Development of Bolt Steel SCM435 Omitting Preliminary Annealing

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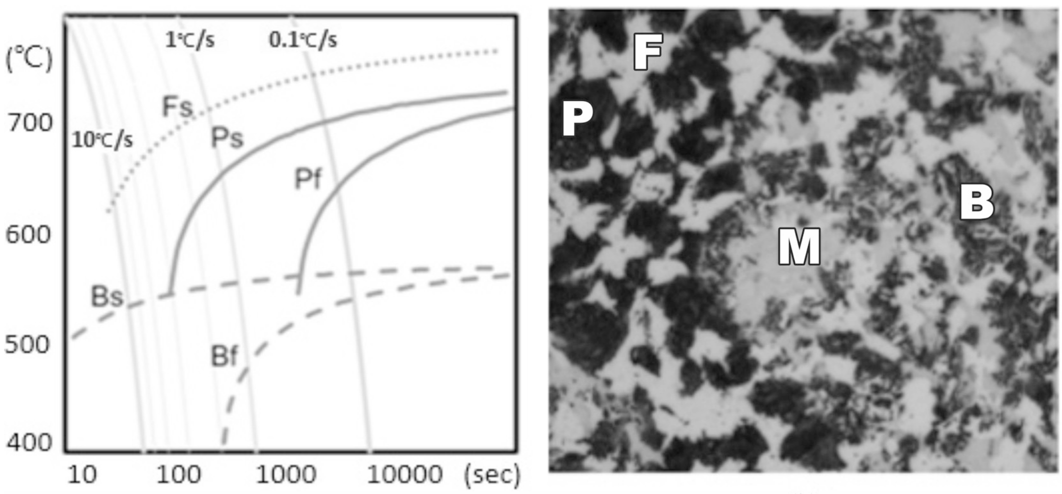
SCM435 bolt steel with a high forging ratio is normally implemented with preliminary annealing before cold drawing of the hot-rolled wire rods. The trend of reducing carbon dioxide emissions and production cost triggers the development of SCM435 wire rods with low tensile strength. Through optimization of chemical composition, improvement of bloom segregation, and controlled rolling, the tensile strength values and variation have been reduced significantly. The newly developed SCM435 product offers the possibility of direct cold drawing of hot-rolled wire rods.

Keywords: Annealing; SCM435; Segregation; Control-rolling

1. INTRODUCTION

In ISO898-1 specification, fasteners have been classified into various property classes, like 6.8, 8.8, and 10.9, etc. Cr-Mo alloy steel SCM435 (AISI 4135) has been extensively applied in class 12.9 high-strength fasteners, which means the tensile strength shall reach 1200 MPa after heat treatment. However, the addition of elements Cr and Mo not only increases the tensile strength but also the hardenability. It represents the continuous cooling transformation (CCT) curve right-shift, resulting in SCM435 microstructure normally containing bainite and martensite, instead of fully ferrite and pearlite (Fig.1).

The existence of martensite can significantly increase the tensile strength but deteriorates the cold-workability. Therefore, preliminary annealing is normally necessary for improving ductility before cold drawing of hot-rolled wire rods, especially for high forging ratio products. (Fig.2) In the past decades, numerous research had announced development of low-strength SCM435[1, 2, 3], and the soft annealing can be omitted before cold drawing. It not only increases the product competitiveness, but also reduces the carbon dioxide



(a) (b)

Fig.1. (a) SCM435 CCT curve (b) SCM435 microstructure.

As rolled wire rods → Annealing → Cold-drawing (high forging ratio)

→ Annealing → Cold-drawing → Cold-heading → Threading → Bolts

Fig.2. SCM435 bolt manufacturing process.

emissions, which has attracted more and more attention recently. Therefore, China Steel Corporation has put effort into investigating the process flow of SCM435 wire rods, and tried to figure out all the manufacturing parameters that influence the hot-rolled microstructure and tensile strength. The final goal is to reduce the hot-rolled tensile strength as much as possible, and thus offer the possibility of omitting preliminary annealing.

2. EXPERIMENTAL METHOD

2.1 Factor Analysis

Aiming for low tensile strength of hot-rolled wire rods, the microstructure of martensite is undesirable. So, the key point is to reduce the hardenability. It has been well known that steel hardenability is associated with three factors:

2.1.1 Chemical Composition

SCM435 chemical composition is mainly composed of C, Si, Mn, Cr, and Mo. According to ASTM A255, elements of high multiplying factors boosts the hardenability remarkably, like Mn, Mo, and Cr. However, the alloy contents must satisfy the JIS or AISI specification requirements. So, it can only be examined whether those alloys have been over-added toward the upper limit of specifications.

2.1.2 Segregation

During continuous casting, macroscopic and microscopic partitioning of alloy elements between liquid steel and growing solid crystals is inevitable, causing non-uniform distribution of chemical elements.[4] Segregation causes enrichment of alloys (e.g., C, Mn, Cr, and Mo) in the centerline of a cast bloom as well as between dendrite arms. These segregation areas will be aligned into longitudinal bands after rolling. These bands, which have higher hardenability in comparison with the matrix, will more easily transform into martensite after hot rolling. Fig.3 shows the SCM435 optical micrograph of longitudinal section. Apparently, the continuous casting process shall be optimized to mitigate segregation influence.

2.1.3 Hot Rolling

Martensite is transformed from austenite under a sufficient cooling rate after hot rolling. In addition to chemical composition, small austenite grain size also leads to lower hardenability. Because austenite grain size is associated with grain recrystallization and growth during hot rolling, the billet reheating temperature, rolling temperature, coiling temperature, and cooling rate shall be optimized.

2.2 Experimental Design

After investigating the chemical composition of the SCM435 heat records, it was discovered some heat numbers produced with high Mn, Cr, and Mo close to the upper limits contributed high to hardenability. So, the alloy design has been optimized into a much narrower range, but still satisfies the specifications. In order to

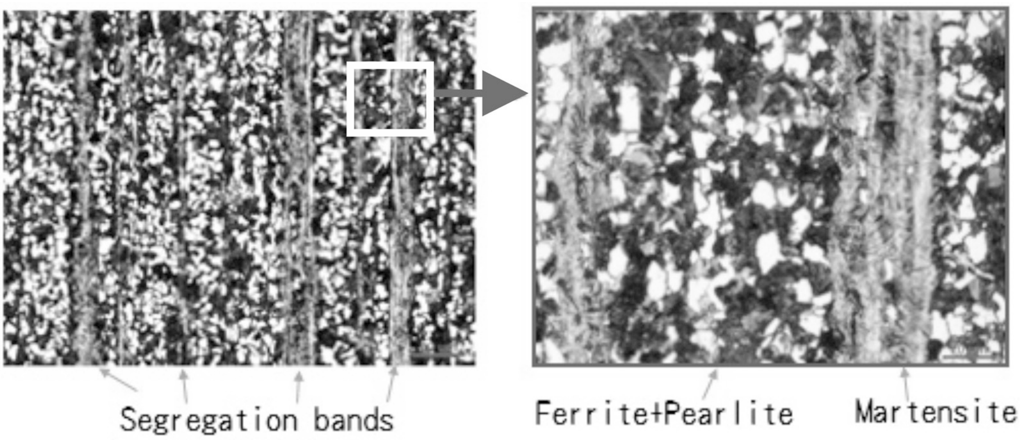


Fig.3. Light micrograph of SCM435 shows segregation bands.

alleviate the influence of segregation, the continuous casting process parameters have been optimized, including casting speed, superheat, cooling rate, and electromagnetic stirring (EMS), etc. Regarding the hot-rolling process, low temperature control rolling retards grain growth and finer austenite grain size could be got. So, the billets reheating temperature, finish rolling temperature, and coiling temperature were reduced by 50°C, 100°C, and 40°C, respectively. In addition, Fig.1 (a) CCT curve shows the cooling rate should be as low as possible in order to avoid martensite transformation. So, the cooling rate has been reduced by 0.2°C/sec. (Table 1)

3. RESULTS AND DISCUSSION

After optimization of the continuous casting process, bloom specimens were acid-etched to examine the segregation patterns. In comparison with the old process, the specimens from the new process showed dotted V-segregation bands. However, the old-process specimens appear as V-segregation lines (Fig.4). According to previous research(5), the dotted bands are considered as minor segregation in contrast to V-segregation lines.

After the breakdown of the blooms, billet specimens were macro-etched and examined again. According to ASTM E381, the old-process specimens were rated as R3~R4 for the random condition, whereas the new-process specimens were rated as R2. (Fig.5) So, it is obvious that the new continuous casting process improves the segregation.

Afterwards, billets of both casting processes were hot rolled into 12mm wire rods. The wire rods were sampled and longitudinal microstructures were examined. (Fig.6) The old-process microstructure contained more and, coarser martensite bands in comparison with the new-process microstructure. It verified the optimized casting process, which produces blooms of minor segregation, can reduce the martensite volume of hot-rolled wire rods, and the cold-workability can be improved.

In order to verify the effect of low-temperature control rolling, billets from the same heat number were hot rolled into 12mm wire rods with different rolling parameters. Then wire rod specimens were sampled to examine the transverse microstructure. (Fig.7). It is obvious that normal rolling shows coarser ferrite and pearlite nodules in comparison with control rolling. It is easily understood that normal rolling applying high temperature, leading to coarse austenite grains, not only reduces the transformation nucleation sites but also increases the hardenability. So, martensite phase can always be discovered in the micrographs of normal-rolling wire rods.

Table 1 Manufacturing parameters modification.

Parameters	Continuous Casting	Reheating Temperature	Finish Rolling Temperature	Coiling Temperature	Cooling Rate
Old Process	Conventional Parameters				
New Process	Optimized	-50°C	-100°C	-40°C	-0.2°C/sec

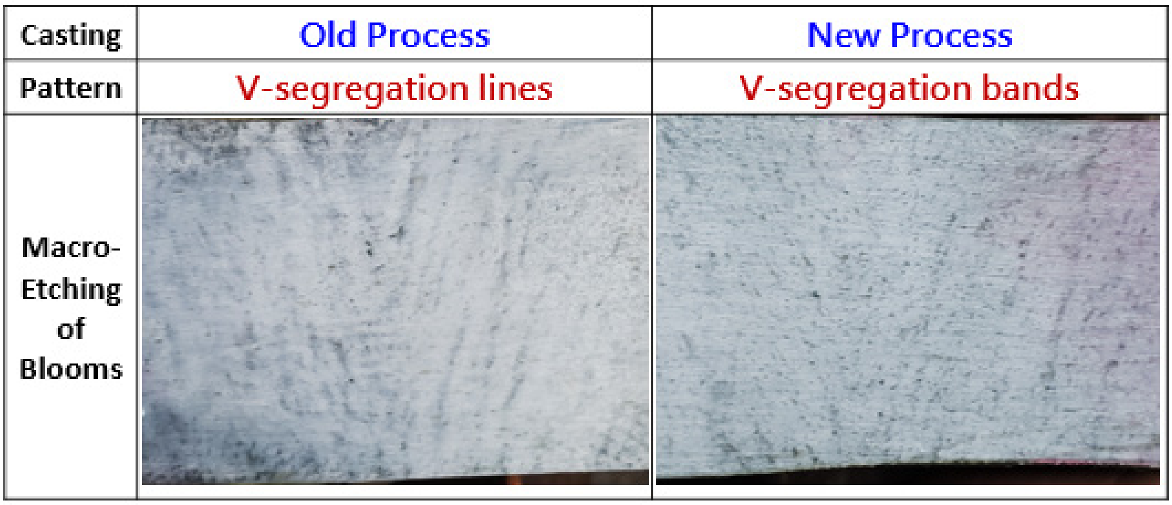


Fig.4. Bloom macro-etching segregation patterns.

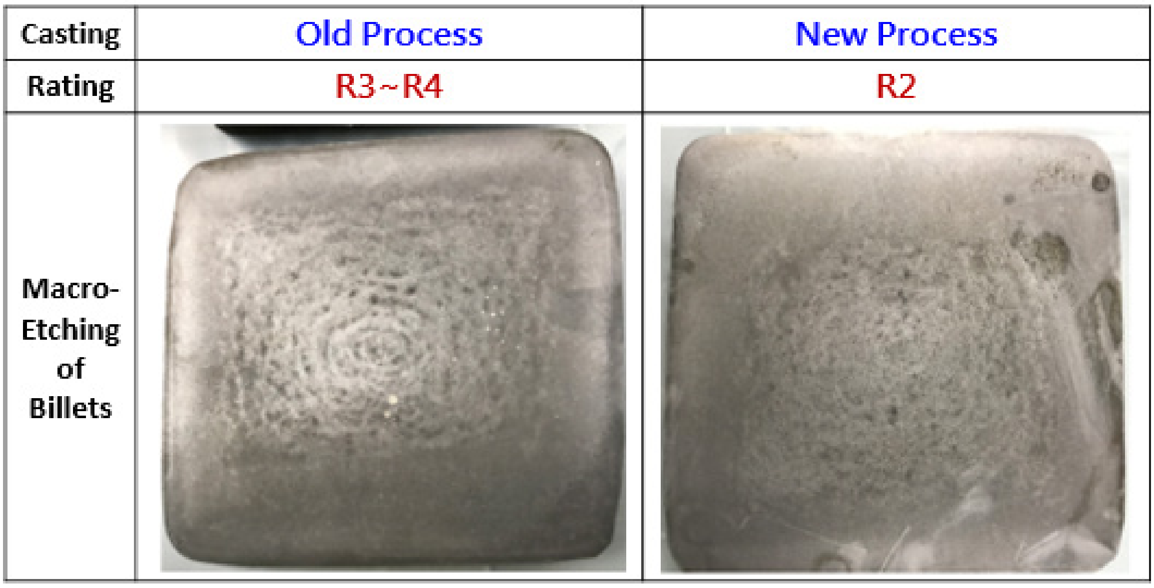


Fig.5. Billets macro-etched and rated according to ASTM E381.

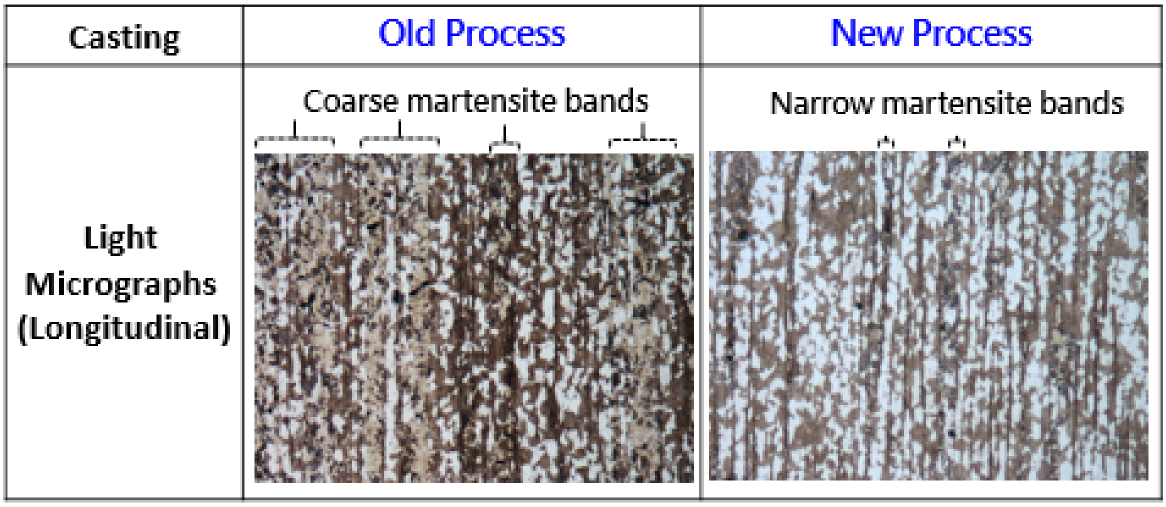


Fig.6. Light micrographs of wire rods from different casting process.

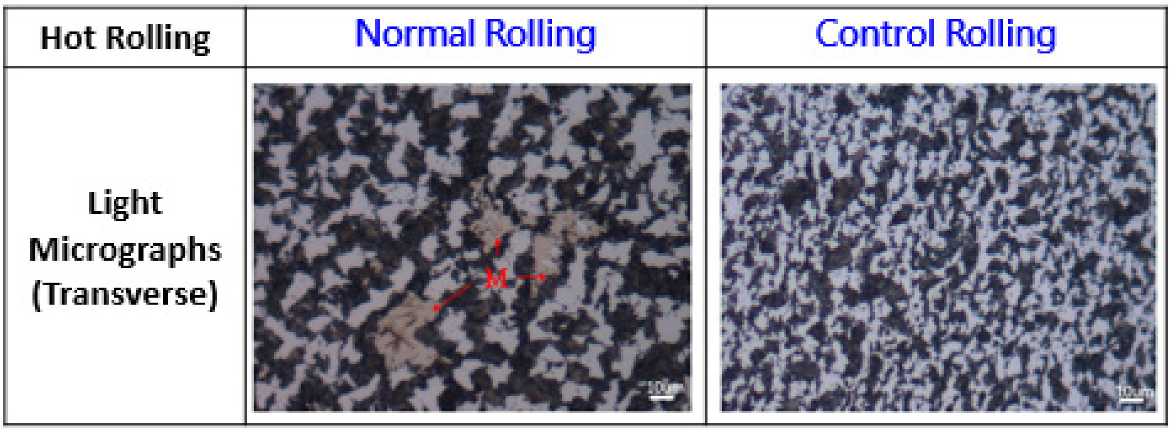


Fig.7. Light micrographs of wire rods of different rolling parameters.

In combination with optimized chemical composition, minor bloom segregation, and control rolling, newly-developed SCM435 wire rods were mass-produced. The tensile strength (TS) was tested and statistically compared with old products. (Fig.8) From the distribution profile, it shows the tensile strength variation has been narrowed, and the average TS reduced from 897MPa to 771MPa effectively. So, the newly-developed SCM435 of low tensile strength provides the possibility of omitting preliminary annealing before cold drawing.

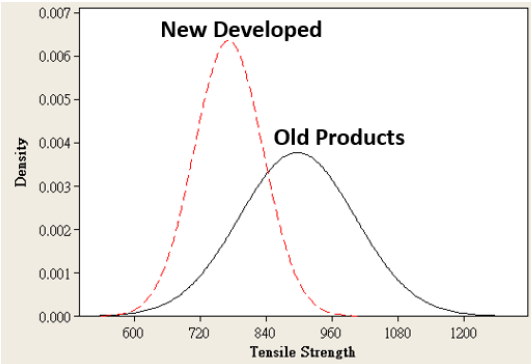


Fig.8. Tensile strength distribution profiles.

4. CONCLUSION

Hot-rolled wire rods of SCM435 typically contains a certain volume of martensite which raises the tensile strength significantly. Preliminary annealing is normally implemented to improve cold-workability especially for bolts of a high forging ratio. In order to decrease the martensite volume, this research aims to reduce the hardenability through optimization of chemical composition, improvement of bloom segregation, and low-temperature control rolling. From the experimental results, minor segregation leads to less and narrower martensite bands. In combination with low temperature control rolling, the tensile strength variation has been reduced, and the average TS decreased by about 126MPa. So, the newly developed SCM435 with low tensile strength offers the possibility of omitting preliminary annealing before cold drawing.

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