International Journal of Research Studies in Science, Engineering and Technology
Volume 7, Issue 8, 2020, PP 15-21
ISSN 2349-476X

The Study on the Behavior of the Melting Process of Scraps in Converter

Ao-nan Zhao[1], Li-qiang Zhang[1]*, Ben-liang Zhang[2], Wei Ou Yang[2], Naqash Ali[1], Wei Zhang[3], Chao-jie Zhang[1]

[1]*School of Metallurgical Engineering, Anhui University of Technology, Ma'anshan 243002, China*
[2]*Ningbo Iron & Steel Limited Company*
[3]*Jiangyin China Resources Steelmaking limited company*

***Corresponding Author:** Li-qiang Zhang, School of Metallurgical Engineering, Anhui University of Technology, China. Email: zhao1048872118@163.com*

ABSTRACT

In this paper melting rate and yield of six types of the steel scrap (heavy steel scrap, multi scrap, self-produced steel, medium steel, particle steel, and steel slag) were studied by thermal experiments and numerical simulation which provides the theoretical basis for batch processing of scrap in a converter. The experimental results showed that the yield of heavy scrap, burden scrap, self-produced scrap, and medium scrap was more than 95%. The yields of particle steel scrap and steel slagwere 61.35% and 46% respectively. The melting rate of scrap in the furnace is not related to the type of the scrap but also on its specific surface area. At the same time, the melting and heat transfer process of medium steel scrap in a spherical, columnar, plate and cubic shapes were simulated numerically. The numerical simulation results were consistent with experimental results indicating that the melting rate of different scrapsare closely related to its shape, larger the specific surface area of the same weight of scrap will have the higher melting rate. For the smelting process of a converter, scrap batching should be carried out according to the type and corresponding melting rate of scrap.

Keywords: *Converter, Melting rate,Scrap yield, Heat transfer,Steel scrap.*

INTRODUCTION

With the increasing competition in the steel industry, China has also the task to reduce the production capacity of strip steel. The resources of the steel scrap in the market are increasing due to lack of iron powder and pellets. Therefore, the market price of pig iron is rising and in order to adapt the market changes, domestic steel industries have explored the ways to add scrap in the hot metal during converter smelting process to reduce the consumption of iron resources such as iron powder and pellets[1]. The foreign metallurgists [2-4] studied the melting of scrap in the early stage process of the converter and concluded that the melting conditions of the steel scrap have an important impact on the temperature rise of the molten pool, slag formation and endpoint hit ratio. Song[5] established a heat transfer equation and studied the temperature and carbon content of the scrap at various points during the heat and mass transfer process. Liu[6-7]found through physical simulation that the dissolution rate of scrap is related to thickness. Shukla [8] studied the dissolution of scrap and liquid melt at the spontaneous heating rate by establishing a mathematical model. Kruskopf[9] calculated the melting rate and thickness of scrap in the converter by using the scrap melting module in a steel heat exchanger. He predicted the melting curve of scrap and evaluate the process of heat and mass transfer between melt and scrap. However, there are few reports on the thermal experiments of scrap melting. The melting process of scrap has an important effect on the blowing process and is of economically beneficial for the steel industry. In this paper, the melting process of different types of scrap was studied. Experimental results and numerical simulation have found that the shapes of scrap, specific surface area and other factors have a great effect on its melting time and melting rate, and the melting yield of different types of scrap steel was also obtained.

MATERIALS AND METHODS

To study melting rate and yield of different scraps against an industrial site, six types of steel scrap were sampled in laboratory to carry out thermal experiment. The six types of scrap is listed as (i) Heavy steel scrap: thickness less than 1000mm × 400mm, billets, etc., (ii) Charged scrap: thickness less than 1000mm × 800mm mechanical waste, parts, trim, etc., (iii) Self-produced scrap: cutting tails of continuously cast billet, rolling steel trim, etc., (iv) Medium scrap: less than 1000mm × 500mm thicker, billet and steel, etc., (v) Particle steel: the scrap in the final slag of converter after the extraction of steel with diameter of 2mm-10mm,(vi) Steel slag: the mixture of steel and slag in the process of slag dumping, smudging, crushing and magnetic separation of the converter slag with the diameter of 10mm-10mm.In this experiment high-temperature furnace and its controlling system were used, including power control cabinet, argon cylinder and its conveying device, gas flow meter, high temperature camera, computer, T-1700VCB high-temperature furnace, thermocouple, tongs and refractory brick. The specific experiment device is shown in Figure 1.

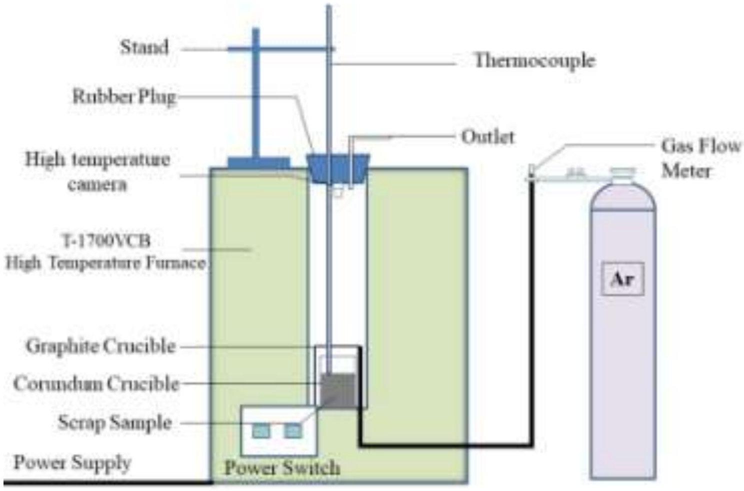


Figure1. *The physical model diagram of T-1700VCB crucible furnace.*

The temperature of the furnace was raised to 1600 °C and installed the temperature measuring thermocouple. The argon pressure reducing valve was connected to the hose and argon gas was injected for 2 to 3 hours to complete the experiment. The temperature of the furnace was made upto 1400 °C to preheat the scrap. When the temperature reached to 1600 °C, the graphite corundum crucible containing scrap sample was placed in the furnace and started to count the time until the sample was completely melted. The melting time of the sample was recorded, when its melting was started and finished, based on the melting time analyzed the melting rate of the scrap. When the scrap sample was melted completely for 30 minutes, it was taken out and cooled to remove the impurities such as slag floating on the upper part of the steel ingot. Then the steel sample was weighed and compared with the initial weight to analyze different types of scrap and its yield. All the scrap melting experiments were carried out in the same way as shown in Figure 2 (in the case of particle steel).

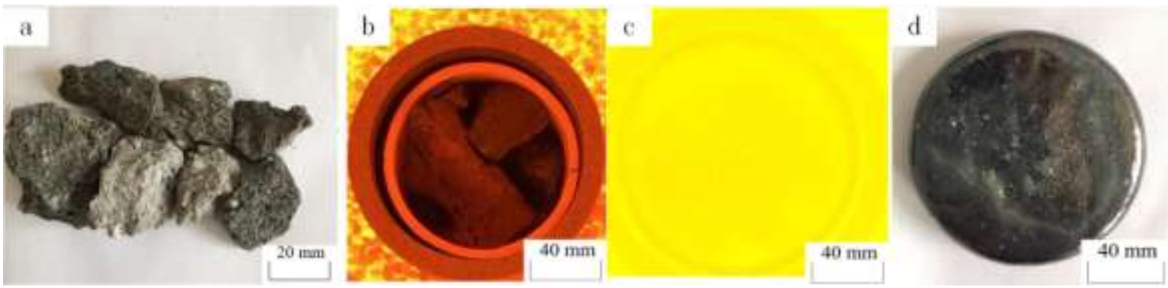


Figure2. *Steel sample preparation and high-temperature melting process (a) Steel sample preparation (b) The steel sample was placed in the furnace (c) The steel sample was completely melted (d) When the steel sample was cooled.*

Mathematical Model and Calculation of Scrap Melting Process

The research was conducted on the melting rate of heavy and medium scrap, mainly the melting process when the scrap steel was added to molten iron. The melting process after adding the scrap to molten iron was studied experimentally. The initial temperature of the scrap is much lower than the molten iron and the temperature of the molten iron reduces rapidly when scrap is added to it. A steel shell of a certain thickness is formed around the surface of the scrap, which gradually melted when reached to the maximum thickness and then the scrap also began to melt. The numerical simulation was used to study the melting process of scrap after adding it to molten iron, and the effect of scrap size on its melting rate was analyzed.

Mathematical Model

Basic Assumptions

A mathematical model based on the heat transfer principle was established for the melting process of scrap, which has the following basic assumptions.

1) Scrap does not chemically react with molten iron during the melting process.

2) Scrap was shaped ideally, such as spherical, cylindrical, plate, and cubic.

Governing Equation

$$\rho c\frac{\partial T}{\partial t}=\frac{\partial}{\partial \chi}\left(\lambda\frac{\partial T}{\partial t}\right)+\frac{\partial}{\partial Y}\left(\lambda\frac{\partial T}{\partial t}\right)+\frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial t}\right), \quad (1)$$

Where ρ is the density (kgm^{-3}), c is the specific heat capacity ($Jkg^{-1}K^{-1}$), λ is the thermal conductivity ($Wm^{-1}K^{-1}$).

Geometrical Model

According to the assumptions, the melting process of scrap is simplified into the process of heat transfer and melting of spherical scrap in the molten iron. The geometric model is shown in Figure3. Considering the symmetry of the model, its 1/8 was calculated as shown in Figure 4 with a mesh size of 5 mm.

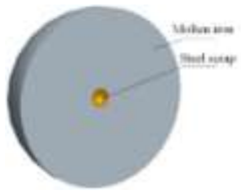


Figure3. *Geometrical model of scrap distribution in molten Iron.*

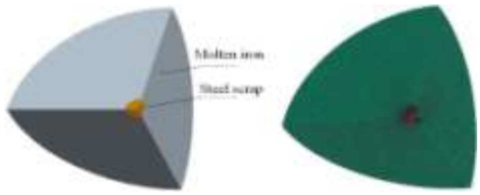


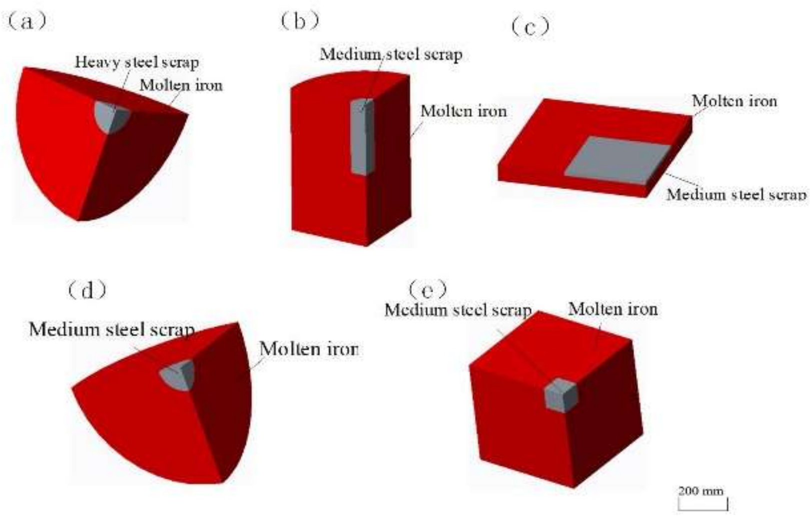
Figure4. *Geometrical model and mesh generation (scrap melting in molten iron).*

Initial Conditions

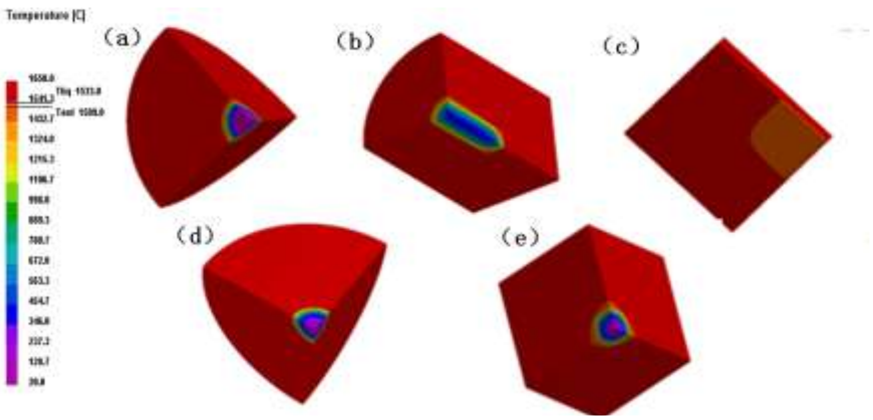
The molten iron temperature at the time of scrap addition was 1650 °C and the temperature of scrap steel was 50 °C.

Numerical Simulation

The numerical simulation of the melting process was carried out for the different shapes of heavy and medium-sized scrap. The weight, size, specific surface area, melting rate and other factors of heavy and medium scraps with different shapes were modelled symmetrically. The numerical simulation was carried out for (a) Heavy steel scrap-spherical shaped (b) Medium scrap with cylindrical-shaped (c) Medium scrap plate-shaped (d) Medium scrap spherical-shaped (e) Medium scrap cubic-shaped. The diagram(i) is the initial model and the model diagram (ii) for the steel scrap placed in molten iron for five minutes. The specific geometrical model is shown in Figure5.



(i)



(ii)

Figure5. *The Figure (i) shows the models of different types of scrap and (ii), The changes in model when the scrap was put into the molten iron for five minutes in which (a) Heavy scrap spherical (b) Medium scrap cylindrical-shaped(c) Plate-shaped (d) Spherical-shaped and (e) Cubic-shaped.*

Results and Discussions

Experimental Results

According to the thermal experiments, the yield and melting time of six different types of scrap are shown in Table 1.

Table1. *Experimental scrap yield and scrap melting schedule*

No.	Types of scrap	Melting time difference (min)	Scrap weight before melting(g)	Scrap weight After cooling (g)	Yield
1	Heavy scrap	6.35	377.80	363.20	96.13%
2	Multi scrap	5.24	416.30	403.50	96.92%
3	Self-produced scrap	13.16	559.80	551.50	98.51%
4	Medium Scrap	4.53	412.50	393.30	95.35%
5	Particle steel	8.10	442.20	271.30	61.35%
6	Slag steel	5.34	398.00	183.10	46.00%

Numerical Simulation Results of Scrap Melting

Numerical simulation of the melting process was carried out for different shapes of heavy and medium-sized scrap. The simulation results are shown in Table 2.

Table2. *The numerical simulation results of the scrap melting*

No	Types of scrap	Weight (kg)	Specification and dimension (mm)	Initial melting time (min)	End melting time (min)	Melting time (min)	Specific surface area (m2/kg)	Melting rate(kg/ min)
1	Heavy scrap - spherical	1182.00	SΦ660	1.90	33.30	31.40	0.001158	35.50
2	Medium scrap-cylindrical	508.00	Φ262×1200	1.40	12.80	11.40	0.002157	39.70
3	Medium scrap - plate	513.00	1100×1100×54	0.90	2.60	1.70	0.005181	198.50
4	Medium scrap - spherical	514.00	SΦ500	1.70	20.20	18.50	0.001529	25.40
5	Medium scrap –cubic	510.00	402×402×402	0.90	18.30	17.50	0.001901	27.80

Discussion

Analysis of the Scrap Melting Rate

The melting rate of heavy scrap is slightly higher than that of medium scrap as can be seen from Table 1. The melting process of heavy scrap and different shapes of medium scrap was simulated numerically. It can be seen in Table 2 that scraps with the same weights and different shapes have a great effect on its melting time. The melting rate and melting time of heavy scrap with the spherical shape was 35.5 kg/min and 31.4 min, while for the medium scrap with the spherical shape was only 25.4 kg/min and 18.5 min. The melting time of heavy scrap is much longer than that of medium scrap.

The melting time and melting rate of steel scrap with the same weight are different. The same weight of medium scrap with different shapes, the complete melting time is in order of spherical > cubic > columnar > plate as shown in Figure 6. The specific surface area and melting rate of steel scraps with the same weight and different shapes is shown in Figure 7.

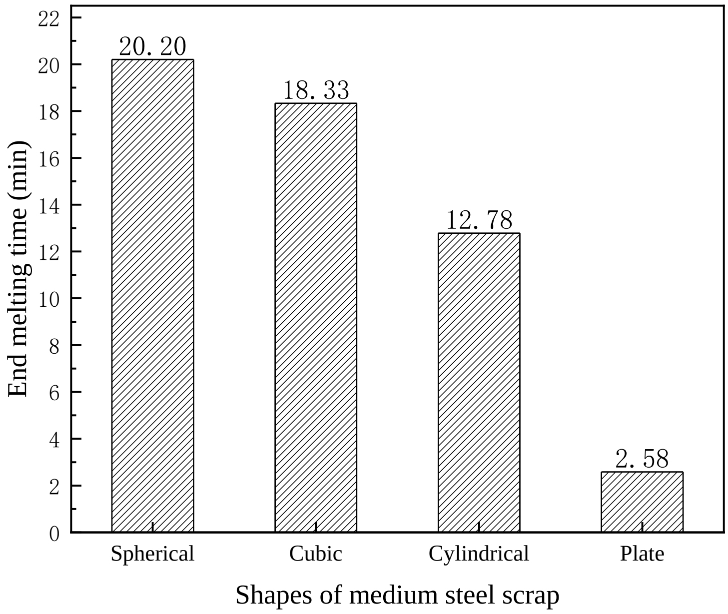


Figure6. *Melting time of the steel scraps with the same weight and different shapes.*

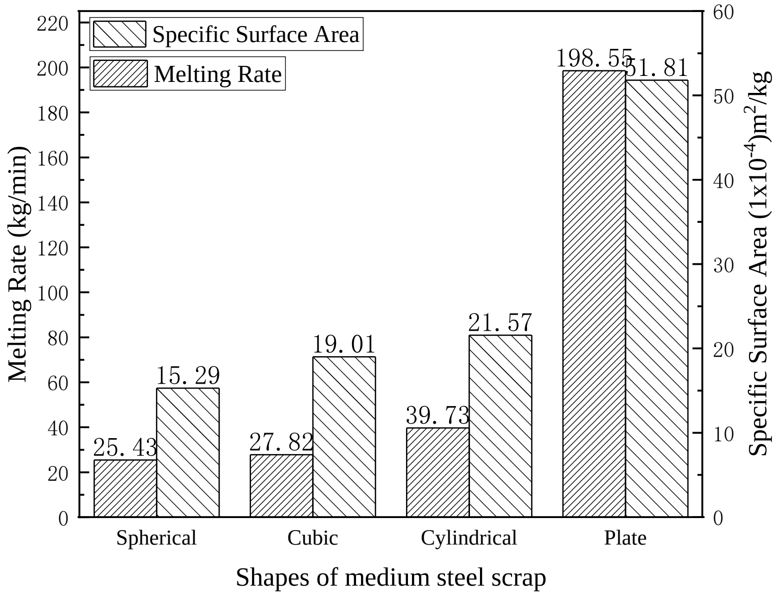


Figure7. *Specific surface area and melting rate of steel scraps with same weight and different Shapes*

The melting rate of medium-sized scrap with the same weights and different shapes was in the order of, plate > cylindrical > cubic > spherical. It can be seen from Figure 7 that the melting rate of scraps has a great relationship with its shape. The difference in shape means that the morphology of scrap is also different. For example, the specific surface area of spherical-shaped scrap is greatly different from that of strip or plate-shaped scrap, so the melting rate is also different. It is easy to know that the larger the specific surface area, the larger will be the heat flux and mass transfer between the scrap and molten iron. Therefore, simulation results are consistent with experimental results. The melting of the scrap mainly depends on the temperature and the transfer of carbon element between the scrap and molten iron. Therefore, it can be considered the specific surface area of scrap is a key factor in determining the melting process of scrap.

For practical applications in the field, a new standard has been formulated for the procurement of scrap from a certain steel plant by the addition of converter scrap. In the new standard, heavy scrap, furnace charge scrap, and medium scrap have great requirements due to their shape and dimension, and all of them have improved the specific surface area. It was concluded that the specific surface area of scrap has a great effect on its melting rate.

Analysis of the Yield of Different Scraps

The melting time of the heavy and charge scrap was higher than that of the medium scrap. The yield of the charged scrap was slightly higher than that of the heavy and medium scrap, which was inconsistent with the field production data. Self-produced scrap had a longest melting time with the highest yield and no bubbles were produced during its melting process. The particle steel had a long melting time, but its yield was 61.35%. The lowest yield only 46% was obtained by the melting of steel slag and a large number of bubbles were produced during the experiment. When the steel slag was melted completely and taken out from the furnace, the impurities in the steel undergo a severe oxidation reaction. After a while, when the reaction was stopped, a black layer of slag appeared on the surface of the sample. The main chemical components of the steel slag are Fe_2O_3, Al_2O_3, MgO, SiO_2, CaO and MnO. The steel slag was not completely separated by the slag magnetic separation and contains a large number of impurities resulting in lower yield than other types of the scrap. This phenomenon did not occur in the other steel samples and the bubbles were also not produced after discharging from the furnace. The chemical composition (mass fraction) of the different scraps after melting is shown in Table 3.

Table 3. *Chemical composition (%) of different scrap after melting*

	Fe	Al	Si	Mn	p	S
Heavy scrap	99.3600	0.2280	0.0559	0.2150	0.0191	-
Multi scrap	98.1700	0.4110	0.2190	0.8310	0.0133	0.0005
Self-produced scrap	99.6200	0.0937	0.0033	0.1330	-	-
Medium scrap	98.8800	0.0453	0.0634	0.2380	0.0434	0.0080
Particle steel	98.5000	0.5890	0.1200	0.0322	0.0312	0.4690
Steel slag	82.7100	7.1100	3.2200	0.4930	0.0773	0.0048

CONCLUSION

The melting process of different types of steel scraps was studied by experiments and numerical simulation method. The melting law of different kinds of steel scraps was obtained preliminarily, which provided a reference for the optimization of different types of scrap in a steel plant.

1. The melting rate of scrap steel has a great relationship with its shape. The melting rate of scrap with the same weight is sorted as plated-shape > columnar shape > cubic shape > spherical shape. The highest melting rate of the scrap with plate-shaped was much higher than that with spherical-shaped.
2. The specific surface area is the key parameter that determines the melting of scraps by heat and mass transfer in the molten iron. The specific surface area of the scrap and the melting efficiency of the converter should be taken into account during the charging.
3. The yields of heavy scrap, multi scrap, self-produced scrap, and medium scrap were higher than 95%, while the yields of particle steel and steel slag were relatively small as 61.35% and 46% respectively.

ACKNOWLEDGMENTS

The successful completion of this project is benefited from the financial support provided by National Natural Science Foundation of China (51874001，U1760108) and the Open Foundation of the State Key Laboratory of Refractories and Metallurgy (G201711).

REFERENCES

[1] Chen Y J. Production Practice of Reducing Molten Iron Consumption by Converter. Xinjiang Iron and Steel. 2018; 147:18-20.

[2] Cen YQ. A method for accelerating the melting of scrap steel in a converter. Shanghai Metals.1992; 15:12-18.

[3] DongikJ. Kinetics of dissolution in molten pig iron. Metallurgical Transactions B, 2012; 43: 1308-1314.

[4] Li J Z. Effect of high scrap ratio on steel-making process. Hebei Metallurgy, 2017; 7: 67-69.

[5] Song Y. Numerical simulation of scrap melting based on finite difference method. Journal of North China University of Science and Technology (Natural Science Edition). 2019; 41:19-25

[6] Liu Y S. Water Model Study on the Feature of Scrap Melting in the Oxygen TOP-Bottom Combined Blowing Process. Journal of Iron and Steel Research. 1990; 2:1-7.

[7] Liu Y S. Theoretical analytical calculation of melting process of scrap steel with ice in water model experiment. Journal of Iron and Steel Research. 1992; 4:15-21.

[8] Shukla A K, Deo B. Scrap dissolution in molten iron containing carbon for the case of coupled heat and mass transfer control. Metallurgical Transactions B, 2013; 44:1407-1427.

[9] Kruskopf A.A model for scrap melting in steel converter. Metallurgical Transactions B, 2015; 46: 1195-1206.

Citation: *Li-qiang Zhang, et al. "The Study on the Behavior of the Melting Process of Scraps in Converter" International Journal of Research Studies in Science, Engineering and Technology, 7(8), 2020, pp. 15-21.*