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Hot Ductility Behavior of Continuous Casting Slab of Copper and Nickel Alloyed Steel

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Copper is deliberately added to low carbon steels to improve corrosion characteristics and increase strength. However, copper as a tramp elements has been reported to encourage transverse cracking by hot shortness of slab surface upon straightening operation during continuous casting. Nickel can be added to compensate for this loss by both increasing Cu extent of solid solution in austenite and decreasing Cu enriched phase in oxide scale. In a continuous casting steelmaking operation, the surface of a slab is under a condition that can be characterized as high temperature, low-cycle fatigue in which the tensile and compressive stress is repeatedly developed. For this reason, for the evaluation of the hot ductility of a slab, considering the fatigue deformation is more feasible before a tensile or compressive test. And also the oscillation mark developed on the surface of slab due to the oscillation of copper mold during continuous casting would results in reduced hot ductility. In this study, the effects of low cycle fatigue and oscillation mark on the hot ductility of copper and nickel containing steels are investigated at various temperatures.

Keywords: *continuous casting, slab, surface crack, hot ductility, fatigue test*

1. Introduction

During continuous casting processes, there are many problems related to the hot ductility of the cast slab. Surface defects such as transverse cracks and edge cracks are regarded to potentially deteriorate the properties of the slab and lead to waste slab during the removal of defects [1,2].

The low carbon steels containing Cu and Ni have been used in ocean structure. Copper has been reported to encourage surface cracks during continuous casting, since iron is preferentially oxidized on the surface of the slab resulting in the formation of copper enriched phase between scale and matrix. At high temperature, copper enriched phase start to melt and penetrate into the matrix along the grain boundary of austenite, thereby hot ductility is reduced. On the other hand, nickel has been added to copper alloyed steel to neutralize the detrimental effect of copper in steel. The strain accumulated during continuous casting and slab surface morphology including oscillation mark should be considered to get more precise hot ductility data for the application in the field.

2. Experimental Procedure

2.1 Specimen

The composition of the experimental specimen is given in Table 1. Two ingot samples were prepared using a vacuum induction melting furnace. Fatigue specimens were machined from the surface of solidified ingot so as to obtain material with a cast microstructure and oscillation mark.

Table 1 Chemical composition of specimens (wt.%).

	C	Si	Mn	S	Cu	Ni
Steel A	0.08	0.22	1.43	0.002	0.23	0.25
Steel B	0.07	0.20	1.56	0.001	0.28	0.86

2.2 Hot ductility test

A cast simulator was used to measure the hot ductility via a simple tensile test in addition to a tensile test after fatigue deformation at a high temperature under an Ar atmosphere.

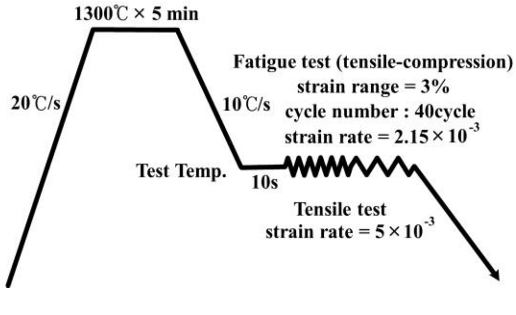

Fig. 1 Thermal history of hot ductility test.

Fig. 1 illustrates the thermal profile that the specimen passes through during a mechanical test as well as the fatigue and tensile tests. The specimens were heated to 1300 ^{o}C and held at this temperature for 5 min for solutionizing. They were then cooled to the testing temperature at the rate of 10 ^{o}C /s, which is similar to the cooling rate during thin slab casting. At the testing temperature, the specimen was held for 10 s in order to reduce the temperature gradient before tensile or tensile after fatigue test.

The high temperature tensile test was conducted in a temperature range of 600 to 1000 ^{o}C, with 50 ^{o}C intervals. The strain rates were 5×10^{-3}/s for those in both continuous casting and thin slab casting. A number of specimens were quenched for microstructural analysis in various conditions.

Fatigue test was performed under conditions in which 10 % fatigue deformation by 40 cycles, and a deformation rate of 7.16×10^{-3} were loaded before the tensile test at the testing temperature. The number of fatigue cycles, 40, was chosen as the number of rolls in the secondary cooling zone is approximately 40.

3. Results and Discussion

Fig. 2 show the hot ductility curve of Steel A. Ductility trough is developed at 800 ^{o}C and ductility reversion is arisen at high and low temperature region in both test conditions. There exists no significant difference of hot ductility between simple tensile test and fatigue test conditions.

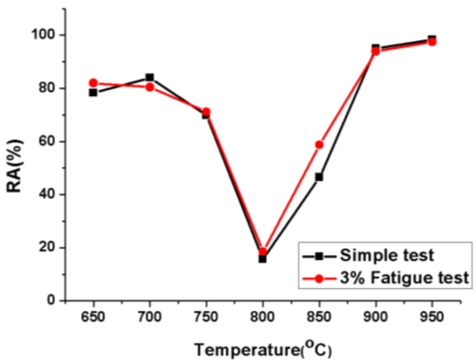

Fig. 2 Hot ductility curves of Steel A.

Microstructures of Steel A quenched at various temperature after fracture is shown in Fig. 3. Ferrite thin film is developed along the prior austenite grain boundary at 800 ^{o}C at which ductility shows lowest value. Increased amount of ferrite is formed at 750 ^{o}C, thereby hot ductility reversion arises at this temperature.

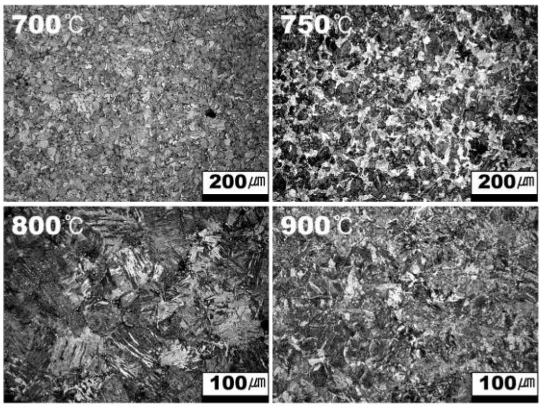

Fig. 3 Microstructures of Steel A quenched at various test temperature after fracture.

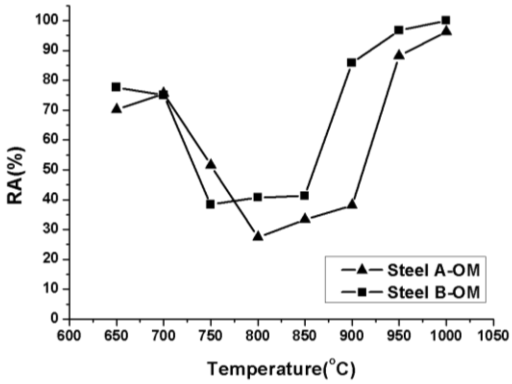

Fig. 4 Hot ductility curves of Steel A and B.

Fig. 4 shows the hot ductility curves of Steel A and B, from which Steel B has increased hot ductility at 900 ^{o}C while Steel A represent lower ductility value. The difference in hot ductility value at this temperature can be ascribed to the lower A_{r3} temperature due to the increased amount of nickel in Steel B.

4. Summary

With increasing nickel to copper ratio, hot ductility of copper containing steel was improved. No meaningful difference of hot ductility between simple tensile test and fatigue test conditions can be ascribed to the result of an increased amount of ferrite due to the low carbon content.

References

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