INFLUENCE OF HEAT TREATMENT ON THE MICROSTRUCTURE AND HARDNESS OF A LOW ALLOYED COMPLEX PHASE STEEL

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Abstract:

Different cooling rates were applied to a complex-phase steel grade CP800 in order to analyze the evolution of its microstructure. The microstructure was characterized and quantified by light optical microscopy (LOM). The amount of retained austenite was measured by a magnetic-volumetric method. To correlate the microstructure with the mechanical properties, Vickers hardness tests were made.

Keywords: advanced high strength steels, complex-phase steels, microstructure, cooling rates

INTRODUCTION

Recent developments in the automotive industry have concentrated on the development of high strength steels. The reduction of mass, CO_2 emissions and fuel consumption accompanied with increasing passenger safety requirements led to cooperation between steel industry, research institutes and the automotive industry. In the framework of the ULSAB-AVC program (Ultra Light Steel Auto Body – Advanced Vehicle Concept), AHSS-grades (Advanced High Strength Steels) were developed, which exhibit higher strength and better formability than conventional automotive steels. AHS steels consist of hard phases like martensite, bainite and retained austenite embedded in a soft ferritic matrix. The family of AHSS, shown in Fig. 1, includes dual-phase steels (DP, ferritic-martensitic), ferritic-bainitic steels, TRansformation Induced Plasticity steels (TRIP, ferritic-martensitic with retained austenite), complex-phase steels (CP, ferritic-martensitic-bainitic with or without retained austenite) and martensitic steels (PM) [1, 2].

The selective formation of phases is the main way to obtain both the desired microstructure and mechanical properties. Therefore, the interaction of production process, microstructure and mechanical properties has to be known.

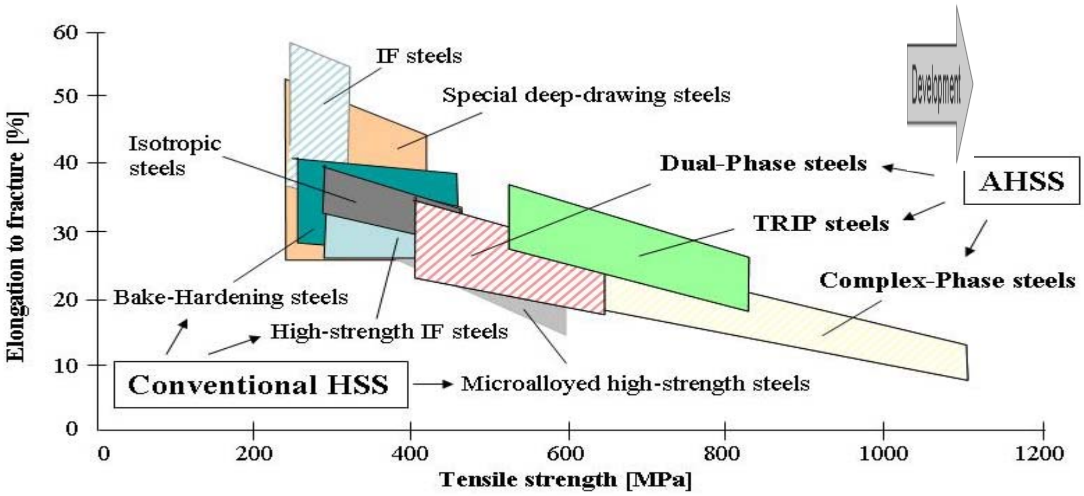

***Fig. 1** Elongation-strength relationship between different steel families and the interdependence between microstructure, production process and mechanical properties*

EXPERIMENTAL PROCEDURE

An industrially produced sheet steel (strength level 800 MPa) was investigated. The steel was hot rolled to a thickness of 3,8 mm with a finishing temperature between 850-920°C and coiled between 680-720°C. After hot rolling the material was cold rolled to a thickness of 1,2 mm and standard head treated in order to crate an complex-phase steel. Its chemical composition as well as its mechanical properties are listed in Table 1.

Table 1 Chemical composition and mechanical properties of a standard CP800 produced by voestalpine Stahl Linz

Grade	Chemical composition [wt.%]						$R_{p0,2}$ [MPa]	R_m [MPa]	A_g [%]	A [%]
	C	Si	Mn	Cr	P	Nb				
CP800	0,14	0,19	2,21	0,27	0,053	0,022	557	865	12,6	17,8

The variation of the cooling rate was realized with a quenching- and deformation dilatometer DIL 805A/D of Bähr-Thermoanalyse GmbH. For the dilatometric investigations specimens were wire cut from the sheet material parallel to the rolling direction (RD) as shown in Fig. 2a.

To study the influence of the cooling rate on microstructure and hardness, specimens were heated up to 850°C (complete austenitization) with a heating rate of 20 K/s. After holding for 60 seconds, the material was cooled to room temperature with cooling rates varying from 0,6 K/s to 120 K/s (Fig. 2b). The dilatation of the specimens was measured continuously to monitor the phase transformations during cooling. From there data and microstructural investigations a continuous cooling-transformation (CCT) diagram was constructed.

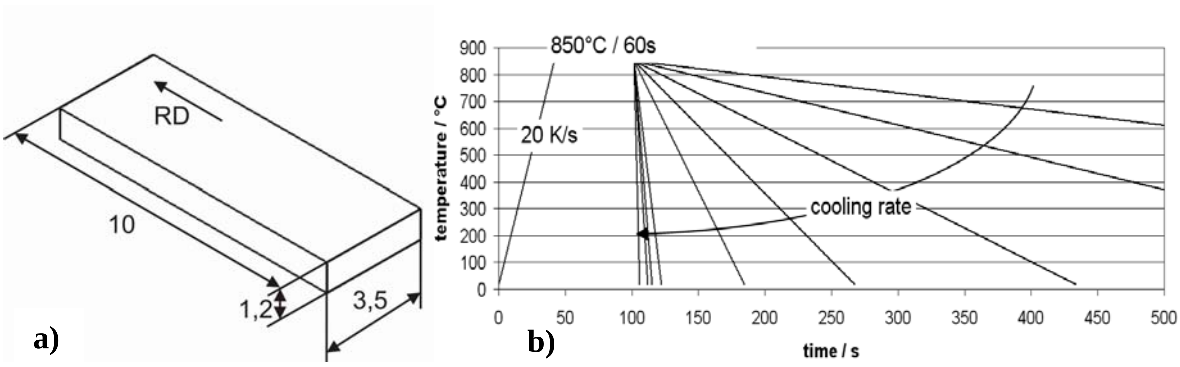

Fig. 2 *a) Specimen dimensions in mm; b) Applied cooling cycles*

The heat treated specimens were prepared metallographically, etched with LePera and analyzed with light optical microscopy (LOM). Ferrite grains appear blue, bainite/tempered martensite (TM) brown, pearlite black and martensite white. Line intercept method was used for a quantitative description of the microstructure, employing a line distance of 5 µm and an analyzed area of 50.000 µm^2 (10 images) for statistic accuracy [3].
The content of retained austenite was measured via magnetic-volumetric measurements (saturation magnetification, Joch-Isthmus method) [4].
The hardness was determined with Vickers HV1 measurements (load 9,807 N), according to DIN EN ISO 6507-1.

RESULTS AND DISCUSSION

The results of the quantitative phase analyses after applying different cooling cycles are shown in Fig. 3. The phase fractions are plotted against the cooling rates (0,6 K/s up to 120 K/s).

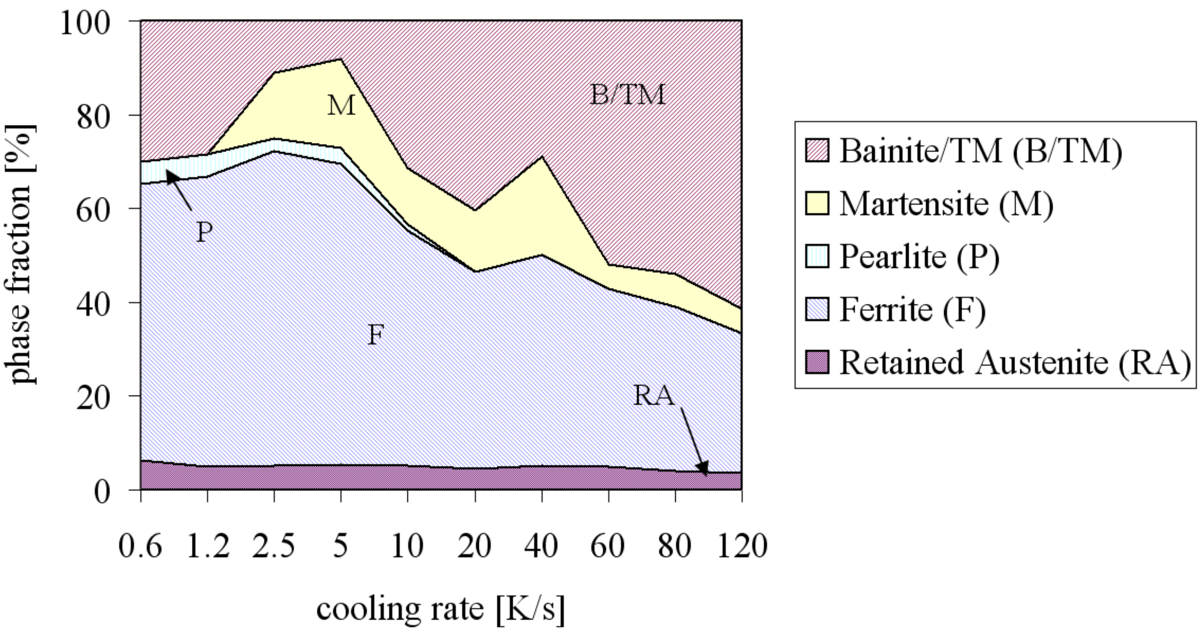

Fig. 3 *Phase fractions of the specimens after the different cooling cycles*

The resulting microstructure after cooling with the lowest cooling rate of 0,6 K/s consists of ferrite (59%), bainite/TM (30%), retained austenite (6%) and some pearlite. With a cooling rate of 20 K/s the microstructure is composed of 42% ferrite, 40% bainite/TM, 13%

martensite, 5% retained austenite and no pearlite. The amount of ferrite decreases to 30% as for a cooling rate of 120 K/s. This is balanced by a higher fraction of bainite. Cooling with high cooling rates makes tempered martensite appear rather than bainite. This is also evidenced by the CCT diagram shown in Fig. 4. Rapid cooling impedes ferrite formation and carbon enrichment of the remaining austenite. The decreased austenite hardenability (due to its low carbon content) and the absence of adequate time for the necessary diffusions of carbon during cooling, both resulting in a high M_s-temperature, provoke the formation of autotempered martensite [5].

Martensite formation takes place at cooling rates above 2,5 K/s. This martensite is auto-tempered and turns into tempered martensite. Since tempered martensite appears similar to bainite, it is not possible to distinguish bainite from tempered martensite from light optical micrographs. This, however, becomes possible by analyzing the dilatometric data.
The amount of retained austenite is in a range between 3 and 6% for all heat treatments, increasing slightly as the cooling rate decreases.

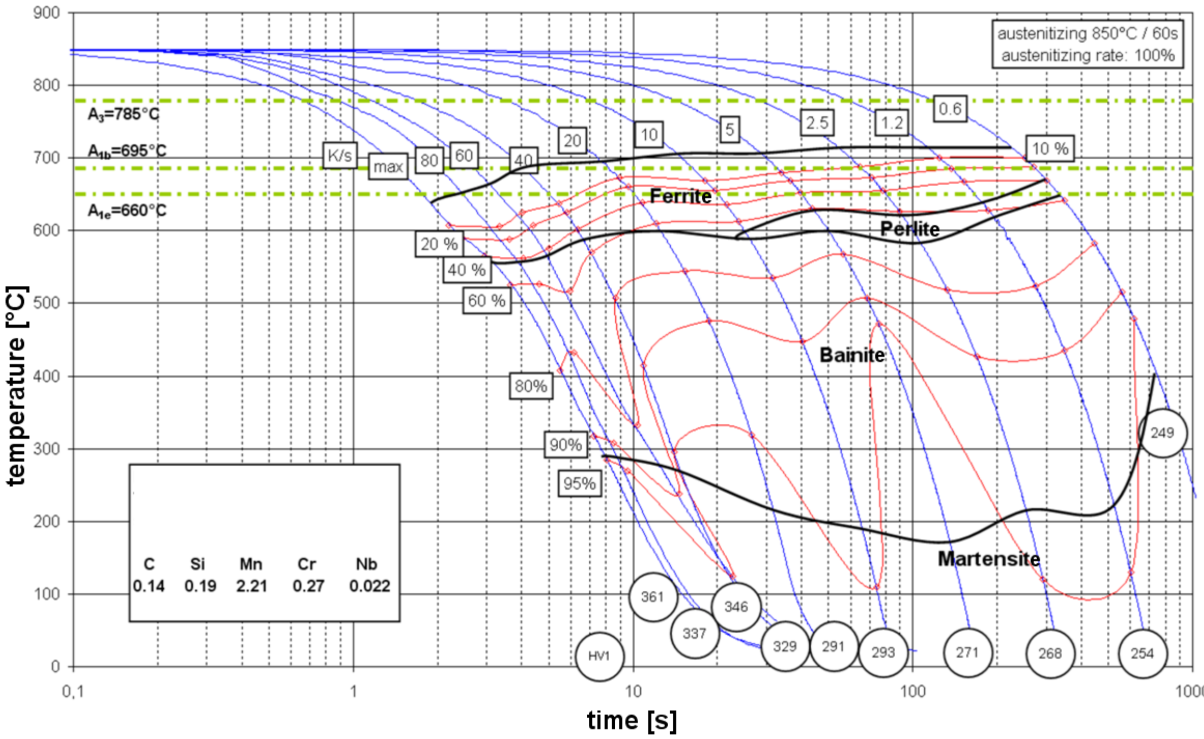

Fig. 4 *CCT of the investigated steel grade*

The microstructure development is illustrated also by the light optical micrographs given in Fig. 5. The microstructure appears fine-grained after application of higher cooling rates due to suppressed grain growth.

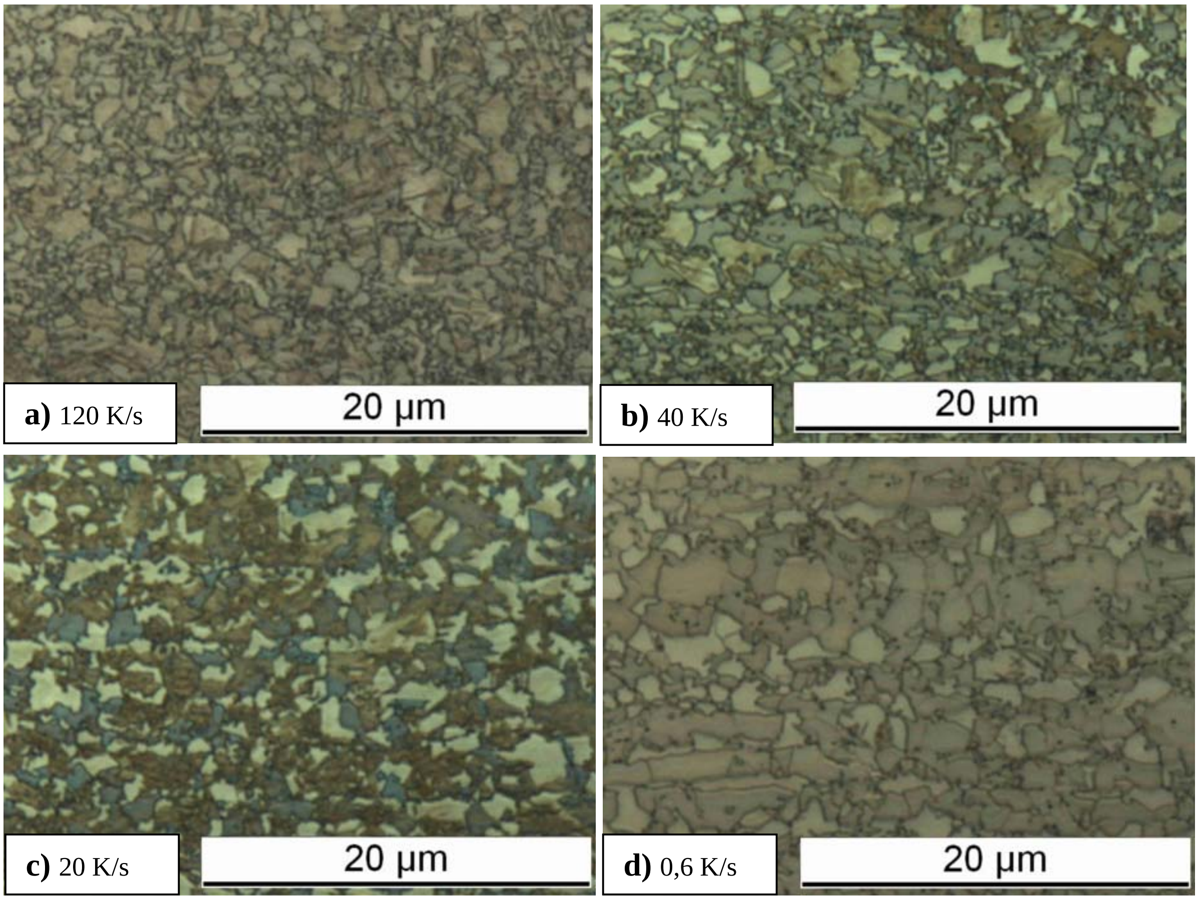

Fig. 5 *Micrographs of selected specimens*

The hardness measurements show a marked dependence of hardness on the microstructure of the specimens. Since the HV1 hardness imprint is larger than 100 grains a mean hardness for the microstructure is determined. This overall hardness increases with increasing cooling rates as can be seen in Fig. 6 (361 HV1 for a cooling rate of 120 K/s, 249 HV1 for 0,6 K/s). As the amount of retained austenite is rather low, the main impact on hardness is due to the fractions of ferrite and bainite/TM. A high amount of bainite and a low amount of ferrite is responsible for a high hardness.

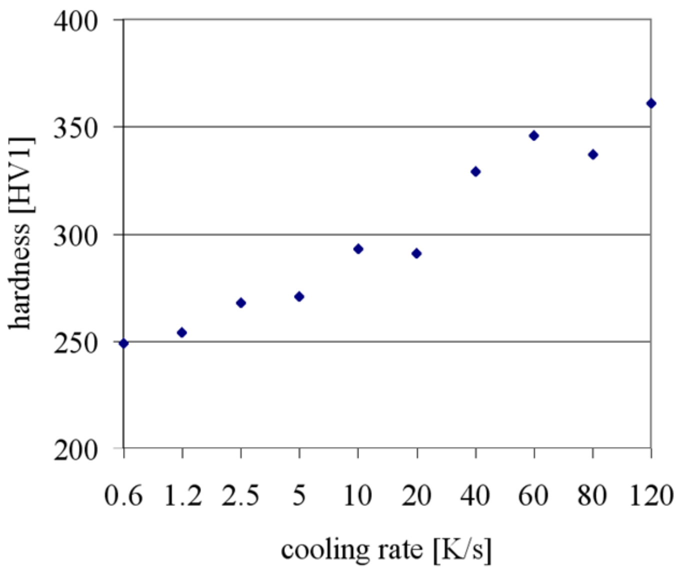

Fig. 6 *Mean steel hardness as function of cooling rate*

SUMMARY

Heat treatments were conducted in the laboratory on an industrially produced complex-phase steel with a strength level of 800 MPa. Different cooling cycles and their effect on the microstructure were investigated. The cooling rate influences the formation of ferrite and bainite/tempered martensite (TM), but has no impact on the amount of retained austenite. High cooling rates suppress ferritic formation and favor the martensitic transformation. At very high cooling rates martensite becomes auto-tempered and is hardly distinguishable from bainite. Hardness of the microstructures increases with increasing cooling rates, increasing bainite/TM fraction and finer grains.

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