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Pressures transmitted through polymeric powders subjected to solid phase compaction

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(Received 16 October 1979)

Recent studies[1] have examined the feasibility of solid phase compaction as a production technique for polymeric powders. In order to carry out a detailed analysis of the compaction process, three materials were selected. These were poly(vinylidene chloride)(PVdC, type VR 558), poly(vinyl chloride)(PVC, type S71/102) and polypropylene. These particular materials were chosen because of their compaction characteristics. PVdC can be compacted into components with strengths up to 30 MPa without difficulty; PVC can be compacted into components but they are relatively weak; and polypropylene does not compact at all under the conditions employed so far. Detailed comparisons have been made between the powders in order to explain the differences observed in their compactability and perhaps improve the compaction characteristics of PVC and polypropylene.

As part of this comparison, tests were carried out to measure the forces transmitted through each powder when it is compacted in a metal die. The die used produced compacts with a diameter of 19 mm and heights ranging from about 1 mm to about 38 mm (h/D from 0.05 to 2). Compaction was achieved using an Amsler test machine to push a closely fitting piston down on to the powder in the die. The upper force was obtained from the read-out of the test machine and the transmitted force was obtained from a load cell in the base of the die.

The results for a compaction pressure (P_1) of 200 MPa and pressing rate of 8 MPa s^{-1} are shown in *Figure 1*. At first glance, there appeared to be a trend between ease of compaction and the transmitted pressure in that the PVdC, which compacts easily, shows the greatest fall-off in transmitted pressure; whereas the polypropylene, which does not compact at all, shows very little fall-off in transmitted pressure. However, this theory was quickly discounted when it was remembered that PTFE can be compacted very easily but, as shown in *Figure 1*, exhibits a negligible loss in transmitted pressure. Therefore, these tests provided little insight into the compactability of different powders but it was considered that the information obtained was extremely relevant to component and die design when using polymeric powders. Many years of research, particularly with metals$^{2-4}$,

ceramics[5] and pharmaceutical materials[6] have shown that die compaction of powdered materials is beset with problems. Most of the difficulties arise from the frictional effects within the powder mass and at the powder/metal interfaces. The resulting loss in the compacting force away from the pressing piston causes heterogeneous densification of the compact with consequent low strengths in the low density areas. It is desirable therefore to be able to predict pressure losses within a compact.

The magnitude of the loss in transmitted pressure can be estimated by considering equilibrium of forces[7]. The applied force acting downwards on the powder is balanced by the upward force F_2 plus the frictional force. For a die of diameter D, the downward force F_1 is given by $\frac{1}{4}\pi D^2 P$ where P is the pressure at that section. Similarly, F_2 will be given by $\frac{1}{4}\pi D^2 (P + dP)$. If it is assumed that the radial pressure is directly proportional to P, then the frictional force at the wall is given by $CP\pi D(dh)\mu$ where μ is the coefficient of friction, C is a constant and dh is the height of the element considered.

So

$$\tfrac{1}{4}\pi D^2 P = \tfrac{1}{4}\pi D^2 (P + dP) + CP\pi D \; dh\cdot\mu$$
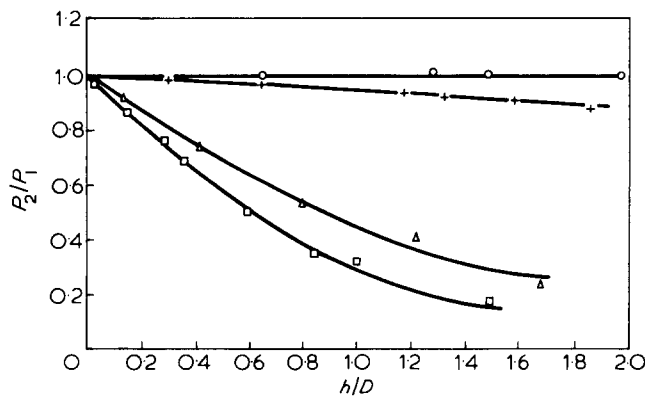

Figure 1 Transmitted pressure ratio as a function of geometry of compacts. ○, PTFE; +, polypropylene; △, PVC; □, PVdC

i.e.

$$\int_{P_2}^{P_1} \frac{dP}{P} = -\frac{4C\mu}{D} \int_0^h dh;$$

$$\ln\left(\frac{P_1}{P_2}\right) = -\frac{4C\mu h}{D}$$

or

$$\frac{P_2}{P_1} = e^{4C\mu\, h/D} \tag{1}$$

To check this type of relation, the data in *Figure 1* were plotted as log P_2/P_1 against h/D. A straight line plot was obtained for each material with a governing equation of the type:

$$\frac{P_2}{P_1} = K^{h/D} \tag{2}$$

which is another form of equation (1). Thus, it is possible to predict the transmitted pressure for any value of h/D from this simple dimensionless relationship. The constant K may be obtained quickly for a particular powder by measuring the transmitted pressure ratio for an h/D value of 1. For PVdC, the value of K is 0.315 as shown in *Figure 2*. This figure also shows that, for this material, K is independent of applied pressure P_1, but, as might be suspected for viscoelastic materials, does depend on the rate of application of pressure. An additional series of tests on PVdC using rates in the range 0.17–20 MPa s^{-1} have shown that the rate effect can be allowed for by modifying equation (2) to the form:

$$\frac{P_2}{P_1} = (a\log R + b)^{h/D} \tag{3}$$

where R is the rate of pressure application and a and b are constants.

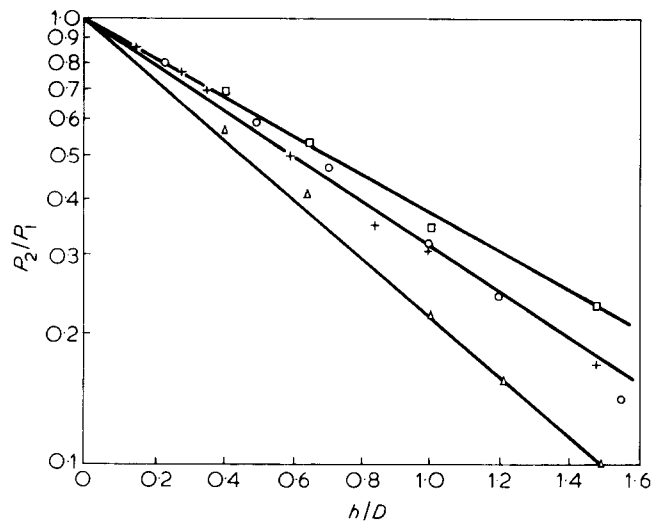For PVdC, when R is in MPa s^{-1}, a and b have values of 0.083 and 0.252 respectively.

Figure 2 Effect of pressure and pressing rate on transmitted pressure ratio.

Symbol	P_1 (MPa)	Rate (MPa s^{-1})
+	200	8.0
○	500	8.0
△	200	0.176
□	200	20.0

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