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To cite this article: Y. Takaki *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **424** 012081

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Separation of steelmaking slag with mechanical stirring by fluctuated magnetic field

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Abstract
Steelmaking slag is by-product of the steelmaking process and has a high content of iron. In order to recover this iron, steelmaking slag is processed with various methods such as crushing, sieving and magnetic separating. Magnetic separators process steelmaking slag in multiple layers for mass production and non-magnetic particles are attracted to a magnet roll by magnetic particles [1]. Therefore, precision of separation is low with conventional pulley magnetic separator. This study proposes an efficient magnetic separating technology. In proposal magnetic separation, a fluctuating magnetic field is generated by rotation of a magnet roll with multiple poles. This quick change of the magnetic field generates strong agitation in the attracted particles and eliminates non-magnetic particles [2]. As the result of separation test with steelmaking slag, the iron content of magnetic side and the overall separation efficiency is higher in proposal method than in conventional method.

Keywords : steelmaking slag; iron; slag recycling; physical separation; magnetic separation

Introduction

In steelmaking process, impurities of molten iron such as silicon (Si), sulfur (S), phosphorous (P) are removed by reaction with CaO and O_2 in the vessel or the converter and discharged as steelmaking slag [3] [4] [5] [6]. To accelerate chemical reaction, CaO and O_2 are injected to molten iron at high blow rate and mixed together. So much iron contaminates into steelmaking slag. For recovering this iron, steelmaking slag is processed with various methods. Fig. 1 shows an example of steelmaking slag processing flow. Firstly, steelmaking slag is cooled in the yard. And then, lumps of slag are crushed into small size by a jaw crusher, an impact mill or a rod mill and classified by a vibrating sieve. Finally, slag is processed by magnetic separator in a particle size for each particle size and iron is separated from slag. Recovered iron is used in iron making or steelmaking process and slag is usually sold to other industries, for example, as a raw material for cement or a roadbed material.

Issue

In steelworks, about hundred thousand tons of steelmaking slag is produced in one year. Therefore, for increasing throughput of magnetic separating process, steelmaking slag is processed in the multiple layers. Fig. 2 shows schema of conventional pulley magnetic separator. Because magnet roll is fixed, magnetic flux density at surface of magnet pulley is constant and attracted magnetic particles don't move. When separating fine particles with pulley magnetic separator, non-magnetic particles are captured to a magnet roll by magnetic particles [1]. As a result, Non-magnetic particles contaminate into magnetic side and precision of magnetic separation decreases.
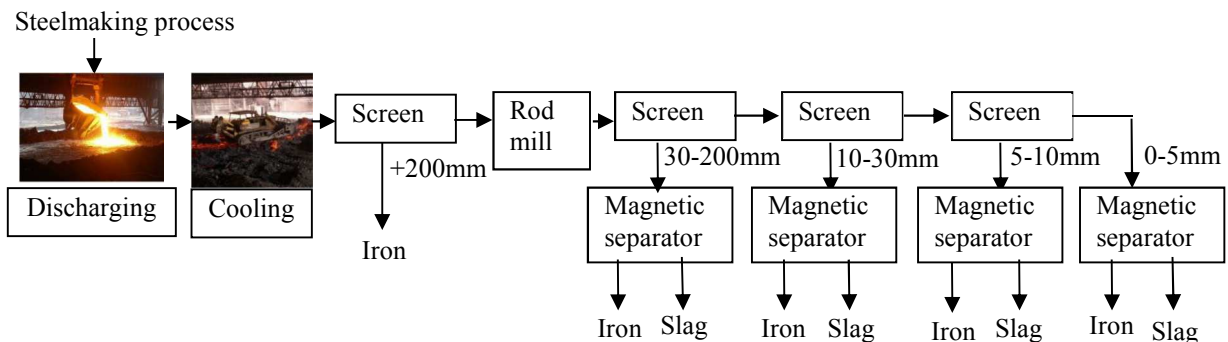

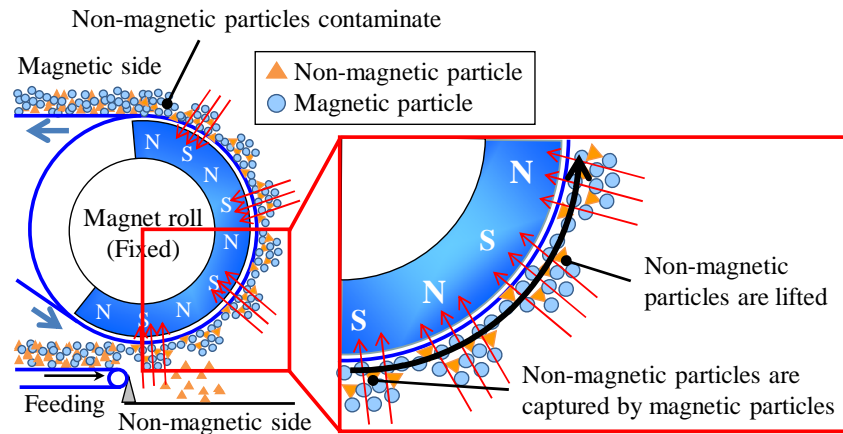Fig. 1: Example of steelmaking slag processing flow.

Fig. 2: Schema of conventional pulley magnetic separator.

Principal of proposal method

Fig. 3 shows a schema of fine particles separation with the conventional method. The fine particles can't move independently and non-magnetic particles are captured by attracted magnetic particle. As a result, non-magnetic particles and magnetic particles are collected together in magnetic side. So separation is not enough. On the other hand, Fig. 4 shows a schema of the proposed method using mechanical stirring by a fluctuating magnetic field. First, the magnetic particles are enriched on the surface of the fine particles. Next, the magnetic particles on surface swing under the fluctuating magnetic field unlike the condition with a static magnetic field and non-magnetic particles fall out. Finally, only magnetic particles remain under the magnetic field, and all the non-magnetic particles have fallen out. The fine particles are stirred intensely by changing the direction and strength of the applied magnetic field. As a result, magnetic particles and non-magnetic particles are separated efficiently.

For practical use, quick fluctuation using a mechanical device is necessary. Methods for generating a fluctuating magnetic field can be divided into methods using electromagnets and permanent magnets. The disadvantage of the electromagnets is that an operating device with a very high specification is necessary, as magnetic flux density is inversely proportional to the frequency of fluctuation. On the other hand, permanent magnets made from a rare earth element magnet with a high magnetic flux density are developed recently. Due to its high flux density, the size of the magnet can be reduced. Eddy current separators use this kind of small magnets in magnetic rolls. The permanent magnet method is used in this study.

Fig. 5 shows a schema of proposal magnetic separator with permanent magnets. When a magnetic roll rotates at R [rpm], the frequency F [Hz] of the fluctuation of the magnetic field is given by

$$F = \frac{N \times R}{60} \tag{1}$$

where, N is the number of magnetic poles. The energy required by this type of device is only that for operation of the magnetic roll, and because permanent magnets do not generate heat, a cooling device is not necessary.
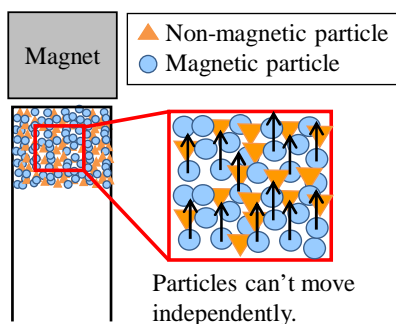

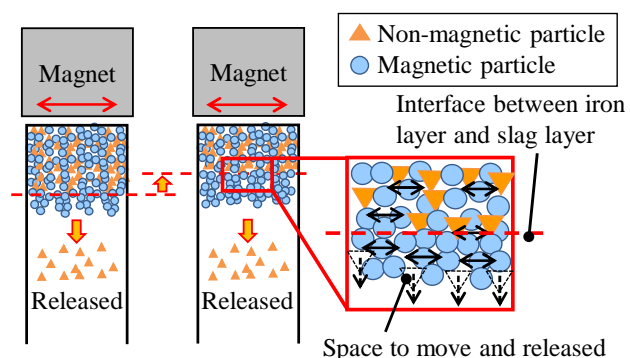Fig. 3: Schema of conventional static magnetic separation.

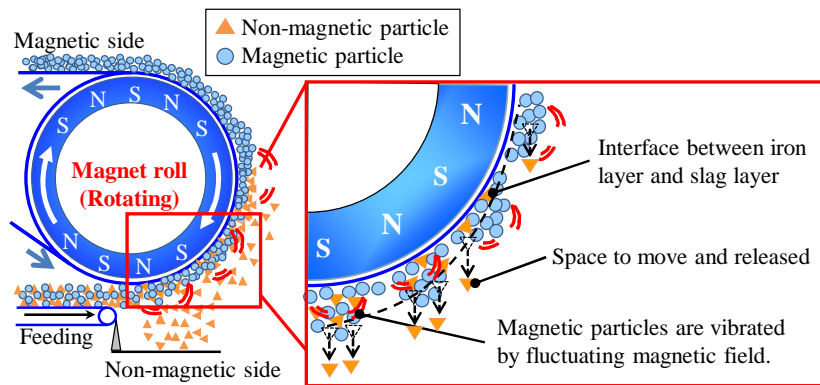Fig. 4: Schema of proposal fluctuating magnetic field separation.

Fig. 5: Schema of proposal magnetic separator.

Separation test of steelmaking slag sample

In order to compare separation precision of conventional method and proposal method, laboratory test with steelmaking slag sample was conducted. Conditions of separation test are shown in Table 1 and properties of slag sample are shown in Table 2. Chemical component of magnetic side and non-magnetic side is analysed.

For evaluation, overall separation efficiency is calculated by Fe content. Overall separation efficiency is used generally for evaluation of separation precision. Definition is following. When mixture of material A and material B is separated, overall separation efficiency E [-] is given by

$$E = r_a + r_b - 1 \tag{2}$$

where, r_a [-] is the recovery rate of material A, r_b [-] is the recovery rate of material B. Recover rate r_a [-] is yield of material A in separation and given by

$$r_a = \frac{x_{ac}}{x_a} \tag{3}$$

where, x_a is the amount of material A in raw material, x_{ac} is the amount of remained material A after separation. Recover rate r_b [-] is calculated in the same way. In this study, material A is Fe and material B is slag (all other components except Fe). Remained material A is Fe in magnetic side. Remained material B is slag in non-magnetic side.

Results of test is shown in Fig. 6 and Fig. 7. As magnetic flux density increases, Fe content of magnetic side decreases. This is because in high magnetic flux density single-edged particles which are low Fe content are attracted to magnet. Anyway, both Fe content and overall separation efficiency is higher with proposal method than with conventional method in all magnetic flux density. From the result of separation test, it is revealed that proposal method performs very good separation for mass product.

However, if frequency of magnetic field is too high, particles will not have enough time to react to fluctuating magnetic force, and fluctuating magnetic field behaves just like static magnetic field. The upper limit of magnetic field frequency is described by Dr. Ishida in theoretical approach [2]. In order to clarify the upper limit of magnetic field frequency, separation test with various magnetic field frequency was conducted. Test conditions are shown in Table 3.

Results of test is shown in Fig. 8 and Fig. 9. At first, as magnetic field frequency increases, both of Fe content of magnetic side and overall separation efficiency increase. On the other hand, in higher frequency than 58 Hz, both of them decrease as increase of magnetic field frequency and finally almost same as conventional method. This result shows that there is upper limit frequency and optimum frequency for magnetic separation.

Table 1: Conditions of separation test.

Magnetic flux density [mT]	36.5, 48, 62, 84.5, 113, 155
Speed of pulley belt [m/min]	15
Thickness of slag sample [mm]	10
Frequency of magnetic field [Hz]	0, 58

Table 2: Properties of steelmaking slag sample.

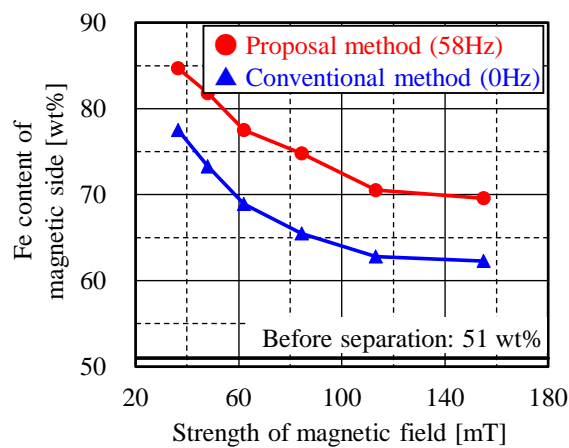|	
Diameter of slag [mm]	0-5
T.Fe content of slag [wt%]	51

Fig. 6: T.Fe content of magnetic side.
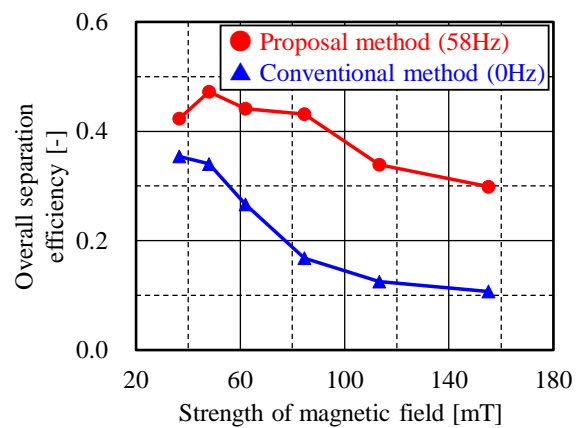(Magnetic field frequency: 0Hz, 58Hz)

Fig. 7: Overall separation efficiency.
(Magnetic field frequency: 0Hz, 58Hz)

Table 3: Conditions of separation test.

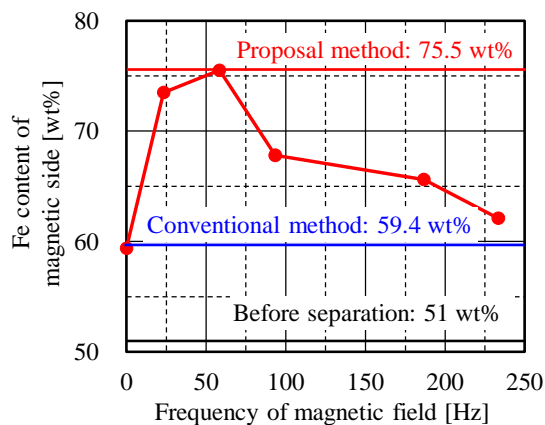| Magnetic flux density [mT]	62
Speed of pulley belt [m/min]	15
Thickness of slag sample [mm]	10
Frequency of magnetic field [Hz]	0, 23, 58, 93, 187, 233

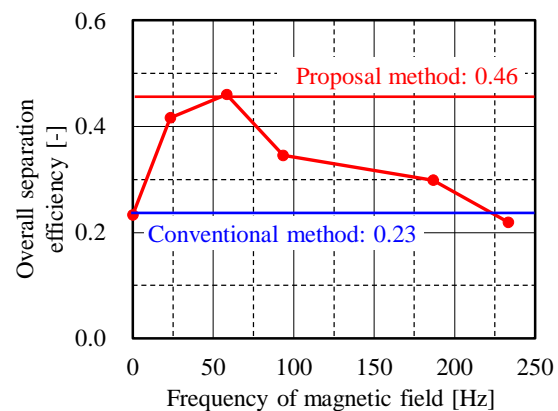Fig. 8: T.Fe content of magnetic side.
(Magnetic force condition 62 mT)

Fig. 9: Overall separation efficiency.
(Magnetic force condition 62 mT)

Conclusion

This study has discussed the new technology of a magnetic separation which can process steelmaking slag in the multiple layers for recycling iron in steelmaking slag. From laboratory test with steelmaking slag sample, it is revealed that new proposal method performs very good separation and there is the upper limit frequency and optimum frequency for magnetic separation.

References

1. J. Svoboda, "Magnetic Techniques of the Treatment of Materials", Kluwer Academic Publishers, (2004).
2. K. Ishida: PhD Thesis of Aachen University, (2014).
3. R. Dippenaar, Ironmaking and Steelmaking, 32, No. 1 (2005), 35-49.
4. R. J. Fruechan, "Overview of Steelmaking Processes and Their Development", The AISE Foundation, (1998), 1-8.
5. P. J. Koros, "Pre-Treatment of Hot Metal", The AISE Foundation, (1998), 413-429.
6. G. J. W. Kor, P. C. Glaws, "Ladle Refining and Vacuum Degassing", The AISE Foundation, (1998), 661-713.