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# Briquetting of UBC by a double roll press Part II: Improvement of the Johanson model

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ABSTRACT

The development of the double roll briquetting technology for UBC (Upgraded Brown Coal) powder is introduced. The previous report noted that the application of the Johanson model to UBC briquetting has some limitations. A solution is provided in this report. The discrepancy between the Johanson model and the actual phenomena is derived from the difference between a flat roll and a pocket roll. A step function conversion from the pressure distribution calculated by the Johanson model offers a simple *and* effective solution. Using this method, it was proved that the linear relationship between the relative strength and the pressure was maintained during scaling up, but the proportional coefficient between the two decreased in accordance with the briquette size. This phenomenon is explained from the viewpoint of rupture theory.


## 1. Introduction

UBC is a low-rank coal upgrading process that was developed by Kobe Steel Ltd., which includes a briquetting sub-process [1]. In a previous report [2], the application of the Johanson model [3] to UBC powder was studied.

First, the following preparations were made:

(1) The concept of relative strength was introduced to compare the strengths of briquettes of different shapes and sizes.
(2) The data for a Jenike cell shear tester were gathered to examine the internal friction of the UBC powder.
(3) The pressure–density curve was obtained to evaluate the relationship between the pressure, the density and the theoretical power rate.

Next, the relationship between the estimated pressure and the actual relative strength was studied to establish a universal logic applicable to machines of all sizes. However, a limitation was found in the calculation method of the pressure distribution. The application of the original Johanson model to UBC powder was difficult. The study to improve the applicability of the Johanson model was continued until a solution was found. The logic and the method for this solution are introduced here as Part II.

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## 2. The limitation of the Johanson model and solution

### 2.1. Limitation

As mentioned in Part I [2], some limitations exist in applying the Johanson model to UBC powder briquetting by double roll press.

- The theoretical power rates calculated by the Johanson model were larger than the actual power rates. The maximum pressure was also overestimated.
- The ratio of the theoretical power rates of almond and pillow briquettes was quite different from the ratio of the actual power rates. This discrepancy is too large to be explained by differences in the power rate efficiency according to briquette shapes.

The dimensions of the almond and pillow pockets and their arrangements in the demonstration machine (1000 mmϕ) are shown in Fig. 1. The result of the pressure distribution calculated by the Johanson model is shown in Fig. 2. Although Eq. (1) is the basic equation, a graphical integration using Eq. (2) was performed instead for the convenience of calculation, using a spreadsheet. The nip angle, which was already estimated to be approximately 10° (0.18 rad) in the previous report [2], was divided into a hundred segments.

$$\frac{dP_L}{d\theta} = \frac{D}{2}\cdot\sigma_\alpha\cdot\left[\frac{d/D + (1 + S/D - \cos\alpha)\cdot\cos\alpha}{d/D + (1 + S/D - \cos\theta)\cdot\cos\theta}(1-f)\right]^K \cos\theta \qquad (1)$$

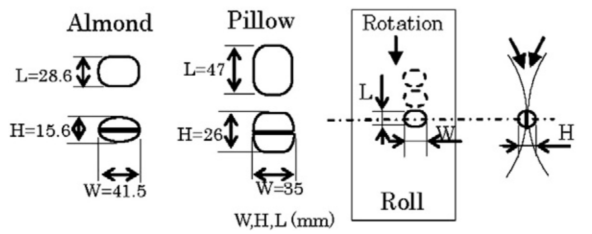


**Fig. 1.** Briquette dimensions and pocket arrangement of the 1000 mmϕ demonstration plant under pressure with a gap of 1 mm.

$$P_L = \frac{D}{2}\cdot\sigma_\alpha\cdot\sum_{i=1}^{i=100}\left[\frac{d/D+(1+S/D-\cos\alpha)\cdot\cos\alpha}{d/D+(1+S/D-\cos\theta_i)\cdot\cos\theta_i}(1-f)\right]^K\cos\theta_i\cdot\left(\frac{\alpha}{100}\right),\quad \theta_i=\left(\frac{\alpha}{100}\right)\cdot i \tag{2}$$

Here, D (m) is the roll diameter, θ (radian) is the angular position in the nip zone, S (mm) is the gap between the rolls, d (mm) is the thickness of the briquette under pressure minus the width of the gap, f (%) is the leak ratio, α (radian) is the nip angle, $P_L$ (N/cm) is the line pressure defined as the roll force divided by the roll width and $\sigma_\alpha$ (Pa) is the pressure at the nip point

The integral of the pressure distribution calculated by Eq. (2) should be equal to $P_L$ (N/m), which is 137,200 N/m in both the almond and pillow cases. Even if the line pressure is the same, the maximum pressure of the almond is higher than that of the pillow because the pressure distributions of the two are different, as shown in Fig. 2. Because the power rate of the almond briquette is actually higher than that of the pillow, the Johanson model describes the phenomena to some degree. However, the estimated value is too high. For example, in the pillow case, the calculated maximum pressure corresponds to the theoretical power rate of 15.9 kWh/t, whereas the actually measured power rate was only 13.15 kWh/t [2].

### 2.2. Solution

The dimensions of the pocket are drawn in Fig. 2 to show that the size of the pocket is quite large compared with that of the nip zone. For the pillow type, the pocket occupies more than half of the nip zone because its longer side is arranged in the circumferential direction, as shown in Fig. 1. Judging from the relative size of the pocket and the nip zone and also from the pressure distribution, the pocket nearest to the roll contact point is subject to almost all of the pressure of the roll. On the other hand, the pressure within a pocket can be equalized, to some degree, similar to a tablet test where a cylindrical mold and a piston are used. If only one pocket is subject to all of the pressure and the pressure is equalized within the pocket, the maximum pressure of the pocket should be calculated for each type by Eqs. (3) and (4). The

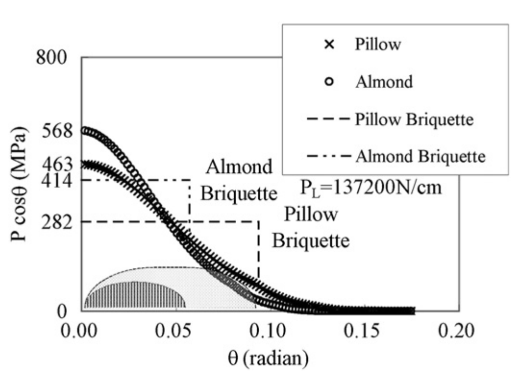


**Fig. 2.** Roll pressure distribution calculated by the Johanson model ($P_L$ = 137,200 N/cm, nip angle = 0.18 rad).

maximum pressure calculated by the Johanson model is much higher. The pressure distribution calculated by the original Johanson model cannot simulate reality when the geometrical relationship of the pocket and the nip zone is as given in Fig. 2

$$\text{Pillow}: P_L/L = 132,700\,(\text{N/cm})/4.7\ \text{cm} = 292\ \text{MPa} \tag{3}$$

$$\text{Almond}: P_L/L = 132,700\,(\text{N/cm})/2.86\ \text{cm} = 480\ \text{MPa}. \tag{4}$$

In Fig. 2, the pressure distribution curve was converted from the original curve to a step function with the width of the step equal to the dimension L of the pocket in Fig. 1 and with the same integrated value as the original curve. When β (radian) is the angle that corresponds to the circumferential dimension of the pocket, the maximum pressure can be calculated by Eq. (5)

$$P_m = \frac{D}{2}\cdot\frac{\sigma_\alpha}{L}\cdot\int_0^\beta\left[\frac{d/D+(1+S/D-\cos\alpha)\cdot\cos\alpha}{d/D+(1+S/D-\cos\theta)\cdot\cos\theta}(1-f)\right]^K\cos\theta\cdot d\theta\quad \text{Here,}\ L=\frac{D}{2}\cdot\tan\beta. \tag{5}$$

The maximum pressures calculated by this procedure are also shown in Fig. 2: 414 MPa for the almond and 282 MPa for the pillow type. The maximum pressure values calculated as $P_L/L$ by the Johanson model and by its step function conversion are summarized in Table 1. The value of the theoretical power rate calculated by the step function conversion method was lower than the actual measured power rate shown in Table 2, and the ratio of the theoretical power rates of the two types becomes much closer to that of the actual power rates. Power efficiency is the ratio of the actual and theoretical power rates, and it was 76.4% for the almond and 80.2% for the pillow type. The results summarized in Table 2 are more appropriate than the original calculation. Because the logic of the Johanson model, such as Eq. (1), was based on a flat roll, this type of discrepancy may occur when the pocket is relatively large for the roll. However, at least for UBC powder, the above simple conversion of the original calculation curve can avoid this problem. This method is simple and effective for UBC powder. The application of this method to other powder should be investigated, taking account of the various properties of each powder.

## 3. The effect of the scale

### 3.1. Generalization of the relationship between strength and pressure

The maximum pressure of the 1000 mmϕ demonstration plant cannot be measured directly, but it can be calculated from the theoretical power rate obtained by the method mentioned in Section 2. The relationship between the briquetting pressure P (Pa) and the theoretical power rate $P_W$ (kWh/t) is shown by Eq. (6), where parameters B, K and λ are reported previously in Part I [2].

$$P_W = -\lambda\cdot\int_{V_1}^{V_2} P dV = -\lambda\cdot 10^{-B}\int_{V_1}^{V_2} V^{-K} dV \tag{6}$$

**Table 1**
Maximum pressure.

| Briquette type | PL | Length | PL/length*1 | Calc'd Johanson theory | |
|---|---|---|---|---|---|
| | | | | Pocket roll | Flat roll |
| | (N/cm) | (cm) | (MPa) | (MPa) | (MPa) |
| Pillow | 137,200 | 4.70 | 292 | 282 | 463 |
| Almond | 137,200 | 2.86 | 480 | 414 | 568 |

(*1) Only one briquette in center receives all roll force.