

Computer Hardness Prediction of Steel after Hardening, with a Portable Quench Tester

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Abstract: - In the paper described useful computer program which calculate hardness distribution on the round bar cross-section of the quenched bar. In the program used J.L. Lamont and W. Craft method for hardness prediction. Presented program cooperated with portable tester of quenchants. The software of tester quenchants enable determine a cooling rate for given quenching fluid in laboratory conditions according to ISO 9950 and in production quenching tank. This cooling rate is determined by Grossmann Number (H [1/in]) which is characteristic for given quenching fluid in the real production tank. A Grossmann Number generated by tester software is it used in discussed program. This situation entitle to assertion that calculated hardness distribution is very near a hardness which will be obtained in real quench tank. It is assumption that such a computer program will be useful in selection of quenchants for given items.

Key-Words: - Heat Treatment, Hardness prediction, Hardenability, Quench tester

1 Introduction

Heat treatment processes for steel, connected with hardening, involve not less than 60% of the overall heat treated loads. These are processes which are decisive to the final service properties of products. The number quoted here should be regarded rather as the minimum. It speaks about the importance of problems related to hardening in the industry, both in the sense of quality and economics.

Research work in the field of quenching of steel, carried out over the past few decades has at least created a window through which it is possible to see what goes on inside that "black hole" [1].

In industrial practice there is a need for an efficient tool which would enable fast and as close as possible to correct answers to the following questions:

What will the hardness profile be in the quenched component?

Which of the available quenching media fulfill the set requirements?

What grade of steel to select in order to obtain the expected mechanical properties in the given production environment?

This paper presents the development of software for computer simulation of hardness distribution in the quenched round bar cross-section which in a sense fulfills the above formulated needs. It is based on both research carried out much earlier, as well as very contemporary investigations.

2 Concept

The possibility of utilization of classical works [2,3] in order to produce an efficient tool for predicting hardness of quenched objects (bar, plate) has come into existence as the result of research [4,5,6] which enabled the calculation of the quench severity factor H [1/in] (Grossmann's number) on the basis of testing of quenchants (Fig.1) in accordance with ISO 9950. Computer software of such a quenchant tester [7] calculates Grossmann's number for each tested quenching medium according to formula [6]:

$$H = 0.002802 \cdot v^{1.201} \cdot \exp(0.1857 \cdot 10^{-7} \cdot v^{2.846}) \quad (1)$$

where:

H – Grossmann's number [1/in],

v – cooling rate [$^{\circ}\text{F}/\text{s}$], at 1300 $^{\circ}\text{F}$ (705 $^{\circ}\text{C}$).

Quench severity (Grossmann's number H [1/in]) in any given quench tank may be determined with the help of the portable quench tester [7]. In accordance with the above quoted standard, for testing the quenching medium's properties a $\frac{1}{2}$ " ($\varnothing=12.7$ mm) probe, made of 304 stainless steel should be used [8].

The hardness profile on the cross-section of the hardened rod may be determined using the method developed by W. Craft and J. L. Lamont [3]. This method is widely used and is based on a set of eleven plots, each of which enables the determination of hardness at a given point on the cross-section of the hardened rod. The hardness on these plots is expressed as a function of distance from the end of a Jominy specimen. Each plot represents the hardness of points on

the cross section of rods of diameter $D=2R$ at a point expressed by the $\rho=r/R$ ratio. The value of ρ varies from $\rho=0$ (center) to $\rho=1$ (surface). The individual plots (example: Fig.2) enable the determination of hardness obtained at a given point on the cross section (ρ) of the object with a diameter D , hardened in a quenching medium D having a quench severity of H .



Fig. 1. Portable quenching media tester type OGJ-01, at a laboratory testing stand

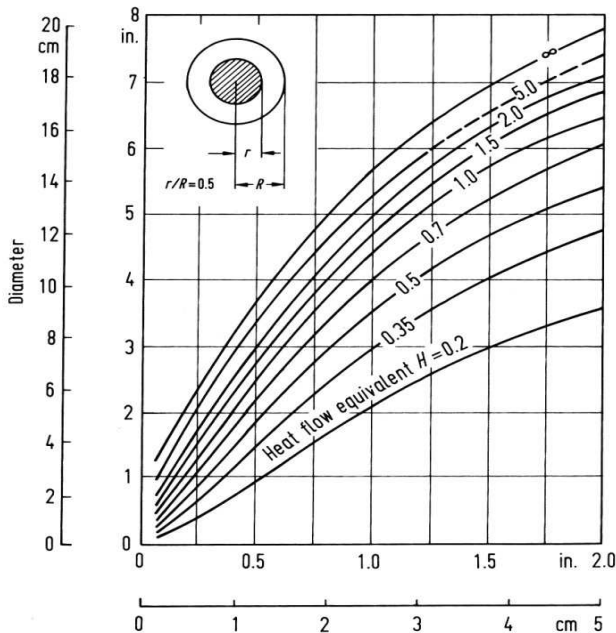


Fig.2 Example of a Crafts-Lamont diagram for radius ratio $r/R=0.5$; relationship between distance x from the quenched end of Jominy specimen and component diameter D for different H values

Different quench severities are portrayed on this plot by a set of curves representing different quenching media, characterized by values of H varying from $H=0.2$ to $H=5$. For computational purposes of the programme computer simulation, each of the eleven curves is approximated by function (2):

$$X(H, D)_\rho = a(H) \cdot D^3 + b(H) \cdot D^2 + c(H) \cdot D + d \quad (2)$$

where:

$X(H, D)_\rho$ – distance from the end face of the Jominy specimen for the given steel, corresponding to the

hardness of that point on the cross section of the rod of diameter D , at a distance ρ from the center, hardened in a quenching medium of quench severity H , as measured on the portable quenchant tester [6,7].

The equation (2) allows the calculation of hardness distribution in the cross section of a rod hardened in a quench tank with a medium for which the quench severity (H) has been measured. The hardness, expressed in HRC, can be determined based on the $X(H, D)_\rho$ value, using standard hardenability bands. Utilizing research works [9,10], which enable the calculation of hardenability curves according to Jominy, based on the chemical composition of the steel, as well as grain size, it is possible to calculate the hardness at the given point on the rod cross section, which corresponds to a given distance from the end face on the Jominy specimen. The following formula (3), proposed by Just [9,10] has been put together:

$$JHRC = (95 \cdot \sqrt{c}) - (0.00276 \cdot E^2 \cdot \sqrt{c}) - (12.28 \cdot \sqrt{E}) + (0.898 \cdot E) - (0.81 \cdot z) - 13 + St \quad (3)$$

where:

x – distance from end face on the Jominy specimen,

c – carbon content [%C],

$St = (20Cr + 38Mo + 14Mn + 5.5Ni + 6.1Si + 39V + 96P)$,

Cr, Mo, Mn, Ni, Si, V, P – alloying element content in wt.%,

z – ASTM grain size.

The above formulas (1,2,3) enable calculation of the hardness distribution on the cross section of a cylindrical rod, hardened in a quench tank with a medium for which the quench severity H (Grossmann's number) has been determined. Calculation of the hardenability curve according to formula (3) is recommended for those cases where the chemical composition of the steel is known. In those cases where the steel grade is known and for which standard hardenability bands are known, the program allows the possibility of interactive utilization of these hardenability bands. The obtained hardness profile is, in this case, a distribution curve within which the hardness of the quenched object should be found.

3 Computer Program

The software developed for computer aided prediction of hardness, when launched, can be interfaced on a screen, as shown in Fig. 3 [11].

The working screen is divided into four fields. Field "A" is used for entering basic data, such as the diameter of the rod (D) and the quench severity (H) of a given quench tank, as determined by the quenchant tester [12]. Field "B" changes, depending on the selected option, of which there are two. Selection of Option 1 (hardenability band) causes a "List box" to appear in field "B", from

which the grade of the hardened steel is selected. After clicking on the List Box and selecting the desired steel grade, the Jominy hardenability band appears in the “D” field (Fig. 4).

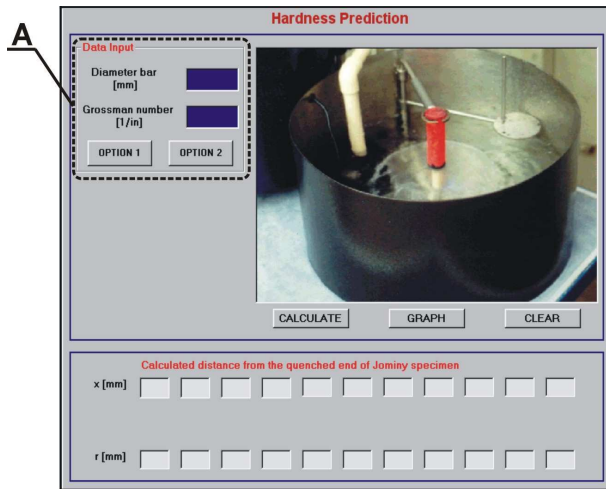


Fig.3. Program screen for calculating hardness profiles on cross section of hardened rods

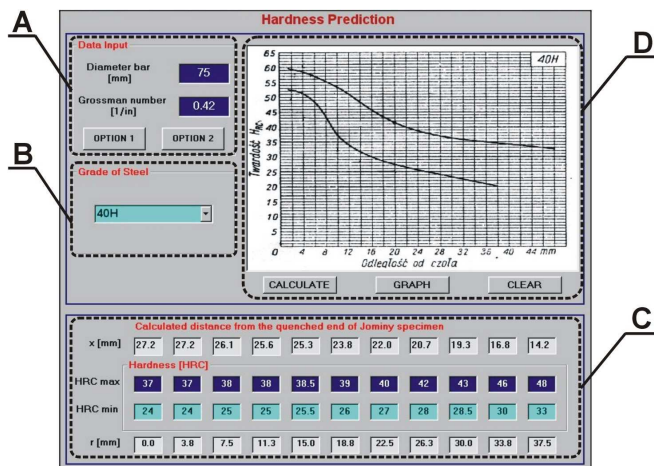


Fig. 4. Program screen with hardenability bands for interactive entering of HRC max. and HRC min. hardness. In this case for ($\varnothing = 75\text{mm}$, $H=0.42[1/\text{in}]$, 40H)

Clicking on the “Calculate” key causes values of x to appear in field “C”, for which HRC max. and HRC min. should be read from the hardenability bands and these values should be entered into the appropriate Text Box windows in field “C”. Entering the read values and clicking on the “Graph” key causes the appearance in the “D” field of a plot of the hardness distribution band on the cross section of the hardened rod, within which the actual hardness will be found upon quenching.

Selection of Option 2 (chemical analysis) causes the appearance in field “B” of text box spaces into which the chemical composition of the given steel and its ASTM grain size are to be entered. For this option, the appearance of field C is changed. In this field, in the appropriate boxes, after clicking on the “Calculate”, values of “x” and “r” as well as calculated HRC hardness, corresponding to the various points of the cross section are displayed. Clicking on the “Graph” tab causes the probable hardness profile of the rod cross section to be displayed in field D (Fig. 5).

Clicking on the “Clear” tab will cause a return to the initial screen.

If after the completion of Option 1 (hardenability bands), Option 2 (chemical analysis) will be selected, after the completion of the latter, the hardness distribution plot obtained with the first Option will also display a superimposed plot of hardness distribution obtained on the basis of chemical composition (Fig. 5).

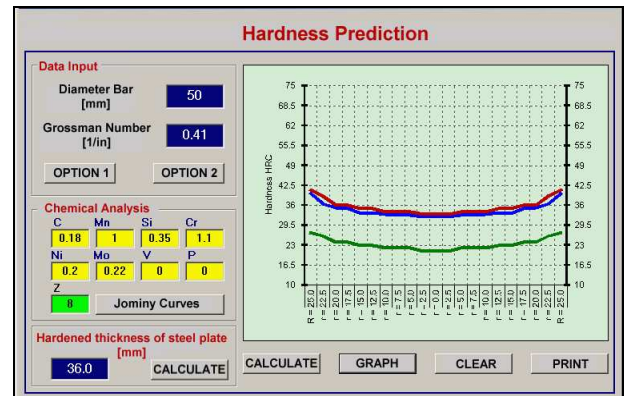


Fig. 5. Program Screen after completion of calculation according to chemical composition. The plot shows results of calculations obtained in Option 1 and in Option 2 for $\varnothing = 50\text{mm}$, $H=0.41[1/\text{in}]$, (18HGM steel)

The set of hardenability bands used by the program can be changed, depending on needs. Hardenability curves according to other standards, e.g. ISO, DIN, ASTM, PN etc. can be used. Another version of this program utilizes digital files of hardenability bands instead of Jominy’s curves shown in the graphical form. In such a case, the interactive procedure is bypassed and the hardness values are calculated after clicking on the “Calculate” tab.

Table 1. Chemical analysis of steels used for experimental testing.

Steel grade	Chemical analysis [%]									
	C	Mn	P	S	Mo	Si	Cr	V	Ni	Cu
1 20 HG (20MnCr5 ISO)	0.2	1.2	0.025	-	-	0.3	1.2	-	-	-
2 18 HGM (18CrMo4 ISO)	0.18	1.0	-	0.02	0.22	0.25	1.1	-	0.2	-

Table 2. Comparison of measurements of hardness distributions on cross sections of hardened rods with computer aided calculations.

Steel grade	Diameter of quenched rod [mm]	Measurement and calculation		Hardness distribution on the cross section $\rho=r/R$						
				$\rho=0$	$\rho=0.2$	$\rho=0.4$	$\rho=0.6$	$\rho=0.8$	$\rho=1$	
20HG (PN) (20MnCr5 ISO)	D=25	HRC Measurement		38	38	39	40	42	44	
		Calculation	Option 1	HRC max	44	44	44	44.5	46	48
				HRC min	30	30	30	31	33	36
		Option 2	HRC	37.7	38.7	39.1	39.6	40.5	44.6	
	D=50	HRC Measurement		31	31	32	32	35	39	
		Calculation	Option 1	HRC max	39	39	39	40	41	44
				HRC min	24	24	24	25	27	30
		Option 2	HRC	30.3	30.6	30.8	31.1	33.1	37.8	
	D=75	HRC Measurement		26	27	27	28	31	36	
		Calculation	Option 1	HRC max	36	38	38.5	40	43	46
				HRC min	24	25	25.5	26.5	27.5	31
		Option 2	HRC	25.7	26.1	26.4	27.1	29.1	34.1	
18HGM (PN) (18CrMo4 ISO)	D=25	HRC Measurement		39	40	41	43	43	44	
		Calculation	Option 1	HRC max	41	41	41	42	43	47
				HRC min	27	27	27	28	29	34
		Option 2	HRC	40.1	40.3	40.6	41.2	42.4	46.2	
	D=50	HRC Measurement		30	33	33	34	34	38	
		Calculation	Option 1	HRC max	33	34	34	35	36	41
				HRC min	21	22	22	23	24	27
		Option 2	HRC	31.8	32.2	32.4	32.7	34.7	39.4	
	D=75	HRC Measurement		27	28	28	29	32	36	
		Calculation	Option 1	HRC max	30	31	31	32	33	37
				HRC min	20	20	21	21	22	24
		Option 2	HRC	27.4	27.8	28.1	28.5	30.7	35.6	

4 Initial Results of Confirmation Tests

Verifications of the program were conducted by the Institute of Precision Mechanics on a rods had different diameters, ranging from 25mm to 75mm, machined out of 18HGM grade steel (18CrMo4 ISO) and grade steel 20HG (20MnCr5 ISO), quenched in oil with a quench severity, as measured by the portable quenchant tester was $H = 0.41$ [1/in]. Chemical compositions of steels used for experimental testing are given in Table 1.

For the above selected experimental tests calculations were carried out, utilizing the described computer software. Results of calculations, as well as results of hardness measurements are given in Table 2.

Calculations according to “Option 1” were made with the utilization of the graphical form of hardenability bands, while “Option 2” represents hardnesses calculated based on the chemical composition of the steel. In the “Measurement” rows the hardness values given those as measured on the cross section of hardened rods. Hardness values are given in 0.2R [mm] intervals.

An assessment of results of calculations and measurements, put together in Table 2 deems them to be satisfactory. Differences between “predicted” hardness and that measured are of the order of several HRC units. In practice, the required hardness which is spelled out on drawings of components designated for hardening and

low tempering is expressed by the upper and lower allowed values. Differences between these hardnesses are most often approx. 4 HRC units (e.g. 58 ÷62 HRC) [13]. Deviation of hardness from the predicted by the presented program and that obtained by hardening is of the same order as the drawing tolerance. Taking into consideration the rapid obtaining of hardness prediction, as well as the simplicity of the software, it is possible to recognize the program as a useful tool for technologists working in an industrial environment.

5 Conclusions

The software for computer aided prediction of hardness of hardened rods presented here has its limitations, similarly to the calculation method on which it is based. Satisfactory results have been determined for rods of diameters not exceeding 125 mm (approx. 5") and not less than 25 mm (approx. 1").

The program is especially useful when there is a possibility of rapid measurement of quench intensity of the quenchant, as expressed by Grossmann's number H [1/in]. It may be utilized for the assessment of quenching possibilities of a given quench tank, as well as to select the optimum quenching medium. It is essential to make use of the appropriate quenchant tester [3].

The question which remains open is one of computer simulation of hardening, utilizing the measurement of quenchant properties with the standard portable tester.

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