Silikáty 33, s. 7—10 (1989)

# THE FORMING OF CERAMIC PASTE, PART II — VERIFICATION OF THE MATHEMATICAL MODEL

JIŘÍ HAVRDA, JANA TRÁVNÍČKOVÁ, FRANTIŠEK OUJIŘÍ

*Department of Silicate Technology, Institute of Chemical Technology, Suchbátarova 5, 166 28 Prague 6*

Received 8. 2. 1988

*Verification of an earlier suggested mathematical model of the flow of ceramic paste, describing the velocity conditions in the circular extruder mouth on forming. The verification was carried out by comparing the calculated and experimental velocity profiles, the average velocity of the* $\alpha$-$Al_2O_3$ *paste and the corresponding conditions in the velocity profile. The satisfactory agreement of the model results and experiment has justified the simplifying assumptions and boundary conditions introduced into the mathematical model.*

## INTRODUCTION

Part I was concerned with the model of flow of ceramic paste through the circular extruder mouth. The assumptions on boundary conditions employed in the formulation of the model can be verified by comparing the model results with those obtained experimentally. For the sake of correct comparison, it is necessary to maintain experimental conditions holding for the respective model, namely:

a) flow in the direction of the circular mouth axis,

b) steady-state, isothermic, laminar flow with a developed velocity profile,

c) the velocity profile has to be determined for the boundary conditions of symmetrical flow with zero velocity at the mouth wall.

## EXPERIMENTAL

The experimental verification of the model was carried out on $\alpha$-$Al_2O_3$ paste containing 76 % of particles 0.1 to 0.8 $\mu$m in size, and with a specific surface area of 7.1 $m^2\,g^{-1}$.

The mix employed is plasticized in two stages. The first stage consists of activating the surface of the oxide by an addition of 1.6 wt. % magnesium stearate and 2 wt. % oleic acid. The second stage involves the actual plastification, i.e. mixing the powdered mixture with 8 wt. % of plasticizer based on kerosene and dibutyl phthalate in the ratio of 59 wt. % kerosene to 41 wt. % dibutyl phtalate.

The paste was then evacuated and formed in a piston extruder with a circular mouth $L_1 = 10 \times 10^{-2}$ m in length and $R_1 = 4.9 \times 10^{-3}$ m in diameter, and with $L_2 = 30 \times 10^{-2}$ m and $R_2 = 15 \times 10^{-3}$ m respectively.

The average velocity of flow of the mix through the mouth was measured during the experiment. The shape of the velocity profile was obtained by colouring the paste before entering the mouth and by cutting the cylindrical body axially after its extrusion from the mouth.

As far as the model was concerned, the velocity profile was calculated from equations (24, 25 — Part I) for the constitutive equation (22 — Part I) in the form:

$$\tau_s = 1.07 + 5.9(\mathrm{d}v_x/\mathrm{d}r)_s^{0.376}. \qquad (1)$$

A comparison of the calculated and experimental velocity profiles is plotted in Figs. 1 and 2. The quantitative comparison between the two results was carried out by comparing the mean flow velocity values and the corresponding positions $\bar{r}$ in the velocity profile, i.e. by means of the function $v_x = f(r)$, as the value of radius $\bar{r}$ is associated with the shape of the velocity profile.

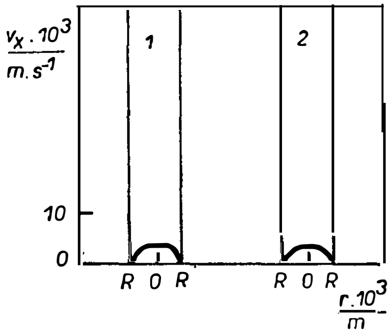

*Fig. 1. Calculated (1) and measured (2) velocity profiles for $R_1 = 4.9 \times 10^{-3}$ m, $L_1 = 10 \times 10^{-2}$ m at $\bar{v}_x = 2.97 \times 10^{-3}$ m s$^{-1}$.*

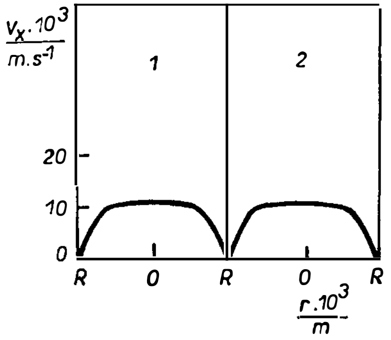

*Fig. 2. Calculated (1) and measured (2) velocity profiles for $R_2 = 15 \times 10^{-3}$ m, $L_2 = 30 \times 10^{-2}$ m at $\bar{v}_x = 7.7 \times 10^{-3}$ m s$^{-1}$.*

In the case of velocity profiles calculated from the model, the mean velocity $\bar{v}_{xm}$ was calculated from equation (26 — Part I) and the position of $\bar{r}_m$, corresponding to $\bar{v}_x$, was determined from equation (24 — Part I).

The average velocity value for the experimental profile corresponds to the mean velocity $\bar{v}_x$ measured. To determine the radius $\bar{r}$ in the experimental velocity profile in view of the difficulties involved in establishing the position of zero velocity on the mouth wall, use was made of the finding that the relationship $\bar{v}_{xi} = f(r_i)$ in the proximity of the mouth wall is linear, as demonstrated by Fig. 3. Linearization of the conditions at the mouth wall yielded a precisioned form of the experimental velocity profile. Its integration provided the mean velocity $\bar{v}_{xv}$ and its corresponding radius $\bar{r}$. By comparing the mean velocity $\bar{v}_{xv}$ thus obtained from the experimental profile with the actually measured average velocity $\bar{v}_x$ it is possible to check the correctness of linearizing the experimental velocity profile in the proximity of the mouth wall. As demonstrated by the values of the two velocities listed in Table I, introduction of this assumption does not lead to any significant error.

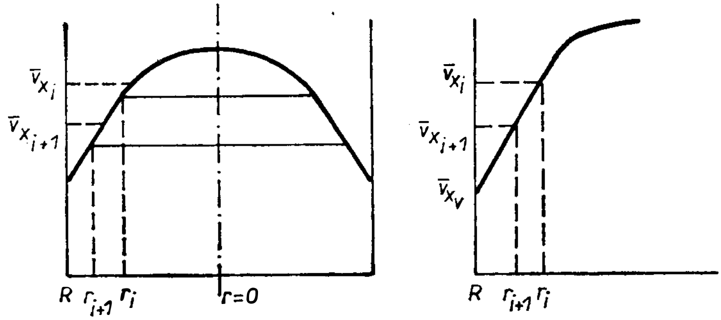

*Fig. 3. Linearization of the relationship* $\bar{v}_{xi} = f(r_i)$.

A comparison of the $\bar{v}_{xm}$ values calculated from the model with the experimentally determined average velocities of paste flow, $\bar{v}_x$, and their corresponding positions of $\bar{r}_m$ and $\bar{r}$, is listed in Table II.

*Table I*

The values of average velocities measured experimentally and evaluated from the experimental velocity profile

| $R \times 10^3$ / m | $L \times 10^2$ / m | $\bar{v}_x \times 10^3$ / m s$^{-1}$ | $\bar{v}_{xv} \times 10^3$ / m s$^{-1}$ |
|---|---|---|---|
| 4.9 | 10 | 2.97 | 3.00 |
| 15 | 30 | 7.70 | 7.80 |

*Table II*

The calculated and experimental average velocities of paste flow and the corresponding positions in the velocity profile

| $R \times 10^3$ / m | $L \times 10^2$ / m | $\bar{v}_x \times 10^3$ / m s$^{-1}$ | $\bar{v}_{xm} \times 10^3$ / m s$^{-1}$ | $\bar{r} \times 10^3$ / m | $\bar{r}_m \times 10^3$ / m |
|---|---|---|---|---|---|
| 4.9 | 10 | 2.97 | 2.91 | 3.14 | 3.24 |
| 15 | 30 | 7.70 | 8.40 | 11.00 | 11.27 |

## CONCLUSION

The mathematical model obtained by resolving the transfer equations for the conditions of paste flow through a circular extruder mouth describes the real flow of the $\alpha$-$Al_2O_3$ paste on forming with an error of 5.6 % in the value of average velocity, and an error of 2.8 % in the shape of the velocity profile expressed by the value of $\bar{r}$.

The satisfactory agreement between the model results and experiment bears out the correctness of the simplifying assumptions and boundary conditions introduced into the formulation of the model.

## TVAROVÁNÍ KERAMICKÉ PASTY, ČÁST II—OVĚŘENÍ MATEMATICKÉHO MODELU

Jiří Havrda, Jana Trávníčková, František Oujiří

*Katedra technologie silikátů, Vysoká škola chemicko-technologická, 166 28 Praha 6*

V práci je ověřen vypracovaný matematický model toku keramické pasty popisující rychlostní poměry v kruhovém ústí lisu. Porovnání výsledků modelu a experimentu bylo provedeno na základě srovnání vypočtených a experimentálně stanovených hodnot středních rychlostí toku a jim odpovídající polohy na rychlostním profilu. Dobrá vzájemná shoda mezi výsledky modelu a experimentu potvrdila oprávněnost zjednodušujících předpokladů a okrajových podmínek zavedených při formulaci úlohy.

*Obr. 1. Vypočtené (1)a naměřené (2) rychlostní profily pro* $R_1 = 4{,}9\ .\ 10^{-3}\ m,\ L_1 = 10\ .\ 10^{-2}\ m$ *při* $\bar{v}_x = 2{,}97\ .\ 10^{-3}\ m\ s^{-1}$.

*Obr. 2. Vypočtené (1) a naměřené (2) rychlostní profily pro* $R_2 = 15\ .\ 10^{-3}\ m,\ L_2 = 30\ .\ 10^{-2}\ m$ *při* $\bar{v}_x = 7,\ 7.\ 10^{-3}\ m\ s^{-1}$.

*Obr. 3. Linearizace závislosti* $\bar{v}_{xi} = f(r_i)$.

## ФОРМОВАНИЕ КЕРАМИЧЕСКОЙ ПАСТЫ; II. ПРОВЕРКА МАТЕМАТИЧЕСКОЙ МОДЕЛИ

Иржи Гаврда, Яна Травничкова, Франтишек Оуиржи

*кафедра технологии силикатов Химико-технологического института, 166 28 Прага 6*

В работе проверяется разрабонная модель протока керамической пасты, описывающая скоростые отношения в кольцевом мундштуке пресса. Сопоставление результатов модели и эксперимента проводили на основании сопоставления рассчитанных и экспериментальным путем установленных величин скоростей протока и им отвечающего положения на скоростном профиле. Хорошее взаимное совпадение между результатами модели и эксперимента доказывает оправданность упрощающихся предположений и граничных условий, вводимых при формулировке задания.

*Рис. 1. Рассчитанные (1) и измеренные (2) скоростные профили для* $R_1 = 4{,}9\ .\ 10^{-3}$*м,* $L_1 = 10\ .\ 10^{-2}$*м при* $\bar{v}_x = 2{,}97\ .\ 10^{-3}$*м* $c^{-1}$.

*Рис. 2. Рассчитанные (1) и измеренные (2) скоростные профили для* $R_2 = 15\ .\ 10^{-3}$*м,* $L_2 = 30\ .\ 10^{-2}$*м при* $\bar{v}_x = 7{,}7\ .\ 10^{-3}$*м* $c^{-1}$.

*Рис. 3. Линеаризация зависимости* $\bar{v}_{xi} = f(r_i)$.

---

**NOVÉ STŘEDISKO FIRMY GTE PRO VÝVOJ SPECIÁLNÍCH KERAMICKÝCH VÝROBKŮ.** Americká firma GTE otevřela Prototype Engineering Center v nové přístavbě k současným laboratořím ve Waltham, Mass. Bude se tam soustřeďovat vývoj dílů z nitridu křemíku pro válce a ventily naftových motorů, rotorů a lopatek turbín a dílů z transparentní yttriové keramiky na kryty antén a okénka řízených střel. Firma chce tímto spojením výzkumu s výrobou urychlit komerční zavedení keramických dílů.
(Ceram. Industry, 1988, č. 1, 139)

*Doušková*