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INFLUENCE OF THE COOLING SPEED ON THE HARDENABILITY OF A HYPOEUTECTOID STEEL

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ABSTRACT
The work contains a study about the influence of the cooling speed on the hardenability of a hypoeutectoid steel which has 0,4%C, 1,5 %Mn, 0,5 %Mo in its chemical composition and also the microstructure obtained for the studied steel in certain continuous cooling conditions (according to the CCT diagram).

KEY WORDS:
hypoeutectoid steel, hardenability, critical hardening speed, CCT diagram

1. Introduction

The hardenability is a technological characteristic given a very big importance in the practice of thermal treatments because it helps to determinate the proportion of martensite obtained by applying the specific treatment named martensitic hardening; this has bigger hardness values and resistance characteristics than those which correspond to the structure resulted through the application of other thermal treatments.

Thus, through hardenability we understand the penetration depth of the quenched area. The hardening penetration depth is the distance from the surface to the layer with a half-martensitic structure (i.e. the layer whose structure is 50% martensite and 50% toostite). Hardenability should not be confused with hardness, as such, or with maximum hardness. The maximum attainable hardness of any steel depends solely on carbon content. The hardenability of steel is governed almost entirely by the chemical composition (carbon and alloy content) at the austenitizing temperature and the austenite grain size at the moment of quenching. Such factors as time at the austenitizing temperature and prior microstructure are sometimes very important variables when determining the basic hardenability of a specific steel composition [3].

A first criterion to appreciate steel's hardenability is the critical hardening speed defined through the minimum cooling speed, which assures the integral transformation of austenite into martensite. This is determined with the help of the isothermal transformation diagram (the TTT diagrams – Time-Temperature-Transformation) and of the anisothermal transformation diagram of the austenite (the CCT diagrams - Continuous Cooling Transformation).

Between the critical cooling speed and the quench penetration depth there is a connection highlighted by the fact that the hardened area always represents that portion from the product's section, which has cooled with speeds equal or higher than the critical cooling speed.

2. Determining the critical hardening speed

The critical hardening speed expresses the transformation stability of the austenite during cooling and is inversely proportional to the minimum incubation period of the under-cooled austenite.

The critical hardening speed is determined from the continuous cooling transformation diagram of the austenite (the CCT diagram) and it is higher when the martensite proportion must be higher. Usually, three critical hardening speeds are determined for some steel (figure 1.1.) [3]:

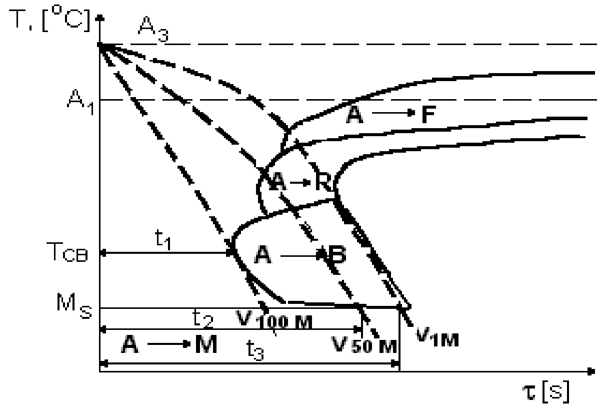

Figure 1. Determining the critical hardening speeds with the help of the CCT diagram

- the inferior critical speed $(v_{cr,i})$, respectively the minimum cooling speed with which about 1% martensite is obtained $(v_{1\,M})$:

$$v_{1\,M} = \frac{A_3 - M_s}{t_3} \tag{1}$$

- the half-martensitic critical speed (v_{SM}), respectively the speed with which 50% martensite is obtained in the hardening structure $(v_{50\,M})$:

$$v_{50\,M} = \frac{A_3 - M_s}{t_2} \tag{2}$$

- the superior critical speed $(v_{cr,s})$, i.e. the minimum speed needed to obtain 100% martensite $(v_{100\,M})$:

$$v_{100\,M} = \frac{A_3 - M_s}{t_1} \tag{3}$$

The CCT diagrams are used in engineering applications to choose the proper steel and the cooling speed needed to obtain a certain type of properties, because the parts are cooled (in air, water, together with the furnace etc.) from the processing temperature which is more economical than transferring the parts in another furnace for a isothermal treatment.

These diagrams establish the degree of transformation of the austenite as a time function for a continuous decrease of the temperature. For this, the specimen is warmed at the austenitisation temperature and then it is cooled with a predetermined speed to measure the degree of transformation, for example through the dilatometric analysis. Except for annealing and isothermal hardening, all the other thermal treatments applied to steels present a continuous cooling phenomenon at different speeds.

3. Study on the microstructure obtained at the sub-cooling of the austenite at a hypereutectoid steel

As the cooling speed grows, the degree of sub-cooling of the austenite in relation with the balance temperature A_1 increases and the interval of the decomposition temperatures decreases [1].

Most heat treatments for steels begin by heating the specimen into the austenite phase field. The resulting austenite is then cooled continuously to room temperature. This is achieved by plunging the specimen into a bath of water or oil, or by removing it from the furnace to cool in air ("normalising"). If very slow cooling is required then the sample is left in the furnace, which is switched off. The actual cooling rates may vary in different regions of the sample. These variations may be large since steels are relatively poor conductors of heat (thermal diffusivity of steel is about 10^{-5} m^2 s^{-1}, of copper about 10^{-4} m^2 s^{-1}).

The properties of steels are sensitive to microstructure. It is useful to know how the microstructure develops in different parts of a specimen during heat treatment. For a given steel composition, a Continuous Cooling Transformation (CCT) diagram can be constructed from experimental data, allowing the microstructural development to be followed as a function of the cooling conditions.

Further on the steel structure is presented (according to the anisothermal transformation diagram of the austenite) which has in its chemical composition 0,4%C, 1,5%Mn, 0,5%Mo sub-cooled with different speeds:

- *small cooling speed*. At small degrees of sub-cooling specific to cooling with the furnace, in the case of the studied steel, the austenite is decomposed in ferrite and pearlite as noticed in figure 2:

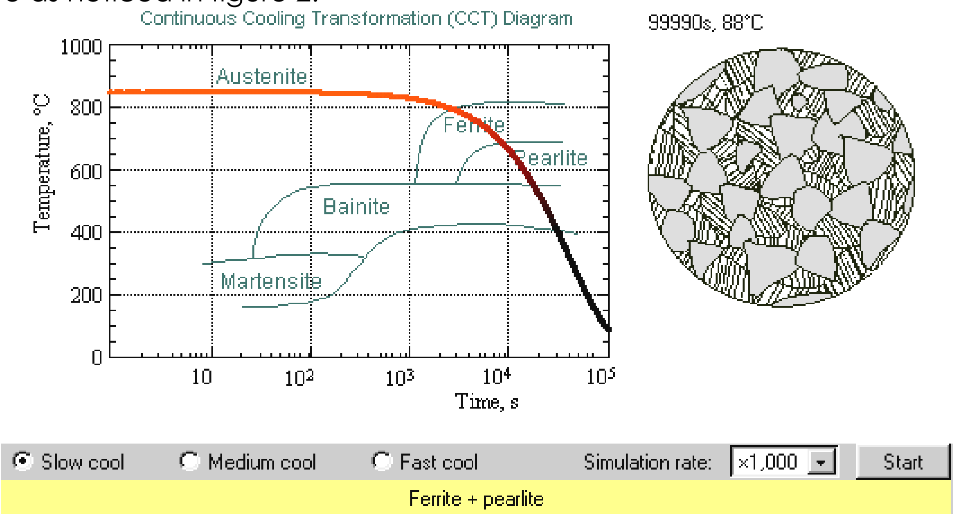

Figure 2. The anisothermal transformation diagram of the austenite sub-cooled with small speed, in the case of the steel with 0,4 % C, 1,5 % Mn, 0,5 % Mo and the resulted microstructure

- *medium cooling speed*. This cooling speed is specific to air cooling and it leads, in the case of the studied steel, to the formation in structure of the bainite (figure 3):

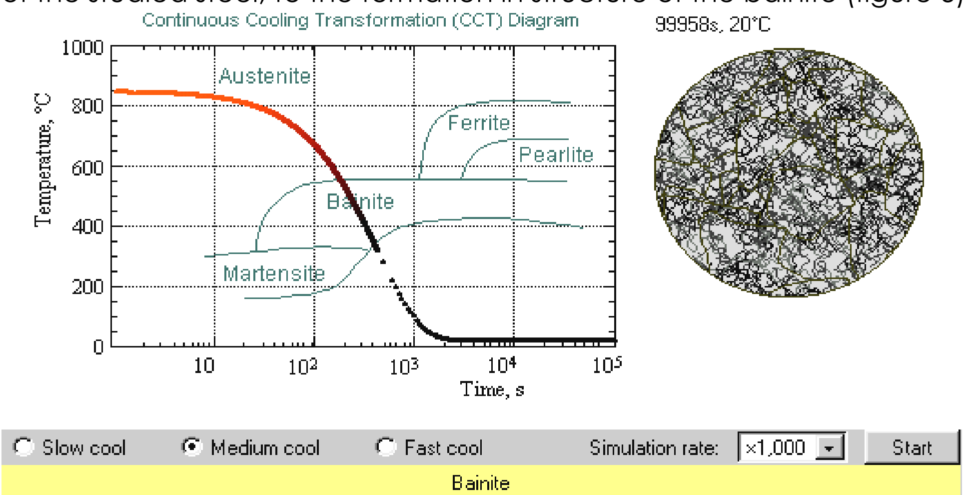

Figure 3. The anisothermal transformation diagram of the austenite sub-cooled with medium speed, in the case of the steel with 0,4% C, 1,5 % Mn, 0,5 % Mo and the microstructure resulted

- *high cooling speed*. At high degrees of sub-cooling, the decomposition of the austenite in a mechanical mixture of ferrite and cementite becomes impossible as the diffusion phenomena are hindered and the entire quantity of austenite sub-cooled until the temperature M_S is transformed into martensite (figure 4).

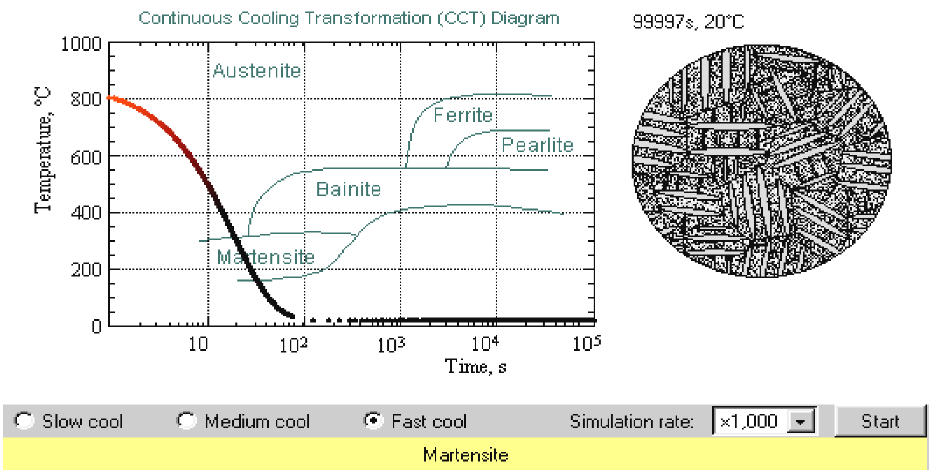

Figure 4. The anisothermal transformation diagram of the austenite sub-cooled with high speed in the case of the steel with 0,4 % C, 1,5 % Mn, 0,5 % Mo and the microstructure resulted

It is known that martensitic transformation is not complete and therefore any hardened steel shall have in its structure a certain quantity of residual austenite. The minimum cooling speed, which assures the integral transformation of the sub-cooled austenite until the M_S point in the martensite is the critical hardening speed. Under the conditions of continuous cooling the austenite does not transform at a certain constant temperature but in a certain temperature interval.

4. Conclusions

The processes, which take place upon the cooling of the austenite present a great theoretical and practical importance because the mechanism and the kinetics of these processes influence the nature, the shape, the size and the distribution of the phases in the steel structure; thus they determine corresponding properties after the thermal treatment.

Hardenability of steel is the property that determines the depth and distribution of hardness induced by quenching from the austenitizing temperature. Steels that exhibit deep hardness penetration are considered to have high hardenability, while those that exhibit shallow hardness penetration are of low hardenability. Because the objective in quenching is to obtain satisfactory hardening to some desired depth, it follows that hardenability is usually the most important single factor in the selection of steel for heat-treated parts. The cooling speed is an essential parameter as it determines the proportion of martensite in the hardening structure. Ideally a completely martensite structure should be obtained (100 M) through quenching but this is practically impossible. To obtain the minimum martensite proportion, steel must be cooled with a proper minimum speed (called critical hardening speed) which is determined from continuous cooling transformation diagram of the austenite (a CCT diagram) and the higher the martensite proportion must be, the higher this speed is. In the case of the studied steel small speed cooling, specific to cooling with the furnace, determines the in structure formation of ferrite and pearlite. At an average cooling speed, which is specific to air-cooling, the bainite appears in the structure and in the case of the high cooling speed the martensite with a certain quantity of residual austenite appears.

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