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Development of NSSC® 160R—High Purity Ferritic Stainless Steel Wire Rod

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Abstract

NSSC developed the high purity ferritic stainless steel wire rod stabilized by Nb, NSSC 160R (16%Cr-0.4%Nb-0.4%Cu-super lowC, N, S). NSSC 160R has superior properties and covers wide range of the applications. The wire of NSSC 160R has high productivity close to the austenitic stainless steel wire by optimizing the production conditions. NSSC 160R wire with high cold forgeability can be forged to complicated forms and it is very effective to abbreviation of the proc-ess and improvement of the productivity of the parts. NSSC 160R prevents intergranular corrosion at the welded parts and improves the durability, because NSSC 160R shows excellent intergranular corrosion resistance after heat patterns of welding. NSSC 160R wire rods are applied to various products widely, fasteners, strong cold forging parts, weld wires, wire nets, electrolytic polishing parts, wires and so on.

1. Introduction

About 25 million tons of stainless steel, mainly plates, are produced annually in the world. Because of their desired properties in terms of corrosion resistance, heat resistance, magnetism and strength, stainless steels are used in a wide variety of products. Stainless steel wire rods manufactured by steelmakers account for a little less than ten percent (some 1.5 to 2 million tons) of the world's output of stainless steel products. They are subjected to various types of working (drawing, forging, cutting, welding, etc.) by secondary product makers and made into final products (screws, shafts, hollow parts, springs, etc.). Stainless steel wire rods are mostly (80% to 90%) austenitic stainless steels, specifically SUS304 (18%Cr-8%Ni).

In recent years, the aggravating of environmental problems, including global warming, has led to strong calls for the manufacturing processes to be simplified and improved product durability (prolonging of product life), mainly in the automotive industry. It is, therefore, very significant to develop new materials that permit manufacturing parts with complicated shapes by cold forging, which is an efficient process and that permit improving the corrosion resistance of welds, which influences the durability of parts markedly. From the standpoint of enhancing the efficiency of cold forging dramatically and improving the corrosion resistance of finished parts, including welds, high-purity ferritic stainless steel is the most desirable.

Under those conditions, Nippon Steel & Sumikin Stainless Steel Corporation (NSSC) decided to develop a versatile, high-purity ferritic stainless steel–NSSC 160R (16%Cr-0.4%Nb-0.4%Cu with extra-low amounts of C, N and S). Unlike austenitic stainless steels, high-purity ferritic stainless steels have a high degree of magnetism. Therefore, NSSC 160R is also effective to improve the efficiency of part fitting using magnetic tools and conducting stricter quality control of parts by applying magnetic flaw detection.

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2. Concept behind Newly Developed Steel

The properties sought in the steel to be newly developed were as follows.

1) Corrosion resistance: The steel should have the corrosion resistance required of SUS304 parts (by use). The corrosion resistance of welds shall be such that the welds are free from intergranular corrosion under the influence of welding heat.
2) Cold workability: The steel shall permit reducing the load required for cold forging to about half that required of SUS304, thereby lightening the load on the forging machine. In addition, the steel shall afford comparable workability to SUS304 and permit cold forging of complex shaped parts.
3) Productivity: The steel shall be comparable in productivity to SUS304 in the wire rod to wire manufacturing process.

In order to achieve the above properties, we studied the development of a high-purity ferritic stainless steel.

There are many reports on the effects of various alloying elements on the properties of high-purity ferritic stainless steels[1, 2]. In particular, we decided to: a) add 0.4-percent Nb in order to prevent the sensitization of welds and heat-affected zones and secure good intergranular corrosion resistance[2], b) minimize the amounts of C and N, which adversely affect the ability to cold forge and corrosion resistance, and the amount of S, which adversely affects corrosion resistance, and to add 0.4-percent Cu in order to improve corrosion resistance[1], and c) implement alloying design with due consideration given to the productivity and performance of the wire rod. As the basic composition, we adopted 16-percent Cr taking into consideration the productivity of wire rod.

(1) Points to note in securing desired corrosion resistance of NSSC 160R

At temperatures from room temperature up to its melting point, high-purity ferritic stainless steel consists entirely of ferrite, in which the solubility of C and N is low and the rate of dispersion of elements contained in the steel is high. Therefore, it is difficult to prevent the sensitization of the steel even when the C and N content is decreased and the rate of cooling from high temperatures is increased. In order to restrain the sensitization effectively, it is necessary to fix any C and N by adding Nb or some other stabilizing element. Nb combines with the C and N dissolved in hot steel in the welding process, etc. to form a carbide/nitride of Nb, and thereby restrains the formation (sensitization) of a Cr carbide/nitride film in the grain boundaries, which can cause intergranular corrosion in the subsequent cooling process.

Fig. 1 shows the effect of Nb addition on the morphology of carbide (nitride) in 16-percent Cr steel. The conditions for the carbide (nitride) in steel air-cooled from 1,100°C differs markedly depending on whether or not Nb is added. When Nb is not added, C and N dissolved in the steel form a film of Cr carbide/nitride in the grain boundaries in the cooling process. By contrast, when Nb is added, the Cr carbide/nitride film is not formed in the grain boundaries since the dissolved C and N are fixed in the form of Nb carbide/nitride. In order to fix C and N dissolved in the steel in the form of Nb carbide/nitride, it is necessary to add at least ten times the amount of Nb compared to the amount of (C + N)[2].

(2) Points to note in securing desired cold formability of NSSC 160R

In order to secure the desired cold formability of a high-purity ferritic stainless steel, it is necessary not only to minimize the amount of (C + N), but also to reduce the amounts of dissolved C and N by adding Nb so as to reduce the work hardening of the steel. On the other hand, if the amount of Nb that combines with the dissolved C and N is excessive, coarse Nb carbide/nitride is formed, reducing the cold forgeability of the steel. Therefore, adding an excessive amount of Nb must be avoided.

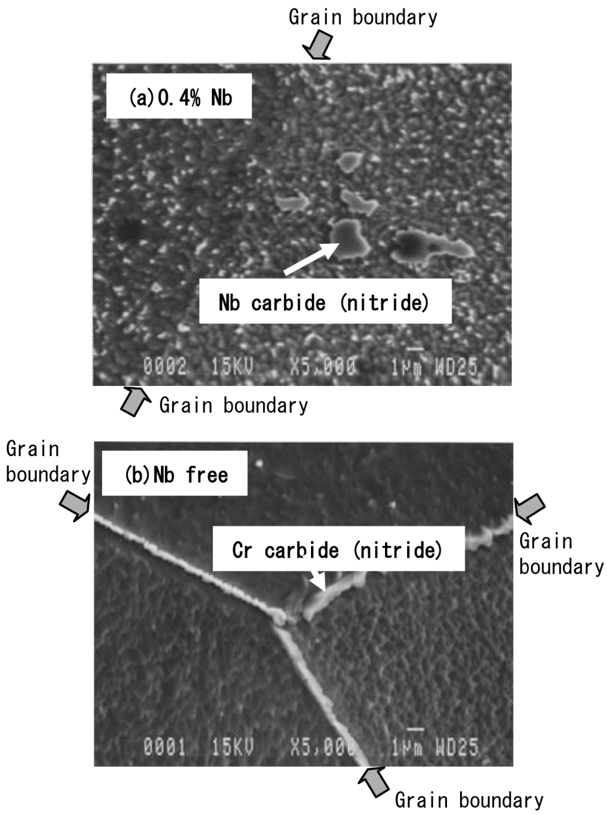

Fig. 1 Effect of Nb content on the morphologies of carbide (nitride) in 16%Cr steels after the annealing (1,100℃, air cool)

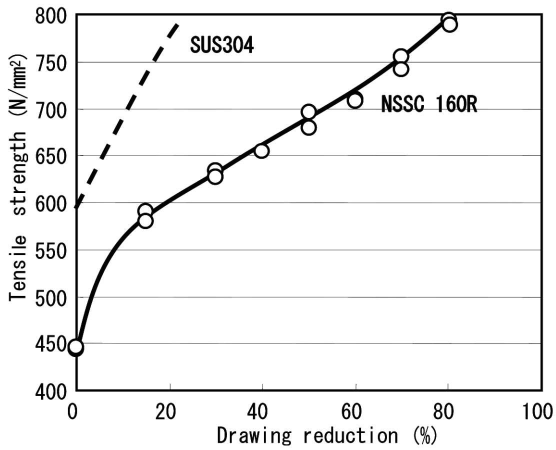

Fig. 2 Work hardening properties of NSSC 160R wire on drawing

NSSC 160R has a tensile strength of about 430 N/mm^2, which is lower than that of SUS304 (about 550 N/mm^2), while the work hardening of NSSC 160R is much less than that of SUS304 (**Fig. 2**).

(3) Points to note in securing desired productivity of NSSC 160R

The raw materials for wire rod are melted, refined and made into steel ingots at the steelmaking plant of a steelmaker. Those steel ingots are hot-rolled into wire rods at the wire rod mill. Those wire rods are drawn, annealed and made into finished products by a wire

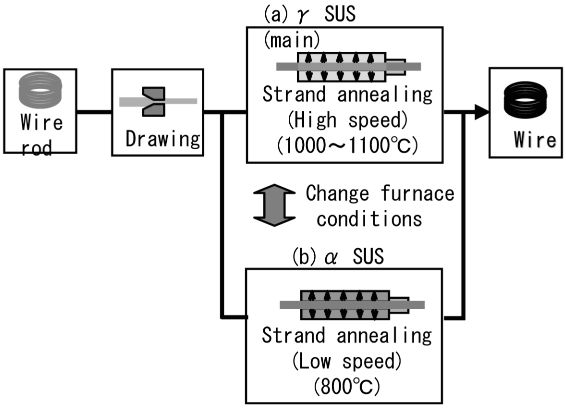

Fig. 3 Typical drawing and strand annealing processes of austenitic and ferritic stainless steels

Table 1 Typical chemical compositions of NSSC 160R

C	Si	Mn	S	Ni	Cr	Mo	Cu	Nb	N
0.01	0.3	0.3	0.002	-	16.2	-	0.4	0.4	0.01

maker.

Since high-purity ferritic stainless steel wire rods are not very tough, the wire tends to break easily in the drawing process. In order to obtain a wire rod that can be drawn stably without breaking, it is effective to limit the content of Cr, since this is detrimental to steel toughness, to within 16 percent. By so doing, it is possible to produce wires of stable quality from wire rods 5.5 mm to 34 mm in diameter.

The wire obtained by drawing a wire rod undergoes strand annealing as shown in **Fig. 3**. Austenitic stainless steel wires are subjected to high-temperature annealing (about 1,100˚C), whereas general-purpose ferritic stainless steel wires are subjected to low-temperature annealing (about 800˚C; this is to restrain the phase transformation and sensitization which can occur at higher temperatures). Therefore, when applying strand annealing to a general-purpose ferritic stainless steel wire, it is necessary to change (lower) the temperature in the annealing furnace that is used mainly for austenitic stainless steel wires. On the other hand, the NSSC 160R steel wire with Nb, etc. added is free from phase transformation even at 900˚C or higher temperatures and produces a structure of uniform grain size without causing sensitization even when it is cooled rapidly from high temperatures as mentioned earlier. (In the case of austenitic stainless steel, since the solubility of C and N is high and the rate of their dispersion in the steel is low, sensitization does not occur when the rate of cooling from high temperatures is increased.) Therefore, NSSC 160R can be subjected to high-speed strand annealing at high temperatures in the range 1,000˚C to 1,100˚C in which austenitic stainless steel wires are strand-annealed.

On the basis of the facts described above, we came up with a new 16%Cr-0.4%Nb-0.4%Cu-extra-low C, N, S steel (NSSC 160R) as a high-purity ferritic stainless steel wire rod whose properties are well balanced and which can be used for a wide variety of wire products (**Table 1**).

3. Major Properties and Application Examples

3.1 Properties and application techniques

3.1.1 Corrosion resistance

Fig. 4 shows the pitting potential on mirror-finished surfaces of various steels (JIS G 0577) and the conditions of rusting of the steels after a salt spray test (JIS Z 2371). In terms of corrosion resistance, NSSC 160R is superior to SUS430 and almost comparable to SUS304.

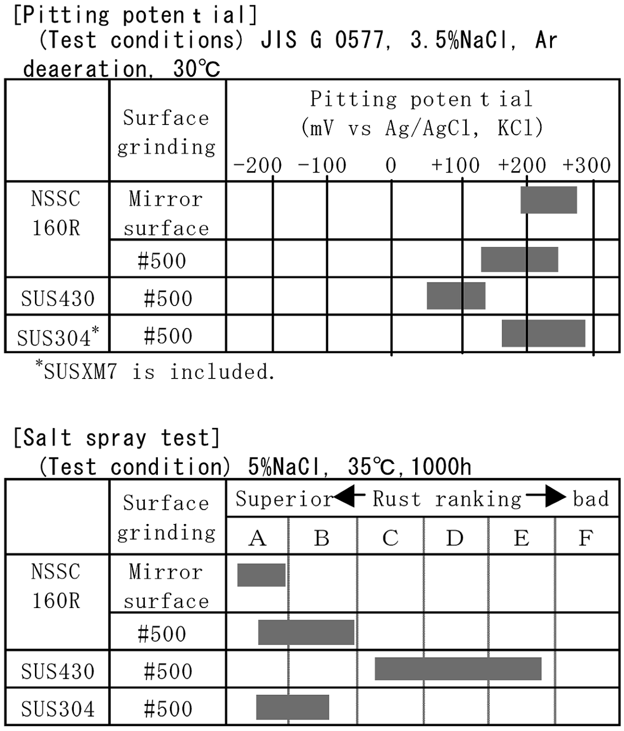

Fig. 4 Rusting circumstance after salt spray test and the pitting potentials of the materials

Many automotive parts and certain other parts are welded together. In those parts, the soundness of the welds is important. SUH 409 plates were TIG and MIG butt-welded, respectively, using various types of welding materials, and the welds were subjected to a modified Strauss test (0.5% sulfuric acid, 5% cupric sulfide) to evaluate their intergranular corrosion resistance. The test results are shown in **Fig. 5**. When the welding material was SUS430 [(c) extra-low (C+N) without Nb and (b) extra-low (C+N) with Nb/(C+N) = 8.6], the welds revealed intergranular corrosion. By contrast, when the welding material was NSSC 160R [(a) Nb/(C+N) = approx. 20], the welds were free from intergranular corrosion. Thus, the weld metal of NSSC 160R has excellent resistance to intergranular corrosion and provides an effective way to improve the durability of parts.

3.1.2 Cold forgeability

When applying strong cold forging to any part with a complicated shape, it is necessary to previously evaluate the basic deformation property of the material. **Fig. 6** shows the forging load (deformation resistance) for each of NSSC 160R and SUS304 cylindrical specimens when they were subjected to simple compression forming. Since NSSC 160R is subjected to very little work hardening because of its body-centered cubic (bcc) lattice structure, it is estimated that the working stress on the high strain side is only about 50 percent that of SUS304. **Fig. 7** shows the critical working ratio at which cracking occurs when flat-headed materials were subjected to strong cold forging. It can be seen that NSSC 160R affords equal or superior formability to SUSXM7 (17Cr-9Ni-3Cu-low C, N), which is an austenitic stainless steel for strong cold forging.

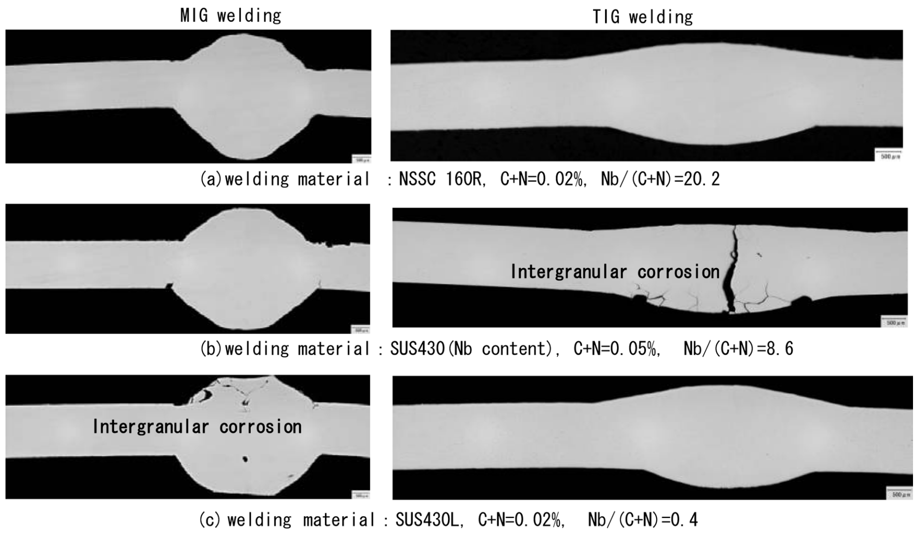

Fig. 5 Intergranular corrosion circumstance of the welds (MIG & TIG) after intergranular corrosion test (modified Strauss test, JIS G 0575, H_2SO_4: 0.5%, $CuSO_4$: 5%)

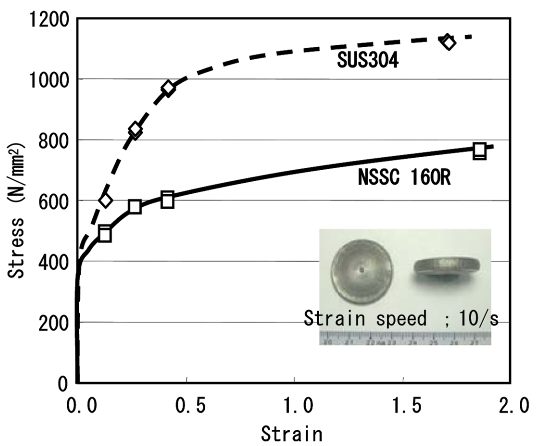

Fig. 6 Stress-strain curves of NSSC 160R and SUS304 on compression processing

3.1.3 Other properties (high-temperature strength and oxidation resistance)

Fig. 8 shows the high-temperature strengths of various types of steels. Since NSSC 160R has Nb added, which increases its high-temperature strength, it has a high-temperature strength higher than that of ordinary austenitic stainless steels at about 700˚C or below. **Fig. 9** shows the oxidation gains in weight of various types of steels when they were subjected to a continuous oxidation test under high temperatures. NSSC 160R consists entirely of ferrite even at a considerably high temperature and forms a dense, Cr-based oxide scale. Therefore, in a high-temperature range exceeding about 800˚C, it displays oxidation resistance better than that of general-purpose SUS304. From the above test results, it is considered that NSSC 160R has excellent heat resistance (high-temperature strength, oxidation resistance).

3.2 Application examples

3.2.1 Welding material

Since NSSC 160R imparts excellent intergranular corrosion resistance to welds, it is used as a welding wire for exhaust system

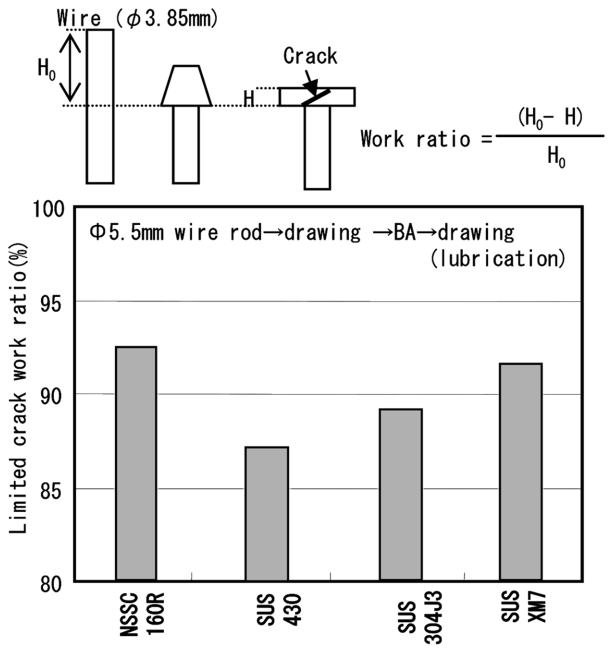

Fig. 7 Limited crack work ratios of the steels on cold forging to the flat-head form

components, etc. of automobiles. It should be noted, however, that the welds can pick up C and N from the atmosphere or oil stains, etc. during the welding process. Therefore, when NSSC 160R is used as a welding material, the value of Nb/(C+N), which influences the intergranular corrosion resistance, is increased to 15 or more. In CO_2 gas welding (MAG welding), the amount of C picked up from the atmosphere is substantially greater. Therefore, it is recommended that TIG or MIG welding using Ar (+ O_2) gas be applied instead of MAG welding.

3.2.2 Cold-forged parts (screws, etc. subjected to strong cold forging)

Since NSSC 160R has excellent cold forgeability, we attempted

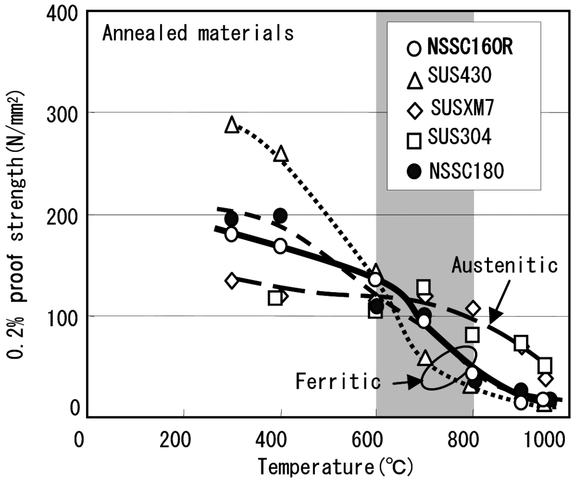

Fig. 8 Effects of temperature on 0.2% proof strength of the materials

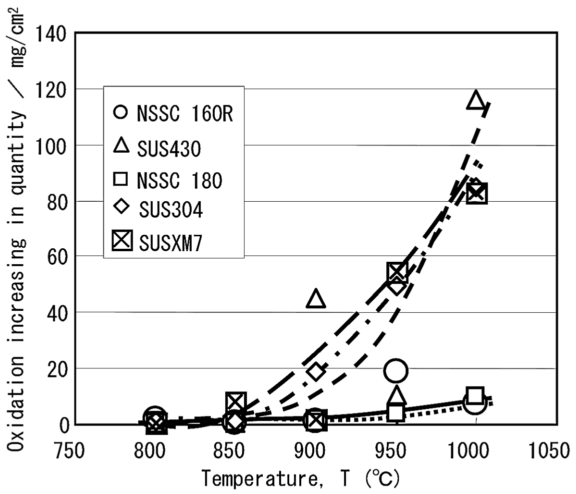

Fig. 9 Oxidation increasing in quantity of the materials (8mm ϕ × 25mm length, surface #600 grinding) after oxidation. Test at T℃ for 200h

to cold-forge an automotive component with a complicated shape that has long been fabricated by machining and welding. As a result, we demonstrated that it is now possible to make the component from a large-diameter (18-mm) wire by strong cold forging (estimated maximum working strain introduced, ε : approx. 3.5) and light machining (solid forming is possible). An example is shown in **Fig. 10**. This process has already been put to practical use. NSSC 160R has proved useful in that it has improved productivity in the process for manufacturing complicated automotive parts through solid forming by cold forging.

Since NSSC 160R affords superior cold forgeability and has strong magnetism because it is a ferritic stainless steel, screws, etc. made from this steel can be used with magnetic tools, thereby improving the efficiency of fastening work significantly. It should be noted, however, that many burrs occur in screws (gaps) because of their form. Therefore, from the standpoint of ensuring the required corrosion resistance, it is recommended that the working on screws be optimized and that the most suitable passivation treatment (i.e., treatment to reinforce the passive-state film on the stainless steel surface by immersing it in nitric acid, etc.) be applied (**Fig. 11**).

Fig. 10 Appearance of NSSC 160R part for automobile cold forged in high degree of working

Fig. 11 Effect of passivation conditions on rust of NSSC 160R screws after salt spray test

3.2.3 Wires

Since NSSC 160R has excellent corrosion resistance and magnetism, it is being increasingly used in diverse fields, especially the food industry. For example, wire netting for food made from NSSC 160R is sanitary and facilitates implementing strict quality control in the manufacturing process because even if a fragment of the wire net breaks off and gets mixed in with the food, it can easily be detected by a magnetic flaw detector. In addition, NSSC 160R is being increasingly used for wire netting for livestock and baskets for miscellaneous goods (for electrolytic polishing) because of its excellent corrosion resistance; wire netting for orchards because of its softness; heat-resistant wire netting because of its superior heat resistance; and wire mesh for glass reinforcement because of its low thermal expansion coefficient, etc.

4. Conclusion

We developed NSSC 160R (16%Cr-0.4%Nb-0.4%Cu-extra-low C, N, S)–a high-purity ferritic stainless steel wire rod with well-balanced properties and a wide scope of application. It was confirmed that NSSC 160R affords comparable productivity to austenitic stainless steel wire rods thanks to optimization of the manufacturing conditions. NSSC 160R wire rod has already been applied not only to screws, parts for strong cold forging, welding materials, various types of wire netting, parts for electrolytic polishing and wires, but also to those products to which austenitic stainless steel wire rods and plated wires have been applied. In the future, we intend to further widen the scope of NSSC 160R applications.

References

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2) Akiyama, Kitani, Goshokubo, Yokoyama, Hirahara, Hoshi: Nippon Stainless Steel Technical Report. 21, 31 (1986)

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