Consideration of steel scrap melting in a cupola

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Summary

This report contains the following information:
A survey based on statistical data concerning the recent increase in the amount of steel scrap and the presence of other elements such as zinc from zinc-coated steel sheet, and the countermeasures being taken by the foundry industry.
The results of a study on the problems caused when a large amount of zinc-coated steel scrap is used as a raw material and melted in an induction furnace, which revealed damage to refractory materials and cooling coils and defects in the molten metal produced, making it clear that an induction furnace is inappropriate for melting when the steel scrap contains zinc etc.
The mechanism of carbon pickup and melting in a cupola of low carbon material as the basis of melting of steel scrap is elucidated by means of simulations and measurements in foundries.
The structure and distinctive operating system of a long-campaign liningless type of cupola developed by Naniwa Roki Co., Ltd. on the basis of this research are demonstrated by giving an example.

Résumé

Nous vous proposons tout d'abord de nous pencher sur les données statistiques afin de mieux saisir la réalité concernant la quantité de riblons qui ne cesse d'augmenter, l'incorporation d'éléments étrangers tel que le zinc et les dispositions prises par les fonderies. Nous étudions ensuite deux problèmes majeurs liés à l'utilisation du four à induction pour la fusion des charges contenant une quantité importante de tôles zinquées : endommagement des revêtements réfractaires et des serpentins réfrigérants, d'une part, et défauts que peut présenter le produit de fusion, de l'autre. Ces problèmes mettent en évidence le fait que ce type de four n'est pas adapté au traitement de riblons en grande quantité. Nous vous proposons par ailleurs de définir, à partir des données fournies par les simulations et les mesures effectuées sur le terrain, le mécanisme de la recarburation et de la fusion, a l'intérieur d'un cubilot, des aciers au carbone à faible teneur. En outre, nous prenons l'exemple d'un cubilot longue campagne sans revêtement intérieur qui a été mis au point par la société Naniwa Roki afin d'en expliquer la structure et le système de fonctionnement.

Zusammenfassung

Zuerst zeigten wir die Resultate einer hauptsächlich auf statistischen Daten basierenden Untersuchung über die seit kurzem erhöhte Menge an Stahlabfall und das Vorhandensein anderer Elemente in diesem Abfall, wie z.B. Zink, sowie die von Gießereien getroffenen Maßnahmen. Hiernach beschrieben wir eine Studie der Probleme, die auftreten, wenn zinkbeschichtetes Stahlblech als Rohmaterial für Schmelzabfall verwendet wird, insbesondere in Induktionsöfen, indem wir das Problem in zwei Kategorien aufteilten: Schäden am feuerfesten Material des Ofens und an den Kühlspulen und die Degradierung des geschmolzenen Metalls. Diese Studie zeigte, daß Induktionsöfen nicht zum Schmelzen großer Mengen zinkbeschichteten Stahlblechs geeignet sind. Anhand von Simulationen und in Produktionswerken vorgenommenen Messungen erklärten wir anschließend den Mechanismus, mit dem kohlenstoffarme Materialien, die den Großteil des zu schmelzenden Stahlabfalls ausmachen, Kohlenstoff aufnehmen und in einem Kupolofen schmelzen. Hierauf folgte eine Erläuterung über den Aufbau und das Betriebssystem einer nicht ausgekleideten Langzeit-Kupolofens, entwickelt vom Forschungsinstitut für Ofenausrüstung in Naniwa Roki, mit Hilfe praktischer Beispiele auf der Grundlage der Forschungsergebnisse.

1 Introduction

The amount of steel scrap delivered to foundries originating as scrap from cutting the steel materials being used by the automobile industry, the annual output of which is almost 10 million vehicles (in Japan scrapped vehicles are disposed of as the source of raw materials for steel making), as well as scrapped household electrical appliances (refrigerators, washing machines, etc.), has reached the level of two and half million tons per year.

Furthermore, the makers of automobiles and household electrical appliances are applying more surface treatment and adding other elements to improve the workability, chemical properties and mechanical properties of steel materials in an effort to improve productivity and respond to changing user needs. In particular, the use of steel sheet with added surface treatment (mainly zinc-coated steel sheet) has increased rapidly, as can be seen from Figure 1, which illustrates the changes in the amount of steel sheet for automobile construction ordered from Nippon Steel from 1976 to 1989. Surface-treated steel sheet now accounts for 60% of all steel sheet for automobile structural use.

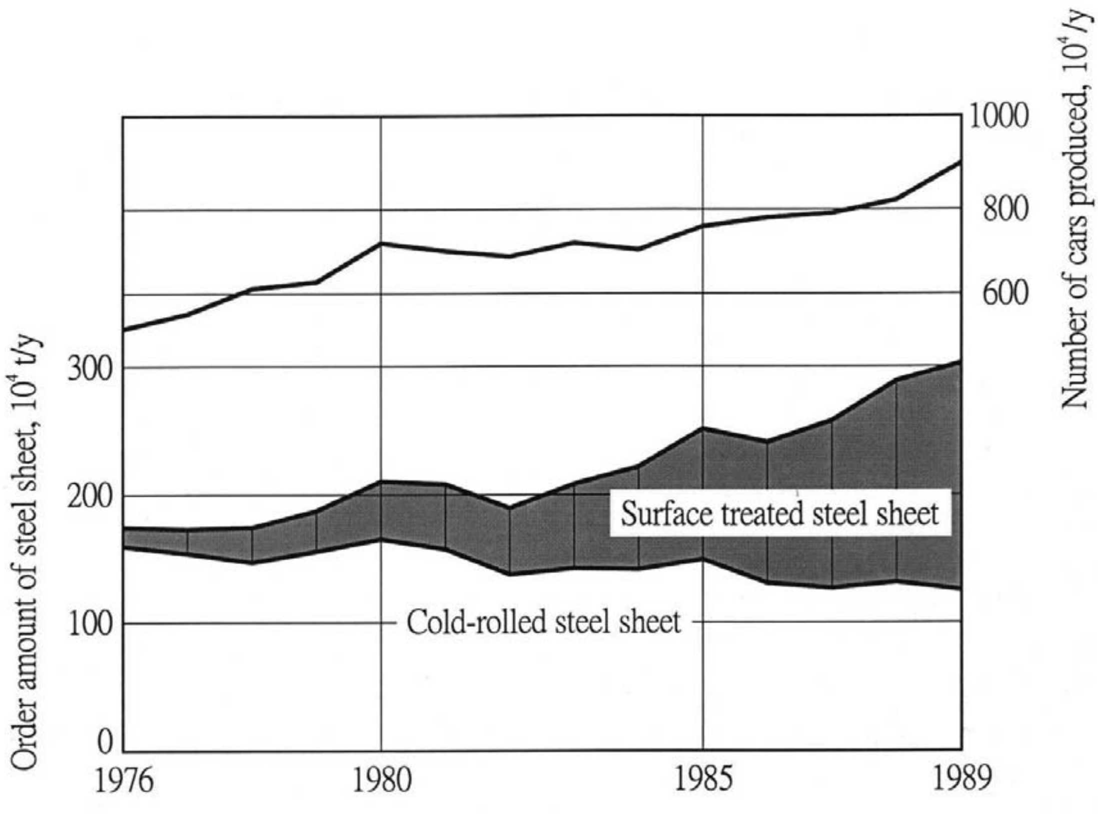


Figure 1: Changes in the amount of steel sheet for automobile construction ordered from Nippon Steel and the number of Japanese cars produced from 1976 to 1989

At foundries, there is a tendency to compound a large amount of the above-mentioned steel scrap as a raw material in order to reduce costs and improve material qualities (the properties of the graphite and matrix are improved when low carbon materials absorb carbon in the cupola and are inoculated).

Steel scrap has a higher melting point than pig iron. In addition, there is a need to establish a melting system incorporating the selection of the proper melting furnace, the optimal operating procedure, measures for collecting dust and hazardous emissions, as well as steps to remove the other elements such as zinc contained in the steel scrap.

In this report, the authors elucidate these problems on the basis of demonstration in a fundamental experiment and in the actual operation of a foundry.

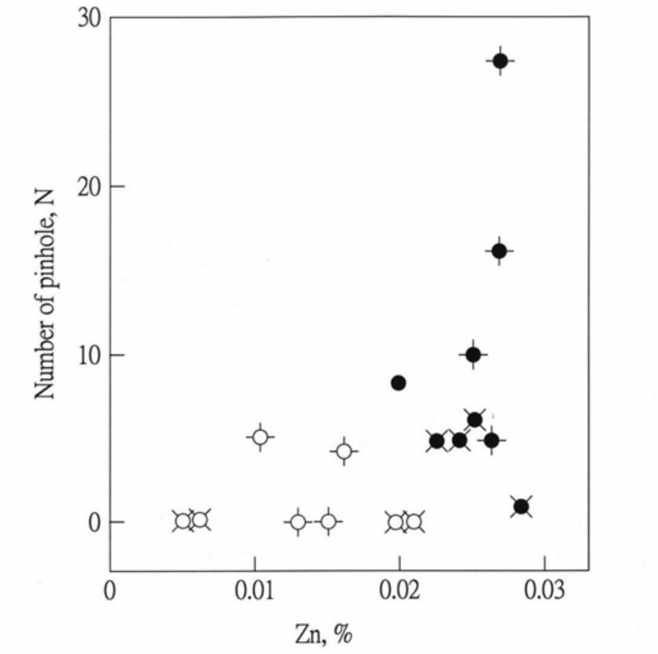
2 The problems encountered in melting zinc-coated steel sheets by an induction furnace.

According to statistical data, among the melting furnaces for cast iron in Japan, the proportion represented by cupolas in 1961 was an overwhelmingly high 92.2%, with arc furnaces at 4.7% and induction furnaces at 1.5%. Since then, arc furnaces have almost gone out of use, while the number of induction furnaces has rapidly increased. The percentage of cupolas used has decreased from 84.6% in 1970, to 63.3% in 1979, to 51.4% in 1986, at the same time, that of induction furnaces has increased to 5.8%, 28.2% and 44.8% respectively and the ratio is now 50:50.

Also during that time, melting steel scrap, especially zinc-coated steel sheet increased rapidly.

Melting such materials in an induction furnace sometimes causes damage to the lining refractory materials and cooling coil of the furnace, in addition to defects in the molten iron material.

For example, Yamada et al. of Toyota Motor Corp.[2)] reported that when zinc-coated steel sheet is melted in an induction furnace with an acid lining, the ZnO generated by the oxidation of zinc combines with the SiO_2 in the lining to form Zn_2SiO_4 with a low melting point, causing damage to the lining materials. Kimura[3)] reported that after about 20 times of melting in a 6-ton furnace, zinc precipitates around the cooling coil by the maximum amount of 1%, causing damage to the coil.



As for the defects in the molten iron, Chida[4] confirmed pinhole defects on the finished surface of FC250 products starting at 0.01% of zinc and increasing rapidly at 0.03% zinc as shown in Figure 2.

Figure 2: Amount of zinc in molten metal and number of pinholes generated, in the case of a large amount of compounding zinc-coated steel sheet in an induction furnace

Yoneda et al.[5] conducted basic research and clarified the fact, as shown in Figure 3, that cast iron with a ferritic structure shows no change up to a zinc content of 0.2%, whereas in that with a pearlitic structure, the tensile strength decreases sharply and the chill decreases too. They explained that although the presence of zinc does not affect the graphite structure, it promotes ferrite development of the matrix structure, causing a decrease in tensile strength.

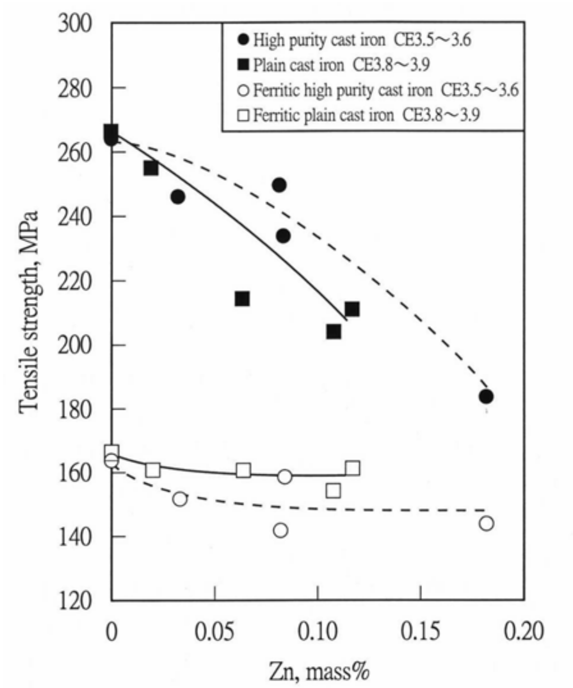


Figure 3: The relationship between the zinc content and tensile strength of cast iron (Fe-75Si, 0.3 mass% inoculation)

Therefore, in the case of induction furnaces where zinc-coated steel sheets are directly charged into the molten metal in the furnace, damages to the furnace refractories and cooling coil, deterioration of the working environment due to ZnO discharged with the smoke, the generation of pinholes and the degradation of molten metal properties such as a reduction in strength.

On the other hand, in a cupola, shaft-type furnace, where the charged metal stays for about 30 minutes in the preheating zone of the furnace, the zinc is completely oxidized during the stay in the preheating zone, forming ZnO fine powder, which is caught in the flue duct, so no damage to the furnace refractories or degradation of the molten iron due to the presence of zinc occurs.

3 Mechanism of carbon pickup and melting of steel scrap (low-carbon material) in a cupola

In the 1960s, Ishino and Etsuo Murata (president of Naniwa Roki Co., Ltd.) [6)] carried out the observation and investigation of the state inside the cupola caused by the rapid and sudden cooling and cease of cupola melting during operation of a midget cupola. Based on their findings experiments by simulation and analysis of the results have been conducted by Hirotoshi Murata et al. An overview of the results is given below.

3.1 Experiment by simulation

In this experiment, a midget cupola with an internal diameter of 340 mm was used. The simulation was performed by adjusting the size and shape of the charge materials such as the metal, coke, and limestone proportionate to those of the large cupola used in actual operation.

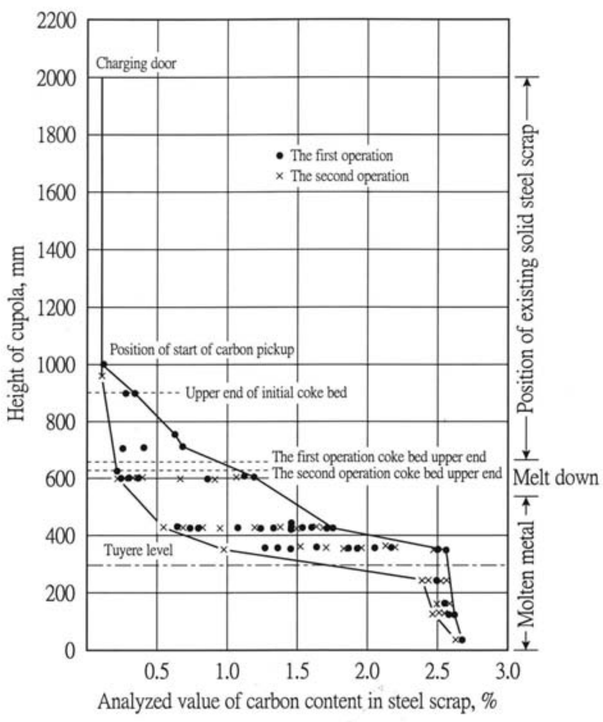


Figure 4: The situation where steel scrap absorbs carbon and is melted in the cupola when subjected to rapid cooling test

In the first place, in order to observe the behavior of carbon pickup and melting of the steel charge in the furnace, the contact conditions of the coke and steel charge and the change in coke bed height, by the rapid and sudden cooling of the furnace in the stage of reaching the stationary state of melting operation (after about 1 hour from the start of operation) and by shutting off the furnace, the inner conditions of the cupola were investigated in detail.

Figure 4 illustrates the amount and position of carbon pickup of the steel scrap in the cupola, and the behavior of the coke bed during operation.

Figure 5 is an example of the measured amount of carbon pickup of the steel scrap by varying the charged coke grain size at the tapping temperature of 1500 °C and Figure 6 shows relationship between the holding time of the molten metal in the well of the furnace bottom and the carbon content of the molten metal.

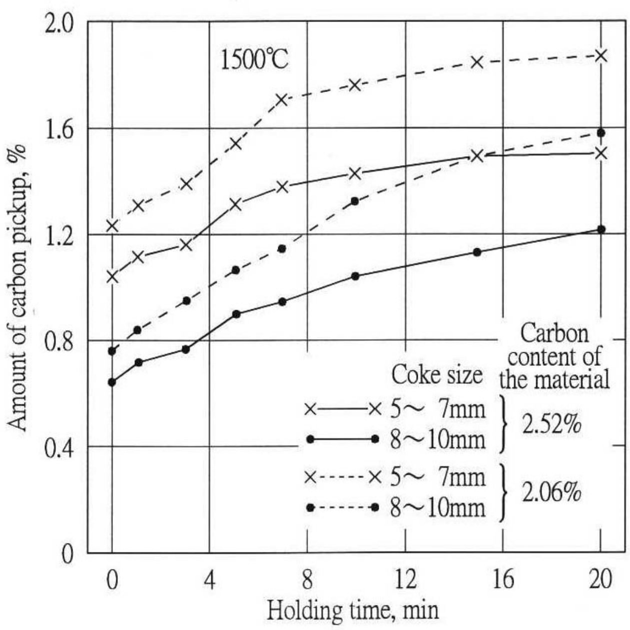


Figure 5: Coke size and amount of carbon pickup in a carbon pickup experiment on molten iron (at 1500 ° C)

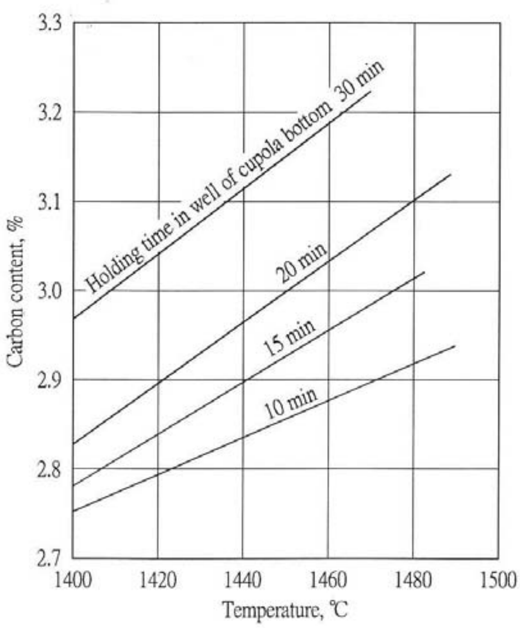


Figure 6: Changes in carbon content of molten metal when held in the well of the cupola bottom

3.2 Mechanism of carbon pickup and melting of steel scrap

a) Carbon pickup of solid steel scrap

It was confirmed that steel scrap in the solid state locally absorbs carbon in the cupola as is evident from Figure 4. It is thought that this is because when the steel scrap makes contact with the coke, an atmosphere abundant in CO gas is formed locally because the supply of carbon from the coke is sufficient at the location where the steel scrap is encircled by coke. However, measurement of the rate of carbon pickup with or without coke coming into contact with the atmosphere (CO%) showed that even in a completely reducing atmosphere, with gas flow of 100% CO, unless solid carbon such as coke exists, carbon pickup of steel scrap is so difficult that at 800~1400°C carbon pickup does not occur unless the temperature is maintained for about four hours.

Consequently there cannot be carbon pickup only through the gas in such a highly oxidizing atmosphere as in a cupola. Even in an atmosphere of 10~15% CO, contact with solid carbon helps carbon pickup. For example, when steel scrap comes into contact with small coke less than 1 mm, it melts at 1350°C, yielding 2.95% carbon content of the iron, and when in contact with 1~3 mm coke, it melts at 1400°C, with carbon content being 3.01%.

From this experiment, it was concluded that carbon pickup of solid steel scrap in a cupola proceeds from the position where the steel scrap makes contact with the coke in the furnace, as shown in Figure 7.

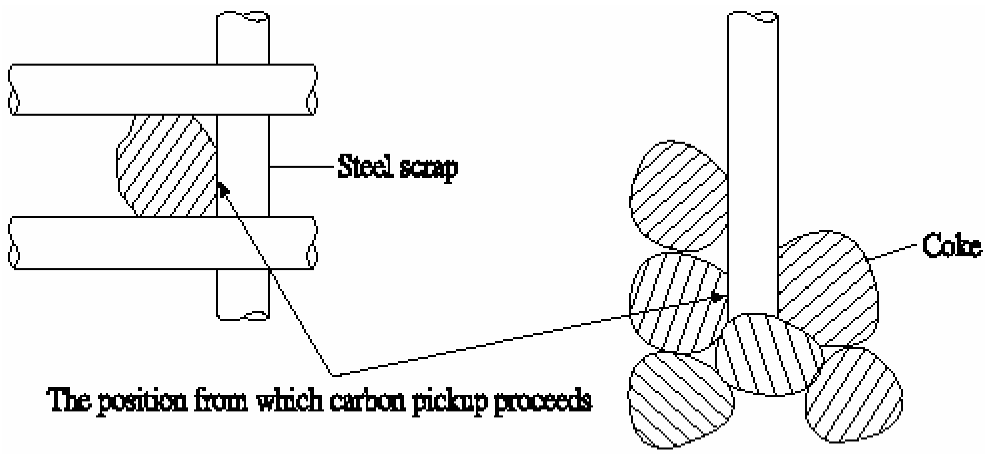


Figure 7: The situation where solid state steel scrap in the cupola locally absorbs carbon

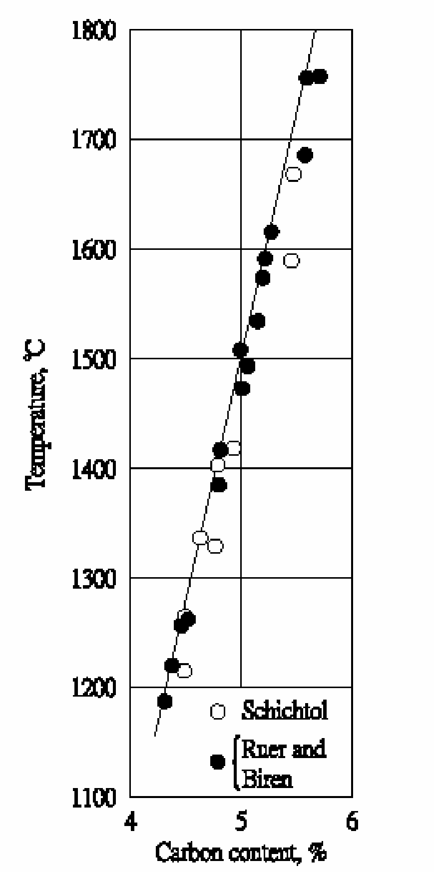
In that position, carbon pickup advances according to the following equation;

$$2CO + Fe \rightarrow \gamma Fe(c) + CO_2 \qquad (1)$$

Generated CO_2 reacts with the carbon in the coke according to the following equation producing CO;

$$CO_2 + C \rightarrow 2CO \qquad (2)$$

It is thought that at the location where it is surrounded by coke, the reaction of carbon pickup proceeds with the steel scrap constantly making contact with the atmosphere abundant in CO caused by the repeated reactions of (1) and (2) above.



b) Carbon pickup after melt-down (carbon pickup of molten iron)

Steel scrap after melt-down absorbs carbon directly from the solid carbon (coke) as it drops through the coke bed as a molten droplet making contact with the coke, forming its existence as melt among the coke grains in the well of the cupola bottom. In this case, when the holding time is sufficient, the steel material absorbs carbon up to the solubility of carbon which Ruer[7)], Schichtol[8)], et al. proposed, as shown in Figure 8.

In our experiment, carbon pickup rapidly slowed, when carbon exceeded 3.5% at 1450°C, 3.7% at 1500°C, and 4% at 1550°C.

Figure 8: The relationship between the carbon solubility of molten iron and temperature

3.3 Factors influencing the amount of carbon pickup

From the above experiment and discussion, we concluded that steel scrap with a low carbon content absorbs carbon mainly by making contact as molten iron with the coke, and an increase in the temperature, time, or area promotes carbon pickup.

Consequently, effective measures for the purpose promoting carbon pickup are: (1) increasing melting temperature, (2) decreasing coke size and increase in contact area, (3) increasing the contact area between the molten iron and carbon by adding additives that constantly remove the ash etc. adhering to the coke surface, and (4) prolonging the holding time of the molten iron in the well of the cupola.

This is evident from the results shown in Figure 5, Figure 6, and Figure 9 of the experiment in which Na_2CO_3 was added for ash removal (b: with coke dried after infiltration of. Na_2CO_3, c: coke and molded Na_2CO_3 powder added).

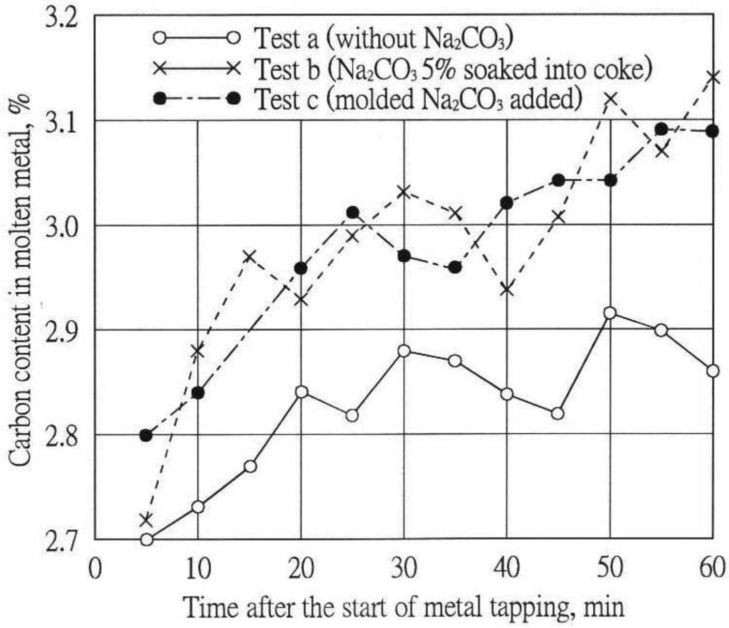


Figure 9: Charge over time of the carbon content of molten metal when melting with soda ash added

4 Structure and operating procedure of a cupola suitable for melting a large amount of compounded steel scrap

Naniwa Roki Co., Ltd. has for many years sought, the ideal cupola and the ideal operating procedure for melting a large amount of compounded steel scrap, which is the basis of cast iron production and which has been rapidly increasing in Japan. We have designed a number of actual furnaces and have established a system for operating the cupola. An example is described below.

4.1 Structure of cupola

Compounded steel scrap requires high temperature melting, so a liningless long campaign operation cupola was adopted. The water-cooled tuyere protrudes a bit, making the distance between the tuyeres and furnace bottom somewhat greater than usual.

Naniwa Roki has, since its foundation in 1963, supplied many cupolas, from the midget type to the large long-campaign type, by responding to our customers' needs. Over 20 long-campaign cupolas have been manufactured and supplied to domestic and overseas clients.

Figure 10 shows an example of the cupola developed by Naniwa Roki on the basis of its accumulated know-how and many years of operating experience.

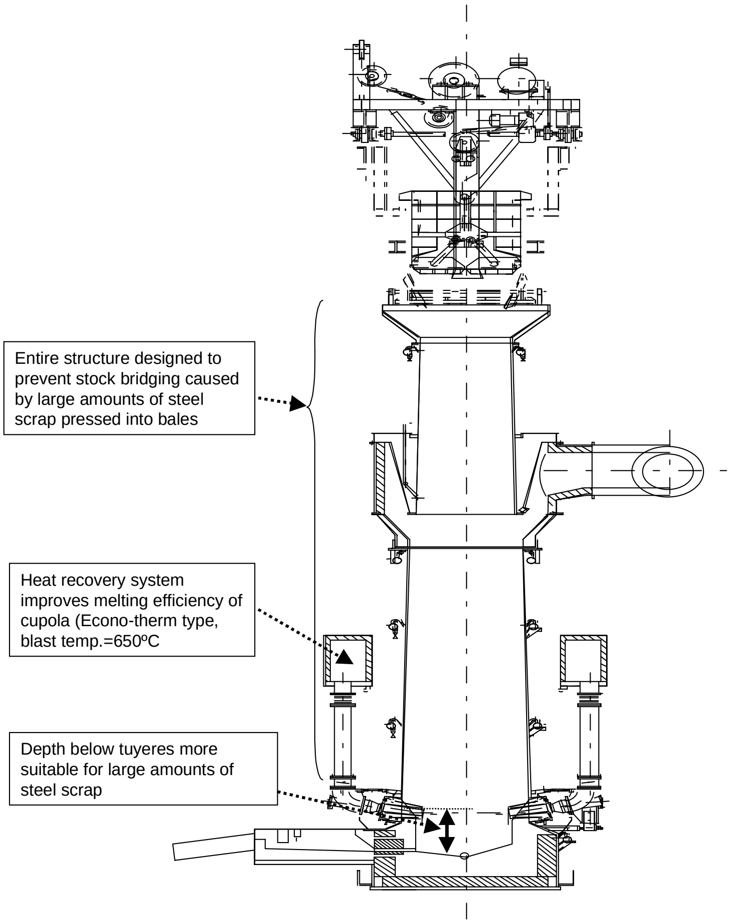


Figure 10: Cupola design by Naniwa Roki

It has the following characteristics.

(1) The results of tests made it clear that as the mixing amount of steel scrap increases more time is needed for carbon pickup. Naniwa Roki has established the technology for maintaining target molten iron properties by relating the variation of the amount of carbon pickup with the dimension of the depth under the tuyeres in the cupola bottom.

(2) Squarish charge material, such as bales, tends to cause stock bridging in the furnace shaft, which needs to be prevented. In the cupola developed by Naniwa Roki, the structure of the off-take part as well as that of melting zone is designed to enable stable material charging.

(3) Because an increase in the amount of steel scrap used necessitates a corresponding increase in heat for melting, Naniwa Roki has established a long-duration stabilized operating system by using technology for recovering high-temperature blast. To be more specific, we developed an Econo-therm heat exchanger system by which high-temperature blast can be easily obtained, modified so as to conform to Japanese foundry practice, and a record of long-

campaign operation has been maintained in a number of foundry shops. In addition, we are planning to adopt a gas system developed by Würz GmbH in the near future.

4.2 Operating procedure

In order to make good use of our accumulated know-how regarding cupola operation, we developed a computerized control system that uses standard personal computers. The system controls temperature, gas pressure, gas volume, flow rate, and differential pressure at each part of the scrap melting system, and allows the operator to set and verify these values on the monitor, to maintain stabile cupola operation. This system allows the operator to control every function and assure operation at the best setting values and maintain stabile operation by visually confirming the system information in real time and taking immediate measures.

Figure 11 is an overview of this system. This system is a combination of the melting technology of Naniwa Roki and the control technology of Yokogawa Electric Corp., one of the major instrumentation and control system manufacturers in Japan.

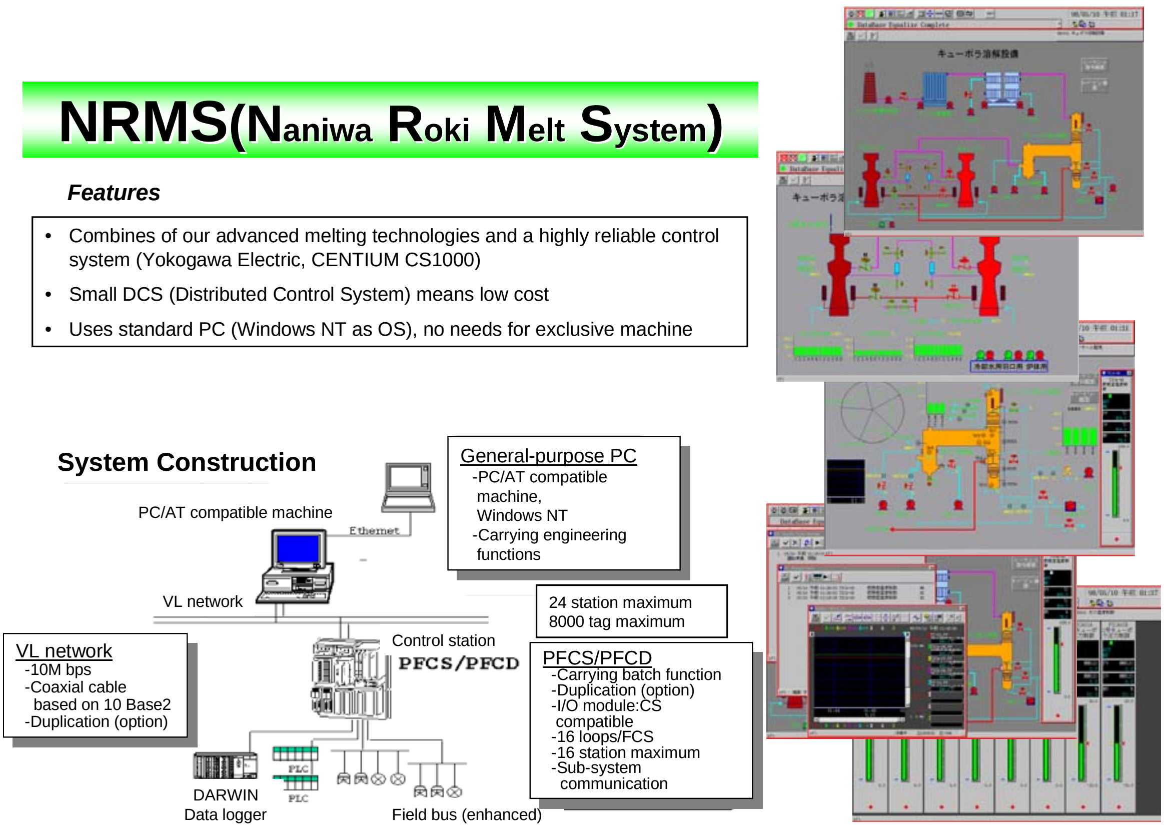


Figure 11: Naniwa Roki cupola operation control system

5 Final remarks

The amount of steel scrap used as a raw material for cast iron melting will continue to increase. Having recognized the advantages of a cupola over an induction furnace as a melting furnace for cast iron, we will continue our basic research on the mechanism of carbon pickup and the melting of steel scrap in a cupola, and our efforts to design a cupola and establish a control system for it that is capable of dealing with steel scrap more effectively.

We intend to research and develop more effective systems and apply the results to actual operation.

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