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A PRACTICAL MEASUREMENTS OF FRICTION COEFFICIENTS DURING COMPACTION PROCESS OF DIFFERENT CERAMIC POWDERS

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Abstract- A practical model was successfully developed which is used to examine the restraint of the friction coefficients to a ceramic powder pressurized sliding through a polished hardened steel die. This research presented a study dealing with control friction on compression process of punch and die device through giving more details regarding the mechanism of friction instead of simple force. In order to arrive at the scientific and practical truth of most studies that concerned with apply powder in compaction process, it is observed that basic phenomenon of interfacial friction has less attention, and then it needs such a measurement of static and dynamic friction coefficient. Both static and dynamic friction coefficients are examined with the variation of the compaction processing parameters. The process parameters under investigation are compaction applied pressure and compaction velocity. Three different types of ceramic powders (namely; Calcium oxide, Kaolin and Zinc oxide) were used in the current study. The experimental work indicates that both static and dynamic friction coefficient variable with compaction processing parameters. However, the static friction coefficient is bigger than the dynamic friction coefficient for all powders used and during the compaction process. It was observed that the range of static friction coefficient (μ_s) is varied from 0.1 to 0.3, while range of dynamic friction coefficient (μ_d) is varied from 0.01 to 0.15. These ranges of friction coefficients are for three different ceramic powders.

Keywords: Ceramic Powders, Friction Coefficient, Powder Compact, Punch-Die.

1. INTRODUCTION

Powder compaction is a complex engineering process. The material undergoes a transformation from a loose powder state to a dense compact, thus physics-based constitutive models are inherently complicated and requires appropriate description. The friction interaction between powder and die wall plays an essential role in powder compaction because it leads to density variation, increased compression and ejection forces and resulting die wear [1]. The materials are set up between the punch and dies to form a compact through moving up the upper punch (this happen in this work), which the force is transmitted to the direction of stationary lower punch by means of friction with minimum value compared to applying force.

Bowden and Tabor [2] they proposed a theory of recognized basic element that used in sliding friction of the solid surface. The three elements were used with un lubricated surface are classified as (i)- the actual interfacial at area contact, (ii)- bonding type and the type of bond and (iii)- material properties within and around contact surfaces regarding conditions of shearing and rupturing area.

There is a general equation related to the calculation of the friction coefficient (μ) with these three basic elements in Equation (1), which is derived as follows [2].

$$\mu = \frac{F}{F_{Fr}} = \frac{A_i S_i + A^* P^*}{F_{Fr}} \tag{1}$$

where, F is the applied force, F_{Fr}, is the friction force, A_i is the interfacial area, A^* is cross-section area of displaced material, S_i is the interfacial shear strength and P^* is the mean displacement pressure.

The interfacial adhesion of the particles of the pressed powder is considered as an essential component for the occurrence of friction in Equation (l) which is agreed by Bikerman [3], who confirmed that the phenomenon of friction process cannot be influenced by adhesion. However, his confirmation is not agreed despite their theory is widely conduct by many works till now. We can reach values of the friction coefficients for powder particles compressed within a mold by measuring axial and radial force constantly during tabulating and compression processes, using the term friction, make slider compress and supporting of mold wall. A number of studies that concerned by mineral stress [4, 5] proposed using the radial force difference (F_r), F_d (high puncture force (F)-low puncture force LPF) and ejection force (F_{ej}) were after reducing the differences in peripheral area to allow passing frictional properties of compact blocks. They derived a simple approach of particles-die wall friction coefficients μ_s and μ_d based on static and dynamic considerations as shown in Equations (2) and (3).

$$\mu_s = F_d / F_r \tag{2}$$

$$\mu_d = F_{ej} / F_{re} \tag{3}$$

where, F_{re} is the radial force during ejection process.

Some workers [6] reported failure of μ_s and μ_d to correlate a range of material undergoing compaction process. But other workers [7, 8] calculate the dynamic friction coefficient from the following equation;

$$\mu_d = \frac{F_{ej}}{F_{DW}} \tag{4}$$

where, F_{DW}, is the residual die-wall force during powder compaction process and F_{ej} is ejection force.

2. MATERIALS AND EXPERIMENTS

The ceramic powders used are Calcium oxide CaO (Kw-Revai chemical Ltd, London, UK) with particle size between 10 to 45 µm (fractional by coulter counter and mean diameter ($\overline{X}$) equal to 33 µm), Kaolin (Chinese clay $Al_2Si_2O_5(OH)_4$ manufactured by K.K. Greef Ltd, Croyden, UK, have a sieve fraction between 45 to 90 µm ($\overline{X}$ =69 µm) and finally, Zinc Oxide ZnO (Hopkin and Williams Ltd, Essex, UK). Within a size range of 90 to 120 µm and mean diameter equal to 101 µm. The last two powders are fractional by using a laboratory sieving machine (Retsch Ltd, UK).

A universal hydraulic testing machine (Model 1190, INSTRON Ltd; High Wycombe, UK) fitted with 22 mm stainless steel die was used to apply pressure. Hardened steel (55 HRC) was suggested to be used in perforating cylinder and molds in order to withstand high pressure and to avoidance both sculpting and abrasion. The die-wall is whetting using fine stone which the depth of groove is measured on the surface located at the end of experiments with minimum than 0.5 µm, and 0.6 µm. It is observed after complete every compaction measurement, the die has been uneven condition and may be subjected to damage. If this happened, the die may hone and its honing oil can be removed by rinse with Methyl Ethyl ketone, MEK that is straight forward perceive by clean with ethanol and acetone by means of ultrasonic. Also, it is decided to use a cylindrical compact die because most of the previous work had been carried out on this shape. Furthermore, a cylinder gives an axis of symmetry perpendicular to the circular cross-section and this would facilitate interpretation of the results. During tests, 0.2 mm clearance is set between the die-wall and the punches. The pressing device consists of two important units; two punches and die assembly as shown in Figure 1.

Figure 1. Photograph of compaction apparatus (die and punch)

3. RESULTS AND DISCUSSION

In this research, several factors were performed in the analysis of experiments which these factors are significantly effects on friction coefficient, the factors are named as: die-wall roughness, groove orientation relative to the movement of powder particles, hardness of powder particles and hardness of die material, particle size, compact porosity of die-wall and the ratio of pressure to force of the die-wall. A mathematical expression of both static and dynamic particles-die wall coefficients of friction were calculated from Equations (4) and (5):

$$\mu_s = F / F_{DW} \tag{5}$$

where, F is the applied force (kN) and F_{DW} is the residual die-wall force (kN).

The compact is ejected throughout the bottom of the die by applying the ejection load at a punch speed of 1 cm/min. An X-Y record is recording the ejection load as the compact moves. The typical curve for the variation in ejection force (F_{ej}) with the compact movement in the die for CaO powder is shown in Figure 2. It can deduce the ejection force from the following curve is 1.8 kN.

The residual die-wall pressure was assumed equal to the lower punch pressure (L_{pp}) after removing the pressure applied [9, 10] so the die-wall force (F_{DW}) can be calculated as follows;

$$L_{pp} = \frac{L_{pf}}{A} \tag{6}$$

where, L_{pf} is lower punch force.

$$F_{DW} = L_{pp} A_s \tag{7}$$

where; A is referred to the area cross-section of powder compact [$A= D^2\times\pi/4$], A_s is the die-wall surface area ($2\pi DHI$), D is the inside die diameter, and HI is the height of the powder bed at the end of the compaction process.

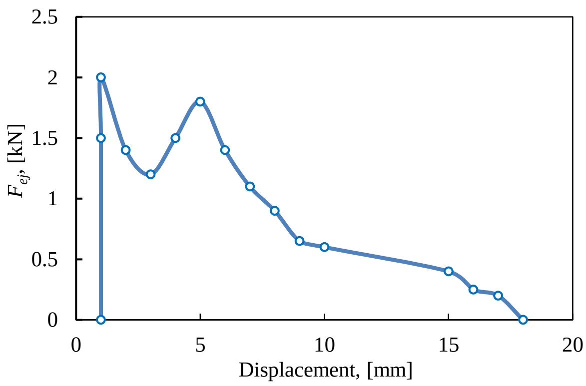

Figure 2. Typical curve for the variation in ejection force (F_{ej}) with the movement of CaO powder compact at velocity 2 cm/min

It uses a sample weight (11 gm) of CaO powder for study the effect of compaction applied pressure on the friction coefficients. The height of the powder after putting the upper punch and tapping the powder (He) is 57 mm. The compaction is carried out on a constant punch speed (5 cm/min) while, the applied pressure of compression varies between 5 to 105 MPa. It is notice that the residual die-wall force (F_{ej}) increases linearly with the applied pressure for CaO powder as shown in Figure 3.

The static friction coefficient (μ_s) is calculated from own Equation (5). Derived in this investigation because it shows that the residual die-wall force (F_{DW}) is an important aspect in the calculation of (μ_s) than other forces which were reported in the literature. James and Newton equation (4) is used for the calculation of the dynamic friction coefficient because it gives a real analysis of the study.

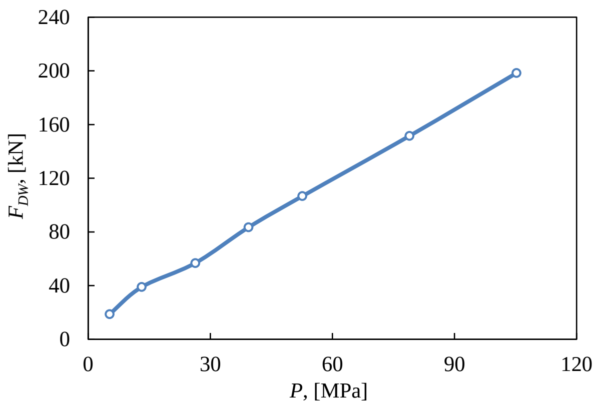

Figure 3. Residual die-wall force (F_{DW}) versus compaction pressure (P) for CaO powder

The both calculations for static and dynamic friction coefficients are plotted against the applied pressure as shown in Figure 4. However, they give a good agreement for CaO powder because it is not adhering to the die-wall. As seen in Figure 4, the (μ_s) increases with an increment of the applied pressure which is proportional with it, but (μ_d) decreases with the increment of the applied pressure. This is because of the increasing of the ejection force (F_{ej}) with the applied pressure as shown in Figures 5 and 6 summarizes the variation of the final height of the compact (HI) and the maximum displacement of the upper punch (a) during different compaction loads. Also, it is found the similarity of the three following figures for Zinc oxide and kaolin powders for the same applied pressure with a slight difference of dynamics friction coefficient not exceed than 2%.

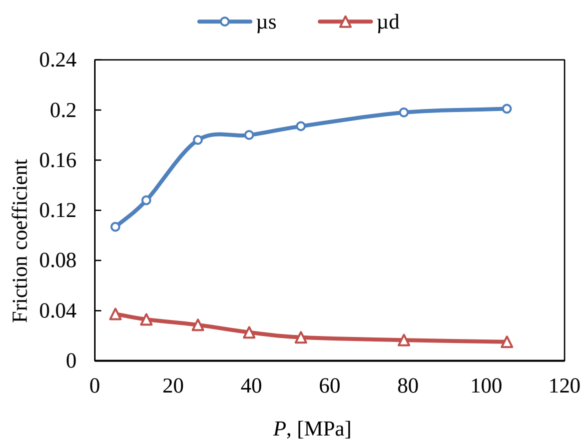

Figure 4. Static (μ_s) and dynamic (μ_d) friction coefficients as function of compaction pressure (P) for CaO powder

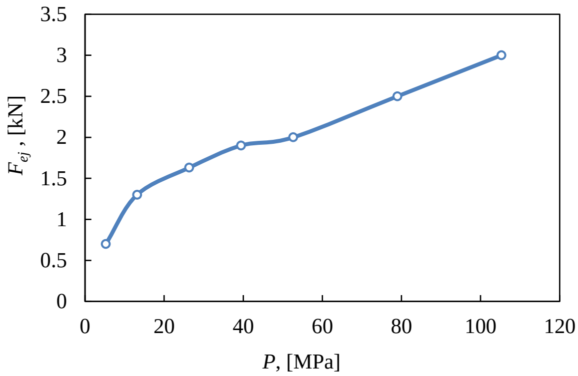

Figure 5. Influence of ejection force (F_{ej}) by compaction of CaO powder at different (P)

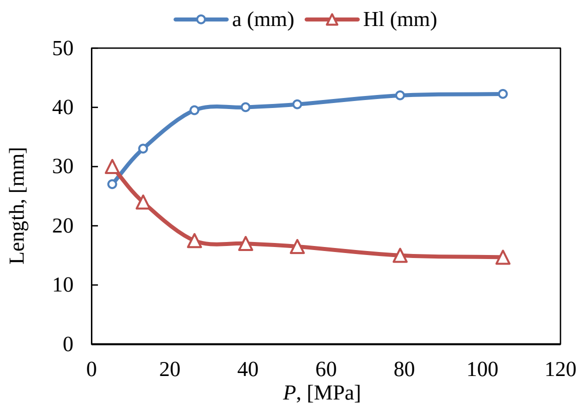

Figure 6. Final height of the CaO powder compact (Hl) and the maximum displacement of top punch (a) versus compaction pressure (P)

It is well known that some powder compaction formulations are acceptable to the change in the speed at which they are compressed and this may lead to difficulties when, for example, production is changed. The presented study will aim to investigate the relationship between the compaction velocity and the friction coefficients (μ_s) and (μ_d) which has not done before. The effect of punch velocity over the range 1-500 cm/min on various compacted materials using constant applied pressure (26.3 MPa), weight (11 gm) and die diameter (22 mm). CaO, ZnO and Kaolin are three powder materials were received from the respective manufacturers.

A typical curve of variation in ejection force (F_{ej}) with the compaction velocity for three powders is shown in Figure 7. However, the ejection force is decreased with increasing the punch speed. This relationship confirms for all powders used. This is because at high speed, lower tensile strength of compact is achieved [10, 11]. At a slower speed of compaction, a high value of dynamic die-wall friction coefficient (μ_d) is noticed as in Figure 8.

There is a dependency of (μ_d) with the displacement, this dependency is generally influenced by using powder which may lead to form a function related to the steel die-wall surface, leading to calculate the contact at interface and also determine the interaction during sliding. The dynamic friction coefficient for ZnO is greater the others (Figure 8).

This is caused by different material properties such as; adhesion, it's made to slide freely at the contact interface with primarily plugging mechanism and the frictional resistance, which is proportional to the load applied. Static friction coefficient (μ_s) is found to decrease with increasing the compaction velocity for three powders used (Figure 9). This may be due to the increasing the residual die-wall force (F_{DW}) as marked in Figure l0, and also due to the increment of maximum displacement of upper punch (a) with decreasing the compaction speed. The results of this work are tabulated in Tables 1 and 2.

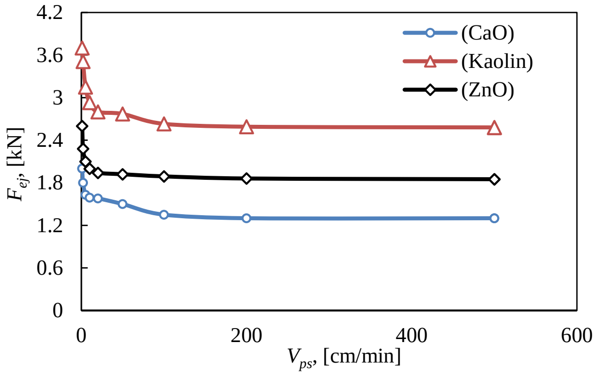

Figure 7. Influence of the ejection force (F_{ej}) by compaction of CaO, Kaolin and ZnO powders for different pressing speeds (V_{ps})

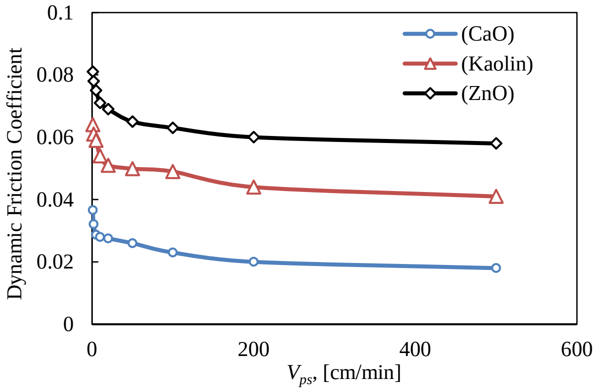

Figure 8. Coefficient of dynamic friction (μ_d) as a function of compaction velocities (V_{ps}) for CaO, ZnO and Kaolin powders

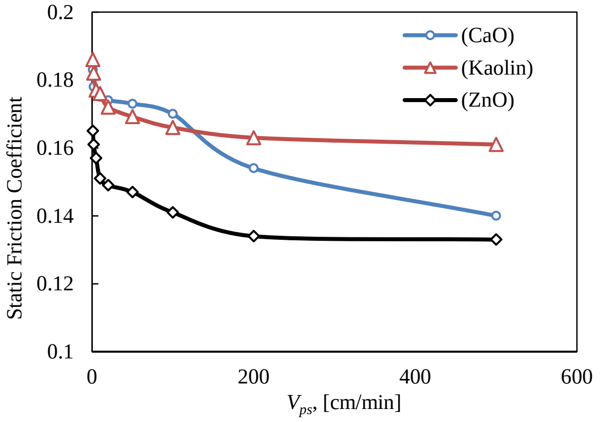

Figure 9. Coefficient of static friction (μ_s) as a function of compaction velocities for CaO, ZnO and Kaolin ceramic powders

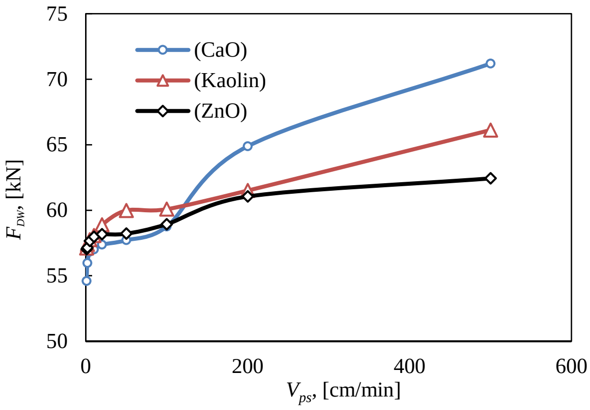

Figure 10. Residual die-wall force (F_{DW}) against the compaction velocities for CaO, ZnO and Kaolin ceramic powders

Table 1. Parameters obtained from compacted a Calcium oxide (CaO) powder, where (P) is the compaction applied pressure

P (MPa)	a (mm)	H_l (mm)	F_{DW} (kN)	F_{ej} (kN)	μ_s	μ_d
5.26	27	30	18.77	0.7	0.1067	0.0373
13.16	33	24	39	1.3	0.128	0.033
26.315	39.5	17.5	56.83	1.63	0.176	0.0286
39.417	40	17	83.49	1.9	0.18	0.0227
52.63	40.5	16.5	106.7	2.	0.187	0.0187
78.95	42	15	151.57	2.5	0.198	0.0165
105.26	42.25	14.7	198.44	3	0.201	0.0151

Table 2. Parameters obtained from compacted a CaO powder at different compaction velocities (V_{ps})

V_{ps} (cm/min)	a (mm)	H_l (mm)	F_{DW} (kN)	F_{ej} (kN)	μ_s	μ_d
1	40.2	16.8	54.6	2	0.183	0.0366
2	39.8	17.2	55.96	1.8	0.178	0.0321
5	39.5	17.5	56.83	1.63	0.176	0.0287
10	39.5	17.5	57	1.59	0.175	0.028
20	39.4	17.4	57.37	1.58	0.174	0.0275
50	39.3	17.3	57.71	1.5	0.173	0.026
100	39	18	58.75	1.35	0.17	0.023
200	37.1	19.9	64.88	1.3	0.154	0.02
500	34.9	22.1	71.19	1.3	0.14	0.018

4. CONCLUSIONS

The following main conclusions have been emerged:

1) We are able from this research to obtain a useful and practical method to verify the wall friction of a powder-pressed mold for soft and hard materials using a pressure system capable of directly measuring the both static (μ_s) and dynamic (μ_d) coefficients of friction.

2) It is believed that the new relation of Equation (5) for measuring coefficient of static friction (μ_s) is accurate and will help solve many problems in powder presses. This modulus increases with the increase of pressure applied to the pressure and decreases with increasing pressure, speed (Figures 4 and 9). This is due to its dependence on the maximum displacement of the upper hole (a).

3) The dynamic coefficient of friction (μ_d) depends on the slip displacement. This parameter decreases significantly when slippage occurs (Figure 4). The modulus may also depend on the normal stress and tensile strength of the compress (Figure 8).

4) The experimental results also indicate that the cleanliness of the wall surface affects the friction behavior of the powder with the mold wall.

Experimental work indicates that the variable coefficient of static and dynamic friction. However, (μ_s) is greater than (μ_d) for all powders used and during the pressing process. The range (μ_s) varies from 0.1 to 0.3, while the range (μ_d) varies from 0.01 to 0.15 for the powders used.

NOMENCLATURES

1. Symbol/Parameters

A_i: Interfacial area
A^*: Cross-sectional of displaced material
F: Applied force
F_d: High puncture force
F_{DW}: Residual die-wall force during compaction
F_{ej}: Ejection force
F_{Fr}: Friction force
F_r: Radial force
S_i: Interfacial shear strength
P: Compaction pressure
P^*: Mean displacement pressure
V_{ps}: Compaction velocity
μ: Coefficient of friction
μ_d: Dynamic coefficient of friction
μ_s: Static coefficient of friction

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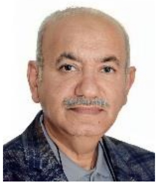

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