Rheological Properties of Grain Dust

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ABSTRACT

EXPERIMENTS were conducted to determine the rheological properties of grain dust collected from the dust control systems of commercial grain elevators. The moisture content of the dust samples ranged from 9 to 15%. Bulk densities of grain dust ranged from 180 to 350 kg/m³ at loose-fill conditions and from 400 to 660 kg/m³ at a pressure of 120 kPa. The compression creep and stress relaxation properties of grain dust can be described by Burger's model and the generalized Maxwell model represented by three Maxwell elements, respectively. A functional relationship expressing bulk density of grain dust as a function of pressure was obtained. The hysteresis loss of grain dust during loading and unloading cycles increased and the degree of elasticity decreased when moisture content increased.

INTRODUCTION

Regulations restrcting dust emission in grain elevators have forced operators to improve dust control. Problems associated with those regulations include handling, processing, and disposal of large quantities of dust collected from control systems. Open-air burning of collected grain dust is generally prohibited, spreading dust on cropland poses weed and insect problems, and returning dust to the grain stream is discouraged.

Many researchers have conducted studies on the utilization of grain dust as a fuel, soil conditioner, or feed. Grain dust can be pelleted and utilized as a feed ingredient in cattle, swine, and poultry rations (Behnke and Clark, 1979; Clark, 1978; Miller Publishing Co., 1979), burned under controlled conditions for heat (Chang et al., 1979), or converted by composting into an organic soil conditioner for use in greenhouses and by gardeners (Chang et al., 1981).

Utilization of grain dust is increasing. Because of this trend it is expected that large quantities of dust will need to be handled, transported, and stored. Grain dust is highly compressible. A knowledge of the compression characteristics and other rheological properties of grain dust is a prerequisite to the proper design of equipment for handling, transporting and storing dust. Rheological properties of biomaterials such as meat, forages, fruits, and grain have been reported by numerous investigators (Ashcroft and Kjelgaard, 1972; Fridley et al., 1968; Prasad and Gupta, 1973; Reidy and Heldman, 1972; Wright and Splinter, 1968; Zoerb and Hall, 1960). However, limited information on these properties of grain dust is available. The objectives of this investigation were to determine the pressure-density relationship and the compression creep and stress relaxation properties of grain dust at various moisture contents.

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THEORETICAL CONSIDERATIONS

Most biomaterials respond elastically and viscously when subjected to stress and strain. This mechanical behavior of biomaterials can be expressed by mechanical models consisting of springs and dashpots (Mohsenin, 1970).

Compression Creep

In compression creep, the material is instantaneously stressed to a specific load or pressure. Then while holding the load constant, the material deforms (creeps) as a function of time. Compression creep behavior of many biomaterials can be described by Burger's model (Mohsenin, 1970):

$$\epsilon(t) = \frac{\sigma_o}{E_o} + \frac{\sigma_o}{E_r}\left(1-e^{-t/T_r}\right) + \frac{\sigma_o t}{\eta_v} \quad [1]$$

where

$\varepsilon(t)$ = strain at time t
σ_o = applied constant stress
E_o = instantaneous modulus or modulus at time 0
E_r = retarded modulus
T_r = η/E_r = time of retardation
η and η_v = viscosity of dashpot

Equation [1] is based on the mechanical model shown in Fig. 1. The first term of the equation, σ_o/E_o, represents the strain due to elastic deformation. The second term indicates the degree of viscoelasticity of a material. The rate at which the retarded strain, σ_o/E_r, occurs is determined by the time of retardation T_r, which controls the general shape of the creep curve during the transition from elastic to viscous. The third term is a measure of viscous behavior of a material. The value of σ_o/η_v represents the slope of the creep curve after it has reached an apparent steady state.

When a bulk of grain dust is suddenly subjected to a stress σ_o, the material deforms an amount σ_o/E_o. Then creep begins, progressing first at a rapid rate and gradually slowing until it reaches steady-state. The time required to reach steady-state creep is controlled by T_r. The total strain at time, t, can be determined from equation [1]. The term $\sigma_o t/\eta_v$ in equation [1] represents permanent deformation in the material after the load is removed.

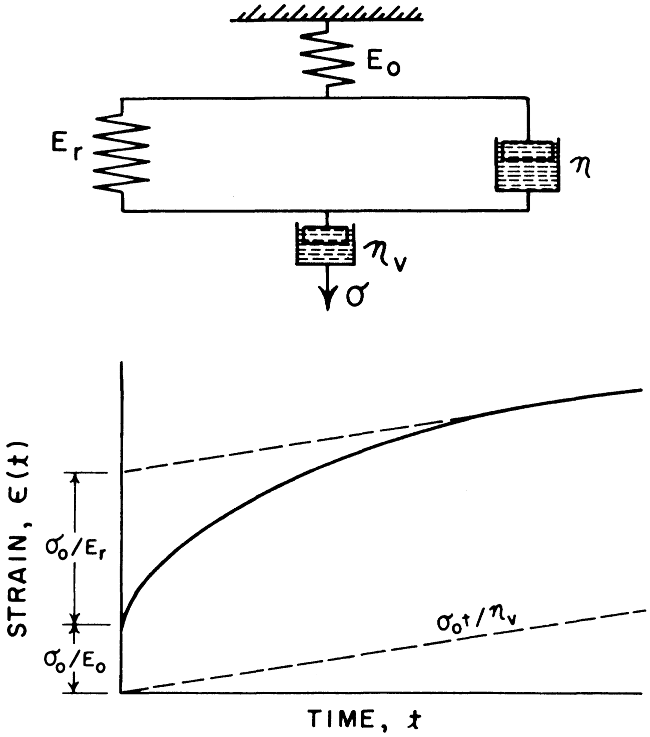

Fig. 1—Four-element Burger's model.

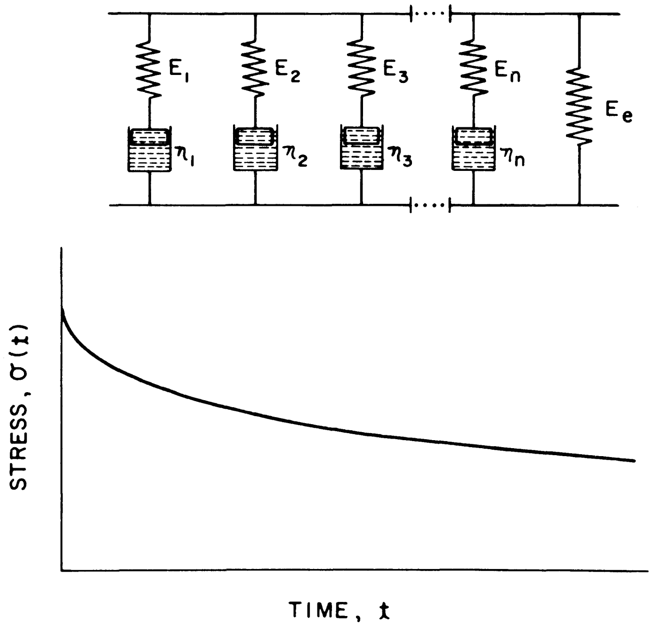

Fig. 2—Generalized Maxwell model.

Stress Relaxation

In the stress relaxation test, the material is instantaneously compressed to a given strain and the decay of stress is measured as a function of time. A representation for stress relaxation is the generalized Maxwell model constructed on n Maxwell elements in parallel and a spring element in parallel with the nth element (Fig. 2). As this general model is subjected to a constant strain, ε_o, at time t = 0, the stress in the model can be represented by the equation (Mohsenin, 1970):

$$\sigma(t) = \epsilon_o\left(E_1 e^{-t/T_1} + E_2 e^{-t/T_2} + \cdots + E_n e^{-t/T_n} + E_e\right). \quad [2]$$

where

$\sigma(t)$ = stress at time t
ε_o = constant strain
E_i = decay modulus associated with ith element, i = 1, 2, ...n
T_i = relaxation time corresponding to ith element, i = 1, 2, ...m
E_e = equilibrium modulus

The time of relaxatin is the time at which the stress in a simple Maxwell element decays to 1/e (about 37%) of its initial stress and is one of the most important parameters obtained from a stress relaxation test.

TABLE 1. MOISTURE CONTENT OF GRAIN DUST

	Moisture content, % w.b.				
Kind of grain dust	Low	Intermediate	High	When collected	Ash content, % d.b.
Wheat 1	9.0	12.1	14.5	9.0	7.6
Wheat 2	9.5	12.6	15.3	9.7	13.9
Sorghum 1	9.3	12.3	15.2	9.6	8.5
Sorghum 2	8.9	11.9	14.0	9.3	8.6
Corn 1	9.8	12.1	14.7	10.4	1.0
Corn 2	8.7	12.3	15.0	9.6	4.7

MATERIALS

Grain Dust

Grain dust is composed of solid particles that become airborne during grain handling. Dust control systems capture these airborne particles in moving air streams. Experiments were conducted with wheat dust, grain sorghum dust, and corn dust collected from the dust control system of commercial grain elevators in Kansas. Two test lots representing each kind of dust were collected from two different elevators. Commercial elevators are the major dust suppliers. Dust samples collected from their dust control systems were assumed to be representative. Three levels of moisture content (Table 1) ranging from 9 to 15% (w.b.) for each kind of dust were used for the determination of rheological properties.

Moisture content of dust was adjusted to desired levels by placing dust samples in a conditioning chamber at 30 °C and 85% RH for 4 to 48 h depending on the moisture content desired. Moisture content of the dust samples was determined by oven method (130 °C for 1 h). After desired moisture contents were obtained, samples were kept in sealed plastic bags. Tests were conducted in an air conditioned room about 22 °C.

Particle size distribution of grain dust (Table 2) was determined by sieving dust samples on a Fisher-Wheeler sieve shaker for 20 min using a set of U.S. standard sieves. The ash content (Table 1) of dust was determined

TABLE 2. PARTICLE SIZE DISTRIBUTION OF GRAIN DUST

	Particle size distribution, %				
Kind of grain dust	<125 μm	125-250 μm	250-500 μm	500-1000 μm	>1000 μm
Wheat 1	33.5	32.0	22.1	7.8	4.6
Wheat 2	33.9	17.5	17.9	16.3	14.4
Sorghum 1	67.6	13.2	9.0	5.8	4.4
Sorghum 2	77.8	6.8	3.8	4.4	7.2
Corn 1	87.7	6.4	3.2	1.9	0.8
Corn 2	80.9	4.8	3.3	4.9	6.1

Each value is the average of two samples.

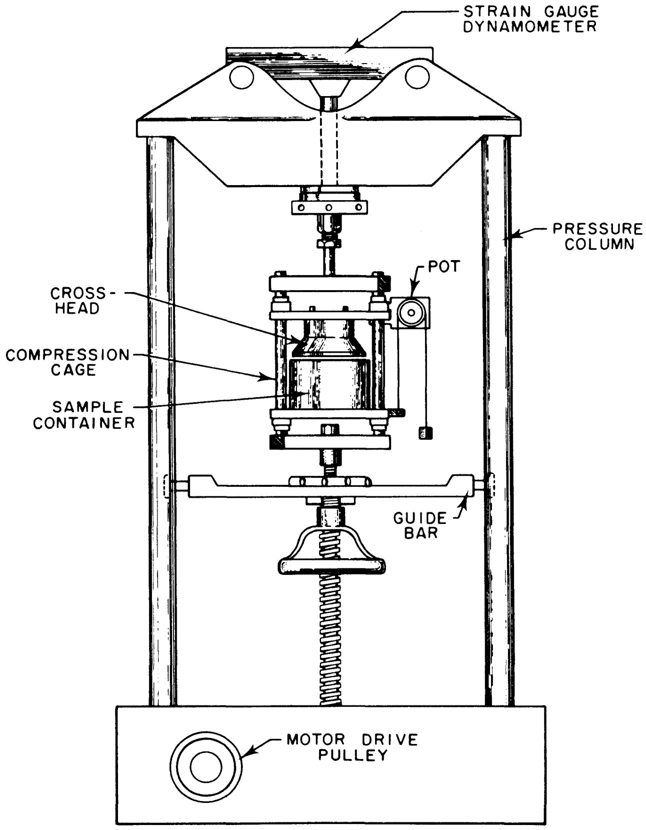

Fig. 3—Schematic of the Dillon Testing Machine.

by AACC method 08-01 (Am. Assoc. Cereal Chem. 1962).

Apparatus

A Dillon Testing Machine Model LWM (Fig. 3) was used to determine the stress-strain behavior of grain dust under slow loading. The device consisted of a compression cage, sample container with smooth inner surfaces (5.7 cm high by 9.5 cm diameter), moving crosshead, strain gauge dynamometer, and a rotary variable potentiometer (POT). The crosshead was driven by a reversible motor and its speed was adjustable by the selection of pulley assemblies. The compression pressure on the test sample was monitored by a strain gauge and the deformation of sample was measured by the POT.

Compression creep and stress relaxation properties of grain dust were determined by a compression machine (Fig. 4) constructed at the U.S. Grain Marketing Research Laboratory (USGMRL). The machine consisted of a moving crosshead, sample container with smooth inner surface (10.2 cm high by 10.2 cm diameter), load cell, POT, and dead weight. Both the crosshead and the bottom of the sample container were made of perforated steel plates with filter paper on one side to allow air to escape during compression. A dashpot, which was attached to the loading column, was used to control the speed of the crosshead during initial loading. The crosshead speed was adjusted to about 5 cm/s in order to reduce escape of dust through the clearance between the crosshead and sidewall of the sample container. The dead weight was adjustable so that a desired pressure could be applied to the sample during the compression creep measurements. An adjustable stop collar on the dead weight guiding rod was used to control the distance of crosshead movement or

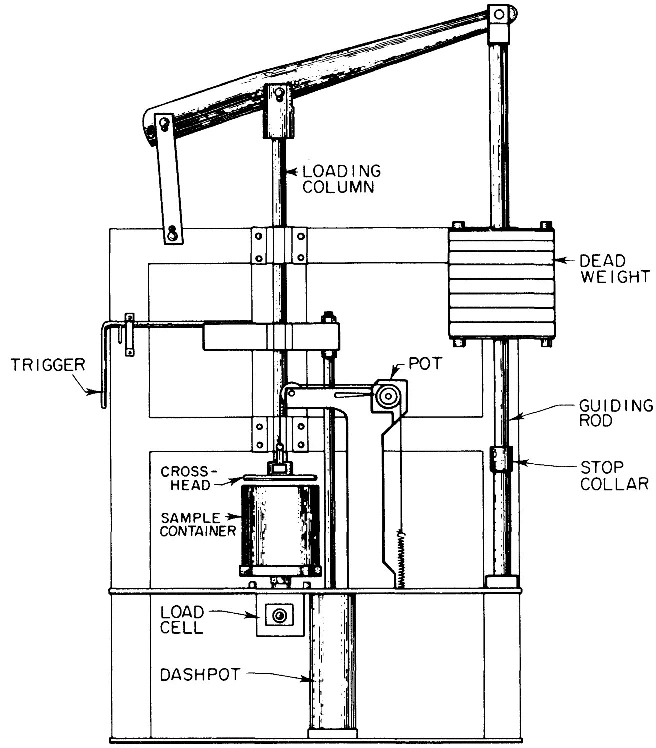

Fig. 4—Schematic of the compression machine constructed at the US Grain Marketing Research Laboratory.

the deformation of the test sample during stress relaxation measurements. The compression pressure, as measured by the load cell, and the deformation, as measured by POT, were simultaneously recorded on a strip chart recorder.

METHODS

Stress-Strain Behavior

For determination of stress-strain behavior under slow loading, the desired amount of grain dust was placed loosely and uniformly into the sample container of the Dillon machine (Fig. 3). The desired sample weight for each kind of dust was predetermined from the average of six samples (two samples for each moisture content) with the same sample filling procedure to fill the container full. During each loading cycle, the crosshead was first positioned at the top surface of the container (0 deformation) then moved at a constant speed of 3 mm/min (initial rate of strain 0.052 cm/cm·min) until a selected pressure of 120 kPa was applied to the sample. Following compression loading, the crosshead movement was immediately reversed and the unloading cycle allowed to proceed at the same speed. The pressure applied to the sample and the deformation of the sample were simultaneously recorded on an x-y recorded during loading and unloading cycles (Fig. 5). Each pressure-deformation curve was used to determine the pressure-density relationship and the degree of elasticity of grain dust as well as the hysteresis loss during loading and unloading cycles. The degree of elasticity was obtained from the ratio of the recovered deformation to the total deformation. The recovered deformation was measured immediately after the unloading cycle was completed. The hysteresis loss was obtained from the ratio of the energy loss in the process of loading and unloading to the total loading energy.

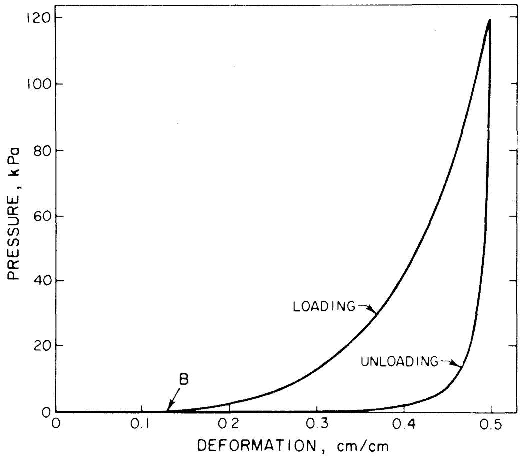

Fig. 5—A typical pressure-deformation curve for grain dust during loading and unloading cycles.

Compression Creep

For determination of compression creep properties, the desired amount of dust was uniformly placed into the sample container of the USGMRL compression machine (Fig. 4). A test was started when a constant load of 55 kPa was suddenly applied to the sample. While holding the load constant, movement of the crosshead or the deformation of the sample versus time was continuously recorded on a strip-chart recorder until the rate of change in strain was less than 0.001 cm/cm·min. It required about 10 min to complete a test.

Data points from each continous deformation curve were used in a non-linear regression computer program (Hartley, 1961) to determine the coefficients in Burger's model (equation [1]). For regression analysis, Burger's model was written in the form:

$$\epsilon(t) = C_1 + C_2 [1-\text{Exp}(-C_3 t)] + C_4 t \quad \ldots\ldots\ldots\ldots [3]$$

Each coefficient in equation [3] has a corresponding value in equation [1]. Thus, $C_1 = \sigma_o/E_o$, $C_2 = \sigma_o/E_r$, $C_3 = 1/T_r$, and $C_4 = \sigma_o/\eta_v$. In this experiment, the constant stress σ_o was predetermined to be 55 kPa. Thus, E_o, E_r, T_r, and η_v can be determined from C_1, C_2, C_3, and C_4, respectively.

Stress Relaxation

For determination of stress relaxation properties, the same procedure used in the compression creep tests was used to fill the dust sample container. A test was started when the sample was suddenly compressed to a given (constant) deformation. The amount of deformation was predetermined such that the initial compression pressure was about 50 to 60 kPa. Following compression, sample relaxation was measured while the crosshead was held stationary by the stop collar. The relaxation pressure or the pressure required to hold the deformation constant as a function of time was continuously recorded on a strip-chart recorder until the rate of change in relaxation pressure was less than 0.2 kPa/min. It required about 15 min to complete a test.

Data points from each continuous relaxation curve were used in a non-linear regression computer program to determine coefficients in the generalized Maxwell model (equation [2]). For regression analysis, equation [2] was written in the form:

$$\sigma(t) = C_1 e^{-tk_1} + C_2 e^{-tk_2} + \cdots + C_n e^{-tk_n} + \epsilon_o E_e \quad \ldots\ldots [4]$$

Each coefficient in equation [4] has a corresponding value in equation [2]. Thus, $C_i = \varepsilon_o E_i$, $k_i = 1/T_i$, where i = 1, 2, ...n. Since strain ε_o was predetermined for each test, E_i and T_i could be obtained from C_i and k_i, respectively.

RESULTS AND DISCUSSION

Stress-Strain Behavior

During slow compression from the starting point to point B (Fig. 5), the pressure required to compress dust was undetectable (<0.2 kPa) by the recorder. This initial stage of low pressure deformation was due to initial settling which may be caused by the presence of pores or air space and weak ruptured cells on the dust surface. During this stage of compression, depending on the kind of dust, bulk density increased 5 to 35% from the intial loose-fill conditions as shown in the last column of Table 3. Average bulk density of dust ranged from 177 to 354 kg/m^3 at loose-fill conditions and from 238 to 399 kg/m^3 at pressure near 0.2 kPa.

As compression proceeded past point B, the required pressure increased gradually then sharply. Data from each pressure-deformation curve during loading were used to obtain a functional relationship expressing bulk density of grain dust as a function of pressure by non-linear regression analysis (Fig. 6). Several forms of functional relationship were evaluated. The one which provided the best fitting of data is:

$$\rho = C_1 - C_2 \text{ Exp}(-C_3 P) + C_4 P \quad \ldots\ldots\ldots\ldots [5]$$

where

p = bulk density, kg/m^3

P = pressure, kPa

C_1, C_2, C_3 and C_4 are coefficients

Coefficients C_1, C_2, C_3, and C_4 for grain dust at various moisture contents are given in Table 4. Plotted curves of density versus pressure are shown in Figs. 7, 8, and 9. The correlation coefficients for the regression were 0.98 or higher with 15 degrees of freedom and the standard deviations ranged from 3 to 9 kg/m^3.

It is apparent from those density curves that bulk density of grain dust increased sharply when pressure increased from 0 to about 10 kPa. Increases in bulk density with pressure declined gradually and reached a constant when pressure increased from about 10 to 20 kPa. At pressure above 20 kPa, bulk density increased slowly but linearly with increasing pressure. At 120 kPa pressure, bulk densities ranged from 400 to 520 kg/m^3 for wheat dust, from 590 to 640 kg/m^3 for sorghum dust, and from 560 to 660 kg/m^3 for corn dust. Bulk densities of sorghum dust and corn dust were larger than those of wheat dust, probably because sorghum dust and corn dust contained a large portion of fine particles (Table 2). In general bulk density of grain dust is affected by its particle size distribution and ash content. A high content of fine particles (<125 μm) and ash would result in a higher bulk density and a high content of large particles (>1000 μm) or trash would result in a lower bulk density. At the same pressure, bulk densities of wheat dust and sorghum dust increased as the moisture content increased. Bulk density of corn dust was less affected by moisture as compared with wheat and sorghum dusts. At

TABLE 3. STRESS-STRAIN BEHAVIOR OF GRAIN DUST

Kind of grain dust	Level of moisture content*	Hysteresis loss, %	Degree of elasticity, %	Strain at 120 kPa, cm/cm	Bulk density at 120 kPa, kg/m^3	Bulk density at pressure less than 0.2 kPa kg/m^3
	Low	80	42	0.44	407	
Wheat 1	Intermediate	81	39	0.50	439	218-245
	High	84	31	0.55	457	
	Low	75	50	0.42	486	
Wheat 2	Intermediate	79	45	0.44	502	282-297
	High	82	40	0.47	520	
	Low	80	37	0.43	615	
Sorghum 1	Intermediate	80	29	0.44	632	354-380
	High	84	26	0.45	640	
	Low	74	37	0.51	591	
Sorghum 2	Intermediate	78	28	0.51	601	292-321
	High	78	26	0.52	607	
	Low	79	13	0.51	656	
Corn 1	Intermediate	79	13	0.49	648	333-399
	High	83	11	0.49	652	
	Low	69	36	0.70	583	
Corn 2	Intermediate	71	32	0.68	560	177-238
	High	72	24	0.69	575	

*See Table 1.

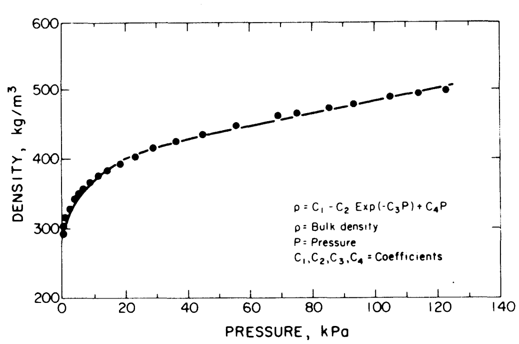

Fig. 6—A typical pressure-density curve for wheat dust.

TABLE 4. COEFFICIENTS FOR EQUATION EXPRESSING BULK DENSITY OF GRAIN DUST AS A FUNCTION OF PRESSURE.

Kind of dust	Level of moisture content*	C_1	C_2	C_3	C_4
	Low	326	65	0.095	0.707
Wheat 1	Intermediate	330	76	0.093	0.933
	High	324	86	0.087	1.135
	Low	396	85	0.094	0.760
Wheat 2	Intermediate	396	92	0.099	0.808
	High	397	97	0.087	1.022
	Low	517	128	0.136	0.837
Sorghum 1	Intermediate	530	127	0.133	0.863
	High	525	138	0.127	0.980
	Low	483	140	0.188	0.939
Sorghum 2	Intermediate	491	148	0.170	0.964
	High	494	155	0.164	0.983
	Low	567	137	0.172	0.770
Corn 1	Intermediate	553	143	0.198	0.821
	High	550	147	0.196	0.901
	Low	447	181	0.123	1.154
Corn 2	Intermediate	436	180	0.118	1.071
	High	435	193	0.125	1.189

*See Table 1.

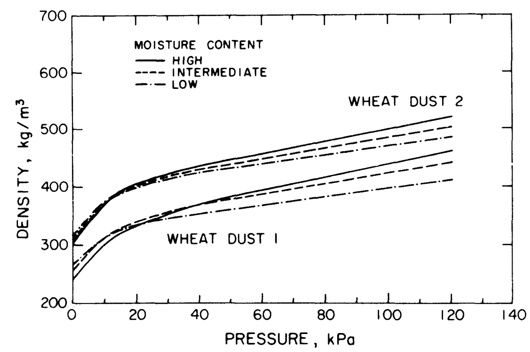

Fig. 7—Pressure-density curves for wheat dust.

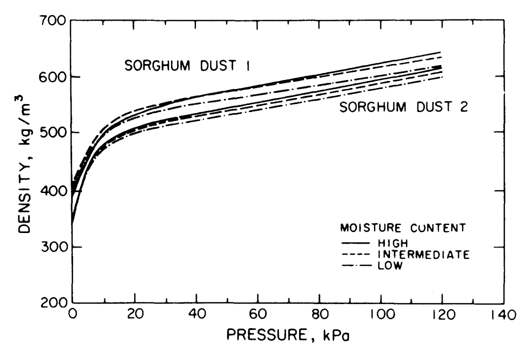

Fig. 8—Pressure-density curves for sorghum dust.

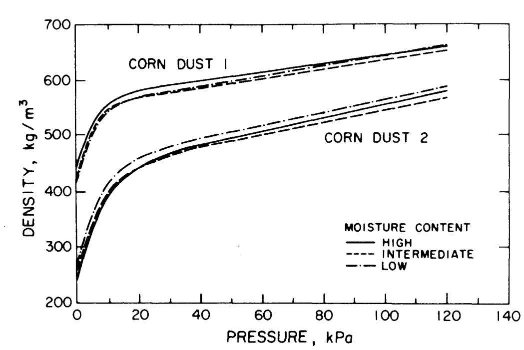

Fig. 9—Pressure-density curves for corn dust.

the same pressure, differences in bulk density between two lots of the same kind of dust were significant. This indicates that physical properties of dust collected from different locations may be quite different.

The relationships between bulk density of dust and pressure obtained in this investigation are valid for the range of pressures tested. It is anticipated that, for a given pressure, bulk density of dust may vary with the speed of compression.

According to equipment specifications, experimental error caused by the instrumentation was less than 0.5%, which was considered to be negligible for this particular application. However, it should be noted that friction between the dust sample and the container wall during compression probably contributed to an error in the pressure measurements. The magnitude of this error was not determined.

Hysteresis loss of grain dust during loading and unloading cycles increased slightly when moisture increased (Table 3). This was expected because the addition of water increases the plasticity of grain dust which in turn increases the hysteresis loss. A similar effect of moisture on hysteresis loss for grain has been reported (Zoerb and Hall, 1960).

Within the ranges of pressure and moisture content tested, the degree of elasticity ranged from 31 to 50% for wheat dust, from 26 to 37% for sorghum dust, and from 11 to 36% for corn dust (Table 3). The degree of elasticity of wheat dust was higher than those for sorghum dust and corn dust. The degree of elasticity of all three kinds of dust tested decreased when moisture content increased.

Comparing the strain of dust at a pressure of 120 kPa (Table 3), wheat dust was significantly more compressible at a high moisture content than at a low moisture content. However, the differences in compressibility were small for sorghum dust and corn dust at different moisture levels. Corn dust 2 was very compressible due to high "bees wings" content.

Compression Creep

To evaluate the validity of Burger's model for describing the compression creep behavior of grain dust, an analysis of variance was performed and the standard deviation and the correlation coefficient were determined for each regression curve (Fig. 10). All F values were highly significant. The standard deviations were 0.003 cm/cm or less and the correlation coefficients were 0.95 or higher with 15 deg of freedom. From the above statistical evaluation, it was concluded that Burger's model will predict the compression creep properties of grain dust.

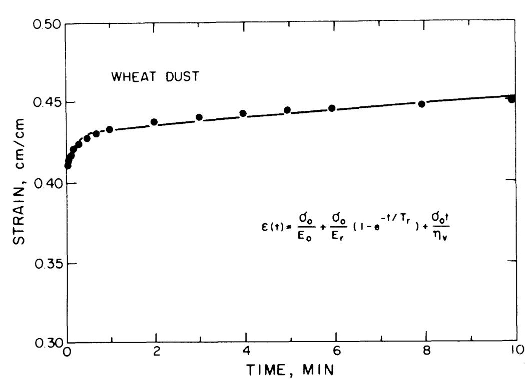

Fig. 10—A typical compression creep curve for wheat dust.

TABLE 5. PARAMETER VALUES OF BURGERS MODEL FOR GRAIN DUST

Kind of grain dust	Level of moisture content	E_o, kPa	E_r, kPa	T_r, s	η_v, 10^6 kPa·s
Wheat 1	Low	164	3586	3.92	3.73
	Intermediate	148	2381	4.97	2.41
	High	136	1882	9.99	1.71
Wheat 2	Low	166	4220	4.66	5.18
	Intermediate	155	3002	5.85	3.14
	High	153	1999	6.00	1.93
Sorghum 1	Low	150	6697	4.52	7.22
	Intermediate	144	4810	5.62	7.00
	High	145	3377	4.65	3.61
Sorghum 2	Low	129	5759	4.23	10.00
	Intermediate	126	4338	4.13	5.99
	High	127	3922	4.29	5.11
Corn 1	Low	133	34133	2.82	66.82
	Intermediate	131	14462	4.76	81.56
	High	132	11063	3.59	11.49
Corn 2	Low	92	6448	3.26	10.18
	Intermediate	91	6339	2.83	9.15
	High	91	3675	3.55	4.49

Parameter values for Burger's model are given in Table 5. Statistical significance of the effect of moisture on parameters of Burger's model was tested by least significant difference at the 5% level. The values of E_o ranged from 90 to 170 kPa. E_o value of wheat dust significantly decreased when moisture content increased. However, the effect of moisture content on E_o was not significant for sorghum dust and corn dust. At the same level of moisture content, E_o value varied with the kind and source of dust. From information on E_o one can calculate the pressure required to compress grain dust to a certain degree of elastic strain.

For all three kinds of dust, the values of E_r significantly decreased with increasing moisture content. This indicated that the higher the moisture content of grain dust the greater the amount of retarded elastic strain.

Time of retardation T_r ranged from 3 to 10 s. T_r is the time required to deform about 63% of the total retarded elastic strain. Moisture content did not significantly affect T_r for all dust samples tested except for the wheat dust 1.

As expected, the value of η_v generally decreased as moisture content increased. A lower η_v value resulted in more viscous yield. After 10 min of compression a small viscous yield was still present.

The Burger's model is normally applied in the case of uniaxial compression. In this case, the compression of a dust sample in a confined cylinder resulted in a force against the sidewall and thus became the case of non-uniaxial compresson. Also the confinement of the sample did not allow flow to occur indefinitely during compression. Therefore, it should be noted that the parameter values determined for the compression creep model are valid only for the time range and conditions tested.

Stress Relaxation

The same statistical procedures used in the

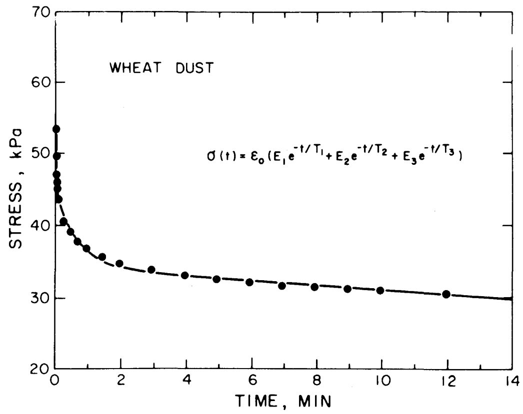

Fig. 11—A typical stress relaxation curve for wheat dust.

compression creep tests were used to eavluate the validity of the generalized Maxwell model and the effect of moisture on the parameters of the model. Three Maxwell element in the generalized Maxwell model were sufficient to describe stress relaxation behavior of grain dust. All statistical F values were highly significant. The standard deviations were 0.5 kPa or less and the correlation coefficients were better than 0.99 with 18 deg of freedom. These statistical values indicated that stress relaxation properties predicted from the model agree well with the experimental results (Fig. 11).

Parameter values for the Maxwell model are given in Table 6. The time of relaxation, T_1, decreased significantly when moisture content increased from low to an intermediate level for wheat dust and sorghum dust and from intermediate to a high level for corn dust. Moisture content had no significant effect on T_2 and T_3 and the differences in T_2 and T_3 among the thre kinds of dust and between two groups of the same kind of dust were not significant.

The time of relaxation is a measure of the rate at which a material dissipates stress after being compressed and maintained at a constant strain. It reflects hold times for dust compression processes such as compacting and pelleting. For any specific problem, it may be desired to eliminate the long or the short relaxation time and consider only the value of the relaxation time which describes the behavior over a range of time important to the problem.

The values of decay modulus, E_1, E_2, and E_3, for all three kinds of dust were significantly affected by moisture content. The values of E_1 decreased but E_2 and E_3 increased when moisture content increased. The differences in E_1, E_2, and E_3 were small between two lots of the same kind of dust.

With the data of decay modulus, one can predict the volume and pressure requirement for a machine to mechanically compact grain dust.

TABLE 6. PARAMETER VALUES OF MAXWELL MODEL FOR GRAIN DUST

Kind of dust	Level of moisture content*	E_1, kPa	T_1, s	E_2, kPa	T_2, s	E_3, kPa	T_3, s
	Low	113	12284	15.1	45.1	15.2	2.00
Wheat 1	Intermediate	108	6880	21.8	49.5	33.5	2.28
	High	89	5748	25.9	41.5	32.5	1.72
	Low	118	15934	14.2	36.9	17.9	1.35
Wheat 2	Intermediate	105	7096	24.0	40.3	25.8	1.60
	High	94	5190	28.8	38.8	32.8	1.58
	Low	127	16322	13.9	36.2	19.5	1.62
Sorghum 1	Intermediate	115	8526	19.7	48.4	25.8	2.01
	High	101	5682	25.8	41.3	32.8	1.82
	Low	115	15182	11.5	46.6	17.6	2.51
Sorghum 2	Intermediate	107	9357	16.8	38.3	22.4	1.66
	High	91	8072	18.0	43.2	22.4	2.01
	Low	115	19234	9.3	35.8	8.8	1.21
Corn 1	Intermediate	110	17448	10.8	41.3	10.6	1.37
	High	111	8670	18.1	51.7	21.5	2.89
	Low	90	15319	8.3	25.5	10.9	0.88
Corn 2	Intermediate	75	13912	8.0	36.0	10.3	1.55
	High	69	6351	16.0	32.1	19.7	1.18

*See Table 1.

SUMMARY AND CONCLUSIONS

Compression creep and stress relaxation properties, degree of elasticity, hysteresis loss, and the pressure-density relationship of wheat dust, grain sorghum dust, and corn dust were determined at room temperature by a Dillon Testing Machine and a compression apparatus constructed at the U.S. Grain Marketing Research Laboratory. Grain dust used for experiments was collected from the dust control systems of commercial grain elevators in Kansas. The moisture contents of the dust ssamples ranged from 9 to 15%.

The compression creep and stress relaxation properties of grain dust can be described by Burger's model and the generalized Maxwell model represented by three Maxwell elements, respectively.

In compression creep tests, it was found that time of retardation ranged from 3 to 10 s and that the higher the moisture content of grain dust the greater the amount of retarded elastic strain. In stress relaxation tests, moisture content had a significant effect on all decay moduli and the long relaxation time T_1, but no significant effect on short relaxation times T_2 and T_3.

Bulk densities of grain dust ranged from 180 to 350 kg/m^3 at loose-fill conditions and from 400 to 660 kg/m^3 at a pressure of 120 kPa. A functional relationship expressing bulk density of grain dust as a function of pressure was obtained as given in equation [5].

Under the conditions tested, the degree of elasticity of grain dust ranged from 10 to 50% depending on moisture content and kind of dust. The degree of elasticity decreased as moisture content increased.

The hysteresis loss of grain dust during loading and unloading cycles ranged from 70 to 85%. It increased slightly with increasing moisture content.

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