ABSTRACT

Mathematical Modelling of Heat Transfer to Improve Water Spray Cooling Technology of Steel Rods

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ABSTRACT

The cooling technologies of wire rods and rebars depend of the steel grade and the destination of the mill product. The structure of the cooling equipment, the values of technological parameters involved in the cooling process must be established as a function of the manufacturers goals.

In the case of hot rolled rods of plain steel or low alloyed steel grades these goals are:

- the improvement of the mechanical properties of the finished products with the specific chemical composition;
- important savings due to the fact that subsequent thermal processes of the hot rolled product are no longer necessary;
- better mechanical properties without the use of expensive microalloying elements;
- the improvement of the weldability obtained by the use of low carbon and manganese steel grades (lower equivalent carbon).

The technological processes applicable in this case, generally assume a high reduction in the last stand of the finishing block after which the rolled rod is intensively cooled using water sprays, followed by temperature equalisation between the surface and core which will take place during the time necessary for the rod to reach the coiler. With such a technology one can obtain a ferrite-pearlitic microstructure, with fine grains in the core and with a tempered martensitic near surface zone.

Some typical technological processes frequently used in the industry taking advantage of the just mentioned principles are: the Temprimar

process developed by Stahlwerke Peine - Salzgitter, Thermocoil process used for example by the Brandenburg Factory Rod Mill, Tempcore process, for which Schloeman - Siemag A.G. has an international license accord, Thermex process, Forseq process, etc.

In the case of the wire rod rolled steel grades the main manufacturers goal refers to obtain characteristics more suitable for subsequent drawings.

Wire rod coiled in the regular manner after hot rolling normally has a fairly coarse structure with pearlite due to the slow cooling rate after the coiling. To improve the wire drawing properties, it is therefore most cases necessary to subject the wire to a patenting treatment sometimes during the drawing process.

Some typical technological processes frequently used in the industry taking advantage of the just mentioned principles are: the Stelmore process, used by Mannesmann Demag Sack, Schloeman - Siemag A.G.etc, the Rochling - Burnbach process developed by Moeller & Neumann, ED (Easy Drawing) process developed by Sumitomo Electric Industries Ltd. etc.

A proper choice of the technological parameters and of the structure of the cooling equipment is based, no matter what technological process one use, on a better modelling of the heat transfer during cooling.

This paper tries to model the heat transfer phenomenon during cooling for a proper analysis of the technological processes just mentioned. In parallel, we also analyse some technological processes used in Romanian rod and wire rod mills. Another feature of this paper is that it can be used to derive control algorithms in the case of automatic controlled cooling processes.

We assumed the cooling zone formed by three different type sub-zones, each with a specific heat transfer mechanism.

No matter the cooling technological process, there exists a zone situated between the last stand of the finishing block and the first water spray cooling zone, in which the product cools (in air), mainly through a radiation and free convection mechanisms. Due to the relatively high rolling speeds (10 - 70 m/s) compared with the lower speeds of the free convection phenomenon, the Grashof similarity criterion (Gr invariant) has very low values and for this type of zone one can neglect the free convection. That is why, in this zone the heat transfer mechanism can be described by the Stefan Boltzmann law.

The water spray cooling zones are characterised by a combined heat transfer mechanism of forced convection, due to the cooling water flux and of radiation through the water vapour film formed at the rolled product surface. The well-known difficulties linked with the use, in this case, of the Fourier equation can be avoided through the use, as is frequently the case in practice, of experimental results extrapolated to similar processes with the help of the similarity theory.

In those zones, between two subsequent water spray cooling zones, whose main function is to equilibrate the rod centre and surface temperatures, the same mixed heat transfer mechanism (radiation and forced convection) is acting, only in this zones the convection belongs to that of the unstable boiling film regime, due to the water driven by the material along its displacement.

We can derive the differential equation system that governs the heat transfer mechanism on each zone.

The paper develops a fully implicit CFD scheme in order to integrate the partial derivatives differential equation system on each zone. The coefficients involved in this equation are computed using the temperatures computed at the previous time step, the errors due to this approximation been minimised with the choice of a low time step (.005 s). This scheme conducts, for zone types II and III, a tridiagonal diagonally dominant linear algebraic equation system, which may be solved for example using the Gauss method. Due to the fact that time is a one-way co-ordinate it is possible an optimal use of the computing memory (we memorise only two n-dimensional vectors together with two (n-1) - dimensional vectors containing all the system coefficients).

On the first type zone, because of the non-linearity of the equations system, we applied the method proposed by S. V. Pantakar, to obtain a linear approximation of the generalised source term (a function of T4) with the use of a relation like the following one: S = SC + SP x T

where coefficients SC and SP are computed as SP = 0 and SC = S computed at the previous iteration.

Solving, with the use of the Gauss method, the system of linear algebric equations yielded with this method just described, one may obtain an approximate temperatures distribution in the cross section of the rolled product, at a certain time, approximation representing the input in an iterative process which will finally converge to the actual temperature distribution.

Our work brings further insight, compared with other studies of heat transfer analysis during the cooling of long rolled products, rolled steel rods and wire rods (Morales R. D. and others, ISIJ International, vol. 30, no. 1, 1990; Anelli E. and others, IQ Special issue, 1993; Sasaki K. and others, Tetsu-to-Hogane, vol. 65. no. 90, 1975; Hoogendoorn C. J. and others, Proc. 5th International Heat Transfer Conference, paper B 3.12, Tokyo, Japan, 1974 etc.) while proposing a general method, applicable to both the technological processes for rolled rods and to the technological processes for rolled wire rods. The paper presents also a comparison between the various relations proposed by different authors for deriving the combined heat transfer coefficients and the necessary corrections, for the case of rolled steel rods and wire rods, yielding from experimental data and also a comparison between various technological processes recommended for a specific product. We are also presenting the spectacular results that were achieved after applying a cooling technology whose parameters were obtained by using the conceived mathematical model. These results permitted several rolled products to be classified in a steel grade with higher tensile strength properties.