Ain Shams University
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Effect of post rolling thermo mechanical processing on microstructure and mechanical properties of hot rolled multiphase reinforcing steel bars.

A Thesis
Submitted in partial fulfilment of the requirements for the degree of M.Sc. in Mechanical Engineering
Production Engineering Department

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The undersigned certify that they have read and recommend to the Faculty of Engineering – Ain Shams University for accepting a thesis, entitled as "Effect of post rolling thermo mechanical processing on microstructure and mechanical properties of hot rolled multiphase reinforcing steel bars" (*تأثير المعالجة الحرارية في عملية الدرفلة علي البنية والخواص لحديد التسليح*). Thesis is submitted by Hany Abd Al Rahman Khalifa, in partial fulfilment of requirement for the Master of Science degree in Mechanical engineering.

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STATEMENT

This thesis is submitted to Ain Shams University for the M.Sc. Degree in mechanical engineering, Production Engineering department.

The work included in this thesis was carried out by the author in the department of Design and Production Engineering, Ain Shams University.

No part of this thesis has been submitted for a degree or qualifications at any other University or institute.

Name: Hany Abd Alrahman Khalifa

Signature:

Date: 11/07/2013

To the soul that embrace my soul,

To the hand that kindled the flame of my life,

To the heart that poured its secrets into my own heart,

I dedicate this.

To the soul of my father

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Hany Khalifa

Summary

A lot of effort has been spent during the last decades in order to determine the optimum methods to produce higher steel strength to meet the recent increasing demand on high strength and diverse microstructure quality steel reinforcement bars. The present work deals with Tempcore process for production of high strength steel rebars via in line quenching and self tempering process.

A mathematical model has been developed for simulating Tempcore process to produce high strength steel. The model deals with bars moving with certain speed, and quenched by pressurized cooling water. The model consists of three parts coupled together in an integrated form, the thermal model, the metallurgical model and the mechanical model. The integrated model is capable of predicting: the temperature distribution of the Tempcore treated bars over the whole cooling rout, the area cooled under martensite formation temperature and Yield Strength of the bar under variable process parameters. The model has been applied to grade B500B, to bar diameters of 10 and 16mm.

In plant, trials were conducted to express the model variables in terms of actual process parameters, namely: bar diameter, rolling finishing temperature, number of active cooling nozzles, their setting, cooling water flow rate and quenching time. A series of quenching tests were performed and the resulting microstructure and mechanical properties studied using optical microscope, microhardness measurement, and tensile tests. Comparison showed good agreement between the predicted and the measured tempering temperature, martensite volume fraction and yield strength. The model developed in the present work showed a great potential to optimize Tempcore process parameters to produce several rebar grades with high degree of flexibility. The model also could be used as a design guide to determine the suitable nozzle dimensions and their settings of each bar diameter and the desired steel grade.

In additional to model verifications the experimental work showed that the presence of martensite throughout the samples contributed to the enhanced strength of Tempcore treated bars. It is also found that the microstructure and tensile properties are affected much with varying Tempcore cooling parameters. With increasing quenching time, the self-tempering temperature decreases and the amount of martensite increases, which affect the, tensile properties. It is also found that the Tempcore process can be adapted through controlling the processing parameters to produce various steel grades with yield strength varying from 400 to 800 MPa from the same chemical composition 0.2% C and 0.6% Mn.

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NOMENCLATURE

T_{intial}	Bar initial temperature and equal to rolling finishing temperature	°C
ρ	the density of the material	Kg/m^3
Cp	specific heat of the material	J/kg.C
T_∞	temperature of the adjacent fluid	°C
hw	Water cooling Convective heat transfer coefficient	$w/m^2.C$
ha	Air Convective heat transfer coefficient	$w/m^2.C$
Q	Total cooling water flow rate	m^3/h
P	Pressure of cooling water	bar
Dh	Hydraulic diameter	
Nu	Nusselt numbers is the ratio of convective to conductive heat transfer across (normal to) the boundary.	dimensionless number
Re	Reynold numbers gives a measure of the ratio of inertial forces to viscous forces	dimensionless number
ν	Dynamic viscosity of water	Pa·s
Rc	radius of cooling pipe.	m
R	steel bar diameter	m
$V_{Relative}$	Relative speed between bar and water	m/S
V_{bar}	Rolling speed (bar speed).	m/S
$T_{Quenching}$	Quenching time	S

$\Delta f^{\backslash}(x)$	First order finite difference	
$\Delta f^{\backslash\backslash}(x)$	Second order finite difference	
Δv	Node volume	m^3
Δt	Time step	S
$T^{t+\Delta t}$	Temperature value at the next time step	°C
Fo	Fourier number equals rate of conducted heat divided by rate of stored heat	dimensionless number
$\propto$	Thermal diffusivity	m^2/s
B_i	Biot number gives a simple index of the ratio of the heat transfer resistances inside of and at the surface of a body	dimensionless number
r	Distance in the radial direction from bar center	M
Δr	Distance Increment in the radial direction from bar center	M
M_s	Martensite start temperature	°C
V_M	Martensite volume fraction	%
V_{core}	Core volume fraction	%
r_m	the distances from bar radius to martensite start layer	m
$Y.S_{MS}$	Yield strength of the formed tempered martensite	Mpa
$Y.S_{Core}$	Yield strength of the composite core	Mpa
T_w	Water Temperature	°C
T_a	Air Temperature	°C
n	Number of active cooling nozzles	
L	Length of cooling nozzle	m

k_w	Thermal conductivity of water	w/m.C
k_a	Thermal conductivity of air	w/m.C
Ar1	The temperature where the transformation from austenite solution to ferrite and cementite (most often pearlite) is complete during cooling. The “r” (arreˆt refroidissant) designates that it is a transformation point achieved by cooling	°C
Ar3	The temperature at which austenite begins to transform to ferrite when during cooling. The “r” (arreˆt refroidissant) designates that it is a transformation point achieved by cooling	°C
TT	Tempering temperature	°C
RT	Rolling finishing temperature	°C
Qt	Quenching time	S
Wfr	Cooling water flow rate	m^3/h
μ	Kinematic viscosity of fluid	m^2/S
CCT	Continuous cooling transformation	
i	Any node in the bar cross section	
T_i	Temperature of any node	°C
TC	Tempcore treated bars	
HR	Hot rolled bars	

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