Numerical study of quenching heat treatment: Influence of the cooling modes on the hardness

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Abstract: - This paper is part of a research project aimed at improving the mechanical properties and microstructural of the grinding ball. In this study, we are interested in the numerical analysis by the finite difference method of quenching to examine the influence of quenching media on cooling rate and hardness. The numerical calculation was carried out using the FORTRAN language. The study is carried out on two alloy steels C32 and C70, simulating cooling curves from TTT diagrams. The results obtained for different cooling modes show that the material structure, the cooling rate and the hardness depend on the cooling medium.

Key-Words: - Numerical analysis, finite difference, quenching media, alloy steels.

1 Introduction

Heat treatment operation is a means of controlled heating and cooling of materials in order to effect changes in their mechanical properties. Heat treatment is also used to increase the strength of materials by altering some certain manufacturability objectives especially after the materials might have undergo major stresses like forging and welding. The quenching process [1-5] is a heat treatment generally used to progress the mechanical properties of steel products [6-7], such as hardness [8], stiffness, and strength, The main rationale of the heating and the investment is the transformation of the early material structure into a homogeneous austenitic phase, during the last stage of the process, forced cooling of the work part is used to induce the appropriate decomposition of austenite into several microstructures [9], ferrite, and Fe carbide, in function on the chemical composition of the processing steel and the cooling rate.

Carlone et Al. [10] presented a numerical analysis of the steel quenching process with a finite element method; concerning the transient temperature field and the thermally induced solid-solid phase transformations. The finishing hardness distribution into the quenched example has been predicted according to the taking into description the chemical composition of the processing material, the final division of each phase and the local cooling rate. Deng and Ju [11] conducted a modeling and simulation a heat treatment process to attain maximum robustness and ductility at a specified hardness and strength. The model is implemented inside the framework of the developed simulation code COSMAP to simulate microstructure, stress and deformation in the heat treated constituent. It is applied to simulate Q&T process of J55 steel. The calculated results show a good accord with the experimental ones. This accord indicates that the model is effective for simulation of Q&T process of steels. Analyzed quenching heat conduction in metallic materials was conducted by Teixeira et Al. [12]. The calculation domain contains the simpler approach lacking thermal–mechanical coupling of deformation, by considering the nonlinear temperature dependence of thermal parameters as the only effect due to those complex behaviors. Fontana et Al. [13] presented a numerical simulation of immersion quenching process of an engine cylinder head, was studied numerically using a commercial code AVL-FIRE v8.5.A comparison of the registered temperature analyses at different monitoring locations with the numerical results an global very good agreement and shows the presence of extreme non-uniformity in the temperature distribution within the solid. Inclusive, the projecting capability of the new boiling model is well demonstrated for real-time quenching applications.

In this work, we are interested in the numerical simulation of quenching heat treatment for different cooling modes to examine the influence of quenching media on the cooling rate and the austenitisation temperature effect on hardness.

2 Material characteristics and parameters of thermal

The alloy steel C32 and C70 are chosen to study in this paper. Their chemical composition detected by spectrometer is shown in Table 1. The austenitization temperature and the quenching time is set at 850 ° C. and 30 minutes, with the critical cooling rate 10 °C/s. A heated cylinder of diameter 50 mm and thermal conductivity k and the medium for quenching is water or oil.

Table 1. Chemical compositions of C30 and C70 steel

Chemical elements	C32 [Wt %]	C70 [Wt %]
Fe	98.0	97.7
C	0.447	0.399
Si	0.32	0.357
Mn	0.59	0.85
P	0.003	0.013
S	0.031	0.037
Cu	0.208	0.262
Al	0.027	0.021
Ni	0.099	0.165
Cr	0.159	0.115

3 Mathematical model

Assuming the processing material as isotropic and considering that there are no mass transport phenomena, the conservation of the thermal equation, according to the first law of Fourier, the equation can be written as:

$$\rho C_P \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + S \qquad (1)$$

4 Numerical method

We choose to solve the thermal equation by the finite difference method. The A.D.I method is employed to calculate the temporal term and the diffusive terms are discretized using a second-order central scheme. The numerical solved was employed in a FORTRAN program. The industrial code "WAM" automatically simulates cooling curves from TTT charts and calculates the hardness.

5 Results and discussion

5.1 Effect of the cooling modes on the hardness

We are initially interested in the influence of cooling model of the piece that immersed in a middle that is going to extract the calories of the piece. The austénitisation temperature and the quenching time are fixed to 850°C and 30 minutes.

In this result provided by computational simulations of cooling processes, performed according to the implemented model and assuming a constant cooling rate for simulation. In Figure 1 and 2, computational results are shown with the well know Time-Temperature Transformation (TTT) diagram.

The quenching media which we are going to study are water and oil.

The figure 1 and 2 present successively the cooling of steel C32 and C70 by water and oil a function of time, it can be observed that the temperature fall in the case of quenching by water faster than oil quenching. It is noted in both steel that the hardness obtained for a water quench greater than that of oil.

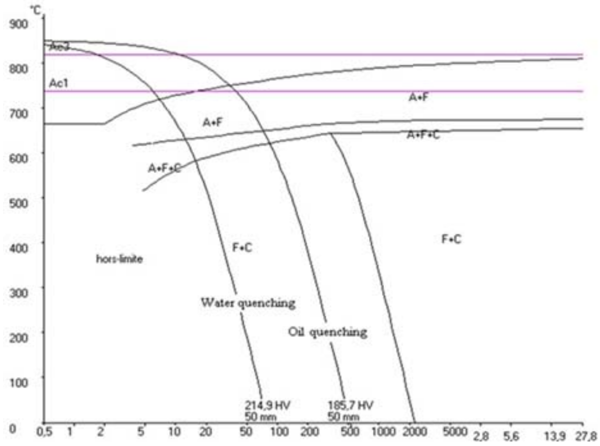

Fig. 1. Cooling curves of C32 steel by water and oil shown on a TTT diagram

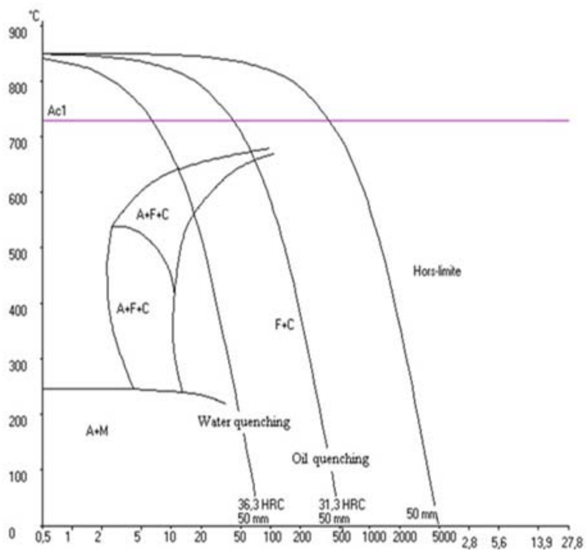

Fig. 2. Cooling curves of C70 steel by water and oil shown on a TTT diagram

5.2 Heat transfer in the cylinder

Finally, the implemented finite difference method has been used to simulate the water quenching process of a C32 steel cylindrical sample, for validation numerical model and to investigate the thermal effects of the process on the work piece. Specimen height and diameter have been assumed, respectively, as 50 mm. Account the cylindrical shape of the sample; a two-dimensional model has been adopted. The number of grid points selected was 51×51. The initial temperature of the sample has been considered as consistent and equal to 850 C. A 90 s water quenching procedure has been simulated considering a temperature dependent heat transfer coefficient, supposing the temperature of the quenching middle as 23C.

In figure 3 are exposed the temperature profiles to the cooling curves of the points A, B, C, D, and E, placed, respectively at radial distances equal to 0, 25, 37.5, 43.75, and 50mm from the cylinder axes. The temperature profiles to the cylinder center (A) and exterior (E), are compared with the results report in [10]. Good accord has been established between the numerically evaluated cooling curves and the reference data. Because evidenced, the negligible effect of the latent heat due to a phase change on the cooling curves relative to the points D and E, in the proximity of the external quenched surface, has been found, due to the small enthalpy change correlated to the austenite_martensite decomposition and to the highly cooling facility on the cylinder surface. A relatively small effect can be observed in the cooling curves to the points B and C, owing to the faster cooling, which implies that the method is completed at a relatively minor temperature, resulting in lower enthalpy variations.

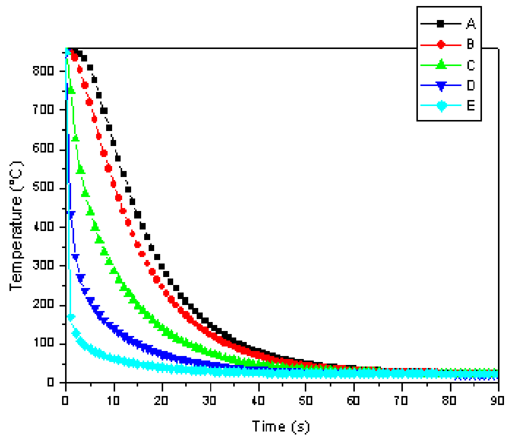

Fig. 3. Temperature profiles on water quenching of C32 steel

6 Conclusion

In this study, the numerical simulation of the process of quenching in steel parts had been presented. Is to appreciate the advantages and disadvantages of this industrial application, it is necessary to study the system from several angles. With the purpose to use results concerning the influence of the cooling medium on the hardness and heat transfer inside a cylinder plunge into the water. The results obtained show that the hardness for cooling by water large than oil, is therefore, recognized as the most effective quenching for the water.

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