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Models for Predicting Tempering Hardness (Austenitic Temperature 900˚C)

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Abstract: ***Hardness of steel depends on type of heat treatment adopted on its composition. The main heat treatment processes are: annealing, normalizing and tempering .the process parameters play a vital role in achieving the required hardness. In this paper different quenching media have been used to accomplish this work with help of Microsoft excel package to find sound model gives relation between hardness and its corresponding tempering temperature. This achieved by doing several experiments at austenitic temperature of 900oc and quenching in oil, water, and brine. Then tempered to different temperatures (200oc up to 600oc) using medium carbon steel (locomotive axle steel).***

Keywords: Hardness, Soaking Time, Austenaic Temperature, Quenching Media

1. Introduction

Medium and high carbon steel properties can be controlled by adding alloying elements materials or by heat treatment process used. In this work an attempt has been made to study the relation between temperatures and hardness, so the aim of this paper is to develop sound models (equations) to predict hardness for any quenching media at any temperature, using MS Excel software. This will provide the operator to predict hardness without conducting experimentation. So this minimizes time and cost and hence increases productivity.

2. Literature review

The approaches of research conducted on material heat treatment taken in the past, have been clearly in two different domains:
a) Either optimization of process parameters**.**
b) Or prediction of mechanical properties

a) Work in process parameters
Brinksmier and Brockhoff [1] have significantly worked on utilization of grinding heat as new heat treatment process. Guo and Sha [2] correlated between processing parameters and properties of marging steels using artificial neural networks. Jaroslav [3] took the help of finite element analysis and treatment processes elaborately. Mafgorzata and Gestwai [4] studied about the use of aqueous polymer quenchants for hardening of carbonitrated parts and conventional quench oil was evaluated to harden carbonitrated parts and resulting micro-structure were compared. Mazumder and Steen [5] developed a heat transfer model for laser material processing. Trzaska [11] developed a computer program for prediction of steel process parameters.

b) Work in prediction of mechanical properties:
Mohammed and Sudhakar [6] have taken the help of artificial neural networks to develop aback propagation model to find the fracture toughness in micro alloy steel. Myllykoskia et al.[7] tried to develop a prediction model for mechanical properties of batch annealed thin steel strip using artificial neural networks modeling . Smoljan et al.[8] did a computer simulation of working stress of heat treated steel specimen. Sorkhabi and Rafiazadeh [9] considered the effect of coating time and heat treatment on structures and corrosion characteristics of Ni-P alloy deposits. Tadashi [10] has worked upon the properties of stainless steel.

Very little work appears to have been carried out in presenting an approach for the prediction of hardness. In this paper therefore, a regression model is developed for prediction of hardness for different heat treatment quenching media (Oil, Brine and Water).

3. Experimental Work

The objective of this work is to present approach for predicting tempering hardness for various heat treatment processes quenched in different media. To develop such approach, set of experiments were conducted under certain facilities and a range of working conditions. The process parameters that were focused upon were temperature, tempering and hardness and type of heat treatment i.e. heating to austenitic temperature of 900oc, soaked to 20 minutes and then cooled in different quenching media (Oil, Brine and Water) for medium carbon steel (Locomotive axle steel) .The composition of this metal according to the British Standard is shown in table (1).

Table 1: Composition (in %) of locomotive axle steel in Sudan

Element	C	Mn	Si	Su	P
%	0.35	1.0	0.6	0.06	0.06

The specimens used in this experiment have dimensions (20x20x17 mm) on which the final hardness was measured by taking the average of five hardness reading.

The table (2) below shows 18 specimens divided into three groups heated to 900°c, soaked for 20 minutes, quenched in different media and tempered.

Table 2: Illustrated 18 specimens heated to 900oc, soaked for 20min and quenched in different media

Quenched media	*Number of specimens*	*Soaking times (Minutes)*	*Heat treated type /and number of specimens*
Brine	6	20	Tempered /5
			Quenched /1
Water	6	20	Tempered /5
			Quenched /1
Oil (vetra 32)	6	20	Tempered /5
			Quenched /1

For all of these specimens, hardness measured using a Rockwell hardness testing machine (C-Scale) and taking the average of five reading for each specimen.

4. Results and Discussions

Heat treated samples under different conditions subjected to Rockwell hardness tester and it was observed that the obtained hardness mostly varies between 25 and 45 HRC .the hardness measuring results are shown in table (3),(4),(5) respectively.

4.1 Oil quenched specimens

The variation of hardness against quenched oil specimens are shown in table (3) below

Table 3: Show the value of hardness for different tempering temperatures on medium carbon steel

Specimens	*Tempering temperatures*	*Hardness (HRC)*
1	As quenched	42.14
2	200	38.46
3	300	38.8
4	400	38.6
5	500	35.9
6	600	25

The regression approach for data in table (3) ,is done in Excel 2010 as good and easy regression software tool. A detailed description of the modeling approach is given in figure (1) below.

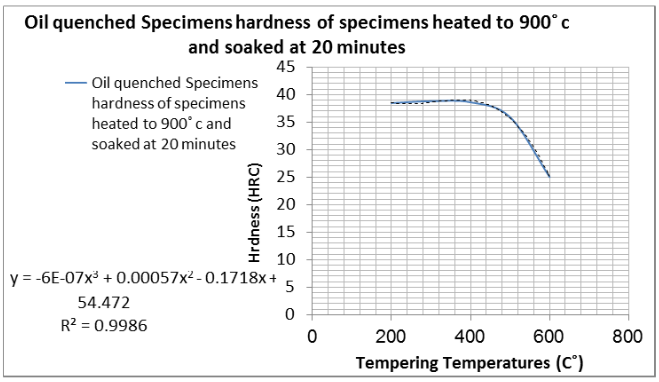

Figure 1: Oil quenched specimens hardness of specimens heated to 900oc and soaked at 20minutes

The best equation represent data in figure(1) is found below by using Microsoft Excel 2010 trend line by R-squared value =0.9986 as shown in figure (1) .

$$y = -6E\text{-}07x^3 + 0.00057x^2 - 0.1718x + 54.472 \quad (1)$$

Where
y stands for hardness (HRC)
x stands for tempering temperatures (C˚)

For example when (x) tempering temperature =200ºc then, the hardness HRC (y) =38.112 by using equation (1).

Model validation
The predicted values and experimental values are compared in table (4) which shows a very low percentage of error.

Table 4: Shows the errors (%) found when using equation (1)

Specimens	*Tempering temperatures (x)*	*Hardness (HRC) (y)*		
		Real value	*Equation value*	*Error %*
2	200	38.46	38.112	1%
3	300	38.8	38.032	2%
4	400	38.6	38.552	0%
5	500	35.9	36.072	0%
6	600	25	26.992	8%

The equation is valid when heating to 900 ˚C, at soaking time 20 minutes and quenching media is Oil, for example if tempering temperature of 250 ˚C is used in above condition gives hardness of (37.772 HRC) i.e. hardness of (37.772 HRC) can be obtained by tempering to 250ºc in the specific condition.

4.2 Brine quenched specimens

The variation of hardness against quenched Brine specimens are shown in table (5) below:

Table 5: Show the value of hardness for different tempering temperatures on medium carbon steel

Specimens	*Tempering temperatures*	*Hardness (HRC)*
1	As quenched	49
2	200	45.9
3	300	44.8
4	400	43.8
5	500	42.9
6	600	32.7

A detailed description of the modeling approach is given in figure (2) below.

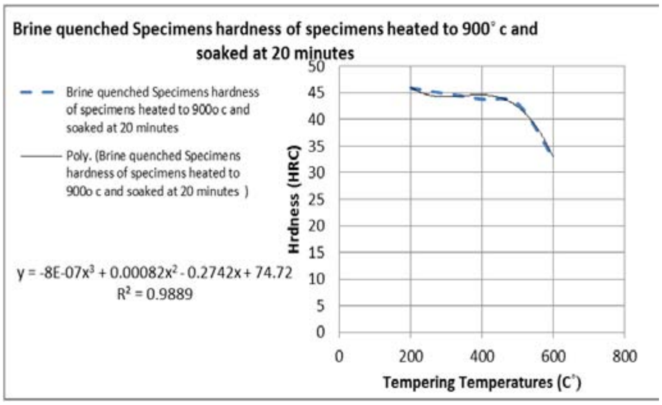

Figure 2: Brine quenched specimens hardness of specimens heated to 900oc and soaked at 20minutes

The best equation represent data in figure (2) is found below by using Microsoft Excel 2010 trend line by R-squared value =0.9889 as shown in figure (2)

$$y = -8E\text{-}07x^3 + 0.00082x^2 - 0.2742x + 74.72 \quad (2)$$

Where

y stands for hardness (HRC)

x stands for tempering temperatures (C˚)

For example when (x) tempering temperature =300°c then, the hardness HRC (y) =44.66 by using equation (2).

Model validation

The predicted values and experimental values are compared in table (6) which shows a very low percentage of error.

Table 6: Shows the errors (%) found when using equation (2)

Specimens	*Tempering temperatures (x)*	*Hardness (HRC) (y)*		
		Real value	*Equation value*	*Error %*
2	200	45.9	46.28	1%
3	300	44.8	44.66	0%
4	400	43.8	45.04	3%
5	500	42.9	42.62	1%
6	600	32.7	32.6	0%

The equation is valid when heating to 900 ˚C, at soaking time 20 minutes and quenching media is Oil, for example if tempering temperature of 250 ˚C is used in above condition gives hardness of (44.92 HRC) i.e. hardness of (44.92 HRC) can be obtained by temping to 250°c in the specific condition.

4.3 Water quenched specimens

The variation of hardness against quenched Brine specimens are shown in table (7) below:

Table 7: show the value of hardness for different tempering temperatures on medium carbon steel

Specimens	*Tempering temperatures*	*Hardness (HRC)*
1	As quenched	48
2	200	48
3	300	48.5
4	400	43.3
5	500	42.7
6	600	39.2

A detailed description of the modeling approach is given in figure (3) below.

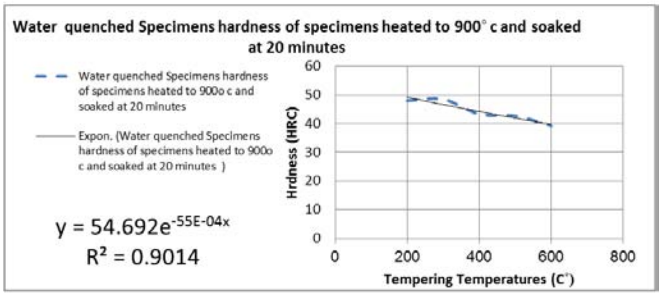

Figure 3: Water quenched specimens hardness of specimens heated to 900oc and soaked at 20minutes

The best equation represent data in figure (3) is found below by using Microsoft Excel 2010 trend line by R-squared value =0.9014 as shown in figure (3)

$$y = 54.692e^{-55E\text{-}04x} \quad (3)$$

Where

y stands for hardness (HRC)

x stands for tempering temperatures (C˚)

For example when (x) tempering temperature =400°c then, the hardness HRC (y) =43.9 by using equation (3).

Model validation

The predicted values and experimental values are compared in table (8) which shows a very low percentage of error.

Table 8: Shows the errors (%) found when using equation (3)

Specimens	*Tempering temperatures (x)*	*Hardness (HRC) (y)*		
		Real value	*Equation value*	*Error %*
2	200	48	49	2%
3	300	48.5	46.4	4%
4	400	43.3	43.9	1%
5	500	42.7	41.5	3%
6	600	39.2	39.3	0%

The equation is valid when heating to 900 ˚C, at soaking time 20 minutes and quenching media is water. For example if tempering temperature of 250 ˚C is used in above condition gives hardness (47.7 HRC).

5. Conclusions

The hardness of specimens quenched in water and brine is maximum compared to those quenched in oil, and it may be accounted to rapid cooling in Brine and water which acts as austenite stabilizer.

The best equations (models) to predict tempering hardness in oil, Brine and water are:

$$y = -6E\text{-}07x^3 + 0.00057x^2 - 0.1718x + 54.472 \quad \text{(Quenched in oil)}$$

$$y = -8E\text{-}07x^3 + 0.00082x^2 - 0.2742x + 74.72 \quad \text{(Quenched in Brine)}$$

$$y = 54.692e^{-55E\text{-}04x} \quad \text{(Quenched in Water)}$$

The above three equation can be used to find the hardness (y) for tempering temperatures (X) from 200oc up to 600 °c and vice versa.

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