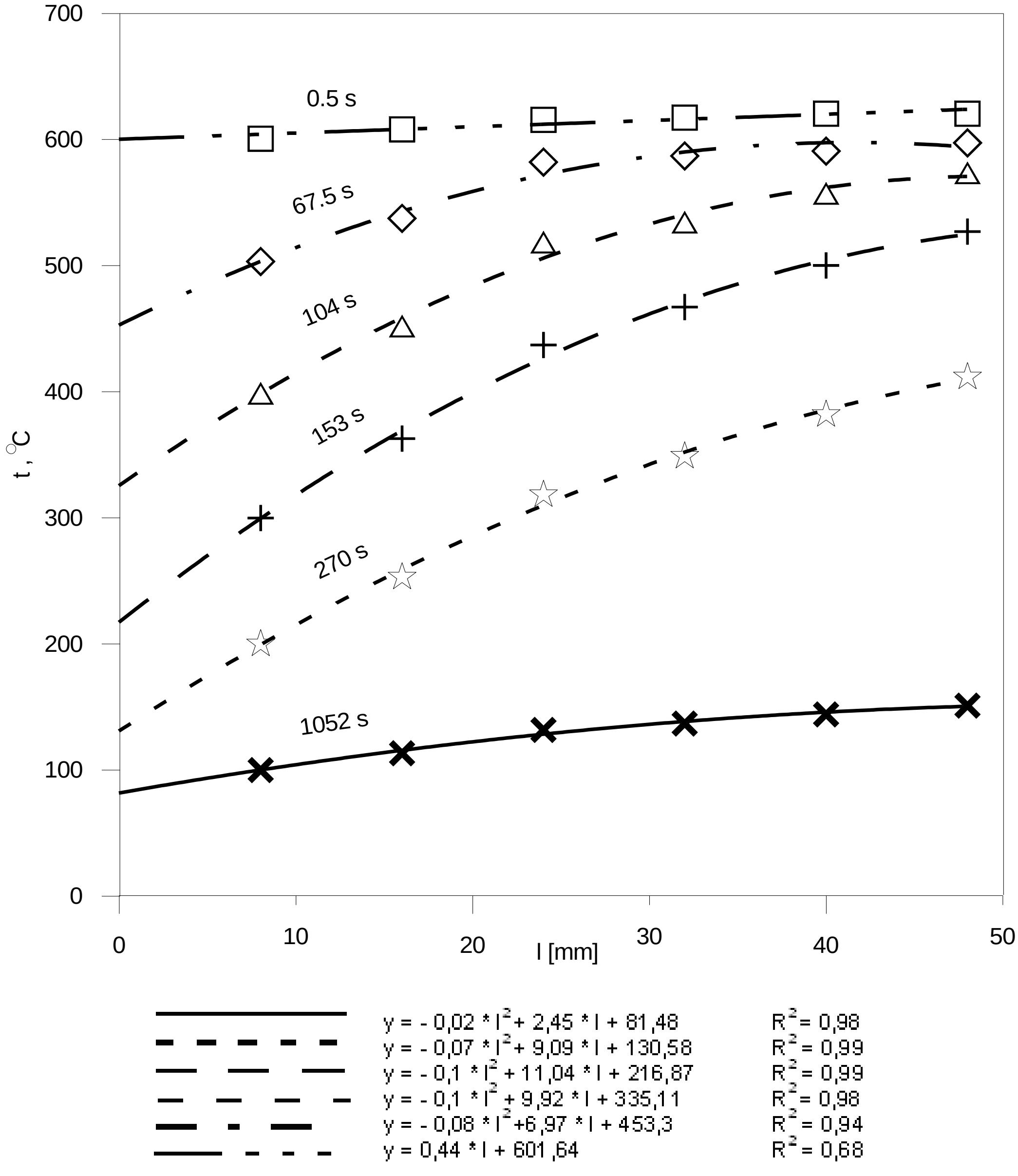


Fig. 8. Curves of temperature gradient in the wall of the die in direction perpendicular to the surface cooled with spray water under pressure 0.05 MPa for different moments of cooling time

In figures 9 and 10 there is shown the change of the temperature gradient when the mold was cooled with a water mist at a pressure of 0.3/0.35 MPa and 0.4/0.45 MPa. It comes off that in the early stage (0.5s) temperature of the specific structure's deepth amounts about 600 °C. Further cooling results in a rise of total temperature gradient, which then peaks in 50th to 78th second. Its value approximates accordingly: 495 degrees for 0.3/0.35 MPa - pressure water mist and 490 °C for a 0.4/0.45 MPa one. Lastly, the gradient steadily decreases with similar intensivity in both types of cooling process.

The comparison of the temperature gradient changes in the mold's structure that was cooled with water mist (fig. 9 and 10,) the one cooled with 0.6 MPa pressure air (fig. 7) and the one cooled by spraying with water (fig. 8) proves that the smallest gradient occures when the die casting is cooled with a compressed air and the highest when the die is cooled with a 0.3/0.35 MPa water mist.

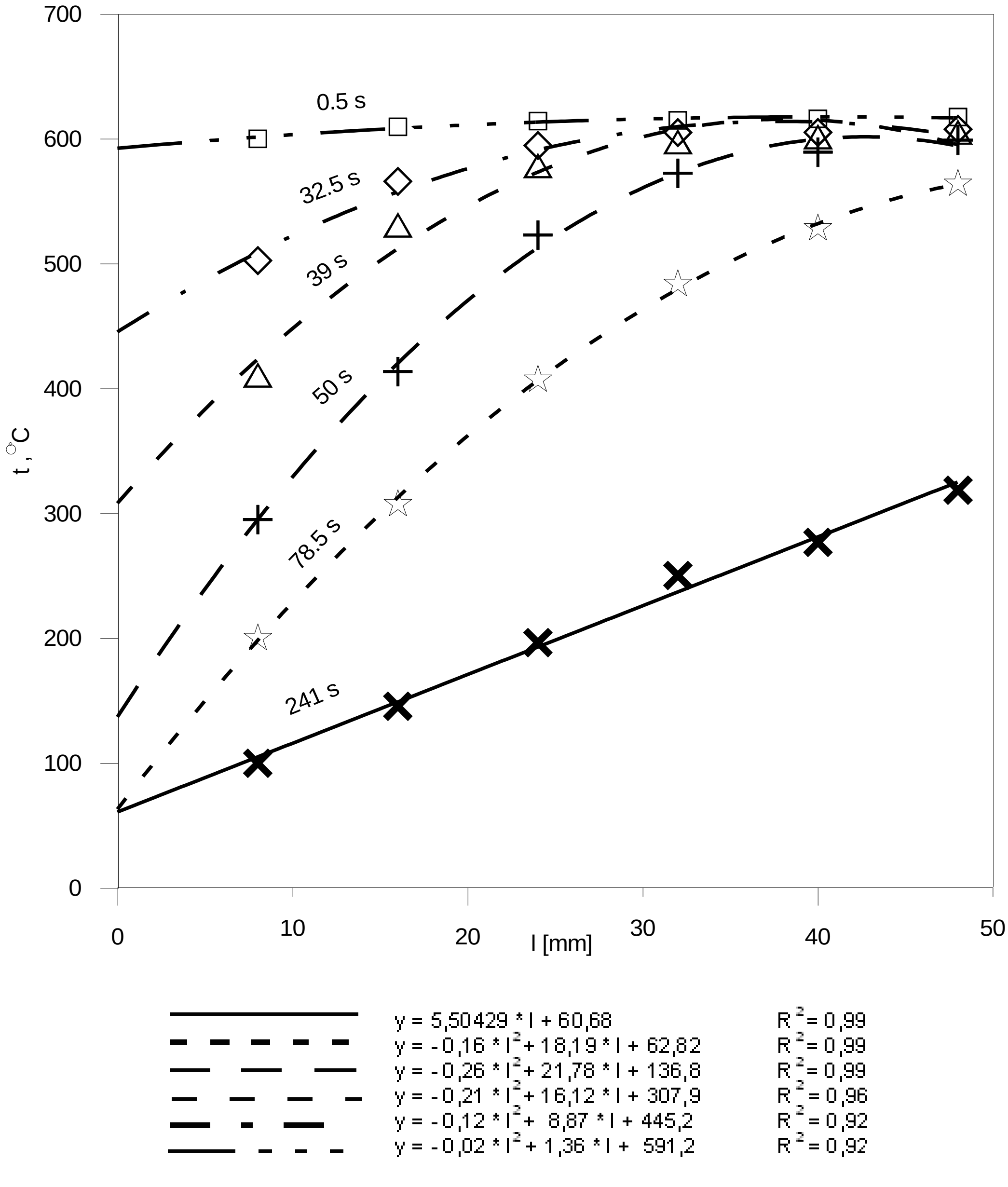


Fig. 9. Curves of temperature gradient in the wall of the die in direction perpendicular to the surface cooled with water mist under pressure 0.3/0.35 MPa for different moments of cooling time

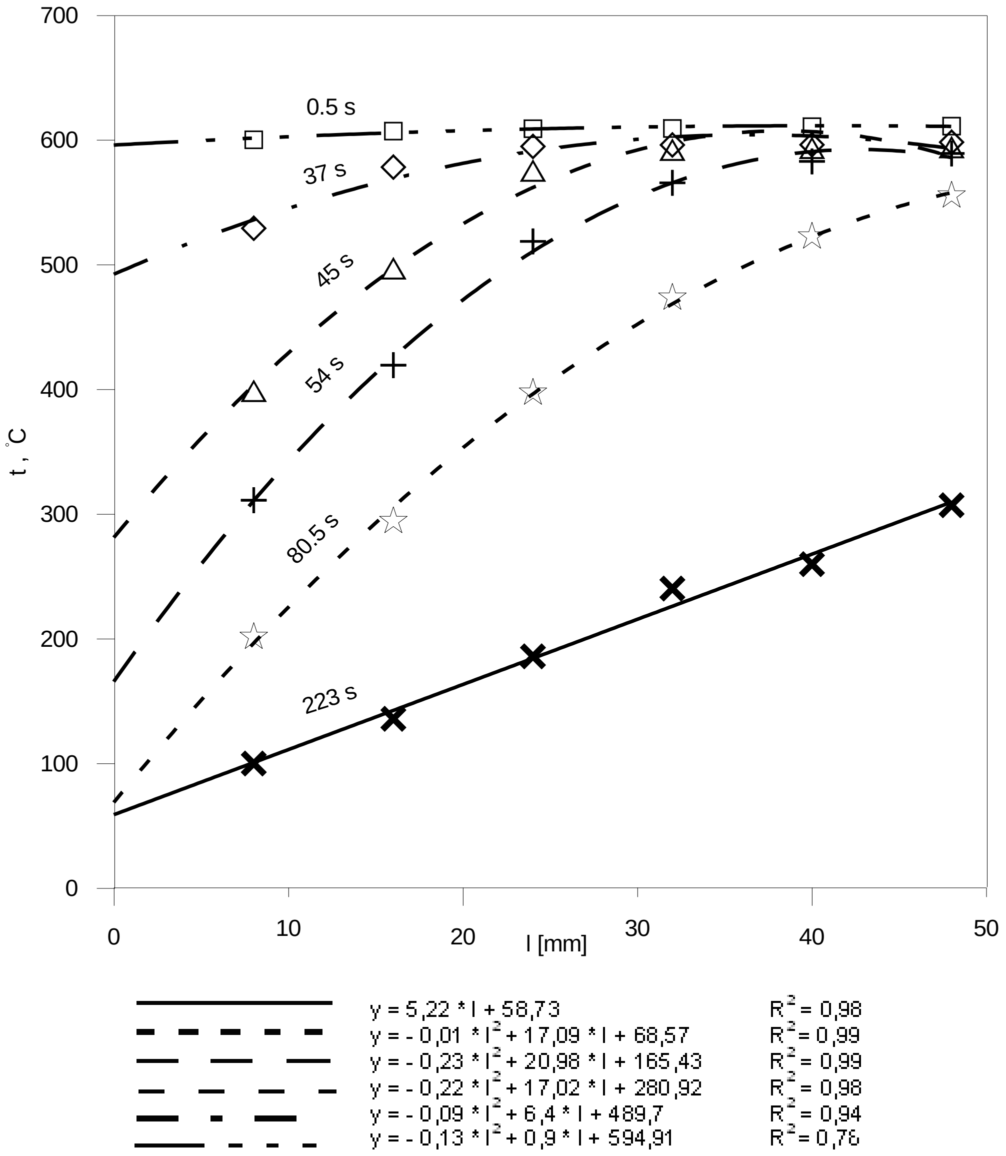


Fig. 10. Curves of temperature gradient in the wall of the die in direction perpendicular to the surface cooled with water mist under pressure 0.4/0.45 MPa for different moments of cooling time

Calculation of the heat transfer coefficient α was carried out accordingly to the law of conservation of energy, based on Fourier and Newton' law:

$$\alpha(T_{ot}-T_{pow}) = -\lambda\,(\partial T/\partial n)_{pow}$$

that is why: $\alpha = -\lambda\,(\partial T/\partial n)_{pow} * 1/(T_{ot}-T_{pow})$

where: - λ - thermal conductivity coefficient of die casting,

- $(\partial T/\partial n)_{pow}$ – temperature gradient for surface layer of die's wall thickness,
- $T_{ot}-T_{pow}$ – the difference between ambient and die's surface temperature.

The presented above outcome of the research of the relation of temperature gradient to mold's wall thickness and the regression equations helped to calculate the temperature on the surface of the casting die.

The figure 11 shows, for example, curves: thermals and derivative and the one calculated - presenting temperature on the mold's surface, all observed at 0.3/0.35 cooling process.

The results suggest that the temperature on the surface dramatically falls and after 96 seconds bottoms out at 45 °C, which is considered stable temperature in further cooling process.

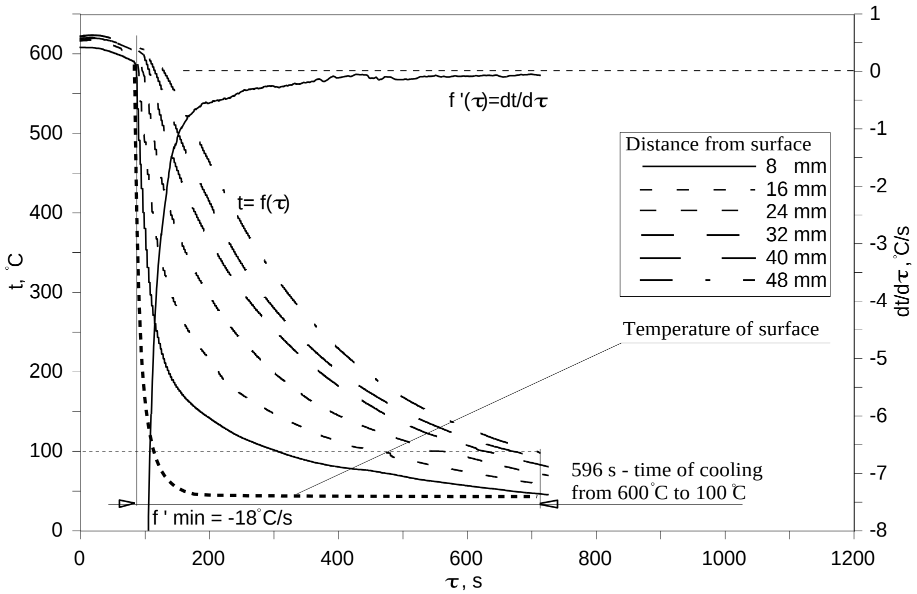
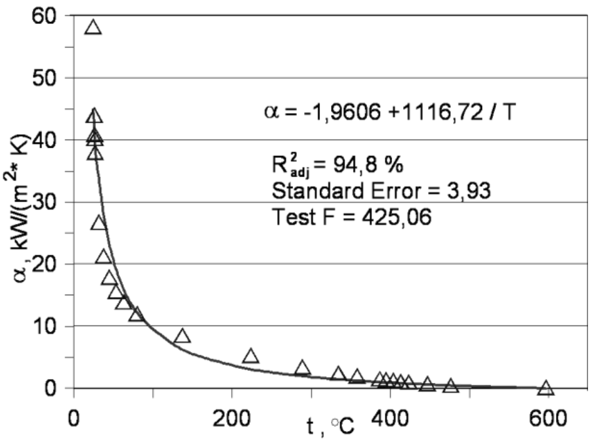


Fig. 11. Distribution of temperature in wall thickness of casting die during cooling with water mist under pressure 0.3/0.35 MPa and the curve fo calculated teperature of die's surface

In figure 12 there were presented the calculation results of and the regresion curve of heat transfer coefficient α between die's surface and 0.3/0.35 MPa water mist depending on the temperature of die's surface.

In figure 13 there were presented the comparison of values of coefficient α of heat transfered from cooled die's surface with forth factors: air compressed to 0.6 MPa, spray water and water mist generated with pressure 0.3/0.35 MPa and 0.4/0.45 MPa.



Rys. 12. Heat transfer coefficient between die's surface and water mist under pressure 0.3/0.35 MPa in temperature depending on the surface's temperature

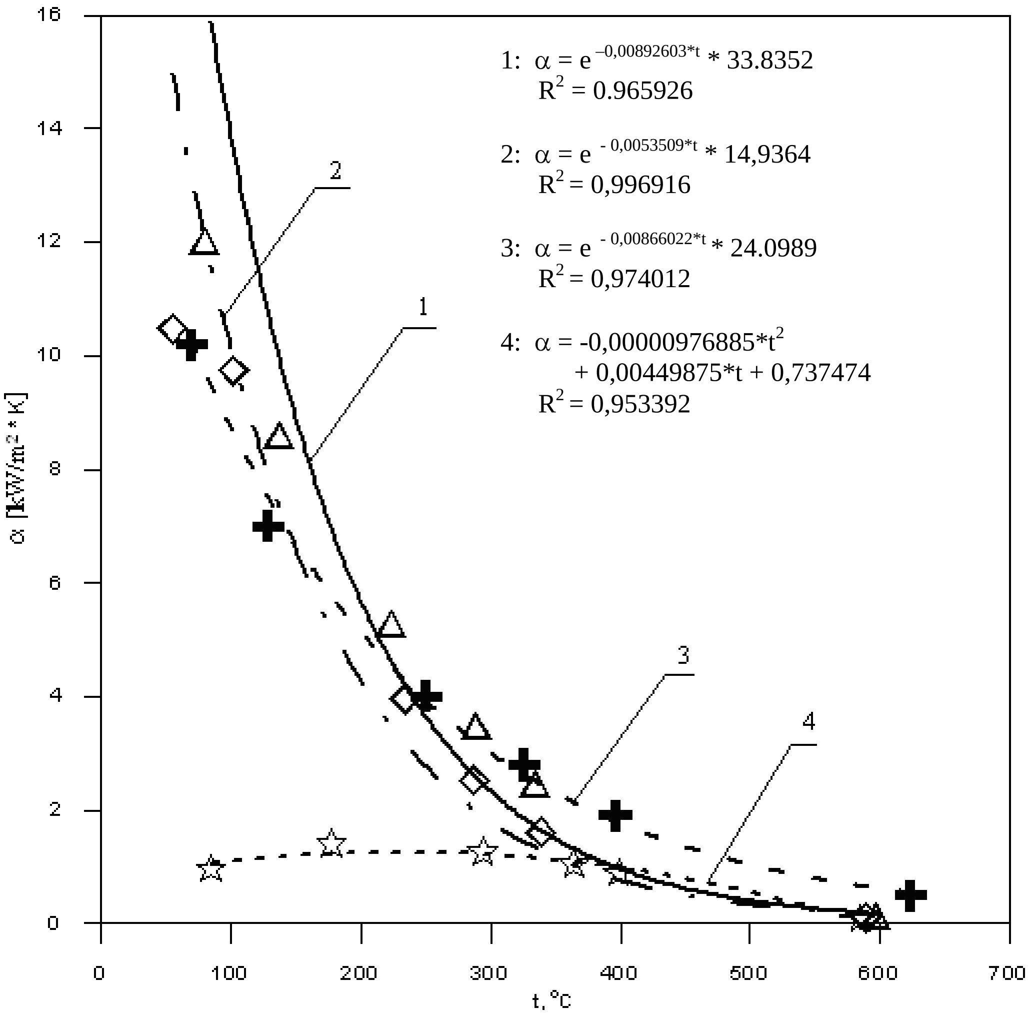


Fig. 13. The effect of cooling medium and the die's surface temperature on heat transfer coefficient α. 1- water mist 0.3/0.35 MPa, 2 – water mist 0.4/0.45 MPa, 3 – spray water 0.05 MPa, 4 - air compressed 0.6 MPa

It comes from the result that coefficient α is changing in wide range of values in depending on kind of cooling medium and of the temperature range of die's surface as well.

One can indicate on the chart the fiels in which occur significant changes of coefficient α. It can find the three ranges of temperature. At the beginning stage of cooling in temperature range 400÷600ºC the biggest values $\alpha \approx 2$ kW/(m^2*K) occur for die cooled with water sprayed under pressure 0.05 MPa. Cooling with water mist or with air compressed 0.6 MPa gives similar values.

It can write as

$$\alpha_{wody} > \alpha_{mgły\ w.} \approx \alpha_{spr.\ pow.} \text{ for } T \approx 400 \div 600°C.$$

The efficiency of heat transfer by water mist clearly icreases below of the temperature 400°C, especially water mist under pressure 0.3/0.35 MPa.

In the temperature range 280÷400 ºC the diference between α values for air compressed and other factors increases more and more.

Predominance of the water mist clearly is growing up in the temperature range 50–280 ºC and as the most effective cooling medium is appearing water mist under pressure 0.3/0.35 MPa in all range of the temperature.

$$\alpha_{\text{mgły w.0,3/0,35}} > \alpha_{\text{mgły w.0,4/0,45}} > \alpha_{\text{wody}} >> \alpha_{\text{spr. pow.}}$$
$$\text{for } T \approx 50 \div 280°C$$

The α coefficient value that was calculated with mathematical model for example in 100 °C is equal around 14 kW/m^2*K.
It comes from presented calculations of heat transfer coefficient that the biggest values and the range of changes has water mist under pressure 0.3/0.35 MPa. The range is much more in compering to both cooling air compressed 0.6 MPa and spray water under pressure 0.05 MPa.

4. Conclusions

The following conclusions result from described examinations:

- designed jets with rotating stream nozzles allow to effective spraying water in surrounding air,
- the smalest gradient of die's temperature is generating air compressed cooling and the biggest one by cooling with water mist under pressure 0.3/0.35 MPa,
- heat transfer coefficient α is changing in wide range of values in depending on both cooling medium and the temperature range of surface,
- gradient of temperature in wall thickness of casting die and heat transfer coefficient α can describe with high correlationed mathematical models.

References

[1] Z. Górny: Odlewanie kokilowe stopów metali nieżelaznych. WNT, Warszawa, 1975.

[2] M. Venkataramana, V. Vasudeva Rao, R .Ramgopal Varma, S. Sunderrajan: Instrumentation to measure heat transfer coefficient at the metal mold interface, Jol Instrument. Society of India 37, 2003, p.157-163.

[3] A. Hamasaiid, M. S. Dargusch, C. J. Davidson, S. Tovar, T. Loulou, F. Rezai-Aria, G. Dour: Effect of mold coating materials and thickness on heat transfer in permanent mold casting of aluminum alloys. Metallurgical and Materials Transactions A, Volume 38a, June 2007, p.1303-1316.

[4] G. Dour, M. Dargusch, C. Davidson, A. Nef: Development of a Non-intrusive Heat Transfer Coefficient Gauge and its Application to High Pressure Die Casting Effect of the Process Parameters, Journal of Materials Processing Technology 169, 2005, 223–233.

[5] L. Lin, R. Ponnappan: Heat transfer characteristics of spray cooling in a closed loop. International Journal of Heat and Mass Transfer 46, 2003, 3737–3746.

[6] R. Władysiak: Zastosowanie mgły wodnej w procesie odlewania kół samochodowych, Archiwum Odlewnictwa nr 22, 2006, 552-561.

[7] R. Władysiak: Intensyfikacja procesu odlewania kokilowego kół samochodowych - Conference proceedings „Polish Metallurgy in Years 2002-2006", Comitee of Metallurgy, 2006, 359-366.

[8] R. Władysiak: Assessment of Effectiveness of Water Mist Cooling of Casting Die, Archives of Foundry Engineering, 2007, vol. 7, Issue 4/2007, p.175-182.