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Special Steel Wire Rods for Cold Forging with High Property

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Abstract

The final uses of special steel bars and wire rods are mainly the important safety parts used in automobiles. To produce the final parts,secondary processes such as annealing, drawing ,machining, and forge forming processes in hot and cold temperature regions and heat treatment processes such as quenching and tempering are necessary. In special steel bars and wire rods, there are strong needs to omitting annealing and extending the life of tools in view of cost reduction and energy saving. This paper outlines mainly the material property of "Direct Softening (DS) - boron steel", "DS-carbon steel" and "DS-low alloy steel" which enables the omission of off-line annealing processes. The developed DS steels are produced by the manufacturing method of NSC original inline special heat treatment.

1. Introduction

Bars and wire rods of special steel are mostly used for safety-related parts of automobiles through post-processing steps such as annealing, drawing, machining, hot and cold forging, and heat treatment for quenching, tempering, etc. For this reason, to reduce the total costs of manufacturing, these steel products are required to be capable of being turned into final products through as small a number of processing steps as possible and causing as small die wear at forging. This paper introduces Nippon Steel Corporation's highly functional wire rod products for cold forging use, developed based on an in-line special heat treatment process original of the company, and capable of doing away with softening annealing and extending the service life of forging dies.

2. High-property Wire Rods for Cold Forging Use (Direct-softening Wire Rods)

2.1 Boron steel wire rods for longer life of forging dies

Steel bolts are mostly made of middle-carbon steel or middle-carbon, low-alloy steel such as JIS SWRCH 45K and SCM 435H through the processes of softening or spheroidizing annealing, cold forging into a bolt shape, quenching and tempering. SWRCH 45K steel is recently being replaced by boron steel to reduce the manufacturing cost of bolts. Boron steel is a kind of steel in which the contents of carbon and other alloying elements are decreased to lower the as-hot-rolled tensile strength and to which boron is added to make up for the decrease in hardenability due to the lower contents of the alloying elements. While it has an advantage of significantly lower production and post-processing costs, its as-hot-rolled strength is not as low as that of SWRCH45K after spheroidizing annealing, and for this reason, its effect to prolong the forging die life was not as good as expected. To solve this problem, Nippon Steel applied its original in-line special heat treatment process to the production of boron steel to achieve a tensile strength equal to or lower than that of SWRCH 45K after spheroidizing annealing.

Fig. 1 compares the tensile strength of the developed boron steel with that of conventional boron steel. Whereas the as-hot-rolled tensile strength of conventional boron steel is higher than that of SWRCH 45K-SA (SA standing for spheroidizing annealing) by about 50 MPa, the tensile strength of the developed boron steel produced through the in-line special heat treatment is as low as 500 MPa, equivalent to that of SWRCH 45K-SA. As a result, compressive flow stress of the developed steel is lower than that of conventional boron steel by about 50 MPa, as seen in **Fig. 2**, and the life of forging dies with the developed steel is about three times that of conventional as-hot-rolled boron steel, as seen in **Fig. 3**. The new boron steel produced through the in-line special heat treatment has solved the long-pending problem of short die life as explained above, and its application is expected to expand.

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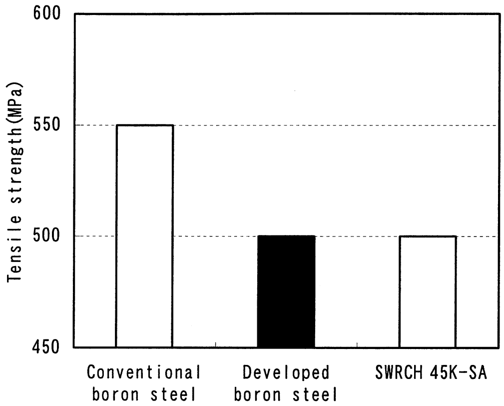

Fig. 1 Tensile strength of boron steel and SWRCH 45K

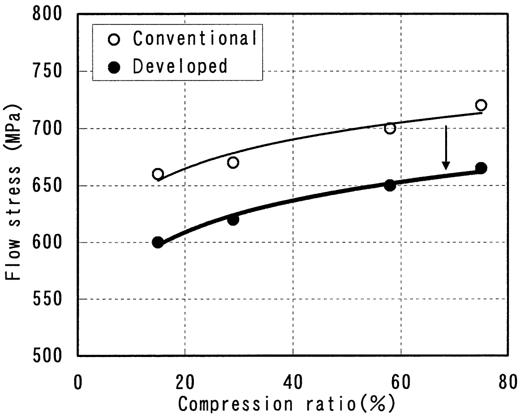

Fig. 2 Relation between compression ratio and flow stress of SAE10B22

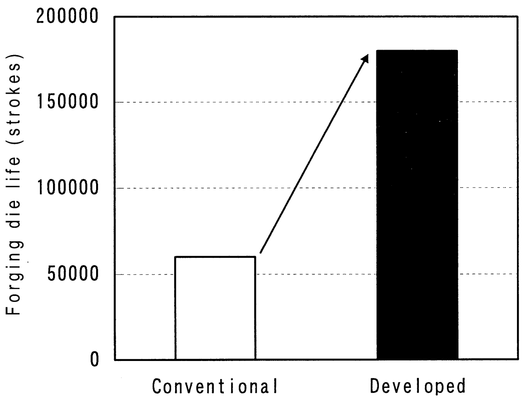

Fig. 3 Forging die life with boron steels

2.2 Wire rods for cold forging to permit omission of off-line annealing

Another type of new product, wire rods for cold forging use to permit omission of softening annealing, is characterized by its low tensile strength and good toughness equivalent to those of conventional products softened through off-line annealing at 700℃ for 7 h. These excellent properties are obtained as a result of in-line special heat treatment for direct softening without having to modify the chemical compositions of conventional wire rod products such as JIS SWRCH 45K and SCM 435H. **Fig. 4** compares secondary work processes required for the developed steels with those for conventional steels. As seen with Example 1, whereas conventional wire rods require off-line softening annealing before wire drawing and cold forging, the developed wire rods can skip the annealing process because, thanks to the in-line special heat treatment included as a part of the hot rolling process, their workability is as good as that obtainable by the off-line softening annealing. **Fig. 5** shows tensile strength of SWRCH 45K and SCM 435H measured at different portions of a coil; the tensile strength of the developed steel (DS) having undergone direct softening during the rolling process is even lower than that of the conventional steel (SA) after off-line softening annealing. While low alloy steel such as SCM 435H tends to exhibit a ferrite and pearlite structure mixed with bainite when rolled by an ordinary hot rolling method, the new in-line special heat treatment stably realizes a ferrite and pearlite structure free of bainite.

As seen in **Photo 1**, SWRCH 45K as conventionally hot rolled has a structure of ferrite and pearlite clearly showing the lamella structure. The developed version of SWRCH 45K having undergone the in-line direct softening process has also a structure consisting of ferrite and pearlite, but the cementite bands of the pearlite lamella structure are partially divided and spheroidized, as seen in **Photo 2**. This shape of cementite gives the softness and toughness to the developed steel. For reference, **Photo 3** shows the structure of a conventional wire rod after off-line softening annealing at 700℃ for 7 h; the cementite bands are partially divided and spheroidized in the same manner as those of the developed product in Photo 2.

Another characteristic of the developed steels is that low tensile strength is obtained throughout the size range of the wire rod mill, without being affected by product size. Nippon Steel's conventional product, Mildalloy[1, 2], is known to have low tensile strength thanks to accelerated ferrite transformation, which results from fine austenite grains obtained through low-temperature rolling and slow cooling. As shown in **Fig. 6,** the size range of Mildalloy is 13 mm or more; with a diameter less than 13 mm, it is difficult to cool the material homogeneously and thus it is impossible to secure low tensile strength.

On the other hand, with the developed steels, it is possible to stably obtain low tensile strength in the diameter range down to 5.5 mm because of the in-line special heat treatment. **Figs. 7 and 8** show the compressive deformation behaviors of SWRCH 45K and SCM 435H, respectively; in the case of SWRCH 45K, the flow stress of the developed version was lower than that of the conventional version by approximately 50 MPa, and in the case of SCM 435H, by approximately 150 MPa.

Next, **Fig. 9** shows the difference in critical upsetting ratio, which is an index of ductility, between the developed and conventional versions of SCM 435H and Mildalloy; upsetting ratio (%), which is given by $(H_0 - H) / H_0 \times 100$, is plotted along the vertical axis, the ratio being obtained by compressing a cylindrical, smooth-surface test piece held at both the circular ends with fluted dies. Whereas the critical upsetting ratio of Mildalloy was approximately 65%, substantially the same as that of the conventional version of SCM 435H without softening annealing, there occurred no cracks to the developed version (direct softening) of SCM 435H up to an upsetting ratio of as high as 80%, like the conventional material after off-line softening annealing.

These test results demonstrate that the wire rods for cold forging use, not requiring off-line softening annealing, produced through the in-line special heat treatment are free from the long-standing size

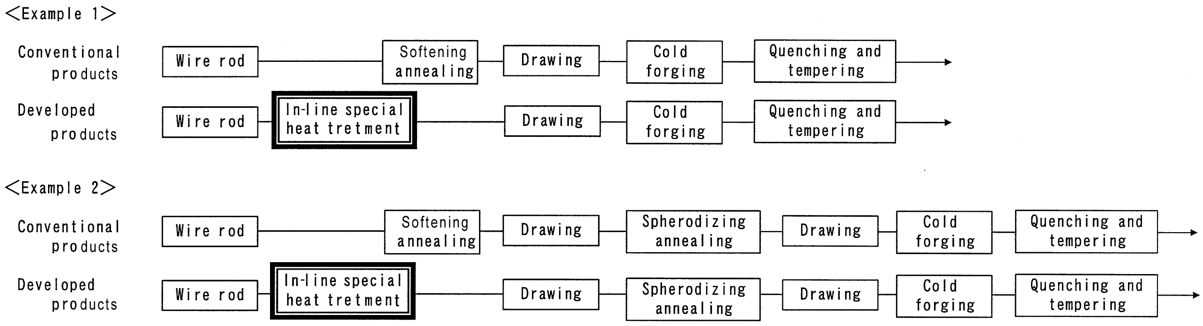

Fig. 4 Secondary working processes for conventional and developed wire rods of special steel

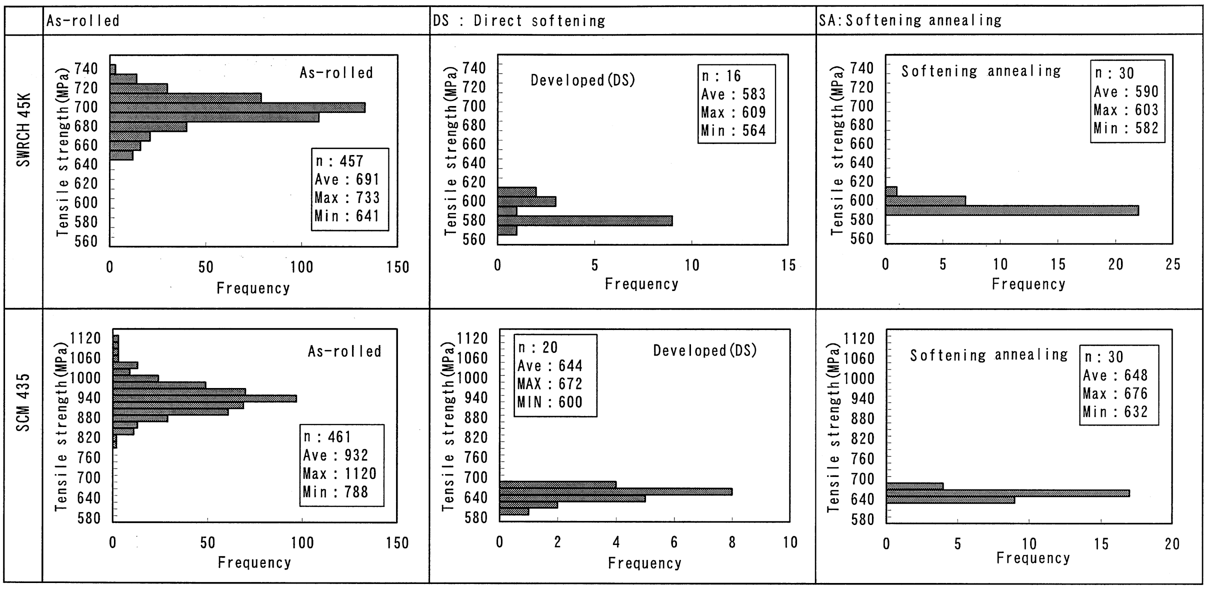

Fig. 5 Tensile strength of SWRCH 45K and SCM 435

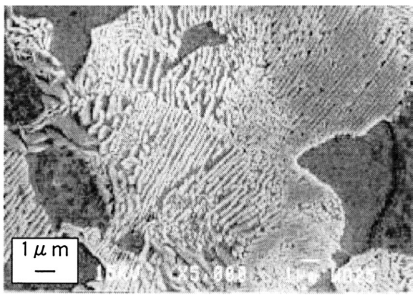

Photo 1 Conventional

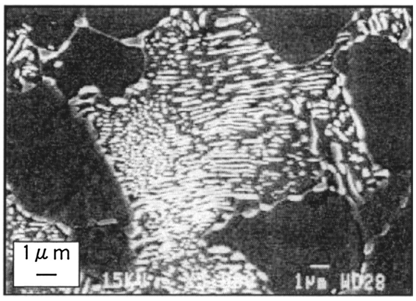

Photo 2 Developed-DS

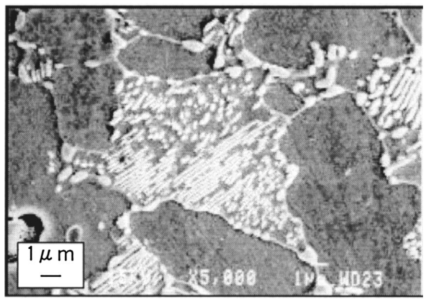

Photo 3 Softening annealing

restriction, have tensile strength even lower than that of materials treated by off-line softening annealing. Thus, the application of the developed wire rod products is expected to expand.

Fig. 10 shows the relation between the carbon equivalent (Ceq) and tensile strength of wire rods of carbon steel, comparing conventional products with the developed direct-softening products, **Fig. 11** that of low-alloy steel, and **Fig. 12** the same of boron steel. The dotted lines show the results obtained with conventional wire rods and the solid lines those of the direct-softening wire rods. These graphs show that the developed direct-softening process is capable of lowering tensile strength of wire rods of a wide variety of steel

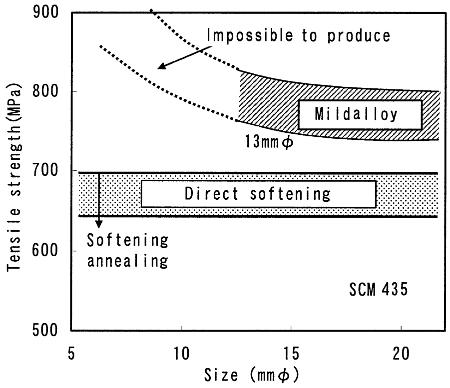

Fig. 6 Relation between size and tensile strength

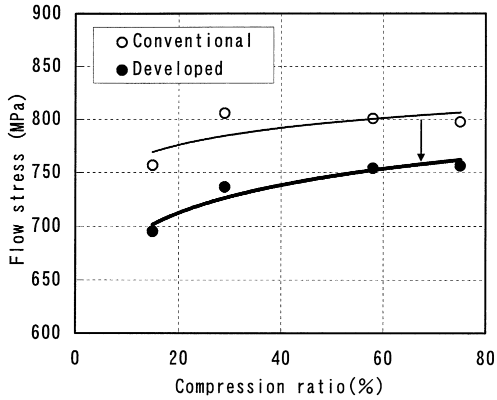

Fig. 7 Relation between compression ratio and flow stress of SWRCH 45K

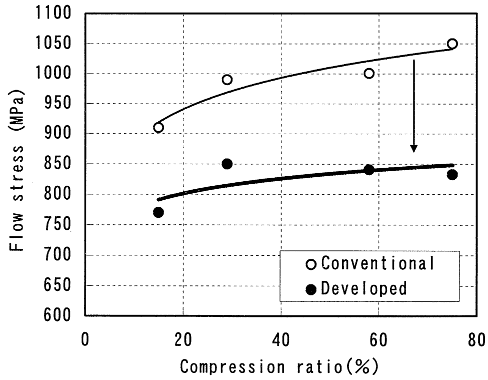

Fig. 8 Relation between compression ratio and flow stress of SCM 435H

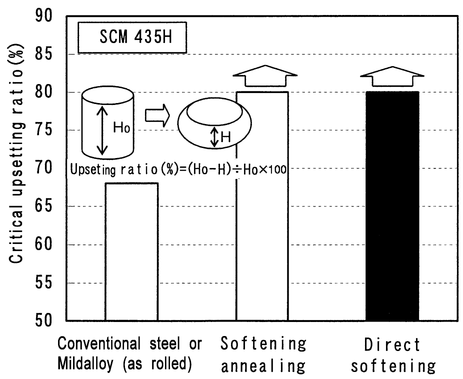

Fig. 9 Critical upsetting ratio of SCM 435H

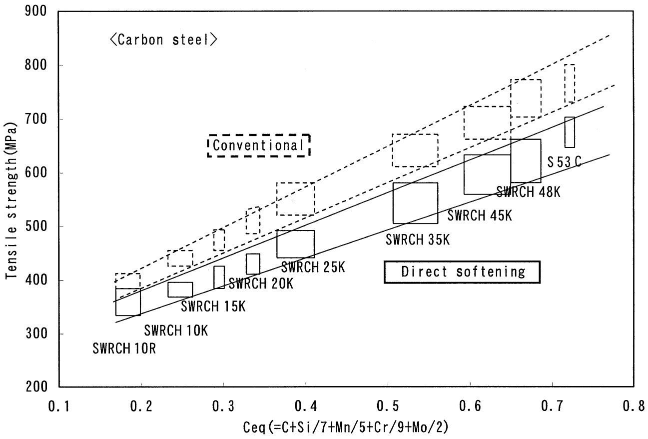

Fig. 10 Relation between carbon equivalent and tensile strength of carbon steel

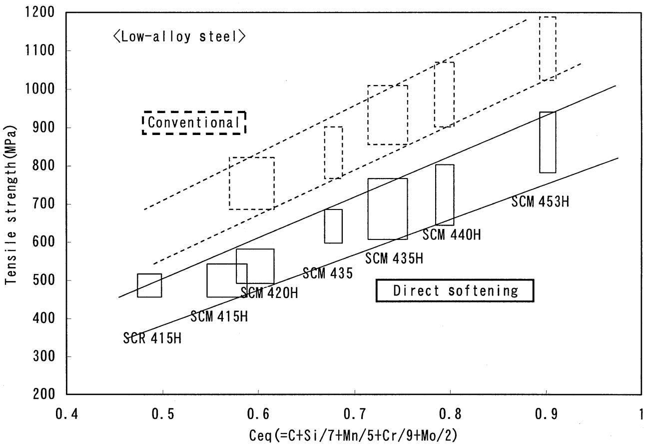

Fig. 11 Relation between carbon equivalent and tensile strength of low-alloy steel

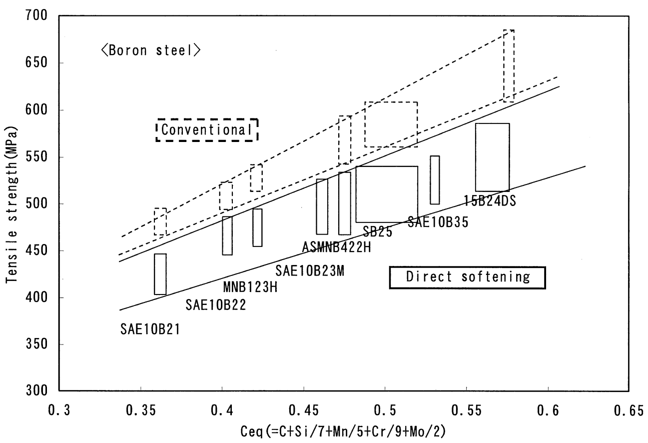

Fig. 12 Relation between carbon equivalent and tensile strength of boron steel

grades and in a wide range of carbon equivalent. Especially in the case of low-alloy steel, the tensile strength of the direct-softening wire rods, free of bainitic structure, was lower than that of conventional wire rods by as large as 200 to 300 MPa. In the cases of carbon steel and boron steel, while both the conventional and developed wire rods have the same metallographic structure of ferrite and pearlite, the developed direct-softening wire rods showed tensile strengths lower than that of conventional products by 50 to 100 MPa. Thus, the newly developed wire rod products are capable of improving the service life of forging dies and omitting the off-line softening annealing.

3. Closing

Many processing steps are required for the manufacture of final machine parts from bars and wire rods of special steel, and for this reason, it is necessary in the development of these steel products to aim at reducing the manufacturing costs throughout the whole steps of post-processing. The high-functionality steel wire rods for cold forging use herein presented exhibit excellent cold-forging performance realizing long die life without requiring modification to the chemical compositions according to JIS and other standards; their low tensile strength and good toughness allow omission of annealing in post-processing. Nippon Steel will continue developing and offering products of its originality that meet requirements of customers.

References

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