DRUG DEVELOPMENT AND INDUSTRIAL PHARMACY, 9(1&2), 139-157 (1983)

A COMPUTER AIDED INVESTIGATION ON STRAIN MOVEMENTS IN COMPACTS UNDER CONSTANT STRESS WITHIN THE DIE

D.N. Travers[+], Metin Çelik[+] and T.C. Buttery[++]
School of Pharmacy[+] and School of Mechanical Engineering[++], Leicester Polytechnic,
P.O. Box 143, Leicester LE1 9BH, U.K.

ABSTRACT

A 2.54cm diameter punch and die set has been used in conjunction with a Mayes Hydraulic Machine to examine strain movements within the die of compacts maintained at constant stress. These were prepared from the bases Avicel PH 101 (AV), Sta-Rx 1500 (ST), Paracetamol DC (PC), Emdex (ED) and Emcompress (EC).

Compression force and punch movements were simultaneously monitored using a CBM microcomputer with disk storage of data.

All compacts showed time dependent consolidation under constant stress when held at 'holding time' of up to 60s. PC, AV and ST exhibited comparable movements but that of ED and EC were less.

Elastic recovery on sudden release of load was followed using machine code logging over a period of 90ms. Large recoveries were recorded for AV, PC and ST. If load release was immediate (zero holding time) then the recovery was greater when compared with recovery after holding times of 30 and 60s, suggesting that some elastic energy was dissipated during the holding time. Elastic recovery of ED and EC was about half that of the other bases. Although these bases also showed reduced recovery with holding time, percentage reduction was smaller than for the other bases.

0363-9045/83/0901-0139$3.50/0

Following elastic recovery, a much slower viscoelastic movement could be demonstrated. It was difficult to clearly demarcate the division between viscoelastic and elastic movement but it appeared that the movement on viscoelastic consolidation was comparable to that on recovery when the load was removed.

There are many references to time dependent effects during tablet compression to be found in the literature. One of the earliest was due to Rees and Shotton (1) who found that the crushing strength of sodium chloride tablets could double after the lapse of one hour from ejection. This has recently been shown by Rue and Barkworth (2) to be due to the existence of a work hardened outer shell which inhibits relaxation by viscoelastic flow.

Several authors (3,4,5) have investigated the stress decay that occurs when a tablet is held at a nominally constant force. Thus Wells and Langridge (5) monitored the fall from a peak pressure of 332MN/m^2 on a tablet prepared in a single punch machine turned by hand. Similar techniques have been described by Rees and Rue (3), Hiestand and others (4) and Shlanta and Milosovich (6). However as Rees and Rue have pointed out, these methods measure stress relaxation under constant strain conditions. Their results and conclusions differed from those of David and Augsburger (7) who compressed the same direct compression bases on a rotary tablet machine. In a rotary machine compression takes place under virtually constant stress conditions because of the buffer effect of the powerful springs fitted to the compression wheels.

This paper describes some techniques and observations on the compression of some direct compression bases using a Mayes Hydraulic Testing Machine (WH Mayes (Windsor) Ltd) which is capable of maintaining constant stress conditions on a compact formed in a punch and die set mounted between the platens.

MATERIALS

The direct compression bases used throughout the study were Avicel PH 101 (Micro-crystalline cellulose), Sta-Rx 1500 (a modified corn starch), Emcompress (an excipient based on dicalcium phosphate), Paracetamol DC (direct compression form of paracetamol) and Emdex (a maltose/dextrose mixture). All materials were used as received from the suppliers and were compressed without internal lubricants after being stored at 40-60°C for twelve hours.

EXPERIMENTAL METHODS

The Mayes machine, though not a purpose built 'Compaction Simulator' as described by Hunter and others (8) has many features which make it suitable for compaction studies. These can be summarised as follows:

1) It is fairly rapid in action. At the fastest load rate of 5000 kN/min a load of 30kN could theoretically be attained in between 0.33 s to 0.37 s though compression times are longer when materials are present in the die.

2) A small preload can be set prior to compaction. This provides an unambiguous reference point as the initial condition for each compaction.

3) The loading rate can be varied and the maximum compression force preset by the operator.

4) The force cell located in the crosshead is warranted to A1 standard (BS 1610.1967). This avoids the need for punch bonded strain gauge networks which can be a frequent source of error (9). The analogue signal from the cell has a maximum value of 10 v which was suitable for applying directly to a specially designed analogue to digital converter (ADC) serving a microcomputer logging system used in the present work.

5) The ram displacement transducer has a range of 20 mm and the voltage output was suitable for many of the procedures described in this paper.

6) Servomechanisms within the press operate to maintain a constant load on the punch thus compensating for the stress relaxation which would normally occur due to time dependent movements in the formed compacts. The load can be maintained for a preset 'holding time' and load release is very rapid at the end of this period.

7) The press has a console which enables the operator to set the conditions and observe digital values of the voltage outputs

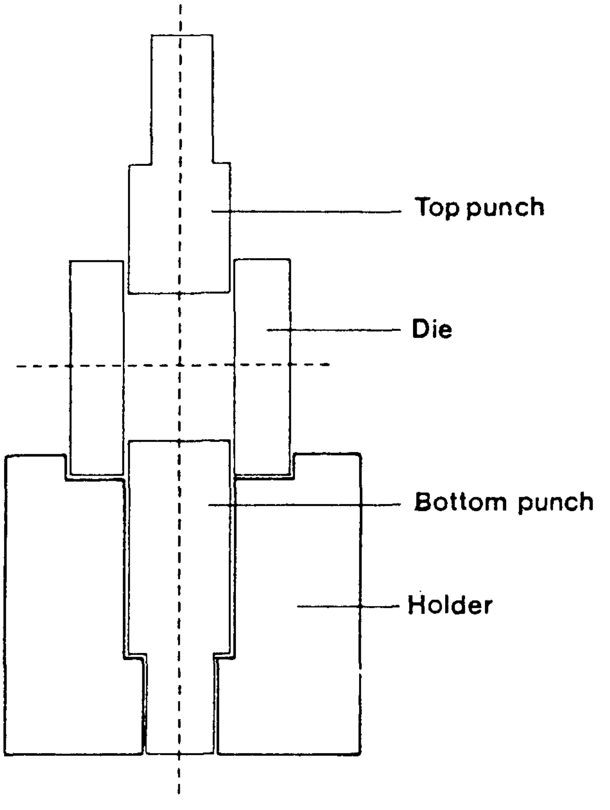

FIGURE 1a

The Punch and Die Assembly.

from the load cell and displacement transducer. These outputs can be connected to external equipment such as chart recorders and data logging apparatus.

PUNCH AND DIE ASSEMBLY

This is shown sketched in Fig. 1a. The internal diameter was 2.54cm and the die wall and flat-faced punches were chrome plated. A known weight of material usually 8g, was poured into the die, and the top punch inserted. In the case of Emdex and Encompress, the die was first lubricated by compressing a compact consisting of a mixture of the material + 50% Magnesium stearate (w/w). After this, compacts of unlubricated material were prepared.

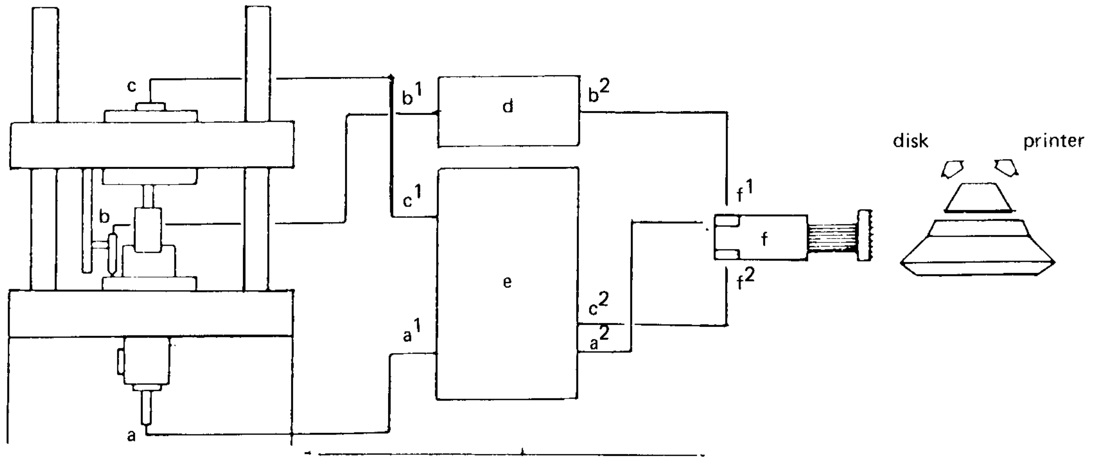

FIGURE 1b

Mayes Machine and Equipment Arrangement (Schematic)

a. Displacement Transducer
b. External Transducer
c. Load Cell
d. Transducer Meter
e. Mayes Machine Console
f. One or Two channel ADC
a', b' etc Connections to Console

TABLE I

Parameters Varied for the Different Bases

MATERIAL / PARAMETER	AVICEL pH 101	STA-RX 1500	PARACETAMOL DC	EMDEX	ENCOMPRESS
Max Load (kN)					
15	*	*			
30	*	*			
45	*	*			
Load Rate (kN/min) 5	*@	*@			
50	@	@			
500	*@	*@			
5000	*@	*@			
Holding Time(s) 0	*+	*+	*+	*+	*+
15	*	*	*	*	*
30	*+	*+	*+	*+	*+
45	*	*	*	*	*
60	*+	*+	*+	*+	*+

This procedure was necessary to prevent the material sticking to the die. In this study the behaviour of unlubricated material was investigated.

The assembly and its holder were placed between the platens of the press and a preload, (5% of final load) then applied. The maximum compression force and load rate were set on the console. A number of conditions and parameters could thus be defined and varied. These are summarised in Table I which also show which factors were varied for each of the individual direct compression bases. When all was ready, the pressing of a single control button set the compaction process in motion. The compact length was around 12.70 mm for most of the compacts.

GENERAL ARRANGEMENT

The press and ancillary equipment is shown in diagrammatic form in Fig. 1b. In addition to the transducers built into the press, a short range displacement transducer (Sangamo 2mm AC type) was attached to a magnetic stand held on the upper cresshead. This was set to register when the compacts had been completely formed and were held under a constant loading. It monitored the further small strain movements which occurred during this holding time. These were always less than 2mm. The output from this transducer was amplified by a Sangamo (Type C56) Transducer-meter and it was calibrated using a micrometer rig, incorporating a Shardlow instrument (0-0.25 mm travel, 6.5 cm drum).

COMPUTER LOGGING

Single Channel Logging

For these experiments, where only one parameter such as punch movement was required as a function of time, one channel sufficed. The general principles have been described by Travers and Webster (10) and logging during tablet compression by computer techniques has been used by Armstrong and Abourida (11) and Lammens and others (9).

An analogue voltage from the appropriate transducer was amplified if necessary and fed to a single channel ADC giving an output of 255 bits for a maximum input of 255 mv. This digitised input passed to the user port of a Model 4016 CBM microcomputer (32K). The operating program was partly written in machine code and data capture was up to 400 readings/s stored at memory location 8192 onwards. The interval time was calculated from two corresponding readings of the computer internal clock recorded at the start and finish of the data logging. All runs under given conditions were performed in duplicate.

Dual Channel Logging

This was used when concurrent values of punch displacement and compression force were required. Programming in BASIC was sufficiently rapid at circa 27 readings/s on each channel. A dual ADC was designed and constructed and data were switched into alternate memory locations by using the 'write' line to the computer second cassette as a programmable switch (12).

Adjacent bytes then contained corresponding data on force and displacement. Since these data were latched almost simultaneously by the dual ADC before acceptance by the microcomputer, they were separated in time by a short period of about 15 μs.

Sequential data files were coded under file names such as AAVUE30F11 when transfered to the floppy disc. This code denoted strain movements at constant stress (A) on Avicel (AV) which was unlubricated (U) and 8g compact weight (E). Compression force was 30kN (3) with no (0) recompression. Load rate was 5000 kN/min (F) and 15s holding time (1). It was the first (1) of the two determinations made under the same conditions.

If data on this run was required for subsequent inspection, the file could easily be identified, read into memory and processed.

RESULTS AND DISCUSSION

When a compact has been formed in the die the application of a constant stress during the holding period will cause further strain movements as the compact consolidates by viscoelastic and plastic flow. When the stress is removed the compact will recover some of this movement. Sharmat (13) using the Mayes

Machine, obtained plots of the type shown schematically in Fig. 2 by feeding the analogue output from the ram displacement transducer to a chart recorder set to 'cut in' when the maximum compression force was attained.

This technique had certain drawbacks. It was difficult to judge the exact point when a constant loading had been attained (point A) and the sudden elastic expansion on load release (B → C) was too rapid to be examined in detail. In the present work these difficulties have been largely resolved by computer logging of data.

Strain Movements At Constant Stress (A → B Fig. 2)

In order to determine the point of maximum compaction force, the two input switching method was used to simultaneously record both compression force and punch movement during the initial compression.

The time at which the load inputs just reached a maximum and constant bit value was taken as the starting point of the constant load period, (point A in Fig. 2). The great advantage of computer logging was that it enabled this point to be more accurately located than could be done using a chart recorder or similar apparatus

When the compression force become 'steady' ie had reached this value, it was held for a predetermined period measured in seconds. The slow BASIC program was adequate to record these strain movements at constant stress. The computer could be programmed to cease logging at the end of this period but only at the expense of a slower logging rate. In practice the holding time was terminated manually.

The two bases which showed most time dependent movement were Avicel and Sta-Rx (Fig 3 region 1) and these are known to be time dependent plastic bases (3).

If the compression force was increased then this viscoelastic movement was less. Sixsmith (14) and Marshall and Sixsmith (15) have reported that Avicel compacts become more plastic at high compaction pressures and this would appear from our results to be accompanied by a decrease in viscoelastic movement.

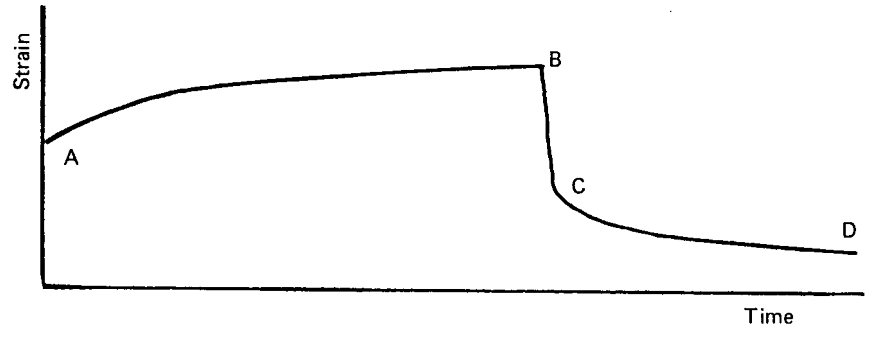

FIGURE 2

Strain Movements at Constant Stress and Relaxation on Load Release (Schematic).

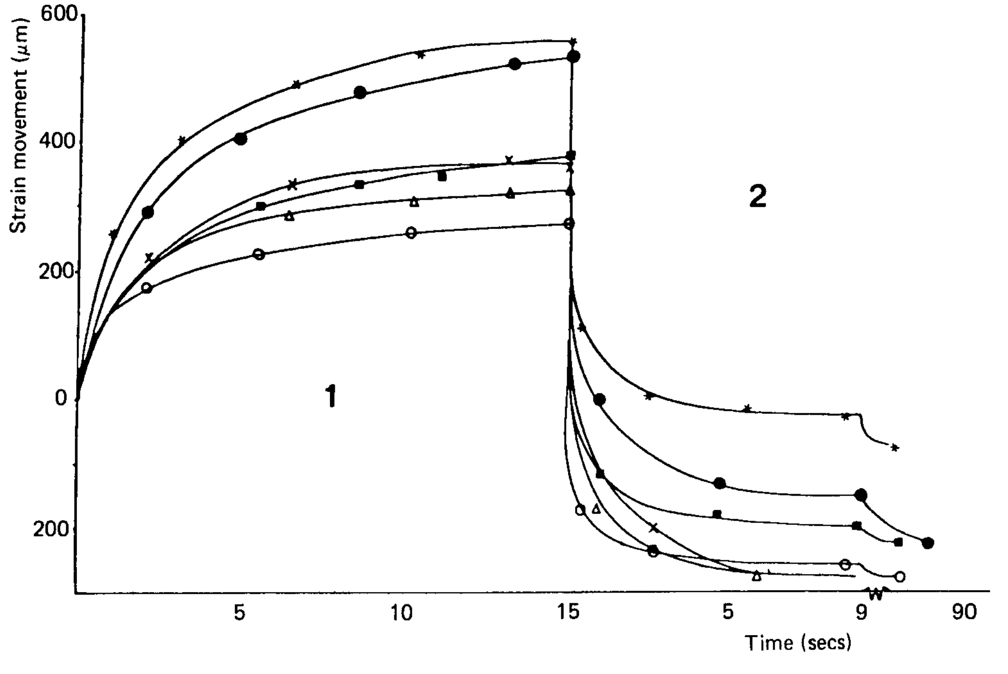

FIGURE 3

Strain Movements at Constant Stress and Recovery of Avicel and Sta-Rx Compacts.

(8gram compacts prepared at load rate of 5000kN/min)

Key (Base, Final Compression Force)

* Avicel, 15kN: ● Sta-Rx, 15kN: x Sta-Rx, 30kN

■ Avicel, 30kN: △ Sta-Rx, 45kN: o Avicel, 45kN

The strain movements increased more slowly as time progressed and their form, as shown in Fig. 3 is similar to that obtained by Shammat for the same bases (13).

The results for all the bases are summarised in Table 2 (←A→)for holding times as given. They are expressed as mm movement for the whole compact and also as µm per g.wt. of compact and µm per cm length of ejected compacts. The values were very small for Emcompress compacts confirming the observation of Rees and Rue (3) that this base does not exhibit time dependent effects to any appreciable extent. Avicel, Sta-Rx and Paracetamol DC compacts showed large strain movements.

Rapid Compact Expansion On Load Release (B → C Fig. 2)

Shammat (13) estimated from his work on these direct compression bases that this expansion took place in about 0.1s and was therefore

TABLE 2

Effect of Holding Time on Strain Movements and Elastic and Viscoelastic Recovery. (Maximum Compression Load was 30kN applied at 5000kN/min).

	A				B				
	STRAIN MOVEMENTS (µm)				ELASTIC & VISCOEL RECOVERY (µm)				
Holding Time(s)→ Material↓	15	30	45	60	0	15	30	45	60
AVICEL pH101	375	394	406	437	669	610	614	567	590
µm/g	46.2	48.6	50.2	53.9	82.5	75.3	75.7	70	72.9
µm/cm	28.6	29.5	31.4	33.9	34.3	49.2	46	44	45.8
STA-RX 1500	378	480	441	504	980	750	665	630	618
µm/g	48.6	61.5	56.5	64.6	124	96.4	85.2	81	79.3
µm/cm	30.2	38.1	35.1	40.3	76	60	52.8	50.1	49.5
PARACETAMOL DC	121	175	176	144	383	379	364	348	363
µm/g	18.5	26.9	27	22.1	58.9	58.2	56	53.6	55
µm/cm	9.5	13.8	13.8	11.3	30	29.8	28.6	27.4	28
EMDEX	121	133	125	128	298	286	270	266	270
µm/g	15.5	17	16.1	16.5	38.2	36.8	34.8	34.4	34.4
µm/cm	9.4	10.3	9.8	10	23.4	22.3	21	20.8	21
EMCOMPRESS	47	55	58	51	266	255	258	251	247
µm/g	4.2	5	5.2	4.6	24.2	23.1	23.5	22.8	22.4
µm/cm	3.6	4.3	4.5	3.9	20.8	19.8	20	19.2	19.2

TABLE 3

Fall of Load on Pressure Release (8g compacts of stated base in die)

	LOAD (kN)					
Time(s)	Blank	Avicel	Sta-Rx	Paracetamol DC	Emdex	Emcompress
0.000	30.31	30.31	30.31	30.31	30.31	30.31
0.037	11.73	11.92	10.55	12.31	12.71	11.34
0.074	4.69	5.08	4.49	4.88	5.27	4.65
0.111	2.34	2.93	2.54	2.73	2.73	2.73
0.148	1.95	2.15	1.95	1.95	1.95	1.95

virtually an instantaenous elastic recovery, but he was unable to examine it in detail. In the present study the data were logged using the fast machine code program over a period of 90ms from the release of load.

It is obvious that no machine is able to release its load instantaneously, but as shown by the results given in Table 3 the load fell to around 10% of its initial value in about 111ms and this rate was the same regardless of the compact present in the die.Values in Table 3 were obtained using the slow BASIC program so the time intervals were rather long (37ms), but the trend is quite clear.

Data of the recovery on load release are given in figures 4a and 4b. At 90ms the compacts were still under appreciable loading so expansion was not taking place under zero load conditions. The computer could not resolve punch movements less than 8 m (≅1 bit) so there is some uncertainty in the points as plotted. However it was evident that for a period of about 12ms after load release the points fell along a single line indicating that this was due to machine characteristics and/or punch expansion and not to any property of the compacts themselves.

After this period the plots diverged quite markedly suggesting that though the compact were still under load, the plots now represented the rapid expansion of the materials. If the initial period of 12 ms was disregarded, the remaining section of the plots could be fitted quite well by two or three straight lines

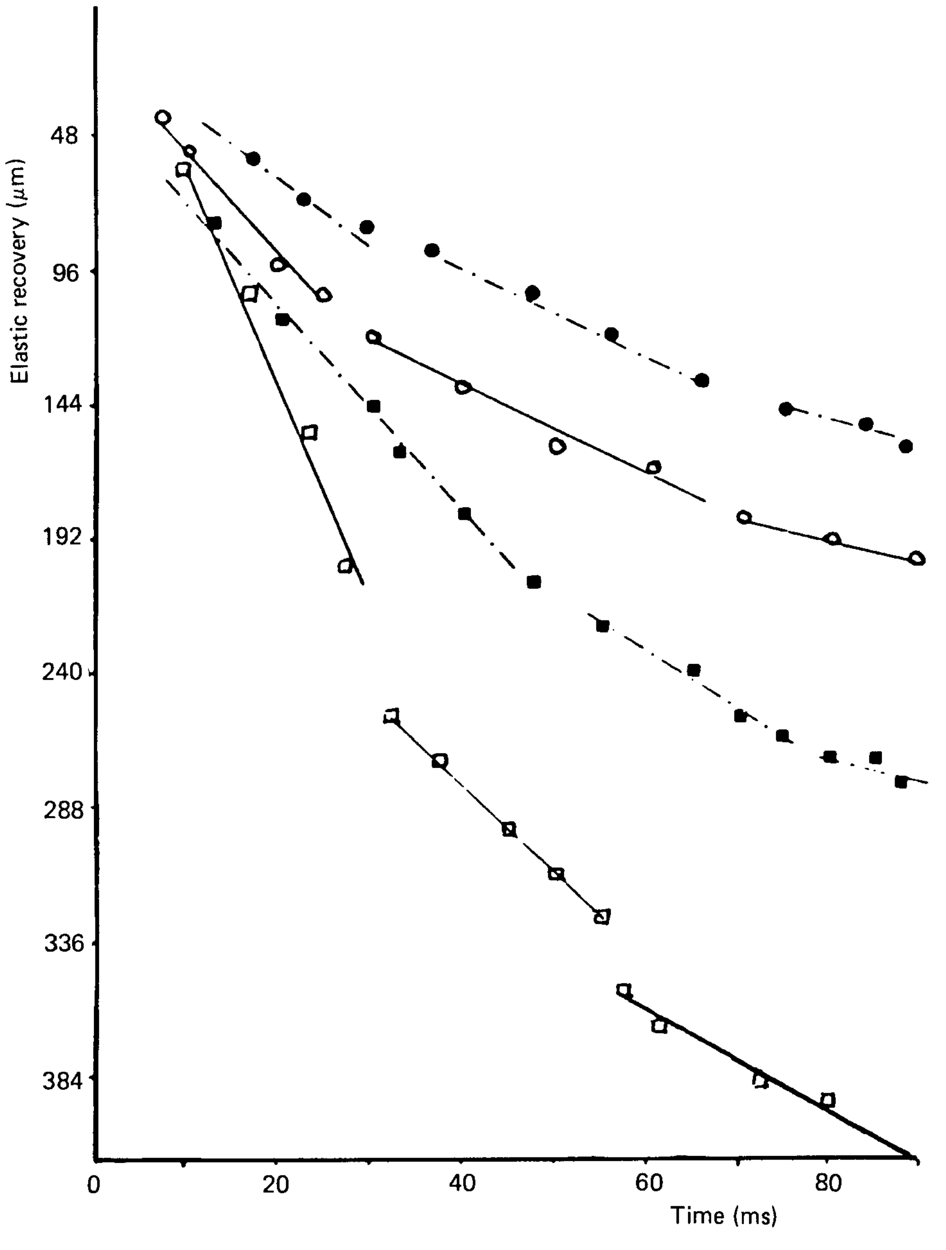

FIGURE 4a

The Effect of Holding Time on Elastic Recovery

Key

■ Avicel and ● Emcompress for zero holding time

□ ○ Same bases for holding time of 30s

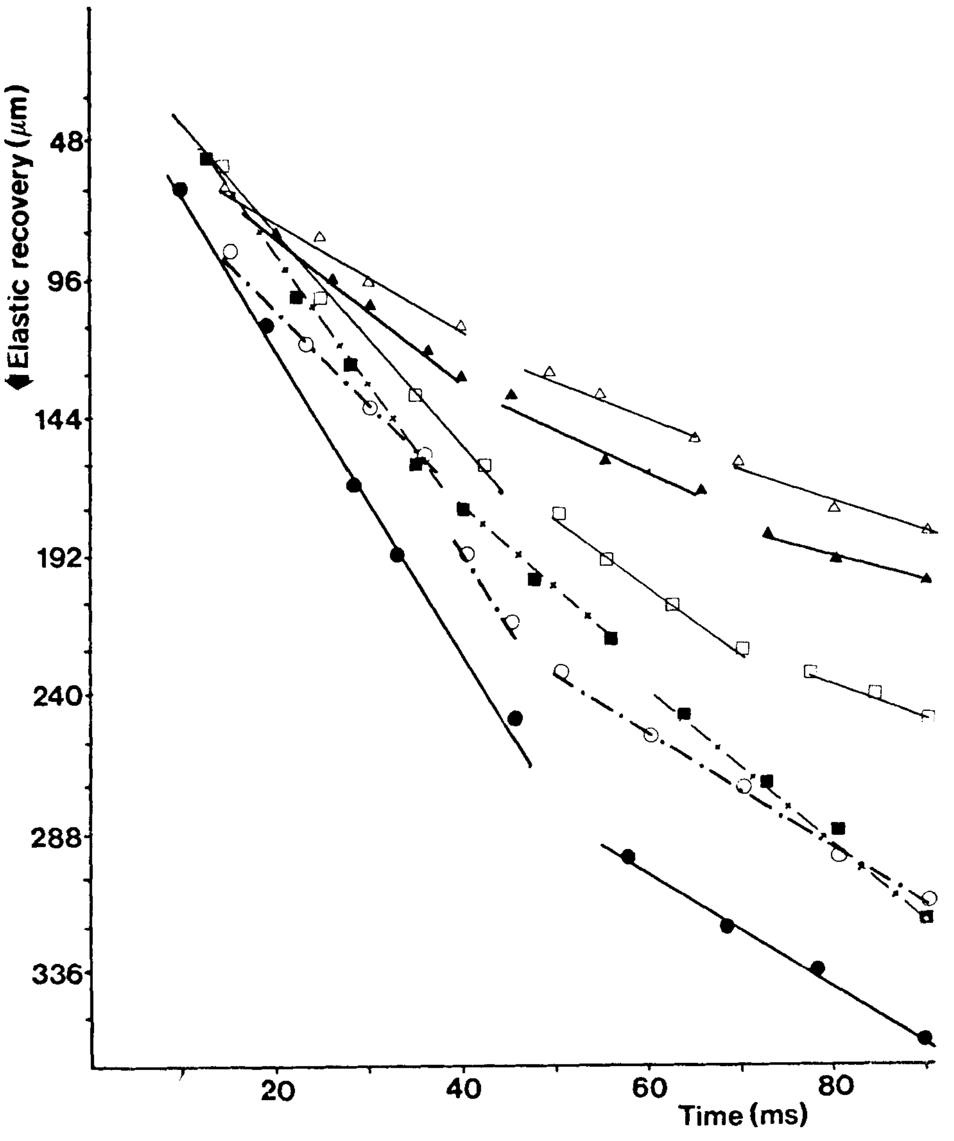

FIGURE 4b

The Effect of Holding Time on Elastic Recovery

Key

● Paracetamol DC ■ Sta-Rx and ▲ Emdex all for zero holding time

○ , □ and △ are same bases for holding time of 30s.

suggesting that a number of separate rate constants were involved in the expansion. Hiestand and others (4) and Rees and Rue (3) arrived at a similar conclusion that stress decay under load would also require the assumption of a number of rate constants in order to fit their data.

An interesting feature of the plots was their dependency on the holding time. If this time was set as low as possible ($<$ 1s) then the expansion was always greater then was the case if the time was 30 or 60s. It is well established that a high 'dwell time' (16) usually yields better tablets. The results shown in Fig. 4a indicate that consolidation under constant stress allows some conversion of elastic energy into viscoelastic and plastic movement with less sudden expansion on release of the compression force and a lesser tendency to lamination.

There was no great advantage in prolonging the holding time since the expansion was almost as great at 60s as it was for 30s holding time. In the interest of clarity, points for 60s holding time have been omitted from Fig 4a and 4b. Sta-Rx and Avicel both exhibited a high degree of elastic recovery from which it can be deduced that their good tabletting properties are not affected by the stresses which may be set up by this expansion. Travers and Cox (17) found that compacts of these materials were very resistant to the shear stresses induced when they were loaded in free axial compression after removal from the die. They therefore may be inherently resistant to internal stress set up when they expand.

Paracetamol DC forms a brittle compact (17,18). It also shows considerable expansion (Fig. 4b). Tablets of this material are notorious for their tendency to lamination, especially if they are compressed quickly. It will be noted (Fig. 4b) , that the expansion was sensitive to holding time and this explains why slow compression is advantagous.

Emcompress and Emdex both form compacts which are weak in shear when they are loaded axially in the free state (17). Consequently, they should be prone to lamination, but as can be seen from figures 4a and 4b they have a low elastic movement which may compensate for this. We would also predict, since their expansion is not so dependent on holding time, that increasing the speed of compression would not be detrimental.

Combined Elastic And Viscoelastic Recovery

Data points for these are combined in Fig. 3 region 2 (Sta-Rx and Avicel) and in Table 2 (← B →) for all the bases examined.

It is difficult from an examination of Fig.3 to separate the rapid elastic recovery from the much slower viscoelastic movement. There are changes of slope in Fig. 4a and 4b for all materials but it is not possible to state with any certainty that any of the lines represent pure elastic recovery. From Fig. 3 it would appear that the start of the viscoelastic period certainly lay between 0.1 and 0.2s from release of load in agreement with the observations of Shammat (13). The end of the elastic period was taken in this work as 0.1s from the release of load, but more detailed analysis of Fig. 4a and 4b may well enable a more accurate demarcation to be ascertained, though there must be a transition period between elastic and viscoelastic movement.

It can be seen from Fig. 3 that viscoelastic recovery measured from 0.1s after load release, was greater at zero or low holding time for Avicel and Sta-Rx. These slow movements are less likely to cause lamination than those due to elastic recovery, but they may contribute to it and they will be decreased by long dwell times in tabletting practice.

Force V Displacement Plots

The Mayes machine can yield data for these plots directly from its internal transducers, though compression times were rather long when compressing the large compacts made in the present study.

Plots for Avicel and Sta-Rx are shown in Fig. 5. The points are mean values from five determinations under the stated conditions There was some variation especially for Avicel compacts which we believe arose from the difficulty of ensuring uniform packing of the powder prior to compaction. Hersey and Rees (19) have shown that Heckel plots (20), which are plots of a function of a

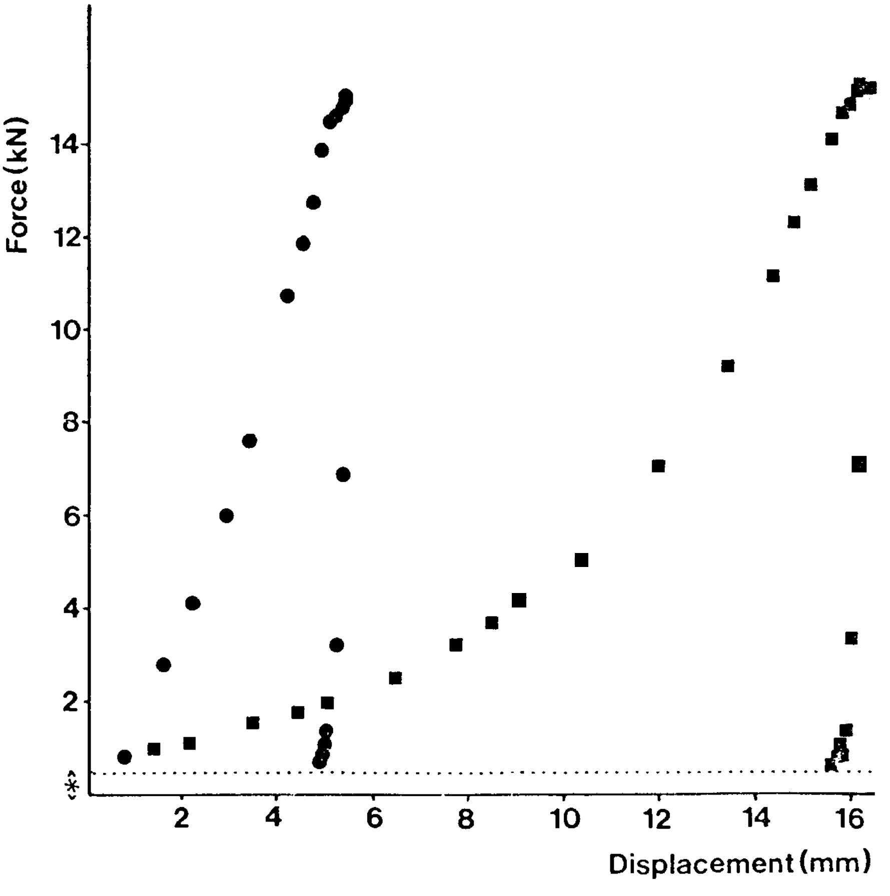

FIGURE 5

Force v Punch Displacement Plots for Avicel ■ and Sta-Rx ●

* Indicates Preload:

8g of Base was taken: Each point is mean of five determinations at 5000 kN/min load rate.

tablet density v compaction pressure, can vary greatly if the initial bed density varies prior to compaction and we observed that the thickness of Avicel compacts did in fact differ from run to run.

The area under the force - displacement plots for Avicel and Sta-Rx did not alter appreciably with rate of load application.

TABLE 4

Force v Punch Displacement Data up to Attainment of Maximum Load (at 5000 kN/min)

Sta-Rx				Avicel			
Time(s)	Force kN	Force Bit Value	Punch Displ. mm	Time(s)	Force kN	Force Bit Value	Punch Displ. mm
0	0.59	3	0.000	0	0.59	3	0.000
0.225	6.06	31	2.902	0.225	1.37	7	2.902
0.636	14.47	74	5.176	0.636	5.08	26	10.431
0.711	14.67	75	5.255	0.711	6.45	33	11.529
0.823	14.86	76	5.333	0.823	8.41	43	13.020
1.085	15.06	77	5.412	1.085	12.71	65	15.059
1.117	15.06	77	5.490	1.117	13.10	67	15.294
1.154	15.06	77	5.569	1.154	13.49	69	15.373
1.339	15.06	77	5.632	1.339	14.47	74	15.765
				1.413	14.67	75	15.843
				1.562	14.86	76	16.000
				1.897	15.06	77	16.157
				1.934	15.06	77	16.235
				1.971	15.06	77	16.314
				2.008	15.06	77	16.314

However as these materials were very compressible and present in a large quantity (8g), it took about 1s (Sta-Rx) or 2s (Avicel) to attain the maximum load of 15 kN at the fastest load rate. This is longer than would occur in practice and it may be that differences could be observed at faster compression rates. However, as shown in Table 4, 96% of the applied load was attained in half the total time of compression so the majority of the compaction was in fact more rapid.

CONCLUSION

The Mayes Machine used in conjunction with computer logging of data has been shown to be a convenient means of studying the compressional behaviour of compacts maintained at constant stress and their subsequent elastic recovery when the load is removed. Determining the extent of elastic recovery after different holding times may be useful practical test to predict the behaviour of granulates at high compression rates.

ACKNOWLEDGEMENTS

We wish to thank Sandoz Ltd, Istanbul, Turkey for the financial support of one of us (Metin Çelik) and Mr A J Larrad, Mr R Webster and Mr R B Coppel for their invaluable technical assistance.

REFERENCES

1. J.E. Rees & E. Shotton, J.Pharm. Pharmac., 22,17S (1970)
2. P.J. Rue & P.M.R. Barkworth, Int.J.Pharm.Tech. & Prod. Mfr., 1, 2 (1980).
3. J.E. Rees & P.J. Rue, J.Pharm. Pharmac., 50, 601 (1978).
4. E.N. Hiestand, J.E. Wells, C.B. Peot & J.F. Ochs, J. Pharm. Sci., 66, 510 (1977).
5. J.I. Wells & J.R. Langridge, Int. J.Pharm. Tech. & Prod. Mfr., 2, 1 (1981).
6. S. Shlanta & G. Milosowich, J.Pharm. Sci., 53, 562 (1964).
7. S. T. David & L.L. Augsburger, Ibid., 66, 155 (1977).
8. B.M. Hunter, D.G. Fisher, R.M. Pratt & R.C. Rowe, J.Pharm. Pharmac., 28, suppl. 65P (1976).
9. R.F. Lammens, J. Polderman & C.J. de Blaey, Int. J.Pharm. Tech. & Prod. Mfr., 1 (1979).
10. D.N. Travers & R. Webster, Manuf. Chemist., 13, 56 (1981).
11. N.A. Armstrong & N.M.A.H. Abourida, J.Pharm. Pharmac., 32, 86P (1980).
12. N. Hampshire, The PET revealed, Computabits Ltd., Yeovil, Somerset.
13. M. Shammat, M.Phil. Thesis (CNAA), Leicester Polytechnic (198
14. D. Sixsmith, Ph.D. Thesis, University of Bradford (1975).
15. K. Marshall & D. Sixsmith, J.Pharm. Pharmac., 28, 770 (1976).
16. T.M. Jones, Act.Pharm. Tech., 6, 141 (1978).

17. D.N. Travers & M. Cox, Drug Dev. and Ind. Pharm., 4, 157 (1978)

18. B.A. Obiorah & E. Shotton, J.Pharm. Pharmac., 28, 629 (1971)

19. J.A. Hersey & J.E. Rees, in "Particle Size Analysis", Eds. M.J. Groves & J.L. Wyatt-Sargent, Society for Analyt. Chem., London (1970).

20. R.W. Heckel, Trans. Metall. Soc., A.I.M.E., 221, 671 (1961).