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THE EXPERIMENTALLY-NUMERIC APPROACH TO CALCULATING OF HEAT TRANSFER PARAMETERS FOR QUENCH PROCESS IN OIL ISORAPID 277MH

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***Abstract**: In the article is presented the methodology of the experimentally-numeric approach to calculating of heat transfer parameters on quenching process in the oil Isorapid 277MH at temperatures from 40 up to 80 °C. Experimentally measured cooling curves from Wolfson test are the input for the numerical calculation of heat transfer coefficients. Combined heat transfer coefficients are calculated using the iteration inverse-numerical-correlation method. The quantification of temperature dependences of the combined heat transfer coefficients as functions of the probe surface temperatures are main results of the article. The derived thermal parameters: heat flux, cooling rates and hardening power value are presented also. Probe cooling process is solved as non-linear and transient numerical analysis by software ANSYS.*

***Key words:** quenching, oil, isorapid, simulation, ansys*

1. INTRODUCTION

Heat treatment is a multiparameters process. The selection of appropriate parameters predicts to achieve required behaviours of treated components. Prediction of treated components behaviour during a cooling process is possible only in the case if the boundary conditions of the process are defined. Before the numerical simulation of cooling process, the combined heat transfer coefficient (C-HTC) on the component surface should be defined quantitatively. The methodology of cooling effect quantification of unagitated oil Isorapid 277HM at temperature 40, 50, 60, 70, 80 °C is presented in the article.

2. EXPERIMENTAL METHOD AND MATERIALS

Isorapid 277HM is fast quenching oil for low, medium and high alloy steel as well as carburized steel. The Isorapid 277HM is quenching oil with very good evaporation stability. The typical oil property is rapid decay of the vapour blanket. The range of recommended working temperatures is from 50 °C to 80 °C. Kinematic viscosity coefficient has value 25.10-6 m2.s-1 for oil temperature 40 °C (*** 2010)

The experimental equipment consisted of electrical resistance furnace of LM 212.10 type, cylinder-shaped experimental probe, oil Isorapid 277HM, portable USB-based DAQ for thermocouples NI USB 9211 for digital record of measured temperatures, personal computer and pneumatically manipulator for probe moving from furnace in to oil. Geometrical and initial conditions of the experiment were based on the Wolfson's quenching test (Bodin at al., 2010). The diameter of the probe was 12.5 mm and its high 60 mm, Fig. 1. Before cooling, the probe was heated up to the initial temperature of 850 °C. The temperatures were measured by the encapsulated 304 SS thermocouple of K type with diameter of 1.5 mm located in the centre of the probe. Temperatures were recorded 5 times per second and set of measurement was repeated six times for constant oil temperature. Temperature measurement started from the moment when the centre of gravity of probe reached the oil level. The temperature records were statistically handled, Fig. 2, and consequently used for the determination of the cooling rate and the temperature dependence of combined heat transfer coefficient applying the inverse-numerical-correlation (INC) method (Alifanov, 1994).

3. THEORETICAL BACKROUND

Heat transfer from the cylinder shaped probe into cooling oil is the combination of radiation, boiling and free convection heat transfer. Transient temperature field of cooled probe is described by Fourier-Kirchhoff differential equation of heat conduction for cylindrical coordinate system (Incropera & Dewitt, 1996). Combined heat transfer coefficient $h_{\mathrm{comb}}(T_{\mathrm{s}})$ [W.m^{-2}.K^{-1}] was determined as the function of the probe surface temperature T_{s} [°C] for constant oil temperature T_{r} [°C]. The condition of equality of heat flux q_{ti} is valid on the probe surface in the time t_{i} [s] by formula

$$-\lambda(T)\,\mathrm{grad}T\Big|_{t_{\mathrm{i}}} = q_{t_{\mathrm{i}}} = h_{\mathrm{comb}}(T_{\mathrm{s}})\big[T_{\mathrm{s}}(t_{\mathrm{i}}) - T_{\mathrm{r}}\big]\ .\ [\mathrm{W.m^{-2}}] \quad (1)$$

For the thermal task is supposed that material of experimental probe (steel DIN 1.4841) has isotropic thermophysical properties and are temperature dependent; $\lambda(T)$ coefficient of heat conductivity [W.m^{-1}.K^{-1}], $\rho(T)$ density [kg.m^{-3}], $c(T)$ specific heat [J.kg^{-1}.K^{-1}], Table 1.

4. NUMERICAL SIMULATION

Engineering-scientific program code ANSYS was the interpretation program of numerical simulation. Geometrical model of the probe was the half part of the cylinder, Fig. 1.

Applied element was axisymmetric with linear base function and surface temperature behaviour. Calculation procedure was transient and nonlinear. Thermophysical material model of the probe material was obtained from experimental measurement laser flash diffusivity method, Table 1. The inverse heat conduction problem of heat transfer solving from the probe into the cooling oil was solved by FEM and evaluated by INC methods.

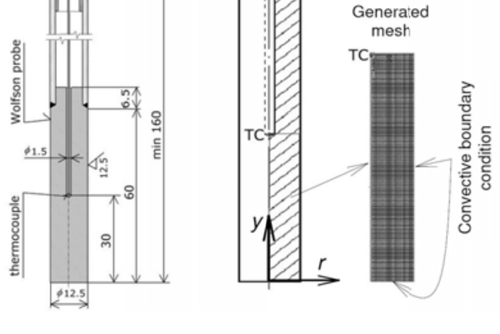

Fig. 1. Probe geometry and geometrical model with generated mesh (TC = location of the thermocouple)

T [°C]	0	200	400	600	700	900
λ [W.m^{-1}.K^{-1}]	13.5	16.8	20.0	23,2	24.8	27.1
c [J.kg^{-1}.K^{-1}]	474	512	535	569	581	600
ρ [kg.m^{-3}]	7880	7814	7731	7645	7601	7511

Tab. 1. Thermophysical properties model of austenitic stainless steel DIN 1.4841

Inverse-numeric-correlation method (INC) was proposed by author of this article and the INC method is applied to solution of direct inverse problems. Through the iterative INC method can find a result which it is very likely and useful for computer prediction of thermal treatment processes; temperature fields, stress-strain states, residual stresses, modelling of microstructural changes, etc. Task solution by the INC method must meet the following criteria: relative error for measured and calculated temperature in the *i*-time must be less than 1.0 %, relative error for cooling rates derived of measured and calculated temperature must be less than 5.0 % and the correlation coefficient between measured and calculated temperatures must be greater than 0.99.

5. RESULTS AND DISCUSSION

Time dependences of cooling curves and cooling rates at unagitated oil temperatures 40, 50, 60, 70 and 80 °C are shown in Fig. 2. For used oil temperatures was calculated the cooling rates: minimum 103 K.s^{-1} and maximum 107 K.s^{-1}.

Combined heat transfer coefficient dependences of vertical probe surface temperatures for unagitated oil are the main results and are shown in Fig. 3.

The vapor phase of cooling oil finishes at surface temperature which depends at oil temperature. With increasing of oil temperature, the heat transfer from the probe surface at the vapor phase increases

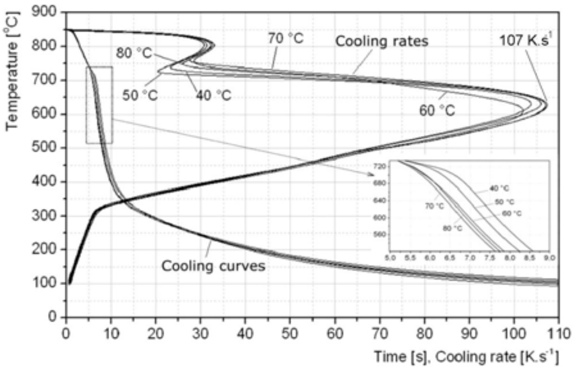

Fig. 2. Cooling curves and cooling rates for oil at temperatures 40, 50, 60, 70 and 80 °C

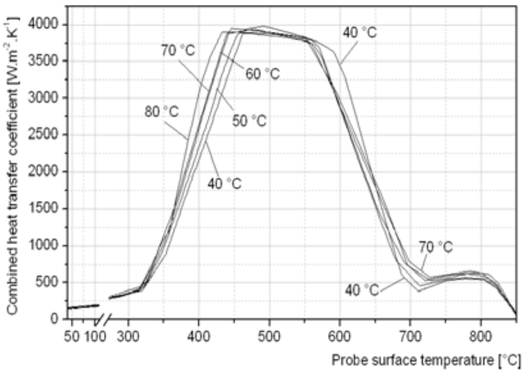

Fig. 3. Combined heat transfer coefficients as a function of surface temperature at chosen oil temperatures

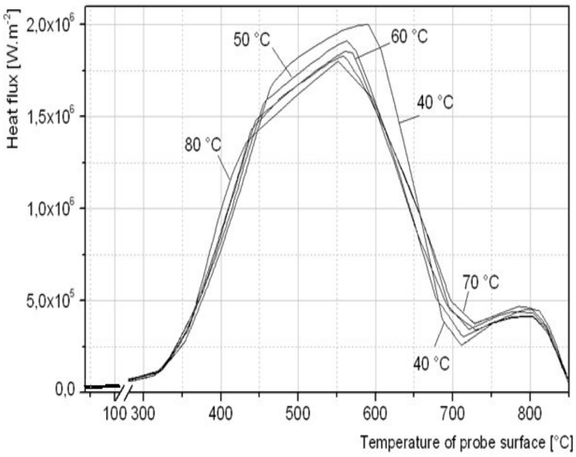

Fig. 4. Dependences of heat fluxes at probe surface temperature

The transition from the vapor phase to boiling phase is in the interval of surface temperature range 729 to 687 °C.If are not take account the oil temperatures 40 and 80 °C then the C-HTC curves are very close and are little depend at surface temperature. The boiling phase exists up to surface temperature 318 °C and heat transfer continues by free convection up to oil temperature. The all values of calculated C-HTC are close to 3910 W.m^{-2}.K^{-1} and are almost the same for used oil temperatures.

The heat flux dependences of the surface temperature are shown in Fig. 4. The maximum of heat flux is 2.0 MW.m^{-2} at probe surface temperature 591 °C using the oil temperature at 40 °C. Minimum of heat flux was calculated for oil temperature 80 °C (1.8 MW.m^{-2}) at probe surface temperature 552 °C.

6. CONCLUSIONS

The study of cooling characteristics confirmed that the oil Isorapid 277HM changes its characteristics principally in the cooling vapor phase process. The obtained results are useful relevant in two directions: 1) combined heat transfer coefficient is possible use as boundary condition of 3th kind and heat flux as boundary condition of 2nd kind in thermal transient analyses as the base for material behaviour by thermal treatment, 2) for heat treatment area value HP shows as a single value the hardening power of oils. For Isorapid 277HM at 70 °C was calculated the highest HP = 883.7. The Isorapid 277HM oil belongs then to a group of oils with high cooling ability.

7. ACKNOWLEDGEMENT

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