

A SIMPLY METHOD DETERMINATION DATA INDISPENSABLY FOR COMPUTER SIMULATION OF HARDENED

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SUMMARY

The paper presents the application of ColdCAST programme, which simulates thermal phenomena in the process of casting, for calculation of a hardness field in the hardened steel castings. The calculation is based on a function relationship between hardness and self-cooling kinetics $HRC=f(S)$ which in turn is based on the results from the modified Jominy end-quench test “Jominy – M”. Also the exemplary results of calculating the hardness field of hardened overhead crane wheels are presented.

1. INTRODUCTION

Integrated computer systems can design subsequent stages of a design basing on a final product geometry input. There is a trend now to design not only optimum treatment operations aiming at required size, shape and surface quality, but heat treatment technology aiming at optimization of the material selection and optimum mechanical properties of the product as well. We can say that a basic task for a constructor and a production engineer is to select an optimum material and to design an optimum heat treatment for a given element in order to reach required mechanical properties of the product.

Different kinds of computer programmes of CAMS and CAE type are very helpful in the material selection and the heat treatment technology design. Most programmes of CAE type [4], which aid to work out an optimum heat treatment technology, calculate predicted results of the heat treatment basing on mathematical models which result from

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CTPc diagrams. However, CTPc diagrams worked out for the same cast steel in different research centres with the use of different apparatus are so much different [6] that they cannot be used for determination of a model.

The model of calculating the results of steel castings hardening suggested by the authors of the paper is based on the results of a modified Jominy end-quench test. This test is easy to make and is neither time-consuming nor expensive; moreover, repeatability of results is very high.

2. JOMINY-M TEST

Modification of Jominy end-quench test commonly used for testing hardening capacity of medium-hardenable steel comprises in thermal insulation of the sample face and side surface; it is presented schematically in Fig.1. To determine self-cooling kinetics of the sample hardened by Jominy-M method the sample cooling curves are recorded along the sample axis in three different distances from the face during the test. Temperature is measured with thermocouples connected with a converter of CRYSTALDIGRAPH type and a computer recording the measurement results. Such a modified Jominy test gives typical hardenability curves and three recorded sample cooling curves – Fig.1. Basing on these results we can determine a hardness function dependence on a cooling kinetics $HRC=f(S)$ for a tested material according to the algorithm presented in a block diagram in Fig.2.

3. DETERMINATION OF $HRC=f(S)$ FUNCTION BASING ON JOMINY - M TEST RESULTS

3.1. Thermal and physical properties determination

The first and basic stage of determining the dependence of hardness on cooling kinetics for a given cast steel is a determination its thermal and physical properties (thermal conductivity, specific heat, density, transformation point and spectral heat of transformation) necessary to determine a secant $S=AB/BC$ [$^{\circ}C/s$] and a thermal simulation of hardening an element of any geometry. It can be done basing on so called converse problem. The Jominy-M test (one way heat flow up to 80 cm from the face) enables to apply one-dimension model [5], which considerably shortens the time and simplifies the determination of thermal and physical data of the material basing on the converse problem.

A one-dimension model applied by the authors to calculation of a converse problem is presented in Fig.3. A finite difference method was used for the calculations, and a difference net was designed on the basis of a preliminary computer simulation of the temperature field for a full Jominy-M test.

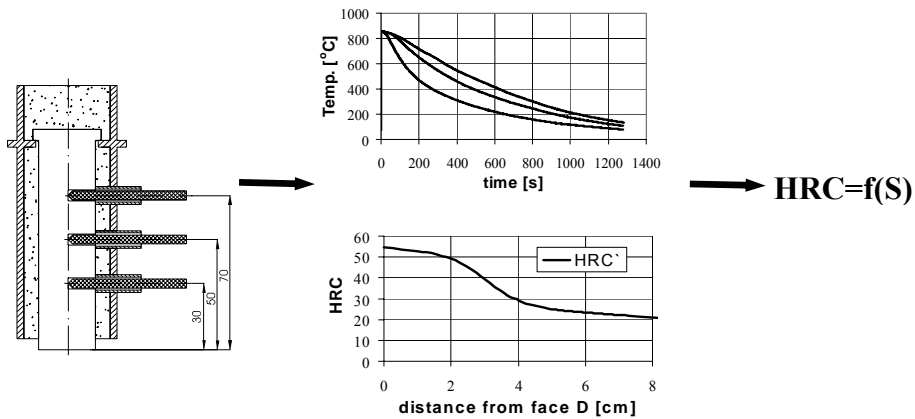


Fig.1 Application of modified Jominy test for determination of $HRC=f(S)$ dependence
 Rys. 1. Zastosowanie zmodyfikowanej próby Jominy do wyznaczenia zależności $HRC=f(S)$

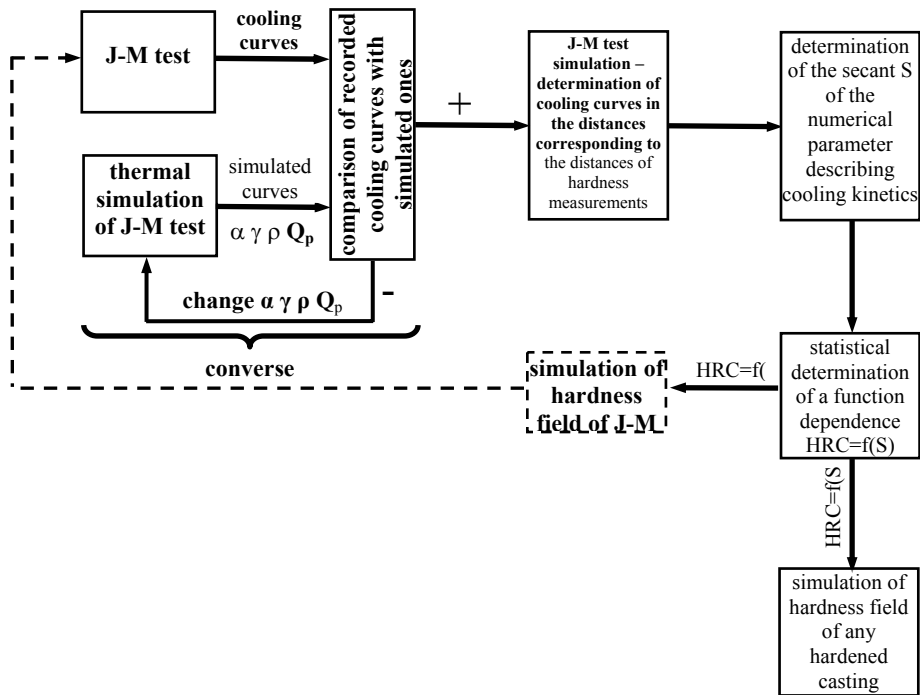


Fig.2 Algorithm for determination of $HRC=f(S)$ function basing on Jominy-M test
 Rys. 2. Algorytm wyznaczenia funkcji $HRC=f(S)$ w oparciu o próbę Jominy-M

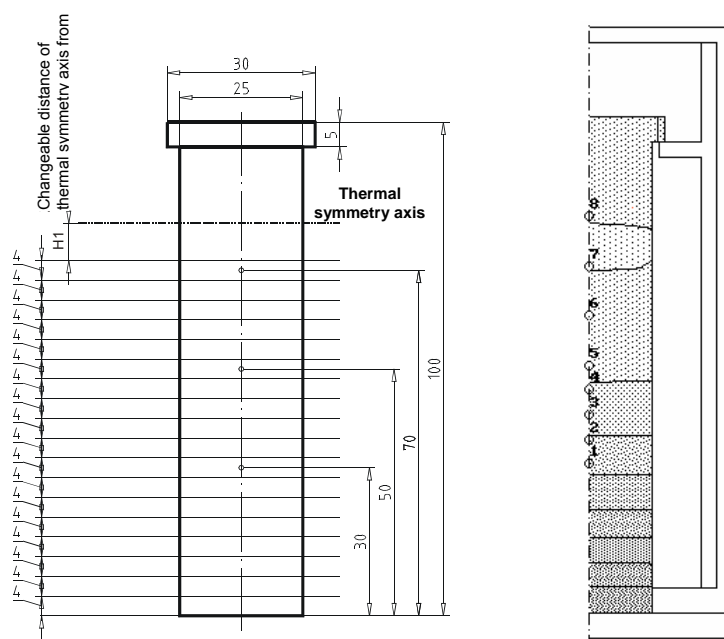


Fig.3. One-dimension model difference net
Rys 3. Jednowymiarowa siatka różnicowa

A difference net constant scale $h_1=4$ [mm] was applied up to the distance of 72 [mm] from the surface for which a constant temperature 10°C and a coefficient of giving up the heat α suitable for the conditions for water contact were set.

A possibility of changing the size of the difference net end element was assumed which meant changing the distance of thermal symmetry axis from the surface being cooled. It was necessary because the distance from Jominy-M sample face, for which the thermal conditions are similar to unidirectional heat flow, depends on the cast steel chemical composition, i.e. on thermal and physical properties of the material.

A finite difference method is not only one of the most accurate methods available applied to calculation of heat flow, but it is a method which makes use of a mathematical model in a direct form, so calculations performed according to this method do not require numerical method application. In such a simple case as a one-dimension model of heat flow the calculations can be made with the use of any mathematical computer programme or spread sheet. The authors used one of the most common spread sheets.

The user's interface improvised in the programme has been presented in Fig.4 together with the calculation results (determined thermal and physical parameters) for L35GSM cast steel.

If the user changes the values λ , ρ , C_p , sets the temperature of transformation beginning and end, and the value of the heat releasing during the transformations, he can obtain during the subsequent iterations an exact overlaying of the curves recorded and the curves resulted from the one-dimension model solution for the set thermal and physical properties. The course of the curves recorded and calculated after each change of thermal and physical data is presented on the biggest diagram. On the four smaller diagrams there are presented thermal and physical data in a temperature function set at the present moment for the calculations.

There is not enough information in literature about thermal and physical properties of iron alloys and their change in the temperature function is hardly ever discussed. This change is usually linear to the transformation temperature at which the change of this dependence takes place. Literature data can only be used for calculating the heat flow of a small kinetics. Under the specific hardening conditions of Jominy-M test thermal and physical properties of the material used for calculations depend not only on the temperature, but on the distance from the surface being cooled as well, because when the distances vary different structures are formed in a short time after starting the cooling; and it is well known that different structures have different thermal and physical properties.

That is why the authors simplified the mathematical model describing the change of thermal and physical properties in a temperature function and assumed their linear variability, which in the temperature range 20 – 1000 is not a big error.

With application of these data a thermal simulation of Jominy-M test can be realised by determining the sample cooling curves along its axis in the distances from its face corresponding to the distances in hardness measurements.

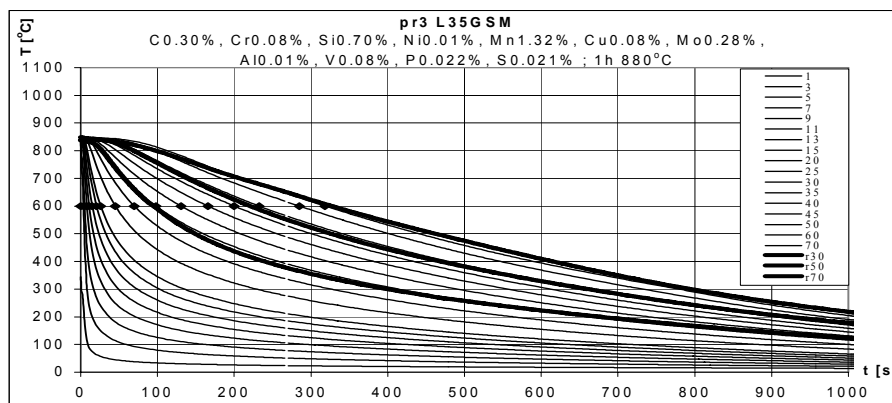


Fig.5 Comparison of cooling curves recorded with cooling curves calculated for the full Jominy-M test in ColdCAST programme with the use of thermal and physical data determined in a converse problem for L35GSM cast steel.

Rys. 5 Porównanie krzywych stygnięcia zarejestrowanych z obliczonymi dla pełnej próby Jominy-M w programie ColdCAST z wykorzystaniem danych termofizycznych wyznaczonych w zadaniu odwrotnym dla staliwa L35GSM

		staliwo L35GSM - pr3			
T_w	10 const.				
p	$7800 f(T)=aT+b$	$a=-0.02$	$b=7800$		
λ	$24 f(T)=aT+b$	$a=0.003$	$b=24$		
C_p	$660 f(T)=aT+b$	$a=0.01$	$b=660$		
α	1500 const.				
h_1	0.004 Const.	$h_1=0.007$	distance of symmetry heat axis from face	79 [mm]	
time step	0.4 idem				
T_{pr}	845 idem				
$Q_{trans.}$	$60000 f(T)$	$T_p=700$	$T_k=300$	$Q_{trans.}=150$	$Q_t=60000$

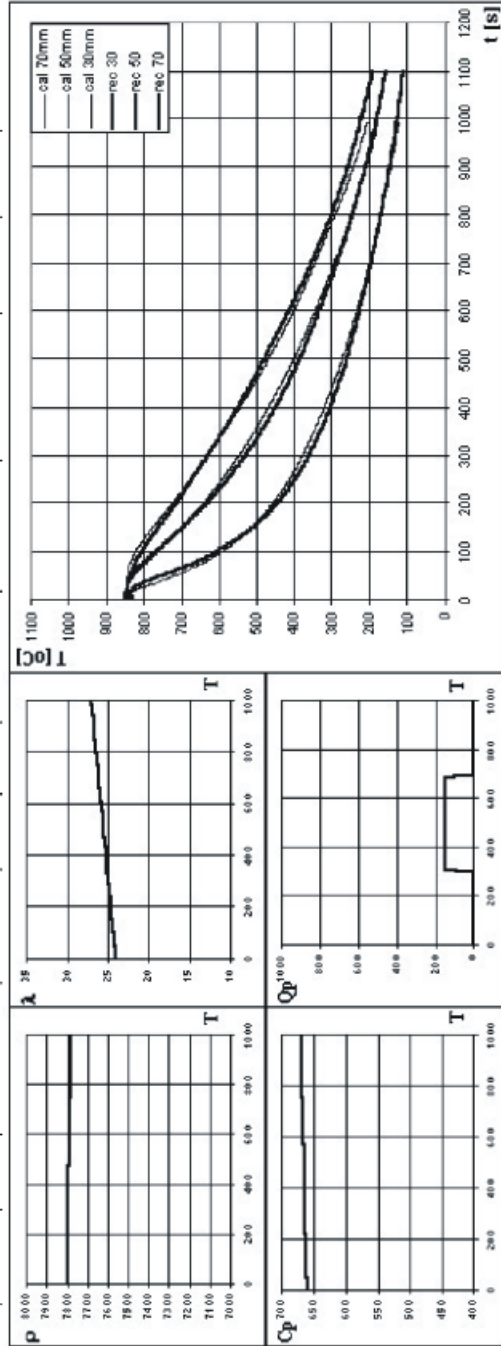


Fig.4 Thermal and physical properties of L35GSM cast steel determined for one-dimension model in a converse problem
 Rys.4 Własności termofizyczne staliwo L35GSM wyznaczone w zadaniu odwrotnym dla jednowymiarowego modelu

3.2. Secant S determination

Next stage is to calculate the secant S, Fig.6, at temperature 600°C for each simulated cooling curve in Jominy-M test. This parameter is a unique numerical index of the sample cooling kinetics in an appropriate distance from its face.

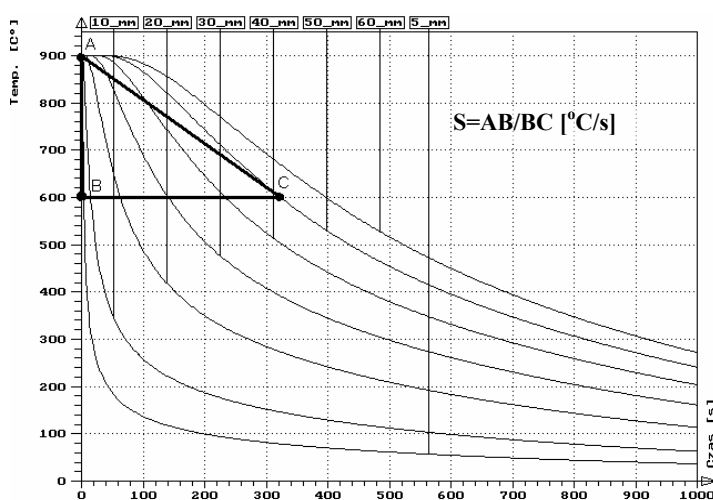


Fig.6 Geometrical determination of secant S
Rys.6. Geometryczne wyznaczenie siecznej S

3.3. Form and parameters of $HRC=f(S)$ function

The last stage of $HFC=f(S)$ function determination is to determine its form and parameters. The best form of the function, according to the authors, is a dependence below (1), and its parameters $B1...B3$ are determined from the S secant set and hardness measurement results (hardenability curves) by a stepwise regression method.

$$HRC=B0+B1 \cdot S+B2 \cdot S^2+B3 \cdot \log(S) \quad (1)$$

Statistical parameters for function parameters determination are relatively high, which means a correct selection of its form, and a good correlation between the hardness and the secant S means that temperature 600°C is optimum for the geometrical determination of a cooling kinetics index based on simulation cooling curves.

Fig.7 presents the values of $B0..B3$ parameters of the function (1) determined by the above described method for L35GSM cast steel. Also a hardenability curve of this cast steel basing on the determined function was calculated and compared to a measurement hardenability curve. The courses of two curves are very similar; some differences

between them result from necessary simplifications introduced into the method of determining the function of hardness dependence on cooling kinetics.

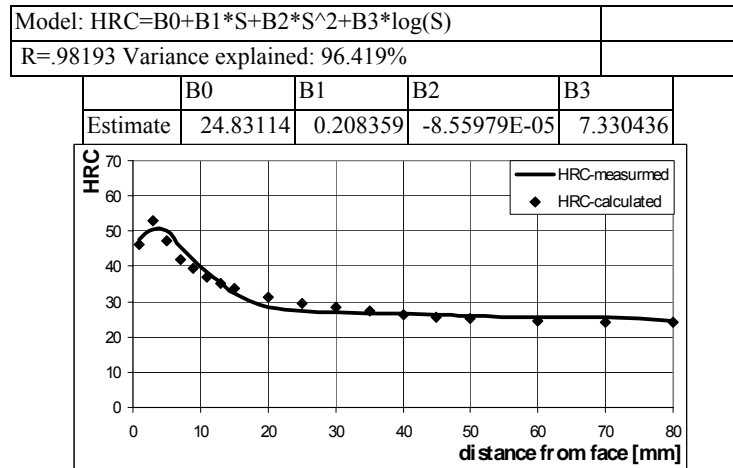


Fig.7 Comparison of measurement hardenability curve and calculated for L35GSM cast steel hardenability curve

Rys.7 Porównanie krzywej hartowności staliwa L35GSM obliczonej z zmierzoną

It can be said that although some necessary simplifications were introduced into the method the results of Jominy-M test correspond to the calculation results to a high degree. Thus, the method worked out by the authors can be successfully applied to generate the data necessary for simulation of a hardness field in the hardened elements by means of ColdCAST programme. This programme can be applied not only to designing casting optimum technologies, but to working out heat treatment technologies as far as required distribution of hardness on a given element section is concerned, particularly for thick-wall steel castings with a complicated geometry.

The described below simulation of hardness field of overhead crane wheel rim hardened according to two technologies may be an example of application of the method and of ColdCAST programme.

4. SIMULATION OF HARDNESS FIELD OF HARDENED OVERHEAD CRANE WHEELS

By applying for a given cast iron the function $HRC=f(S)$ described above and a simulation programme ColdCAST adopted for this purpose we can simulate a hardness penetration pattern after hardening on the section of element of any geometry and hardened according to any technology. To do this we have to input the thermal and physical data and parameters of $HRC=f(S)$ function to a file with the data for simulation calculations and to input a geometry of the treated element and to assume an

appropriate hardening technology. Figures 8 and 9 present the results of simulation of overhead crane wheels hardness field, the wheels being hardened according to two different technologies.

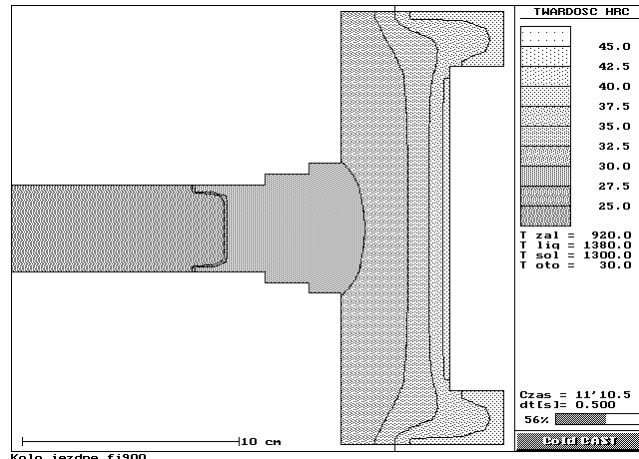


Fig.8 Hardness penetration pattern on the section of overhead crane wheel rim hardened by immersion in water on 1/5 circumference of the turning wheel

Rys. 8. Rozkład twardości na przekroju wieńca koła suwnicy hartowanego poprzez zanurzenie w wodzie na 1/5 obwodu obracającego się koła

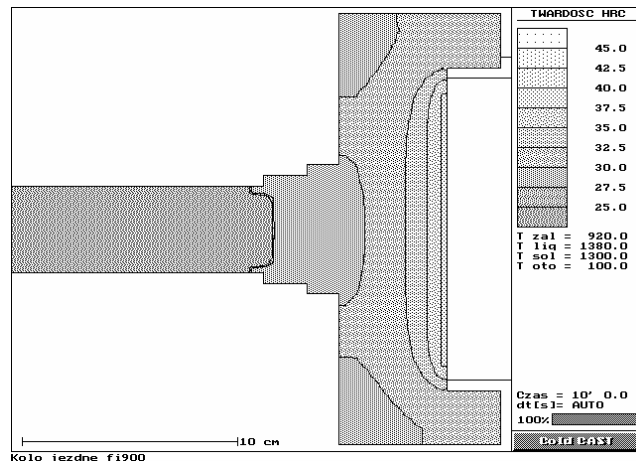


Fig.9 Hardness penetration pattern on the section of overhead crane wheel rim hardened by water spray on 1/3 circumference of the turning wheel

Rys. 9. Rozkład twardości na przekroju wieńca koła suwnicy hartowanego poprzez natrysk wodny na 1/3 obwodu obracającego się koła

5. SUMMARY

Hardness of overhead crane hardened wheels calculated from $HRC=f(S)$ function was different from hardness of the wheels hardened in industrial conditions maximum of 3HRC. This value is a permissible error in a classical Jominy test and makes this model very accurate. Simple and relatively cheap Jominy-M test is a perfect tool to generate the data necessary or a computer simulation of hardened steel casting hardness field.

The simulation programme ColdCAST together with Jominy-M test are very helpful in casting technology design as well as heat treatment technology.

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PROSTA METODA WYZNACZANIA DANYCH NIEZBĘDNYCH DO KOMPUTEROWEJ SYMULACJI HARTOWANIA

STRESZCZENIE

W artykule przedstawiono zastosowanie programu ColdCAST, symulującego zjawiska cieplne w procesie odlewania, do obliczeń pola twardości hartowanych odlewów staliwnych. Program dokonuje obliczeń na podstawie funkcyjnej zależności twardości od kinetyki stygnięcia $HRC=f(S)$, którą wyznacza się w oparciu o wyniki zmodyfikowanej próby Jominy. Przedstawiono także przykładowe wyniki obliczeń pola twardości hartowanych kół jezdnych suwnicy.

Reviewed by prof. Stanisław Pietrowski