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2.25%Cr-1%Mo 합금계 열연강판 제조기술

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Manufacturing 2.25Cr-1Mo Steel In Hot Rolling Strip Mill

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Abstract

The thermomechanical control process (in hot rolling strip mill) was employed to produce 2.25Cr-1Mo steel, which is to be construction material for the steam generator for power plant. Although the Conventional processes has been the primary means of producing the 2.25Cr-1Mo steel, an alternative method was used to meet the specification of ASTM heat treatment for A387-22-Class1 using autotempering after coiling in hot rolling strip mill. The microstructures, tensile properties at various temperatures, and creep-rupture properties have been investigated to compare the properties with those of materials produced by the conventional process and to certify the application of the thermomechanical control process to an actual process of manufacturing 2.25Cr-1Mo steel, this in turn, will reduce the cost of the process. About 14 to 34% glanular bainite (remainder proeutectoid ferrite) formed in a coil, and this variety of volume fraction stems from the different cooling rates, which varies with position of the coil after coiling. Tensile testing from room temperature to 700°C indicated that strength increases with test temperature showing peaks at around 600°C. Creep-rupture properties have been being investigated at the temperature of 500°C with 27.5, 32Kg/mm^2 loads and have showed no rupture for over 1000 hours.

Key words: Hot rolling strip mill, 2.25Cr-1Mo steel, Thermomechanical control process

1. Introduction

Because of its good formability, weldability and corrosion resistance, 2.25Cr-1Mo steel has been widely used by the power and petroleum industries for the fabrication of pressure vessels. Since this steel is one of the strongest low-alloy steels available for high-temperature service, it has been considered for use in steam generator. Recently, heavy industry companies are contemplating the use of lighter but mechanically better material in designing steam generator for power plant to improve process-efficiency and lower production costs. For the welded finned-tube wall of a heat exchanger, they needed plates with 4.0~10mm thickness. At this range, it is hard to control the processing conditions in a plate mill. For these reasons, the thermomechanical control process was employed to manufacture 2.25Cr-1Mo steel in a hot rolling strip mill.

ASTM (American Society of Test and Material) and ASME (American Society of Mechanical Engineers) approve a material with strict specification about chemical composition, heat treatment, and mechanical properties - tensile properties at various temperatures up to 583 °C from room temperature, even after PWHT (Post Welded Heat Treatment). Therefore, we needed to find the optimal conditions for manufacturing 2.25Cr-1Mo steel in a HR strip mill by varying the alloying elements and temperatures. The object of the present work was to apply the thermomechanical control process to the manufacturing of 2.25Cr-1Mo steel in an annealed condition (normalizing and tempering).

2. Theoretical Reviews

2.1 Heat treatment

Autotempering after coiling in HR strip mill was employed for the heat treatment specification, which is "accelerated cooling from austenitizing temperature by air blasting or liquid quenching, followed by tempering with minimum temperature, 675 °C". In HR strip mill, rolling finishes above Ar3 temperature and strips toward down-coiler are water-cooled by laminar flow. After coiling they are subjected to autotempering during a slow coil cooling [1]. When the strip is coiled at constant temperature, its subsequent cooling rate varies with position in a coil. The initial rate of change of temperature varies from cooling rate at a rate of about -3.3 °C /min at the top and tail ends to an initial transient heating rate of about 0.55 °C /min at the middle of the coil. Such differences in initial cooling rates may give rise to slight difference in properties along the length of the coil. After transient period of less than one hour, the cooling rate at all points converge to just over 0.55 °C /min for the next five hours. This process is the same as that of quenching and tempering followed by a large deformation [2]. Fig1 and Fig2 show schematic diagram of cooling curve of coil after coiling and the result of actual cooling rate simulation, respectively. But we didn't consider the increase in heat (recalescence) during the transformation, austenite to ferrite while simulating it.

2.2. Creep-rupture properties

The metallurgical processes that cause strengthening in 2.25Cr-1.0Mo steel have been discussed and can be used to explain the creep-rupture behavior. When steels contain substitutional and interstitial elements in solution that have an affinity for each other, these elements can interact to form atom pairs or clusters. Baird and Jamieson showed that these clusters could form dislocation atmospheres that hinder dislocation motion and therefore strengthen the steel. They termed this process "interaction solid solution hardening." In annealed 2.25Cr-1.0Mo, it is this molybdenum and carbon that gives rise to interaction solid solution hardening. During the anneal heat treatment, the proeutectoid ferrite that forms is supersaturated with respect to molybdenum and carbon. With time at temperature, molybdenum and carbon are removed from solution to form Mo_2C, thus making it unavailable for further strengthening by interaction solid solution hardening. Once supersaturation is relieved, creep is controlled by the movement of dislocations through the ferrite matrix that contains a high density of Mo_2C precipitate particles. Mo_2C has different reaction kinetics for the precipitation that occurs in the proeutectoid ferrite and bainite. Although the equilibrium microstructure is the same in both, namely ferrite and M_6C, the rate of approach to the equilibrium microstructure differs. An intermediate precipitate in each phase is Mo_2C, a precipitate that greatly enhances the creep strength. In bainite, however, several intermediate reactions that form Cr_7C and $M_{23}C_6$ hasten the disappearance of Mo_2C, thus accelerating the loss of its creep-strengthening effect [5]. Therefore 2.25Cr-1Mo steel with large amounts of proeutectoid ferrite may be a preferred starting material for high-temperature service [3].

2.3. Microstructure

According to Bain and Paxton [4] the solubility of carbon in ferrite in carbon steel at the lowest temperature at which carbon may be rejected from the ferrite is probably much less than 0.01wt%. For the steels of this work, which contain the carbide-forming elements, chromium and molybdenum, a still lower solubility is expected. Therefore, carbon content has influence only on the grain size of the steel, which stems from a difference in austenite grain size resulting in a smaller surface area for the heterogeneous nucleation of ferrite.

Classically, bainite is divided into an upper and lower variety, as distinguished by microstructural differences that are related to the isothermal-transformation temperature at which the bainite is formed [5]. Other microstructural variation has been proposed: Habraken and Economopoulos reported the types of microstructures formed in the range where bainite characteristically forms. They labeled the structures as granular bainite. The author stated that granular bainite were more easily produced by continuous cooling whereas classical bainite formed more readily during isothermal transformation. The microstructure is composed of the granular islands and the binitic ferrite matrix. It was found that the granular product "islands" are composed of both twinned martensite and dislocated martensite [6].

The cooling rate and carbon content in alloys largely influence the volume fraction of granular bainite. As stated above, the most desirable 2.25Cr-1Mo steel is one with more amounts of super-saturated carbon and molybdenum or fine carbide precipitates in proeutectoid ferrite, thus avoiding the formation of granular bainite. It can be achieved by finding optimum conditions between the cooling rate of the strip undergoing deformation and the carbon content of the steel in a HR strip mill.

3.Results

3-1. Microstructures

The basic structure of 2.25Cr-1.0Mo produced in POSCO's HR strip mill was proeutectoid ferrite and granular bainite as expected and noted in the theoretical review. Because the extreme ends of the coil (about 5 meter for each) undergo rapid cooling, resulting in more bainite formation than at the middle of the coil, bainite volume fractions are different at each of the coil's position of in the rolling direction. Fig3 shows that the bainite volume fraction difference varied from 14% to 34% at the middle and the top&tail of the coil respectively. It was reported that normalized 2.25Cr-1Mo steels with 0.030%C and 0.120%C followed by tempering contained 15~20% and almost 100% bainite respectively. After tempering, the amount of the second phase is unchanged. In terms of bainite volume fraction, the microstructure of this work showed the feature of the tempered 2.25Cr-1Mo steels with around 0.10% carbon content. SEM was used to view the shapes of precipitates dispersed in the steel. Fig4 shows that at the middle of the coil, precipitates, which are globular carbides, in bainite were coarser than those at the tail of coil due to slower cooling rate. Thus, they would be expected to have enough time to reach a more stable state. But we couldn't detect any actual difference in the chemical composition of the precipitates in the two parts (middle and top&tail) of the coil by EDX SPECTRA. Fig 5 and 6 shows the result of TEM and EDX SPECTRA. Mo_2C and $Cr_{23}C_6$ were detected around phase boundaries. It was reported that tempering of commercial 2.25Cr-1.0Mo steel at 704°C caused a reduction in the dislocation density and the formation of at least two types of precipitate [7]. Those are the coarse precipitate particles formed in the 'islands' and the finer, rather evenly distributed plate-like precipitate, Mo_2C [5]. It can be concluded that 2.25Cr-1Mo steel manufactured in the HR strip mill consists of the same microstructure as that of conventionally manufactured one in annealed condition.

3-2. Tensile Properties

The variety of tensile properties along the length of the coil was measured. Although ordinary variety of tensile property resulting from the difference in cooling rate ranges from 1 to $3Kg/mm^2$, its variety went up to about $15Kg/mm^2$. After removing 5 meters of coil's top&tail, it decreased to about $6Kg/mm^2$. Fig7 shows the variation of tensile strength along with the position of the coil.

High-temperature tensile properties testing showed that TS and YP increased with temperature showing peaks at around 500°C and 400°C respectively (fig8). Both of them decreased abruptly around 600°C and it seemed that small grain size was related with this result. Based on the result of this work, the temperature at which 2.25Cr-1Mo steel is supposed to be used should be under 600°C. No degradation occurred after PWHT. Even further strengthening occurred after it, resulting in a 3 to $5Kg/mm^2$ increase in TS.

3-3. Creep-rupture Test

For the constant-load creep-rupture tests at 500°C loads, two specimens were loaded with $33.2kg/mm^2$ and $26.6kg/mm^2$. This test was made in air on constant load-arm creep frames. It has remained for over 1000 hours without a rupture since the test started. In Fig.9, data from the High-Temperature Material Data book is presented with the result. In Fig.10, the data from the 2.25Cr-1.0Mo steel manufactured in POSCO's thick plate mill is also given for comparison.

4. Conclusion

2.25Cr-1.0Mo steel manufactured in POSCO's HR strip mill consisted of bainite and proeutectoid ferrite. In terms of microstructure, this work agrees with the results of the conventional process - normalizing and tempering. The bainite volume fraction varied with its position in the coil, thus resulting in the difference of tensile property. Although mechanical properties showed variation with respect to position in the coil, it did not exceed the tolerance of ASTM and ASME. Also, it showed better mechanical properties at high temperature up to 500°C. More study should be done on the creep-rupture properties and high-temperature tensile property for application of the thermomechanical control process to 2.25Cr-1.0Mo steel manufacturing.

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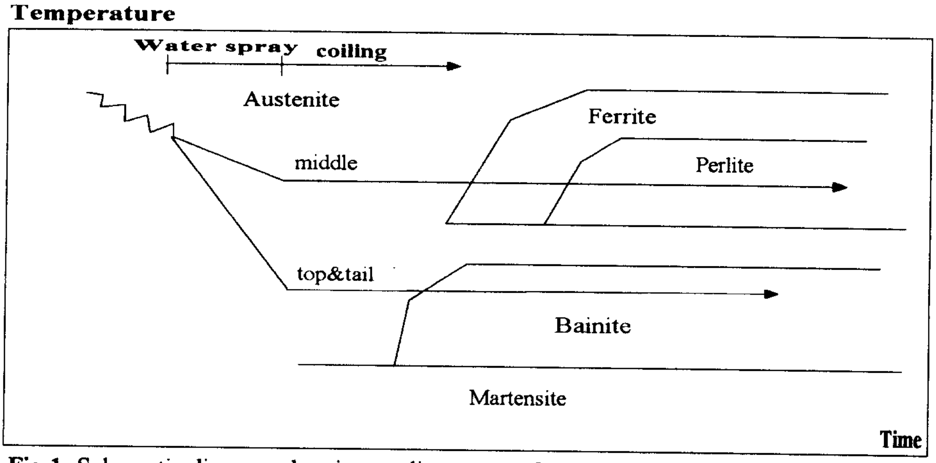


Fig.1 Schematic diagram showing cooling curve of coil after coiling.

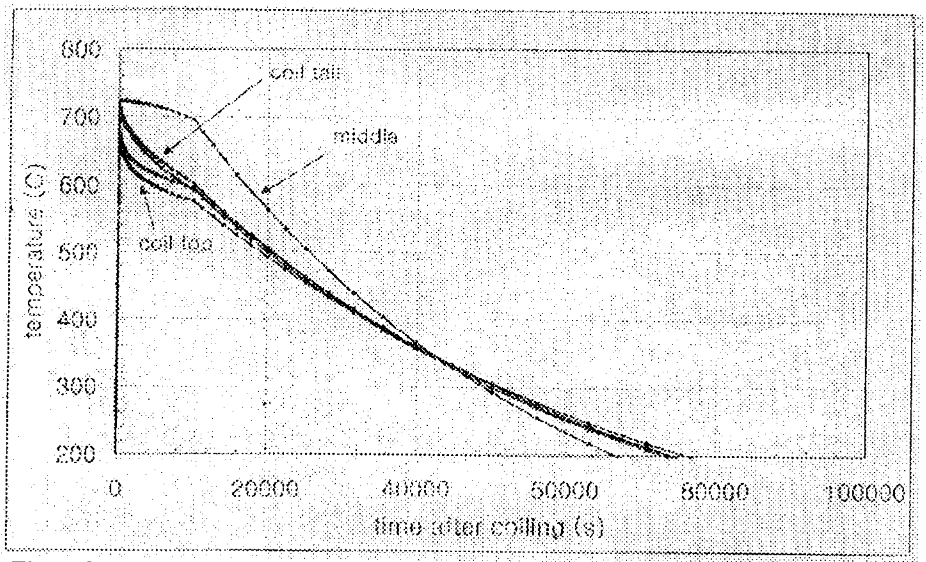
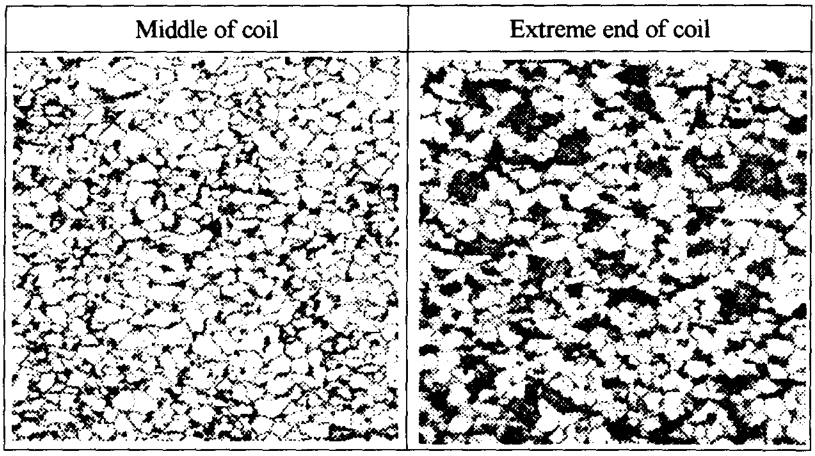


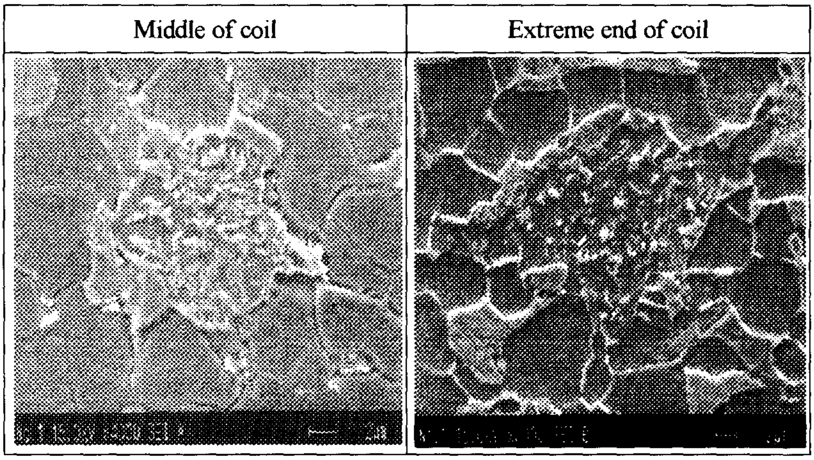
Fig.2 Cooling curve simulation result based on C-Mn-Cr-Mo component and coil size of actual 2.25Cr-1Mo steel in POSCO'S HR strip mill.



Middle of coil

Extreme end of coil

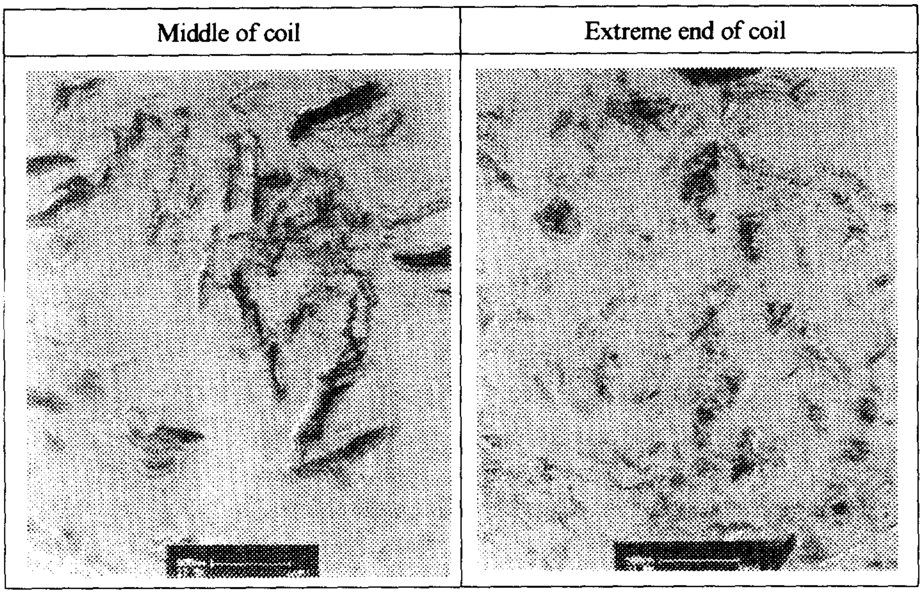
Fig.3 (Optical Microscope, magnification x500)
Bainite volume fraction varies with the position of coil, which ranges from 14% to 34% approximately.



Middle of coil

Extreme end of coil

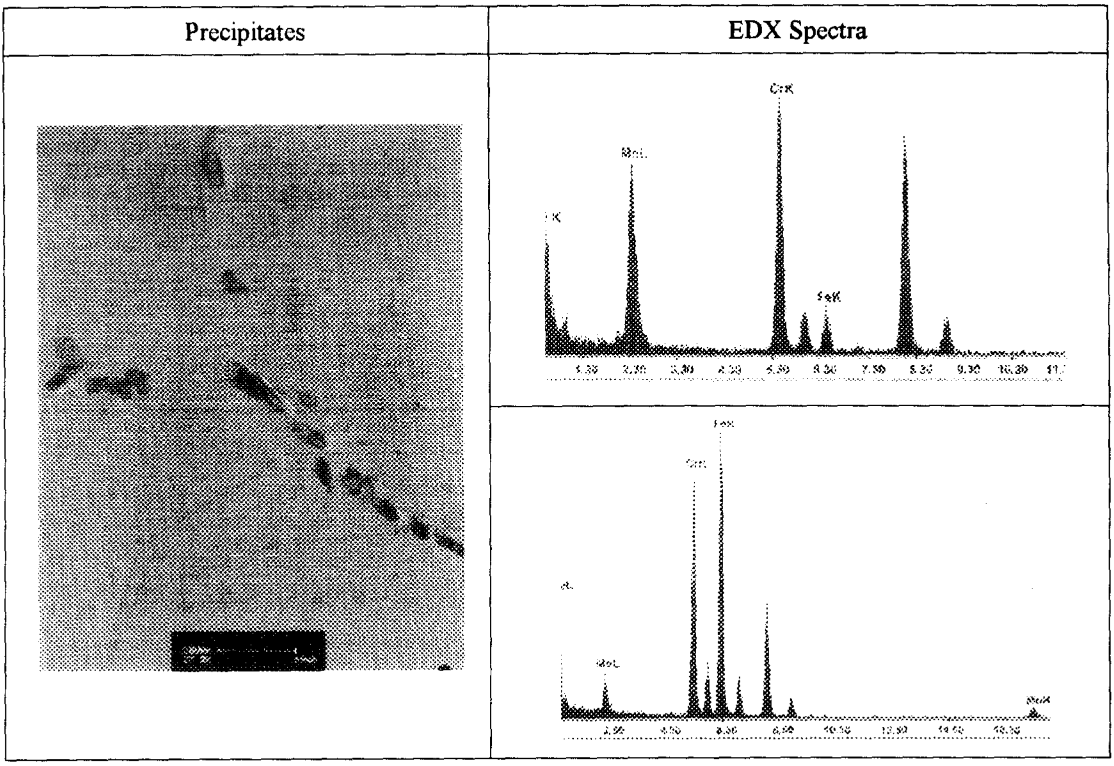
Fig.4 Granular Bainite Shape (by SEM, magnification x4000)
Shapes of precipitates in bainite are different at each position of coil.



Middle of coil

Extreme end of coil

Fig.5 Surface replica of 2.25Cr-1Mo steel at different positions of coil.



Precipitates

EDX Spectra

Fig.6 Chemical Composition Analysis by EDX Spectra. Metastable precipitates(Mo2c,Cr23C6) were detected along the phase boundaries.

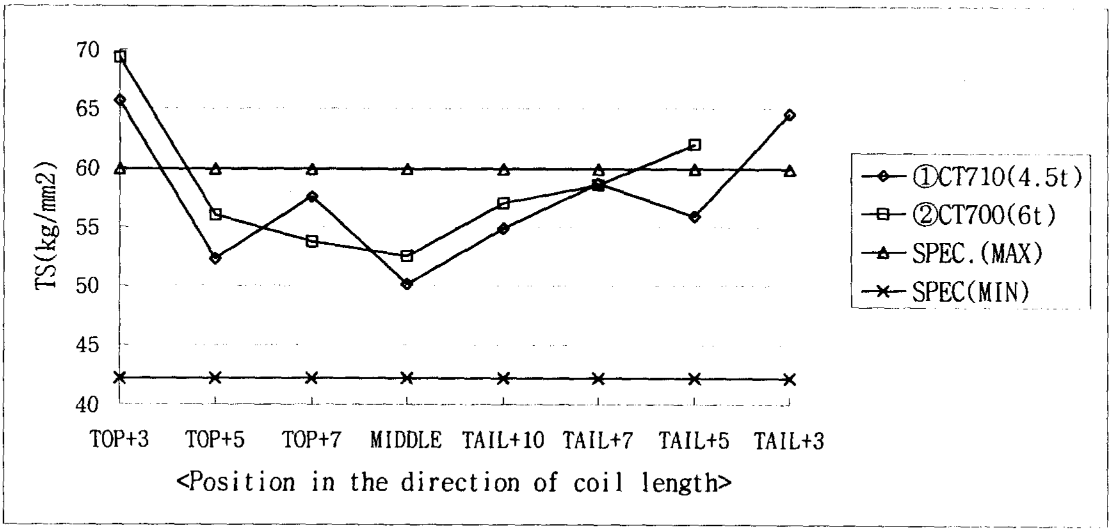


Fig.7 Tensile strength variation with position in coil resulting from bainite volume fraction

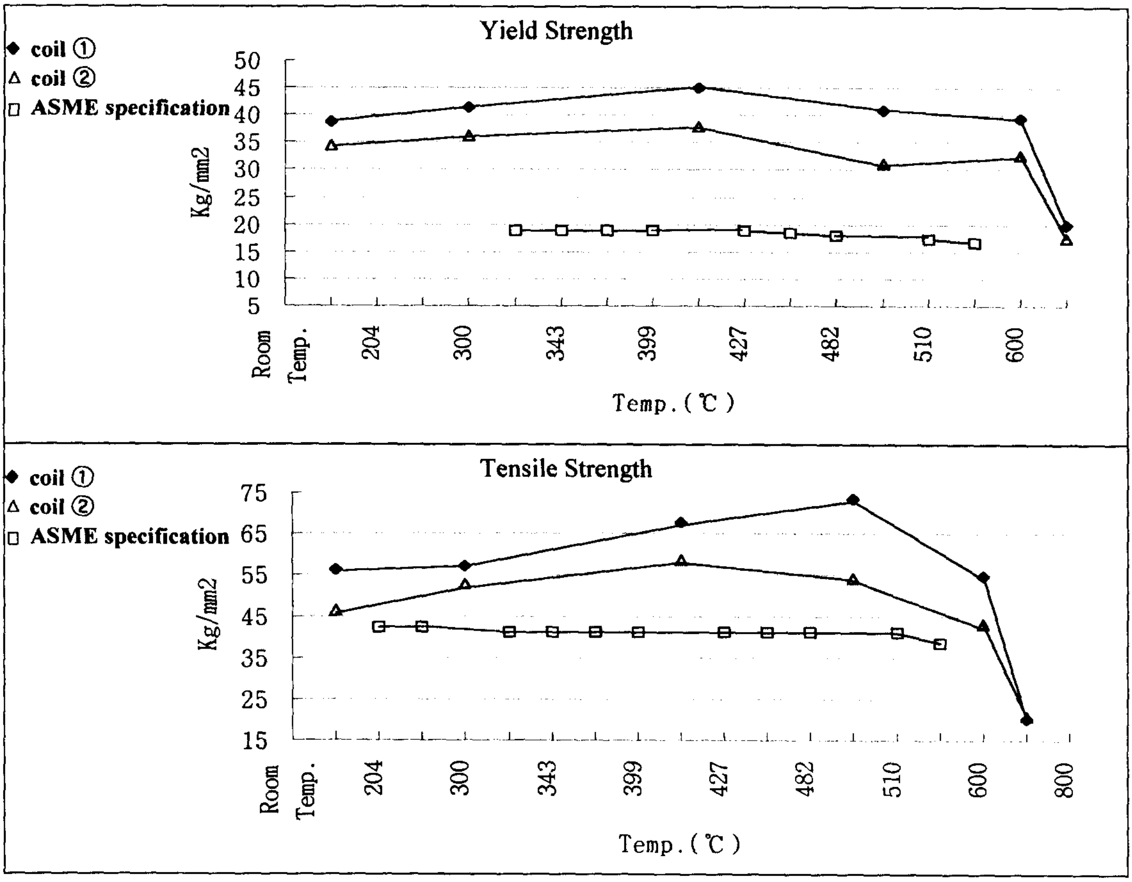


Fig.8 High-temperature Tensile properties of POSCO's HR 2.25Cr-1Mo steel.