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Technical Progress in Steelmaking and Casting for Special Bar and Wire Steel at Muroran Works

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Abstract

Muroran Works, Nippon Steel Corporation manufactures special bars and wire rods mainly for automotive parts. In steelmaking plant, many technologies have been developed to manufacture high grade special steel and to suit the users' various needs, e.g. multi-refining converter (MURC), secondary steelmaking and casting to improve steel cleanliness, and near net casting and compact high reduction process (NCR). Authors describe recent advances and prospects in steelmaking and casting technologies for manufacturing special steel in Muroran Works.

1. Introduction

Founded in 1909, Nippon Steel Corporation's Muroran Works (hereinafter simply called "Muroran") is the only integrated iron and steel works in Hokkaido and manufactures special steels for bars and wire rods. Nearly 90% of the products of Muroran are special steels, which are used mainly for critical automotive components (the engine, driving system, and undercarriage) and various parts of industrial machinery and construction equipment (**Fig. 1**). Since 1994, Muroran has also been manufacturing bars and wire rods in cooperation with Mitsubishi Steel Muroran, Inc. (hereinafter called "MSR") and secondary processors/users (**Fig. 2**). In this report, we describe the progress in steelmaking technology for manufacturing special steel bars and wire rods at Muroran.

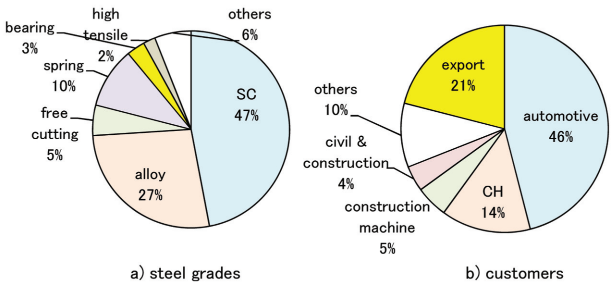

Fig. 1 Product mix of Muroran Works (2011.4-2012.3)

2. Outline of Muroran Works

In 1994, the ironmaking department of Muroran was separated from Nippon Steel Muroran Works, and the former was used to establish 80% of a joint venture with MSR, known as Hokkai Iron & Coke Corporation. Since then, Hokkai Iron & Coke has been the supplier of hot metal to Muroran's basic oxygen furnace (converter) and electric furnace. The steel source used at Muroran is converter

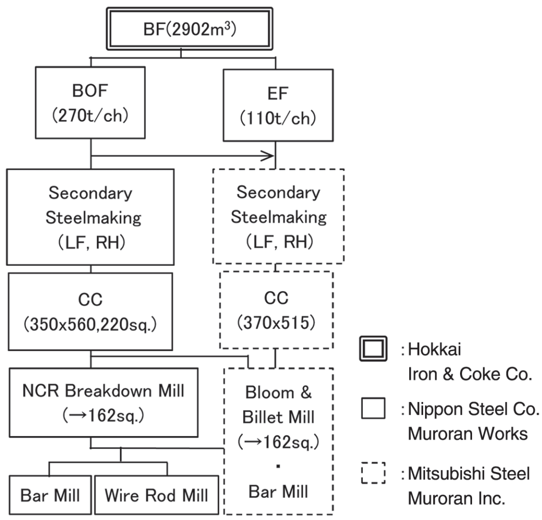

Fig. 2 Process routes of Muroran Works

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steel (with a heat size of 270 t/ch), which is passed through the ladle furnace (LF) and vacuum degassing equipment (RH) and is cast on the No. 3 continuous caster (3CC). The crude steel production capacity of Muroran is about 1,500,000 tons a year. The 3CC is a curved-type continuous caster having a machine radius of 12 m. It is capable of casting medium-section bloom (BL) (220 mm square) and large-section BL (350 mm × 560 mm). The medium-section BL has advantages in terms of isotropy and cost because it is obtained by the near-net-shape casting process, whereas the large-section BL is advantageous in terms of the removal of nonmetallic inclusions (hereinafter simply called "inclusions") in the mold because it is obtained by the large cross-section bloom casting process. Either casting process is selected according to the steel grade with consideration given to the above characteristics.

Medium-section BL and large-section BL are rolled on separate lines. The former is rolled in a 4-pass continuous horizontal-vertical (HV) rolling line called NCR (near net casting and compact high reduction) line, and the latter is rolled in a medium and large-section rolling (reversing rolling + continuous HV rolling) line. In either case, the bloom is rolled into a 162 mm square billet (BT). After inspection and conditioning, the BT is rolled into bars (19 mm to 120 mm across) and bars-in-coil (BIC) (19 mm to 60 mm across) at the bar mill or into wire rods (5.5 mm to 22 mm across) at the wire rod mill according to the product size.

On the other hand, the steel source used at MSR (with a heat size of 110 t/ch) consists of converter steel transported from Muroran and electric furnace steel made from scrap and hot metal (with a mixing ratio of 30% to 50%). After being subjected to the LF/RH treatment, the steel is cast on a continuous caster. The crude steel production capacity of MSR is about 700,000 tons a year. The continuous caster is a curved type having a machine radius of 16 m. It casts large-section BLs (370 mm × 515 mm), which are mostly rolled into large-diameter bars by the medium- to large-section rolling line of MSR.

3. Progress of Steel Refining Technology

3.1 Development of multi-refining converter (MURC) process

For primary refining, desiliconization and dephosphorization of hot metal use of a torpedo car (TPC) had been applied in the past. However, since the pretreatment of hot metal using a TPC was inefficient, owing to the small reactive interface, the pretreatment time was so much longer than the cycle time of converter that difficult preparatory work was required to synchronize them.

Under this condition, and in conjunction with the surplus production capacity of its converter, Muroran developed a new process called the Multi-Refining Converter (MURC) process whereby the surplus production capacity of the converter was utilized to deslag and decarbonize the hot metal after desiliconization and dephosphorization [1-3] (**Fig. 3**). This new process has made it possible to attain a turndown phosphorus content, after decarbonization, of $P \leqq 0.025\%$, within 70 minutes of steelmaking cycle time on a consistent basis. In addition, since the process has significantly increased the thermal capacity and eliminated the need for tapping after dephosphorization, it has become possible to use large quantities of scrap in the hot metal pretreatment process. In the MURC process, the hot metal dephosphorization and decarbonization are performed in the same converter. Therefore, the deslagging ratio during intermediate deslagging determines the attainable turndown phosphorus content (**Fig. 4**). This means that it is important to form an easy-to-remove slag during desiliconization and dephosphorization of the hot metal.

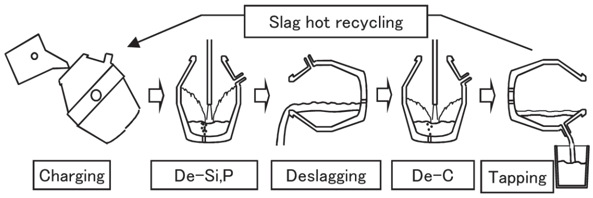

Fig. 3 MURC process

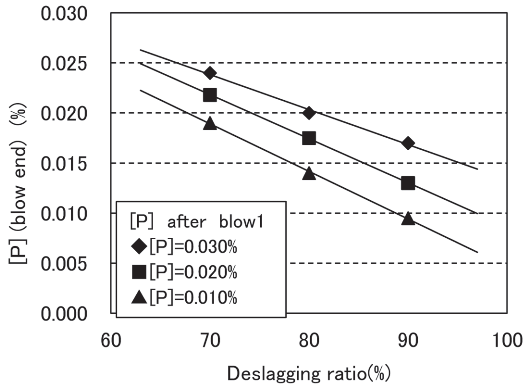

Fig. 4 Relationship between deslagging ratio and P at blow end [1)]

In order to improve the deslagging ratio without causing the hot metal to flow out of the converter, it is necessary to control the slag composition and foaming condition by the top-blowing lance and thereby secure a slagging ratio of 70% or more on a consistent basis.

3.2 Development of the F-MURC process

However, the inadequacy of the dephosphorization process became conspicuous in light of the increasingly stringent regulations on inclusions demanded by special steels, which required a reduction of the phosphorus content and the setting of a low limit to the end-point carbon content. Therefore, the TPC pretreatment of hot metal could not be completely replaced with the MURC process. Under that condition, Muroran developed a new process called the Flexible MURC (F-MURC) process that applies, as required, the tapping & slagging process that minimizes the influence of rephosphorization by the residual slag (**Fig. 5**).[1, 4)] With the MURC process, the intermediate deslagging ratio was about 70%. As a benefit, the F-MURC process has made it possible to almost completely separate the slag from the dephosphorized molten metal and reduce the phosphorus content of the hot metal charged for decarbonization by

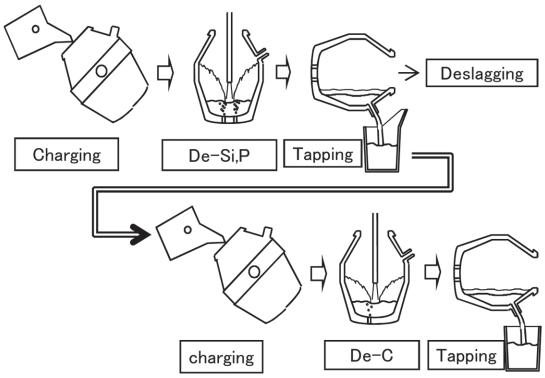

Fig. 5 F-MURC process

tapping the whole of the hot metal subjected to desiliconization and dephosphorization, removing the slag from the converter completely, and then recharging the dephosphorized hot metal into the converter.

Owing to the F-MURC process, the dephosphorization process capacity increased dramatically, allowing for a turndown phosphorus content after decarbonization of P ≦ 0.010%, even with an end-point carbon content greater than 0.50%. As a result, it became possible to omit the TPC pretreatment of hot metal. The F-MURC process comprises three patterns of processing: the MURC process, the tapping and deslagging process using a single converter, and the tapping and deslagging process using two exclusive converters. The MURC process that uses the same furnace is the most advantageous in terms of thermal capacity and is capable of melting scrap most efficiently. On the other hand, the process using two exclusive converters is the most advantageous in terms of the dephosphorization process capacity, but it is not capable of melting scrap very efficiently and hence it does not permit increasing the scrap mixing ratio significantly. Thus, the salient feature of the F-MURC process is that it permits selecting the optimum processing pattern according to production level, steel grade, and furnace repair timing.

3.3 Maximizing the effect of the F-MURC process by applying all LF treatment

The quality requirements of special steel bars and wire rods have become increasingly stringent. Especially prominent is the ever-increasing demand for exceptionally clean special steels and high-alloy special steels reflecting the increase in proportion of case-hardening steel, tough and hard steel, and non-tempered steel. Under these conditions, with the aim of further enhancing the cleanness of molten steel, improving the thermal distribution in the refining processes, and streamlining the material flow, Muroran installed an additional LF and started implementing secondary refining of the entire molten steel using a pair of LFs in 2008 (**Fig. 6**).[5)]

From the standpoint of increasing the capacity of the dephosphorization process using a converter, it is effective to lower the end-point temperature (**Fig. 7**). As a result of a redistribution of the secondary refining thermal load between BOF and LF and the implementation of the BOF operation at a low end-point temperature, made possible by the installation of the additional LF (**Fig. 8**), it became possible to expand the application of the MURC process in such a way that is more advantageous in terms of the thermal capacity and yield (except for certain high carbon, extra-low phosphorus steels) than the tapping & slagging process (**Fig. 9**). The secondary refining operation based entirely on the LFs also made it possible not only to lower the converter end-point temperature but also to avoid the heating of aluminum combustion in the RH process, thereby restraining the formation of alumina-based inclusions. In addition, as the basic processes were integrated into a single BOF-LF-RH process, the individual processing stations could be synchronized and the material flow could be rectified. As a result, it became possible to dramatically reduce the loss of heat and the waste of process capacity by solving the problems ascribable to the coexistence of LF-treated material and RH-treated material: ① the reversing of tapping (such as the reversing of a ladle in LF treatment by a

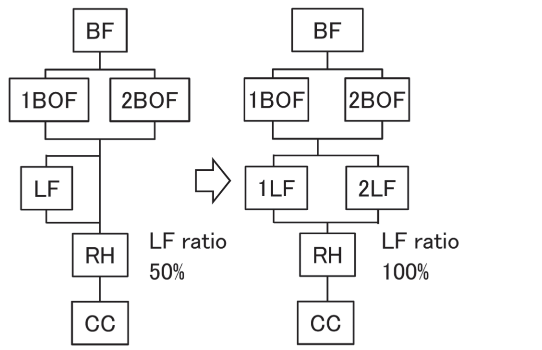

Fig. 6 Steelmaking process before/after investment in No.2 LF

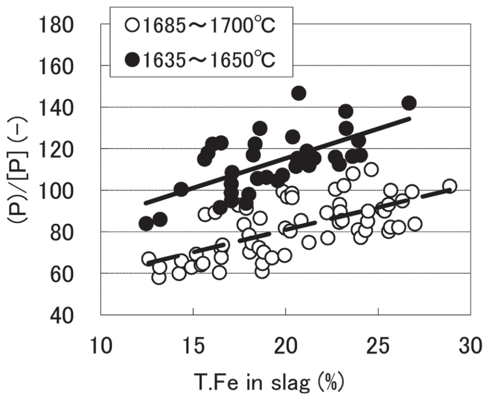

Fig. 7 Relationship between T.Fe in slag and distribution ratio of P[5)]

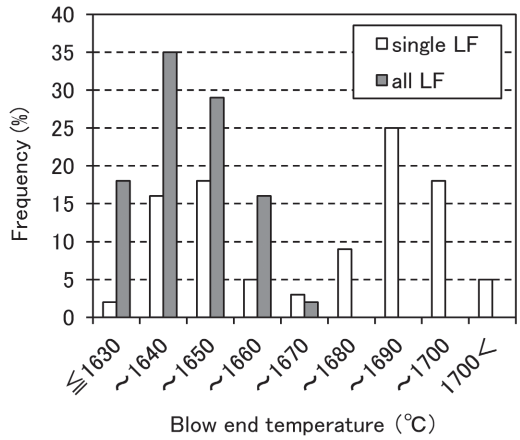

Fig. 8 Distribution of blow end temperature[5)]

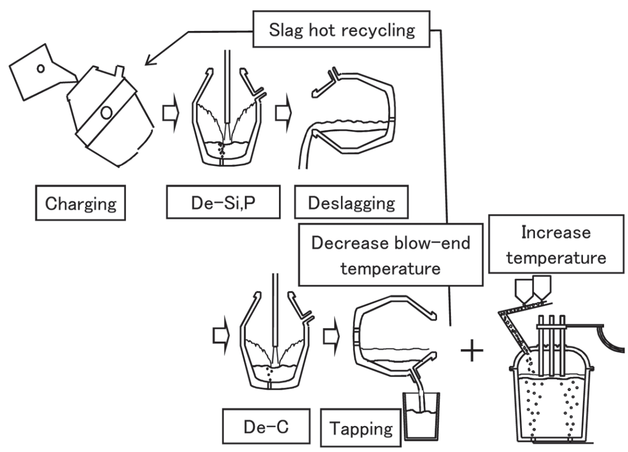

Fig. 9 MURC process combined with LF

succeeding RH material to be charged into a converter), ② preceding tapping (the stand-by of converter-tapped steel prior to RH treatment for adjustment of the timing in continuous casting), and ③ extended casting time (the extension of continuous casting time to wait for refining treatment).

4. Progress of Continuous Casting/Blooming Technology

4.1 Development of the NCR process

The 3CC was put into operation in 1981 as a continuous caster for SL and BL (350 mm × 560 mm). As Muroran came to specialize the manufacturing of bar and wire rods, it was modified into a continuous caster for BT (162 mm square) and BL. Since BL has a large cross section, continuous casting of BL offers high productivity and is suitable for manufacturing highly clean steel products. However, BL required a blooming process, which made the continuous casting of BL disadvantageous in terms of cost (e.g., the cost of fuel for the reheating furnace). On the other hand, the near-net-shape casting of BT does not require the cost of billeting; however, because of the small cross-sectional area of BT, the final product size was limited by the rolling ratio and the productivity was low. Under those conditions, Muroran developed in 1998 the so-called NCR process that features the advantages of near-net-shape casting (superior isotropy and low cost) and the advantages of large-section casting (high productivity and easy removal of inclusions).[6-8] The NCR process combines a medium-section (220 mm square) BL casting process with a direct-coupled blooming process. The principal specifications of the NCR process are shown in **Fig. 10** and in **Tables 1** and **2**.

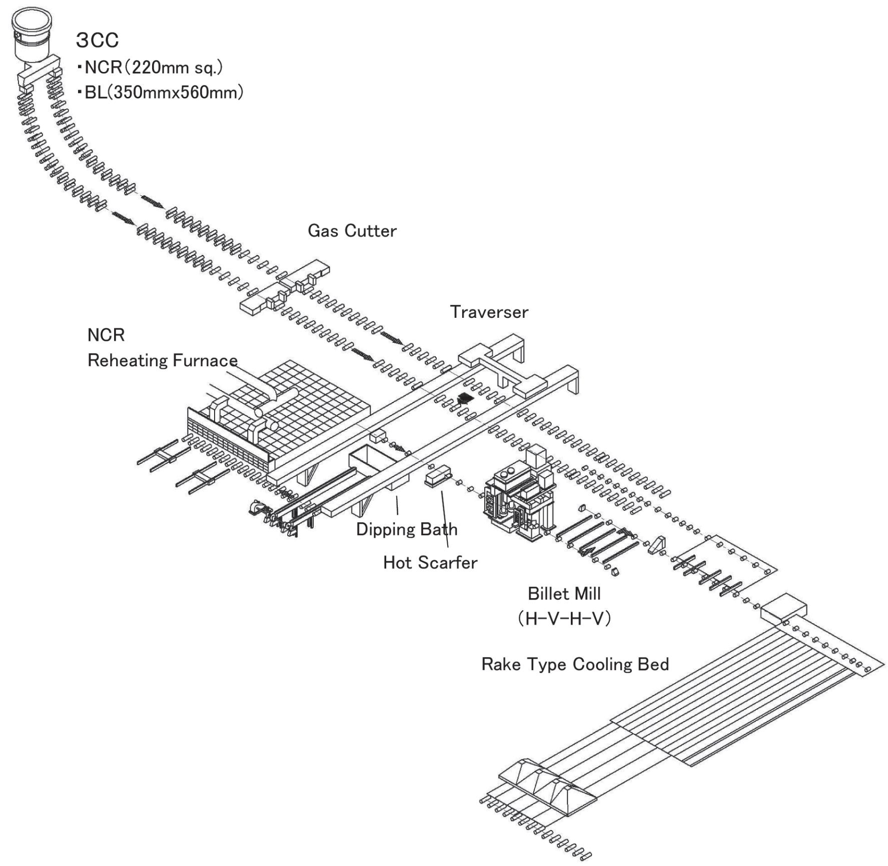

Fig. 10 Layout of continuous caster and NCR

Table 1 Main specifications of continuous caster

	Main specifications
Machine type	Curved (R = 12m, unbending points = 4)
Tundish	T-type 40t Induction heating
Section sizes	220mm sq. Triple × 2strands = 6 350 × 560mm Twin × 2strands = 4
Level control	Eddy current sensor
EMS	Mold, strand
Secondary cooling	Mist
Soft reduction	Mechanical

Table 2 Main specifications of NCR

	Main specifications
Reheating furnace	① Walking beam type 4-zone continuous furnace ② Length 19.2m, width 14.2m ③ Energy-saving burner ④ Fuel : Mixture gas (BFG + LDG + COG)
Rolling mill	① Housing type compact mill ② Size reduction : 220mm sq. → 162mm sq. ③ Finishing speed : 45m/min

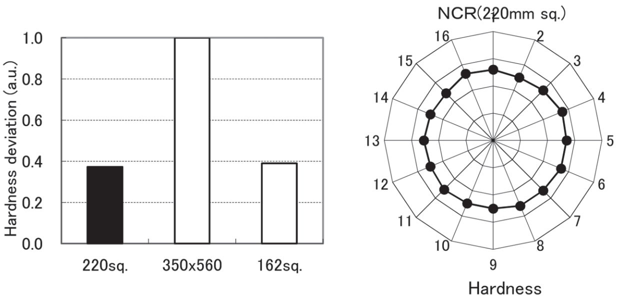

Fig. 11 Hardness deviation of bar (26mmφ) [8]

Owing to the effect of a square, medium-section mold, the variance in material quality within the cross section is small for NCR. **Fig. 11** shows the hardness of the first quarter portion of the surface layer (measured at 16 points in the circumferential direction) of each of the bars (26 mm across) rolled from the NCR BL (220 mm square), large section BL (350 mm × 560 mm), and as-cast BT (162 mm square). It can be seen that the variance in hardness of bars rolled from the square-section steels (220 mm square, 162 mm square) is smaller than that of the bar rolled from the large-section BL. Through the effect of large-reduction rolling by large-diameter rolls, the NCR process allows the deformation to reach the center of the cross section, thereby helping to reduce the center porosity and centerline segregation.

4.2 Concept of improving billet qualities

In this subsection, we shall explain the various approaches Muroran takes towards improving the qualities of billets for special steel bars and wire rods, with a focus on inclusions, segregations, and surface defects.

4.2.1 Inclusions

Since the special steel bars and wire rods manufactured at Muroran are used mainly for critical parts of automobiles, it is important to reduce inclusions that can cause those parts to fracture. As a result, the manufactured bars and rods are required to be exceptionally clean.

Muroran employs technologies for improving the cleanliness of steel in its integrated processes from steelmaking to secondary refining and continuous casting. Applying all LF treatments is one of those technologies. For the 3CC, Muroran seals the tundish (TD) in Ar/N_2 as a measure to prevent reoxidation of the molten steel in the TD, uses a large-sized TD (capacity: 40 tons) and implements flux refining as measures to promote the removal of inclusions, and applies high-precision meniscus level control by using a Eddy current sensor, together with a mold electromagnetic stirrer (M-EMS), to prevent entrapment of inclusions in the mold. In addition, since the properties of inclusions are largely influenced by the temperature of molten steel in the TD, Muroran developed in 1986 a TD induction heater,[9] which is used to control the molten steel temperature (**Fig. 12**).

4.2.2 Segregations

Centerline segregation and V-segregation in continuously cast steel cause deterioration of steel workability in cold extrusion and cold drawing. They can cause chevron cracking and cuppy breakage of wire. In the case of high-carbon bearing steel, coarse carbides formed in the centerline segregation cause the steel fatigue strength to decline.

In order to prevent the formation of centerline segregation and V-segregation in continuously cast steel, it is important to stop the flow of molten steel that accompanies the solidification shrinkage in the final stage of solidification. For the 3CC, Muroran applies the soft reduction on the final stage of solidification whereby a deformation, corresponding to the amount of solidification shrinkage of bloom, is applied to the molten steel in the final stage of solidification to restrain the molten steel flow and thereby prevent the formation of centerline segregation and V-segregation (**Fig. 13**).[10]

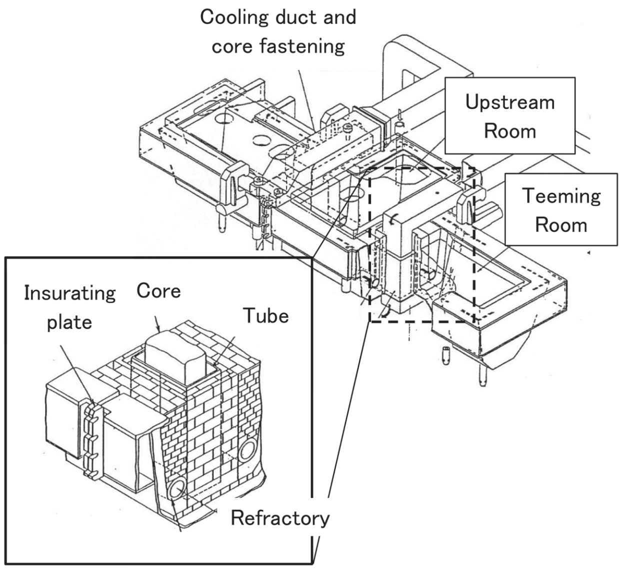

Fig. 12 Tundish induction heating equipment

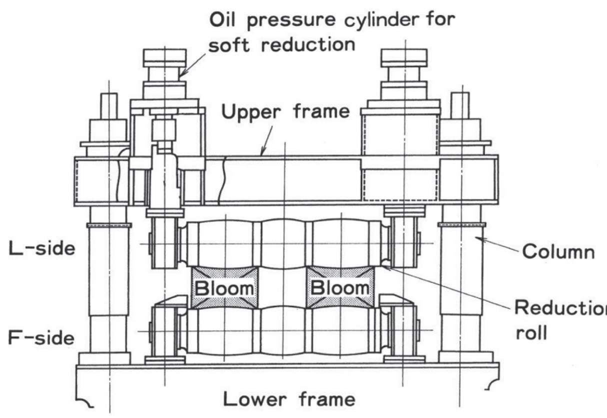

Fig. 13 Mechanical soft reduction [10]

Compared with the soft reduction in the final stage of solidification in SL-CC, the soft reduction in the final stage of solidification in large-section BL-CC is subject to a large deformation resistance of the solidifying shell at the narrow-face side. Therefore, it is necessary to secure equipment with sufficient strength to withstand the reaction force of reduction. That would require an extra investment in the equipment. In order to avoid that, Muroran also developed crown roll soft reduction technology whereby the central part across the bloom width that is susceptible to the centerline segregation is selectively reduced so as to prevent the formation of segregations efficiently.[10]

Although the technology for soft reduction in the final stage of solidification was developed originally for large-section BLs, the application thereof was eventually expanded to continuous casting

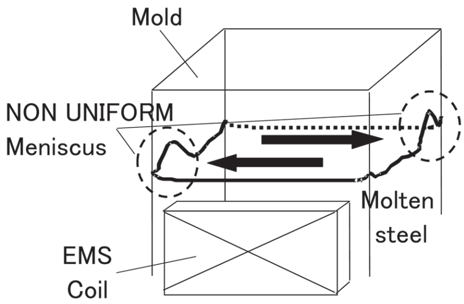

Fig. 14 Schematic illustration of initial solidification [13]

of small-section BTs[11] and medium-section BLs. On the 3CC, in addition, the soft reduction in the final stage of solidification is applied after the solidification structure is equiaxed by low-temperature casting utilizing the TD induction heater and by M-EMS[12] to secure a high level of uniformity on a consistent basis.[10] Promoting the formation of an equiaxed solidification structure is effective not only to reduce centerline segregations and V-segregations but also to prevent such internal defects as microcavities and centerline porosity that can occur during solidification shrinkage, and, hence, it helps improve the internal qualities of blooms appreciably.

4.2.3 Surface defects

Special steel bars and wire rods are required to have high strength, large load bearing capacity, and excellent cold workability. In order for them to meet these requirements, it is important that they have superior surface qualities. On the 3CC, Muroran applies various technologies for preventing surface defects.

These technologies include the use of mist in the secondary cooling as a measure to ensure uniform cooling of blooms, bloom surface grain refinement utilizing dipping bath as a measure to prevent the embrittlement of grain boundaries, the application of a mold powder for deducing the heat flux and the optimization of M-EMS[13] to prevent depressions (DPs) in hypoperitectic steel (C ≒ 0.10%). The M-EMS increases the supply of heat from the molten steel to the solidifying shell, thereby restraining the non-uniform solidification due to slow cooling. On the other hand, an excessively intense stirring of the molten steel raises the level of meniscus as the stirred molten steel flow hits against the narrow face of the mold, thereby promoting non-uniform solidification of the shell (**Fig. 14**). At Muroran, therefore, the intensity of M-EMS is optimized for each individual steel grade from the standpoint of stabilizing the initial solidification of molten steel, as well as preventing the entrapment of mold powder in the molten steel.

5. Conclusion

Muroran started manufacturing bars and wire rods in 1969 when its wire rod mill was put into operation. Since then, it has continually developed new operational and equipment technologies for dependable production of special steel bars and wire rods, especially high-grade products of spring steel, bearing steel, case-hardening steel, and cold forging steel. In the future, in order to adequately meet diversified needs of the customer and market, Muroran intends to implement optimum production of bars and wire rods taking advantage of the advanced processes of the Muroran complex comprising Mitsubishi Steel Muroran Inc. In the field of steelmaking, for example, Muroran uses either a large (270 t/ch) heat size of Muroran or a small (110 t/ch) heat size of MSR according to the specific purpose, employs converter steel and electric furnace steel, each in its proper way, and ensures optimum selection of the casting lines (NCR, Muroran BL, MSR BL). Under the new organization of Nippon Steel & Sumitomo Metal Corporation, to be inaugurated in October 2012, we would like to maximize the synergy between the strengths of the two companies, including the special steel bars and wire rods and the manufacturing lines of Sumitomo Metal Industries, Ltd.

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