DOI: 10.24425/amm.2020.133695

KANG-MIN KIM[1], JONG-HO BAE[1], JEONG-WHAN HAN[1*]

EFFECT OF ASPECT RATIO ON IRON-ORE BRIQUETTES DURING TWIN-ROLL BRIQUETTING

In the ironmaking, sizes of raw materials such as iron ores and coke must be adjusted for subsequent process in the blast furnace. The depletion of high grade iron ore in recent years necessitates a technology that can utilize low-grade fine iron ores. Thus, steelmakers have been studying the sinter-briquette complex firing process that employs a method of charging the sinter feed together with briquettes made of fine iron ore. In this process, larger briquettes increase the briquette productivity per unit time but decrease the green strength of briquettes and they can break during transportation and charging. Thus, the briquette shape is very important.

Therefore, in this study, we simulate a twin roll briquetting process using the DEM analysis and compared the compressive force distributions in the briquette for different aspect ratios. This study is a new attempt, because research cases by numerical methods on the same or similar systems are very rare. Consequently, the optimal aspect ratio is 0.5 at briquette height 20 mm, 2.0 at 30 mm, and 1.5 at 40 mm. Also, the average compressive force increased in proportion with the pocket height at the same aspect ratio. Therefore, to increase the pocket depth for high productivity, the pocket height must also be increased for obtaining high strength briquettes.

Keywords: Numerical analysis, discrete element method, roll briquetting

1. Introduction

Typically, integrated steelworks produce products through ironmaking, steelmaking, continuous casting, and rolling. Ironmaking is the process of obtaining molten iron from iron ore. In a high temperature and high pressure furnace called the blast furnace, coke and hot blast react to form a CO gas atmosphere; thereafter, iron ore (iron oxide being its main component) is reduced by the CO gas, and molten iron is produced. Therefore, the sizing of iron ore is very important pretreatment process. Small particles have a good reducibility owing to their high specific surface area; however, too small particles reduce gas permeability in the blast furnace. The agglomeration process is indispensable because most iron ores are produced in the powder form. In addition, the depletion of high-grade lump ores in recent years [1] has necessitated a technology that can utilize low-grade ores, to this end, steelmakers have been studying a method that uses briquettes made by compacting fine ores [2,3]. Twin-roll briquetting, illustrated in Figure 1, is a commercial process for the mass production of briquettes. The briquette shape is controlled by pocket design. Increasing the pocket depth improves briquette productivity; however; their strength may be reduced as compressive force is not transferred to the interior. Thus, we perform a twin-roll briquetting simulation using EDEM, which is a commercialized discrete element method (DEM) based particle behavior analysis software and investigate the effect of aspect ratio on the compressive force applied on the briquette. Based on the results of this analysis, the proper briquette shape is considered.

2. Discrete element method (DEM) analysis

2.1. DEM

DEM is the most popular numerical method used to calculate solid particle behavior [4-6]. It calculates the repulsive force according to the overlap distance between the contacting particles to predict the motions and positions of particles, that are assumed to be undeformed rigid spheres. The governing equations are as follows [7]:

$$m_p \frac{dv_p}{dt} = \sum_{j \neq i}^{N_c} F_c + F_f + F_g \quad (1)$$

[1] INHA UNIVERSITY, DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING, 100 INHA-RO, NAM-GU, INCHEON 22212, REPUBLIC OF KOREA

* Corresponding author: jwhan@inha.ac.kr

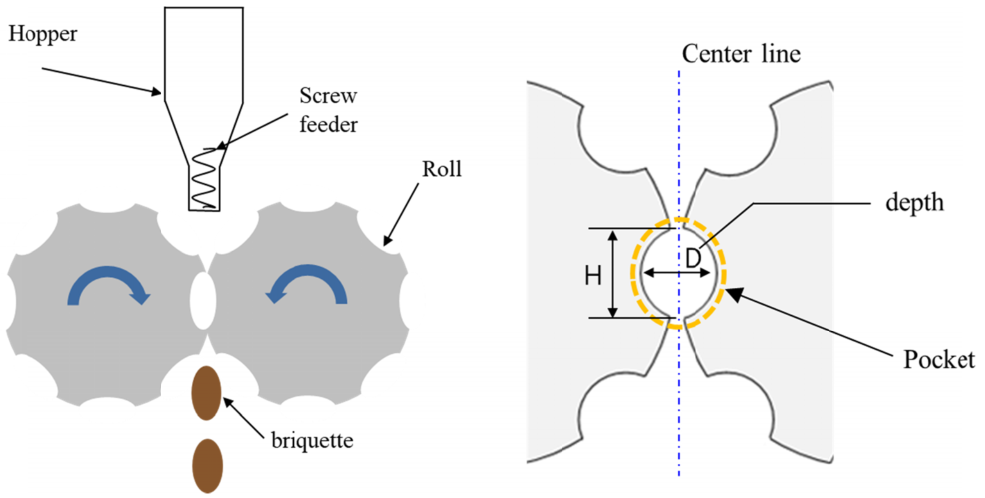

Fig. 1. Schematic diagram of the twin-roll briquetter

$$I_p \frac{d\omega_p}{dt} = R_p \sum_{j \neq i}^{N_c} \left(F_{cs} - F_r \right) \tag{2}$$

m_p – particle mass
v_p – particle velocity
t – time
F_c – interparticle contact force
N_c – number of particles in contact
F_f – force on the particle from fluid
F_g – gravitational force
I_p – moment of inertia
ω_p – angular velocity
R_p – particle radius
F_{cs} – tangential force in the direction of shear
F_r – rolling resistance

In the commonly used Hertz-Mindlin particle-contact model, as shown in Figure 2, particles overlap each other when a load is applied, and they are separated by a repulsive force when the load is removed. However, we used an elasto-plastic adhesion model to simulate plastic deformation due to pressurization by maintaining the particle-overlap state even after the load was removed. In the elasto-plastic adhesion model, the force, F_n, when applied to and removed from the load is expressed as follows:

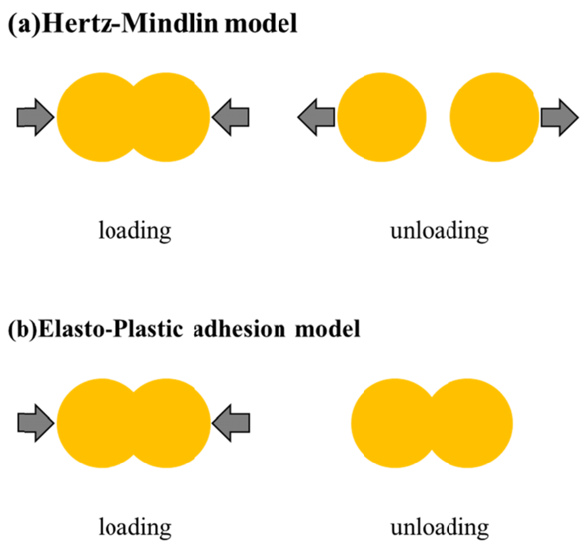

Fig. 2. Contact model of DEM: (a) Hertz-Mindlin model, (b) Elasto-plastic adhesion model

$$F_n = -\begin{cases} K_l \delta_n & \text{for loading} & \left(K_1\delta_n < K_2\left(\delta_n - \delta_0\right)\right) \\ K_u\left(\delta_n - \delta_0\right) & \text{for unloading/reloading} & \left(\delta_n > \delta_0\right) \\ 0 & \text{for unloading} & \left(\delta_n \le \delta_0\right) \end{cases} \tag{3}$$

In this equation, K_l, K_u, δ_n, and δ_0 represent the initial stiffness, unloading/reloading stiffness when the load is removed or reapplied, overlap distance when the load is applied, and overlap distance when the load is removed, respectively.

2.2. Condition of twin roll briquetting simulation

Particle properties and interaction coefficients were measured in the real sample for use in particle modeling. The chemical composition of the fine iron ore used in the measurement presented in Table 2. The particle interaction coefficients are important because they affect the motion of the modeled particles. The bounce height of a particle was measured, and the restitution coefficient was calculated; the static friction coefficient was calculated by measuring the repose angle of the particles, and then DEM simulation of repose angle measuring test was performed to obtain the rolling friction coefficient [8]. As a result, the repose angle, which is close to the experimental value obtained from the real sample, was measured with a particle-particle and a particle-wall rolling friction coefficients of 1.5 and 0.78, respectively. The twin-roll briquetter for DEM simulation was 3D-modeled on an actual briquetting machine. The diameter of the briquetter roll shown in Figure 3 was 1400 mm; the width of the pocket was fixed at 50 mm, whereas the height and depth of the pocket were varied. The particle properties, particle interaction coefficients, and briquetting conditions used in the simulation are summarized in Table 2.

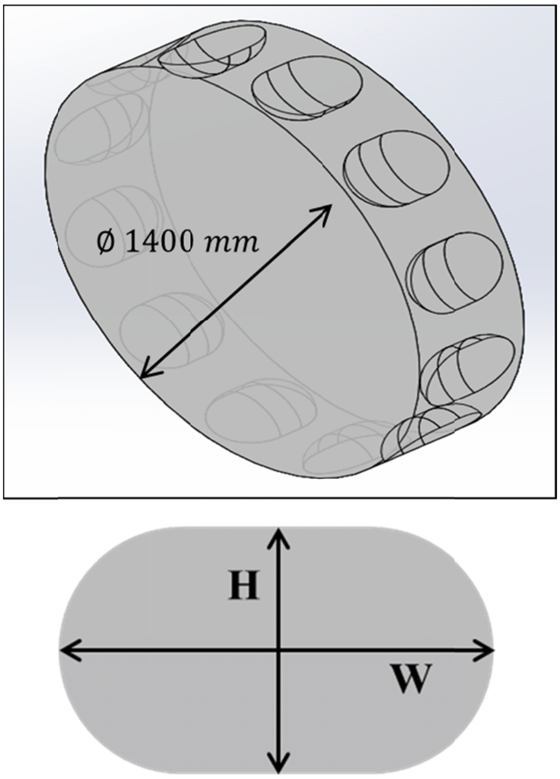

Fig. 3. 3D model of the briquetter roll

TABLE 1

Chemical composition of fine iron ore

Fe_2O_3	83.15	[wt.%]
SiO_2	9.14	
Al_2O_3	5.87	
CaO	0.19	
MnO	1.30	
MgO	0.35	

TABLE 2

Particle properties and briquetting conditions

Particle property	Particle diameter		1.0	[mm]
	Particle density		4.0	[g/cm^3]
	Poisson's ratio		0.3	[-]
Interaction coefficient	Restitution coefficient	Particle-Particle	0.172	[-]
		Particle-Wall	0.294	
	Static friction coefficient	Particle-Particle	0.903	
		Particle-Wall	0.8	
	Rolling friction coefficient	Particle-Particle	1.5	
		Particle-Wall	0.78	
Pocket	Width		50	[mm]
	Height		20-40	
	Depth ratio(D/H)		0.5-2.0	[-]
Twin roll briquetter	Roll diameter		1400	[mm]
	Rolling speed		3	[RPM]

3. Results and discussions

3.1. Unidirectional compacting

To verify the reliability of the DEM analysis, a simple unidirectional compacting experiment and simulation were performed. A cylindrical briquette was prepared by filling and compacting 2 g of the sample in a mold with an inner diameter of 10 mm, as shown in Figure 4. As a result of the briquette-density measurement, shown in Figure 5, both the experiment and the DEM analysis exhibited the same tendency, and the deviation was estimated to be from 0.045 to 0.053 g/cm^3. This difference of density is thought to be due to the fact that the particles set as rigid spheres in the DEM analysis did not deform during compacting. Thus, it is considered that the elasto-plastic adhesion model and method of particle modeling used in this DEM analysis was valid.

3.2. Twin roll briquetting

Typically, compressive force distribution in a briquette made of powder is often uneven owing to the wall effect observed during briquetting. However, as shown in Figure 6, the

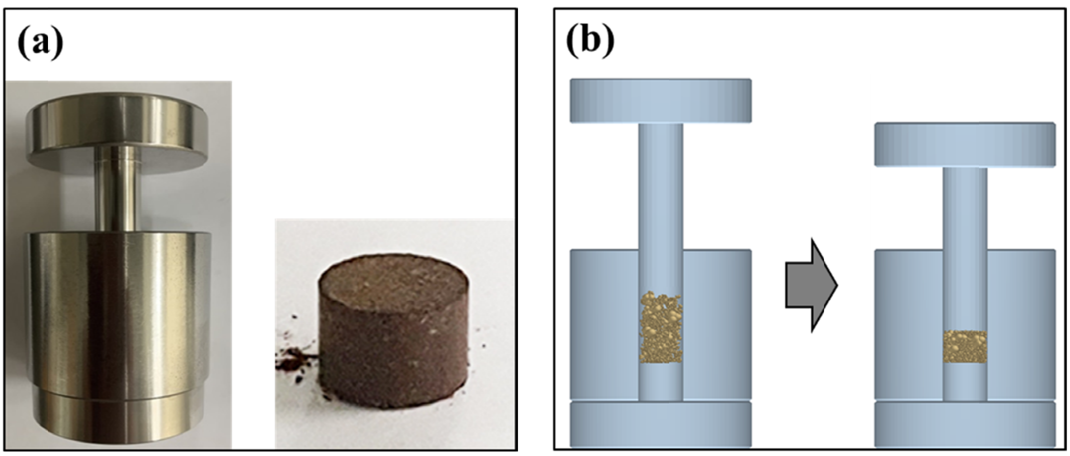

Fig. 4. Unidirectional compacting: (a) mold and briquette used in the experiment, (b) DEM simulation

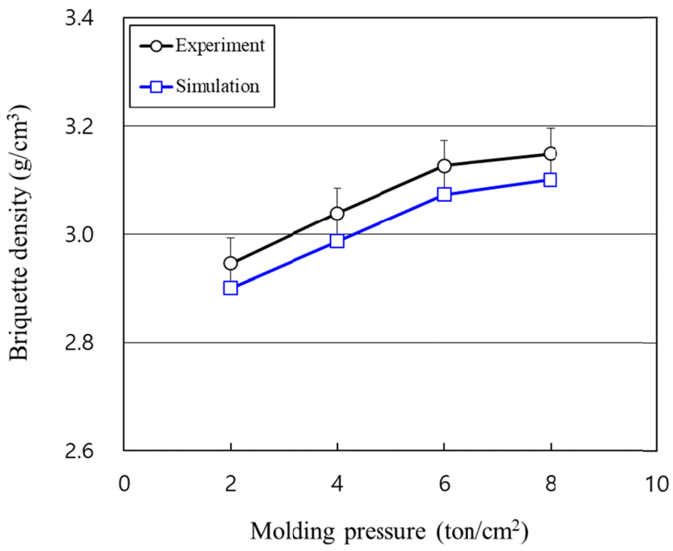

Fig. 5. Briquette density with molding pressure

compressive force distribution in briquettes manufactured by twin-roll briquetting was uniform, irrespective of the briquette size and shape. This result suggests that the wall effect did not occur during twin-roll briquetting.

The average compressive force was calculated for each pocket height and is presented in Figure 7. It is evident that the compressive force distribution, according to the height in the briquette, was uniform as described above, and the compressive force was the highest at an aspect ratio of 0.5 at 20 mm, 2.0 at 30 mm, and 1.5 at 40 mm. In other words, the aspect ratio at which briquetting is the best varies with pocket height. However, even at a fixed aspect ratio, the compressive force increased in proportion with the pocket height. This is shown in Figure 8, in the initial stage of filling the pocket with particles, as the pocket height increases, the number of particles increases, and thus, the compressive force tends to increase owing to the heavy weight in the vertical direction during filling. In addition, the area of the inlet through which the particles are filled is enlarged, and the thickening of the particles stream is also considered to have an influence.

4. Conclusions

In this study, twin-roll briquetting simulation was performed using DEM analysis to investigate the effect of aspect ratio on fine iron-ore briquettes. The conclusions are summarized below.

1) The elasto-plastic adhesion model was used as the particle contact model for the briquetting simulation; to verify the reliability of this model, the briquette densities by performing a unidirectional compacting experiment and a DEM analysis showed similar tendency.
2) It is thought that the wall effect is not observed during twin-roll briquetting because the compressive force distribution in the briquette is uniform, irrespective of the briquette size and shape.
3) In the pocket design, the optimum aspect ratio varies with respect to pocket height, however, at the same aspect ratio, the average compressive force tends to increase in proportion with the pocket height. This result was obtained to be loaded heavy weight in the vertical direction owing to the increase in particle weight and flow thickness.
4) To increase the pocket depth for high productivity, the pocket height must also be increased for obtaining high strength briquettes.

Acknowledgments

This research was financially supported by 2020 InHa University research fund.

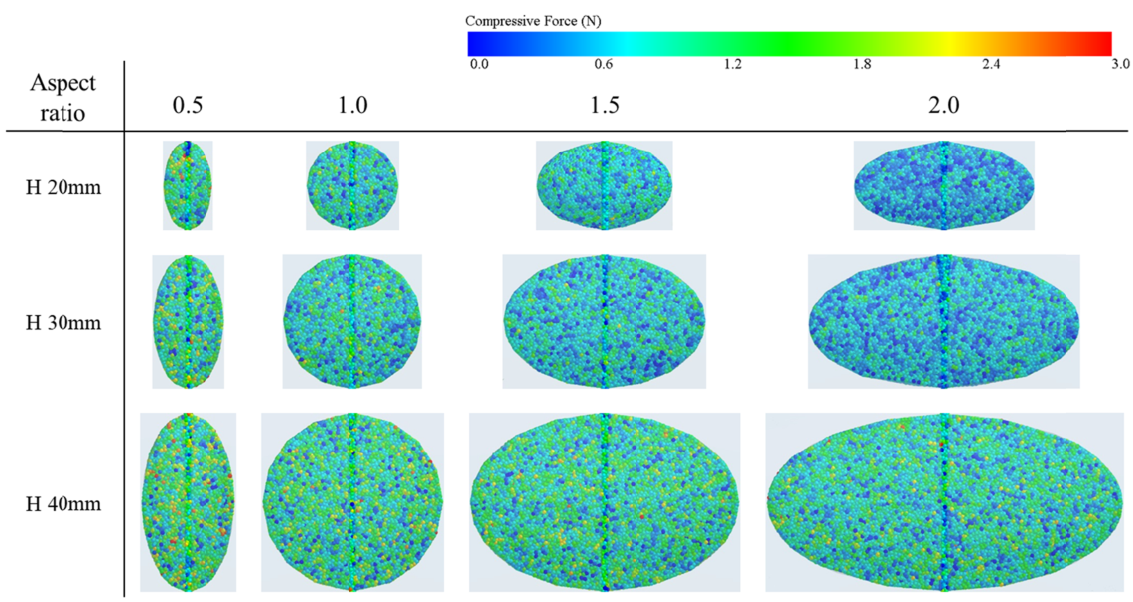

Fig. 6. Compressive force distribution in the briquette

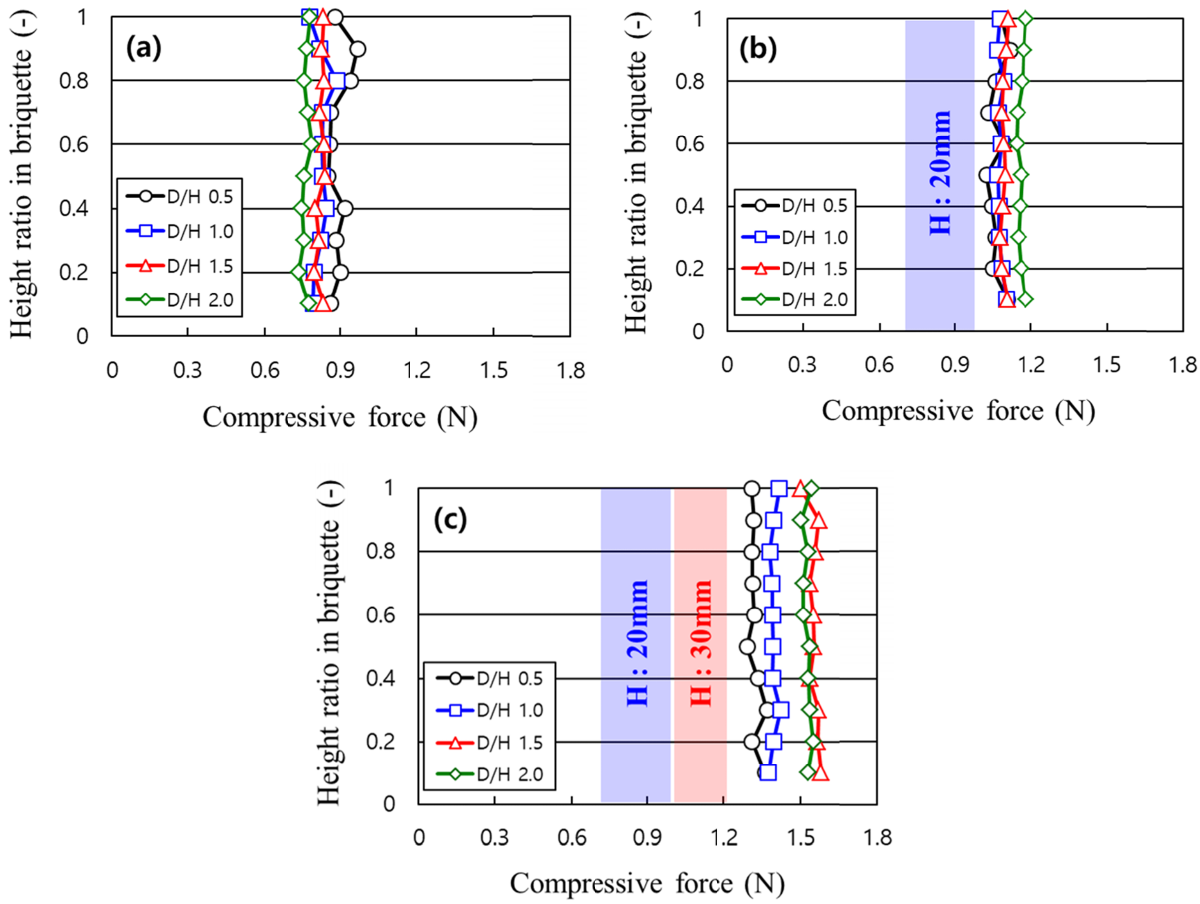

Fig. 7. Average compressive force with height at the center of the briquette: (a) H = 20 mm, (b) H = 30 mm, (c) H = 40 mm

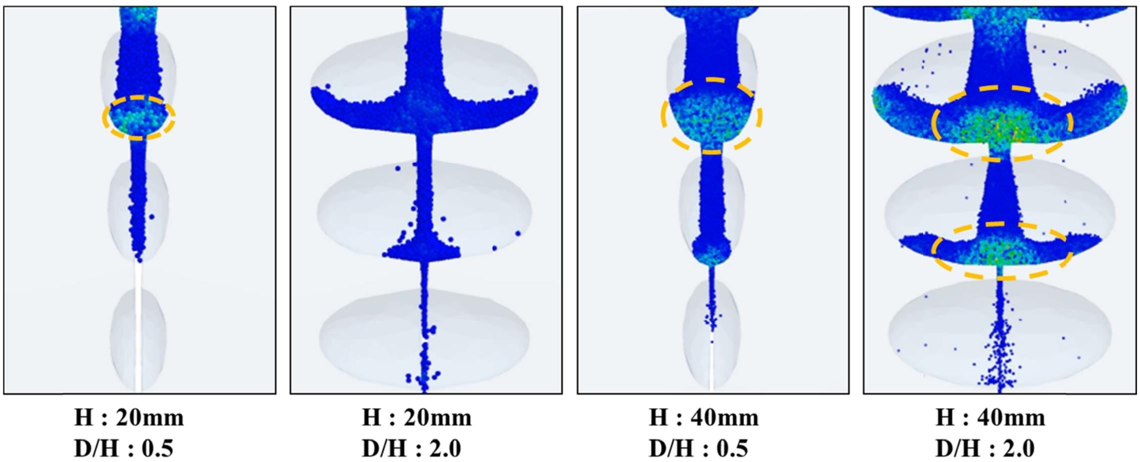

Fig. 8. Particle filling at the initial stage

REFERENCES

[1] M.I.A. Barustan, S.M. Jung, Met. Mater. Int. **25**, 1083 (2019).

[2] H. Sato, S. Machida, K. Ichikawa, M. Sato, T. Ariyama, K. Takeda, Tetsu-to-Hagané **92**, 123 (2006).

[3] T. Jiang, G.H. Li, H.T. Wang, K.C. Zhang, Y.B. Zhang, Ironmaking and Steelmaking **37**, 1 (2010).

[4] T. Kawaguchi, T. Takeda, Y. Tsuji, Trans. Jpn. Soc. Mech. Eng. B **61**, 71 (1995).

[5] S. Yuu, T. Abe, T. Saitoh,T. Umekage, Adv. Powder Technol. **6**, 936 (1996).

[6] J. Kano, F. Saito, Powder Technol. **98**, 166 (1998).

[7] S. Ueda, T. Kon, H. Kurosawa, S. Natsui, T. Ariyama, H. Nogami, ISIJ Int. **55**, 1232 (2015).

[8] K. M. Kim, J. H. Bae, J. I. Park, J. W. Han, Met. Mater. Int., Online publication (2019).