Establishing CCT Diagrams for Sinter Hardening Grade Cr-Mo Prealloyed Steels

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Abstract

A CCT diagram for Cr-Mo prealloyed sintered steels suitable for sinter hardening was established by combining dilatometry data, microstructural studies and microhardness measurements of the material. CCT diagrams deepen the understanding of material properties after sinter hardening and support the design of materials on an industrial scale by providing information about required cooling rates for successful sinter hardening of these materials.

Keywords : sinter hardening, Cr-Mo prealloyed steels, CCT diagrams, dilatometry

1. Introduction

Sinter hardening is of growing importance for the production of structural parts in the global PM market[1]. Cr-Mo prealloyed steel powders, which have been introduced to PM in recent years, are well suited for sinter hardening. Knowledge about the hardenability of these materials and the resulting material properties is indispensable for the successful parts production by sinter hardening.

Continuous-**C**ooling-**T**ransformation diagrams[2] were developed to provide information on hardenability of materials. Since sinter hardening differs in several ways from classical hardening processes, CCT diagrams for sinter hardening steels are modified to simulate the peculiarities of the sinter hardening process[3].

In sinter hardening the austenitisation temperature T_A is in fact the isothermal sintering temperature, therefore T_A in a CCT diagram should be chosen near the real sintering temperature. Contrary to conventional CCT diagrams, which utilize linear cooling operations, sinter hardening is done with exponential cooling operations. This fact is taken into account in the design of CCT diagrams for sinter hardening. Industrial scale sinter hardening processes work in a comparatively small range of cooling rates, CCT diagrams simulating such processes reflect this by a set of cooling operations near the cooling rates of interest. The time axis of the resulting diagram therefore does not have to be scaled logarithmically.

2. Experimental and Results

A sinter hardening grade Cr-Mo prealloyed steel was chosen as testing material. Samples with the dimensions 4mm x 4mm x 10mm were prepared from already sintered materials for the dilatometric measurements (high speed dilatometer DIL-805A, Bähr). The samples were heated with 20K/s to 1100°C and austenitised for 5min in vacuum. The rapid cooling was achieved by a severe quench with Ar 5.0. For each of the materials exponential cooling operations from 1100°C to 100°C were performed at several cooling rates and the dimensional change of the samples was measured. Dimensional change of the examined material during cooling operations occurs not only because of thermal contraction but also due to martensite and/or bainite formation. As soon as a transformation of austenite (fcc unit cell) to bainite or martensite (bcc unit cell, elongated in case of martensite) starts, a significant expansion of the material occurs. The start temperature of the expansion can be detected by plotting the dimensional change per second against temperature during the cooling operation. Since the correlation between time and temperature during the cooling operation is

$$T = T_A e^{-kt} \tag{1}$$

(T_A is the austenitisation temperature of 1100°C, k is a constant representing the velocity of cooling) and the dimensional change due to thermal expansion is

$$\Delta L = \alpha L(T - T_0) \tag{2}$$

(α is the thermal expansion coefficient, L is the sample length at T_0 = 20°C), the correlation between relative dimensional change per second [%/s] and temperature during the cooling operation is

$$\frac{d(\frac{\Delta L}{L})}{dt} = -k\alpha T \tag{3}$$

provided there is no dimensional change due to transformation. Any deviation from the linear behaviour illustrated in (3) is caused by transformation of austenite.

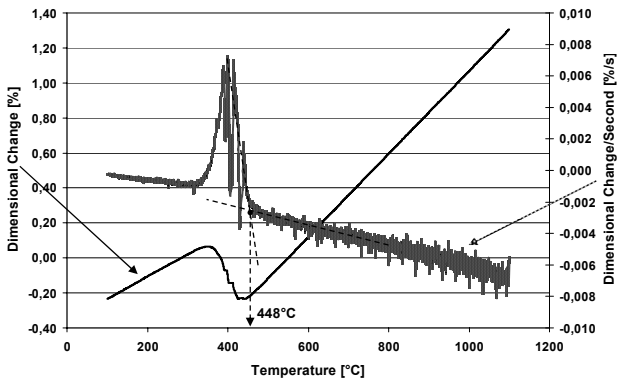

Fig. 1. Detection of a transformation (austenite to bainite) by observing the dimensional change per second: Start of the transformation at 448°C.

For ease of handling each cooling operation was labeled by a theoretical linear cooling rate CR in [K/s] obtained by

$$CR[K/s] = \frac{1000K}{(t_{100°C} - t_{1100°C})s} \qquad (4)$$

The observed transformation temperatures at different cooling rates were combined to a CCT diagram. After the dilatometric measurements the samples were metallographically prepared[4] and the microstructures examined. The matrix hardness was measured (HV 0,05).

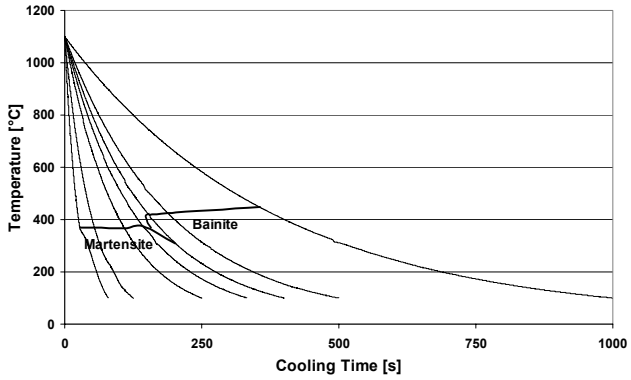

Fig. 2. CCT diagram of the examined material.

A fully martensitic microstructure could be obtained at cooling rates above 2,5K/s calculated with (4), transformation of austenite to martensite started at approx. 370°C (Fig. 2).

Cooling rates of 2,5K/s or lower yielded dual phase bainitic/martensitic microstructures or pure bainite.

Table 1. matrix hardness at various cooling rates

CR[K/s]	16	8	4	3	2,5	2	1
HV0,05	493	472	467	487	486	437	382

The matrix hardness of the material is in the range of 467 to 493HV0,05 after cooling at 2,5K/s or faster. Slower cooling rates yield significantly lower hardness values (Table 1).

3. Summary

A CCT diagram of a Cr-Mo prealloyed sinterhardening steel was established. Compared to conventional CCT diagrams three modifications were done to achieve a better simulation of the real sinterhardening process.

An austenitisation temperature of 1100°C was chosen to reflect the isothermal sintering temperature in sinterhardening. The cooling operations were performed utilizing exponential cooling curves. The small interval containing the observed cooling rates permitted a linear scaling of the diagrams time axis. Transformations were detected by observing the relative dimensional change per second against temperature, each deviation from a linear correlation is caused by a crystallographic transformation of the material.

Dilatometry is a suitable method for detecting small amounts of bainite. Matrix hardness dropped from 486HV0,05 after cooling at 2,5K/s to 437HV0,05 after cooling at 2K/s. Both cooling rates produce a dual phase martensitic/bainitic microstructure. However, the matrix hardness at 2,5K/s (486HV0,05) is virtually the same as the matrix hardness of fully martensitic microstructure (approx. 480HV0,05). The amount of bainite formed at 2,5K/s is therefore not sufficient to lower the matrix hardness significantly, matrix hardness measurements would not have been a suitable method to detect the formed small amount of bainite.

4. References

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