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# Development of Long Life Material for Converter Shell and Shortening of Construction Period by Hydrogen Gas Cutting Method

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***Abstract:***

*Converter shell can be deformed by creep in a long period of operation and must be renovated before clearance between furnace shell and trunnion ring reaches the limit value. JFE Steel has developed long life material for converter shell and shortened construction period by hydrogen gas cutting method.*

## 1. Introduction

The clearance between the converter shell and the trunnion ring is measured and renovation work is performed before the clearance reaches the limit value in order to prevent contact between the converter shell and trunnion ring due to creep deformation of the shell and equipment trouble such as trunnion ring cracking or damage, ultimately leading to a converter collapse accident. In renovation of the converter shell, the cost of producing the converter and construction costs are on the scale of several ¥100 million, and the effect on production is also serious, since a lengthy equipment shutdown is necessary. For these reasons, measures for long life of the converter shell and shortening of the construction period in converter shell renovation have been demanded.

Against this background, JFE Steel developed a long life material for the converter shell considering prevention of weld cracks while maintaining creep strength, and also shortened the converter shell renovation period by applying the hydrogen cutting method, as described in the following report.

## 2. Long Life Material for Converter Shell

### 2.1 Development of Long Life Material for Converter Shell

#### 2.1.1 Material design concept of SM400C-Mod.

Conventionally, a rolled steel for welded structures (JIS: SM400C) had been used as the material for the converter shell in steelmaking shops at JFE Steel's West Japan Works Fukuyama and Kurashiki and other plants considering weldability at the repair of shell melting damage and partial renovation of deformed and cracked parts. Although SM400C has excellent weldability, its creep resistance strength was poor. To avoid the risk of contact between the shell and the trunnion ring due to creep deformation, it had been necessary to carry out partial or total renovations of the converter shell from time to time. Therefore, when total renovations of the shells of No. 1 and No. 2 converters at the Fukuyama No. 3 Steelmaking Shop were carried out in 2002 and 2003, a 0.5% Mo-low C steel (named SM400C-Mod.) was adopted as a creep deformation-resistant material. However, after the renovated converters had been in service for 2 years, cracking which appeared to be reheat cracking occurred in field welds of the brick support hardware around the tap hole.

The material design concept of the SM400C-Mod. used in the renovations of No. 1 and No. 2 converters at Fukuyama No. 3 Steelmaking Shop is shown in

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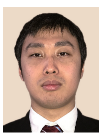

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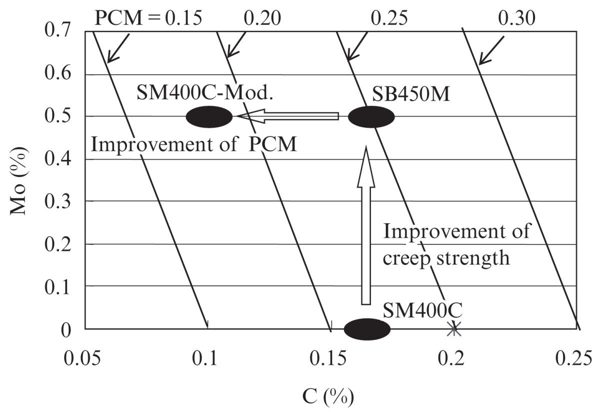



Fig. 1 Approach to material design

**Fig. 1**. First, Mo was added to increase creep strength. Although the creep strength of steel generally increases in proportion to Mo addition, that effect becomes saturated at around 0.5% Mo. Therefore, Mo addition was set at 0.5%, which was the same as in SB450M. Moreover, weldability was also required in the converter shell, since welding repair is necessary when a hole occurs in the shell due to abnormal erosion of the bricks, etc. It is necessary to reduce C to obtain weld crack sensitivity (PCM) equal to that of the conventional SM400C, but a certain amount of C is necessary because the C content affects mechanical strength. For this reason, a C content of approximately 0.1% was decided so as to secure a certain level of mechanical strength together with weldability. The result of this material design, SM400C-Mod., has high creep strength while also providing satisfactory weldability, and thus was the optimum material for use in the converter shell.

However, as described above, cracking that appeared to be reheat cracking occurred in field welds. The main factor in this problem is considered to be a relative decrease in grain boundary strength as a result of the increase in intragranular strength due to Mo addition. As countermeasures, the field welding method was improved as an emergency measure, and development of a reheat cracking resistant material was decided as a permanent measure.

### 2.1.2 Development and composition design of reheat cracking-resistant material

As indexes of reheat cracking resistance, $\Delta G$, expressed by Eq. (1), is generally used for Nb-free Cr-Mo steels and PSR, expressed by Eq. (2), is used for Nb-added Cr-Mo steels, and the respective compositions are designed so that $\Delta G<0$ or PSR<0[1].

$$\Delta G = Cr + 3.3Mo + 8.1V - 2 \quad \cdots\cdots (1)$$

$$PSR = Cr + 2Mo + Cu + 10V + 7Nb + 5Ti - 2 \quad \cdots (2)$$

The candidates for the new material considered in this study were Sample 1 (0.5% Mo, Nb-, V-free) and Samples 2 and 3 (existing material and developed material, 0.3% Mo, Nb-, V-added), as shown in **Table 1**. Because both Nb-added and Nb-free materials were studied, including the conventional SM400C, SB450M and SM400C-Mod., and no appropriate index exists for a comparative evaluation of their reheat cracking resistances, the materials were evaluated by the index PSR-Mod., which is a synthesis of the two equations, using the larger of the coefficients in $\Delta G$ and PSR for each constituent element. PSR-Mod. is shown in Eq. (3). A material can be evaluated as having reheat cracking resistance if PSR-Mod.<0.

$$\text{PSR-Mod.} = Cr + 3.3Mo + Cu + 10V + 7Nb + 5Ti - 2 \quad \cdots\cdots (3)$$

When the reheat cracking resistance of each material is evaluated using PSR-Mod., as shown in **Fig. 2**, SM400C-Mod. has PSR-Mod.=0. Therefore, as in the case of SB450M, there is a possibility of reheat cracking. On the other hand, the evaluation by PSR-Mod.

Table 1 Chemical component of sample

| Material | C | Si | Mn | Mo | Nb | V | Ca (ppm) |
|---|---|---|---|---|---|---|---|
| SM400C | 0.12 | 0.23 | 1.11 | | 0.00 | 0.00 | |
| SB450M | 0.24 | 0.25 | 0.87 | 0.52 | 0.00 | 0.00 | |
| SM400C-Mod. | 0.10 | 0.25 | 0.85 | 0.49 | 0.02 | 0.02 | |
| Sample 1 (additive-free Nb, V + Mn + Ca) | 0.10 | 0.25 | 1.05 | 0.49 | | | 20 |
| Sample 2 existing material (0.3%Mo) + Ca | 0.09 | 0.25 | 1.50 | 0.29 | 0.01 | 0.05 | 20 |
| Sample 3 (0.3%Mo + Nb, V + Ca) | 0.10 | 0.25 | 1.05 | 0.30 | 0.02 | 0.02 | 20 |

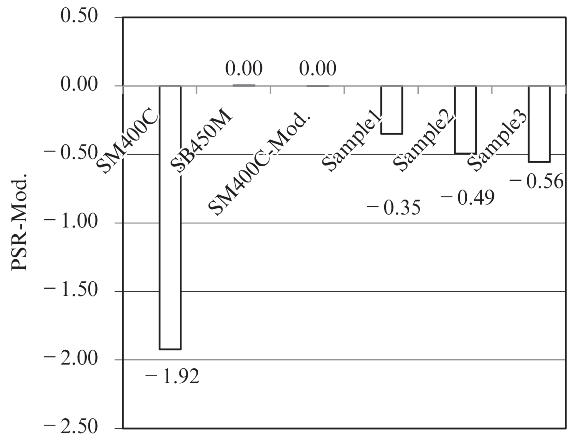



Fig. 2 PSR-Mod. of materials

indicated that reheat cracking is not a problem in the above-mentioned candidate materials.

It may be noted that 20 ppm of Ca was also added to all the candidate materials as a measure to prevent reheat cracking. Reheat cracking is a type of intergranular cracking that occurs in the coarse-grained heat affected zone (CGHAZ), which is affected by stress concentration, during high temperature use. Reducing impurity elements and performing heat treatment are effective preventive measures, and Ca addition is effective for reducing impurity elements. Addition of Ca can prevent loss of toughness and cracking by forming CaS (calcium sulfide) by the chemical reaction shown in Eq. (4), and thereby suppressing formation of MnS (manganese sulfide).

$$Ca + S = CaS \qquad (4)$$

#### 2.1.3 Results of creep test and Charpy impact test

A creep test was conducting using a total of 6 materials, including the three conventional materials and three candidate materials shown in Table 1, and their creep deformation resistance was evaluated. Concretely, the test was carried out in a range (temperature: 530 to 620°C, stress: 60 to 130 MPa) near the temperature and stress obtained as a result of coupled analysis of a heat transfer analysis and stress analysis, which were conducted separately, and creep resistance was evaluated by the time until cumulative strain due to creep deformation reached 2%. The value of 2% corresponds to the allowable deformation set in order to prevent contact between the converter shell and the trunnion ring due to creep deformation of the shell. The results were graphed using the Larson-Miller parameter (L.M.P.) expressed by Eq. (5), as shown in **Fig. 3**.

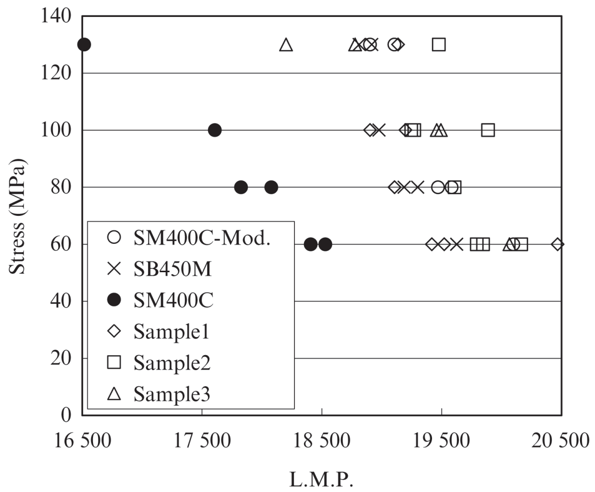



Fig. 3 Result of creep test

$$\text{L.M.P.} = T(\log t + C) \qquad (5)$$

$T$: temperature (K), $t$: time (h), $C$: constant (20 in case of general heat-resistant steels)

At the same stress, the steels with plots on the right side (large L.M.P.) in Fig. 3 have excellent creep resistance because the atmospheric temperature is large or loading time to 2% cumulative strain is large. Based on this result, Samples 1 to 3 are all greatly superior to SM400C and are also equal or superior to SM400C-Mod., and can be used without problems.

Next, reheat cracking resistance was evaluated by low temperature toughness after high temperature use, assuming actual operating conditions. A total of 6 materials (conventional and candidate materials described above) were evaluated. As the evaluation method, accelerated tests of the base metal and the heat affected zone (hereinafter, HAZ) of each material were conducted by the step cooling (hereinafter, SC) method, and low temperature toughness was evaluated by the Charpy impact value. The results are shown in **Fig. 4**. In Samples 2 and 3, sharp decreases were observed in the Charpy impact value in the HAZ, and as shown in **Fig. 5**, and the transition temperature was also near 30°C, indicating a possibility of low temperature brittle fracture due to a loss of toughness under the low temperature condition during furnace repairs, etc.

#### 2.1.4 Selection of Long Life Material for Converter Shell

As described in the previous section, a creep test and Charpy impact test were conducted for SM400C-Mod., which has a combination of high creep strength and weldability, and three candidate materials, Samples 1 to 3, with composition designs aimed at developing a material with superior reheat cracking resistance. Based on the results of the Charpy impact values after SC of the HAZ, it was concluded that Sample 1 is the optimum material.

As described above, Sample 1 was selected as the material for the converter shells of Fukuyama No. 2 Steelmaking Shop No. 2 and No. 3 converters, which were the next converters scheduled for renovation at that time. Sample 1 was named CMC steel, taking the initial letters of the symbols of its distinctive elements, low (0.1%) C, 0.5% Mo-added, 20 ppm Ca-added, Nb-, V-free. Use of CMC steel as the converter shell material could be expected to result in a long life converter with excellent deformation resistance and crack resistance.

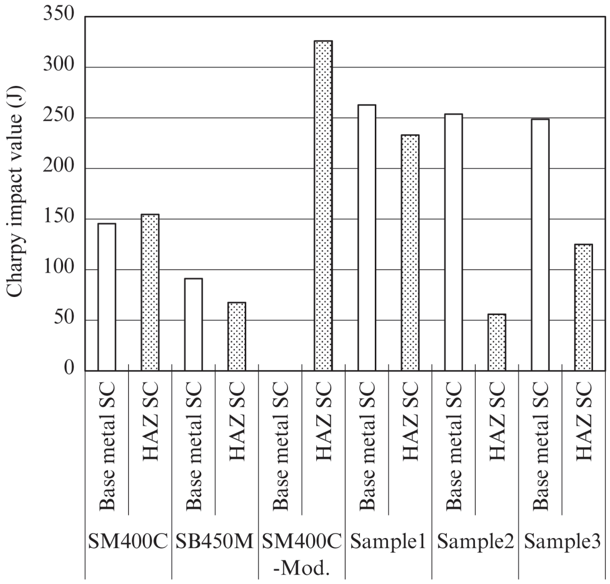



Fig. 4 Charpy impact value at 20˚C

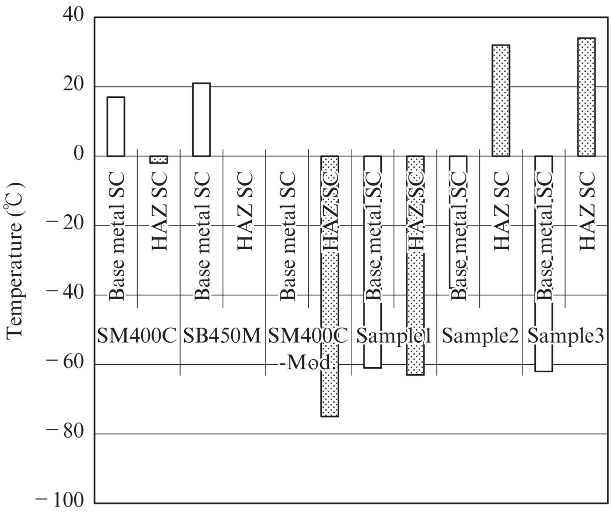



Fig. 5 Transition temperature

## 2.2 Effect of Long Life Material

### 2.2.1 Actual deformation before and after total renovation of converter shells at Fukuyama No. 3 Steelmaking Shop

**Figure 6** shows the trend of shell deformation before and after adoption of SM400C-Mod. at Fukuyama No. 3 Steelmaking Shop. Before adoption, deformation exceeded 100 mm after about 100 000 charges, but after adoption, deformation was on the order of 20 to 40 mm. In other words, the shell deformation rate was reduced to 20 to 40% of that before adoption.

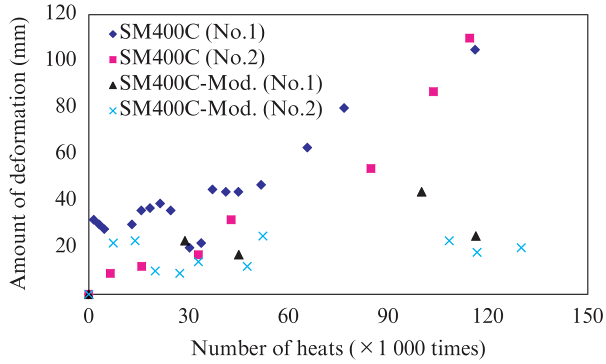



Fig. 6 Amount of deformation after using SM400C-Mod.

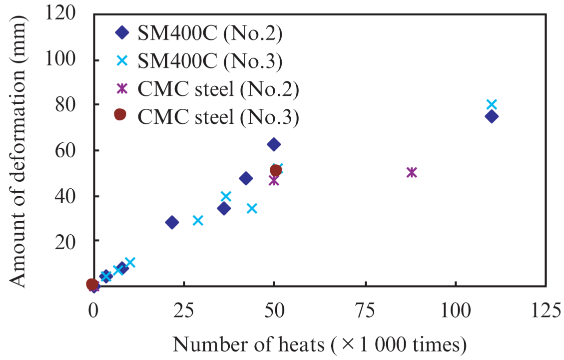



Fig. 7 Amount of deformation after using CMC steel

### 2.2.2 Actual deformation before and after total renovation of converter shells at Fukuyama No. 2 Steelmaking Shop

**Figure 7** shows the trend of shell deformation before and after adoption of CMC steel at Fukuyama No. 2 Steelmaking Shop. Before adoption, deformation after about 100 000 charges was approximately 80 mm. After adoption, deformation at about 80 000 charges was around 50 mm, and the shell deformation rate was 78% of that before adoption.

### 2.2.3 Future outlook

At No. 3 Steelmaking Shop, where SM400C-Mod. was adopted, deformation of the converter shell decreased and long converter life can be expected. Deformation also decreased at No. 2 Steelmaking Shop, where CMC steel was adopted, but the effect was not as large as in the creep test results described in section 2.1.3. In the future, the cause of the larger actual deformation of the converter shells at No. 2 Steelmaking Shop in comparison with the creep test results will be investigated, and the effectiveness of the CMC steel will be assessed.

## 3. Shortening of Construction Period by Hydrogen Gas Cutting

### 3.1 Partial Renovation of Converter Shells

As described at the beginning of this paper, total renovations of the converter shell are carried out to prevent high temperature creep deformation of the central part of the shell leading to contact between the shell and the trunnion ring. A partial renovation is performed when local deformation occurs in the converter shell. Recently, a partial renovation of the upper part of a converter shell was carried out at Fukuyama No. 3 Steelmaking Shop. In partial renovations, the damaged part is removed by gas cutting, and the reused part of the existing shell is smoothed by polishing with a grinders. Thus, it is possible to shorten the construction period by making the as-cut surface as smooth as possible, as this reduces the amount of polishing work. Therefore, hydrogen gas cutting was applied in the partial renovation at Fukuyama No. 3 Steelmaking Shop to obtain a smooth gas-cutting surface.

### 3.2 Hydrogen Gas Cutting

Hydrogen gas cutting is a gas cutting method in which steel is oxidized by blowing cutting oxygen on a steel plate that has been preheated with hydrogen gas, the steel is melted by the oxidation heat, and the molten steel is blown out of the cut by the oxygen jet[2)]. As a feature of hydrogen gas cutting, the cutting speed is faster than in general gas cutting using propane or acetylene. This is because the combustion velocity of the hydrogen flame is faster than that of the propane or acetylene flames, producing in a narrow flame that transmits concentrated heat energy to the material being cut[2)]. **Figure 8** shows the relationship between the cutting speed and the notch depth in hydrogen gas cutting and acetylene gas cutting. The cutting speed of acetylene gas cutting reaches its speed limit at 160 mm/min, whereas hydrogen gas cutting reaches its limit speed at 320 mm/min. In addition, the minimum notch depth for acetylene cutting was 1.5 mm, but in contrast, the minimum in hydrogen gas cutting was 0.5 mm. Thus, these results showed that hydrogen gas cutting has a faster cutting speed than acetylene gas cutting, and its cutting surface is also smooth.

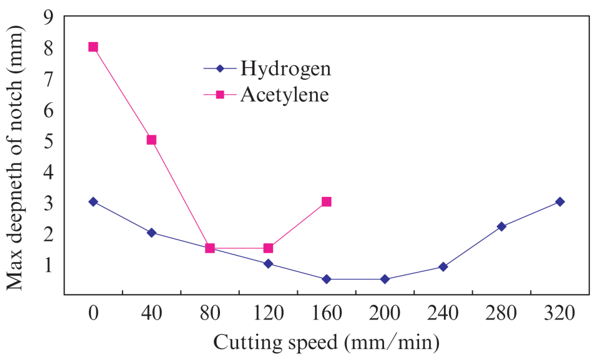



Fig. 8 Relationship between cutting speed and notch depth

**Photo 1** and **Photo 2** show the cutting surfaces with acetylene gas cutting and hydrogen gas cutting, respectively. In comparison with the acetylene gas cutting surface, the hydrogen cutting surface is smooth and displays few irregularities. Based on this, a shortening of cutting surface polishing time can be expected. The smooth cutting surface with hydrogen gas cutting is the result of stable cutting owing to the narrow flame and large heat energy per unit of surface area.

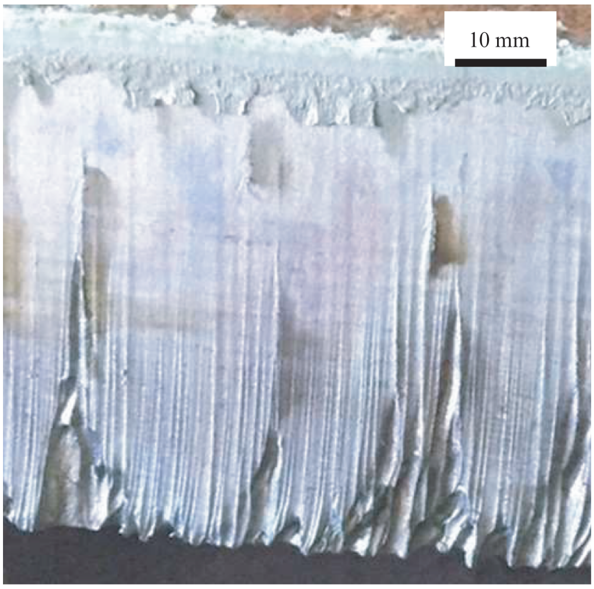



Photo 1 Cutting surface by acetylene gas

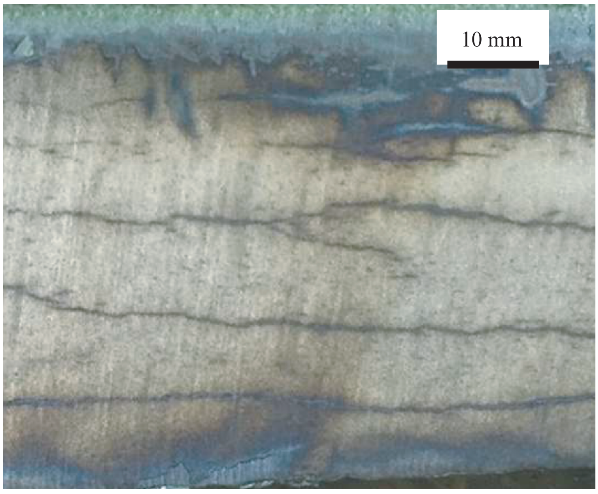
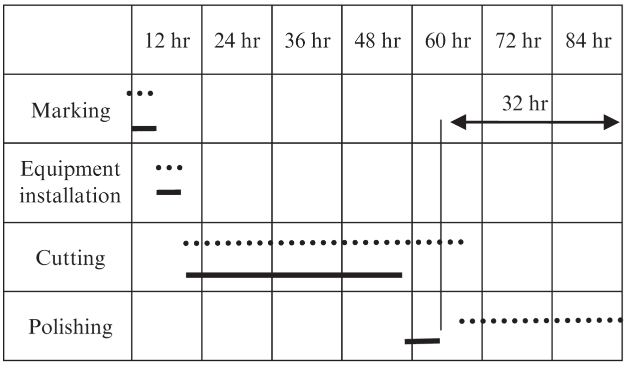



Photo 2 Cutting surface by hydrogen gas




…Past schedule of acetylene gas cutting

− Schedule of hydrogen gas cutting

Fig. 9 Shortening achievement

### 3.3 Application of Hydrogen Gas Cutting to Actual Converter

Hydrogen gas cutting was applied in a partial renovation of the upper part of a converter shell at Fukuyama No. 3 Steelmaking Shop. **Figure 9** shows the results of shortening of the construction period by application of hydrogen gas cutting. This figure shows a comparison of the actual schedule with hydrogen gas cutting and the originally-planned schedule with acetylene gas cutting. As a result of applying hydrogen gas cutting, the cutting speed was increased by 20% and cutting time was shortened by 10 hours. In addition, polishing time could also be shortened by 22 hours owing to the smooth gas-cutting surface.

## 4. Conclusion

This paper introduced the development of a long life material for the converter shell and shortening of the construction period by application of hydrogen gas cutting.

(1) In the development of the long life converter shell material, composition design was performed using the newly-proposed index PSR-Mod. and Ca was added to prevent intergranular cracking in order to improve reheat cracking resistance, which had become a problem with the SM400C-Mod. used in No. 1 and No. 2 converters at Fukuyama No. 3 Steelmaking Shop. A creep test and Charpy impact test after step cooling (SC) of the HAZ were conducted with three candidate materials, Samples 1 to 3. Sample 1, which was named CMC steel, was selected as the material for the shells of No. 2 and No. 3 converters at Fukuyama No. 2 Steelmaking Shop.

(2) As the effects of long life materials for the converter shell, when SM400C-Mod. was adopted, the shell deformation rate was reduced to 20 to 40% of that before adoption, while the deformation rate was reduced to 78% with the CMC steel.

(3) Use of the hydrogen gas cutting method resulted in an increased cutting speed and smooth cutting surface, realizing a 32-hour shortening of the construction period in comparison with the past results.

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