Investigation of Bell-less Charging Based on Full Scale Model Experiments*

By Yoshimasa KAJIWARA,** Takao JIMBO,** Tadatsugu JOKO,****
Yo-ichi AMINAGA**** and Takanobu INADA**

Synopsis

The burden distribution in bell-less charging was investigated by the use of a full scale experimental apparatus and simulation models were developed on the basis of experimental results.

The discharge behavior of burden from the bunker was found to be primarily funnel flow and was quantitatively evaluated by the simulation model considering the distribution of particle velocity in the flow region above discharge hole. Sinter showed stronger tendency to funnel flow than coke.

The burden trajectory in the chute and outside the chute was successively estimated by solving the equation of motion on a single particle.

The mixed layer formation was observed in bell-less charging as well as bell-armor charging. The extent of the mixed layer formation in bell-less charging was found to be expressed by the same experimental formula for bell-armor charging through the proper evaluation of "formation energy of mixed layer".

A simulation model of burden distribution was developed on the basis of experimental results. The validity of the simulation model was confirmed by the comparison with experimental results in various charging schedules. The simulation model was successfully applied to the flat profile charging.

1. Introduction

The burden distribution in the blast furnace significantly affects the gas flow distribution, chemical reactions, and heat and mass transfer in the furnace. Therefore the control of the burden distribution at the blast furnace top is indispensable for the blast furnace operation as well as the control of the blasting condition at blast furnace tuyeres.

In order to improve the controllability of the burden distribution, a bell-less charging equipment was developed and installed to commercial blast furnaces. Many researches have been performed to understand the burden distribution in bell-less charging both by experimental¹⁻³⁾ and theoretical^{4,5)} approaches.

However, the mixed layer formation in bell-less charging and the discharge behavior of burden from the bunker at the blast furnace top are not yet fully investigated. Although the importance of the mixed layer formation during ore dump in bell-armor charging is recognized^{6,7)} and some preliminary studies were carried out on the mixed layer formation in bell-less charging,⁸⁾ no quantitative investigations were performed up to present due to the restriction of the required height of the apparatus and the complexity of the problem.

Regarding the discharge behavior of burden from

the bunker, although some experimental approaches were conducted,⁹⁾ no quantitative formulation on the transition of particle size with time from the bunker was established and applied for the estimation of the particle size distribution in the blast furnace.

A full scale experimental apparatus was constructed in the coke yard of Kashima Steel Works to investigate these phenomena and the simulation model of burden distribution was developed on the basis of the analysis of the experimental results. As an application of the simulation model, the flat profile charging was performed by the full scale experiments and found to be in good agreement with the prediction by the simulation model.

II. Experimental Apparatus

The full scale experimental apparatus is illustrated in Fig. 1. The features of the apparatus are as follows.

- (1) The height of the throat was decided such that the dump of at least two charges is possible to investigate the mixed layer formation.
- (2) The dimensions of the bunker are the same as that of Kashima No. 2 BF, which will be equipped with bell-less top, to hold the entire volume of one burden dumping.
- (3) The distributing chute and the driving unit are the same as those of Kashima No. 2 BF to secure

Fig. 1. Full scale experimental apparatus.

* Received January 23, 1984. © 1984 ISIJ
** Hasaki Research Center, Central Research Laboratories, Sumitomo Metal Industries, Ltd., Hasaki-machi, Kashima-gun, Ibaraki 314-02.
*** Formerly Hasaki Research Center, Central Research Laboratories, Sumitomo Metal Industries, Ltd. Now at Wakayama Steel Works, Minato, Wakayama 640.
**** Kashima Steel Works, Sumitomo Metal Industries, Ltd. Kashima-cho, Kashima-gun, Ibaraki 314.

the same burden flow in the chute as the actual one. The chute angles in Table 1 were so selected that the charged burden impinges onto the wall and the middle of the radius at the maximum chute angle of 53 deg and at the minimum chute angle of 27 deg, respectively.

The rest of the chute angles were assigned by the equal interval of the falling position of burden in the radial direction. Table 2 shows the standard pattern of multi-ring charging.

As measuring items, the burden profile was measured by the usual mechanical sounding method and the actual distribution of ore to coke weight ratio (O/C) was measured by the magnetometer⁷⁾ for the quantitative investigation of the mixed layer formation. To prevent the fluctuation of magnetometer measurement due to the segregation of lump ore and pellet, the ore charge consisted of sinter exclusively. For the study of discharge behavior from the bunker, the burden was painted in different colors before charging into the bunker and the discharged burden from the bunker was collected by the usual sampling box method,⁵⁾ which was also adopted for burden trajectory measurement.

The materials used in the experiments were the same coke and sinter as those used in commercial blast furnaces.

III. Experimental Results and Discussion

The experimental results will be reported with the progress of the movement of burden from the bunker with discussions on each subject, that is, discharge behavior of burden from bunker, falling trajectory of burden, mixed layer formation, and simulation model of burden distribution in bell-less charging.

1. Discharge Behavior of Burden from Bunker

The existence of the distribution of particle size in the bunker affects the blast furnace operation, since the discharge behavior of burden from the bunker causes the segregation of particle size in the furnace.⁹⁾ Therefore, the investigation of the burden flow in the bunker is required both for the design of bunker and the selection of the charging schedule.

The entire volume of burden was divided in equal amount into 3 or 4 heaps and painted in different colors as tracers. The painted burden was charged into the bunker in layers and the discharge behavior of burden from the bunker was investigated by the analysis of the results of the intermittent sampling of discharged burden from the bunker.

Figure 2 shows the transition of the mixed ratio of tracers discharged from the bunker. The actual discharging time was about 105 sec for both sinter and coke under the control with the flow control gate. The maximum values of each tracer appear in the order of the top, middle, and bottom layer for sinter and bottom, top, and middle layer for coke. This fact reveals that the burden in the bunker behaves primarily in the funnel flow and the intensity of the funnel flow for sinter is higher than that for coke. Furthermore the transition of the particle size in Fig.

Table 1. Assignment of chute angle.

Chute position	1	2	3	4	5	6	7	8	9	10	11
Chute angle (deg)	53	51	49	47	45	42	39	36	33	30	27

Table 2. Standard charging schedule.

Burden	Chute position										
Coke	1	1	2	2	3	3	4	4	5	5	6
Sinter	1	1	2	2	3	3	4	4	5	5	6

Fig. 2. Transition of mixed ratio of tracers discharged from the bunker.

Fig. 3. Transition of particle size discharged from the bunker.

3 indicates the increase of particle size with time for both sinter and coke. The reason of the notable increase of sinter size with time is attributed to the

facts that the tendency to the funnel flow is stronger for sinter and the size segregation of sinter in the bunker is appreciable as shown in Fig. 4 due to the wide size distribution of sinter as compared with coke.

For the quantitative evaluation of the discharge behavior of burden from the bunker, a simulation model illustrated in Fig. 5 was developed. The following assumptions were made as the approximation.

(1) The model is two-dimensional corresponding to the cross section of the bunker.

(2) The profile of burden and the distribution of particle size in the bunker are approximated by the first degree function of the position of a particle based on the experimental results.

(3) The burden flow in the bunker occurs in the order of the flow in the flow region just above the discharge hole designated A in Fig. 5(a) and the flow to the flow region above discharge hole from the surroundings designated B in Fig. 5(a). Angles in Fig. 5 are notated as follows:

- θ_1 : deposit angle of burden at surface
- θ_2 : angle of flow region above discharge hole
- θ_3 : angle of burden flow to flow region above discharge hole.

Fig. 4. Radial distribution of particle size in the bunker.

Fig. 5. Outline of simulation model for the discharge of burden from the bunker.

(4) The burden flow in the flow region above discharge hole should have the velocity distribution, since the result of the tracer test in Fig. 2 showed only one peak of the mixed ratio of 1.0 for the bottom layer of coke. If the flow is a complete mass flow or a complete funnel flow, the peak of the mixed ratio of 1.0 should appear for top, middle, and bottom layer of both sinter and coke.

To consider this fact, a particle in the flow region above discharge hole designated ● in Fig. 5(b) is assumed to flow down with horizontal velocity corresponding to the horizontal velocity gradient of particles designated ○ in Fig. 5(b). The formulation is expressed by Eq. (1), which was used for the analysis of solid flow in the slit-type bin by R.M. Nedderman and U. Tüzün.¹⁰⁾

$$U = -C \frac{\partial V}{\partial x} \dots\dots\dots(1)$$

where, U, V : velocity component in horizontal and vertical direction, respectively (m/sec)
 C : constant (m)
 x : horizontal distance from the center of the discharged hole (m)

The equation of continuity is expressed by Eq. (2).

$$\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \dots\dots\dots(2)$$

where, y : vertical distance from the discharged hole (m)

By the combination of Eqs. (1) and (2), the following partial differential equation and its solution are obtained.

$$\frac{\partial V}{\partial y} = C \frac{\partial^2 V}{\partial x^2} \dots\dots\dots(3)$$

$$V = \frac{Q}{\sqrt{4\pi C(y+y^*)}} \exp \left\{ -\frac{x^2}{4C(y+y^*)} \right\} \dots\dots(4)$$

where, Q : discharge volume at $x=0$ and $y=-y^*$ (m²/sec)
 y^* : distance between the discharge hole and the imaginary apex of the conical part of the flow region (m)

When the velocity at $x=0(V_c)$ is introduced, Eq. (4) is rewritten as follows.

$$\frac{V}{V_c} = \exp \left\{ -\frac{x^2}{4C(y+y^*)} \right\} \dots\dots\dots(5)$$

Based on these assumptions the transition of the mixed ratio of tracers was simulated by the model and the best fitting with experimental results was obtained as shown in Fig. 6 under the conditions listed in Table 3. The symbols used in Fig. 6 correspond with those in Fig. 2. Since both θ_2 and θ_3 of sinter are larger than those of coke and the velocity distribution of sinter is steeper than that of coke, the strong tendency to funnel flow of sinter is quantitatively represented.

By the use of these conditions obtained the transition of the particle size was computed. The agreement with the experimental results was good as

Fig. 6. Data fitting of discharge behavior from the bunker by the simulation model.

Fig. 7. Comparison of measured transition of particle size with calculated one.

Table 3. Best fitting condition of discharge behavior of burden from the bunker.

	θ_2 (deg)	θ_3 (deg)	Velocity distribution in flow region above discharge hole
Sinter	90	60	$\frac{V}{V_c} = \exp\left(-\frac{X^2}{0.3}\right)$
Coke	80	50	$\frac{V}{V_c} = \exp\left(-\frac{X^2}{0.5}\right)$

demonstrated in Fig. 7 with standard deviation of 2 mm for both coke and sinter.

2. Falling Trajectory of Burden

In order to investigate the burden flow from the distributing chute, the falling burden was sampled at 4 different vertical levels by the sampling box method. The distributions of the volume flow rate and particle size within the falling trajectory are shown in Fig. 8. As reported by M. Kondon *et al.*⁵⁾, the main trajectory of the accumulated volume flow rate of 50 % lies closer to the upper stream of burden. Moreover coarse particle flows closer to the upper stream of

Fig. 8. Distributions of volume flow rate and particle size in the falling trajectory of coke.

Fig. 9. Measured falling position of burden at stock level.

burden and the distribution of particle size at each vertical level resembles each other. Therefore, the screening of particle size has been already established in the distributing chute.

The change of the falling point at stock level is shown in Fig. 9 with change of the chute angle. The distance of the falling point from the wall decreases monotonously with the increase of the chute angle. Furthermore sinter falls closer to the wall than coke at each chute angle.

The trajectory of a particle in the chute was estimated by solving Eq. (6) as equation of motion of a single particle with the assumption of no interaction between particles as proposed by Krcek *et al.*¹¹⁾

$$m\vec{a} = m\vec{g} - 2m(\vec{\omega} \times \vec{v}) - m(\vec{\omega} \times (\vec{\omega} \times \vec{r})) + \vec{T} + \vec{F} \dots\dots(6)$$

where, m : mass of a particle (g)
 $\vec{a}$: acceleration of a particle (cm/sec²)
 $\vec{g}$: acceleration of gravity (cm/sec²)
 $\vec{\omega}$: angular velocity of chute (rad/sec)
 $\vec{v}$: velocity of a particle (cm/sec)
 $\vec{r}$: position of a particle (cm)

- $\vec{T}$: reaction force from chute wall (g·cm/sec²)
 $\vec{F}$: friction force against chute inner surface (g·cm/sec²)

When the cross section of the chute is a half cylinder, Eq. (6) is rewritten in the cylindrical coordinate system by the use of notations shown in Fig. 10.

$$\frac{dZ^2}{dt^2} = g \sin \alpha - 2\omega R \cos \alpha \cdot \cos \theta \frac{d\theta}{dt} + \omega^2 \cos \alpha \cdot (Z \cos \alpha - R \sin \alpha \cdot \cos \theta) - \frac{\eta}{m|\vec{v}|} \frac{dZ}{dt} |\vec{T}| \dots\dots\dots(7)$$

$$R \frac{d^2\theta}{dt^2} = -g \cos \alpha \cdot \sin \theta + 2\omega \cos \alpha \cdot \cos \theta \frac{dZ}{dt} + \omega^2 \sin \alpha \cdot \cos \alpha \cdot Z \sin \theta + \omega^2 R \cos^2 \alpha \times \sin \theta \cdot \cos \theta - \frac{\eta}{m|\vec{v}|} \cdot R \frac{d\theta}{dt} |\vec{T}| \dots\dots\dots(8)$$

where,

$$|\vec{T}| = m \left[g \cos \alpha \cdot \cos \theta + 2\omega R \sin \alpha \frac{d\theta}{dt} + 2\omega \cos \alpha \cdot \sin \theta \frac{dZ}{dt} + \omega^2 R - \omega^2 \cos \alpha \cdot \cos \theta \times (Z \sin \alpha + R \cos \alpha \cdot \cos \theta) + R \left(\frac{d\theta}{dt} \right)^2 \right] \dots\dots\dots(9)$$

$$|\vec{v}| = \sqrt{\left(\frac{dZ}{dt} \right)^2 + \left(R \frac{d\theta}{dt} \right)^2} \dots\dots\dots(10)$$

η : friction coefficient (—)

In Eqs. (6) and (9), the underlined terms should be included from the point of view of the force balance, though they were lacked in the original paper by Krcek *et al.*⁽¹¹⁾

Figure 11 shows the calculated results of the changes of velocities, accelerations, and the “climbing angle” (θ) of sinter at chute angle 53 deg in case of the chute of Kashima No. 2 BF based on the conditions listed in Table 4. As reported by Kondoh *et al.*,⁽¹²⁾ Coriolis force plays an important role in the acceleration in θ direction as well as gravity force and causes the

Fig. 10. Notations used for Eq. (7).

increase of the “climbing angle”. However, after the velocity in θ direction takes maximum value, it takes minimum value in the downstream of the chute. This is explained as follows. As the positive component of the acceleration in θ direction, Coriolis force increases in proportion to particle velocity and the centrifugal force increases in proportion to the distance between the particle and the rotation axis of the chute. Therefore these two forces increases with the falling-down of particle in the chute. On the other hand, the gravity force acts as the negative component of the acceleration in θ direction. However the absolute value of the gravity force increases with function of $\sin \theta$ as described by Eq. (8). As a result, at the “climbing angle” of 30 deg under the current test condition, the summation of Coriolis force and the centrifugal force exceeds gravity force and the sign of the acceleration in θ direction changes from negative to positive resulting in the minimum value of the velocity in θ direction. The “climbing angle” finally reaches 36 deg at the tip of the chute.

Next the falling trajectory of a particle outside the chute was calculated under the gravity field with the calculated velocity at the tip of the chute as initial conditions. The calculated results shown in Fig. 12 are in good agreement with experimental results,

Fig. 11. Change of velocities, accelerations, and “climbing angle” along chute length calculated by the single particle model.

Table 4. Calculating conditions in the single particle model.

Items	Sinter	Coke
Charged mass (t/ch)	148	37
Apparent density (t/m ³)	3.50	1.00
Charging time (sec)	105	105
Angular velocity (rad/sec)	0.838	0.838
Charging velocity (cm/sec)*	120	100
Friction coefficient (—)*	0.550	0.625

* Model parameters

though the friction coefficients and the initial velocity at the root of the chute were selected as model parameters. The disagreement with experimental results below the chute angle of 39 deg still requires future investigation.¹³⁾ However, at present, it can be attributed to the unsuitable selection of friction coefficients or the decrease of effective sliding length of particle in the chute, since the initial velocity, the other model parameter, remains almost constant.

3. Mixed Layer Formation

Although mass of ore charged into the blast furnace per unit time in bell-less charging is less than about 1/10 of bell-armor charging, noticeable formation of mixed layer was observed in the full scale experiment as shown in Fig. 13. In the figure, mixed layer is defined as layer which contains 25 to 75 vol% of coke. When ore is charged onto coke surface, part of coke near the falling position of ore is scooped out and is transported toward the center to form large mixed layer in the central region. As a result, the actual *O/C* distribution in the radial direction differs from the one estimated from the profile measurement before and after the charging.

Figure 14 demonstrates the significant difference of *O/C* in the central region measured by the magnetometer from the one calculated from profile meter measurement. On the contrary *O/C* near the falling position of ore is slightly increased because of the decrease of coke layer thickness caused by the collision of ore.

To provide quantitative formulation on the mixed layer formation, experimental results was tried to summarize in terms of "formation energy of mixed layer" (E_M).⁷⁾ With regard to the mass of ore effective to the mixed layer formation, mass of ore in one dump is entirely concerned with the mixed layer formation in bell-armor charging of the normal operation range, since the charging is completed in several seconds. However, in bell-less charging, mass of ore effective to the mixed layer formation is expected to be limited up to the completion of covering of coke surface by ore.

This is confirmed by the discrete charging of burden as shown in Fig. 15. After the 4th turn there still exists coke surface near the wall and coke layer without ore is observed in the central region. After the 6th turn the coke surface near the wall disappears and the mixed layer formation is terminated.

Based on these experimental results, the following definition of "formation energy of mixed layer" was introduced for bell-less charging.

$$E_M = E_K + E_P = \sum_{i=n_1}^{n_2} \frac{1}{2} m_i v_i^2 + m_i g H_i \quad \dots\dots(11)$$

where, E_K : collision energy of ore (kgm²/sec²)
 E_P : potential energy of ore at falling position of ore (kgm²/sec²)
 m_i : charged mass of ore at *i*-th turn (kg)
 v_i : component of ore velocity in the direction of coke surface at *i*-th turn (m/sec)

Fig. 12. Comparison of measured trajectories with calculated one.

Fig. 13. Mixed layer formation in bell-less and bell-armor charging.

Fig. 14. Comparison of *O/C* distribution measured by magnetometer with calculated one from profile meter measurement.

H_i : vertical distance between falling position of ore and the burden surface at furnace center at *i*-th turn (m)
 n_1, n_2 : starting and finishing turn of the mixed layer formation, respectively (—)

Fig. 15. Formation process of mixed layer during charging.

Figure 16 shows the relation between the extent of the mixed layer formation and the “formation energy of mixed layer”. The increase in coke layer thickness at the center (ΔL_c) was adopted as the measure of the extent of the mixed layer formation, because the radial distribution of the change of coke layer thickness was observed to be the first degree function of the radial position. ΔL_c is evaluated by the summation of increase of coke layer thickness without ore and the increase of coke layer thickness in the mixed layer. The relation between E_M and ΔL_c in bell-less charging is the same as the one in bell-armor charging as expressed by Eq. (12) when E_M is evaluated by Eq. (11).

$$\Delta L_c = 3.49 \times 10^{-4} \times E_M - 136 \dots\dots\dots(12)$$

When charging conditions are decided, E_M is fixed by Eq. (11), then ΔL_c is evaluated by Eq. (12) and the distribution of the mixed layer formation in the radial direction can be estimated.

4. Simulation Model of Burden Distribution in Bell-less Charging

Based on the experimental results and their analysis mentioned before, a simulation model of burden distribution in bell-less charging was developed. The flow chart of the model is shown in Fig. 17. The main remarks are as follows.

- (1) The burden trajectory at the desired chute angle is estimated by the single particle model.
- (2) The surface profile is estimated on the basis of experimental results at various charging schedule with corrections of the gas flow and the burden descent.
- (3) The particle size distribution in the radial direction is calculated such that at each turn the distribution of particle size after the settlement of

Fig. 16. Relation between “formation energy of mixed layer” and ΔL_c in bell-armor and bell-less charging.

Fig. 17. Outline of the simulation model of burden distribution in bell-less charging.

charged burden on the burden surface is described by a function of radial position on the basis of burden sampling results and the average particle size in each turn is evaluated by the bunker discharge model.

- (4) The O/C distribution in the radial direction is calculated with consideration of the mixed layer formation estimated by Eq. (12).

The validity of the simulation model was confirmed through the comparison with experimental results. First of all, the O/C distribution in the radial direction calculated by the simulation model is compared with actual one measured by the magnetometer as shown in Fig. 18. Secondly the particle size dis-

tribution in the axial direction calculated by the simulation model is compared with the actual one measured by the sampling of burden fixed with resin. (Fig. 19) The good agreement in these two comparison confirms the applicability of the simulation model to actual operations.

Next, as an application example of the simulation model, the possibility of the flat or horizontal profile by the effective use of the bell-less charging was investigated. By the adoption of the flat profile, the improvement of the controllability of the burden distribution is expected because of the restraintment of the mixed layer formation and the minimization of

the particle size segregation on the burden surface. Through trial and errors by the simulation model, a charging schedule shown in Fig. 20(a) was selected and the full scale experiment was performed. Although the experimental apparatus cannot provide burden descent, a flat profile was realized at the stock level as shown in Fig. 20(b) and the agreement with the calculated results is good. Furthermore, the O/C distribution in the radial direction with correction of burden descent existed in actual blast furnaces is also uniform. This fact suggests the possibility of the permeability control by the exclusive control of particle size distribution in the radial direction, though further research on this matter is required both in theoretical and practical aspects.

IV. Conclusion

The burden distribution in bell-less charging was investigated by the use of a full scale experimental apparatus and simulation models were developed on the basis of experimental results. The following results were obtained.

- (1) The discharge behavior of burden from bunker is primarily funnel flow and can be quantitatively estimated by the simulation model with consideration of the distribution of particle velocity in the flow region above discharge hole.
- (2) Sinter has stronger tendency to funnel flow than coke.
- (3) The burden trajectory in the chute and outside the chute is successively simulated by the single particle model and it is found that Coriolis force plays

Fig. 18. Comparison of O/C distribution measured by magnetometer with calculated one.

Fig. 19. Comparison of particle size distribution measured from sampling results with calculated one.

Fig. 20. Simulation test on the flat profile charging.

an important role in the increase of "climbing angle".

(4) The extent of the mixed layer formation in bell-less charging can be expressed by the same experimental formula used for bell-armor charging, when the effective mass of ore for the mixed layer formation is considered.

(5) A simulation model of burden distribution in bell-less charging was developed with consideration of the burden trajectory, particle size distribution in the radial direction caused by the change of particle size from bunker with time, and the mixed layer formation.

(6) The charging schedule for the flat profile was predicted by the simulation model and was verified by the full scale experiment.

Acknowledgements

The authors are indebted to Dr. Nishioka, General Manager, Dr. Kunitake, Assistant General Manager, and Dr. Hatano, Assistant to General Manager of Central Research Laboratories, Sumitomo Metal Industries, Ltd., for their helpful advices.

REFERENCES

- 1) T. Nagai, J. Kurihara, H. Takahashi, K. Okumura, K. Okabe and M. Kondoh: Proc. 6th McMaster Symposium, ed. by W-K Lu and R. J. Nightingale, McMaster University Press, Hamilton, (1978), 13-1.
- 2) Y. Shimomura, Y. Kushima and T. Ashimura: *Tetsu-to-Hagané*, **65** (1979), S589.
- 3) I. F. Carmichael and C. Notman: Proc. HF80 Conference, IRSID, (1980), I-1-1.
- 4) M. Giuli, M. Palchetti and G. Gondolfi: Proc. 6th McMaster Symposium, ed. by W-K Lu and R. J. Nightingale, McMaster University Press, Hamilton, (1978), 14-1.
- 5) M. Kondoh, Y. Konishi, K. Okabe, S. Tomita, S. Hashizume and J. Kurihara: Proc. HF80 Conference, IRSID, (1980), I-3-1.
- 6) H. Nishio, T. Ariyama, K. Wakimoto and A. Yamaguchi: *Tetsu-to-Hagané*, **68** (1982), 1523.
- 7) Y. Kajiwara, T. Jimbo and T. Sakai: *Trans ISIJ*, **23** (1983), 1045.
- 8) Hirohata Steel Works, Nippon Steel Corp.: 54th Iron-making Comm., Joint Research Soc., ISIJ, May 1979, (Private).
- 9) T. Fukutake, T. Fujita and Y. Tanaka: *Kawasaki Steel Gihō*, **14** (1982), 405.
- 10) R. M. Nedderman and U. Tüzün: *Powder Technology*, **22** (1979), 243.
- 11) B. Krcek, V. Bocká, L. Broz and J. Mrazek: *Hutnické Listy*, **32** (1977), 466.
- 12) M. Kondoh, K. Okabe, J. Kurihara, K. Okumura, and S. Tomita: *Tetsu-to-Hagané*, **63** (1977), S441.
- 13) S. Kajikawa, G. Nakatani, A. Maki, N. Saito, H. Nishio, T. Ariyama and M. Sato: *Tetsu-to-Hagané*, **69** (1983), S52.