

Corn Kernel Damage Due to High Velocity Impact

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PHYSICAL damage to field-shelled corn is a common problem in the grain industry. Field shelling and artificial drying often make corn kernels susceptible to damage (broken or cracked kernels) in subsequent handling operations and possibly lowering the market value of the corn.

Much of the physical damage to corn during handling is due to impact of kernels against some object. For example, high velocity impact occurs in field shelling, in some grain throwing and conveying equipment, and with free fall into deep concrete silos or bins.

This study was conducted to determine the damage to corn kernels from high velocity impact as related to kernel moisture, impact velocity, type of impact surface and angle of impact surface with respect to direction of kernel movement.

PREVIOUS WORK

Several authors have published results on aerodynamic characteristics, including terminal velocities, of grain. Bilanski et al, 1962 and Hawk et al, 1966 have reported that the terminal velocities of single grain kernels in free fall range from 26 to 35 fps. Fiscus et al, 1969, determined free fall velocities of corn streams from drop distances up to 85 ft. For streams from 12-in. orifices, stream velocities reached approximately 67 fps in 85 ft. Terminal velocity was not reached in that distance, and the grain stream was still accelerating. Limited results on the effect of high velocity impact on damage to grain have been reported except for the work by Fiscus, et al, 1969. They found that

breakage for grain falling on a surface perpendicular to kernel movement can be represented mathematically by a power function of velocity.

Louvier and Calderwood (1967) determined the amount of breakage from dropping milled rice from various heights onto other rice, concrete and steel. Most breakage resulted from dropping rice onto steel; the least from rice onto rice. By inclining the steel or concrete impact surface to 45 deg, breakage was reduced approximately 60 percent. Breakage increased with drop height up to 60 ft. Breakage was significantly higher in rice at 11 percent moisture than in rice at 13 percent moisture content.

Clark et al, 1967 studied effects of high velocity impact on loss of germination and other damage to cottonseed. He concluded that: (1.) at energy absorption levels above three in.-oz, slowly applied loads were more detrimental to seed germination than dynamic loads; (2.) cottonseed was more susceptible to damage when impacted on the side than on the end; (3.) there was no direct relationship between moisture content and damage.

Bilanski (1966), from results of high and low velocity impact studies, found corn kernels weakest when placed on edge and, in general, strongest when placed on their flat side. Chung (1969) recently investigated the damage to corn caused by a pneumatic conveyor operated over a range of conditions. He found that high conveying velocity was the most important cause of increased corn damage. The effect was more pronounced at the lower moisture content.

shown in table 1. Including all levels of each variable there are 288 (4 by 4 by 3 by 3 by 2) treatment combinations; with 3 replications, the number of tests totaled 864.

Kernel velocities ranged from 49 to 93 fps and were chosen to include velocities attained in free fall stream flow (Fiscus, 1969).

The corn kernels were impacted against three types of materials: concrete, steel, and urethane. Angles of impact with the surfaces were 90 deg and 45 deg. The materials and angles are typical of those used in commercial grain facilities.

The corn was classified into eight groups as shown in table 2. Only the small-small-flat (No. 2), large-round (No. 3), and large-medium-flat (No. 5) kernels were used in these tests.

A modified pneumatic conveying system was used to impart desired velocities of corn kernels for impact (Fig. 1). Kernel velocities were determined by both high speed photography and radio-active-tracer techniques with good correlation between the two methods. Detailed procedures and equipment for measuring velocity are given in reference (Keller, 1970).

Corn used was hand-shelled, sorted into various size or shape classifications, then dried with room air to the desired moisture content. Tests were run at room temperature.

Three samples of 40 sound kernels each were hand-picked from each of the three size classifications. Kernels were individually dropped into the system as fed through the feeder, impacted against

TABLE 1. APPROXIMATE LEVELS OF EXPERIMENTAL VARIABLES

Experimental variables	Levels tested			
	1	2	3	4
Kernel velocity, fps	49.5	62.2	81.6	93.1
Moisture content, percent	22.2	19.1	15.2	12.3
Size and shape	large round	small small flat	large medium flat	large medium flat
Impact surface	urethane	steel	concrete	concrete
Impact angle	normal	45 deg		

TEST PROCEDURE AND EQUIPMENT

Experiments were conducted by pneumatically projecting corn kernels against selected materials and then evaluating damage caused by the impact. Kernel damage was evaluated as a function of five independent variables: kernel impact velocity, impact surface, angle of impact, kernel moisture, and kernel size and/or shape. A factorial design was used; levels of variables are

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Authors' Note: Reference to a company or product does not imply approval or recommendation of the product by USDA to the exclusion of others that may be suitable.

TABLE 2. CLASSIFICATION AND DISTRIBUTION OF TEST CORN ACCORDING TO SIZE AND/OR SHAPE

Designation	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Classification	small medium flat	small small flat	large round	large flat	large medium flat	medium round	large	residue
Sieve opening, in.	$\frac{11.5-12.5+}{64 \quad 64}$	$< \frac{11.5+}{64}$	$> \frac{14.5}{64}$	$\frac{12.5-14.5}{64 \quad 64}$	$< \frac{12.5}{64}$	$> \frac{12.5}{64}$	$> \frac{28 (R)}{64}$	$< \frac{17 (R)}{64}$
1969 corn	percent	percent	percent	percent	percent	percent	percent	percent
Test 1	3.11	11.80	5.36	7.59	65.76	4.58	0.48	1.32
Test 2	1.39	3.66	12.00	16.16	60.87	2.05	3.66	0.19
Test 3	2.02	6.76	7.86	10.54	67.84	3.03	1.72	0.22
Test 4	1.76	5.00	8.58	11.47	69.22	2.97	0.71	0.28
Test 5	1.81	6.24	7.93	9.01	69.44	2.95	2.19	0.42
Average	2.01	6.69	8.34	10.96	66.62	3.11	1.75	0.49

the selected surface, then visually inspected for kernel damage. Fisher's Fast Green FCT dye was used to help detect damage.

Kernels were classified into three damage categories as follows:

- cracked - kernel coat damage, small cracks and large cracks as long as the kernel was completely intact,
- broken - kernels cracked or chipped and not completely intact,
- sound - kernels not damaged

RESULTS

Corn kernels were inspected after impact for cracked and broken damage. Results are presented as percent of total kernels damaged, the sum of cracked plus broken kernels.

An analysis of variance computer program (ARDVARK)*, based on a factorial design, was used to analyze the total damage results. Main effects (kernel velocity, moisture content, size and shape, surface, and angle of impact) were significant ($\alpha=0.05$). There was considerable interaction among main effects except for velocity times size or shape,

size or shape times angle, and velocity times size or shape times angle. Size or shape appeared to be the least significant main factor, so subsequent analyses were made with all size and shape kernels combined. The results presented are for all three classifications combined.

Multiple linear regression was attempted to get a best fit relationship for total damage versus kernel velocity for each moisture level. Initial correlation results indicated that velocity effects contributed most to the statistical fit, but, interaction between main effects prevented any single function from adequately describing the experimental data.

Generally, as moisture level at which the kernels were tested decreased, total damage changed from proportional to kernel velocity to proportional to the natural logarithm of velocity. Individual regression analyses were run on each moisture level for all test combinations,

based on the following models: $D = \ln V$; $D = V^2$; $D = V^{0.5}$; $D = V^{0.75}$; where D = percent of kernels damaged and V = kernel velocity in ft per sec. Again no single model adequately describes all the experimental data. A detailed analysis and report of the curve fitting was given by Keller (1970). Plotting total damage versus kernel velocity on log-probability paper yielded straight lines and are shown for 90 deg impact angles in Fig. 2 and 45 deg impact angles in Fig. 3. Not only did total damage versus kernel velocity yield straight lines, but also different moisture content lines tended to be parallel. The physical significance of such relationships are likely more than just coincidental. One may justify these relationships by considering the incident of impact damage of kernels at different kernel velocities as a random process depending on the time parameter (stochastic process).

Considering that in our experiments there were only two possible classifica-

* KSU Statistical Laboratory.

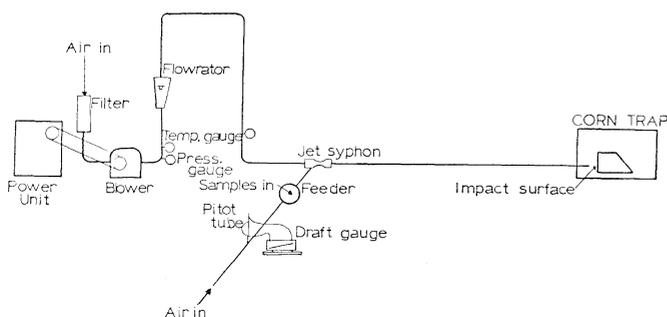


FIG. 1 Schematic diagram of experimental system.

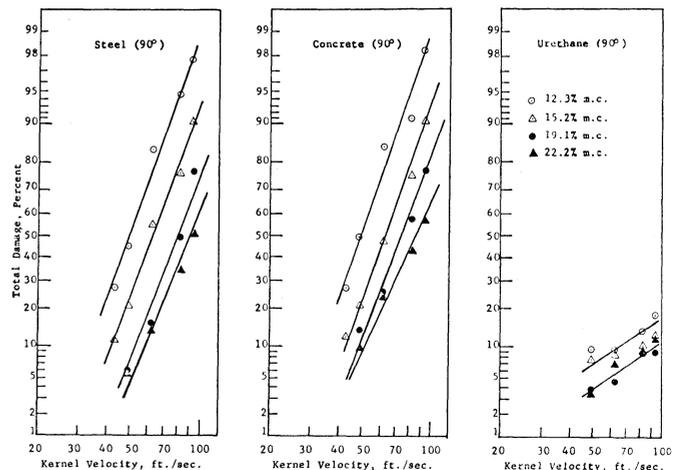


FIG. 2 Plots of total damage at different kernel velocities on log-probability paper for steel, concrete, and urethane at 90 deg. impact angle.

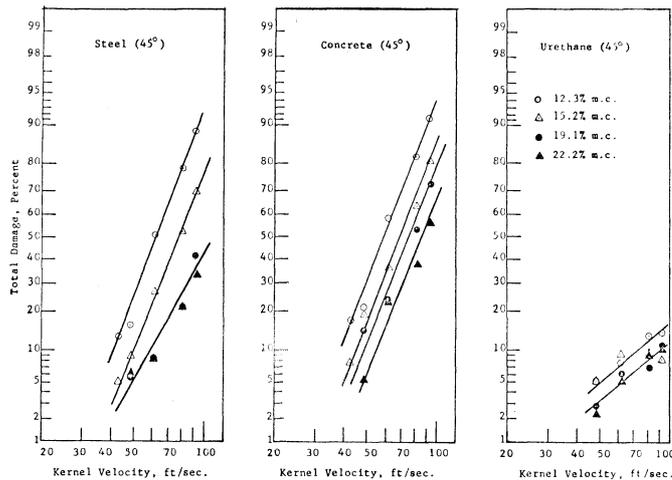


FIG. 3 Plots of total damage at different kernel velocities on log-probability paper for steel, concrete, and urethane at 45 deg impact angle.

tions of kernels, the probability distribution of the number of damaged kernels from random samples would follow a binomial distribution. Furthermore, binomial distribution theoretically can be approximated by normal distribution when sample size is large. However, it appeared that the actual damage distribution was not a true normal but rather a skewed normal. In general, a skewed normal distribution can be normalized by a logarithmic normal distribution, which, indeed, was the case. These experiments can be considered as a stochastic process governed by a normal probability equation with a logarithmic variate.

Kernel velocity accounted for more difference in kernel damage than did the other variables tested. In general, as kernel velocity increased, total damage increased. For a particular moisture level, the percentage of total damage occurring as broken kernels increased as kernel velocity increased.

The kernel velocity ranged from the upper limit of pneumatic conveying velocities through the corn stream free fall velocities reported by Fiscus et al, 1969. Damage percentages ranged from 5 to 98 percent. Below velocities of 50 fps damage was less than 15 percent in corn with the moisture contents between 19.1 and 22.2 percent.

At the lower corn moistures tested, the percentage of damage increased. Total damage was linear with respect to kernel velocity for the moisture contents between 14 and 19 percent.

The impact surface also significantly affected total damage. Damage with

urethane was only one-fifth that with steel and one-sixth that with concrete. The mean total damage was significantly greater with concrete than with steel, probably because of concrete's rougher surface. Urethane seemed to absorb enough of the impact energy to reduce kernel cracking and breaking. Its smooth surface also helped reduce damage. Damage of kernels impacted against urethane was composed mostly of cracked kernels.

Reducing the angle of impact from 90 deg to 45 deg decreased the mean total damage by 25 percent for all observations, except with the urethane surface. A combination of the 45 deg impact angle and the concrete surface produced total damage results similar to those with the 90 deg angle. The rougher concrete surface produced a greater shear, which accounted for the increased damage with the 45 deg impacting angle. The most pronounced difference in total damage as a function of impact angle was with the steel surface where damage was reduced 33 percent when the angle was changed from 90 deg to 45 deg.

Impact damage to corn kernels in these tests differs little from that due to pneumatic conveying (Chung, 1969). Most of the damage classified as "cracked" was small cracks at the tip cap or at the dent of the kernel. The majority of the cracks were longitudinal originating at the tip cap of the kernel and extending upwards.

At higher moisture contents, kernels classified as broken were mostly those not severely damaged and with only a small part of the kernel missing. At

lower moisture contents the severity of cracking increased with a larger portion of total damage classified as "broken".

CONCLUSIONS

Within the limits of this investigation the following conclusions were drawn:

1. Kernel velocity, moisture content, impact surface, angle of impact, size and shape all significantly influenced impact damage to corn kernels — kernel velocity most, size and shape least. Kernel damage increased with increased kernel velocity and was related more to this than any of the other factors tested.

2. As the moisture content at which the corn kernels were tested was decreased from 22.2 to 12.3 percent, the damage increased. The corn in the moisture content range of 19.1 to 22.2 percent had similar total damage; while kernels at moisture contents below 15.25 percent had greatly increased damage.

3. Damage with a urethane impact surface was one-fifth that with steel and one-sixth that with concrete.

4. Reducing the angle of impact from 90 deg to 45 deg reduced the mean total damage by 25 percent for all observations, except with the concrete impact surface where the difference was small.

5. Most broken kernels were split longitudinally. Larger cracks occurred at high kernel velocities and lower kernel moisture content.

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