

# Melting of steel scrap – A worldwide phenomenon

- Steelworld Research Team



Steel is an alloy consisting mostly of iron, with a carbon content between 0.2 percent and 2.1 percent by weight, depending on the grade. Carbon is the most cost-effective alloying material for iron, but various other alloying elements are used such as manganese, chromium, vanadium, and tungsten. Carbon and other elements act as a hardening agent, preventing dislocations in the iron atom crystal lattice from sliding past one another.

Varying the amount of alloying elements and form of their presence in the steel (solute elements, precipitated phase) controls qualities such as the hardness, ductility, and tensile strength of the resulting steel. Steel with increased carbon content can be made harder and stronger than iron, but is also less ductile. Though steel had been produced by various inefficient methods long before the Renaissance, its use became more common after more efficient production methods were devised in the 17th century. Steel is one of the most recycled materials in the world, and, as of 2007, more than 78 percent of steel was recycled in the United States. In the United States, it is the most widely recycled material; in 2000, more than 60 million metric tons were recycled.

The most commonly recycled items are containers, automobiles, appliances, and construction materials. For

example, in 2007, more than 97 percent of structural steel and 110 percent of automobiles were recycled, comparing the current steel consumption for each industry with the amount of recycled steel being produced. A typical appliance is about 75 percent steel by weight and automobiles are about 65 percent steel and iron.

The steel industry has been actively recycling for more than 150 years, in large part because it is economically advantageous to do so. It is cheaper to recycle steel than to mine iron ore and manipulate it through the production process to form new steel. Steel does not lose any of its inherent physical properties during the recycling process, and has drastically reduced energy and material requirements compared with refinement from iron ore. The energy saved by recycling reduces the annual energy consumption of the industry by about 75 percent, which is enough to power eighteen million homes for one year.

Scrap steel is a valuable iron source. With the growing consumption of steel in the world, a problem of surplus scrap steel is coming sooner or later to surface with steady increase in scrap generation against stagnant steel production that uses scrap steel. Against this background, steel majors have been working on the development of technology for melting large amount of scrap. In 1993, Hirohata Works in Japan shut down its blast furnace and

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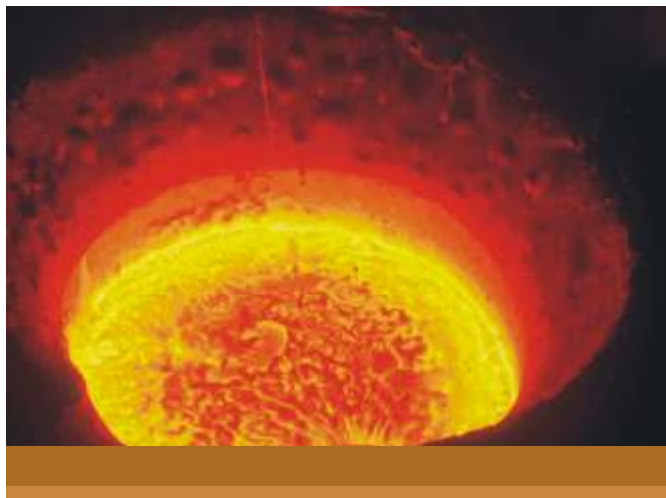
commercialized the process of melting scrap in the basic oxygen furnace (BOF). This paper presents BOF scrap melting process currently undergoing at Nippon Steel and its activities concerning the recycling of scrap as typified by steel cans are introduced.

### Introduction

Heavy melting steel (HMS) or heavy melting scrap is a designation for recyclable steel and wrought iron. It is broken up into two major categories: HMS 1 and HMS 2. The difference between the two is HMS 1 does not contain galvanized and blackened steel, whereas HMS 2 does. The melting process begins with the customer's metal specification for the casting, which determines what type of scrap metal will be used to 'charge' the furnace. Once charged, the furnace uses three electrodes, each supplying 6,500 amps of electricity, to melt the scrap metal. At various points in the melt process, samples are taken to determine the chemical composition of the molten metal. Using a spectrometer as a guide, alloys are added to the furnace to bring the molten metal in the proper specification. Once the metal is within the desired specification, and at a temperature near 3,000 degrees F., it is poured into a preheated ladle for transfer to the pouring lines.

At the pouring lines, molten metal is 'poured' into the appropriate molds. Due to the lifting pressure of molten steel, molds will often be 'weighted' or 'clamped' to prevent them from separating at the Cope/Drag meeting point. After pouring, the mold is allowed to cool for approximately 30 minutes before it is taken to the shakeout. At SWS, poured molds are dumped into a vibrating conveyor. In the conveyor, the molds are broken up by the vibration, which exposes the casting for removal. The sand from the mold is separated and process through a reclamation system for reuse in mold and core making.

Along with the increasing steel accumulation, scrap supply has been increasing. Steel scrap is consumed mainly in electric arc furnaces (EAFs) and partly in the blast furnace (BF)-basic oxygen furnace (BOF) process. Scrap is an iron



source that needs no reduction energy, as compared with iron ore. Increasing the scrap consumption by developing a process that can increase the scrap recycle ratio which not only contribute to energy conservation, but also solve such problems as exhaustion of natural resources and global warming due to increasing emissions of carbon dioxide gas (CO<sub>2</sub>). This is one of the challenges confronting the steel industry.

Nippon Steel commissioned a BOF scrap melting process at Hirohata Works in June 1993 to pioneer a new form of scrap melting. Steel cans and other scrap generated in the market are recycled and melted into steel products.

### Significance of scrap utilisation technology

Scrap may be broadly classified into home scrap generated at steelworks, prompt industrial scrap generated in the course of steel processing at machine shops and the like, and dormant scrap comprising obsolete, worn or broken products of steel consuming industries.

Generation of home scrap has little changed in recent years thanks to various measures taken to improve yield, such as continuous casting. This is also true to prompt industrial scrap, which reflects the cost saving efforts of users. Dormant scrap now accounts for a little over one half of the total scrap supply, and is predicted to increase further with increasing accumulation of steel in the market. Generally, generation of dormant scrap can be estimated from the service life and accumulation of various steel products. Roughly speaking, the generation of dormant scrap is proportional to the accumulation of steel in the market. In recent years, generation of dormant scrap has increased with increasing steel accumulation.

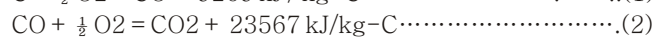
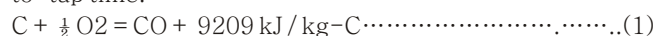
### Melting point of steel

Melting point of steel depends on the alloy of steel. The term alloy is almost always used incorrectly these days, especially amongst bicyclists. They use the term to mean aluminum. What the term alloy really means is a mixture of metals, any kind of metals. Almost all metal used today is a mixture and therefore an alloy. Most steel has other metals

added to tune its properties, like strength, corrosion resistance, or ease of fabrication. Steel is just the element iron that has been processed to control the amount of carbon. Iron, out of the ground, melts at around 1510 degrees C (2750°F). Steel often melts at around 1370 degrees C (2500°F).

### Progress in technology of melting scrap in BF-BOF process

In the BOF steelmaking process that uses the heat of carbon from CO to CO<sub>2</sub>, however, is much greater than that from C to CO. If the secondary combustion (post combustion) step from CO to CO<sub>2</sub> is utilized, the amount of scrap melting can be increased without prolonging the tap-to-tap time.



In normal BOF operation, the ratio of CO burned to CO<sub>2</sub> (the post combustion ratio) is 5-10 percent. It has been confirmed that the amount of scrap melting can be increased by increasing the post combustion ratio. For example, the scrap ratio can be increased by 3-4 percent by increasing the post combustion ratio by 10 percent.

In view of the importance of grasping the post combustion behaviour during BOF refining, companies worked to clarify the mechanism of post combustion.

According to process, oxygen is discharged from the top blowing lance nozzle propagates through the supersonic and transition speed regions until it becomes a free jet. The reaction between the oxygen jet and the CO gas (gas produced decarburisation) entrained by the free jet forms a jet predominantly composed of CO<sub>2</sub>. In the surface layer of the CO<sub>2</sub> jet or at velocities lower than the critical velocity, some CO<sub>2</sub> escapes from the CO<sub>2</sub> jet while accompanying the CO gas flow generated at the lower hot spot. The post combustion ratio depends on the ratio of the amount of fugitive CO<sub>2</sub> to the amount of CO generated by the decarburization reaction. The possibility of controlling the post combustion ratio from the jet behaviour has been elucidated.

A coal top blowing process (ALCI process) was developed



as a positive method of adding a heat source in the BOF. The ALCI process injects coal at high speed into the bath in the furnace and promotes the post combustion of CO by a lance with main and auxiliary oxygen holes. As compared with the conventional top coke addition process, the ALCI process was found to provide a higher scrap ratio at the same amount of carbon combustion. This benefit may be explained from improvements achieved in the carbon yield and post combustion ratio. However, the whole new BOF scrap melting process has also been developed.

### BOF hot heel scrap melting process

In early nineties, the conventional BOF scrap melting process saw a revolution with the advancement of technology. When the switchover was made from the conventional BF-BOF process, the new process concept was formed from the following considerations :

- 1) Utilise the existing BOF to reduce the equipment cost and retain the freedom of raw material and fuel use.
- 2) Separate the scrap melting furnace and the decarburizing furnace to secure high productivity and high product quality.
- 3) Minimise the total production cost through the effective utilization of waste energy, such as recovering the off-gas via the OG system of the BOF plant.

In the new process, scrap is charged into the melting furnace from above through a chute, and coal and oxygen are blown into the charge as fuels through the bottom of the furnace. The scrap is rapidly melted by the heat of post combustion by the top lance as well. Upon completion of the scrap melting period, a half of the hot metal is tapped from the melting furnace, desulfurised and otherwise treated, and charged into the decarburizing furnace.

In the process, fast and stable melting of scrap by leaving a half of the each heat in the melting furnace is obtained. Steps like stable production of clean steel through the treatment of quasi-steel by the process similar to the conventional process, extended refractory life under low-temperature melting, simultaneous securement of melting heat source by controlling the post combustion ratio and

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utilizing the recovered off-gas and bottom injection of pulverized coal in the utilization of low cost coal and from the viewpoint of hot metal carburization in the vicinity of scrap melting were also followed.

### Scrap melting behaviour

In the 5-ton furnace, copper was added to hot metal before scrap melting, and the scrap melting ratio was determined from the dilution of the copper. The bath temperature variation during the melting period was also measured. In the initial melting stage, the bath temperature dropped, and the melting ratio did not rise. After 10 minutes into the melting process, the melting ratio and bath temperature both started to rise.

The carbon and temperature profiles near the scrap hot metal interface during the melting process are promoted by the following conditions:

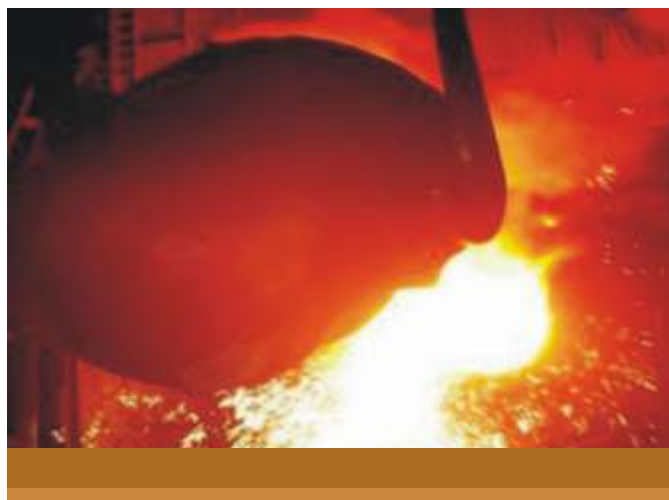
- 1) Increase of interface carbon content  $C_5$ , with increasing bath carbon concentration
- 2) Increase of interface carbon content  $C_5$  and interface temperature  $T_5$  with increasing bath stirring force
- 3) Rise in the bath temperature

To quantify the factors that promote the scrap melting, a melting behaviour model that allows for simultaneous heat and mass transfer, and a BOF heat and mass balance model were combined to build a scrap melting model. It was confirmed that the model brings out results that practically agreed with the experiment results.

### Effect of coal melting on scrap

For appropriate control of the bath carbon concentration during the scrap melting period and for the promotion of the above mentioned scrap melting behaviour, the melting behaviour of the coal injected into the hot metal must be clarified. The melting of coal was analysed using the 500-kg and 5-ton furnaces.

Various carbonaceous materials were placed on the molten iron bath in the 500-kg furnace, and the resultant carburization rate under gas stirring was measured. The apparent mass transfer co-efficient was calculated from



the obtained carburization rate and bath cross-sectional area, and was compared with the sulfur content of coal. The carburization rate decreases with increasing sulfur content. The effect can be explained by the action of sulfur that is a surface active element. The carburization rate increases with decreasing volatile matter of coal.

Assuming that the coal melting rate is controlled by the metal mass transfer, a model for predicting the coal melting rate was studied.

The carburization rate measured without top blowing is considered to correspond to the difference between carburization from the bottom-injected coal and carburization from the bottom blown oxygen. As the bath carbon concentration increases to approach saturation the melting rate of the bottom - injected coal declines. When the coal is high in sulfur and low in carburization nature, the coal melting rate is lower under a lower bath carbon concentration.

Measurements were made also of the carbon concentration in the dust generated when scrap was melted with the top-blown oxygen. When different types of coals were used, unmelted coal particles were observed in the dust if the carburization rate fell below a certain level. Thus, the promotion of coal melting calls for the selection of low-sulfur and low-volatile coal and the injection of pulverized coal. Control of the post combustion ratio with attention focused on the lance conditions, and optimization of the scrap melting rate that depends on the bath carbon concentration and stirring force and of the coal melting rate as required to maintain the desired bath carbon concentration are important in new hotheel BOF scrap melting process.

### Future outlook

Recycling of used materials is becoming a worldwide trend, as symbolized by the issues of the global environment. The hotheel BOF scrap melting process will draw attention as a new process that can solve the iron source problem while making effective use of the structure of existing steel plant.