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DEPENDENCE OF COMPRESSION PHASE ON ELASTICITY OF THE MATERIAL

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SUMMARY

It is shown that the Pmax value obtained during the tabletting process is statistically independent of machine motor velocity.

To explain this phenomenon, an analogic model composed of a spring and two or three Maxwell bodies grouped in parallel was used to represent the behaviour of powders during compaction. It was observed that during the compression phase, the recorded force may be represented by the response given by the set of springs alone.

The shock absorbers intervene just before and after the Pmax, when the upper punch velocity is very low or nil.

It was possible to obtain these results after determining the law representing elasticity in relation to the deformation applied to the powders.

The consequences of these phenomena are discussed.

INTRODUCTION

Stress relaxation measurements show that pharmaceutical powders behave like visco-elastic materials. In previous reports (1,2), it was possible to classify these materials according to their degree of plasticity.

Likewise, in other studies (3,4) undertaken to examine globally the mechanisms involved in tablet formation under normal production conditions, two constants, Kp and Kr, were calculated after linearizing data representing the compression and decompression phases of the same materials. These constants again indicated the same plasticity classification as before.

Since it may be considered that the second Kr constant defined during the decompression phase mainly depends on the degree of plasticity of the material for the maximal displacement applied (Dmax), it was hypothesized that the first Kp constant could represent its degree of elasticity .

The purpose of this study was to examine this assumption during the tabletting process , i.e., do pharmaceutical powders behave like a set of springs alone during the compression phase?

As the stiffness of a spring does not depend on deformation speed, we studied the influence of the rotational speed of the machine motor on maximal force Pmax.

Moreover, we propose an equation for reproducing the compression force curve, P = f(t), in relation to time.

EXPERIMENTAL

1) MATERIALS TESTED

Tablets of acceptable hardness were prepared with:

- saccharose (sugar)
- AVICEL PH 101
- ENCOMPRESS
- Fast-flow lactose
- Micronized sodium chloride..

When a lubricant was necessary, we used 0.5% magnesium stearate.

2) APPARATUS AND OPERATING MODE

Tablets were made using an instrumented reciprocating tablet machine FROGERAIS, Type OA, equipped with two 12mm diameter punches and a speed-variator on the electric motor of the machine.

Data recorded in a MAURER Transitory memory were then stored in a microcomputer.

The data processing method has been described (3,5)

2-1) EXPERIMENTS PERFORMED UNDER NORMAL PRODUCTION CONDITIONS

Three different motor speeds were used.

V1 : normal working speed

V2 : intermediate working speed (V2= 5/6 * V1)

V3 : low working speed (V3 = 2/3 * V1).

V3 is the lowest speed at which the motor does not stop during the tabletting process..

As machine speed may influence tablet weight (6), we used products with a very good flow rate.

The die depth was 1cm.

2-2) EXPERIMENTS PERFORMED WITH VERY LOW SPEED DEFORMATION.

The aim here was to compare the above results with those obtained at a very low deformation speed.

In this case, the product underwent a nearly constant deformation speed, applied manually, according to a protocol previously described to conduct relaxation measurements (1).

Two die depths (6,8 and 8,85 mm) and two speeds of the lower punch (L.P.) displacement (0.2mm/sec. and 0.5 mm/sec.) were used.

The maximal force Pmax was noted as soon as the material underwent constant deformation.

Each experiment was repeated five times.

3)RESULTS AND DISCUSSION

3-1) INFLUENCE OF THE SPEED OF PUNCH DISPLACEMENT ON Pmax VALUES

Table I shows the results obtained under normal production conditions with the mixture of crystalized saccharose (particles < 500 μm) and magnesium stearate.

For each experiment, we noted :

- the Pmax;
- the upper punch (U.P.) speed corresponding to the first measured value of force (initial speed);
- the compression time, i.e., the time between the first value of force and the first value of Dmax;

TABLE I : Influence of punch speed on Pmax values and compression-relaxation times.

MATERIAL	SACCHAROSE + 0.5% Magnesium stearate		
MACHINE MOTOR SPEED	NORMAL WORKING V1	INTERMEDIATE V2	LOW V3
Pmax Newt.	20549 ± 637	20863 ± 946	20486 ± 836
INIT. SPEED µm/ms	81.3 ± 9.1	68.1 ± 5.6	57.2 ± 10.5
COMPRESSION TIME ms.	69.3 ± 5.3	91.9 ± 11.0	105.1 ± 13.7
COMP-RELAXAT TIME ms	88.8 ± 5.9	113.5 ± 8.0	139.7 ± 14.5
AVERAGE TABLET WEIGHT g	1.052 ± 0.006	1.058 ± 0.005	1.055 ± 0.005

(*) n=5 trials

- the compression-relaxation time, which is the sum of the compression time and the Dmax plateau time;
- the average tablet weight;

When the motor speed decreases, it may be seen that:

- the initial speed of the U.P. decreases;
- the compression time and the compression-relaxation time increase;
- Pmax values and the average tablet weight are not statistically different ($p<0.05$).

Under these experimental conditions, Pmax values are independent on motor speed.

These results have already been observed by some manufacturers using a rotary tabletting machine equipped with strain-gauged upper and lower punches.

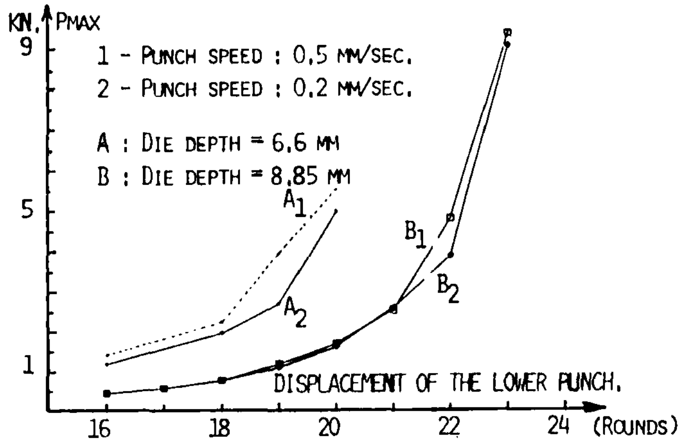

Fig. 1 : Variations of maximal force Pmax in relation to L.P. displacement, L.P. speed and die depth (a round = 0.345 mm)

Moreover, these experiments show that under normal production conditions, the saccharose mixture behaves like a set of springs.

The same was not true when a low deformation speed was used. Figure 1, obtained with AVICEL PH 101, shows that for the same punch displacement (expressed here by the *number of revolutions of* the crank) , the highest Pmax is obtained with the highest speed and the lowest die depth ($p<0.05$).

Under these conditions, when the time *of* the compression phase increases, the measured force decreases. It may be considered that during compaction, powders behaves like a set of springs together with dissipating elements like shock-absorbers.

In a previous work (1), a similar model was proposed to represent the powder's behaviour during stress relaxation measurements, when a constant deformation is applied.

Likewise, this model may be accepted to represent the compression phase. However, in this case, it seems that the shock-absorbers act as force-dissipators when deformation speed is very low or nil.

During the compression phase and under normal production conditions, the U.P. speed is very low just before the maximal displacement Dmax.

Why did this phenomenon not modify Pmax values?

For this reason, we checked whether powders behave like a set of springs alone during the tabletting process.

3-2) DEFORMATION-ELASTICITY RELATIONSHIP OF PHARMACEUTICAL POWDERS DURING STRESS RELAXATION EXPERIMENTS.

The aim of this investigation was to determine the deformation-elasticity relationship under these experimental conditions, and then to transpose these results to "dynamic conditions".

After a stress relaxation measurement (1), it is possible to consider that the residual force Pr obtained after 40 seconds represents the resistance offered by the elastic component of the material.

Likewise, this force represents the resistance of the spring using a Wischert model (1).

The residual force Pr depends on the elasticity of the material and the deformation applied ; it may be written as follows :

$$Pr = K * D \qquad \text{(eq. 1)}$$

K being a coefficient depending on Young's modulus and on the shape of the tablet. D is the L.P. displacement applied.

During a series of experiments performed with AVICEL PH 101 and a die depth of 10 mm, Pr was studied in relation to the L.P. displacement D.

The operating mode has been described (1), but here the same powder mass underwent deformation several times, with an interval of 10 min. between each crank revolution.

In these conditions, after each deformation, the relaxation of the material had enough time to occur completly . Therefore, Pr was perfectly representative of the elastic component.

Table II shows the residual force in relation to the number of revolutions of the crank measured during an experiment.This number N of revolutions is proportional to the displacement D applied (1).

TABLE II: residual force Pr during stress relaxation measurements in relation do the number of revolutions of the crank.

NUMBER OF REVOLUTIONS OF THE CRANK N	RESIDUAL FORCE Pr Newtons
12	247
13	302
14	416
15	580
16	949
17	1600
18	2055
19	3686
20	4666
21	6431
22	10902

Figure II shows that the coefficient K of equation 1 (K = Pr/D or K= f(Pr/N)) in relation to the number N of revolutions of the crank follows an exponential law.

hence

$$K = A * EXP(B * N) \quad \text{(eq. 2)}$$

with

$A = 0.322$

$B = 0.329$

and R2 which estimates the correlation

$R2 = 0.990$

The residual elasticity of a material is an exponential function of the deformation applied or of the punch displacement.

3-3) FORCE-ELASTICITY RELATIONSHIP DURING COMPACTION PROCESS IN DYNAMIC CONDITIONS

As Pmax is statistically independent of motor speed and powders behave like a set of springs alone,

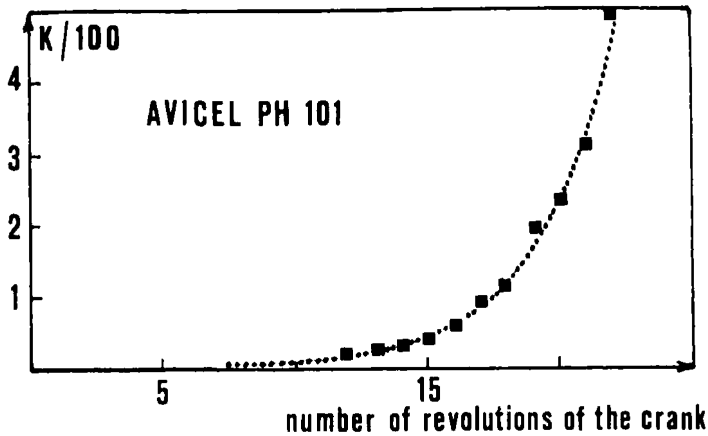

Fig 2: Variations of K in relation to the number of revolutions of the crank.

the transposition of the above results gives the following equation:

$$Pt = D(T)t * A1 * EXP (B1 * D(T)t) \quad \text{(eq. 3)}$$

Pt and D(T)t respectively being the U.P. force and the U.P. displacement measured at time t, and A1 and B1 being two constants.

The function curve describing the U.P. displacement of an eccentric tabletting machine in relation to time is well known to be a sinusoïd (7,8).Only the lower part of this curve intervenes during the compression phase.

Since this curve is dissymetrical with respect to the Dmax "plateau" (5,7), a good approximation of the ascending phase of the punch displacement is given by the equation of a parabola (5).

D(T)t at time t may be written as follows:

$$D(T)t = at2 + bt + c \quad \text{(eq. 4)}$$

Since the elasticity during powder packing is nil and as the material would behave like a set of springs

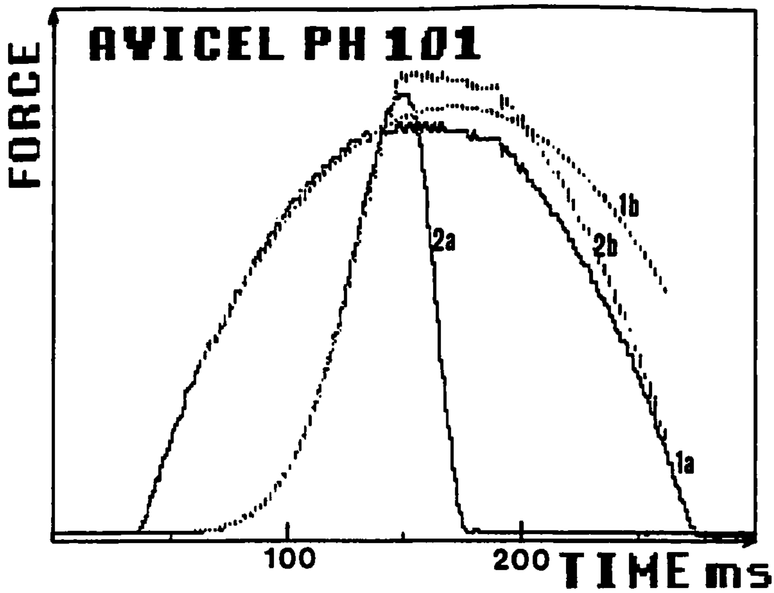

FIG.3 : FORCE AND DISPLACEMENT IN RELATION TO TIME (Avicel PH 101)
1a and 2a : experimental curves
1b and 2b : calculated curves.

alone during the compression phase, equation 4 may be simplified.

$$D(T)t = at2 + bt \qquad (eq.\ 5)$$

Equation 3 may be as follows:

$$Pt = D(T)t * A1 * EXP\ (B1 * (at2 + bt)) \qquad (eq.\ 6)$$

Figures 3 to 6 both represent the force measured during the compaction of various materials as a function of time (full line) and the corresponding force calculated by the means of equation 6 (dotted line).

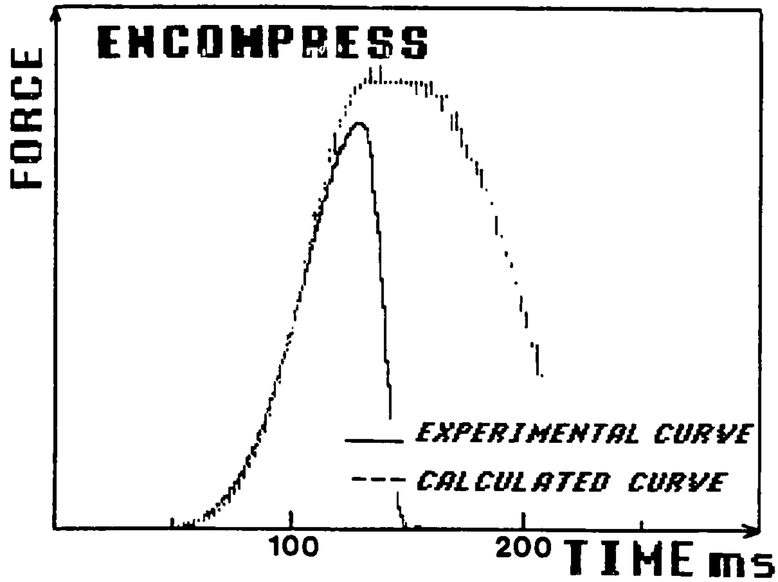

FIG.4 : FORCE IN RELATION TO TIME (Encompress).

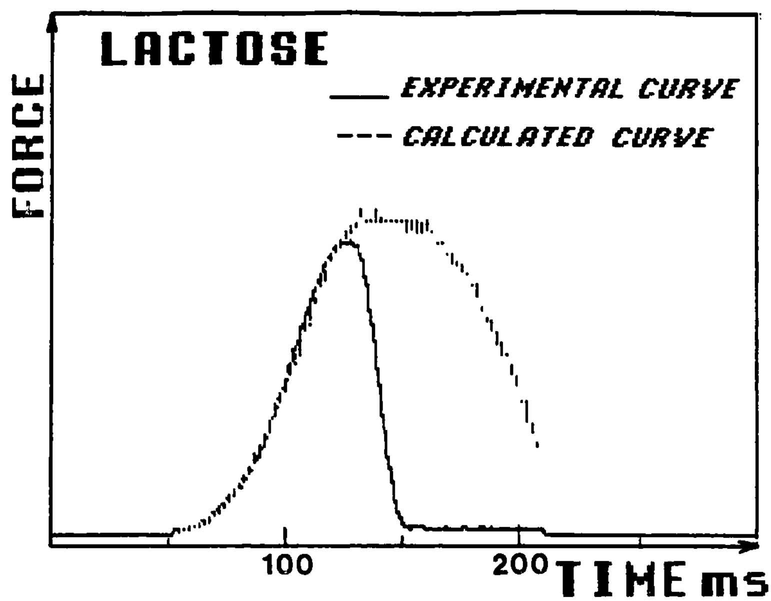

FIG.5 : FORCE IN RELATION TO TIME (Lactose)

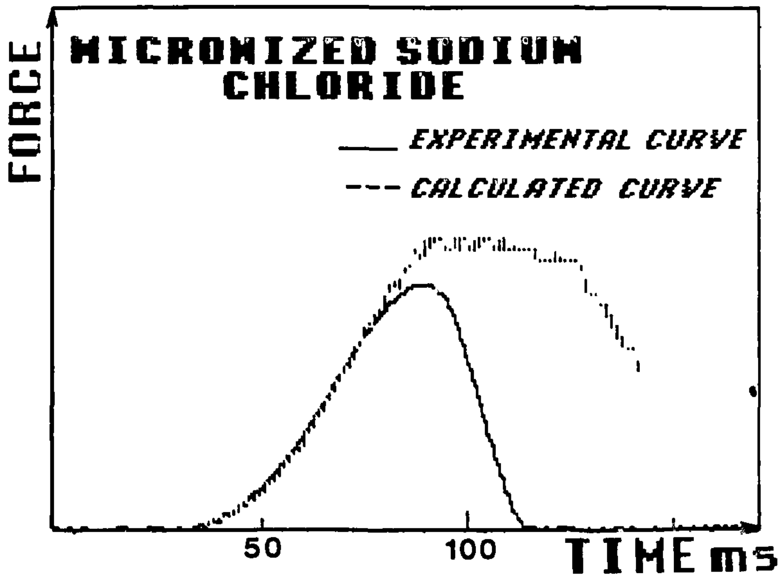

FIG.6 : FORCE IN RELATION TO TIME
(Micronized sodium chloride)

Figure 3 involves, in addition, the U.P. displacement and the theoretical displacement given by equation 5.

It may be seen that equation 6 may represent the force during the compression phase. The correlation coefficient obtained for the four products is always higher than 0.98 with more than 80 measurements.

In all cases, the calculated curve of the force and the experimental force are different only in their upper part, near the Dmax, where the punch speed is very low.

Likewise, it may be observed that the maximal magnitude of the calculated curve is slightly greater than the experimental curve. This phenomenon supposes that the tablet undergoes the beginning of stress relaxation just before the Dmax.

This work shows that Pmax and Dmax do not coincide in time, and explains the shift in time observed with some products in a previous study (5).

The calculated force after the Dmax represents the response in time which should be given by a spring whose elasticity is the same as that of the powder undergoing a displacement Dmax.

CONCLUSIONS

In this study, it has been shown that during compaction, powders do not have the same behaviour when different speeds of deformation are applied.

Thus, for low speed deformation, powders behave like a set of springs and shock-absorbers, but like a set of springs alone for high speed deformation.

During the compaction of powders under normal production conditions, the speed of punch displacement decreases from around 100 mm/sec to zero (3,5) when the upper punch reaches Dmax. Therefore, powders first behave like a set of springs and then, near the Dmax, like a set of springs and shock-absorbers.

In another study (9), it was established that this transition occurs when the punch speed is lower than about 7mm/sec. for Avicel PH 101 and about 6mm/sec. for sorbitol.

In previous work (1) we proposed a Wischert model composed of two or three Maxwell bodies and a spring grouped in parallel for representing the behaviour of powders during stress relaxation measurements. In addition, it was shown that the time constant which characterizes the relaxation of each Maxwell body was of the ratio 1/10/1000, the smallest being around the second.

Since the compression time in normal production conditions is lower than 100 ms, and plastic flow only occurs when the punch speed is lower than about 7mm/sec., it may be expected that only one Maxwell body and a spring grouped in parallel would intervene during tabletting performed in dynamic conditions.

In a forthcoming work, this model wil be tested to reproduce the totality of the compression force in relation to time.

The present work shows that during the compression phase, energy supplied by the machine motor is first used to overcome die wall friction, elastic resistance and particle fragmentation when it occurs. Tablets only begin to retain energy near the Dmax when the punch speed is low, and this continues during the Dmax plateau time .

For this reason, DAVID and AUGSBUCHER (10) observed that microcristalline cellulose and compressible starch tablets are significantly stronger when the compression cycle is increased from 0.09 up to 10 sec., or when the flywheel of the rotary tablet machine is turned by hand at 0.5 rpm.

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