Automation systems for heat treatment and controlled cooling of plates and bars

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Be it a plate or a bar, uniformity of mechanical properties is an important indicator of superior quality. To manufacture such products the cooling systems are required to be properly controlled and tuned. In the conventional practice, the mechanical properties are tested after the product is manufactured. This leaves no room to take any corrective action. An accurate estimation of property during actual processing stage itself is required to control the cooling system. Danieli has developed PQM and QTB PLUS systems for monitoring and control of plates and bars respectively in real time. The estimation of mechanical properties such as Yield Strength, Tensile Strength, Hardness, and Elongation is made with the help of a series of interconnected, physically based mathematical models, complemented by empirical and data driven techniques to include processing uncertainties. The accuracy of the PQM system is ± 54 MPa for both YS and UTS, and ± 32 points for HV. And that for the QTB PLUS system is ± 20 MPa for YS, and ± 25 MPa for UTS. Such systems are useful for Testing, Quality Assurance, and Process Control. QTB Plus has been implemented in Riva Plants at Verona (Italy) and Seville (Spain). PQM is scheduled to be implemented in Iran this year.

KEYWORDS:
mechanical testing, property, prediction, process control, plate, bar

INTRODUCTION

Plates and bars are heat treated after manufacture to impart desired mechanical properties suitable for their use. Heat treated steel plates are used in the manufacturing and construction industries where the demand for combination of high strength, toughness, weldability and wear resistance exceed those obtained from as-rolled products. The Quenched and Tempered Plates (Q&T) are particularly suitable for pressure applications and structurals such as large storage tanks, earth-moving equipments etc. Plates are expected to be produced with uniform mechanical properties throughout. In case of plain bars, rebars, and wire rods, the controlled cooling is applied after final rolling to obtain the quenched and self-tempered structure for superior strength. Better and tougher quality is ensured through composite structures of tempered martensitic rim and ferritic-pearlitic core. With the technical collaboration of Centro Sviluppo Materiali (CSM), Rome, DANIELI Automation has recently developed process automation systems to predict and control the mechanical properties of heat treated plates and controlled-cooled bars. The Plate Quality Monitor (DANIELI-PQMTM) estimates in real time the Yield strength (YS), Tensile strength (UTS), and Hardness (HV) of a plate after quenching and tempering operation. The properties are predicted at different locations, across the width and through the thickness of the plate for microalloyed fine grain weldable steels, Chromium-molybdenum steel, and Chromium-molybdenum-Nickel steels with different alloying elements (<5%). On the other hand, DANIELI-QTB PLUSTM predicts and controls the properties of quenched and tempered bars – the YS, UTS and HV, of low carbon steels. The estimation of property is based on the final microstructure and its evolution during quenching and tempering operations.

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PRODUCTION OF HEAT TREATED PLATES

Fig. 1 shows the effect of carbon equivalent, CE(IIW), and different production process routes on the strength of plates. Steel plates are produced through different routes. They are supplied in 'As-rolled" ("U"), 'Normalised' ("N"), 'Quenched' ("Q") or 'Quenched & Tempered' ("Q&T") conditions, as shown in Figs. 2A-C respectively. Heat treated plates are produced through Quenched and Tempered (Q&T) routes (Fig. 2C). Apart from these conventional routes, there are other advanced Thermo-mechanical Controlled Processing (TMCP) routes, used for production of plates. TMCP route takes advantages of different strategies of controlled rolling and accelerated cooling (ACC) to produce plates with a wide range of properties. These are shown in Figs. 2D-G.

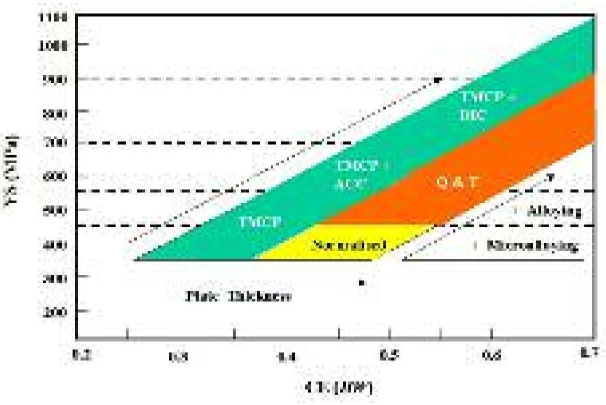


FIG. 1 ***Effect of heat treatment and carbon equivalent on plate strength [1].***

Effetto del trattamento termico e del carbonio equivalente sulla resistenza della lamiera.

Heat-treated steel plates are used in construction, marine and pipeline industries where the demand for combination of high strength, toughness, weldability and abrasion resistance exceeds those obtained from as-rolled products. The Q&T plates are used for structural applications, welded pipes, pressure vessels, offshore platform, petrochemicals, earthmoving and construction, mining and quarrying.

The Q & T steel is fully killed, calcium treated and desulphurised to achieve low sulphur levels and a very low inclusion content in order to control the morphology of sulphide. The heat treatment is carried out after hot rolling to achieve superior properties. Depending on the grades the plates are heated in the range 880ºC and 930ºC. The heated plates are then water quenched at very high cooling rates using high pressure jets at both top and bottom surfaces across the full width.

The quenched structure is predominantly bainite and martensite. For improved toughness the tempering of hard and brittle martensite is required. Tempering is usually done in another roller hearth furnace. The furnace is usually direct-fired. The temperature used is usually Ac_1 – 100 i.e., about 600 ºC. In Fig. 3 a dual-purpose furnace for Tempering & Normalising (TNF) is shown.

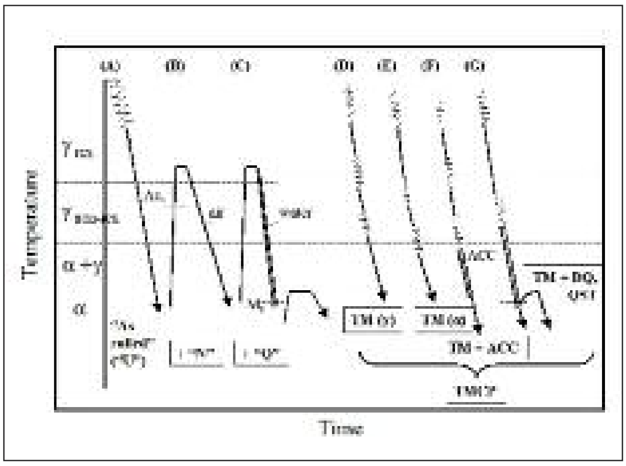
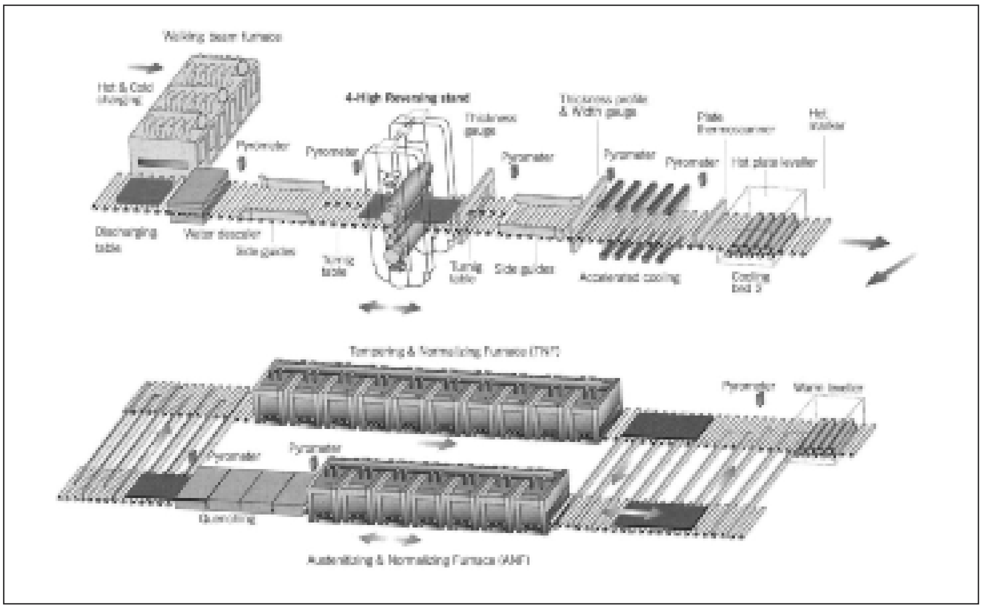


FIG. 2 ***Schematic showing As-rolled, normalized, Q&T and TMCP routes [2].***

Schema rappresentante le tipologie di prodotto come-laminato, normalizzato, temprato e rinvenuto, e con processo termomeccanico controllato.

FIG. 3
Typical Plate Rolling Mill with heat treatment facility.

Tipico impianto di laminazione lamiere con area di trattamento termico.



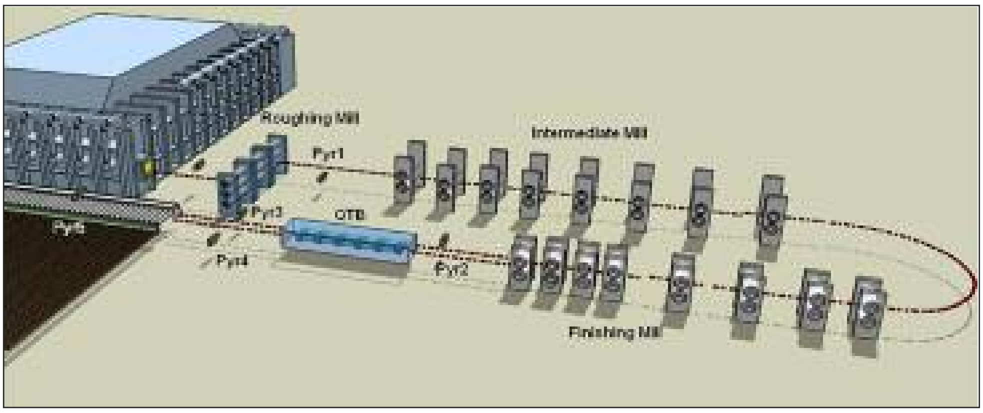
PRODUCTION OF QUENCHED AND TEMPERED BARS

Figure 4 shows a typical layout of the Bar and Rod Mill. The mill produces bars typically of diameters between Φ 8 and Φ 32 mm in steps of 2 mm. The steel grades produced are B450C and B500C, according to the normative UNI ENV 10080 for rebars. The billets are heated in a reheating furnace at about 1200 ºC in the austenite region, and are then passed through subsequent reductions in the rolling stands to obtain the desired diameter of the bars. The hot rolling process is mainly carried out in three steps - roughing, intermediate, and finish rolling. In roughing the scale is removed and the billet is subjected to primary deformation. The roughing stand exit temperature is about 1050 – 1080 ºC. In the second or intermediate step, the cross-section of the billet is progressively reduced and its length is increased. In the final step of finish rolling the bar is rolled to its final diameter. In case of rebar, the desired rib profile is embossed. The end rolling temperature is about 1080 – 1100 ºC. The final rolling speed is 30 m/s (for the smallest diameter bar Φ 8 mm), and 6 m/s (for largest diameter bar Φ 32 mm). In a bar mill slit rolling is applied to smaller diameter bars of Φ 8 - 12 mm bar to improve productivity.

Bar from the mill is quenched in the water quenching section. For relatively smaller diameter bars of Φ 8 - 12 mm, typically 11 small nozzles are used. And for larger diameter bars of Φ 14 - 32 mm, usually 15 nozzles are used. The water flow rates through the booster pumps vary between 150 - 750 m^3/hr, and pressures vary between 9 – 14 bar. After quenching the excess water on the surface of the bar is stripped off and dried. The bar is then cooled on the cooling bed.

The control of the quenching process is done through the adjustment of water pressure and flow rate depending on the bar diameter, finish rolling temperature, and rolling speed. During quenching the surface temperature of bar is brought below the Ms temperature, and a uniform martensite rim is formed. As the bar comes out of quenching section, heat from center of the bar flows from core to rim. The martensite subsequently gets tempered, and tempered martensitic ring forms. Various sections within the bar undergo different cooling rates; as a result, different

FIG. 4
Plant layout of Riva Acciaio, Verona (Italy).
Layout dell'impianto di Riva Acciaio, Verona (Italia).



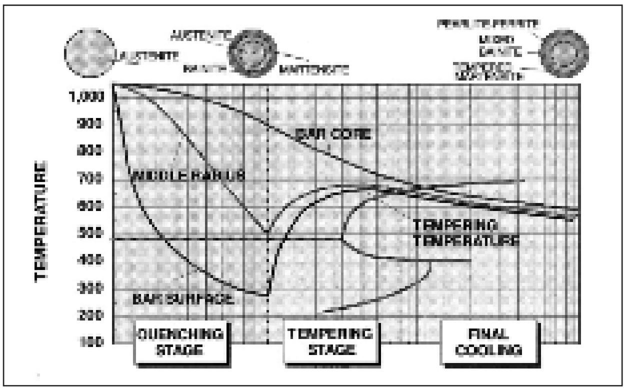


FIG. 5 ***CCT Diagram showing Quenching and Self-Tempering.***
Diagramma CCT indicante il trattamento di Tempra e Auto-Rinvenimento.

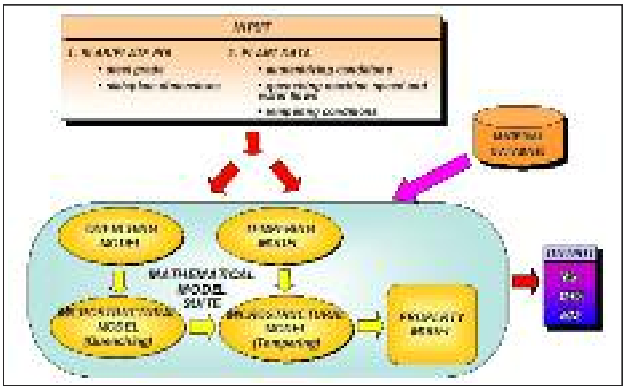


FIG. 6 ***Architecture of Plate Quality Monitor (PQM).***
Architettura del Plate Quality Monitor (PQM).

phases exist from the core to rim. The microstructure of bar has tough core comprising ferrite, pearlite, and sometimes very little bainite; and tempered martensitic rim. In between these two regions there exists bainite rich area, as shown in Fig. 5.

AUTOMATION SYSTEMS

The architecture of the Plate Quality Monitor (PQM) is shown Fig. 6. A set of interconnected models forms the 'Mathematical Model Suite'. It receives the Primary Data Input (PDI) as steel chemistry, and plate dimensions. The plant data are real-time data collected, screened and fed to the suite for processing. Material database supplies the thermal properties of steel. The output of the PQM system is the estimation of properties. This can be compared with the desired property that the customer wants, and the process can be controlled accordingly. A detailed description of PQM can be obtained elsewhere [3].

Like PQM, the QTB PLUS system is based on a group of models at the heart (Fig. 7). The difference is that it needs an additional Artificial Neural Network (ANN) model to complement the assessment from the mathematical based models. The Quality Control System (QCS) compares the predicted property from the model with its desired property to configure the QTB Cooling system. A detailed description of QTB PLUS system can be obtained elsewhere [4].

MATHEMATICAL MODELS

Thermal Model

The purpose of the thermal model is to obtain the cooling or heating curve during quenching and tempering respectively. This then gives the basis to calculate the cooling rate at any given temperature range.

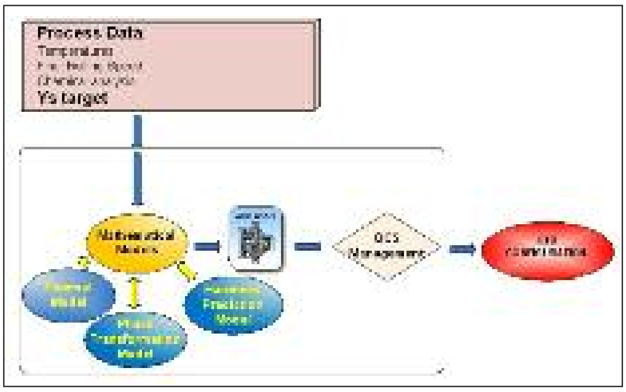


FIG. 7 ***Architecture of advanced Quenched and Tempered Bar System (QTB PLUS).***
Architettura del sistema avanzato Quenched and Tempered Bar (QTB PLUS).

PQM:
For modelling quenching and tempering operation, it is assumed that the heat loss takes place mostly from the top, bottom, and side of the plate. This means heat conduction in the cross-sectional plane is more important than longitudinal plane. The two-dimension transient heat conduction equation is given below (1a).

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(D\frac{\partial T}{\partial y}\right) + \frac{\dot{q}}{\rho c} + s \cdot h(T - T_2) \tag{1a}$$

where T is temperature, t is time, D is thermal diffusivity (= k/ρc), k is thermal conductivity, ρ is density, and c is specific

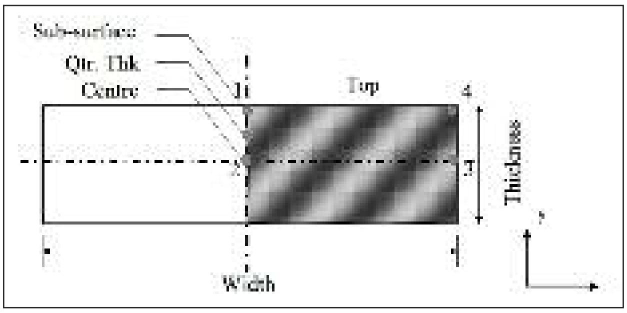


FIG. 8 ***Solution domain for finite difference scheme in a plate.***

Dominio delle soluzioni per uno schema alle differenze finite in una lamiera.

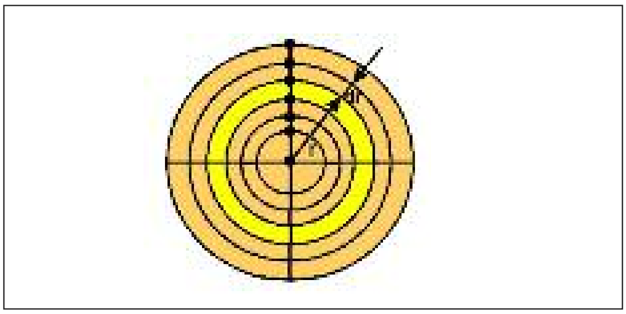


FIG. 9 ***Solution domain for finite difference scheme in a bar.***

Dominio delle soluzioni per uno schema alle differenze finite in una barra.

heat of the steel grade. The s is surface area, and h is the heat transfer coefficient. The $\dot{q}$ is heat released from transformation ($= \Delta H \cdot (df_v/dt)$) where ΔH is the enthalpy change. These thermal properties are temperature dependent. s and h are surface area and heat transfer coefficient respectively.

QTB PLUS:
While is it convenient to construct the heat conduction equation in Cartesian coordinates in case of plate, the use of cylindrical coordinate system is more handy in case of rods. Following the assumption of radial heat flow, the one-dimensional transient governing heat conduction equation is used.

$$\frac{\partial}{\partial r}\left(k\frac{\partial T}{\partial r}\right)+\frac{k}{r}\left(\frac{\partial T}{\partial r}\right)+q_{TR}=\rho C\frac{\partial T}{\partial t} \tag{1b}$$

where q_{TR} is the heat released due to the transformation of austenite to other phases (i.e. ferrite, pearlite, bainite or martensite). The model incorporates temperature dependent thermal conductivity and specific heat at various phases.
Although the quenching with high-pressure water jets from the nozzles remove large portion of the heat from the outer surface of bar, heat loss in air on cooling bed is also substantial. As a result the overall heat loss (q_{ov}) has been calculated taking both radiation and convective mode of heat transfer into consideration.

$$\begin{gathered} q_{ov}=q_C+q_R=h_{SC}(T_s-T_A) \\ h_{sc}=\sigma R\varepsilon\left(T_s^2+T_A^2\right)\times(T_s+T_A) \end{gathered} \tag{2}$$

where R is radiation factor, comprising the emissivity of steel and the relative geometry of material. 'σ' and 'ε' are Stephan-Boltzman constant, and emissivity of rod respectively. T_S and T_A represents the surface temperature of bar and the atmosphere (in K) respectively.

Microstructural Model
The microstructural models use the cooling rate calculated from the thermal model to obtain different microstructural constituents.

PQM:
In case of heat-treated plates, an empirical model is developed to estimate the microstructural constituents. For steels with an alloy content < 5 wt %, the volume fractions of microstructural constituents and the hardness (HV^Q) after a given continuous cooling, based on the evaluation of the critical cooling rates necessary to obtain given amounts of as cooled microstructure [5,6]. Hardness after quenching of any given microstructural constituent (i=ferrite (F), pearlite (P), bainite (B), and martensite (M)) is estimated using an empirical relationships depending on steel chemical composition and cooling rate.

$$HV^Q{}_i=A_i+B_i\,Log_{10}(CR) \tag{3a}$$

The overall hardness after quenching (HV^Q) is predicted from the estimated microstructure

$$HV_Q=HV^Q{}_{FP}\cdot\frac{F\%+P\%}{100}+HV^Q{}_B\cdot\frac{B\%}{100}+HV^Q{}_M\cdot\frac{M\%}{100} \tag{3b}$$

QTB PLUS:
In case of quenched and tempered bars it has been assumed that the austenite to ferrite, pearlite, and bainite transformation kinetics obeys the Avrami type equation [7]

$$X=1-\exp(-kt^n) \qquad k=P(1)\exp\left[-\left(\frac{T-P(2)}{P(3)}\right)^{P(4)}\right] \tag{4}$$

where X is fraction transformed, t is time, b and n are kinetic constants. The value of n depends on the type of nucleation site (whether grain boundary, grain edge, or grain corner), and can be treated as constant for a particular transformation. On the other hand, k is a function of temperature and changes during the course of transformation. The value of k can be calculated using a modified Gaussian function of following type [8], where P(1) is the maximum value of k, P(2) is the temperature of the nose of the TTT curve, P(3) is proportional to the nose width thickness at mid height of the TTT diagram, and P(4) is the sharpness of the curve.
The kinetics of martensitic transformation is assumed to follow the equation proposed by Koistinen and Marburger [9]

$$X=1-\exp(-h(M_s-T)^n) \tag{5}$$

where X is the fractional transformation, T is the temperature of steel, and h and n are constants. M_s temperature depends on the grade of steel, and is calculated using Steven and Haynes [10].

Structure Property Model
The Structure Property Model estimates the mechanical properties from the microstuructural constituents.

PQM:
To estimate the mechanical properties after a tempering treatment, a tempering parameter P_T, depending on tempering temperature (T_T) and tempering time (t_T) is calculated as:

$$P_T=\left(\frac{1}{T_T}-\frac{R}{\Delta H_T}\cdot\ln(t_T)\right)^{-1} \tag{6}$$

where T_T is the tempering temperature (K), t_T the tempering time (h), ΔH_T the activation energy, which is independent on the carbon content and as-cooled microstructure (ΔH_T=419 ± 21 kJ mol^{-1}), and R the gas constant. If the tempering parameter P_T ex-

ceeds a critical value P_{cr}, a fast decrease in hardness occurs. Bainite and Martensite only are involved in this process.
To evaluate the hardness of Martensite and Bainite after tempering, the following expressions are used:

$$HV^T{}_i = A_i - B_i \cdot \frac{1000}{P_T} \quad (7a)$$

where i = Martensite or Bainite. The average hardness after tempering HV_T is computed as:

$$HV_T = HV^Q{}_{FP} \cdot \frac{F\% + P\%}{100} + HV^T{}_B \cdot \frac{B\%}{100} + HV^T{}_M \cdot \frac{M\%}{100} \quad (7b)$$

To compute the yield strength and the ultimate tensile strength after tempering, empirical relationships, dependent on the hardness after tempering, are used:

$$UTS = e + f\,HV_T \qquad YS = c + d\,HV_T \quad (8)$$

where the coefficients e, f, c, d have been tuned for the steels of interest.

QTB PLUS:
The property model uses the law of mixture to estimate the comprehensive hardness as given in the following equation.

$$HV = X_m HV_m + X_b HV_b + (X_f + X_p) HV_{f+p} \quad (9)$$

where HV is the total hardness in Vicker's scale. X_m, X_b, X_p and X_f are the volume fraction of martensite, bainite, pearlite and ferrite respectively; and HV_m, HV_b, HV_{f+p} are hardness of martensite, bainite and mixture of ferrite and pearlite respectively.

Artificial Neural Network Model (ANN)
To achieve the desired degree of predicted accuracy, the best approach is to integrate an ANN model on top of the mathematical models described above. This methodology combines the flexibility of ANN with the information from the metallurgical models. The feed-forward network with a hidden layer of neurons in between the input and the output layers has been found to represent accurately the complex relationships between the mechanical properties and the process parameters. Due to large number of input variables the number of input neurons are large. Only two output neurons – one each for YS and UTS, build the output layer. The network is trained using the Backpropagation (BP) algorithm. The best network topology has been identified by comparing the selection (validation) performance of a set of networks with different configurations where the lowest error between actual mechanical properties and predicted values are obtained. Thus, the best network is selected with highest level of accuracy with largest value of coefficient of determination (R).

RESULTS & DISCUSSION

PQM:
Figure 10 shows the temperature evolution in Steel 25CrMo4 plate of 60 mm thick and 1100 mm wide during quenching operation after austenitising at 1000 ºC for 1 hr. The steel chemistry is shown in the Table 1.
The temperature evolution at three different points through the thickness of the plate – the center, the sub-surface, and the quarter thickness are shown. At any point of time the center temperature is higher than those at quarter thickness or at the surface.
Figure 11 shows temperature evolution within the plate during tempering operation in TNF at four different points of the plate as shown in Fig. 8. The tempering temperature is 675 ºC. The figure shows temperature evolution at the center is slower than the side of the plates. It also shows the time required for temperature equalization between the side and the center of the plate.

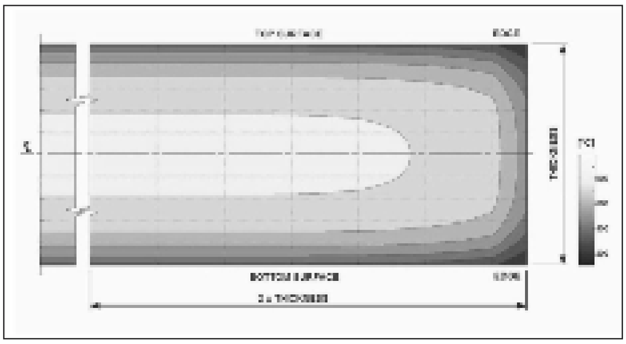


FIG. 10 ***Contour plot of temperature within the plate at 100s during quenching.***

Profilo di temperatura lungo la sezione di una lamiera dopo 100 secondi durante la tempra.

C	Mn	Cr	Mo	P	Si	Al
0.26	0.75	1.05	0.23	0.01	0.2	0.02

TAB. 1 ***Chemical Composition of Steel 25CrMo4 Plate (% wt).***

Composizione chimica dell'acciaio 25CrMo4 (% peso).

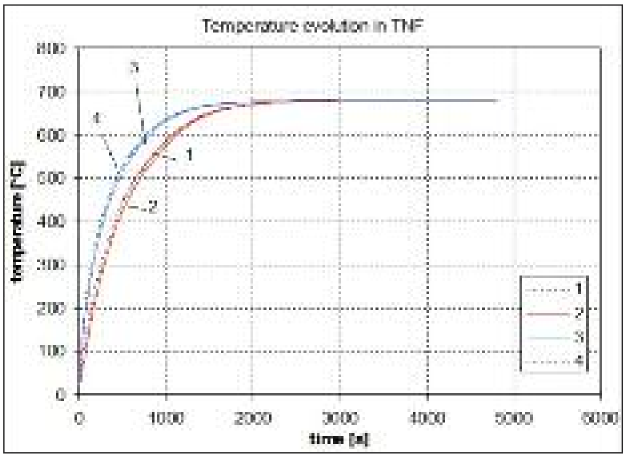


FIG. 11 ***Temperature evolution during tempering.***

Evoluzione della temperatura durante il rinvenimento.

The system has been validated for different steel grades and different tempering conditions, using previous experimental data. Tempering temperatures ranging from 585 °C to 710 °C, and tempering times ranging from 35 min to 70 min have been considered. In Figs. 12a-c the comparisons between the calculated and the experimental mechanical properties of 197 samples and of 7 different grades are reported.
A good match is obtained between the predicted and the observed values. Table 2 summarises the accuracy and reliability of the system.

QTB PLUS:
Figure 13 shows the temperature evolution at different sections of the annular rings of 24 mm diameter TMT rebar, the chemistry of which is shown in Table 3.
During quenching, the surface temperature drops below M_s temperature. As soon as the bar is out of the water-cooling section, recalescence takes place due to flow of heat from core to rim. Fi-

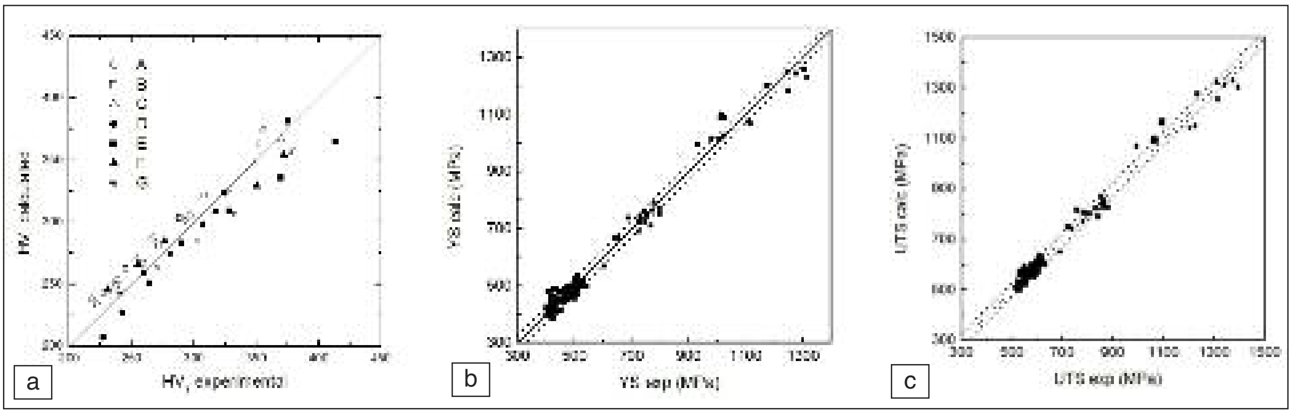


FIG. 12 ***Computed versus experimental mechanical properties after tempering: a) Hardness; b) Yield Strength; and c) Ultimate Tensile Strength.***

Proprietà meccaniche stimante contro sperimentali dopo il rinvenimento: a) Durezza; b) Resistenza a snervamento; e c) Resistenza a carico massimo.

nally the surface, the core, and the mid section temperatures become uniform.

Figure 14 shows the microstructure of martensitic rim and ferritic-pearlitic core of the rebar. For validation of the model, the microhardness measurement values are compared with the model predicted ones. The measured hardness are shown as filled diamonds in the figure. A good match ensures the accuracy of model prediction.

Figure 15 shows the microstructure of martensitic rim (1) and ferritic-pearlitic core (2) of Φ 24 mm TMT rebar. The property model predicts the hardness profile across the section as shown in the figure. For validation of the model, the microhardness measurement values are compared with the model predicted ones. The measured hardness are shown as filled diamonds in the figure. A good match ensures the accuracy of model prediction.

To determine the accuracy and reliability of the system 136 rebar samples were taken between diameters Φ 8 – 32 mm for comparison between predicted and actual mechanical properties. The rebar samples are of low carbon steel with C 0.18 – 0.24, Mn 0.6 – 0.8, and Si 0.15 – 0.3 by wt. The carbon equivalents are

Reliability %	Accuracy YS MPa	 UTS MPa	 HV
68.4	± 27	± 27	± 16
95.2	± 54	± 54	± 32

TAB. 2 ***Performance summary of PQM System.***

Sommario delle prestazioni del sistema PQM.

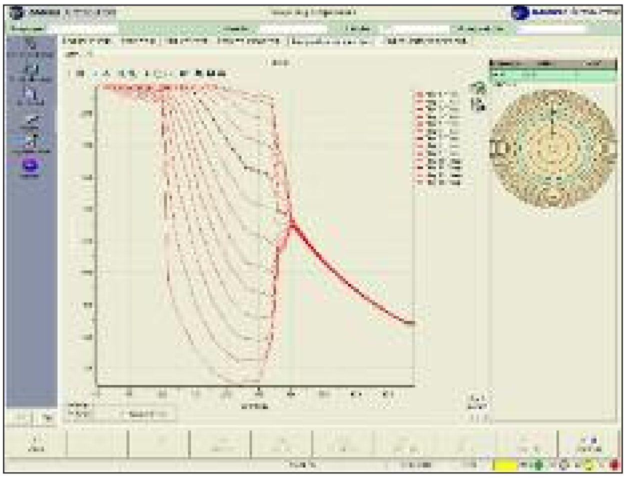


FIG. 13 ***Temperature evolution during quenching and self-tempering.***

Evoluzione della temperature durante tempra ed auto-rinvenimento.

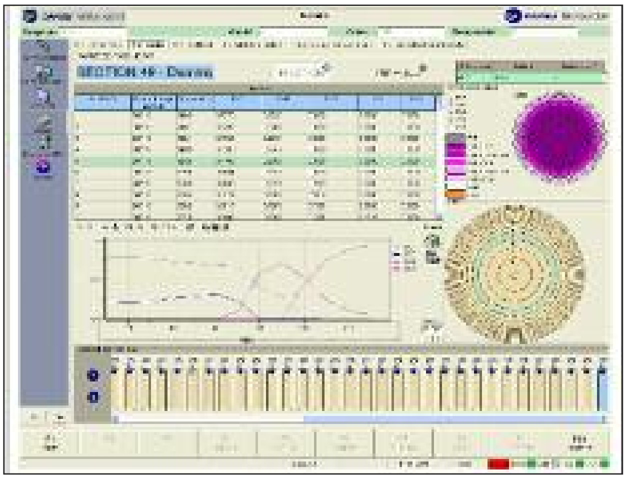


FIG. 14 ***Volume fractions of microstructural constituents in Φ 24 mm rebar.***

Frazioni volumetriche dei costituenti microstrutturali in una barra nervata di Φ 24 mm.

C	Mn	Si	Cr	Mo	V	Ni	Cu	S	P	CEQ
0.195	0.8	0.27	0.068	0.015	0.001	0.081	0.026	0.038	0.021	0.37

TAB. 3
Chemistry of Φ 24 mm TMT rebar (% wt).

Composizione chimica di una barra nervata di Φ 24 mm (% peso).

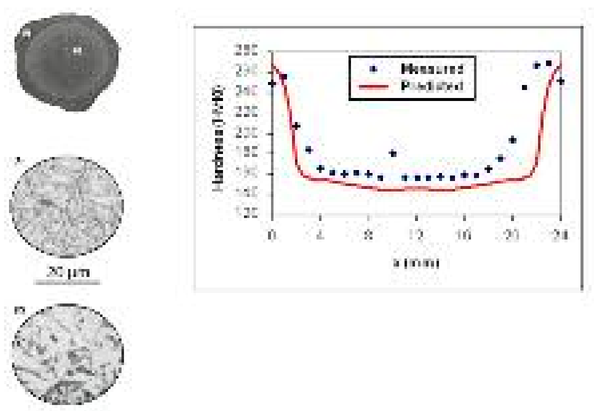


FIG. 15 ***Right - Comparison of actual and predicted hardness of Φ 24 mm rebar; left – Microstructure.***

Destra – Confronto della durezza Misurata contro Predetta di una barra nervata di Φ 24 mm; sinistra - Microstruttura.

Reliability %	Accuracy YS MPa	UTS MPa
68.4	± 9.57	± 11.32
95.2	± 19.14	± 22.64

TAB. 4 ***Performance of QTB PLUS System.***

Prestazioni del sistema QTB PLUS.

around 0.4. The YS and EL are more than 500 MPa and 12% respectively. Figures 16a-c show the comparison between measured and predicted values of YS, UTS, and UTS/YS ratio. A good match is obtained between the actual and predicted properties. Table 4 summarises the accuracy and reliability of QTB PLUS system.

CONCLUSION

To produce better quality products with uniform properties after heat treatment Danieli has developed two systems – one for the flat products (PQM) and another for the long products (QTB PLUS). The Plate Quality Monitor, an online system, has been developed successfully for prediction of mechanical properties of Q & T plates. The system has been validated with actual mechanical testing measurements. Good agreement has been obtained between the actual and the predicted properties. The error between the actual and the predicted values show normal distribution. The system predicts the mechanical properties at different locations within the plate. The prediction accuracy for 95.4% reliability (± 2) levels for all the measures are - HV ± 32, and YS and UTS ± 54 MPa each. The system has been integrated with the current Heat Treatment Plant Level II system.

Similarly for production of better quality long products – plain and rebar, and wire rod, the QTB PLUS system has been successfully developed. It can predict and control the mechanical properties such as YS and UTS. For any desired yield strength the system automatically computes and controls the quenching parameters. The system has been validated and implemented in Riva, Bar Mills at Verona (Italy) and Seville (Spain). The accuracy of the system was found to be ± 20 MPa for YS and ± 25 MPa UTS. The system is useful for better control of properties, optimization of processes, rationalization of grades, reduction of downgrades, and minimization of yield-loss.

REFERENCES

[1] Voestalpine Grobblech, “High Strength Heavy Plates”, May 2008, p. 7

[2] Streisselberger A., Bauer J., Flüss P., Hillenbrand H. G., and Cordon P., “High Strength Steel Plates for Linepipe in Grades up to X100”, Proc. of the Int. Symposium on “Materials for Resource Recovery & Transport”, ed. L. Collins, Calgary, Alberta, Canada, August 16-19, 1998, pp. 237 - 247

[3] Mukhopadhyay A., Polo A., Vidoni M., Cesile C., and Giovanni Z., “Online System for Controlling Mechanical Properties of Quenched and Tempered Plates”, Paper No 98, Proc. 3rd Int. Conf. on Thermomechanical Processing of Steels, 10-12 September 2008, Padua, Italy

[4] Mukhopadhyay A., Galasso L. M., Ena M., Buzzi G., “QTB Plus: Better Control for Mechanical Properties of Quenched and Tempered Bars”, AISTech 09, 4-7 May 2009, America’s Centre, St. Louis, USA

[5] Maynier Ph., Dollet J. and Bastien P., Rev. de Métall. 67, 1970, pp. 343-351

[6] Maynier Ph., Dollet J. and Bastien P., “Hardenability Concepts with Application to Steel”, ed. D V Doane and J S Kirkaldy, TMS-AIME, Warrendale, PA, 1978, pp. 163 - 168

[7] M. Avrami : J Chem. Phy., 9, 1941, 177

[8] B. Donnay, J. C. Herman, V. Leroy, U. Lotter, R. Grossterlinden and H. Pircher: 2nd Int. Conf. on Modelling of Metal Rolling Process, ed. P. Ingham, T. Teichert and K. Waterson, IOM, London, 1996, 23

[9] D. P. Koistinen and R. R. Marburger: Acta Metall., 7(1959), 59

[10] W. Steven and A. G. Haynes: J. Iron Steel Inst., 183, 1956, 349

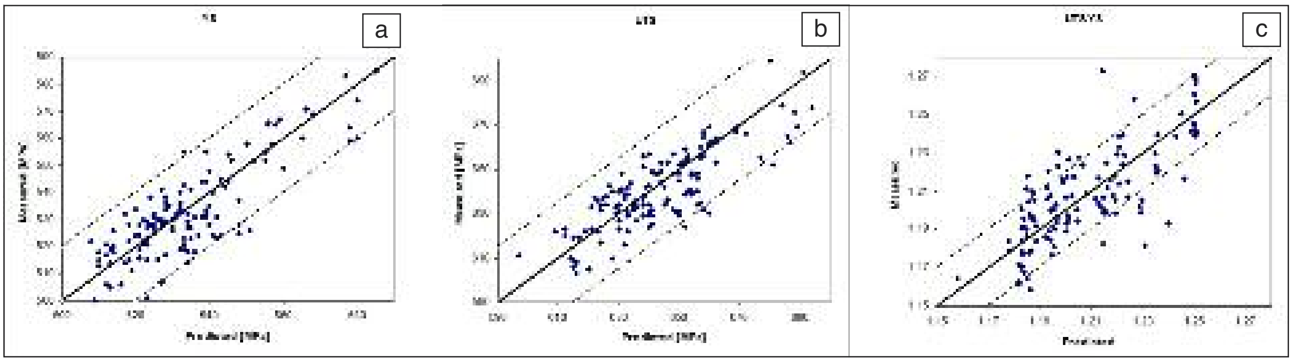


FIG. 16 ***Comparison between Actual vs. Predicted values of (a) YS, (b) UTS , and (c) UTS/YS ratio.***

Confronto tra i valori Misurati contro Predetti di (a)YS, (b) UTS, e (c) rapporto UTS/YS.

Abstract

Sistemi di automazione per trattamento termico e raffreddamento controllato di lamiere e barre

Parole chiave: trasform. di fase, tratt. termomeccanici, modellazione, controllo processi, qualità

Sia per una lamiera che per una barra, l'omogeneità delle proprietà meccaniche è un indicatore importante di qualità superiore. Per produrre questa tipologia di prodotti è necessario che i sistemi di raffreddamento siano propriamente controllati e regolati. Nella pratica usuale, le proprietà meccaniche vengono controllate dopo che il prodotto è stato fabbricato. Questo fa sì che non possa essere apportata nessuna azione correttiva. Un'accurata stima delle proprietà durante il processo di produzione è richiesta per controllare il sistema di raffreddamento. Danieli ha sviluppato i sistemi PQM e QTB PLUS per il monitoraggio ed il controllo delle proprietà meccaniche di lamiere e di barre in tempo reale.

La stima delle proprietà meccaniche come la resistenza allo snervamento YS, la resistenza a carico massimo UTS, la durezza HV e l'allungamento è eseguita tramite una serie di modelli matematici con base fisica, interconnessi fra loro, sostenuti da dati empirici e da linee guida per includere le incertezze del processo. L'accuratezza del sistema PQM è ± 54 MPa sia per YS che per UTS, e ± 32 punti per HV. Per il sistema QTB PLUS è ± 20 MPa per YS e ± 25 MPa per UTS. Questi sistemi sono utili per testare, per assicurare qualità e per il controllo di processo. Il QTB PLUS è stato implementato in due impianti del gruppo Riva, a Verona (Italia) e Siviglia (Spagna). Il PQM verrà implementato quest'anno in Iran.