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Characterization on carbide of a novel steel for cold work roll during solidification process

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ABSTRACT

A novel steel for cold work roll was developed in this work. Its phase structures were determined by X-ray diffraction, and phase transformation temperatures during the cooling process were measured by Differential Scanning Calorimeter. The Fe–C isopleths of the steel were calculated by Thermo-Calc to preliminarily determine the characteristic temperatures of the different phases. Then the specimens were quenched at these characteristic temperatures. The typical microstructures were observed by Optical Microscopy and Field Emission Scanning Electron Microscopy with Energy Disperse Spectroscopy. The results show that α-Fe, MC, M_2C and M_7C_3 precipitate when the specimen is cooled slowly to room temperature. According to the DSC curve and the Fe–C isopleths, the characteristic temperatures of the phase transformation and carbide precipitation are chosen as 1380 °C, 1240 °C, 1200 °C and 1150 °C respectively. Primary austenite precipitates at 1380 °C, then eutectic reaction occurs in residual liquid after quenching and the eutectic microstructures distribute along the crystal grain boundary. The eutectic MC is leaf-like and eutectic M_2C is fibrous-like. Both of them precipitate in ternary eutectic reaction simultaneously at 1240 °C, grow together in the form of dendrite along the crystal grain boundary. Secondary MC precipitates from the austenitic matrix at 1200 °C and nucleates at the position where eutectic MC located accompanied by the dissolving of eutectic carbides. The mixed secondary M_2C and M_7C_3 precipitate at 1150 °C. The secondary M_2C is strip-like and honeycomb-like, while the M_7C_3 is chrysanthemum-like and maze-like.

1. Introduction

The work roll is one of the key workpieces in the rolling equipment. With the rapid development of rolling technology, the work roll with higher performance is needed urgently [1,2]. The cold work roll works at room temperature and suffers large rolling force. The rolling accidents, such as strip broken, roll sticking and crack, occur frequently during the cold rolling process [3].

Recently, the Cr-series forged roll has been developed rapidly, in which, the Cr content increases from 2 wt.%, 3 wt.% to 5 wt.% [4]. Alloy element Cr exists mainly in the M_7C_3, which can increase the roll hardness, and reduce the abrasion and wastage in accident obviously [5], so the rolling accident-resistance of the cold work roll has been improved largely. However, its wear resistance can't be satisfied with the requirement of rolling product with higher performance [6]. Nowadays, high speed steel (HSS) roll has been widely applied because of its higher hardness, better wear resistance and hardenability [7]. The HSS employed for roll contains more alloy elements such as W and Mo, which can form different types of carbides and improve the hardness and wear resistance of the

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roll obviously [8–10]. In recent years, the researches of HSS roll focused mostly on the influence of alloy elements on microstructure and property, refinement of the carbide and crystal grain, elimination of carbide network, as well as optimization of heat treatment [11–13]. However, traditional HSS roll contains more expensive alloy elements W and Mo, which can increase the manufacturing cost significantly. Meanwhile, cracks appear easily on the surface of the HSS roll because of net carbides during the forging process [14], which means that the HSS cannot be used to manufacture the forged cold work roll, so the application of HSS roll is restricted widely.

Based on the advantages of both Cr-series forged roll and HSS roll, a novel steel for cold work roll was designed by calculation and experiment, in which the alloy elements W, Mo contents were reduced and Cr content was increased. The carbide precipitation rule of the novel steel with different tungsten (W) contents has been calculated using Thermo-Calc [15]. The precipitation kinetics of the carbide at characteristic temperatures has been investigated during quenching process [16]. Meanwhile, the stable and meta-stable carbides in the novel steel have been determined during the tempering process [17]. In order to simulate the forging process of the novel cold work roll, the hot compressive experiment has been carried out and the hot deformation behavior has been analyzed in detail [18], referring to the hot deformation researches of a kind of ledeburitic tool steel with similar chemical composition [19,20]. Nowadays, the novel cold work roll has been forged successfully.

The forgeability of novel steel for cold work roll is related not only with chemistry composition but also with its microstructure. During solidification process of the steel, a series of complicated phase transformations occur, such as austenite crystallization, eutectic reaction and primary, secondary carbides precipitation. The formation, aggregation, growing, transformation and dissolving of MC, M_2C and M_7C_3 result in the accumulation and diffusion of the alloy elements during the cooling process, and affect the microstructure and properties of the cold work roll directly. Therefore, it is significant to characterize the carbide in the novel steel for cold work roll during solidification process, which can provide the theory basis for the forging process, so as to obtain the cold work roll with the excellent performances finally.

2. Experimental Materials and Methods

The specimens were taken from the self-designed steel for cold work roll, whose chemical composition is listed in Table 1.

The phase structures of the steel for cold work roll at room temperature were determined by D/max-2500/PC X-Ray Diffractometer (XRD). In order to measure the temperatures of phase transformation and carbide precipitation, the specimens were machined into Φ3 × 1 mm, and heated above the melting temperature, then cooled at different cooling rates (25 K/min and 35 K/min) by STA449C Differential Scanning Calorimeter (DSC). The Fe–C isopleths of the steel were calculated by Thermo-Calc according to its chemical composition. Combining with the DSC results, the phase reaction and the type of the precipitated carbide corresponding to different exothermic peaks were preliminarily determined, and the characteristic temperatures were also identified. The specimens were firstly heated up to 1400 °C and held for 10 min, then cooled slowly to the characteristic temperatures in furnace, and quenched quickly into the water to fix the microstructures.

The specimens were polished and etched in aqua regia (HNO_3 + 3HCl), and then observed by Axiovert 200 MAT optical microscope (OM). Carbides were examined using Murakami etchant [21] (3 g $K_3Fe(CN)_6$ + 10 g NaOH + 100 ml H_2O), in which black M_2C, brown M_7C_3, and gray MC were selectively etched. Additionally, the matrix was deeply etched in an etchant of 5 g $FeCl_3$ + 10 ml HNO_3 + 3 ml HCl + 87 ml ethylalcohol [22] to observe the three dimensional morphology of MC, M_2C and M_7C_3 by S4800-II Field Emission Scanning Electron Microscope (FESEM). The compositions of different carbides were analyzed quantitatively by Energy Dispersive Spectroscopy (EDS).

Table 1 – Chemical compositions of the steel for cold work roll (wt. %).

Element	C	Cr	Mo	V	W	Mn	Si	Fe
Content	1.1–1.2	10–11	2–3	2–3	1–1.5	0.3–0.5	0.3–0.5	Bal.

3. Results and Analysis

3.1. *Analysis of Equilibrium Microstructure*

3.1.1. *Fe–C isopleths of the Steel for Cold Work Roll*

The Fe–C isopleths of the steel between 1100 °C and 1500 °C, calculated by Thermo-Calc, are shown in Fig. 1. The carbon content of the steel is 1.2 wt.%, as marked by the dashed line on the diagram, and the intersections between the dashed line and phase line are 1410 °C, 1210 °C, 1200 °C and 1190 °C respectively. The phase transformation reactions in the main phase region are listed in Table 2.

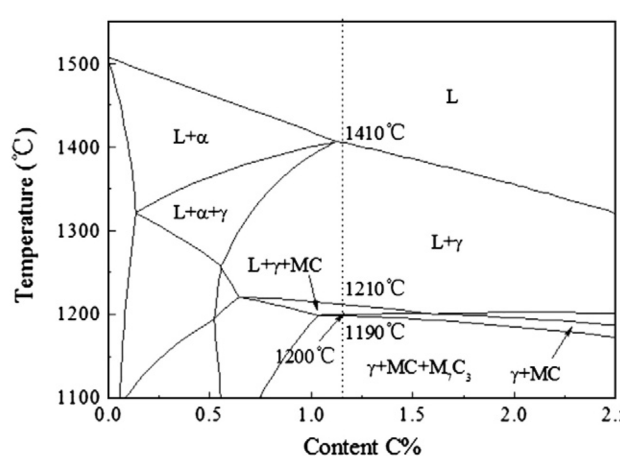

Fig. 1 – Fe–C isopleths of the steel for cold work roll.