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VIBRATION FORMING OF CARBON BLOCKS

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Abstract

ÅSV have been making prebaked anodes for aluminium reduction cells by vibration forming techniques since 1959.

The first part of this paper gives a short description of ÅSV's latest equipment for this purpose, in which the vibratory energy is provided by electrically driven excentric shafts located underneath the bottom of the mould. During vibration (1800 rpm), a restraining weight 0.4 kp/cm^2 (5.7 psi) is placed on top of the paste - so the process involves a multidegree of freedom system. The second part of the paper gives the results from extensive laboratory investigations where restraining weight, applied force on restraining weight, amplitude and frequency were varied. The resulting compaction efficiency on the paste was measured.

It has been found that this efficiency depends on the amplitude of relative motion of restraining weight to mould, and the kinetic energy of this weight. The apparent density of the green carbon block will increase with increasing kinetic energy, providing the amplitude is large enough. The optimum amplitude will depend on the properties of the green paste and the height to width ratio of the block to be formed.

Introduction

The purpose of the forming operation is to compact the aggregate of the mix so that the pitch-coated particles are in intimate contact and the shaped body is free of void space or entrapped air.

A wide variety of forming methods have been used but extrusion, compression moulding, and vibration moulding are the most common in making artificial carbon blocks. For the fabrication of such blocks for the aluminium industry, the simple concept of vibratory compaction of the paste offers significant economic and technological advantages. In this paper, vibratory compaction will indicate the use of relative high frequency (20 Hz or more) and low energy pulses. The necessary equipment is cheap in purchase compared with presses for extrusion and compression. The relative small forces involved means that the moulds do not have to be as strong as in other forming methods. A properly designed vibratory unit can therefore be used in making a wide varity of carbon blocks. It is readily seen that this forming process will become even more advantageous in the future if the development towards larger carbon blocks continues.

The first part of this paper gives a brief description of ÅSV's latest vibratory unit for making prebaked anodes. The design of this unit was based on experience gained with a test unit consisting of two vibrators with moulds for making ordinary anodes, 500x 710x1380 mm (19.7x28x54.4 in.). However, with this test unit we were only able to investigate the effect of frequency up to 1800 RPM and eccentric force. It was concluded that a more basic knowledge would be needed in order to fully optimize the process. Some work has been done to determine the effect of frequency, amplitude etc. on the compaction density of the paste (1, 2, 3). However, it is difficult to deduce a general rule from the work reported, because vibration conditions are not clearly discribed.

ÅSV therefore has carried out extensive laboratory investigations on the various parameters affecting this forming process. The results of these investigations will be presented in the second part of this paper.

The ÅSV vibrator

The results obtained with the test vibrator showed that green apparent density of the anodes increases with increasing eccentricity and frequency. The maximum frequency obtainable with this vibrator was 1740 RPM corresponding to an eccentric force of 18,400 kg (40,572 lb.). These figures were the basis for the design of ÅSV's latest unit for making prebaked anodes at Årdal. Table I gives a description of the vibratory unit in figures.

Table I

Some typical figures for the ÅSV-vibrator.

Weight of mould and attachment	3250 kg (7166 lb)
Weight of counterweight	3300 " (7277 lb)
Eccentric shaft RPM	1840
-"- force	20600 kg +20%(45423 lb)
Amplitude of mould	2.4 and 0.9 mm(0.095 and 0.035 in)
Amplitude of counterweight	1.0 mm (0.039 in)
Vibration time	2.5 min.
Capasity, anodes pr. hour (with two tables operating)	25

The vibrator is shown in Figure 1. Each shaft consists of a fixed unbalanced weight of 86 kg (189.6 lb) with its mass center 30 mm (1.18 in) from the center of rotation. Additional two weights are attached to each shaft, the position of which can be set so as to add to or subtract from the fixed unbalanced weight. This gives the ± 20 % to the eccentric force listed in Table I.

The vibrator is mounted on eight Cushyfoot 17/346 rubber dampers. The bottom of the mould is at the same level as the plant floor.

The mix is transported from the ko-kneader to the two hoppers above the vibratory mould. From these hoppers the mix is dropped directly into the mould in such a way that no further levelling is needed. The counterweight is lowered and allowed to rest on top of the paste, and vibration is started.

Following vibration and release of counterweight, one of the end walls of the mould is lifted and the finished green carbon block is drawn out on the bottom plate of the mould. A total of three vibrators were built, but only two are operated simultaneously. The whole process is automatic operated, but with possibilities for manual operation whenever wanted.

Laboratory investigations on factors affecting vibration efficiency

Apparatus

An ED 52 Vibraflux vibrator with adjustable frequency, amplitude and eccentric force was used. The eccentric element consist of two unbalanced shafts, rotating in opposite directions. The maximum frequency is 3000 RPM and the maximum impact is 7000 kp.

The vibrator is spring mounted and the total weight of table, mould and attachment is 650 kg (1433 lb.). The counterweight can be varied between 52 kg (114 lb.) and 200 kg (441 lb.). It is possible to evacuate the mould and/or apply air pressure on the counterweight. Moulds with length 700 mm (27.6) and diameters 100 and 150 mm (3.9. and 5.9 in) were used, attached to the vibratory table as shown on Fig. 2. The moulds were heated in a heating chamber before use.

The amplitudes of motion of table and counterweight were measured using displacement transducers and transducer amplifier system BKF-1 from AB Bofors, Sweden. The same amplifier is used in measuring the acceleration with a Kyowa acceleration transducer (Japan) and the strain on mould walls with strain gages.

Experimental procedure

The green paste was made by mixing aggregate and binder in a 50 ltr. (1.76 cu.ft.) sigma blade mixer at 145°C for 15 minutes. Each charge containes approximately 30 kg (66 lb.) paste, enough for making four vibrated test specimens and one pressed reference specimen. Vibration time was set to 3 minutes, while the pressed specimens were kept at 50 kp/cm^2 (711 psi) for 1 minute. The test specimens were tested for green apparent density after cooling in air.

The aggregate size distributions used are shown graphically in Fig.3. SD-1 is the ÅSV standard for pre-baked anodes.

Frequency

The results obtained with the test vibrator mentioned above, indicated that the compaction efficiency increases with increasing frequency up to approximately 1800 RPM.

Fig. 4 shows some results obtained with the laboratory vibrator operated at different frequencies. It is seen that the increase in green apparent density of the block continues as the frequency is raised above 1800 RPM.

The eccentric force will depend on the frequency according to the equation.

$$F(t) = m_e r w_e^2 \sin w_e t \qquad \text{I}$$

where

$F(t)$ = eccentric force, kg
m_e = eccentric mass, kg sec.^{2} m^{-1}
r = eccentricity, i.e. distance between center of motion and center of m_e
t = time, sec.
w_e = frequency, sec.$^{-1}$

According to this equation another way of increasing the eccentric force is by increasing the eccentricity r. This has been done, and the curves d and e in Fig. 5 are the results obtained. The curves a, b and c are the same as in Fig. 4, using eq. I in calculating the corresponding forces. It can be seen that the green apparent density increases with increasing eccentric force. The effect of frequency on the compacting efficiency is due to the fact that it affects this eccentric force.

Amplitude

The green carbon block will have some elasticity depending on paste formulation, temperature and raw materials used. We have experienced that vibration is inefficient if the compression of the paste does not exceed this elasticity. The compression will depend on the relative motion of mould and counterweight and the forces involved. In the laboratory we have investigated the effect of this relative motion between mould and counterweight on the compaction efficiency and on the density distribution in the block. The motion of the counterweight was controlled using air pressure as shown in Fig. 2.

Some typical results from these investigations are given in Fig. 6 and Fig. 7. It is shown that there excists an optimal relative motion between mould and counterweight. The laboratory test specimens were approximately 400 mm (15.8 in) long and 100 and 150 mm (3.9 and 5.9 in) in diameter. In making these carbons the relative motion should be between 5 and 6 mm (0.2 and 0.24 in) in order to achieve the highest green apparent density and the most homogeneous blocks. However, it must be emphasized that this holds for our laboratory vibrator, and that other optimal values will be found with other vibrators and pastes. The total restraining weight on top of the paste seem to have no significant effect on this optimum.

Fig. 7 shows that though the relative motion significantly affects the homogenity of the blocks, it was difficult to completely eliminate the density gradients. We have found that this inhomogenity is due to energy losses to the wall of the mould. However, with blocks with a height to width ratio of 2:1 or less it can be seen from Fig. 8 that the loss has no significant effect on the homogenity.

In order to learn more about this energy loss the pressure distribution in the mould during vibration was derived from strain measurements on the mould. The results are shown in Fig. 9. It is clearly demonstrated how the increased impact between counterweight and paste caused by increased amplitude of mould, is lost throughout the block.

These measurements of strains in the mould enabled us to calculate the ratio between radial and axial pressure during vibration. The results, as shown in Fig. 10, indicate that this ratio will decrease with increasing relative motion between mould and weight. If the pressure loss was due to dry friction against the wall of the mould, this loss should decrease with decreasing radial pressure. This is not the case, and therefore it must be concluded that the loss at least partly is due to viscous damping between paste and mould. This damping will be a function of the relative velocity between wall and paste, and therefore will increase with increasing amplitude (Fig. 9).

Restraining weight

Fig. 4 and Fig. 5 indicates a relation between total restraining weight on top of the paste and the resulting green apparent density of the paste. The density can apparently be improved by increasing the mass of the counterweight and/or forcing the weight with for instance air pressure. In Fig. 11 the green apparent density is shown as a function of mass of counterweight expressed as static pressure on top of the paste in kg/cm^2. It is shown that the heaviest counterweight gives the maximum of compaction.

Application of an external force on the counterweight seems to offer some advantages in that a high compaction efficiency can be achieved with counterweights of reasonable sizes. In Fig. 12 it is shown that the optimum pressure or force on the counterweight will increase with increasing mass of counterweight and amplitude and frequency of mould. The compaction efficiency is shown in Fig. 13 to depend on the kinetic energy of the counterweight, this energy being a function of mass times the square of the frequency.

These findings on the effect of the kinetic energy of the counterweight have been confirmed by plant tests. By application of hydraulic pressure on the weight of one of the three ÅSV vibrators for making anodes at Årdal, we were able to increase the green apparent density of the anodes from 1.56 g/cm^3 (97.39 lb/cu.ft) to 1.61 g/cm^3 (100.51 lb/cu.ft). We measured the motion and acceleration of mould and weight during these tests, and the results are given in Table II.

Table II. The ÅSV Vibrator

Green apparent density of anodes at different vibration conditions.

Applied pressure on counterweight kg/cm^2	Amplitude mm		Acceleration G		Green apparent density g/cm^3
	Mould	Weight	Mould	Weight	
0	2.4/0.9	1.0	8.9/3.4	3.5	1.56
0.63	1.0	1.7	3.6	6.6	1.61
0.95	0.6	0.9	2.4	3.4	1.56
1.27	0.6	0.9	2.4	3.5	1.55
1.58	0.6	0.8	2.3	3.0	1.55

In general, the acceleration is related to kinetic energy. From Table II it then is shown the highest kinetic energy of counterweight gives the most dense carbon blocks. Further it is seen that there is an optimum value for the applied pressure on the counterweight. In Fig. 14 it can been seen that this optimum corresponds to the pressure necessary to force the counterweight to move in the opposite direction of the mould, creating the maximum impact on the mix.

Conclusion

In vibration forming of carbon blocks the compaction efficiency is found to depend mainly on two factors; 1) the kinetic energy of the counterweight on top of the paste in the mould and 2) the relative motion of mould to weight. The compaction efficiency will increase with increasing kinetic energy providing the relative motion is sufficient.

The optimum relative motion between mould and counterweight will depend on the paste properties and on the height to width ratio of the block to be formed.

References

1. Galipeau, A. , "Carbon Body Forming Methods. Laboratory Studies".
   Arvida Symposium 1970.Not published.

2. Bain, C.A., "Use of Vibrators to make Commercial Sized Carbon Bodies".
   Arvida Symposium 1970. Not published.

3. Hirt, W., "Entwicklung in der Abformtechnik vorgebrannter kohlenstoffsteine". Erzmetall, Bd xxl, H 4, 178-180 (1968).

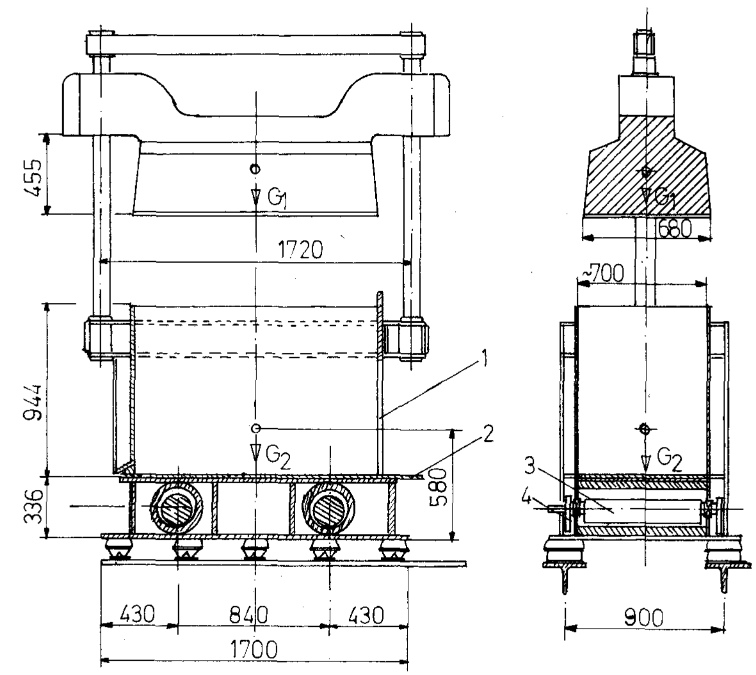

FIG. 1 SCHEMATIC DRAWING OF THE ÅSV VIBRATOR FOR MAKING PREBAKED ANODES IN ÅRDAL

G_1 = total weight of counterweight; 3300 kg

G_2 = —— " —— mould; 3250 "

1; end wall to be lifted when anode is pulled out
2; bottom plate is pulled out with anode on
3; fixed eccentric weight
4; adjustable eccentric weight

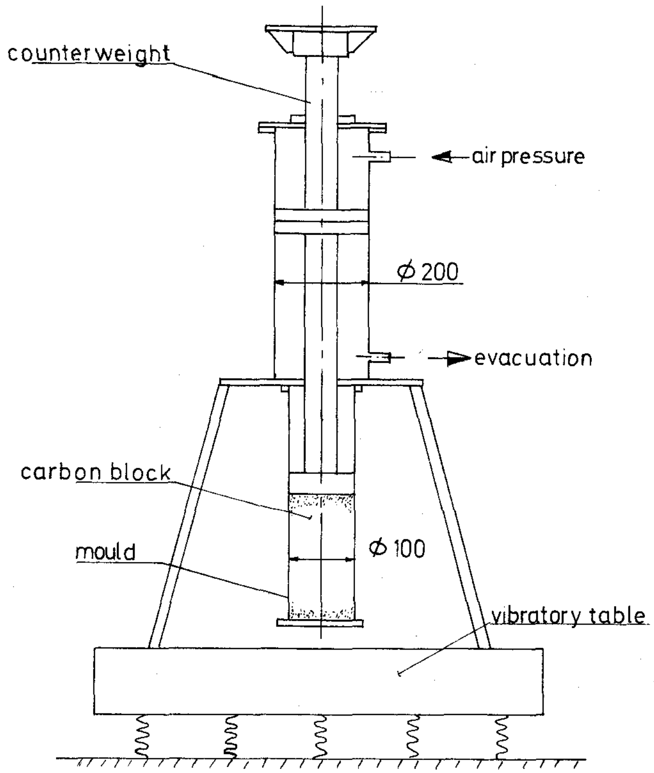

FIG. 2 SCHEMATIC DRAWING OF LABORATORY VIBRATOR

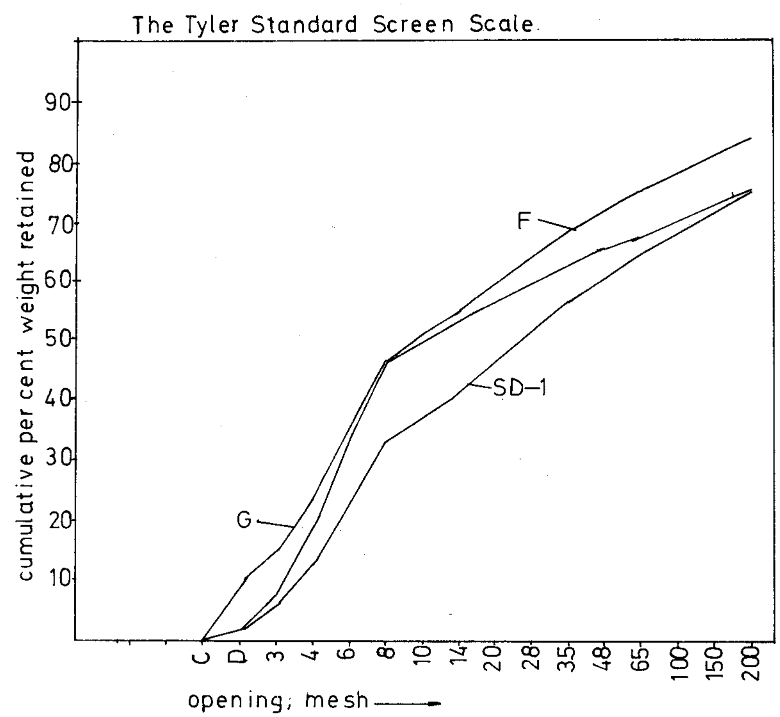

FIG. 3 CUMULATIVE DIAGRAM OF AGGREGATE SIZE DISTRIBUTIONS

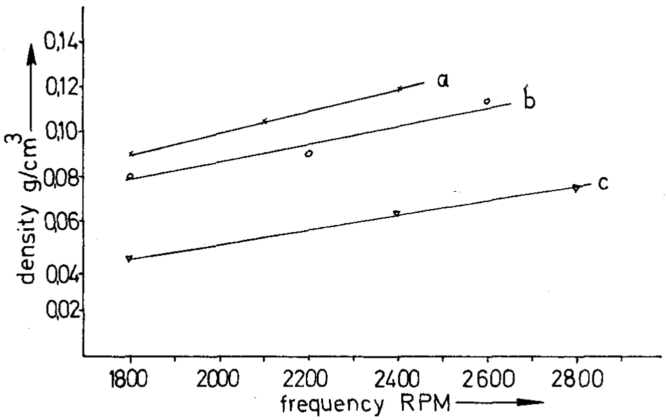

FIG 4 GREEN APPARENT DENSITY COMPARED WITH PRESSED REFERENCE ANODES

a) counterweight 1,30 kg/cm^2, optimal pressure on counterweight

b) counterweight 0 96 kg/cm^2, optimal pressure on counterweight

c) counterweight 1,30 kg/cm no pressure on counterweight

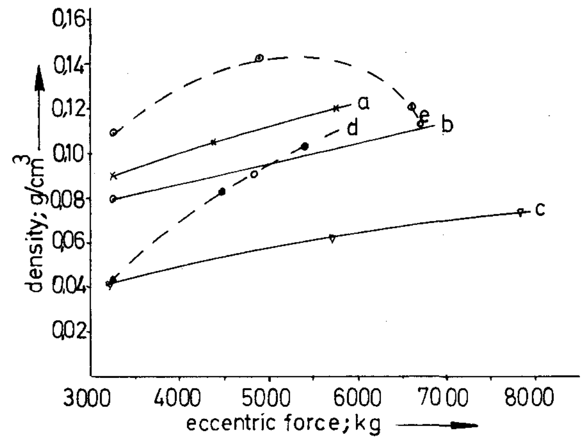

FIG 5 GREEN APPARENT DENSITY COMPARED WITH PRESSED ANODES VS. ECCENTRIC FORCE

a, b and c; same as in FIG 4

d) counterweight 1,30 kg/cm^2, optimal pressure on counterweight

e) counterweight 1,30 kg/cm no pressure on counterweight

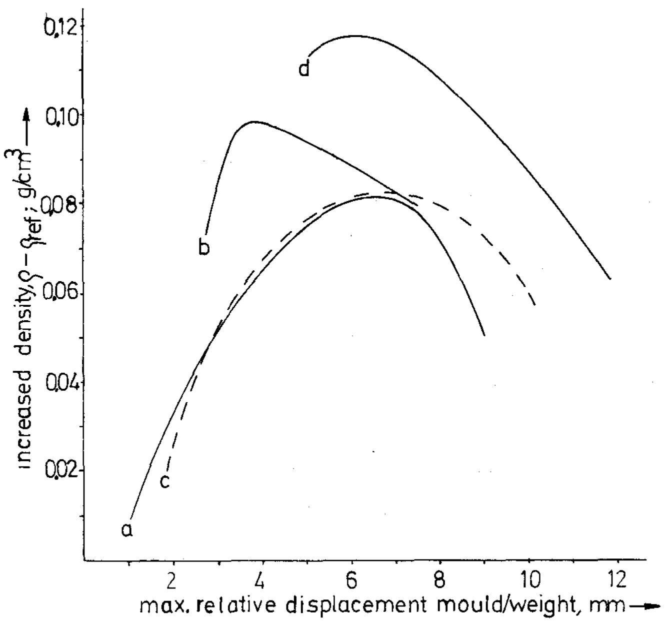

FIG.6 GREEN DENSITY VS. RELATIVE MOTION OF MOULD TO WEIGHT

a) mass of counterweight 0,59 kp/cm^2 ; 2100 RPM
b) —— " —— 0,66 " 2400 "
c) —— " —— 1.30 " 1800 "
d) —— " —— 2,58 " 1800 "

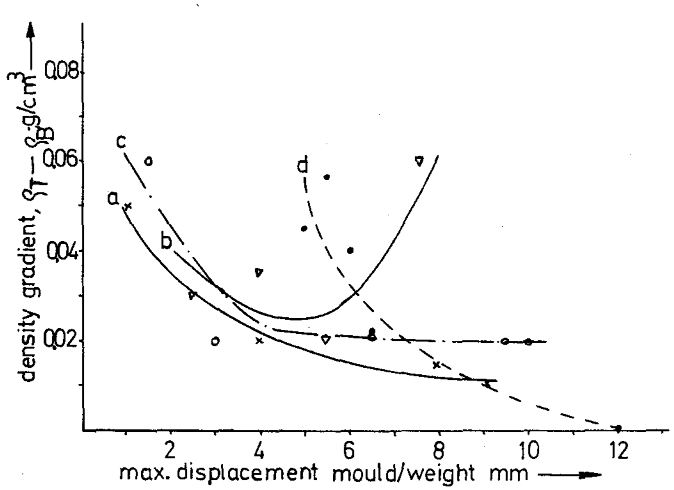

FIG.7 DENSITY GRADIENTS. VS RELATIVE MOTION OF MOULD TO WEIGHT

ρ_T = density in upper half of carbon block
ρ_B = —— " —— lower —— " ——

a) mass of counterweight 0.59 kg/cm^2 2100 RPM ×
b) —— —— 0.66 " 2400 " ▿
c) —— —— 1.30 " 1800 " o
d) —— —— 2.58 " 1800 " •

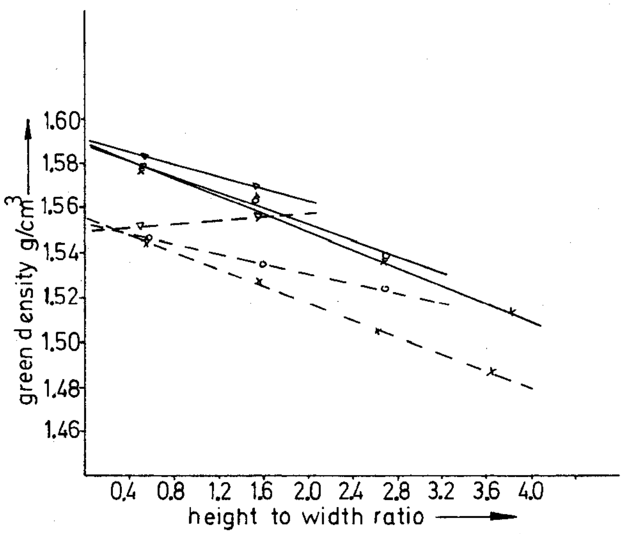

FIG. 8 GREEN DENSITY VS. HEIGHT TO WIDTH RATIO OF ANODES OF DIFFERENT LENGTH

—— counterweight 1.30 kp/cm², 1800 RPM

– – – —//— 0.66 " –"–

diameter of mould: 100 mm

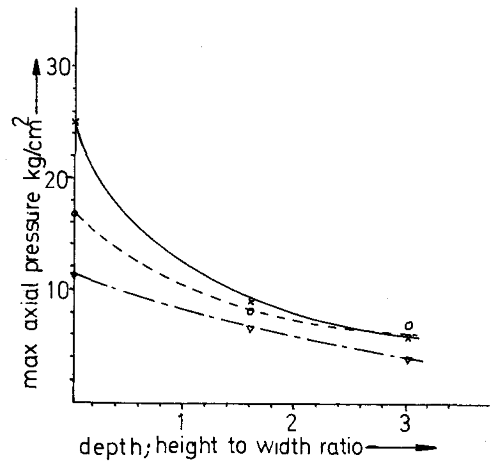

FIG 9 AXIAL PRESSURE DISTRIBUTON IN PASTE DURING VIBRATION

— amplitude of mould 2.1 mm

– – – —//— 1.6 "

–·– —//— 1.1 "

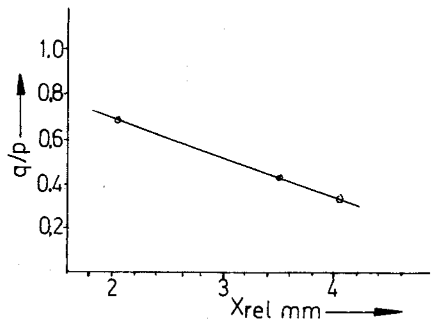

FIG. 10 RATIO OF RADIAL TO AXIAL PRESSURE VS. AMPLITUDE OF RELATIVE MOTION OF MOULD TO COUNTERWEIGHT.

q = radial pressure in mould
p = axial ——〃——
X_{rel} = max. amplitude

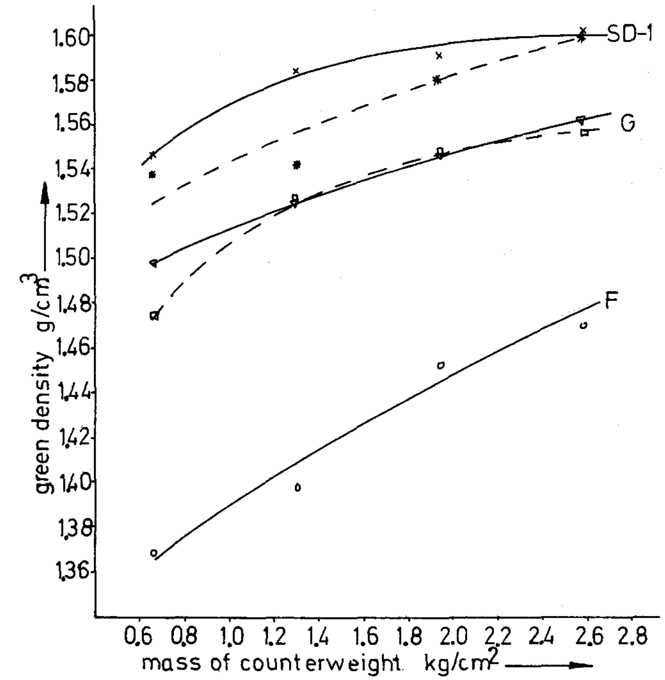

FIG. 11 GREEN DENSITY OF ANODES VS. STATIC PRESSURE FROM MASS OF COUNTERWEIGHT ON TOP OF PASTE IN MOULD

SD 1 and G: —— 16% pitch, - - - 15% pitch
F: 14% pitch

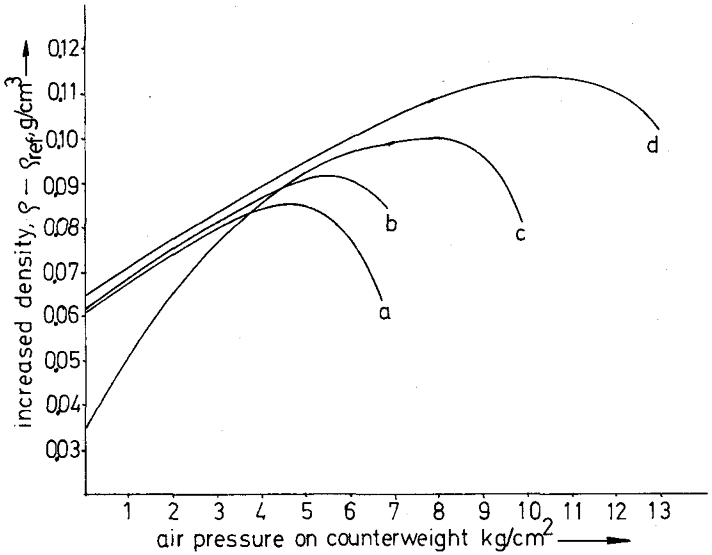

FIG. 12 GREEN DENSITY VS. AIR PRESSURE ON COUNTERWEIGHT ON TOP OF PASTE IN MOULD

a: mass of weight 1.30 kg/cm^2; ampl. mould 1.1 mm; 1800RPM
b: —— " —— 1.30 — ; —— " —— 1.6 " ; 1800 "
c: —— " —— 0.66 ; —— " —— 1.1 " ; 2400 "
d: —— " —— 1.30 ; —— " —— 1.1 " ; 2400 "

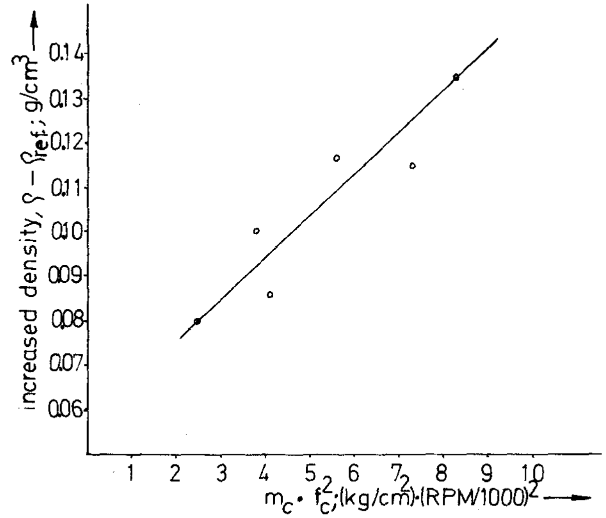

FIG. 13 GREEN DENSITY OF ANODES AS FUNCTION OF KINETIC ENERGY OF COUNTERWEIGHT.

m_c = mass of counterweight
f_c = frequency of counterweight

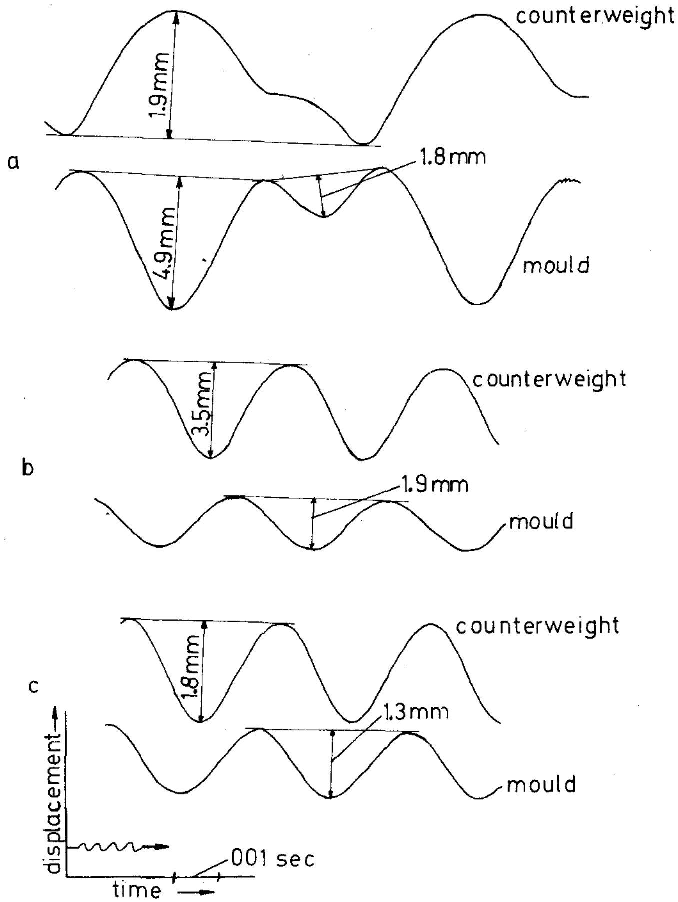

FIG.14 MOTION OF COUNTERWEIGHT AND MOULD AT DIFFERENT VIBRATION CONDITIONS WITH THE ASV VIBRATOR

a; no hydraulic pressure

b; hydraulic pressure; 063 kg/cm^2 (optimum)

c; —— " —— ; 095 "