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Prevention of surface hot shortness, development of banded structure, and mechanical properties of hot rolled Cu-bearing steel

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ABSTRACT

The development of microstructural banding and surface hot shortness during hot rolling in a 1.4 wt% Cu-bearing steel was studied. Different hot rolled states were produced by cross rolling, air cooling, and furnace cooling to investigate the effect of initial microstructure on the mechanical properties. It was revealed that to insure the hot workability of Cu-bearing steel against liquid metal embrittlement and prevention of the failure, a good practice is conducting hot working operations at temperatures below the melting point of copper to suppress the formation of liquid Cu-enriched phase that penetrates into grain boundaries. Cross rolling was found to be a promising approach to decrease the anisotropy of the rolled sheets resulted from the presence of the banded structure. Moreover, air-cooling yielded maximum strength due to its resultant fine and complex microstructure. These results can find application in processing and optimization of mechanical properties of steel sheets.

1. Introduction

Copper is added to steel to enhance its corrosion resistance [1] and to increase the strength through precipitation hardening in concentrations >0.75% [2–6]. However, Cu and Fe have only limited mutual solubility, which might become a major problem in hot working due to surface hot shortness [7–9]. Moreover, the alloying elements segregate to areas between dendrite arms during solidification, which make the material susceptible to microstructural banding during hot working. This banded microstructure can adversely affect the mechanical properties of the material [10,11]. Therefore, during processing of as-cast Cu-bearing steel, the development of banded structure and hot workability might be matters of concern. The present work is dedicated to these subjects.

2. Experimental details

A typical Cu-bearing low-alloy steel with 0.2 wt% C, 1 wt% Mn, 0.75 wt% Al, 1.34 wt% Si, and 1.4 wt% Cu, was prepared by vacuum induction melting (VIM). The hot rolling operations were performed at 1150 and 1000 °C up to 55% reduction in thickness using simple and cross rolling techniques. After the last rolling pass, the samples were air/furnace cooled to room temperature. The cold rolling operations were applied to achieve sheets with 1 mm thickness (~87% reduction in thickness). During cold rolling, the cross hot rolled samples were cross cold rolled. The microstructural observations were performed on RD-ND, TD-

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ND, and RD-TD planes after etching in 2% Nital solution. The mechanical properties were investigated by tensile tests using a universal testing machine. The tensile specimens were prepared according to JIS-Z-2201 with the gage length of 8 mm for investigation of mechanical properties along the rolling and transverse directions.

3. Results and discussion

3.1. The as-cast and hot-rolled states

Fig. 1a represents the Fe-Fe_3C phase diagram along with the as-cast and hot rolled (at 1150 °C) microstructures. The as-cast microstructure (Fig. 1b) is an ferritic-pearlitic microstructure, in which the fraction of α-ferrite (the light areas) in the as-cast microstructure is equal to ~0.69. Based on the lever rule, the fraction of proeutectoid α-ferrite should be equal to $(0.78-0.2)/(0.78-0.02)=0.76$. Similarly, the fraction of δ-ferrite at the peritectic temperature can be calculated as $(0.53-0.2)/(0.53-0.08)=0.73$. It can be seen that these three values are comparable and the light areas in the as-cast microstructure have inherited the dendritic form of δ-ferrite. Conclusively, it seems that these areas have formed at the same place that the primary δ-ferrite was formed during solidification. Therefore, it can be deduced that the inhomogeneity in chemical composition between δ-ferrite dendrites and the interdendritic areas (as a result of segregation of alloying elements such as Mn) remains after formation of 100% austenitic structure during cooling after solidification. As a result, the austenite becomes chemically inhomogeneous and the Ar_3 temperature (the temperature at which austenite/ferrite transformation starts during cooling) will be different in various locations in the austenite phase. During cooling, ferrite forms in areas with high Ar_3 temperature and reject carbon toward areas with low Ar_3 temperature. Therefore, pearlite will form in high Mn areas.

As shown in Fig. 1c, the dendritic structure is being destroyed by 10% hot rolling reduction. By further reduction to 40%, the initial microstructure has vanished completely (Fig. 1d). Finally, identifiable bands of ferrite and pearlite forms after 55% hot reduction as can be seen in Fig. 1e.

The formation of banded structure can also be explained by the inhomogeneity in the chemical composition of austenite as follows. The alloying elements (particularly Mn) segregate to areas between dendrite arms during solidification. Then during cooling, the material becomes completely austenitic. However, there are rich and lean regions from alloying elements in the structure. During hot rolling, both regions become pancaked. Finally, after cooling to room temperature, the Mn-lean areas with high Ar_3 temperature transform to ferrite and then pearlite forms in the Mn-reach areas. As a result, alternative bands of ferrite and pearlite appear in the microstructure. Therefore, it can be concluded that while the hot rolling operation can destroy the dendritic microstructure, it can result in the development of banded structure.

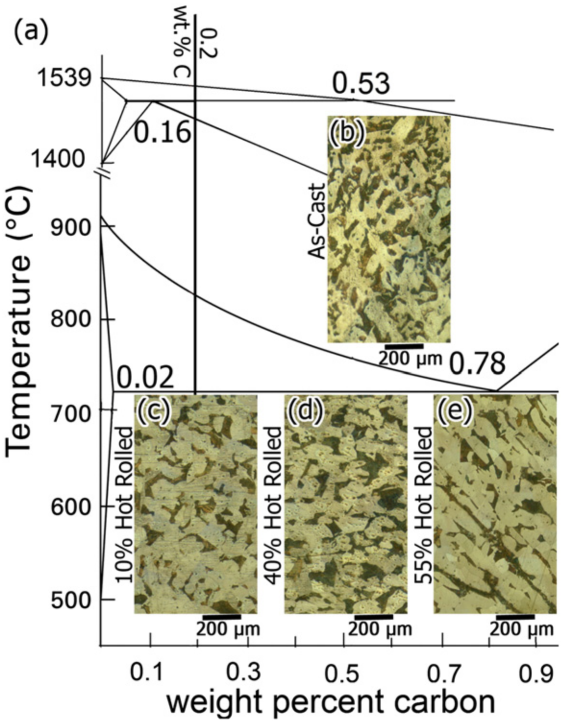

Fig. 1. Fe-Fe_3C phase diagram along with the as-cast and hot rolled (at 1150 °C) microstructures. The hot rolled samples were furnace cooled from the hot rolling temperature to easily detect the destroying of the dendritic structure and the development of the microstructural banding.