CORN KERNEL DAMAGE DUE TO HIGH VELOCITY IMPACT

by

DUANE LEE KELLER

B. S., Kansas State University, 1970

A MASTER'S THESIS 4871

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1970

Approved by:

T O Hodges
Major Professor

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THIS IS AS RECEIVED FROM CUSTOMER.

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INTRODUCTION

Today's highly mechanized corn harvesting has caused an alarming problem for the American farmer, corn buyer, exporter, and equipment manufacturer. The recent technological changes of harvesting with field shellers, harvesting at high moisture contents, artifical drying, and the extensive use of high speed mechanical handling equipment has caused a significant increase in corn kernel damage.

Harvesting of high moisture corn produces some deformed corn kernels and is blamed for most of the mechanical damage to corn kernels. Corn harvested at moisture levels between 20-35 percent needs immediate drying. Increased rates of harvesting and processing have forced most buyers and processors to turn to faster means of handling--high capacity conveyors and elevators, high speed grain throwers, and pneumatic conveyors.

The problem of corn kernel damage is important and large in scope. First, field shelling causes most of the mechanical damage to the kernel, due largely to the high moisture content, at harvest. When field shelling equipment for corn was first developed and introduced, kernel damage was relatively low because the ears were harvested and shelled at low moisture contents (25). Secondly, artificial drying is not detrimental to the corn kernel if drying is conducted in the proper way. Over drying and/or drying at excessively high air temperatures produce corn kernels that are brittle and easily broken when handled. Increases in the amount of mechanical handling of corn has accentuated the problems caused by artificial drying.

A large proportion of the corn that is mechanically damaged is due to the impact of the corn kernel against some object. This impact may occur at high velocities such as in the cylinder of a field-sheller, being conveyed by a pneumatic conveyor into a boxcar, or being dropped to the bottom of a silo. Little research has been done to determine at what velocities and to what extent damage does occur.

It is important that the physical and morphological properties of the corn kernel be determined so as to be able to determine a relationship between certain kernel properties and kernel damage. A knowledge of these properties is necessary for the design of useful and efficient equipment for harvesting, processing, transporting, and storing of agricultural products (9).

This investigation has attempted to produce a relationship between kernel damage and kernel impact velocity, moisture content, kernel classification, impact surface and the angle of impact.

OBJECTIVES

The objectives of this investigation were:

1. To study effects of kernel velocities on corn kernel damage.
2. To study the relationship of kernel moisture to kernel damage.
3. To study the affect of impact surface characteristics on impact damage.
4. To determine the relationship of corn kernel impact damage to angle of impact.
5. To analyze the relationship between impact damage variables: kernel velocity, moisture content, surface, and angle of impact.

LITERATURE REVIEW

Corn Kernel Damage

According to Bailey (2), corn is damaged after harvesting in two ways: (a) it may spoil and molds may cause deterioration, chemical decomposition, heating and bad odors, or (b) the kernel may be broken. Previous investigations have shown that the higher the moisture content, the greater the mechanical damage to kernels during shelling (2).

Mold readily invades damaged kernels. It penetrates chipped, cracked, or crushed seed coats and feeds upon the energy stored in the kernels. Tests have shown that carefully hand-shelled, 28 percent corn has between 1 and 2 percent mechanical damage. Corn shelled mechanically at 28 percent moisture can be damaged severely. It is not unusual for 25 to 35 percent of the kernels to have visible damage. Causes of damage include high moisture shelling; improper adjustment of combine or picker-sheller; high speed operation of combine, picker-sheller, or loading and unloading equipment; and insect damage in the field and in storage (28).

The principal losses in corn quality now are from broken kernels. The average amount of corn screenings cleaned out before the grain gets to the consumer is over three percent. Bailey (2) suggests that in order to improve the quality of the corn one must:

1) Harvest at 23 percent moisture or less
2) Limit kernel temperature in drying to 140 degrees F.

3) Dry not below 14.5 percent moisture

4) Dry not more than 7 percent in one pass

5) Artifically heat grain not over $1\frac{1}{2}$ hours

6) Avoid batch drying with continuously heated air without turning the grain.

Thus there are two main parameters affecting kernel damage during mechanical harvest: plant parameters and machine parameters (26). Waelti (25) concluded that most threshing research has shown that high cylinder speed is the chief factor causing grain damage. Other machine parameters, such as cylinder-concave clearance and type of cylinder bars, seem to affect kernel damage only slightly.

Zoerb (29) has conducted the most extensive investigation of the properties of corn kernels. He concluded that moisture content has the greatest influence on the mechanical properties of grain and that all of the strength properties generally decrease in magnitude as the moisture increases. He showed that energy required for seed rupture by impact increases as the moisture increases. Ekstrom (9) determined such properties as the modulus of elasticity, modulus of toughness, ultimate stress, and ultimate strain for corn kernels. Waelti (25) attempted to determine the physical and morphological properties of the kernels and cobs and to correlate these to kernel damage as a result of the shelling operation. His findings were (a) that as the kernel moisture content decreased, the kernel size decreased, (b) kernel strength and stress increased as kernel moisture decreased, (c) kernel detachment force was independent of kernel moisture or other kernel properties, (d) as kernel moisture decreased, kernel damage decreased, (e) low kernel damage was associated with low detachment force, high kernel strength, low kernel deformation, and cob strength.

Hawk, Brooker, and Cassidy (16) investigated the aerodynamic characteristics of certain grains. Characteristics included the aerodynamic drag and terminal velocity of grains. Two methods of determining these are: (a) numerically differentiating a time of free fall versus length of fall curve to obtain values of velocity, and (b) adjusting the air velocity of a vertical airstream until the kernel is suspended with little vertical movement, this being the terminal velocity. At terminal velocity, the drag force is numerically equal to the weight of the kernel. Results of three researchers show the range of terminal velocity for a single kernel:

	feet per second
Hawk (16)	26.8 - 32.5
Uhl and Lamp (16)	26 - 42
Bilanski, Collins, and Chu (4)	34.9

Hawk (16) concluded that terminal velocity increases as the weight of the particle increases, even if the particle volume remains constant. Hence, terminal velocity alone is not a satisfactory aerodynamic characteristic of a particle.

Fiscus, Foster, and Kaufmann (11) determined grain stream velocities using high speed photography for wheat, corn, and soybeans. They concluded that (a) the velocity attained by a falling stream of grain exceeded the terminal velocity of single kernels at drop distances of about 50 feet, (b) grain velocities from the grain thrower used in their tests were about equal to those of a grain stream after 40 feet of free fall, (c) the velocity of grain discharging from the bucket elevator used in these tests was about equal to that of a grain stream after a drop of 10 feet, and (d) a falling stream of grain has not reached terminal velocity after being dropped 80 feet.

Artificial Drying Damage

Thompson and Foster (24) found that shelled corn dried with heated air (140° to 240° F.) was two to three times more susceptible to breakage than the same corn dried with unheated air. Stress cracks (endosperm fissures), while practically nonexistent in crib-dried ear corn, were found in all samples of shelled corn dried artificially and accounted for much of the increased susceptibility to breakage. Such breakage contributes to downgrading of corn and to its susceptibility to molds and insect damage.

Another factor involved in breakage of corn, as indicated by laboratory breakage tests, was handling at low moisture levels or at low temperatures. Breakage increased as the amount of sheller damage increased (24).

Drying speed, expressed in terms of moisture loss in percentage points per hour, was the most significant factor in stress-crack development according to Thompson and Foster. Stress-crack evaluation can be useful in predicting increases in fine material that may be expected from breakage during handling. Shelled corn that was artificially dried exhibited characteristic cracks or checks. The cracks developed in the kernel endosperm; the seed coat was not ruptured. When the seed coat was removed the endosperm broke easily at the stress cracks.

Foster (13) stated that high-speed and high-temperature drying may damage grain in several ways. Stress cracks or endosperm fissures make the grain more susceptible to breakage when being handled.

Stress cracks in corn also lower its value for dry milling where there is a premium for a high yield of large grits. Overheating the grain increases the difficulty of separating the starch from the gluten and protein in the wet milling process used by the corn refining industry.

Ekstrom (9) stated that it is improbable that stress cracks are caused exclusively by a temperature gradient in the kernel. A simple model study of the corn kernel showed that a temperature difference of at least 175° F. must exist between the center and the outer surface of the kernel in order for cracking to occur due to temperature effects alone. Therefore, moisture gradient stresses or a combination of moisture stresses and thermal stresses most likely cause stress cracks in corn kernels.

Chung (7) reported that internal cracks are detrimental to storage and handling because they (a) increase respiratory activity, (b) enhance moisture movement, (c) harbor greater numbers of mold spores, insect eggs, and bacteria, and (d) are much more likely to heat.

Saul and Steele (22) have determined maximum allowable storage time for shelled corn at various moisture contents and amounts of mechanical damage.

Commercial Handling Damage

According to Bilanski (3), the history of the grain kernel will affect its damage resistance. For example, the state of maturity at which the grain was threshed, the storage conditions, and methods of handling in general are factors which to an undeterminable extent will influence its strength. A basic knowledge of the energies and forces involved in damaging grain could be used to design grain-handling equipment so as to minimize grain damage.

Fiscus (11) found that grain temperature and moisture significantly affected breakage during commercial handling. Breakage was found to be an exponential function of velocity. The effect of velocity on breakage was greatest in those lots of grain at low moistures and temperatures. In an attempt to reduce grain quality deterioration, an investigation to determine the extent and causes of the physical damage to grain that occurs as a result of its being handled by the equipment used in marketing channels was conducted. They measured grain breakage against handling methods (drop test, grain thrower, and bucket elevator), grain types (corn, wheat, and soybean), and conditions (moisture content and grain temperature). The results were: (a) corn incurred more breakage than soybeans, and soybeans more breakage than wheat; (b) dropping grain from heights greater than 40 feet caused more breakage than any other handling method tested; (c) impact of the grain on concrete caused more breakage than grain on grain, (d) the grain stream from an 8-inch diameter orifice incurred more breakage than the grain from a 12-inch diameter orifice, and (e) breakage was greater at low grain moistures and temperatures (12).

With the increased need for handling of agricultural materials has come the need for better and more economical mechanical conveying equipment. The pneumatic conveyor has partially met this need. However, one of its disadvantages is the high probability of material damage. Person and Sorenson (20) have conducted research to determine the minimum air velocity for conveying and air velocities at which germination damage occurs. Results showed that at minimum air velocities, standard germination procedures showed no immediate damage to the grain; however, results of cold soil tests after 14 months storage indicated considerable damage to the germinating properties of the grain.

Chung (6) recently investigated the nature and extent of mechanical damage to corn conveyed in a pneumatic system. He concluded that air velocity was the most significant factor causing corn damage. Lower moisture contents resulted in higher amounts of damage. Size and/or shape of kernels was also a statistically significant factor with highest amount of damage occurring in round shape, with large medium flats and small small flats were damaged nearly the same but less. Corn at higher moisture contents may be conveyed with a higher air velocity than lower moisture corn without causing extensive damage.

High Velocity Impact Damage

There has been a limited amount of research conducted on the effect of high velocity impact on damage to grains. Louvier and Calderwood (19) conducted a series of tests to determine the amount of breakage which would result from dropping milled rice from various heights onto simulated bin floors. The velocity of the rice at time of impact was determined by measuring the time of dropping for various free fall heights. Surfaces of rice, concrete and steel were used and the greatest amount of breakage resulted from dropping rice onto steel and the least from dropping rice onto rice. Breakage was reduced approximately 60 percent by inclining the steel or concrete impact surface to 45 degrees. The amount of breakage increased with height up to 60 feet. The amount of breakage was significantly higher for rice at 11 percent than at 13 percent moisture content.

Clark (8) in an attempt to determine the effect of high velocity impact on the germination and damage of cottonseed concluded that: (a) at energy absorption levels above three inch-ounces, slowly applied loads are more detrimental to seed germination than dynamic loads; (b) cottonseed is more susceptible to damage from impact on the side rather than on the radical end of the seed; (c) there was no direct relationship between moisture content and damage.

Bilanski (3) stated that results of high and low velocity impact studies showed that the corn kernel was weakest when placed on edge and, in general, was the strongest when placed on its flat side.

Methods of Evaluating Grain Damage

Chung (7) stated that in general, grain damage can be classified into two categories--external and internal. Both damages might result from either physical (structural) or physiological change in grains at the fields and during storage and handling. Physical change enhances certain physiological changes which would further deteriorate grains. External damage (physical) is caused mostly by combines and handling equipment while internal damage (physical) is caused mainly by climatical or environmental changes of air surrounding grain.

Schmidt (23) defined mechanically damaged kernels as any that are broken or chipped or having minute cracks in the seed coat.

Kaminski (17) said that the ASAE Grain Harvesting Standards Subcommittee defines grain damage to be damage that is attributed to the machine.

Various methods of evaluating grain damage have been developed. A review of the procedures showed the methods to be either visible grain damage tests or invisible damage tests as follows:

A. Evaluation of External or Visible Grain Damage

   Mechanical particle sizing

   Visual inspection

   Optical scanners

B. Evaluation of Internal or Invisible Grain Damage

   Fatty acid test

Standard germination test

Staining reactions

Candling device

Radiographical examination

MATERIALS AND METHODS

Conveying System

The pneumatic conveying system located in the Agricultural Engineering laboratory was used for the experimental tests. Essentially, the system was used to obtain the desired velocities. The system comsisted of an air blower, air flow meter, steam jet syphon, air-inlet duct, conveying pipe, temperature and pressure gauges, impact surfaces, and a kernel collection trap. Plate 1 is a photograph and Plate 2 is a schematic diagram of the complete impacting system.

The air blower was a M-D-3-Lobe Rotary Positive blower (Model 3200, Series 11) which supplied part of the volume of air for the low volume, medium pressure system. The blower delivers maximum air capacity at a maximum pressure of 12 psig. and a maximum temperature of 350° F. The capacity of air delivered by the blower was controlled by varying the output of the power unit using a Reeves Variable Speed Drive. A relief valve was employed to control overloading of the blower.

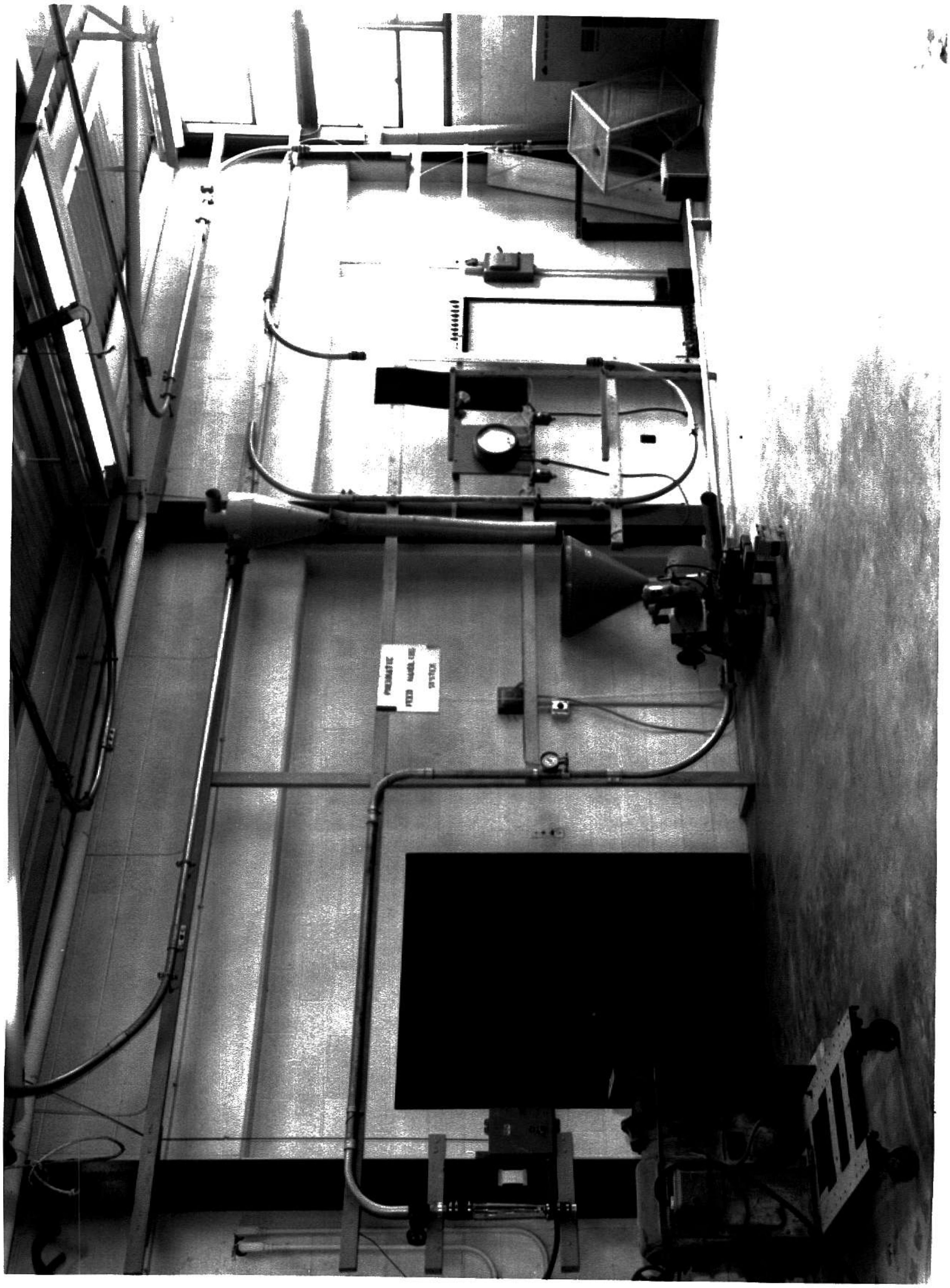
A flowrator (Model 10A1027, Fischer and Porter) was used to measure the volumetric flow rate of air. The flowrator was calibrated to measure 180 cubic feet per minute of air at a 100 percent reading at an air temperature of 100° F. and system pressure of 2 psig.

A $2\frac{1}{2}$-inch steam jet syphon (Model 4PG455) with a type 60 nozzle was placed in the conveying line to accelerate the kernels. The syphon end of the jet was connected to a Drop-Thru

EXPLANATION OF PLATE I

Photograph of pneumatic conveying system and impacting surface.

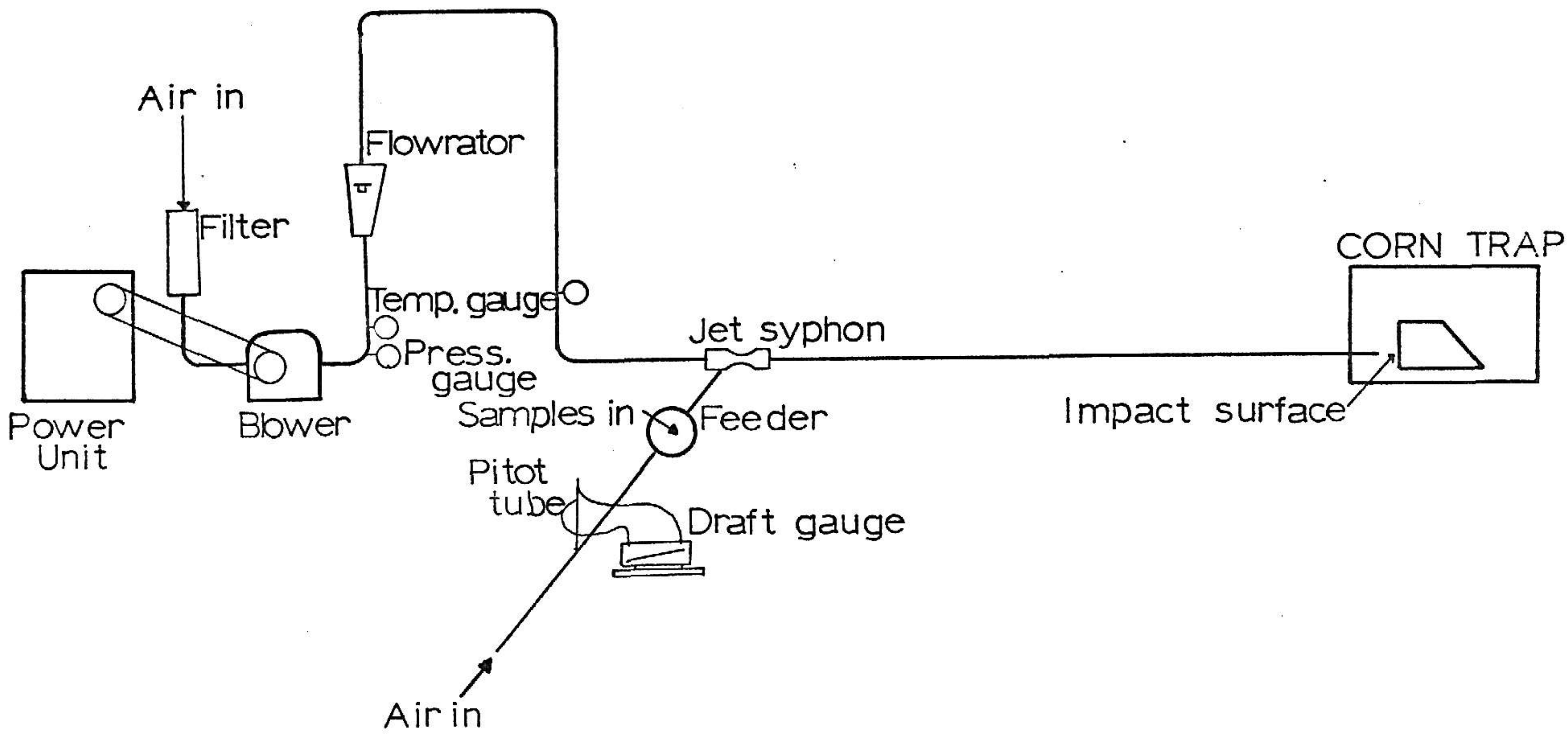
PLATE I



EXPLANATION OF PLATE II

Schematic diagram of impacting system.

PLATE II


Air in
Flowrator
Filter
CORN TRAP
Temp. gauge
Jet syphon
Press. gauge
Power Unit
Blower
Samples in
Feeder
Impact surface
Pitot tube
Draft gauge
Air in

Airlock Feeder (Model DEF-76). The feeder was modified by adding a handle to the vane shaft to allow manual feeding of the corn kernels. A four-foot piece of 3.46" I.D. inlet duct was connected to the feeder to enable an additional amount of air to be taken into the system. The increased volume of air was needed to obtain the higher kernel velocities. The jet syphons air through the duct and feeder with the feeder introducing the kernels into the main system. The kernels were then brought into the conveying pipe (13 feet and 6 inches long aluminum conveying tubing with an inside diameter of 1.9 inches) and discharged against various surfaces. The kernels were conveyed 14 feet 6 inches from the jet syphon to the impact surface.

Impact Surfaces

Three surfaces (concrete, steel and urethane) were used to simulate actual surface conditions in commercial handling of grain. The steel surface was a piece of 1/8" x 9" x 12" sheet steel mounted on a 3/4" plywood backing. The urethane surface was a piece of 1/4" x 9" x 12" poly-elastromer (Armstrong) mounted on a 3/4" plywood backing. The concrete surface was a 8" x 8" x 16" smooth concrete block whose surface texture is similar to a concrete grain silo. A wood structure was built to allow the surfaces to be interchanged and placed in either a 45° or 90° impact angle for the stream of the kernels. A screen box was built to trap the kernels after impact. For the 45° and 90° angle, the surfaces were positioned 6 inches, along the center line of the conveying pipe, from the end of the conveying pipe.

Corn Samples

Yellow dent corn (Funk G-5757) harvested in 1969 was used for the impact damage investigations. The corn was hand harvested in October of 1969 at a 25% moisture content. The ear corn was immediately stored at a temperature of 35^{o}-40^{o} F. The ear corn was hand shelled at five different times throughout the duration of the investigations.

Corn kernels have different physical characteristics because of inherent variety characteristics, growing season, and climatic conditions. Various varieties of corn have different kernel size distributions. To study the effects of size and/or shape of kernels on the degree of impact damage the corn was sorted with a grader into eight different sizes and shapes: small-small-flat (#2), small-medium-flat (#1), medium-round (#6), large-medium-flat (#5), large-flat (#4), large-round (#3), large kernel (#7), and residue (#8). Each fraction of shelled corn was weighed. The percent fractions by weight are shown in Table 1.

For this investigation, only small-medium-flat (#2), large-round (#3), and large-medium-flat(#5) were considered. These three classifications were of distinct sizes and/or shapes.

Air Velocity Measurements

A flowrator was used to determine the amount of air that the pump supplied to the system. The flowrator readings in percent were converted to volumetric units by multiplying by 180 cubic feet per minute. Temperature and pressure corrections were used to determine the actual corrected volume of air by using

TABLE 1.--Classification and distribution of test corn according to size and/or shape

Designation	#1	#2	#3	#4	#5	#6	#7	#8
Classification	Small medium flat	Small small flat	Large round	Large flat	Large medium flat	Medium round	Large	Residue
Sieve opening (in.)	$\frac{11.5}{64}$-$\frac{12.5+}{64}$	<$\frac{11.5+}{64}$	>$\frac{14.5}{64}$	$\frac{12.5}{64}$-$\frac{14.5}{64}$	<$\frac{12.5}{64}$	>$\frac{12.5}{64}$	>$\frac{28}{64}$ (R)	<$\frac{17}{64}$ (R)
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1969 Corn								
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	.19
Test 3	2.02	6.76	7.86	10.54	67.84	3.03	1.72	.22
Test 4	1.76	5.00	8.58	11.47	69.22	2.97	.71	.28
Test 5	1.81	6.24	7.93	9.01	69.44	2.95	2.19	.42
Average	2.01	6.69	8.34	10.96	66.62	3.11	1.75	.49

correction factor curves that were supplied with the flowrator.

The amount of air supplied by the air inlet duct was determined by the use of a pitot tube and an "Ellison" inclined tube draft gage. Construction of the inlet duct, air straighter, and placement of the pitot tube followed the specifications of the National Association of Fan Manufactures Standard Code (10). An egg crate type straighter was placed immediately in front of the pitot tube to straighten the air flow and to reduce turbulance. Initially, a 12-point velocity pressure traverse across the circular duct diameter was conducted according to N.A.F.M. (10) specifications. The velocity pressure readings were corrected to standard dry air conditions of 70° F., 29.92" of Hg and 0.07495 lbs. per cubic feet. Corrected velocity pressure readings were converted to air velocities. The average air velocity of the traverse points was calculated and used to determine a coefficient, K, where

$$K = \frac{\text{average air velocity of all traverse points}}{\text{air velocity of the centerline of the duct}}$$

Thereafter, only a centerline pitot tube reading was needed to determine the air velocity in the inlet duct while actually conducting the investigations.

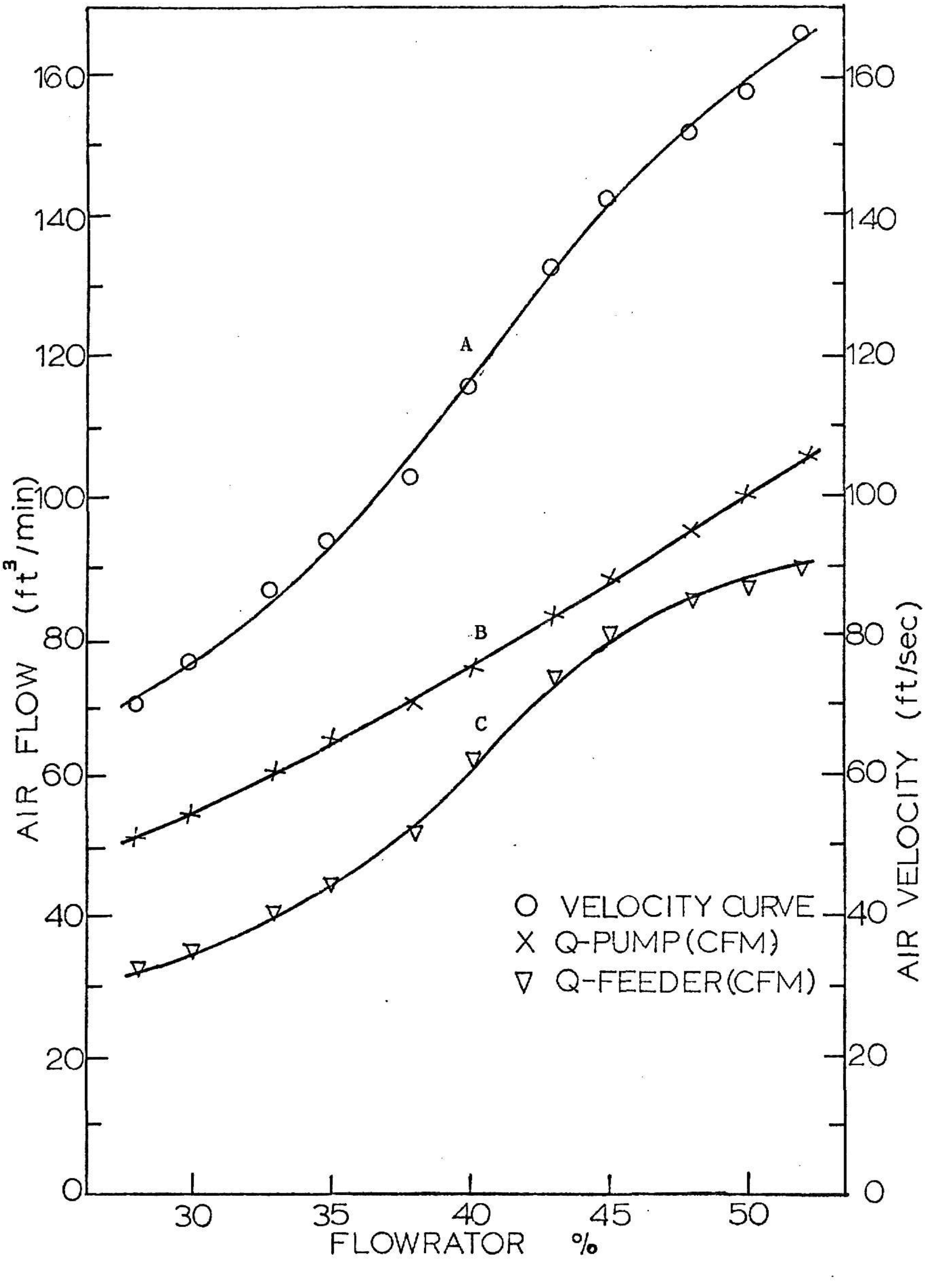
The air velocity in the conveying pipe was determined by adding the quantities of air supplied by the pump and the inlet duct. The total quantity of air supplied and the air velocity in the pipe at various flowrator readings are presented in Plate 3.

EXPLANATION OF PLATE III

A - Plot of flowrator reading versus air velocity

B - Plot of flowrator reading versus air quantity supplied by the air blower

C - Plot of flowrator reading versus air quantity supplied by the feeder inlet.


AIR FLOW (ft³/min)
AIR VELOCITY (ft/sec)
FLOWRATOR %
0
20
40
60
80
100
120
140
160
30
35
40
45
50
A
B
C
O VELOCITY CURVE
X Q-PUMP (CFM)
▽ Q-FEEDER (CFM)

Kernel Velocity Measurements

Kernel velocities were measured by two different techniques; a) high speed photography, and b) a radioactive tracer technique. A Red Lakes Laboratory Hycam Model K20S4E 16 mm. high speed motion picture camera was used for filming. The camera was equipped with a light generator which placed marks on the edge of the film at intervals of one millisecond. The camera was operated at film speeds of 4000 frames per second. White posterboard with .05 foot vertical grids was used as the filming background. Plate 4 shows the camera, lights, and pneumatic conveying system assembled for filming.

The developed film was viewed with an Optical Data Analyzer Projector. The timing marks were used to calibrate the speed of the film. Since the film is accelerating to its maximum speed during the first part of the film, only kernels on the last half of the roll of film were measured. There were usually between five and ten kernels per roll. The kernel velocities reported in Table 2 are for the six-inch distance from the end of the conveying pipe to the impact surface.

Another procedure of measuring particle (kernel) velocity was the radioactive tracer technique. Various pieces of electronic equipment were tried, and the final design of the system is schematically represented in Plate 5. Two model DP3 scintillation probes (B. J. Electronics, Borg-Warner Corporation) were used to detect the passage of the radioactive corn while being conveyed in the conveyor pipe. The scintillation probes were connected to a Model DVI (B. J. Electronics), variable high voltage power

EXPLANATION OF PLATE IV

Photograph of highspeed photography system.

PLATE IV

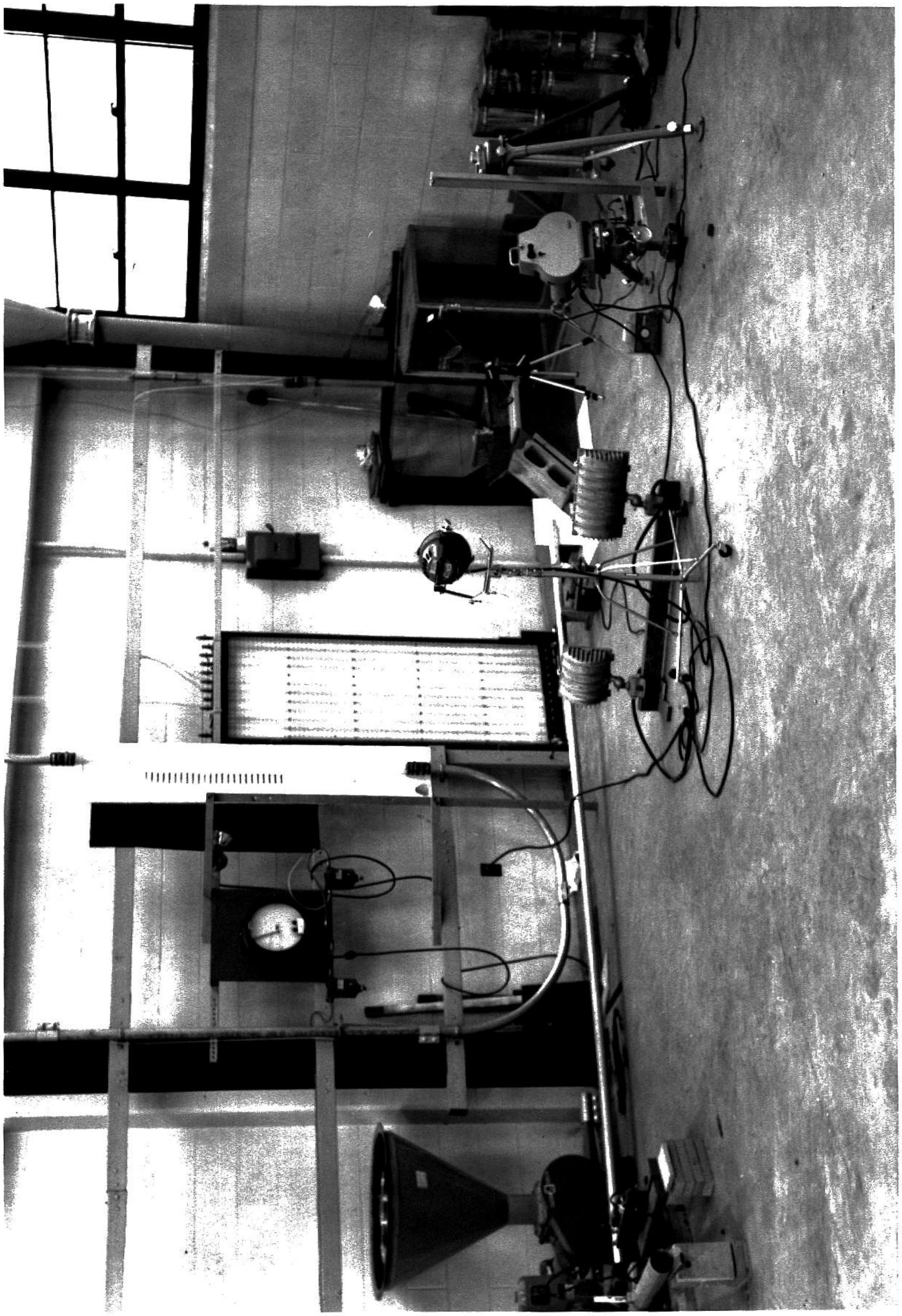


TABLE 2.--Corn kernel velocities measured by high speed photography and radio-active tracer technique

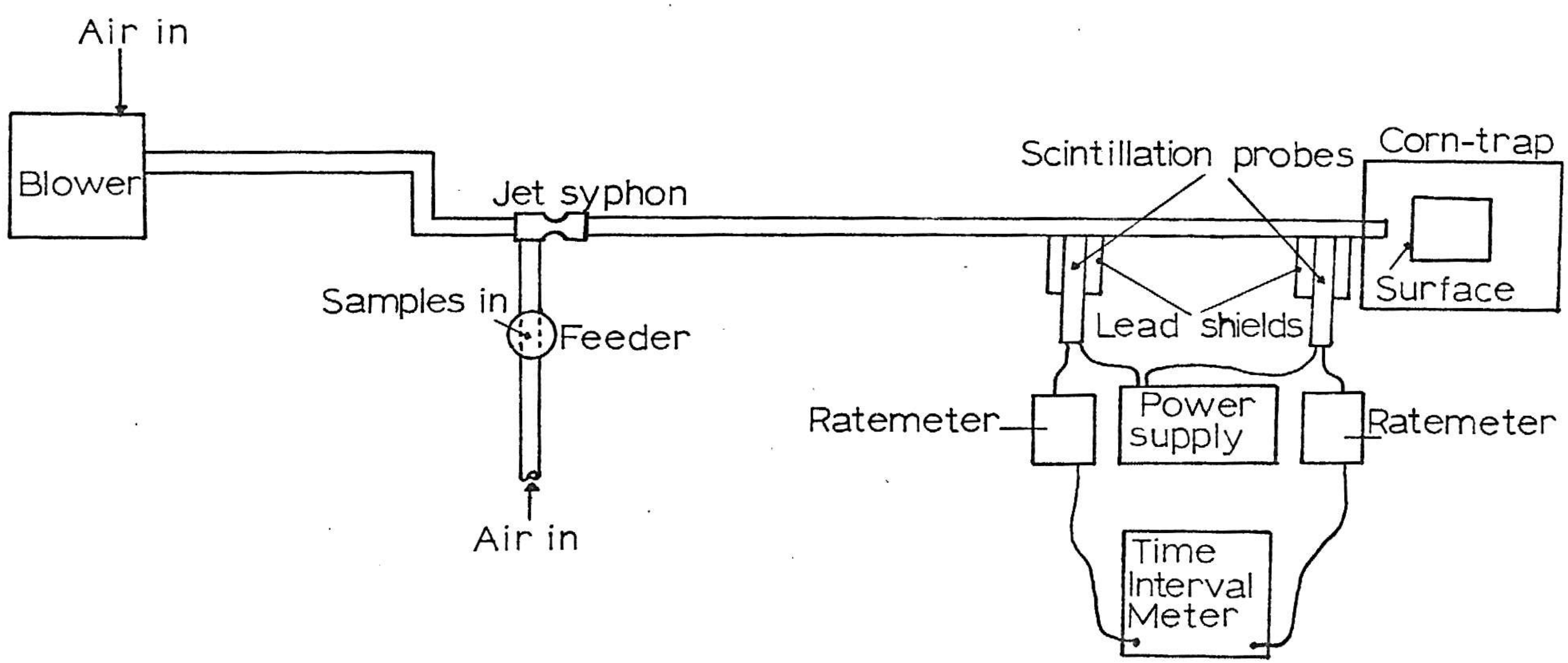
Technique	Flowrator	Air velocity	Kernel velocity High	Kernel velocity Low	Kernel velocity Mean	Standard deviation	C.V.[1/]
	Percent	F.p.s.	F.p.s.	F.p.s.	F.p.s.	F.p.s.	Percent
High speed photography	30	76.29	53.14	44.69	49.51	± 3.34	6.75
	38	103.92	70.87	55.12	62.25	± 4.84	7.77
	44	136.50	89.25	76.92	81.61	± 3.88	4.75
	52	160.74	102.06	84.16	93.07	± 6.22	6.68
Radio-active tracer	30	76.29	52.50	42.50	48.27	± 3.83	7.95
	38	103.92	74.33	59.83	66.78	± 4.10	6.14
	44	136.50	94.73	76.08	87.25	± 5.14	5.89
	52	160.74	111.52	87.20	103.77	± 6.76	6.52

1/ Coefficient of variation.

EXPLANATION OF PLATE V

Schematic diagram of radioactive tracer technique.

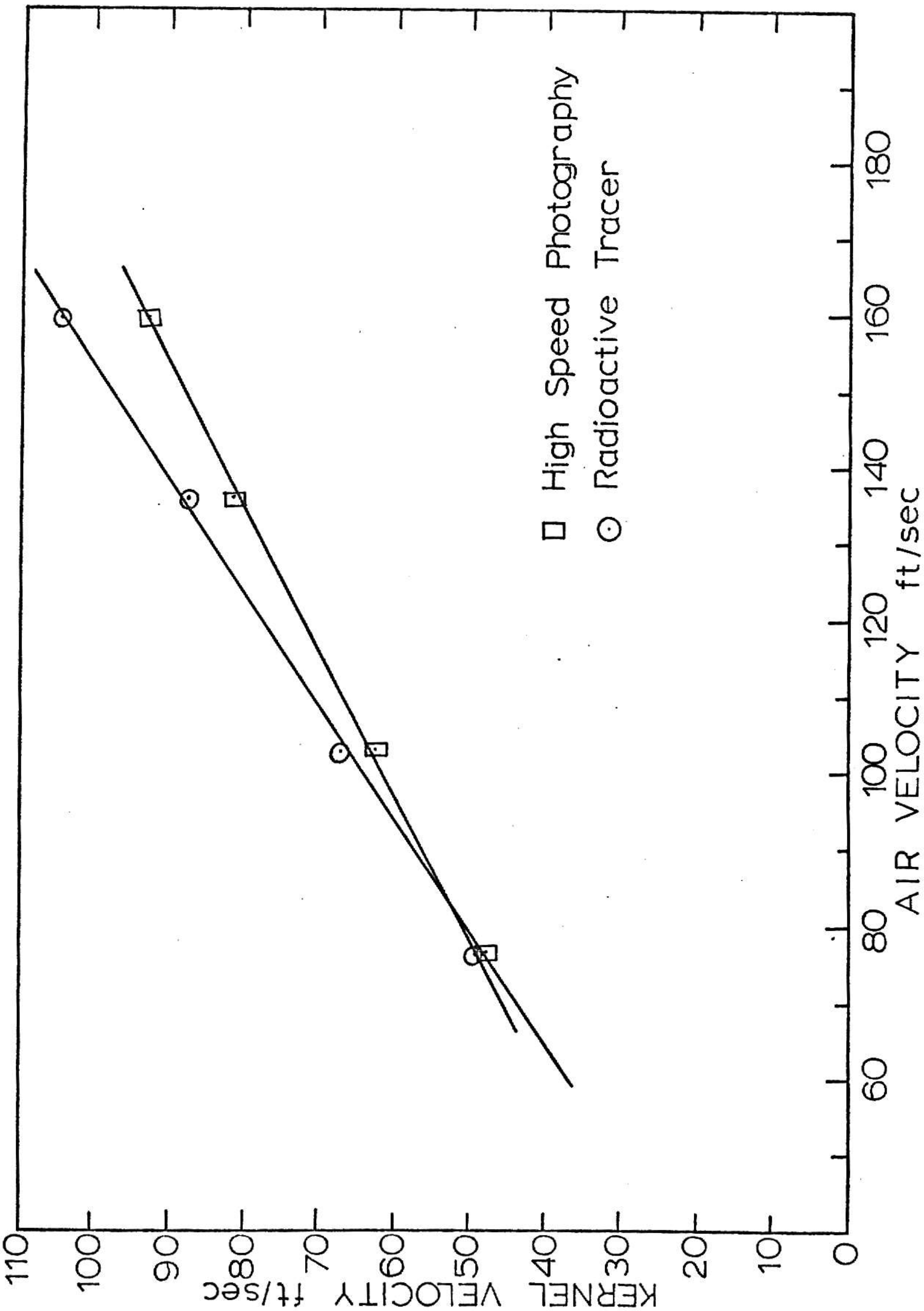
PLATE V


Air in
Blower
Jet syphon
Samples in
Feeder
Air in
Scintillation probes
Corn-trap
Surface
Lead shields
Ratemeter
Power supply
Ratemeter
Time Interval Meter

EXPLANATION OF PLATE VI

Characteristic curves for corn kernel velocities.

PLATE VI


High Speed Photography
Radioactive Tracer
AIR VELOCITY ft/sec
60
80
100
120
140
160
180
KERNEL VELOCITY ft/sec
0
10
20
30
40
50
60
70
80
90
100
110

supply. The output from each detector was fed to a ratemeter. Ratemeters, similar to the Baird Atomic, Inc., Model 432A, Research Ratemeter, were built by the Kansas State University Department of Nuclear Engineering. When the d-c output from a ratemeter exceeded a given value, firing of a neon bulb caused the current to flow in the final stage of the ratemeter. Output from the ratemeters were fed to a Beckman/Berkeley, Model 7250R, Time Interval Meter where the pulses were shaped and amplified. A sharp change in the pulse from the ratemeter triggered the Time Interval Meter oscillator (21).

For these investigations, the scintillation probes were placed three feet apart at the end of the conveyor tube. The corn kernels were activated in the rotary thimble rack of the Kansas State University Triga Mark II reactor for 30 minutes at a power level of 250 kilowatts. The Time Interval Meter oscillator was triggered on when the radioactive corn passed the first probe and off when the corn kernel passed the second probe. The Time Interval Meter would then give a digital readout with a resolution of 5u second. Plate 6 shows the characteristic curves for corn kernel velocities.

Corn Moisture Content Determination

A Motomco moisture meter was used to determine the moisture content of the corn. All moisture content readings were corrected for temperature differences.

EXPERIMENTAL DESIGN

In conducting the investigation of damage to corn due to high velocity impact, five independent variables were studied: kernel velocity, moisture content, size and/or shape, impact surface, and angle of impact. Levels of each experimental variable are summarized in Table 3. The experimental design was a factorial design with five independent variables. Including all different levels of each variable, there were (4x4x3x3x2) 288 treatment combinations and 3 replications of each treatment effect for a total of 864 tests.

The kernel velocity range was chosen from 49 feet per second to 93 feet per second. Fiscus (12) reported that grain falling in a stream-line will approach 70 feet per second when dropped 85 feet. The velocity levels chosen will investigate this particular region of conveying grain for impacting damage.

A fairly wide range of moisture contents were selected in an attempt to include all phases of possible corn kernel damage; harvesting, hauling, drying, and commercial handling.

The corn was classified into different sizes and/or shapes to see if varieties with all large or all small or all round kernels will vary differently in the amount of impact damage.

Impact surfaces chosen represented the possible types of surfaces that corn may and does strike while being handled.

Angles of impact were measured from the centerline of the conveying tube with the 90^{o} angle being normal to the tube.

TABLE 3.--Levels of Experimental Variables

Experimental variables	Levels			
	1	2	3	4
Kernel velocity (f.p.s.)	49.51	62.25	81.61	93.07
Moisture content (%)	22.2	19.1	15.25	12.3
Size and/or shape	Large round (#3)	Small-small flat (#2)	Large-medium flat (#5)	----
Surface	Urethane	Steel	Concrete	----
Angle	90°	45°	---	----

Treatment conditions = 4 x 4 x 3 x 3 x 2 = 288

Three replications

Total tests = 3 x 288 = 864

40 kernels per replication

EXPERIMENTAL PROCEDURE

For each level of moisture content, ear corn was taken from refrigerated storage, hand shelled, and sorted into the various size and/or shape classifications. Corn kernels were dried to the desired moisture content by exposing the kernels on flat pans to unheated room air.

The actual experimental procedure was conducted in the following manner. Samples of the three size and/or shape classifications were removed from refrigerated storage. Three samples of forty kernels each were hand picked for each size and/or shape. In hand picking the sample kernels, kernels that were already broken or cracked externally were excluded. The corn kernel samples were at a temperature of 65^{o}-75^{o} F. while being impacted.

For each test the flowrator reading, air temperature, pump pressure, pitot tube velocity pressure, barometric pressure, and room temperature were recorded to determine the air velocity. Kernels were individually fed through the feeder and impacted against the surface. The samples of forty kernels were collected in the receiving trap and placed in metal containers. After individual samples were impacted, they were ready to be inspected for damage.

A green dye, "Fisher's Fast Green FCF", was used to aid in detecting any damage. The corn samples of forty kernels were first treated with green dye so any damage (chips or cracks) in the kernel seed coat could be easily viewed. Damage was evaluated using visual inspection with the aid of green dye.

Kernels were classified into three categories: cracked, broken, and sound. The categories were defined as follows:

cracked -- kernel coat damage, small cracks and large cracks as long as the kernel is completely intact,

broken -- any kernel that is cracked or chipped and is not completely intact,

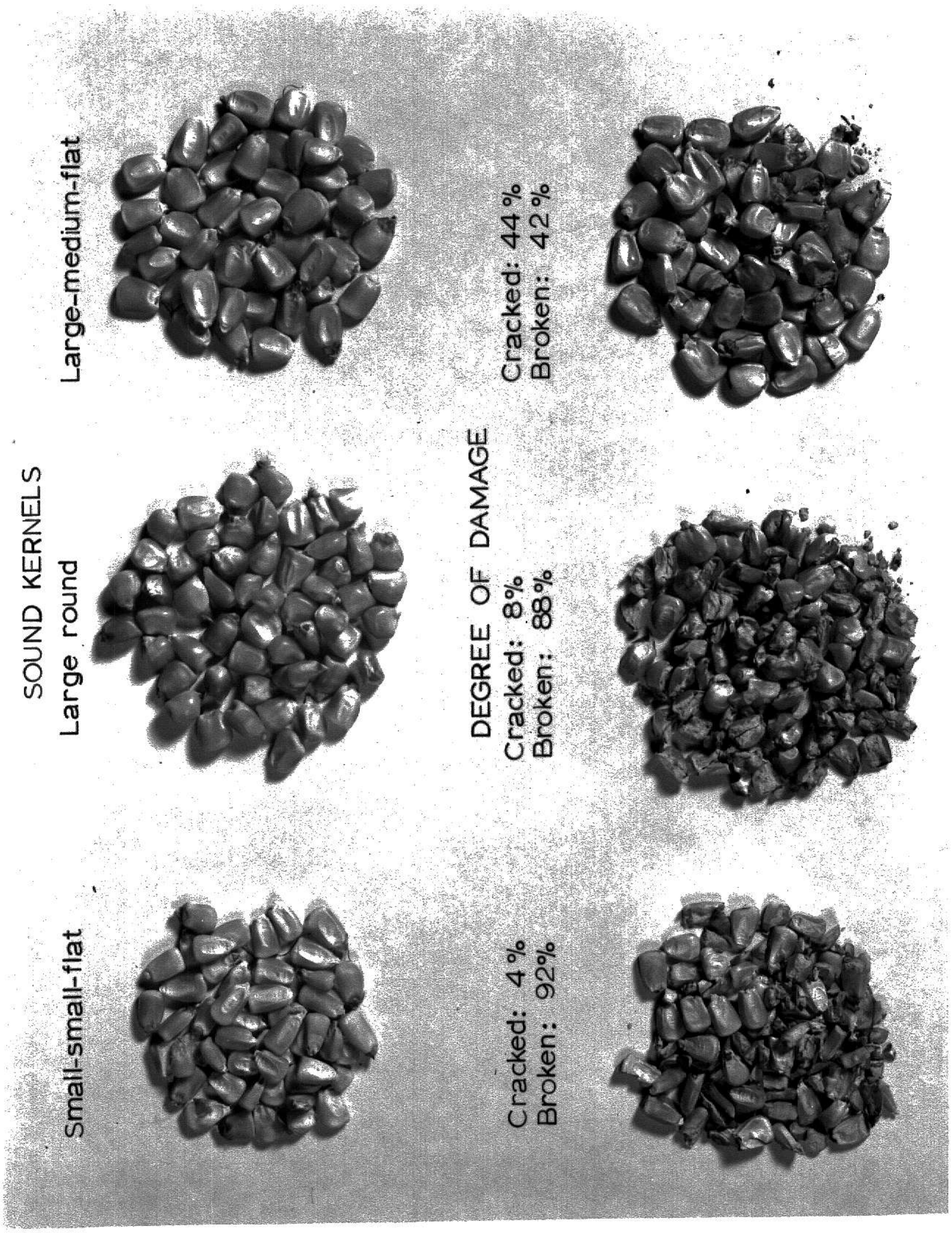
sound -- any kernel that is visibly undamaged.

Samples were inspected according to the preceding criteria with the number of broken kernels being determined by subtracting the number of sound and cracked from forty. Percentage of each category was determined by count. Total damage was the sum of cracked and broken kernels. Different classifications of kernels and categories of impact damage are shown in Plate 7.

EXPLANATION OF PLATE VII

Corn kernel classifications and examples of various degrees of impact damage.

PLATE VII


SOUND KERNELS
Small-small-flat
Large round
Large-medium-flat
DEGREE OF DAMAGE
Cracked: 4%
Broken: 92%
Cracked: 8%
Broken: 88%
Cracked: 44%
Broken: 42%

RESULTS

Corn kernel damage due to high velocity impact was evaluated by individual kernel inspection with the aid of "Fischers" green dye test. Total damage and broken kernel damage are shown in Tables 8 through 10 in Appendix 1. As the kernel velocity was increased, the broken kernels contributed a larger portion of the total damage. Broken kernel damage versus kernel velocity was plotted in Figure 1 and Figure 2. For this investigation all statistical analyses were employed on total damage results.

Analysis of Variance

The statistical experimental design for the investigation was a factorial design with five factors. An analysis of variance computer program (ARDVARK)[1] was employed to analyse the following statistical model:

$$X_{ijklmn} = + V_i + M_j + C_k + S_l + A_m + (VM)_{ij} + (VC)_{ik} + (VS)_{il} + (VA)_{im} + (MS)_{jl} + (MC)_{jk} + (MA)_{jm} + (CS)_{kl} + (CA)_{km} + (SA)_{lm} + (VMC)_{ijk} + (VMS)_{ijl} + (VMA)_{ijm} + (VCS)_{ikl} + (VCA)_{ikm} + (VSA)_{ilm} + (MCS)_{jkl} + (MCA)_{jkm} + E_{ijklmn}$$

where X_{ijklmn} = a sample total kernel damage

+ the grand average of all X_{ijklmn}

1/ KSU Statistical Laboratory.

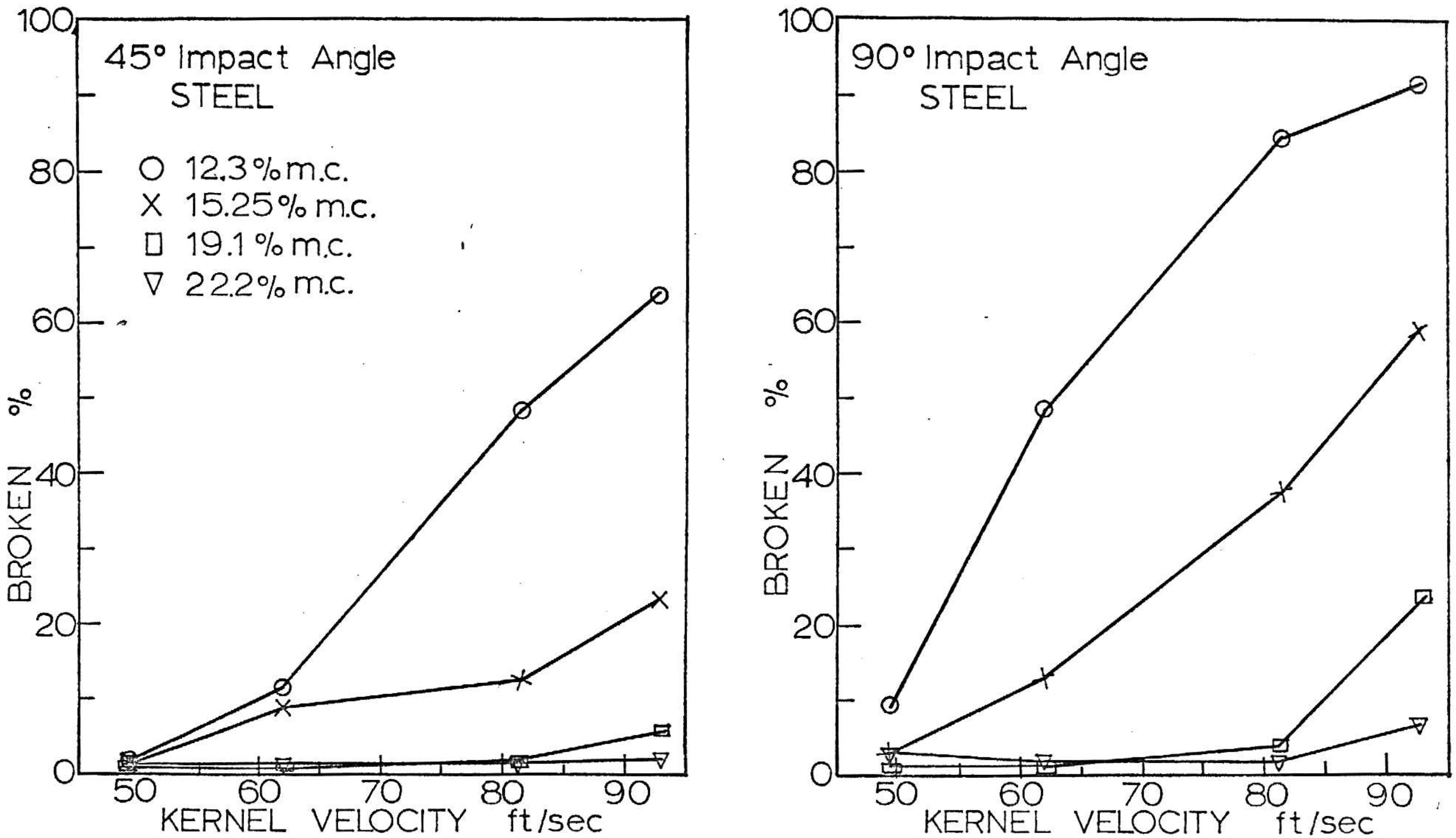


Figure 1.--Broken damage for all sizes and/or shapes combined versus kernel velocity for steel at different moisture contents.

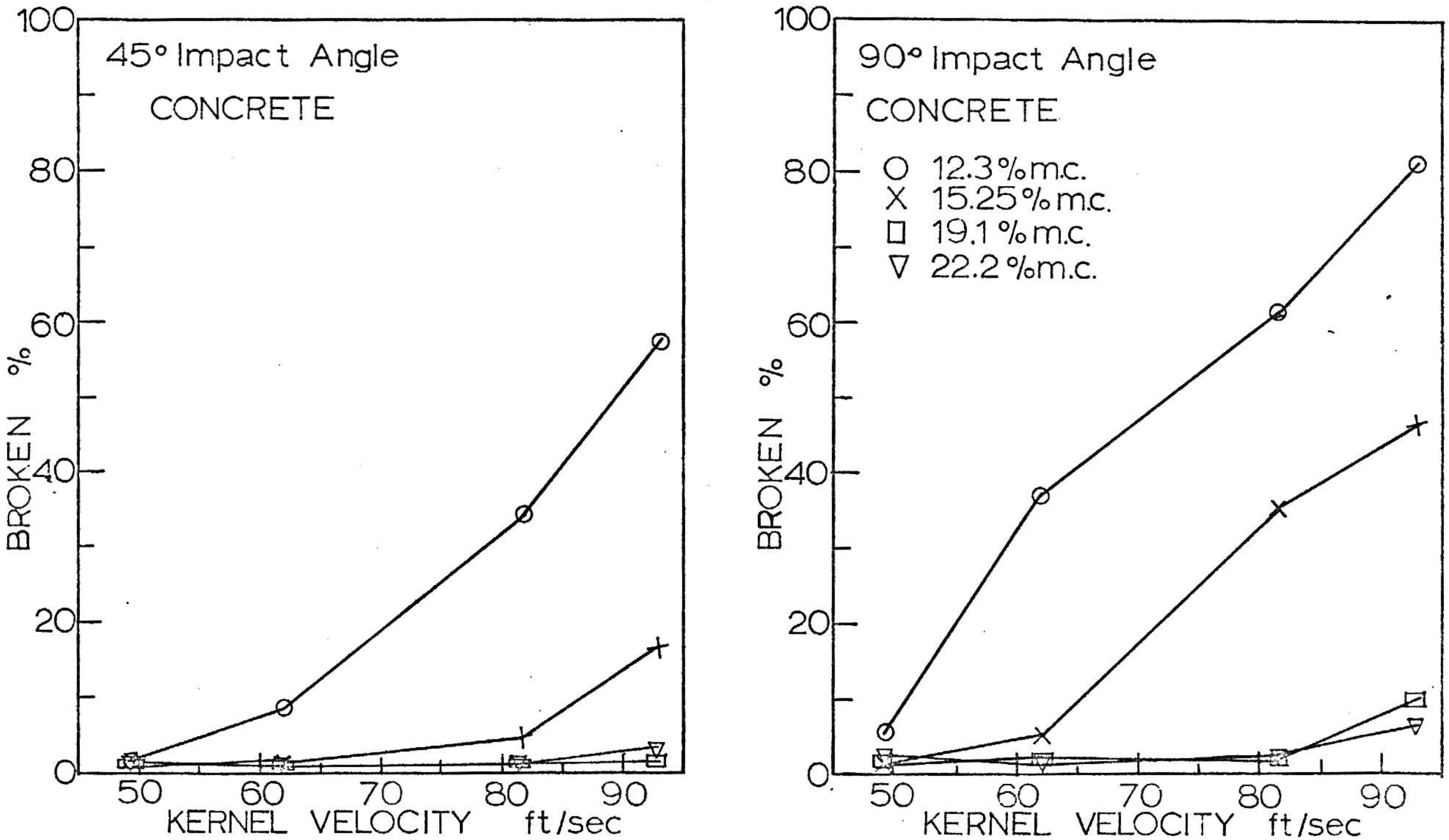


Figure 2.--Broken damage for all sizes and/or shapes combined versus kernel velocity for concrete at different moisture contents.

V_i = the true average effect for the i treatment of velocity;

M_j = the true average effect for the j treatment of moisture;

C_k = the true average effect for the k treatment of size and/or shape;

S_l = the true average effect of the l treatment of surface;

A_m = the true average effect of the m treatment of angle;

- all other terms are interactions of either the first or second order of the main effects:

E_{ijklmn} = the random error of total damage with the assumption of homogeneity of variance for all sample means.

Tables 11 through 14 in Appendix II show the analysis of variance for total damage for the complete investigation and for each of the surface conditions; concrete, steel, and urethane.

The results of the analysis of variance were used to test various statistical hypotheses. The decision to accept or to reject the test hypothesis was based on the "F" distribution. The decisions are summarized in Tables 4 through 7.

Conclusions from the results of the hypotheses tested (Table 4) show the main effects (kernel velocity, moisture content, size and/or shape, surface, and angle of impact) were very significant

Table 4.--Summary of statistical hypothesis tested for all experimental treatment combinations.

Hypothesis		F		
Test	Alternate	Calculate	F.05	Decision
$V_i=0$	$V_i \neq 0$	2351.47	2.60	Reject
$M_j=0$	$M_j \neq 0$	1399.96	2.60	Reject
$C_k=0$	$C_k \neq 0$	26.36	3.00	Reject
$S_1=0$	$S_1 \neq 0$	4910.94	3.00	Reject
$A_m=0$	$A_m \neq 0$	633.66	3.84	Reject
VM=0	VM≠0	40.35	1.88	Reject
VC=0	VM≠0	1.90	2.10	Accept
VS=0	VS≠0	407.21	2.10	Reject
VA=0	VA≠0	3.87	2.60	Reject
MS=0	MS≠0	279.60	2.10	Reject
MC=0	MC≠0	7.02	2.10	Reject
MA=0	MA≠0	34.71	2.60	Reject
CS=0	CS≠0	7.02	2.37	Reject
CA=0	CA≠0	1.96	3.00	Accept
SA=0	SA≠0	170.56	3.00	Reject
VMC=0	VMC≠0	1.77	1.67	Reject
VMS=0	VMS≠0	15.84	1.67	Reject
VMA=0	VMA≠0	19.43	1.88	Reject
VCS=0	VCS≠0	0.80	1.75	Accept
VCA=0	VCA≠0	2.78	2.10	Reject
VSA=0	VSA≠0	8.25	2.10	Reject
MCS=0	MCS≠0	2.50	1.75	Reject
MCA=0	MCA≠0	0.86	2.10	Accept

Table 5.--Summary of statistical hypothesis tested for treatment combinations for urethane.

Hypothesis		F		
Test	Alternate	Calculate	F.05	Decision
$V_i=0$	$V_i\neq0$	63.93	2.60	Reject
$M_j=0$	$M_j\neq0$	27.09	2.60	Reject
$C_k=0$	$C_k\neq0$	2.23	3.00	Accept
$A_1=0$	$A_1\neq0$	14.61	3.84	Reject
VM=0	VM≠0	4.94	1.88	Reject
VC=0	VC≠0	0.36	2.10	Accept
VA=0	VA≠0	1.58	2.60	Accept
MC=0	MC≠0	1.93	2.10	Accept
MA=0	MA≠0	1.92	2.60	Accept
CA=0	CA≠0	1.49	3.00	Accept
VMC=0	VCM≠0	0.95	1.67	Accept
VMA=0	VMA≠0	0.86	1.88	Accept
MCA=0	MCA≠0	1.58	2.10	Accept
VCMA=0	VMCA≠0	1.09	1.67	Accept

Table 6.--Summary of statistical hypothesis tested for treatment combinations for steel.

Hypothesis: Test	Hypothesis: Alternate	F: Calculate	F: F.05	Decision
$V_i=0$	$V_i\neq 0$	1526.06	2.60	Reject
$M_j=0$	$M_j\neq 0$	1260.32	2.60	Reject
$C_k=0$	$C_k\neq 0$	17.94	3.00	Reject
$A_l=0$	$A_l\neq 0$	843.16	3.84	Reject
VM=0	VM≠0	45.94	1.88	Reject
VC=0	VC≠0	2.36	2.10	Reject
VA=0	VA≠0	18.05	2.60	Reject
MC=0	MC≠0	9.37	2.10	Reject
MA=0	MA≠0	23.33	2.60	Reject
CA=0	CA≠0	1.21	3.00	Accept
VMC=0	VMC≠0	2.01	1.67	Reject
VMA=0	VMA≠0	24.71	1.88	Reject
MCA=0	MCA≠0	0.67	2.10	Accept
VMCA=0	VMCA≠0	1.42	1.67	Accept

Table 7.--Summary of statistical hypothesis tested for treatment combinations for concrete.

Hypothesis		F		
Test	Alternate	Calculate	F.05	Decision
$V_i=0$	$V_i\neq0$	1764.11	2.60	Reject
$M_i=0$	$M_i\neq0$	785.08	2.60	Reject
$C_k=0$	$C_k\neq0$	23.50	3.00	Reject
$A_1=0$	$A_1\neq0$	176.90	3.84	Reject
$VM=0$	$VM\neq0$	27.78	1.88	Reject
$VC=0$	$VC\neq0$	1.19	2.10	Accept
$VA=0$	$VA\neq0$	2.80	2.60	Reject
$MC=0$	$MC\neq0$	2.52	2.10	Accept
$MA=0$	$MA\neq0$	33.54	2.60	Reject
$CA=0$	$CA\neq0$	1.07	3.00	Accept
$VMC=0$	$VMC\neq0$	2.12	1.67	Reject
$VMA=0$	$VMA\neq0$	9.34	1.88	Reject
$MCA=0$	$MCA\neq0$	1.30	2.10	Accept
$VMCA=0$	$VMCA\neq0$	1.19	1.67	Accept

at the α = .05 level. A plot of total damage for 19.1% moisture corn versus kernel velocity for the various classifications (Figure 6) shows there to be very little difference for the experimental levels tested.

There was a considerable amount of interaction among the main effects except for velocity x classification, classification x angle, velocity x classification x angle. With this in mind, it appears that size and/or shape is the least significant main factor. It is for this reason that all subsequent analyses were conducted with small small flats, large medium flats, and large round kernels combined.

Results of the analysis of variance for total damage for the urethane surface (Table 5) show size and/or shape to be the only non-significant main effect. All interaction effects were shown to be non-significant at α = .05.

Table 6 shows all main effects for the steel surface to be significant at the .05 level. Surface classification, moisture x classification x angle, and velocity x moisture x classification x angle interactions were the only non-significant effects.

The final analysis of variance for total damage for concrete (Table 7) shows all main effects are significant. All interactions including size and/or shape classification were non-significant.

Multiple Linear Regression

Multiple linear regression was employed in an attempt to find the best fit for total damage versus kernel velocity (Figures 3 through 5) for various moisture levels. Data points for these figures are the means for all sizes and/or shapes combined for that particular surface and angle of impact. After initial multiple linear regressions are run, it was concluded that the velocity effect contributed nearly all of the statistical fit. Viewing the plots of total damage versus kernel velocity shows that no single function will describe all of the experimental data. For this reason, individual regressions were run on each moisture level for all combinations.

Curvelinear regression analysis was employed to find the best fit with the following transformations being applied:

$$D = \text{Ln } V$$

$$D = V^2$$

$$D = \text{SQRT } V$$

$$D = V^{.75}$$

where D = total damage

V = kernel velocity.

The extreme amount of interaction between main effects prohibited a single, unsophisticated, meaningful function from describing the experimental results. Generally, as the corn samples decreased in moisture content, total damage changed from a function of total damage being proportional to the kernel velocity squared to total damage being proportional to the natural logarithm of velocity.

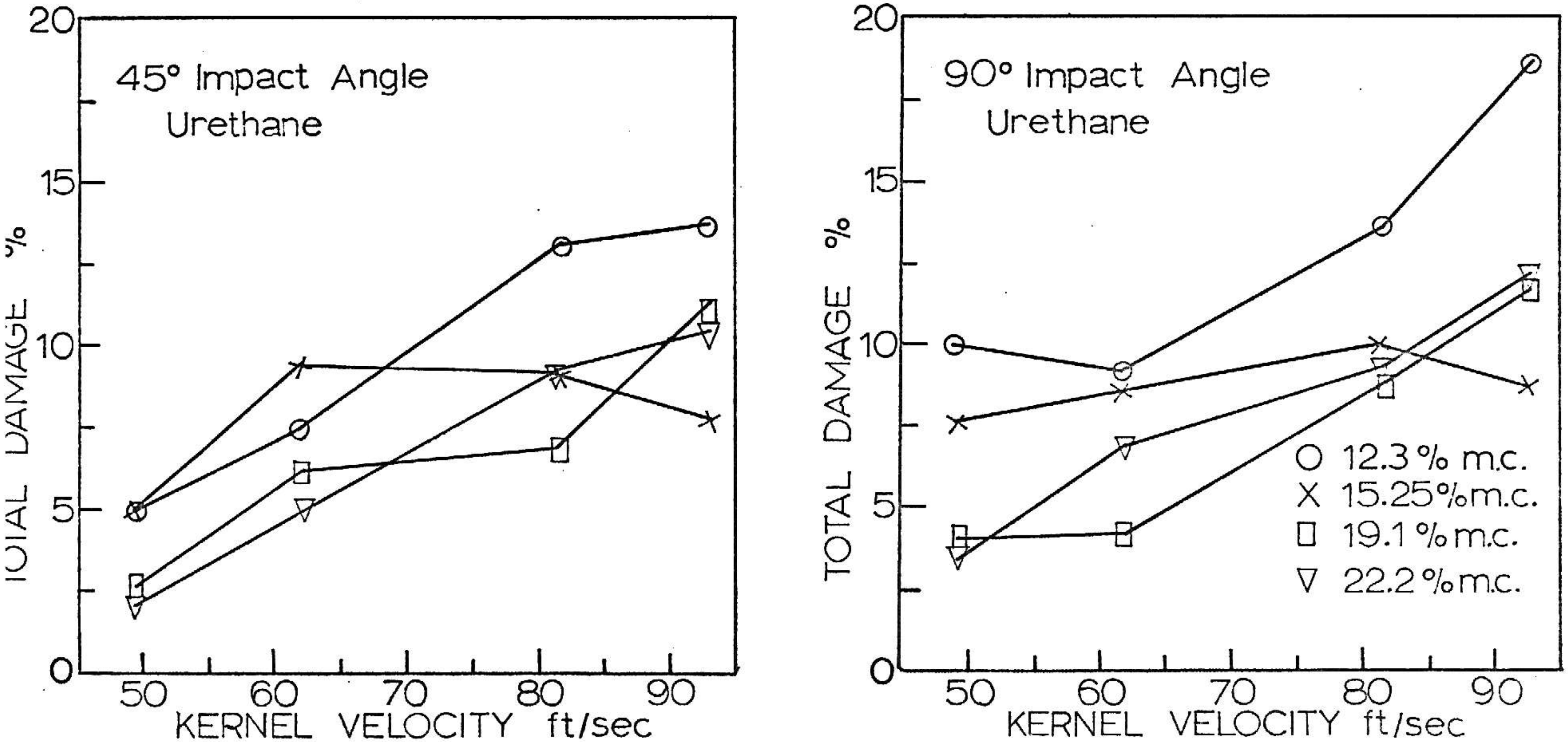


Figure 3.--Total damage for all sizes and/or shapes combined versus kernel velocity for urethane at different moisture contents.

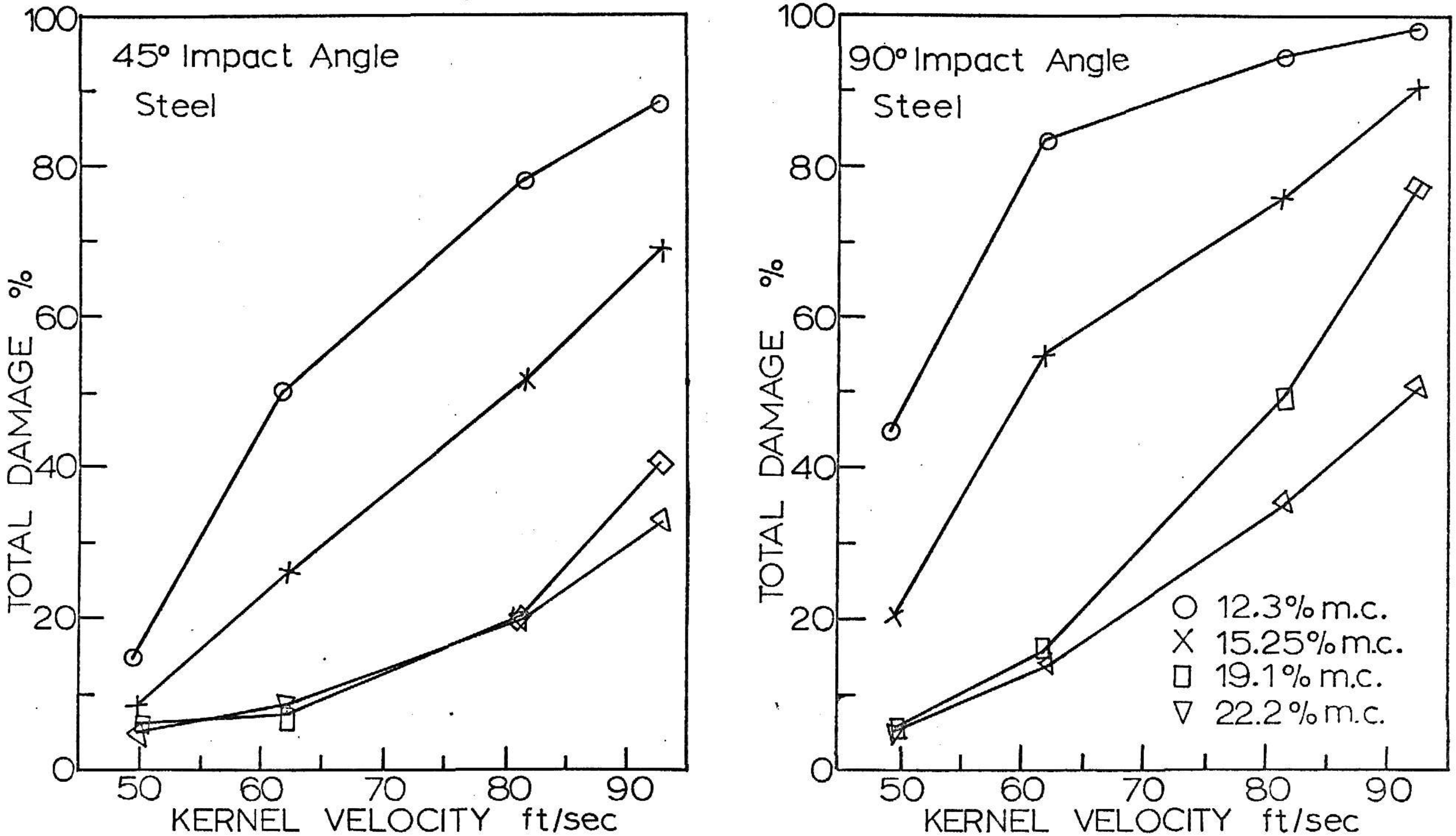


Figure 4.--Total damage for all sizes and/or shapes combined versus kernel velocity for steel at different moisture contents.

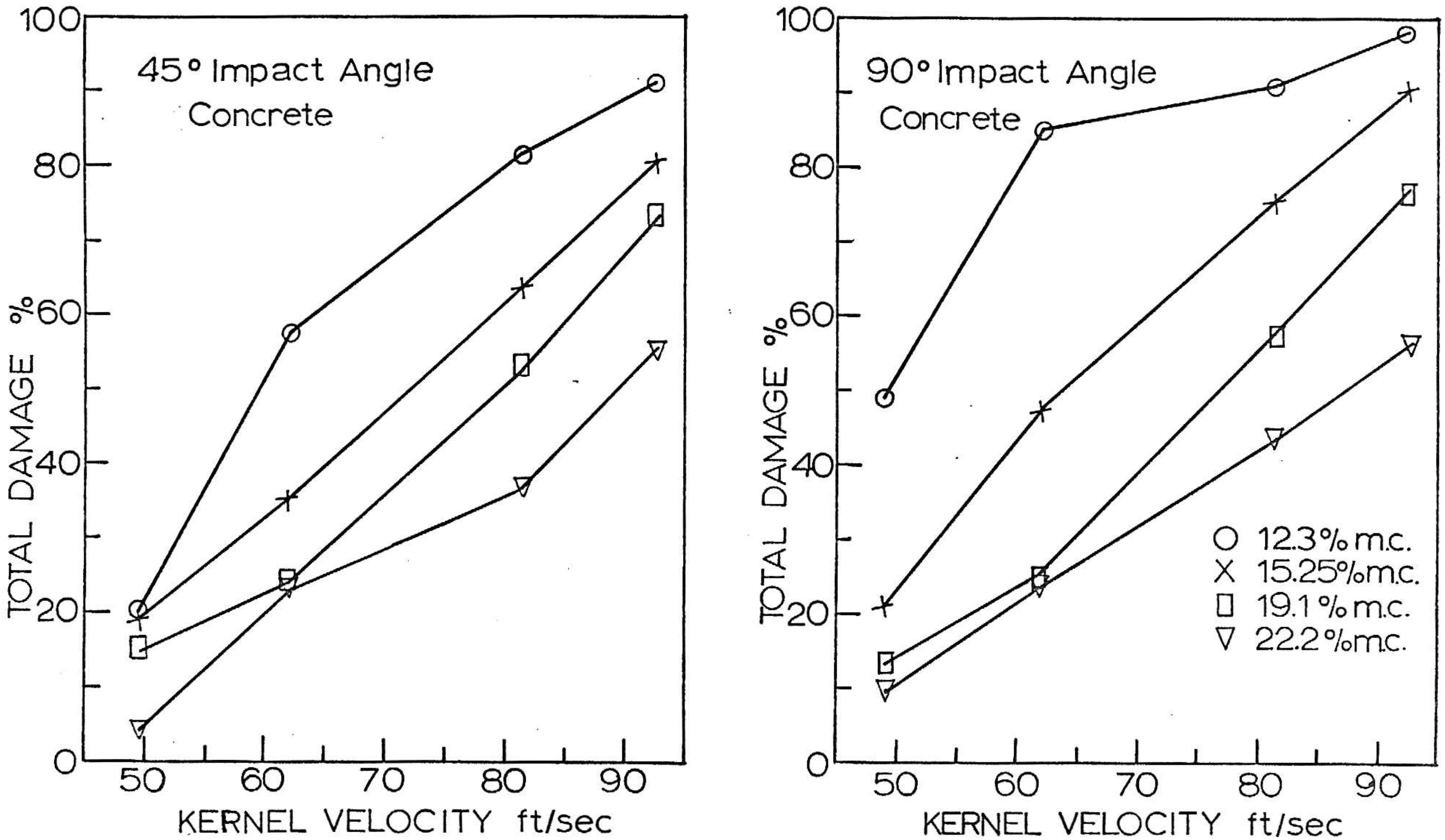


Figure 5.--Total damage for all sizes and/or shapes combined versus kernel velocity for concrete at different moisture contents.

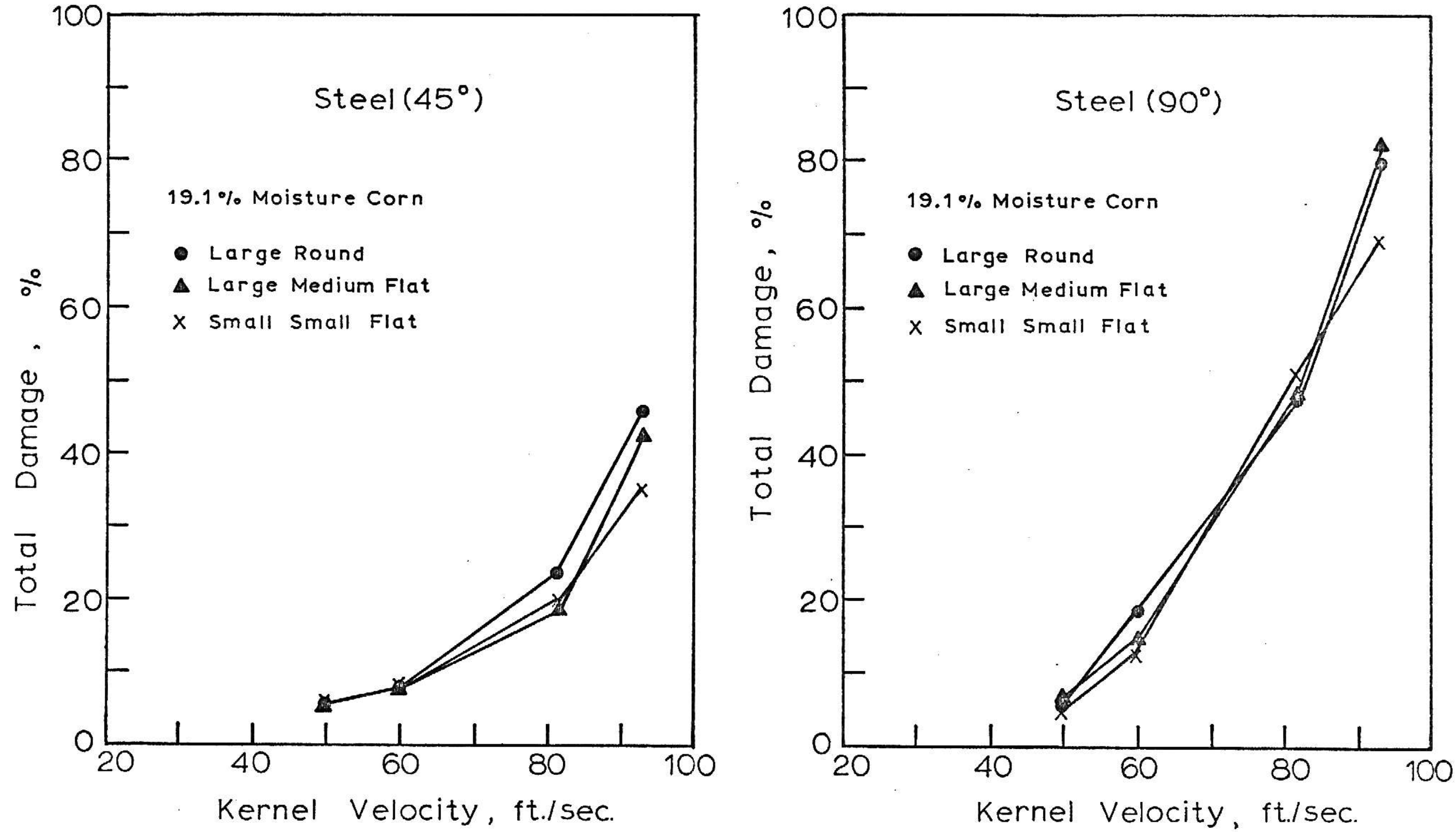


Figure 6.--Total damage for small-small flats, large-medium-flats, and large-round kernels versus kernel velocity for 19.1% moisture corn.

Through the use of the transformations it was possible to find a more significant fit. The predicted equations of best fit for the various moisture levels were chosen by using the statistic R-squared which is a measure of the "goodness of fit". It is interesting to note that exceptionally high R-squared's of .85 to .95 were observed for the steel and concrete surfaces while R-squared's of only .44 to .56 were obtainable for urethane. Plates 8 through 13 show the prediction equations with sample data points plotted.

EXPLANATION OF PLATE IX

Prediction equation of best fit for the 90^{o} impact angle for urethane.

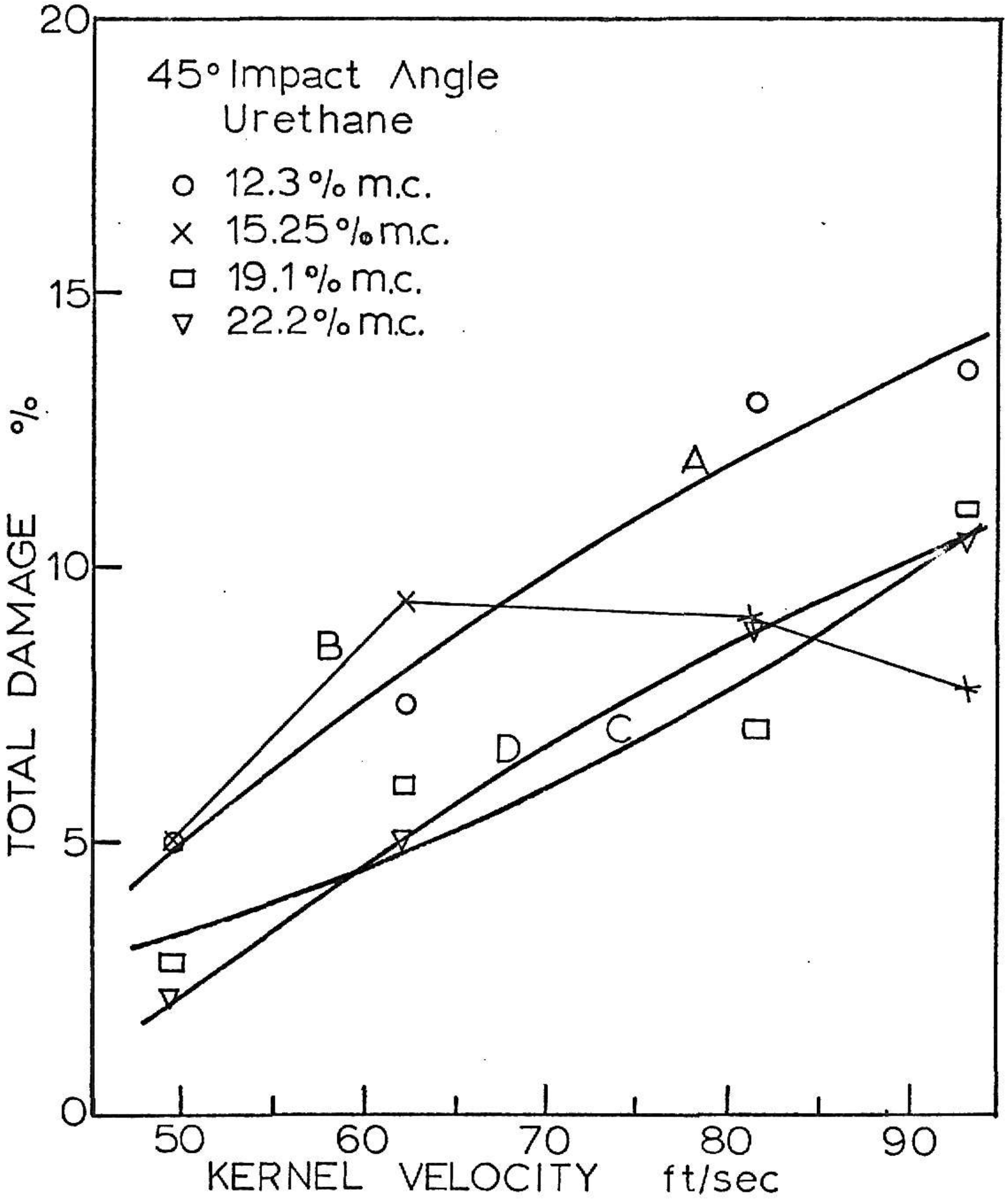
$A = 5.2666 + .00137\ V^2$ $R^2 = .4434$

No predicted equation for B

$C = -0.22546 + .0013761\ V^2$ $R^2 = .5583$

$D = 0.86117 + .0012985\ V^2$ $R^2 = .5586$

PLATE VIII


45° Impact Angle
Urethane
○ 12.3% m.c.
× 15.25% m.c.
□ 19.1% m.c.
▽ 22.2% m.c.
A
B
C
D
TOTAL DAMAGE %
KERNEL VELOCITY ft/sec
0
5
10
15
20
50
60
70
80
90

EXPLANATION OF PLATE VIII

Prediction equation of best fit for the 45^{o} impact angle for urethane.

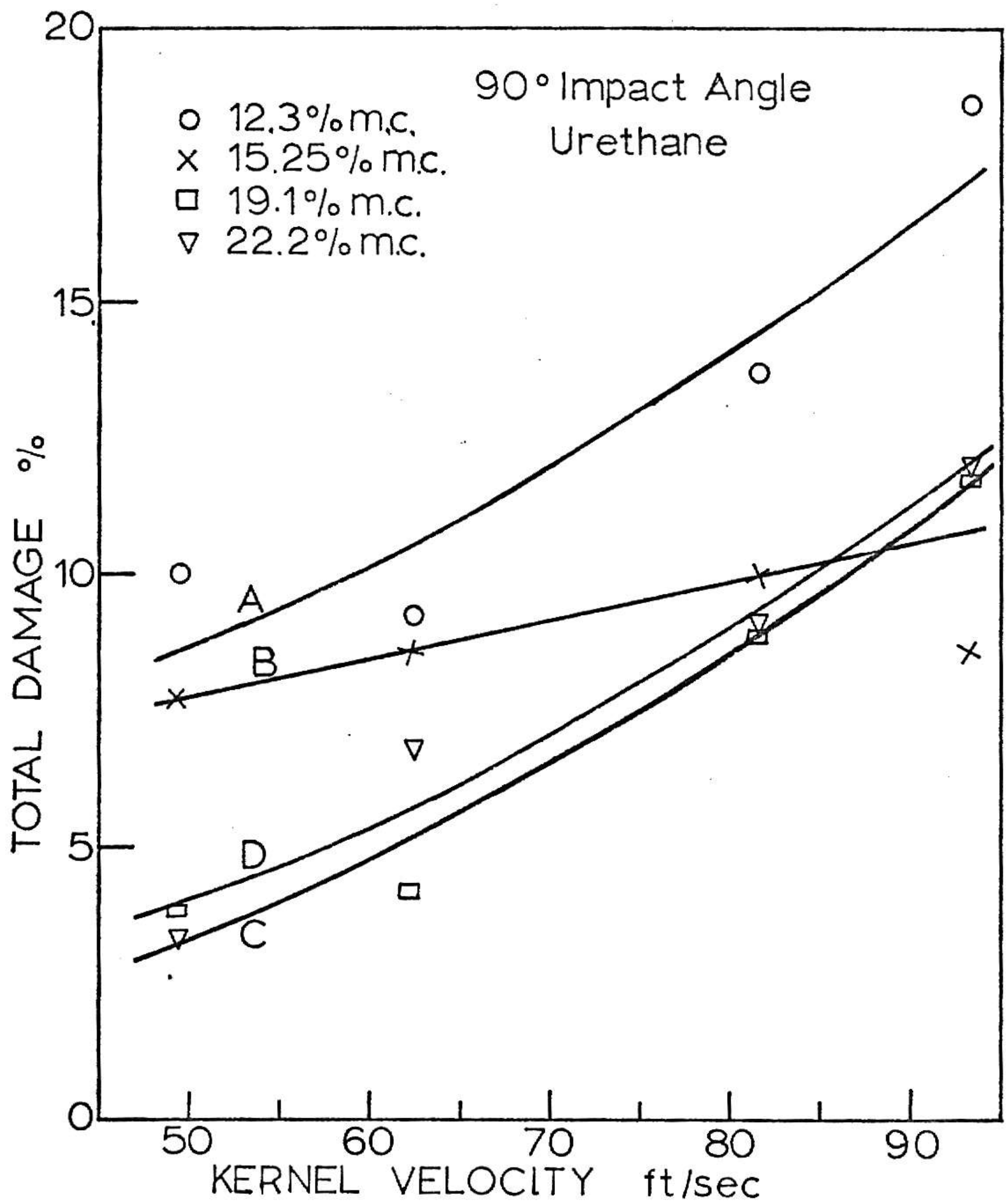
$A = -52.83725 + 14.763 \ln V$ $\quad R^2 = .4710$

No predicted equation for B

$C = 0.41372 + .001168\ V^2$ $\quad R^2 = .5462$

$D = -50.2968 + 13.427 \ln V$ $\quad R^2 = .5685$

PLATE IX

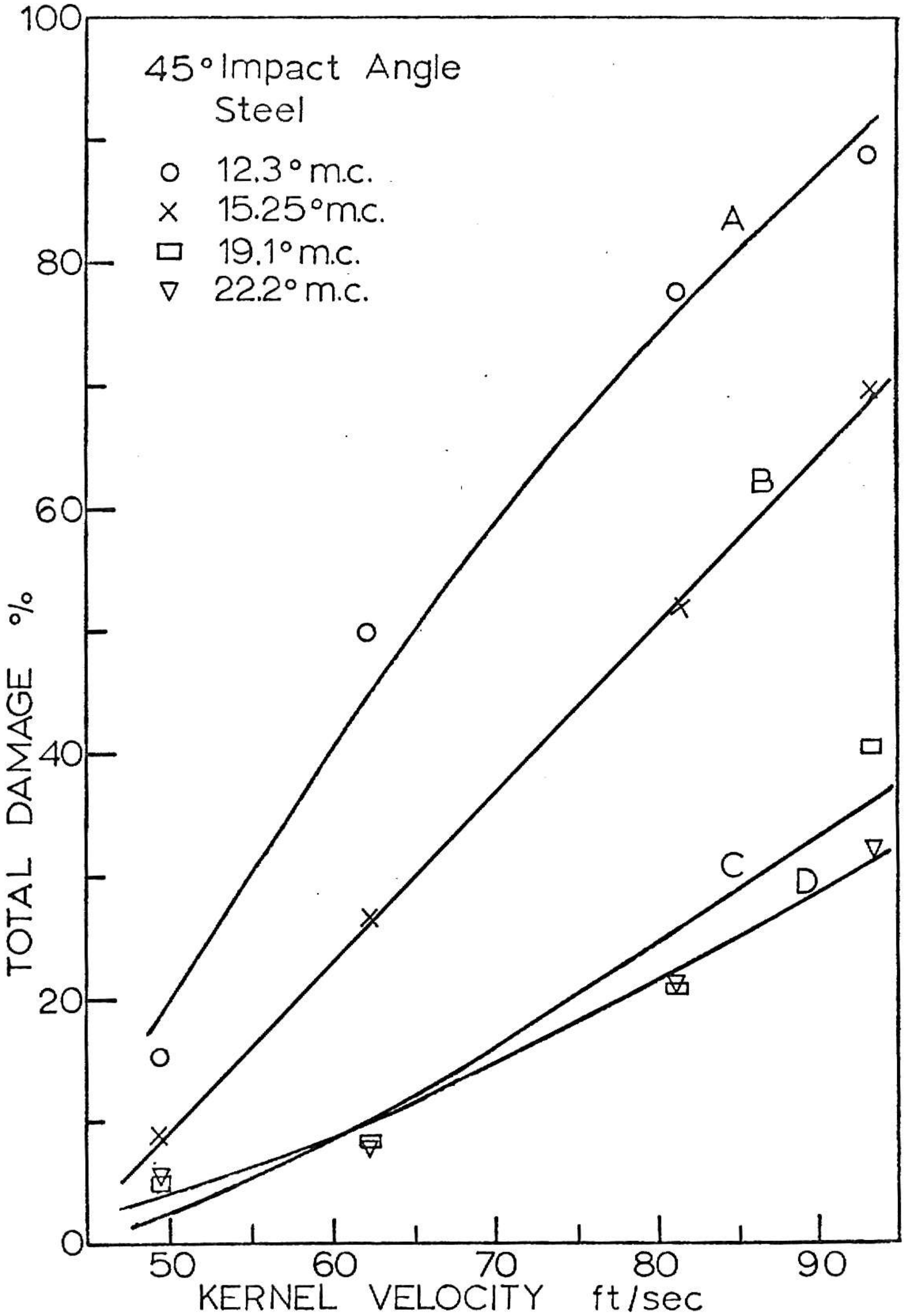

90° Impact Angle
Urethane
o 12.3% m.c.
x 15.25% m.c.
□ 19.1% m.c.
▽ 22.2% m.c.
A
B
C
D
20
15
10
5
0
50
60
70
80
90
TOTAL DAMAGE %
KERNEL VELOCITY ft/sec

EXPLANATION OF PLATE X

Prediction equation of best fit for the 45^{o} impact angle for steel.

$A = -432.248 + 115.5626 \ln V$	$R^2 = .9506$
$B = -59.7966 + 1.3781 V$	$R^2 = .8848$
$C = -11.6524 + .0055918 V^2$	$R^2 = .8250$
$D = -6.934 + .0044122 V^2$	$R^2 = .7803$

PLATE X

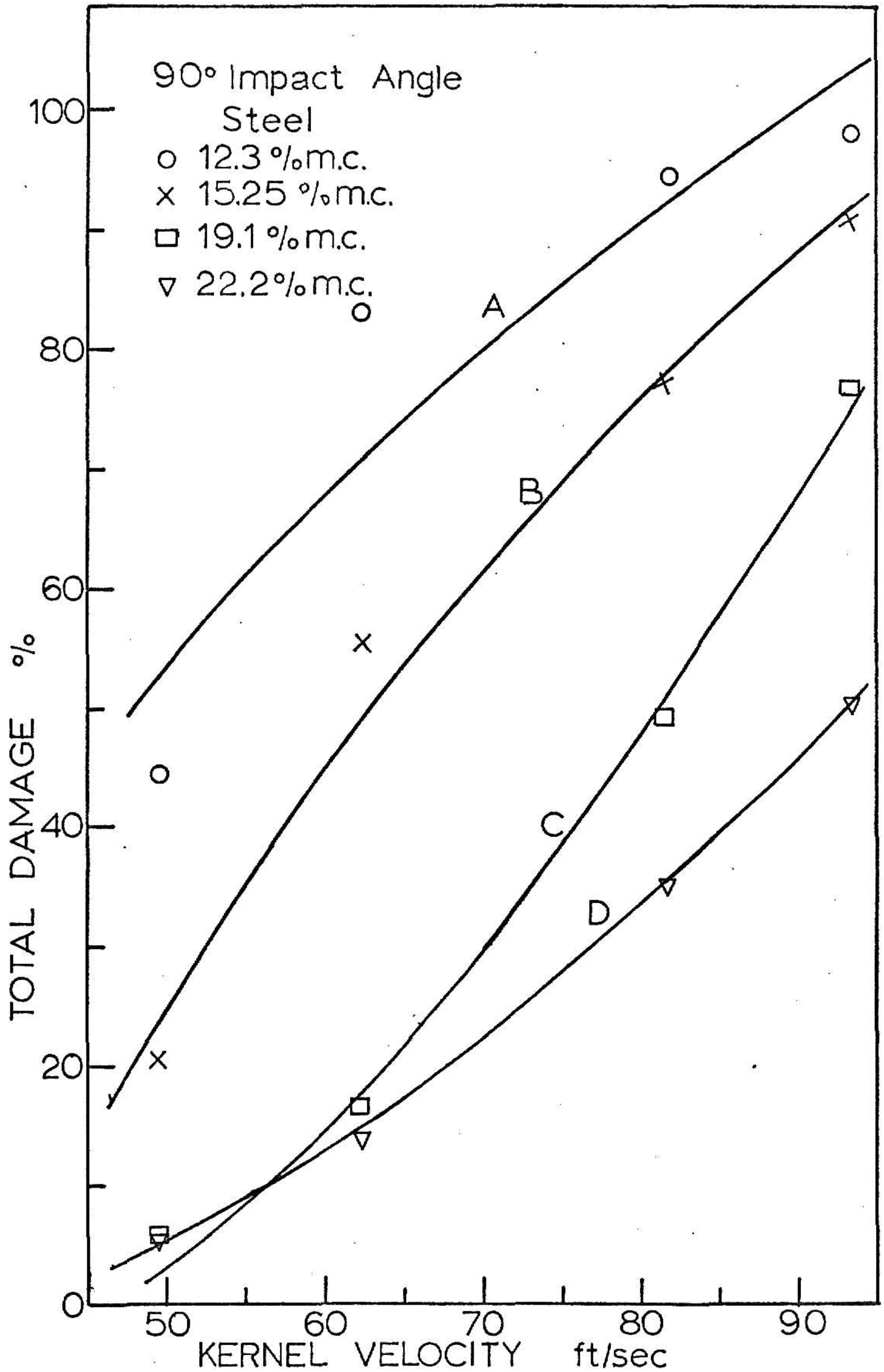


45° Impact Angle
Steel
o 12.3° m.c.
× 15.25° m.c.
□ 19.1° m.c.
▽ 22.2° m.c.
A
B
C
D
TOTAL DAMAGE %
KERNEL VELOCITY ft/sec
100
80
60
40
20
0
50
60
70
80
90

EXPLANATION OF PLATE XI

Prediction equation of best fit for the 90^{o} impact angle for steel.

$A = -260.189 + 80.208 \text{ Ln } V$	$R^2 = .8177$
$B = -392.054 + 106.644 \text{ Ln } V$	$R^2 = .9167$
$C = -26.68213 + .01171 \ V^2$	$R^2 = .9483$
$D = -14.16985 + .0074632 \ V^2$	$R^2 = .9298$


90° Impact Angle
Steel
○ 12.3 %m.c.
× 15.25 %m.c.
□ 19.1 %m.c.
▽ 22.2%m.c.
A
B
C
D
TOTAL DAMAGE %
0
20
40
60
80
100
50
60
70
80
90
KERNEL VELOCITY ft/sec

EXPLANATION OF PLATE XII

Prediction equation of best fit for the 45^{o} impact angle for concrete.

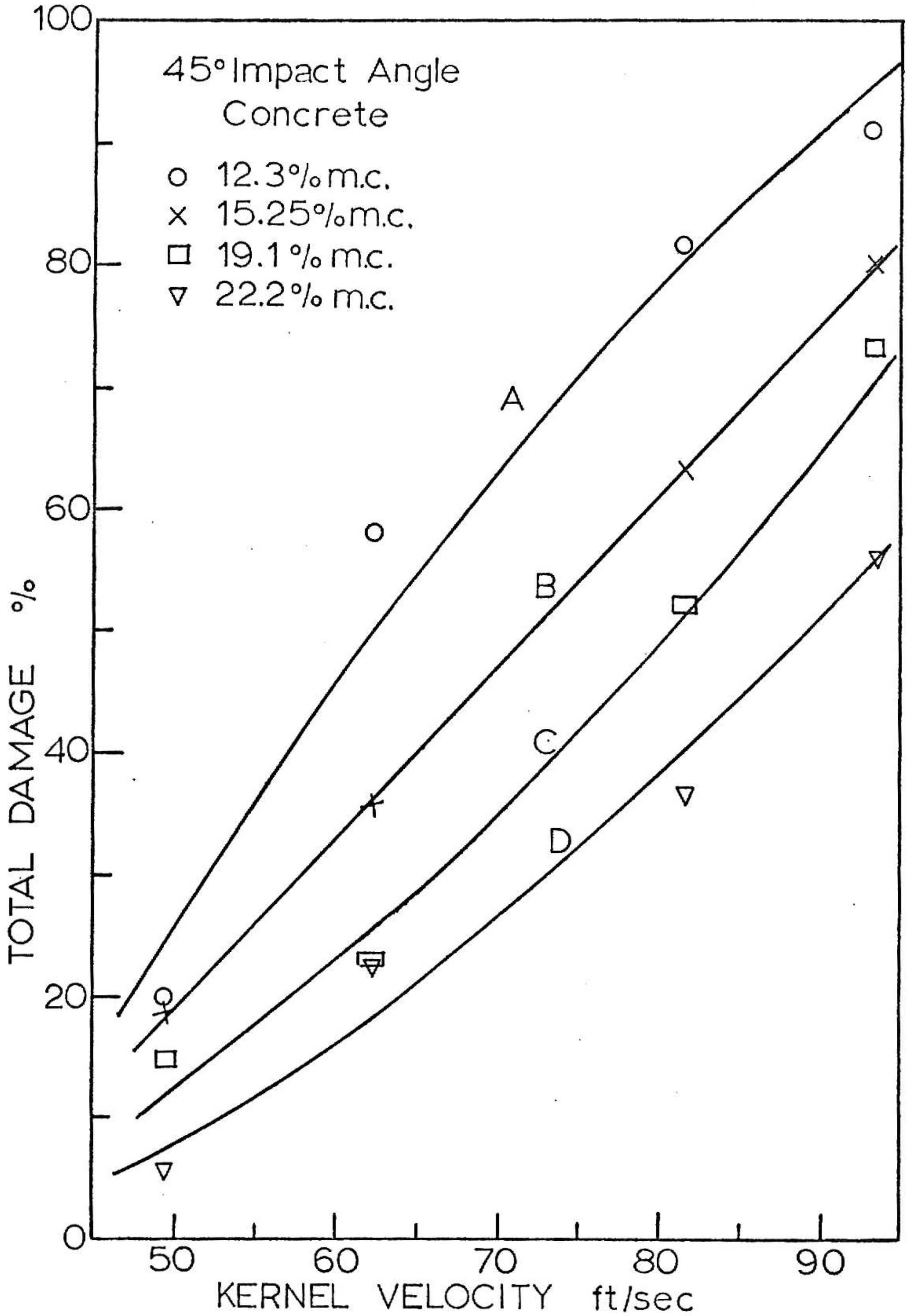
$A = -407.59 + 110.86 \ln V$ $\quad R^2 = .9436$

$B = -51.537 + 1.41307\ V$ $\quad R^2 = .9538$

$C = -11.210 + .009475\ V^2$ $\quad R^2 = .9273$

$D = -11.30205 + .0077032\ V^2$ $\quad R^2 = .8936$

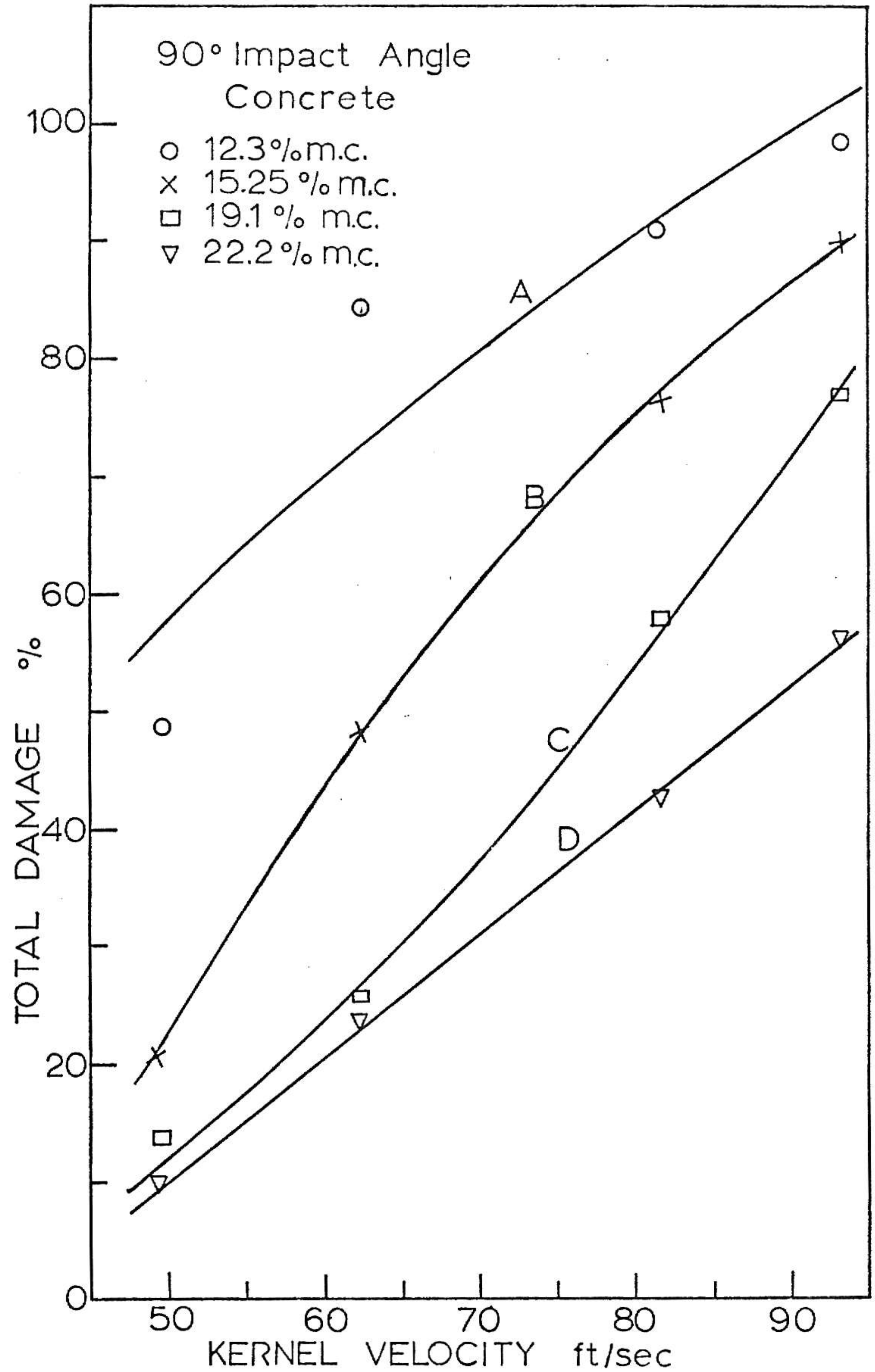
PLATE XII


45° Impact Angle
Concrete
○ 12.3% m.c.
× 15.25% m.c.
□ 19.1 % m.c.
▽ 22.2% m.c.
A
B
C
D
TOTAL DAMAGE %
KERNEL VELOCITY ft/sec
0
20
40
60
80
100
50
60
70
80
90

EXPLANATION OF PLATE XIII

Prediction equation of best fit for the 90^{o} impact angle for concrete.

$A = -224.20 + 71.875 \ Ln \ V$	$R^2 = .8029$
$B = -406.51 + 109.628 \ Ln \ V$	$R^2 = .9591$
$C = -14.154 + .01158 \ V^2$	$R^2 = .9359$
$D = -43.136 + 1.0655 \ V$	$R^2 = .8696$


90° Impact Angle
Concrete
○ 12.3% m.c.
× 15.25 % m.c.
□ 19.1 % m.c.
▽ 22.2 % m.c.
A
B
C
D
TOTAL DAMAGE %
0
20
40
60
80
100
50
60
70
80
90
KERNEL VELOCITY ft/sec

DISCUSSION OF RESULTS

The results of the statistical analyses show that all main factors except size and/or shape are very highly significant. All interactions except those which include size and/or shape were also significant. The experimental effects of the main factor on total damage are discussed individually.

Kernel Velocity

Kernel velocity had the most significant effect on total damage for each surface condition. In general, as the kernel velocity increased, total damage increased. For a particular moisture level, the percentage broken kernels of the total damage increased as the kernel velocity increased.

The kernel velocity range observed begins at the upper limit of pneumatic conveying velocities and extends upward to include corn stream velocities that are attained from falling in grain silos (11). The experimental kernel velocity range observed produced percentage total damage which ranged from 5% to 98%. Below kernel velocities of 50 feet per second there appears to be very little variation in total damage for the moisture content range between 19.1% and 22.2% with expected total damage ranging from 1% to 15%.

Moisture Content

In general, as the moisture content decreased, the percentage of total damage increased. The moisture content determined the extent of total damage for each experimental velocity level.

At moisture contents of 19.1% m.c. and 22.2% m.c., little difference in total damage was observed for the three lower velocity levels. Total damage was linear with respect to kernel velocity for the moisture content range between 14% moisture content and 19% moisture content.

The moisture content of 12.3% seemed to produce a greater extent of total damage than the 15.25% level and was a function of the natural logarithm of kernel velocity.

A velocity-moisture content interaction seems to be responsible for the different velocity functions which best describe the experiment results for the various moisture content levels.

Size and/or Shape

The size and/or shape factor had the least significant effect of the main factors on total damage. The plot of total damage versus kernel velocity for the different size and/or shape classifications (Figure 6) illustrates that there is very little difference in percentage total damage between small small flats, large medium flats, and large rounds. For this reason, the three size and/or shape classifications were combined for analysis of data.

The small small flats were the least sensitive to total damage for both of the impacting angles. The mean total damage was the highest for the large medium flat kernels. Future investigations of impact damage could be conducted without considering the size and/or shape of the corn.

Surface

Surface effect had the most significant effect on total damage for the complete investigations. Urethane decreased the mean total damage by 5 times over steel and by 6 times over concrete. The mean total damage for concrete was significantly greater than that for steel.

Specifically, urethane appears to absorb a large enough portion of the impacting force to reduce the probability of cracking or breaking. Its smooth surface texture also aids in reducing damage. Total damage observed for kernels impacted against urethane was composed mostly of cracked kernels.

The smooth surface texture of the steel surface was probably responsible for lower total damage for steel than that observed for concrete. The surface texture of the concrete surface was similar to that of a concrete grain silo.

Impacting Angle

By reducing the angle of impact from 90° to 45° a reduction in the mean total damage of 25 percent was observed for all observations. There was very little difference in total damage between the 90° impacting angle and the 45° impacting angle for urethane.

An interaction between the 45° impact angle and the concrete surface produced total damage results that were similar to the 90° impact angle results. The rougher surface texture of the concrete block produced a greater degree of shear which accounted for the increased damage for the 45° impacting angle.

The most pronounced difference in total damage was observed for the steel surface were total damage was reduced by 33 percent with impaction against the 45^o angle.

Damage

Impact damage to corn kernels is slightly different in appearance from that of damage to corn kernels due to pneumatic conveying. Most of the damage classified as "cracked" were small cracks that occurred either at the tip cap or at the dent of the kernel. The majority of the cracks were longitudinal cracks that originated at the tip cap of the kernel and spread upwards.

At the higher moisture contents kernels that were classified as broken were mostly kernels that were not severely damaged but did have a part of the kernel missing. Decreasing the moisture content caused the severity and intensity of cracked kernels to increase with a larger portion of the total damage being classified as "broken". Broken kernels were either kernels with a complete corner sheared off or kernels which were longitudinally split into several pieces.

Data Plots

In analyzing the data the observed values of total damage was plotted on normal, log-normal and log-log function paper in an attempt to present the data in its best form. Because the total damage is related to varying functions of kernel velocity for different moisture levels, the individual regression lines were used to predict the percent total damage. The regression equation predicted for the steel and concrete surfaces provided exceptionally good fits with R-squared's of between .85 to .95. The results of the prediction equations are valid only for the kernel velocities investigated. For this reason it is impossible to extrapolate backwards to lower kernel velocities in order to predict percent total damage that could be observed.

It was found that percent total damage versus kernel velocity plotted as an experimental straight line on log-probability paper and that different moisture content levels tended to be parallel to each other as illustrated in Plate 14 and Plate 15. The physical significance and meaning are unknown but the results are perhaps more than just coincidental.

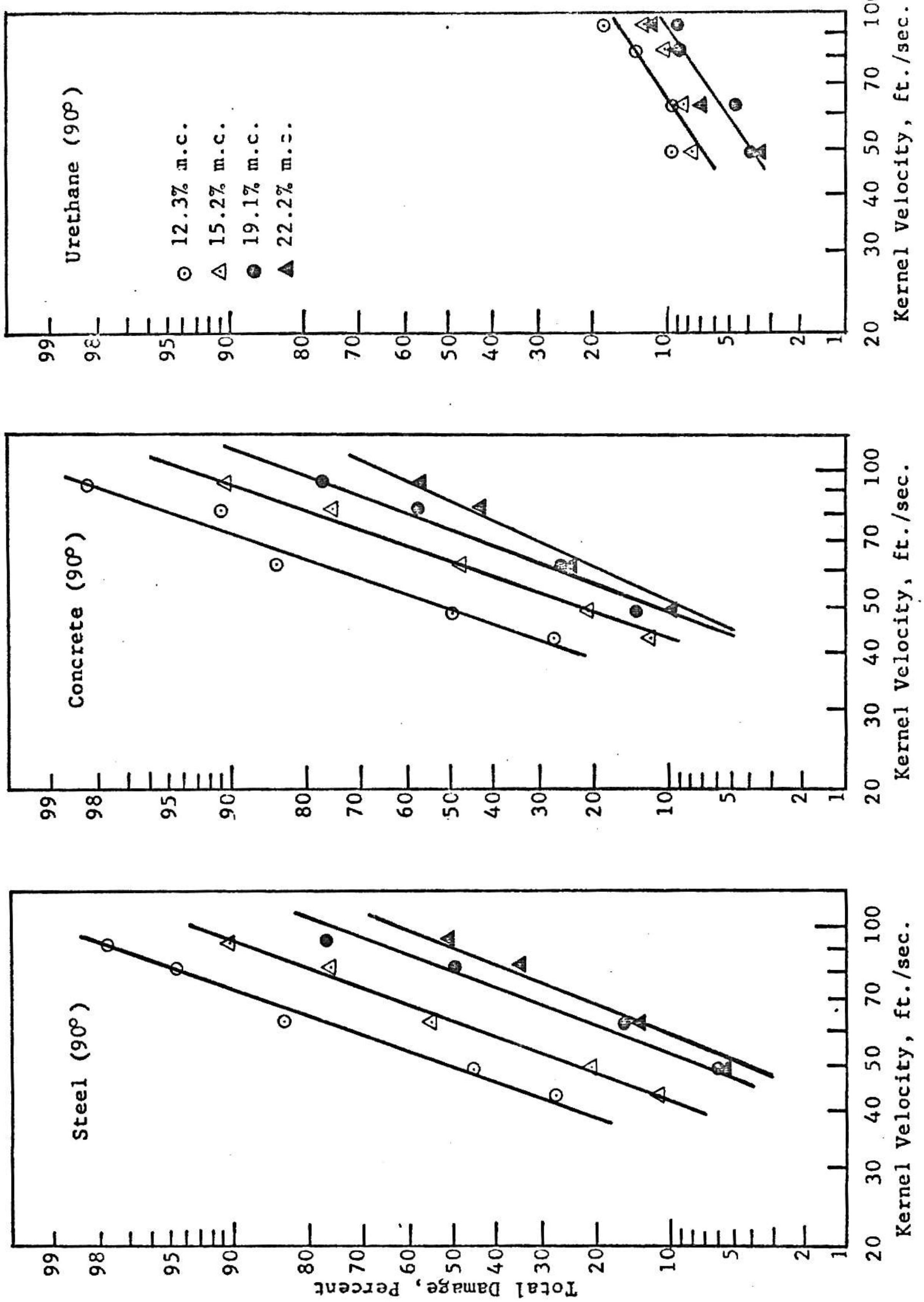
Radioactive Tracer Technique

The radioactive tracer technique was a method employed in an attempt to find a more economical and quicker means of obtaining the velocity of the corn being conveyed. The results of the highspeed camera and the tracer technique compare favorably within experimental variance. All preliminary indications show this method to give accurate results with a minimum amount of time.

EXPLANATION OF PLATE XIV

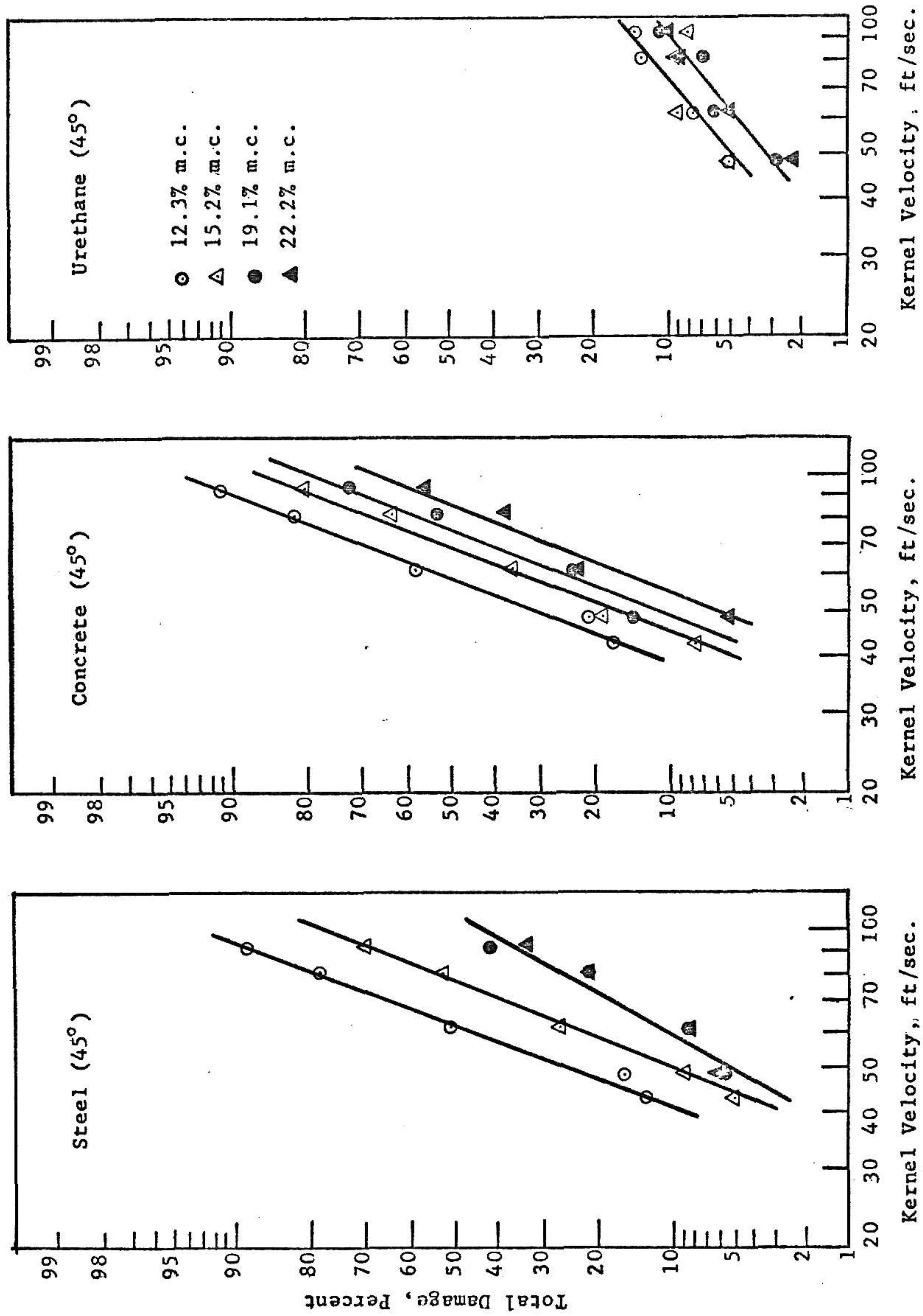
Total damage at 90^{o} impacting angle versus kernel velocity on log-probability function paper.

PLATE XIV


Urethane (90°)
12.3% m.c.
15.2% m.c.
19.1% m.c.
22.2% m.c.
Concrete (90°)
Steel (90°)
Total Damage, Percent
Kernel Velocity, ft./sec.

EXPLANATION OF PLATE XV

Total damage at 45^{o} impacting angle versus kernel velocity on log-probability function paper.


Urethane (45°)
12.3% m.c.
15.2% m.c.
19.1% m.c.
22.2% m.c.
Concrete (45°)
Steel (45°)
Kernel Velocity, ft/sec.
Total Damage, Percent

CONCLUSIONS

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

1. Kernel velocity, moisture content, surface condition, angle of impact, size and/or shape were all found to be significant factors in causing impact damage to corn kernels. Surface condition and kernel velocity were the most significant effects.
2. As the moisture content of the corn kernels decreased from 22.2% to 12.3%, the percentage of total damage increased. The moisture content range of 19.1% to 22.2% had similar total damage results. Decreasing the moisture content below 15.25% greatly increased the percentage of total damage.
3. Kernel velocity was responsible for the majority of total damage. Increasing kernel velocity caused increased total damage.
4. Urethane surface reduced total damage by 5 times compared to steel and 6 times compared to concrete.
5. Reducing the angle of impact from 90^{o} to 45^{o} reduced the mean total damage by 25% for all observations. Total damage at the 45^{o} impact angle for concrete did not seem to be significantly different than that at 90^{o}.

6. Most broken kernels were usually split longitudinally. As the moisture content was lowered and the kernel velocity increased, kernels classified as "cracked" became cracked to a greater extent.

SUGGESTIONS FOR FUTURE RESEARCH

Future investigations should be conducted in a similar manner as this one to study impact damage for corn that is mechanically shelled or for corn that is artificially dried at various drying temperatures.

The highspeed photography film should be viewed to obtain coefficient of restitution values for corn kernels impacting off of surfaces of steel, concrete, and urethane.

Further studies should be made in an attempt to explain the straight line representation of total damage versus kernel velocity on log-probability function paper. The log-normal distribution parameters should be estimated for the results of this investigation.

Further attempts to describe the results of impact damage using a Beta-distribution function appear promising and need to be considered. In order to estimate the distribution parameters, a complete range of total damage from 0% to 100% is needed for each moisture level. For this reason, additional tests should be run using higher kernel velocities for the higher moisture corn and lower kernel velocities on the lower moisture corn.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to his major advisor, Dr. Teddy O. Hodges, Professor of Agricultural Engineering, for his thoughtful guidance and excellent advice throughout the course of this investigation; to Dr. Do Sup Chung, Assistant Professor of Agricultural Engineering, for his unlimited support and endless encouragement; to Professor Harry A. Converse for his guidance while conducting the investigation; to Dr. George H. Larson, Head of Agricultural Engineering Department, for his cooperation and to the USDA Personnel for their assistance.

The author wishes to thank Dr. Jason C. Annis, Mechanical Engineering Department, and Dr. Harry B. Pfost, Grain Science and Industry, for their suggestions as members of his advisory committee.

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APPENDIX I

Broken damage and total damage for the complete investigation.

Table 8.---Impact Damage--Urethane

Moisture	Kernel velocity	90*		45*	
		Broken	Total damage	Broken	Total damage
Percent	(f.p.s.)	Percent	Percent	Percent	Percent
Large rounds					
1 (22.2)	49.51	2.0	4.0	0.00	0.00
	62.25	3.33	6.66	2.67	8.00
	81.61	3.33	10.67	.67	8.00
	93.07	3.33	14.00	3.33	10.00
2 (19.1)	49.51	.83	5.00	.83	2.50
	62.25	0.00	2.50	.83	6.66
	81.61	0.00	6.67	.83	5.83
	93.07	.83	15.00	3.33	10.83
3 (15.25)	49.51	2.50	8.33	.83	5.00
	62.25	1.67	7.50	.83	7.50
	81.61	1.67	10.00	.83	9.17
	93.07	2.50	8.33	1.67	6.67
4 (12.3)	49.51	0.0	10.0	.83	4.17
	62.25	0.0	8.33	0.00	6.67
	81.61	2.5	13.33	1.67	9.17
	93.07	4.17	15.00	2.50	10.83
Small small flats					
1 (22.2)	49.51	0.0	1.33	0.0	1.33
	62.25	2.67	5.33	4.00	5.33
	81.61	2.00	6.67	2.00	11.33
	93.07	3.33	10.00	6.00	12.00
2 (19.1)	49.51	1.67	3.34	.83	3.33
	62.25	0.00	5.83	.83	5.83
	81.61	2.50	10.00	1.67	7.50
	93.07	5.00	6.67	5.00	10.00
3 (15.25)	49.51	.83	5.83	0.00	6.67
	62.25	.83	7.50	.83	9.17
	81.61	1.67	7.50	1.67	10.83
	93.07	5.00	10.00	2.50	6.67
4 (12.3)	49.51	0.00	7.50	1.67	5.83
	62.25	2.5	11.67	2.5	6.67
	81.61	4.17	11.67	5.83	15.83
	93.07	10.00	20.00	4.17	10.83
Large medium flats					
1 (22.2)	49.51	.67	4.67	0.00	3.34
	62.25	3.33	8.67	0.67	1.67
	81.61	2.00	10.67	1.33	8.00
	93.07	3.33	12.00	2.67	8.67
2 (19.1)	49.51	.83	3.33	.83	2.50
	62.25	0.00	4.17	.83	5.83
	81.61	1.67	10.00	2.50	7.50
	93.07	1.67	9.17	6.67	12.50
3 (15.25)	49.51	2.50	9.17	.83	3.33
	62.25	4.17	10.83	4.17	11.67
	81.61	1.67	12.50	.83	7.50
	93.07	2.50	7.50	5.00	10.00
4 (12.3)	49.51	.83	12.50	.83	5.00
	62.25	1.67	7.50	2.50	9.17
	81.61	5.00	15.83	7.50	14.17
	93.07	5.83	19.17	8.33	19.17

*Average value of three replications.

Table 9.--Impact Damage--Steel

Moisture	Kernel velocity	90*: Broken	90*: Total damage	45*: Broken	45*: Total damage
Percent	(f.p.s.)	Percent	Percent	Percent	Percent
Large rounds					
1 (22.2)	49.51	6.67	8.67	3.33	9.33
	62.25	2.00	16.00	1.33	8.67
	81.61	2.00	36.67	0.00	22.67
	93.07	10.00	56.00	2.67	36.67
2 (19.1)	49.51	1.67	5.84	0.00	5.83
	62.25	.83	18.33	0.00	7.50
	81.61	2.50	47.50	0.83	23.33
	93.07	25.83	80.00	5.83	45.83
3 (15.25)	49.51	4.17	19.17	2.50	10.83
	62.25	7.50	49.17	2.50	22.50
	81.61	25.00	65.00	7.50	45.00
	93.07	58.33	90.00	12.50	55.00
4 (12.3)	49.51	10.83	45.83	.83	11.67
	62.25	40.83	79.17	6.67	43.33
	81.61	78.33	92.50	43.33	75.83
	93.07	87.50	96.67	51.67	81.67
Small small flats					
1 (22.2)	49.51	1.33	4.00	0.00	3.33
	62.25	1.33	10.00	1.33	7.33
	81.61	2.67	29.33	1.33	20.00
	93.07	6.67	43.33	2.67	23.33
2 (19.1)	49.51	0.00	4.17	0.00	5.00
	62.25	.83	12.50	1.67	9.17
	81.61	5.83	50.83	1.67	19.17
	93.07	24.17	69.17	5.83	34.16
3 (15.25)	49.51	3.33	19.17	1.67	10.00
	62.25	13.33	54.17	3.33	24.17
	81.61	44.17	79.17	8.33	47.50
	93.07	50.83	85.83	21.67	74.17
4 (12.3)	49.51	4.17	40.00	.83	16.67
	62.25	52.50	85.00	11.67	52.50
	81.61	83.33	94.17	51.67	77.50
	93.07	94.17	97.50	67.50	91.67
Large medium flats					
1 (22.2)	49.51	2.0	4.67	.67	6.00
	62.25	.67	14.67	2.00	7.33
	81.61	1.33	40.00	.67	20.00
	93.07	4.67	52.67	2.00	38.67
2 (19.1)	49.51	.83	7.50	1.67	5.00
	62.25	.83	15.00	0.00	7.50
	81.61	3.33	49.16	3.33	18.33
	93.07	18.33	82.50	5.83	42.50
3 (15.25)	49.51	2.50	22.50	1.67	5.00
	62.25	16.67	61.67	3.33	31.67
	81.61	44.17	83.33	22.50	62.50
	93.07	69.17	95.00	35.83	78.33
4 (12.3)	49.51	3.33	48.33	4.17	17.50
	62.25	53.33	85.83	17.50	54.17
	81.61	91.67	96.67	49.17	80.83
	93.07	94.17	99.17	71.67	91.67

*Average value of three replications.

Table 10.--Impact Damage--Concrete

Moisture	Kernel velocity	90*		45*	
		Broken	Total damage	Broken	Total damage
Percent	(f.p.s.)	Percent	Percent	Percent	Percent
Large rounds					
1 (22.2)	49.51	4.00	14.00	4.00	7.33
	62.25	.67	24.67	.67	24.00
	81.61	2.67	52.67	.67	38.00
	93.07	9.33	62.00	.67	56.67
2 (19.1)	49.51	0.00	10.00	0.00	15.00
	62.25	2.50	25.00	1.67	29.17
	81.61	.83	55.00	.83	56.66
	93.07	6.67	84.17	1.67	76.67
3 (15.25)	49.51	.83	21.67	.83	21.67
	62.25	6.67	41.67	1.67	33.33
	81.61	27.50	80.00	5.00	64.17
	93.07	42.50	90.83	12.50	78.33
4 (12.3)	49.51	6.67	48.33	.83	21.67
	62.25	40.00	90.83	5.83	55.00
	81.61	54.17	88.33	30.83	82.50
	93.07	78.33	100.00	45.00	88.33
Small small flats					
1 (22.2)	49.51	1.33	8.67	.67	2.67
	62.25	.67	20.67	1.33	21.33
	81.61	2.00	34.67	1.33	30.00
	93.07	6.00	54.00	5.33	54.00
2 (19.1)	49.51	0.00	6.67	1.67	12.50
	62.25	.83	19.16	1.67	19.17
	81.61	4.17	57.50	.83	46.66
	93.07	7.50	70.83	1.67	63.34
3 (15.25)	49.51	0.00	20.00	2.50	15.83
	62.25	5.83	45.83	3.33	41.67
	81.61	20.84	69.17	3.33	60.00
	93.07	37.50	89.17	10.00	75.83
4 (12.3)	49.51	2.50	47.50	1.67	17.50
	62.25	28.33	80.83	5.83	60.83
	81.61	66.67	90.83	35.00	76.67
	93.07	77.50	95.83	55.83	89.17
Large medium flats					
1 (22.2)	49.51	2.67	5.33	0.00	5.33
	62.25	.67	26.00	0.00	24.60
	81.61	4.00	42.00	1.33	41.00
	93.07	4.67	52.67	3.33	56.67
2 (19.1)	49.51	2.50	24.17	0.00	15.83
	62.25	0.00	27.50	0.00	22.50
	81.61	3.33	60.83	0.00	53.33
	93.07	15.00	76.67	2.50	80.00
3 (15.25)	49.51	.83	20.83	.83	19.17
	62.25	4.17	54.17	.83	32.50
	81.61	29.17	77.50	6.67	66.67
	93.07	59.17	91.67	22.50	86.67
4 (12.3)	49.51	7.50	50.83	.83	20.83
	62.25	41.67	82.50	14.17	57.50
	81.61	64.17	93.33	36.67	86.67
	93.07	88.33	99.17	72.50	95.83

*Average value of three replications.

APPENDIX II

Analysis of variance for total damage for the complete investigation and for urethane, concrete, and steel surface.

Table 11.--Analysis of variance for total damage for all treatment combinations.

Source of variation:	df	SS	MS	F
Velocity	3	19.9821	6.6607	2351.47***
Moisture	3	11.8965	3.9655	1399.96***
Classification	2	0.1494	0.0747	26.36**
Surface	2	27.8212	13.9106	4910.94***
Angle	1	1.7949	1.7949	633.66***
V x M	9	1.0287	0.1143	40.35**
V x C	6	0.0323	0.0054	1.90
V x S	6	6.9209	1.1534	407.21***
V x A	3	0.0329	0.0109	3.87**
M x S	6	4.7519	0.7920	279.60***
M x C	6	0.1193	0.0199	7.02**
M x A	3	0.2950	0.0983	34.71**
C x S	4	0.0795	0.0199	7.02**
C x A	2	0.0111	0.0056	1.96
S x A	2	0.9662	0.4831	170.56***
V x M x C	18	0.0904	0.0050	1.77*
V x M x S	18	0.8075	0.0449	15.84**
V x M x A	9	0.4952	0.0550	19.43**
V x C x S	12	0.0272	0.0022	0.80
V x C x A	6	0.0472	0.0079	2.78*
V x S x A	6	0.1403	0.0234	8.25**
M x C x S	12	0.0848	0.0071	2.50**
M x C x A	6	0.0146	0.0024	0.86
ERROR	718	2.0338	0.00283	
TOTAL	863	79.6231		

* Significant at $\alpha = 0.05$

** Significant at $\alpha = 0.01$

*** Very highly significant

Table 12.--Analysis of variance for total damage for urethane surface.

Source of variation:	df	SS	MS	F
Velocity	3	0.19436	0.06478	63.93**
Moisture	3	0.08237	0.02746	27.09**
Classification	2	0.00453	0.00226	2.23
Angle	1	0.01480	0.01480	14.61**
V x M	9	0.04511	0.00501	4.94**
V x C	6	0.00218	0.00363	0.36
V x A	3	0.00481	0.00160	1.58
M x C	6	0.01175	0.00196	1.93
M x A	3	0.00584	0.00195	1.92
C x A	2	0.00302	0.00151	1.49
V x M x C	18	0.01707	0.00095	0.95
V x M x A	9	0.00790	0.00088	0.86
M x C x A	6	0.00960	0.00160	1.58
V x M x C x A	18	0.01986	0.00110	1.09
ERROR	198	0.20067	0.00101	
TOTAL	287	0.62391		

* Significant at $\alpha = 0.05$

** Significant at $\alpha = 0.01$

*** Very highly significant

Table 13.--Analysis of variance for total damage for steel surface.

Source of variation:	df	SS	MS	F
Velocity	3	12.2979	4.0993	1526.06***
Moisture	3	10.1564	3.3855	1260.32***
Classification	2	0.0964	0.0482	17.94**
Angle	1	2.2648	2.2648	843.16***
V x M	9	1.1107	0.1234	45.94**
V x C	6	0.0380	0.0063	2.36*
V x A	3	0.1454	0.0485	18.05**
M x C	6	0.1511	0.0252	9.37**
M x A	3	0.1880	0.0627	23.33**
C x A	2	0.0065	0.0033	1.21
V x M x C	18	0.0971	0.0054	2.01*
V x M x A	9	0.5974	0.0663	24.71**
M x C x A	6	0.0107	0.0018	0.67
V x M x C x A	18	0.0689	0.0038	1.42
ERROR	198	0.5318	0.002682	
TOTAL	287	27.7614		

* Significant at $\alpha = 0.05$

** Significant at $\alpha = 0.01$

*** Very highly significant

Table 14.--Analysis of variance for total damage for concrete surface.

Source of variation:	df	SS	MS	F
Velocity	3	14.4107	4.8036	1765.11***
Moisture	3	6.4096	2.1365	785.08***
Classification	2	0.1279	0.0640	23.50**
Angle	1	0.4814	0.4814	176.90***
V x M	9	0.6805	0.0756	27.78**
V x C	6	0.0194	0.0032	1.19
V x A	3	0.0229	0.0076	2.80*
M x C	6	0.0412	0.0069	2.52
M x A	3	0.2738	0.0913	33.54**
C x A	2	0.0058	0.0029	1.07
V x M x C	18	0.0989	0.0055	2.12*
V x M x A	9	0.2288	0.0254	9.34**
M x C x A	6	0.0212	0.0035	1.30
V x M x C x A	18	0.0586	0.0033	1.19
ERROR	198	0.5388	0.00272	
TOTAL	287	23.4196		

* Significant at $\alpha = 0.05$

** Significant at $\alpha = 0.01$

*** Very highly significant

CORN KERNEL DAMAGE DUE TO HIGH VELOCITY IMPACT

by

DUANE LEE KELLER

B.S., Kansas State University, 1970

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1970

ABSTRACT

The purposes of this investigation were: (1) to study effects of kernel velocities on corn kernel impact damage; (2) to determine the relationship of kernel moisture content to kernel impact damage; and (3) to determine the affect of impact surface characteristics and angle of impact on corn kernel impact damage.

Five main factors were studied: (1) kernel velocities (49.5 fps, 62 fps, 81.6 fps, and 93 fps); (2) moisture content (12.3%, 15.25%, 19.1%, and 22.2%); (3) size and/or shape of kernels (small-small flats, large-medium flats, and large rounds), (4) surface condition (urethane, steel and concrete); and (5) angle of impact (90° and 45°). Corn kernel impact damage was measured by visually inspecting the kernels and classifying broken or cracked kernels as total damage.

Tests were carried out by using a modified pneumatic conveying system to impact the individual kernels against the various surfaces. Kernel velocities were measured by using high speed photography. Sound (undamaged) kernels were used for each test.

The results showed that all main factors except size and/or shape were highly significant in explaining impact damage. Kernel velocity was responsible for the majority of total damage with increasing kernel velocity causing increased total damage. The moisture content determined the extent of total damage for each experimental velocity level. As kernel moisture content

decreased the total damage increased. At moisture contents of 19.1% and 22.2%, little difference in total damage was observed for the lower velocity levels. Total damage was linear with respect to kernel velocity between 14% moisture content and 19% moisture content. Decreasing the moisture content below 15.25% greatly increased the percentage of total damage.

Impact surface effect was highly significant due to the large difference between the effect of urethane and that of concrete or steel. Total damage for urethane was 1/5 of that for steel and 1/6 of that for concrete. Steel and concrete were not significantly different. Reducing the angle of impact from 90^o to 45^o reduced the mean total damage by 25%.

Most broken kernels were usually split longitudinally or had a complete corner chipped off. Percent total damage versus kernel velocity plotted as an experimental straight line on log-probability paper with different moisture content levels tending to be parallel to each other. This is the best representation of the impact damage results but further study of the physical meaning of the log-normal distribution applied to impact damage must be conducted.