CORN DAMAGE BY IMPACT

by

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INTRODUCTION

One of the problems arising as a result of mechanization in production and handling of agricultural products has been mechanical damage to the crop during harvesting and during subsequent handling as well as processing on and off-the-farm.

In mechanical handling of seeds and grains, damage occurs in threshing as well as mechanical conveying by screw conveyor, pneumatic conveyor and other equipment. Damage, as referred to here, is the failure of the product due to either (1) excessive deformation when it is forced through fixed openings or (2) excessive forces when it is subjected to impact against surfaces or objects. This second consideration is the matter of study in this investigation.

Damage to the kernels of seeds and grains could reduce monetary value of products, affect their milling quality, result in greater losses in sifting and could decrease the germination capacity and seedling development. Mechanical damage to the hull of some products increases the possibility of insect and mold development in storage.

The damage resulting from impact forces is usually referred to as cracking which may vary from complete splitting of the kernel to small hairline cracks invisible to the human eye. Even small cracks in the seed coat may allow soil bacteria to enter the seed and destroy the nourishment supply before a plant is established. The factors affecting the extent of grain damage depend upon the history of the crop which involves, (1) variety, (2) stage of maturity, (3) previous storage, (4) handling and drying conditions, and (5) moisture content of the seed. In addition, design and operating characteristics of the machine that subjects the kernels to impact forces also affect grain damage.

All the subjects discussed above apply extensively to the corn industry in the United States as well as many other countries around the world, where corn is a main constituent of the everyday diet. It is estimated that 50 million tons of corn are consumed every year around the world, mostly in the tropical and subtropical areas. While most of these countries do not have a modern technology for corn production at the present time, they are moving forward and will be soon facing some of the side effects that technology brings along with progress and improvement to agriculture.

REVIEW OF LITERATURE

Grain Damage by Impact

One of the most common causes of mechanical damage to agricultural products is shear and impact during mechanical handling. Some of the concepts involved in the mechanics of impact and its implications to agricultural products will be presented in this review.

Mechanics of Impact

The concept of impact is based on the fact that some forces created by a collision are exerted and removed in a very short period of time, known as duration of impact, and that the collision produces stress waves that travel away from the region of contact. No general impact theory has been developed to date. The base of current theories were established by Hertz (1896) who introduced the contact phenomenon for elastic bodies.

Analysis of numerous experiments has shown that the Hertz theory of contact provides a good description of the collision of two spheres or the impact of a sphere against a thick plate only if the materials are hard and the initial velocity is low (Goldsmith, 1960). For soft materials or higher impact velocities, the Hertz theory must be replaced by an analysis accounting for plastic deformation. Among others, the hydrodynamic theory and the theory of plastic strain has been considered (Goldsmith, 1960).

Despite some inconsistencies, the relative simplicity of elastic solutions, using the Hertz law, and the fact that the method provides good correlation with experimental results have been the main reasons for extensive use of this approach.

Four Phases of Impact

Bowden and Tabor (1954) divided the impact of colliding bodies into four phases:

1. Initial elastic deformation during which the region of contact will be deformed elastically and will recover fully without residual deformation.

2. Initial stage of plastic deformation during which the mean pressure (calculated using equations based on the Hertz theory) exceeds the dynamic yield pressure of the material and the resulting deformation will not be fully recovered.

3. Full plastic deformation during which the deformation continues from elastic-plastic to fully plastic until the pressure falls below the dynamic yield pressure.

4. Elastic rebound during which a release of elastic stresses stored in both bodies takes place.

These four phases of impact have been demonstrated through collision experiments by dropping spheres of hard and soft material against another sphere or against flat surfaces (Andrews, 1931; Tabor, 1948; Bowden and Tabor, 1954). Deformation-time curves for the four phases of impact are shown in Figure 1. In the case of perfectly elastic impact an axis of symmetry exists about the point of maximum deformation, while a

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unsymmetrical curve is obtained in the case of elastic- plastic impact. In the case of the perfectly plastic impact, the bodies do not separate.

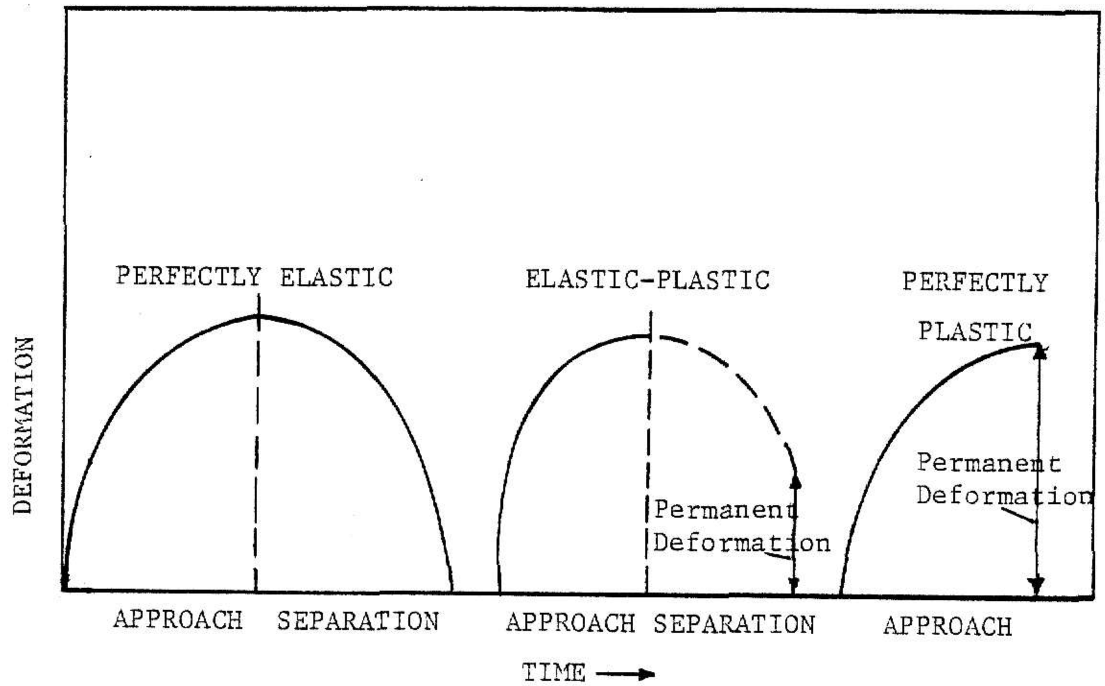

Figure 1. Four Stages of Impact Shown as Deformation-Time Curves (Mohsenin, 1970)

Aerodynamic Characteristics of Grain

The air velocity and the energy required for movement of grain in an air stream are important design criteria for modern harvesters, grain cleaners, pneumatic conveyors and other equipment. Such design criteria should be based on the aerodynamic characteristics of grain.

The aerodynamic drag and terminal velocity of grain has been investigated under two methods. One of these is based on time measurements of single kernels falling from different heights. A curve of length of fall versus time is plotted and numerically differentiated to obtain values of velocity. Newton's law concerning free-falling bodies is then used to find the drag force at each velocity. Terminal velocity is usually obtained by extrapolation of the data.

The second method utilizes a vertical air stream, where a kernel of the grain under study is placed. The air velocity is adjusted until the kernel is suspended with little or no vertical movement. Since the forces acting in the body are then in equilibrium, the air velocity is equal to the terminal velocity of the kernel, and at this velocity, the drag force is equal to the weight of the kernel.

Hawk, Brooker, and Cassidy (1966) conducted investigation on aerodynamic characteristics of three selected grains (wheat, soybeans and corn) using the second method described above.

Results showed that terminal velocity increased as the weight of the particle increased, even if the particle volume remained constant. Table 1 is a summary of the ranges of terminal velocities as determined by Hawk et al. (1966) and as reported by other researchers.

TABLE 1. Terminal Velocities of Selected Grains

	Terminal Velocity (m/s)		
	Wheat	Soybeans	Corn
Hawk et al. (1966)	6.5-8.0	12.1-13.5	8.2-9.9
Uhl and Lamp (1964)	5.8-9.9	9.1-18.3	7.9-12.8
Bilanski (1964)	8.8-9.9	-	-
Bilanski et al.(1962)	9.0	13.5	10.6

The terminal velocities credited to Bilanski et al.(1962) were determined from data obtained by dropping kernels of grain in still air (First method). Equations were derived for each grain expressing distance as a function of time and terminal velocity. A single value of terminal velocity was then found for each grain that minimized the mean square deviation of the experimental points from the analytical curve.

Based on the work of Fiscus et al.(1971) with shelled corn, the free fall velocity of grain streams can be expected to greatly exceed the terminal velocity of individual kernels. They found that at drop distances of about 15.2 m (50 ft) the velocity attained by a falling stream of grain exceeded the terminal velocity of a single kernel and that a stream of shelled corn falling from a 30.5 cm (12 in) orifice reached a velocity of 20.3 m/s (4000 ft/min) at 25.9 m (85 ft) with the grain still accelerating.

Effect of Impact Velocity, Moisture Content and Mechanical Properties of Grain on the Extent of Damage

King and Riddolls (1960) conducted research on damage to wheat and peas in threshing operations using different combinations of drum speed and concave clearance. They concluded that when wheat or peas are harvested for seed, even at fairly low moisture contents, visible and invisible damage can be kept to low levels by avoiding excessive high drum speeds. Since close concave clearance appears to have little effect except at very high drum speeds, total damage can be reduced to a minimum by keeping the drum speed low and getting the necessary degree of threshing by adjusting the clearance between drum and concave.

Extensive investigation conducted by Zoerb (1960) on mechanical properties of grain revealed the moisture content as the factor that most influenced the properties of grain, with all of the strength properties generally decreasing as the moisture content increased. However, energy required for seed rupture by impact was shown to increase as the moisture content increased.

Mitchell and Rounthwaite (1964) studied the resistance of two varieties of wheat to impact induced by striking the individual grains with a rotating hammer. Germination tests of visually undamaged grains showed that the speed of impact was the main cause of damage. At hammer speeds beyond 16.7 m/s (3280 ft/min) the damage increased, with about 75 percent of the grain being damaged at speeds above 35.6 m/s (7000 ft/min). At lower levels of moisture, increasing impact speed increased the amount of visually damaged grain, as expected, due to brittleness of the grain. Increasing impact speed also reduced germination capacity of the apparently undamaged grain with a marked effect on grain with higher moisture content. The relationship between percentage of undamaged grains and impact speed was given by the following approximate equation

$$y = 94 + 39\ S - 1.6\ S^2$$

where y is percent of undamaged grain and S is impact speed in ft/min x 10^{-2}. While the above equation accounts for impact speed only, statistical analysis showed that impact speed accounted for 97.3 percent of the variation among the undamaged grain as compared to only 93.5 percent when moisture levels alone were included in the analysis.

Bilanski (1966) attempted to express breaking strength and damage to seed in terms of impact forces and energy. In his experiment, the grain was dropped one at a time, into the path of a rotating paddle revolving at speeds similar to a threshing cylinder. The energy imparted to the grain was calculated from $K E = 1/2\ m\ (rw)^2$, where m is the mass of the grain, r is the distance between the center of rotation and the point of impact with the grain, and w is the angular velocity of the paddle in rad/second. Seeds were also subjected to lower rate of impact by holding individual grains on an anvil and striking them with a pendulum of known potential energy. By increasing or decreasing the levels of impact until all of the grains broke at the upper level and remained unbroken at the lower level, the upper and lower limits of strength were determined. Twelve settings with 20 samples tested at each setting were tried for each of the five diferent grains investigated. Criteria for damage were visible cracks of the seed, cracks on the seed coat of the soybeans, cracked hull in oats, or the excessive deformation in the case of high moisture grain. Results of this investigation showed that size, moisture content and orientation of the grain all influenced its damage resistance. The two larger grains (corn and soybeans) required a greater amount of energy to cause damage than did the smaller grains.

Under both low and high velocity impact, more energy was required to damage the grains having a higher moisture content than those having a lower moisture content. A high moisture grain which takes a greater amount of energy to break is not as resistant to deformation as a low moisture grain. If hardness of grain is defined as resistant to deformation, then addition of moisture to grain reduces hardness.

At lower impact velocities, where the grain could be positioned on the anvil, Bilanski (1966) found that orientation also influenced the breaking strength. Zoerb (1960) and Arnold and Roberts (1967) also reported the effect of orientation on damage, but results are not conclusive. While each type of grain reacted somewhat different to the various tests, in general larger grains or grains with higher moisture content required greater amount of energy to damage. However, requirement of a larger amount of energy to break a grain does not necessarily mean higher load as energy is a function of both force and deformation. As noted by Bilanski, in actual threshing operations, similar grains could probably withstand greater impact energies since the hulls and straw also would act as impact absorbers, leaving less energy to be absorbed by the grain.

Leonhardt et al.(1961) investigated the relationship between the impact energy absorbed by sorghum seed and resulting mechanical damage to seed. In their tests the kernel was shot with a spring loaded gun at a known velocity against a cantilever beam with strain gages mounted at its base. After the impact, the seeds were planted and the extend of damage was evaluated by means of germination tests. Figure 2 shows the plotting of damage against impact velocity at different levels of moisture content.

As seen from these graphs, the number of damaged seeds increased with either an increase in the impact velocity or a decrease in the moisture content of the kernel or both. This trend increased rapidly at velocities greater than 13.72 m/s (2700 ft/min). A relationship between energy absorbed and corresponding seed damage, however, is not given. It

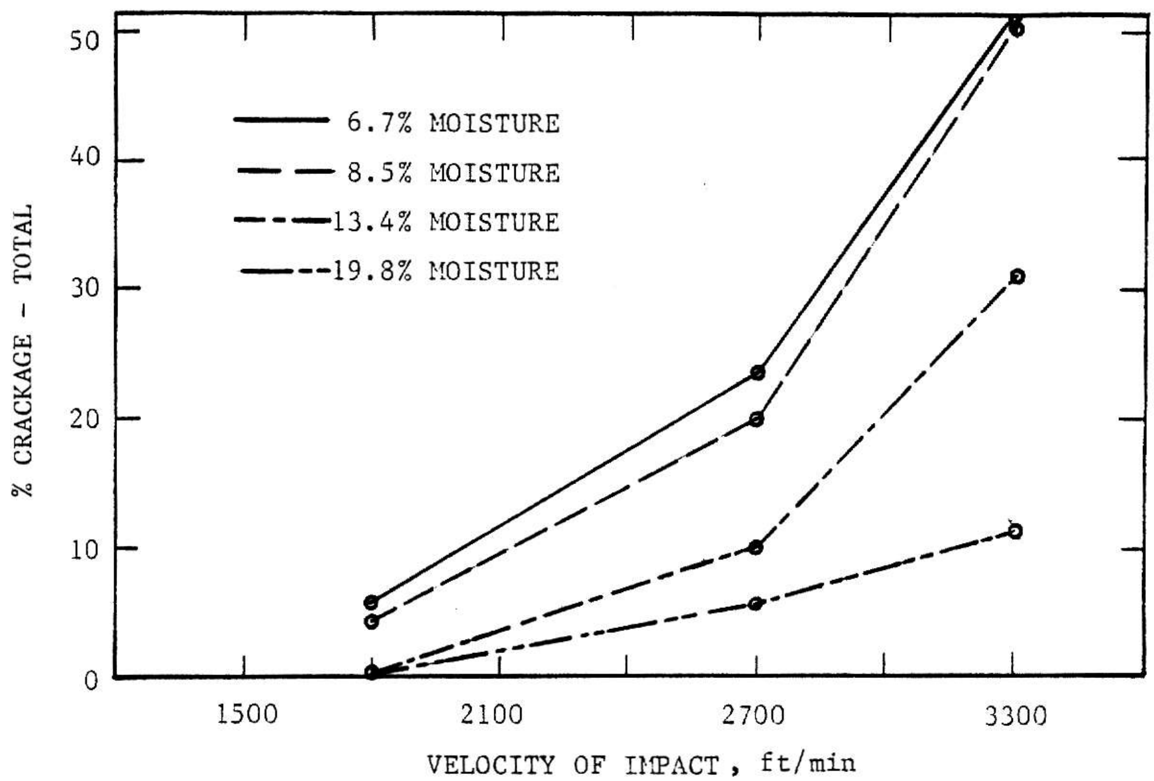

Figure 2. Damage to Sorghum Seeds as Affected by Moisture Content and Impact Velocity (Leonhardt et al., 1961)

was only reported that at an impact velocity of 16.76 m/s (3300 ft/min), seeds initially absorbed from 93 to 96 percent of their initial kinetic energy. The energy was calculated from the known mass and initial velocity of the seed using the equation $K E = 1/2 m v^2$.

Louvier and Calderwood (1967) 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 the 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 surface to 45 degrees. The amount of breakage was significantly higher for rice at 11 percent moisture content than at 13 percent.

Chung (1969) 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 in causing damage to corn. Lower moisture contents resulted in greater amount of damage. Size and/or shape also proved to be a significant factor in corn damage.

The influence of high velocity impact on the extent of damage to grain has been little investigated through the years, but increasing rates of harvesting and handling, and extensive use of high speed equipment have turned this subject into an important matter to consider in future research.

High velocity impact in cottonseed germination has been reported by Clark et al. (1969). Results of this work showed that the optimum cottonseed moisture content for minimum germination reduction fluctuated around 8 to 10 percent, wet basis, and that the maximum seed impact velocity to assure at least 80 percent germination and low seed crackage was 25.3 m/s (4980 ft/min). These tests also showed that visible damage and germination reduction are not necessarily directly related in the cottonseed,and while moisture content was found to affect the extent of impact damage, no direct relationship could be established.

The effect of high velocity impact on naturally dried, hand-shelled corn was investigated by Keller et al. (1972). Kernel velocities ranging from 15.1 m/s (2970 ft/min) to 28.3 m/s (5580 ft/min) were used in running the tests, which were carried out using a modified pneumatic conveying system. Corn kernels of different moisture content, size and shape were impacted against surfaces of concrete, steel and urethane, and the resulting damage was then measured by visually inspecting the kernels and classifying broken or cracked kernels as total damage. The results showed that all factors, except size and shape, significantly affected the extent of impact damage on corn. Kernel velocity was found to be the most significant factor in causing damage to the kernels, with increasing kernel velocity leading to increased total damage. When plotted against kernel velocity on log-probability paper at different levels of moisture content and impact angle, percent of total damage could be represented as an experimental straight line. However, a relationship explaining impact damage as a function of the main factors investigated was not given.

INVESTIGATION

Objectives

The objectives of this investigation were:

1. To study damage to corn due to impact as affected by:

   a. Kernel velocity

   b. Grain moisture content

   c. Impact surface characteristics

   d. Angle of impact

2. To develop a relationship between corn damage due to impact and the variables mentioned above for each surface under study.

Experimental Design

Because of its efficiency and broad scope, a factorial design was chosen as the experimental design for this investigation. Four independent variables were studied: kernel velocity, moisture content, impact surface and angle of impact. Table 2 summarizes the different levels of each experimental variable.

TABLE 2. Levels of Experimental Variables

Variable	Levels			
	1	2	3	4
Kernel Velocity (m/s)	17.84	21.86	26.50	29.75
Moisture Content (%)	12.0	15.5	19.0	-
Surface (material)	Urethane	Steel	Concrete	-
Impact Angle (degrees)	45	90	-	-

Including all different levels, 72 (4x3x3x2) treatment combinations were tested and 3 replications of each treatment effect were run, for a total of 216 tests, each test consisting of 40 previously selected sound kernels.

The range of kernel velocities was chosen according to the results of previous research in related areas. Fiscus et al. (1971) found that a stream of shelled corn falling from a 30.5 cm orifice reached a velocity of 20.3 m/s at 25.9 m, and at this point the grain was still accelerating. Keller et al. (1972), investigating the effect of high velocity impact on corn damage, used kernel velocities ranging from 15 m/s to 28.3 m/s. In general, the range of velocities used was representative of most of the phases of corn movement: harvesting, hauling, handling, processing, etc. The range of moisture contents also attempted to include the levels at which corn is moved. Impact surfaces used represent the possible types of surfaces (steel, concrete) found in commercial operations of the corn industry.

Materials and Equipment

A modified pneumatic conveying system located in the Agricultural Engineering laboratory (at KSU) was used in the experiment to obtain the desired kernel velocities. The main components of the system, as shown in Figure 3, are an air blower, airflow meter, steam jet syphon, air-inlet duct, conveying pipe, impact surface and collection trap.

The air blower is a MD-3 Lobe Rotary Positive pump (Model 3200, Series 11) the main function of which was to supply part of the air volume required to convey the corn kernels through the system. At maximum pressure of 82.73 kPa (12 psig) and temperature of 177 ^{o}C (350 ^{o}F) the blower was able to deliver its maximum air capacity, which was controlled by varying the output of the power unit with a Reeves Variable Speed Drive.

A Fisher and Porter flowrator, model 10 A 1027, was used to adjust the volumetric flow rate of air to the desired levels. This instrument was calibrated to measured 0.085 cu m/s (180 cu feet/min) of air at a 100 percent reading at an average air temperature of 37.8 ^{o}C (100 ^{o}F)

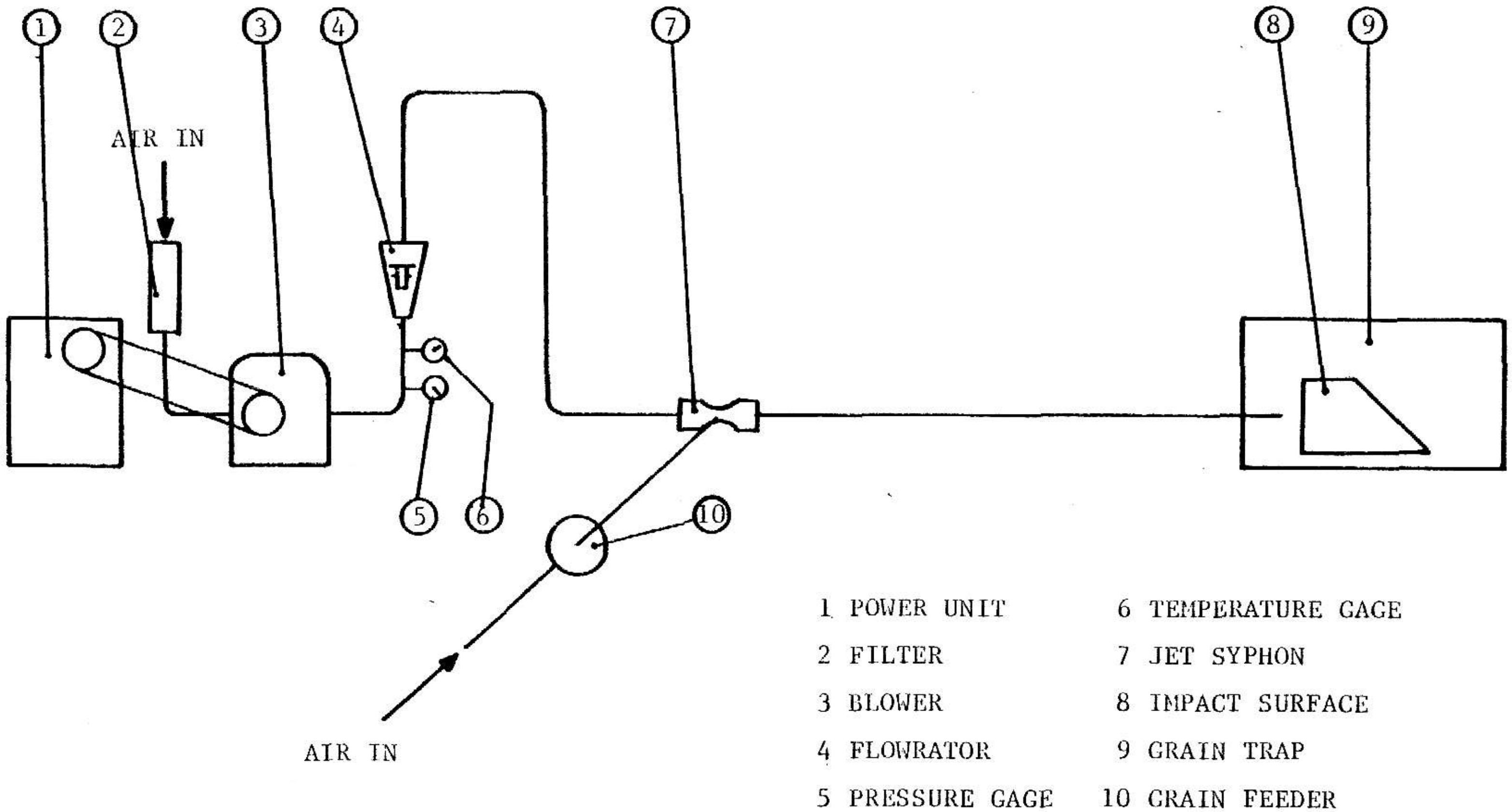

FIGURE 3. Schematic Diagram of the Experimental Conveying System.

and system pressure of 13.79 kPa (2 psig).

A 63.5 mm (2.5 in) jet syphon (Model 4 PG 455, type 60 nozzle) located in the conveying line was used to accelerate the kernels to the required velocities. A Drop-Through Airlock Feeder (Model DEF-76) was connected to the syphon end of the jet, and through it the kernels were manually dropped one at a time, into the system. Since an increase in the volume of air was needed to obtain the higher kernel velocities, a 87.9 mm (3.46 in) diameter duct 1.22 m long, was connected to the feeder in order to take additional air into the system. The conveying line consisted of an aluminum pipe, 48.3 mm in diameter and 4.1 m long, that discharged the corn kernels against the impact surface.

Two materials, steel and concrete, were chosen as impact surfaces to simulate the actual surface conditions found in commercial operations. A third surface, urethane, was used as a mean of comparison to the extent of damage associated with the other surfaces. A rectangular piece of a steel sheet, 3.2 mm x 203.2 mm x 228.6 mm mounted on a plywood backing, 18.1 mm (3/4 in) thick, was used as the steel surface. The urethane surface was a piece of 6.4 mm x 228.6 mm x 304.8 mm polyelastomer mounted in a 18.1 mm plywood backing, and the concrete surface was simulated by a 20.3 cm x 20.3 cm x 40.6 cm (8 in x 8 in x 16 in) smooth concrete block with a surface texture similar to that of a concrete silo. A wood frame was used to allow the surfaces to be interchanged and placed at either 45 or 90 degrees impact angle with respect to the conveying line, and a screen box was also built to prevent the kernels from dispersing after impact.

Mechanically shelled yellow dent corn (1980 harvest), provided by the USDA Grain Marketing and Research Center was used for running the impact tests. An Aeroglide batch drier (Aeroglide Corporation/Machinery Manufacturers, serial No. 25498-1) was used to artificially dry the corn -at a temperature of 82.2 ^{o}C (180 ^{o}F)- to the desired levels of moisture content required for the tests; and a Motomco moisture meter (Model 919, Serial No F-320) was then used to determine the respective moisture content of the corn, corrected for temperature differences.

In classifying the corn damage a strand sizer shaker Model No. G 7009 7 equipped with a 4.76 mm Official Grain Dockage round-hole sieve was used to separate the broken kernels.

Methods and Procedures

Mechanically-shelled corn, obtained from the USDA Grain Marketing and Research Center, was cleaned and divided in three portions, intended to be used for every level of moisture content in the experiment. The grain was dried to the respective moisture content using an Aeroglide batch drier.

Seventy two samples consisting each of 40 sound kernels were hand picked from corn dried to the desired moisture content. After placing the samples in plastic bags they were divided at random in two groups, corresponding to the two impact angles in the experiment. The division of samples was performed in such a way to obtain three samples (replications) for every combination of impact angle, impact surface and kernel velocity. The samples so divided, were weighted and placed in cold storage at a temperature of 1.7 ^{o}C (35 ^{o}F) until the tests were performed.

In running the actual experiment, the kernels were dropped one by one through the feeder into the system and impacted against the surface previously selected. For each experimental test the flowrator reading, air temperature, system pressure and room temperature were recorded in order to determine the kernel velocity. The 40 kernels collected in the receiving trap were picked up and sieved on the strand sizer shaker using an official 4.76 mm round-hole sieve. After the sieving was completed both portions of grain, the one on the collecting pan (broken kernels) and the one left on the sieve (material size larger than 4.76 mm) were weighed. The kernels left on the sieve were visually inspected for any external damage, and the difference between the weight of the sound kernels left after this inspection and the weight of the original 40 kernel sample was classified as total damage.

Kernel Velocity Determination

As mentioned before, a flowrator was used to determine the amount of air that the pump supplied to the conveying system. The flowrator reading were converted to volumetric units by multiplying by 0.085 cu m/s (180 cu ft/min) and correcting for temperature and pressure differences with respect to original calibration (from manufacturers). The air velocity in the conveying pipe and kernel velocity were determined by using Figures 4 and 5, which were developed by Keller (1970) working with the same equipment and same conditions used in this experiment. For more detailed procedures on kernel velocity measurements refer to

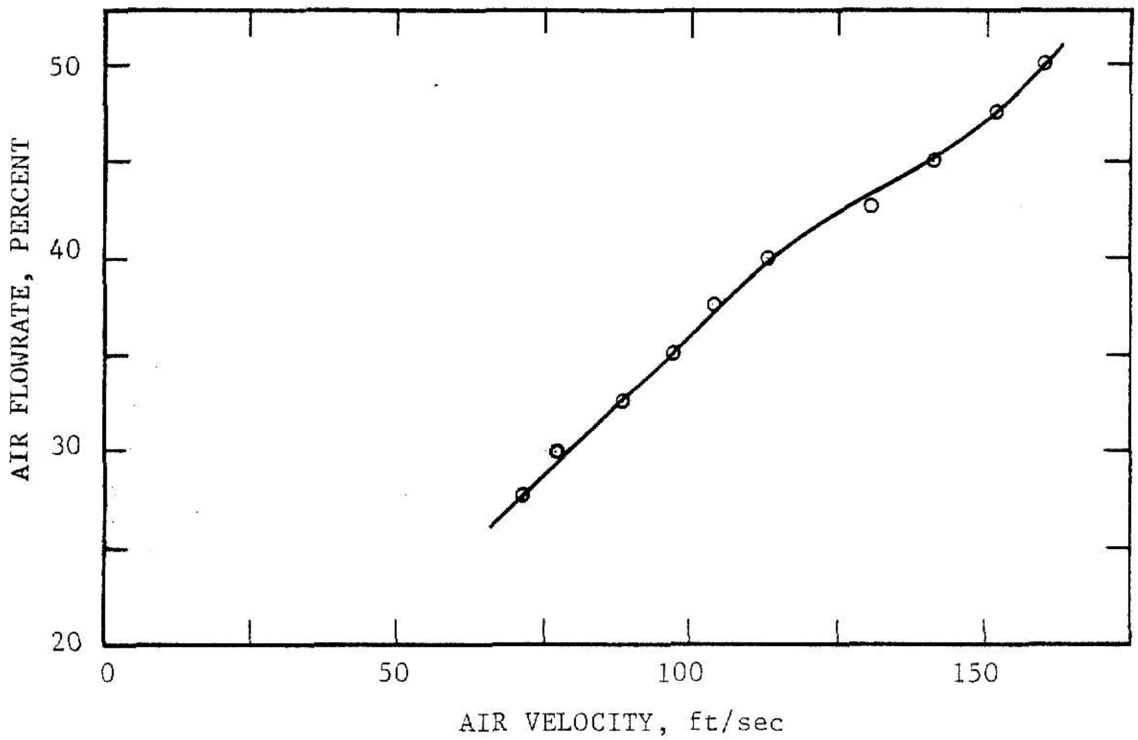

Figure 4. Plot of Flowrator Reading Versus Air Velocity Developed for the Agriculture Engineering Conveying System (Keller, 1970).

Keller (1970) (Also see Keller et al.,1972).

Corn Damage Evaluation

The methods of classifying grain damage due to impact forces varies depending upon the objectives of the researchers. Those persons concerned primarily with the effect of handling upon government grades in marketing (Fiscus et al., 1971; Thompson and Foster, 1963) have used screening operations to establish levels of breakage. Others (Bilanski, 1966; Keller et al, 1972) have been interested in specific types of damage. After impact they visually inspected the individual kernels in each of their samples to determine the percentages of various types of damage. A combination of both procedures was selected to use in this investigation.

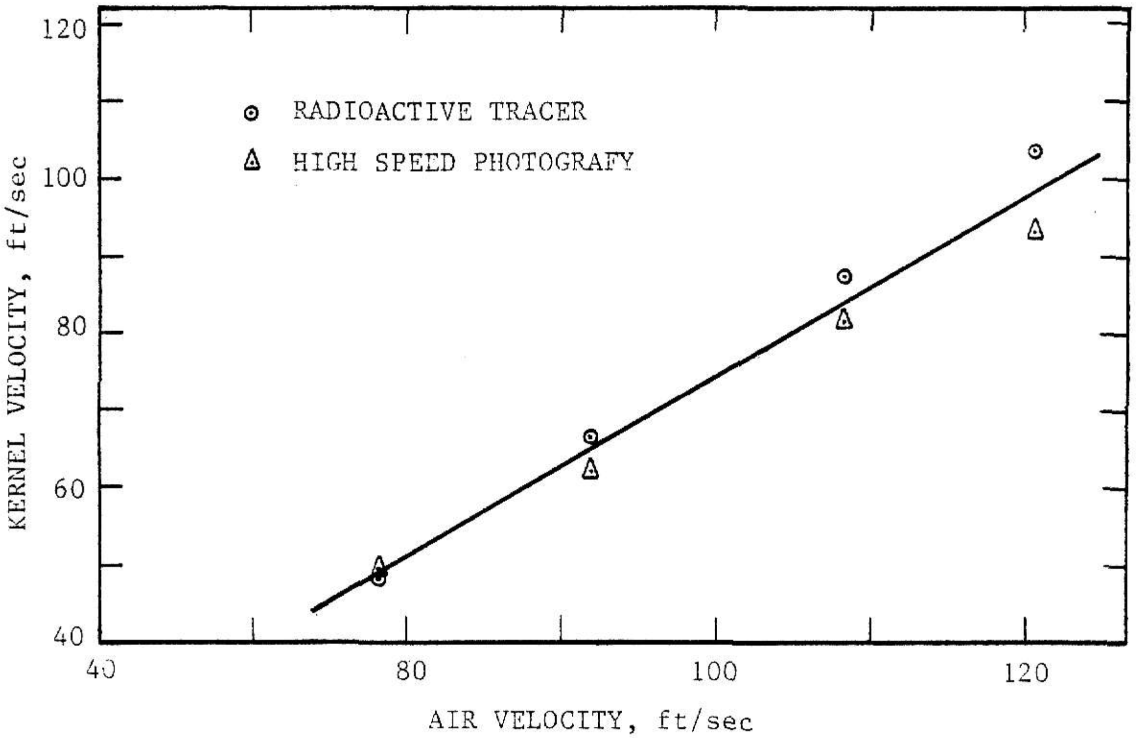

Figure 5. Plot of Kernel Velocity Versus Air Velocity for a Single Kernel Flow (Keller, 1970).

In evaluating damage, corn kernels were classified in three categories:

a. Undamaged: no visual evidence of physical damage.

b. Breakage: broken kernels passing through an official 4.76 mm round hole sieve.

c. Total damage: any visible damage on kernels which includes kernel coat damage, splitted tips, small and large cracks and any broken material.

Figure 6 shows examples of different levels of damage for urethane, concrete and steel obtained from the sieving procedure and visual inspection of the corn samples.

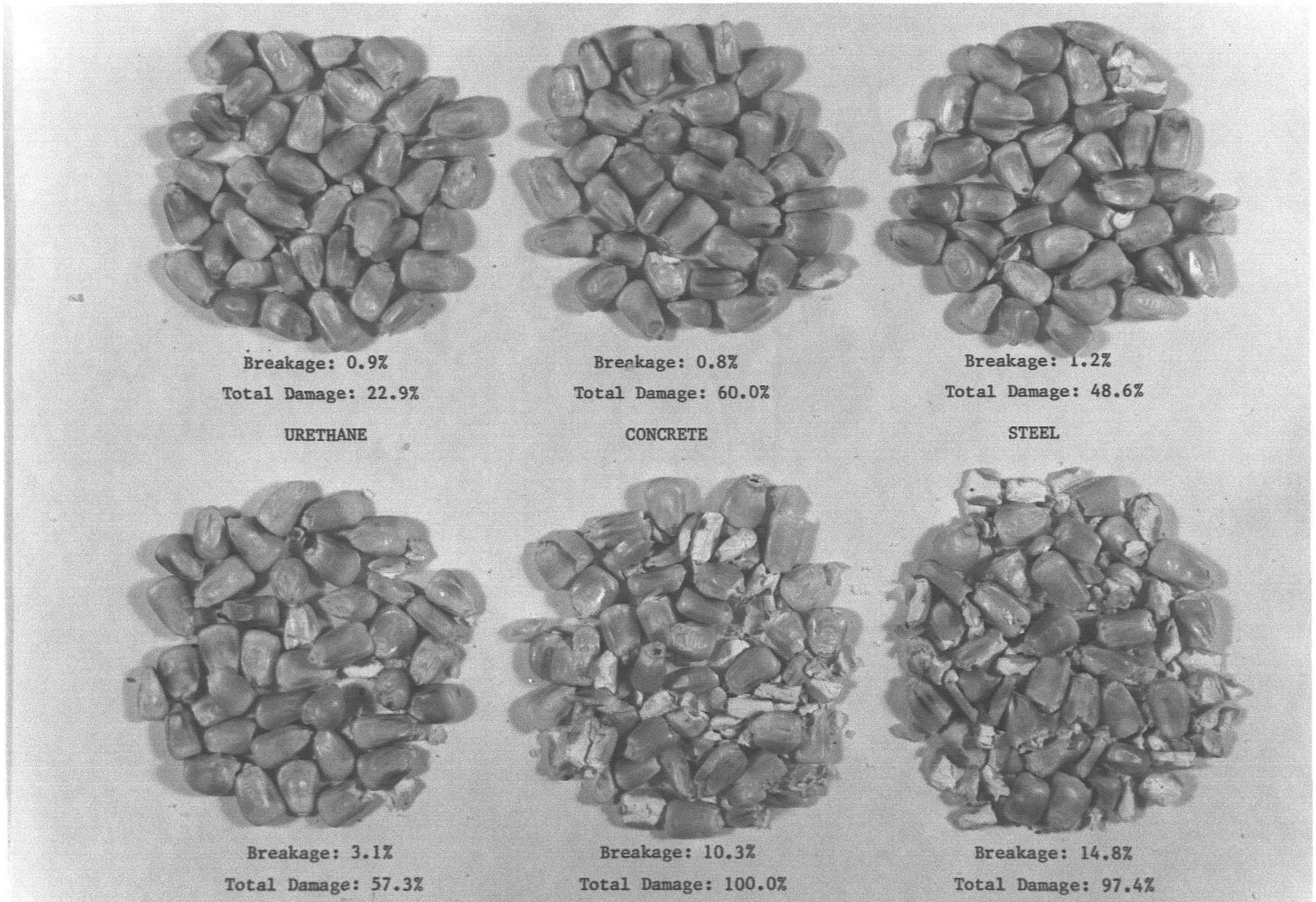

Figure 6. Examples of Different Levels of Corn Damage by Impact.

RESULTS AND DISSCUSSION

The experimental data collected after the tests and after the damage evaluation are presented in Tables 13 through 24 in Bppendix A. Analysis of variance was performed to test the significance of the variables measured with respect to the extent of corn damage resulting during the experimental tests. Multiple Regression analysis was used to determine equations predicting damage as a funtion of kernel velocity, moisture content and angle of impact for each surface under investigation and for both levels of damage: total and breakage.

The results of statistical analysis showed that all main factors tested in the experiment significantly contributed to the extent of breakage and total damage resulting during impact of corn kernels against the test surfaces. A discussion of the effect of each variable in both types of damage by impact is presented individually.

Breakage Damage

Kernel Velocity

Kernel velocity was a very significant factor accounting for the differences in the extent of broken kernels resulting by impact. In general, as the kernel velocity increased, breakage damage increased.

Increasing the kernel velocity from 17.84 m/s to 21.86 m/s (net increase of 4.02 m/s) increased the amount of broken kernels 1.9 times (90 percent) for all observations (2 times for urethane, 2.1 times for concrete and 1.8 times for steel). For all observations, a kernel velocity of 26.50 m/s caused 2.1 times more corn breakage than a kernel velocity of 21.86 m/s (net velocity increase of 4.64 m/s). For urethane, the same velocity increase produced 1.4 times more breakage, for concrete broken kernels increased 2.1 times and for steel 2.4 times more breakage was observed. As the kernel velocity was increased to 29.75 m/s (net increase of 3.25 m/s) the amount of broken kernels increased 1.6 times for all observations (1.8 times for urethane, 1.6 times for concrete and 1.5 times for steel).

As seen from these results, for all observations the amount of broken kernels resulting from impact seems to be linearly related to kernel velocity. In general, the same statement is true for concrete and steel. A more complicated relationship is observed in the case of urethane, where a higher net increment in kernel velocity did not result in a greater increase on broken corn.

The effect of kernel velocity became more evident as the corn moisture content was reduced. At 19.0 percent moisture content, a kernel velocity increment from 17.84 m/s to 29.75 m/s increased the amount of breakage by only 2.2 times. At 15.5 percent moisture content breakage increased 6.2 times for the same velocity increment. At 12.0 percent moisture content the increase in broken kernels was more drastic: 16 times more breakage was observed when kernel velocity was increased to 29.75 m/s.

Moisture Content

Moisture content was the factor that most significantly accounted for the differences observed in corn breakage resulting from impact. In general, as moisture content was decreased the amount of broken corn increased.

Reducing moisture content during the tests from 19 percent to 15.5 percent increased the amount of breakage 1.9 times for all observations. For urethane, corn breakage increased 1.3 times due to the same variation in moisture content. For concrete and steel, the amount of broken corn observed at 15.5 percent moisture content was 2.1 times greater than at 19.0 percent moisture content.

A decrease in moisture content from 15.5 percent to 12.0 percent greatly increased the amount of corn breakage: 2.6 more broken corn was reported for all observations. For urethane, the same decrease in moisture content resulted in 2.1 times more breakage; for concrete the broken kernel damage increased 2.8 times and for steel the same variation in corn moisture produced 2.7 times more broken kernels.

Little or no difference in the amount of breakage was observed among the levels of moisture content tested for the lower kernel velocity, but as the kernel velocity was increased, significant differences in the extent of corn breakage were found among the levels of moisture tested. At a kernel velocity of 21.86 m/s, 30 percent increase in breakage resulted when moisture content was decreased from 19.0 percent to 15.5 percent, and 3 times more breakage was observed when the grain moisture content was decreased from 15.5 percent to 12.0 percent. At 29.75 m/s, a moisture reduction from 19.0 percent to 15.5 percent resulted in 2.6 times more broken corn, and a reduction from 15.5 percent to 12.0 percent produced 2.5 more breakage.

Impact Surface

Surface of impact was the third factor in importance accounting for the variation in the extent of broken corn resulting from impact.

Urethane reduced corn breakage by 3/5 times over concrete and by 2/3 times over steel. Breakage was reduced 18 percent when the steel surface was replaced with a concrete surface. As observed from these results, urethane appeared to have absorbed a large portion of the impact energy of the corn kernels, thus reducing their chances for cracking or breaking. Concrete and steel did not seem to differ each other much with respect to the level of corn breakage resulting from impact.

Angle of Impact

Angle at which kernels impacted the test surfaces was the least important factor accounting for the variation in the extent of corn breakage resulting from the impact. Still, it significantly affected the test results. Reducing the impact angle from 90 degrees to 45 degrees the average amount of broken kernel was reduced 34.7 percent for all observations. For the urethane surface, no significant decrease was observed for the same angle variation, while for concrete such reduction in the impact angle decreased the amount of broken corn 30 percent. For steel, the same angle variation resulted in 52 percent less broken corn.

As observed in these results, the extent of corn breakage was reduced to less than half when the impact surface was turned from 90 degrees to 45 degrees with respect to the grain stream. A simple explanation to this might be that due to the smoothness of the steel surface the corn kernels striking the surface at a 45 degree angle tended to slip along the impact area, thus keeping most of their kinetic energy. On the other hand, a straight impact (90 degrees angle) of the corn kernels caused that most of the kernel kinetic energy were transformed into impact forces and deformation, resulting in a lot more cracking and breaking.

Total Damage

Kernel Velocity

Kernel velocity was a highly significant factor affecting the extent of total damage resulting from impact. As seen in the test data for total damage, Tables 13 through 18, as kernel velocity was increased corn total damage increased.

Increasing the kernel velocity from 17.84 m/s to 21.86 m/s increased the amount of total damage 30 percent for all observations. For urethane, total damage increased 34 percent, for concrete 30 percent and for steel 25 percent. Varying the kernel velocity from 21.86 m/s to 26.50 m/s increased the total damage by about 22 percent for all observations. For urethane the total damage increase was 28 percent, for concrete 23 percent and for steel only a 17 percent increase was observed.

As the kernel velocity was increased from 26.50 m/s to 29.75 m/s, the corn total damage increase was only 12 percent for all observations. For urethane the damage increase was 21 percent and for concrete and steel only a 9 percent increase was observed. As was the case for breakage damage, the effect of kernel velocity on total damage was more evident when combined with the moisture content effect.

Moisture Content

In general, as moisture content decreased the amount of corn total damage resulting from impact decreased. For all observations, reducing moisture content from 19.0 percent to 15.5 percent increased the amount of total damage 33 percent. For urethane the increase in total damage was 70 percent, for concrete 30 percent and for steel the increase in total damage amounted to only 18 percent.

Reducing moisture content from 15.5 percent to 12.0 percent increased total damage 23 percent for all observations (as compared to a 160 percent increase in corn breakage for the same moisture reduction). For urethane and concrete total damage increased only 16 percent and for steel total damage went up 32 percent for the same moisture reduction.

As seen from the results above, the rate at which total damage increased became smaller for concrete and urethane as grain moisture content was reduced. This, however was not the case for steel. The rate of increase in total damage almost doubled when corn moisture content was reduced from 15.5 percent to 12 percent. Thus, total damage due to impact against a steel surface seems to be highly related to moisture content in a non-linear fashion, likely a squared function of moisture.

Impact Surface

Impact surface was the most important factor accounting for the differences in the extent of corn total damage, mostly due to the effect of urethane. Urethane reduced corn total damage 43 percent over concrete and 44 percent over steel. No significant reduction was observed replacing concrete by steel or vice versa.

As was the case for breakage damage, urethane appeared to have absorbed a greater amount of the impact energy, thus diminishing the possibility of kernel skin damage, tip separation or kernel cracks.

Angle of Impact

Of all main factors tested, angle of impact had the least influence in the variation of corn total damage results. Reducing the impact angle from 90 degrees (perpendicular to grain stream) to 45 degrees reduced total damage by 12.5 percent (1/8) for all observations. For urethane no significant reduction was observed (the same is true for breakage damage), while for concrete 11 percent reduction resulted from such angle variation. For steel a 21 percent decrease in total damage was reported. The same explanation given in the case of corn breakage reduction for steel could be applied here. The "slipping effect" of the corn kernels impacting the steel surface produced fewer splitted tips, less skin damage and less cracking that otherwise would be considered as total damage.

Comparison of Results

Results of corn total damage by impact obtained in this investigation were compared with results reported by Keller (1970), who performed a similar investigation using naturally dried, hand-shelled corn.

As was expected, a greater extent of damage was observed in this investigation, where artificially dried, mechanically-shelled corn was used. For all observations, total damage observed here was 1.9 times (90 percent) greater than the average total damage reported by Keller. 5 times (400 percent) more total damage resulted when artificially dried, mechanically-shelled corn kernels impacted a urethane surface. Results for concrete showed 1.5 times (50 percent) more damage in this investigation, and 1.8 times (80 percent) more damage was also reported here for the steel surface.

Differences in total damage results were also observed at the two impact angles tested in both experiments. At 90 degrees, results for this investigation showed 1.8 times (80 percent) more total damage than Keller's, and at 45 degrees 2 times (100 percent) more impact damage was reported for corn kernels that were artificially dried and mechanically shelled.

In general,the comparison of both set of data also demonstrated that the results reported by Keller showed a less degree of impact damage to corn kernels for all levels of kernel velocity and moisture content tested in both experiments.

Analysis of Variance

Analysis of variance and Multiple Regression analysis were perfomed using a statistical computer package (SAS 79), due in part to the simple and powerful procedures this package has for manipulating data and in part to the availability of the package in the KSU Computer Center.

The following statistical model was used in analyzing the data for each category of damage:

$$X_{ijklm} = V_i + M_j + S_k + A_l + (VM)_{ij} + (VS)_{ik} + (VA)_{il} + (MS)_{jk} + (MA)_{jl} + (SA)_{kl} + (VMS)_{ijk} + (VMA)_{ijl} + (VSA)_{ikl} + (MSA)_{jkl} + (VMSA)_{ijkl} + \epsilon_{ijklm}$$

where

X_{ijklm} = a sample kernel damage + the grand average of all observations

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

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

S_k = the true average effect for the k treatment of surface

A_l = the true average effect of the l treatment of angle

- all other terms are interactions of the main effects

ϵ_{ijklm} = the random error of kernel damage with homogeneity of variance for all sample means.

Analysis of Breakage Data

Results of the analysis of variance, based on breakage data by a sieve analysis are shown in Table 3. As seen in this table, all the main factors and their interactions significantly affect the amount of broken kernels resulting during the impact, with moisture content being the most significant effect. Velocity levels also contribute significantly to the extent of broken kernels due to impact, and the interaction of moisture content and velocity is by far the most significant interaction found in this analysis. In general, the levels of moisture content at which corn is handled should be considered when selecting a handling system, machine settings (speeds, openings, etc) if grain damage is to be kept at minimum levels. On the other hand, angle of impact appears to be the least significant effect, with all the interactions including the variable angle having the lowest F values. Thus, the effect of angle of impact on corn breakage seems to be the least important among the main factors examined.

In order to further examine the data and results obtained, the analysis of variance for all treatment combinations was broken down into analysis of variance for each surface in the experiment. Tables 7 through 9 in Appendix A, show the ANOVA results for urethane, concrete and steel,respectively. The level of significance for rejection of the null hypothesis (Ho): that the group means for each variable are equal (i.e. there are no significant differences among the levels of each variable), was set at $\alpha = 0.05$. This applies to all analysis of variance presented in this work.

TABLE 3. Analysis of Variance for Breakage Data for All Experimental Treatment Combinations.

Source of Variation	Degrees of Freedom	Sum of Squares	F	Level of Significance	Decision1/
Angle (A)	1	220.14	123.01	0.0001	Reject
Moisture (M)	2	1743.67	487.15	0.0001	Reject
Velocity (V)	3	1545.65	287.89	0.0001	Reject
Surface (S)	2	650.59	181.76	0.0001	Reject
A*M	2	69.89	19.52	0.0001	Reject
A*V	3	117.50	21.89	0.0001	Reject
A*S	2	175.88	49.14	0.0001	Reject
M*V	6	908.46	84.60	0.0001	Reject
M*S	4	421.53	58.88	0.0001	Reject
V*S	6	301.88	28.11	0.0001	Reject
A*M*V	6	39.37	3.67	0.0020	Reject
A*M*S	4	60.02	8.38	0.0001	Reject
A*V*S	6	86.27	8.03	0.0001	Reject
M*V*S	12	224.04	10.43	0.0001	Reject
A*M*V*S	12	60.60	2.82	0.0017	Reject

1/ This decision is based in the null hypothesis that the group means for each effect are equal.

The ANOVA results for urethane show that moisture content and kernel velocity were the most significant factors affecting the extent of broken kernels during impact. Angle of impact did not significantly affect the extent of corn damage, neither did any of the interactions involving angle.

The ANOVA results for concrete also reveal that moisture content significantly affected the amount of broken corn resulting from impact of the kernels against a concrete surface. Kernel velocity was also a significant factor, and to a lesser degree, angle of impact. The only interaction where no differences in level means were found was the one involving angle and kernel velocity.

Analysis of Total Damage Data

Analysis of variance of the factorial design for total damage is shown in Table 4. The same discussion and observations pointed out in the analysis of breakage data are valid for the analysis of total damage. The main differences with regard to total damage, however, seem to be due to the different types of surfaces used in the experiment.

The analysis of variance results for steel indicate that all the main factors and their interactions should be considered when making decisions concerning corn handling operations, from harvesting, shelling and conveying rates to dropping grain into steel bins. As in the other ANOVA results, moisture content was shown by far to be the most significant factor influencing the extent of broken kernels during impact. Surface was here the most significant factor, and the interactions involving surface were the most significant interactions influencing the extent of total damage.

Tables 10 through 12 in Appendix A, show the analysis of variance of total damage for urethane, concrete and steel, respectively. As in

TABLE 4. Analysis of Variance for Total Damage for All Treatment Combinations.

Source of Variation	Degrees of Freedom	Sum of Squares	F	Level of Significance	Decision[1]
Angle	1	3955.00	462.36	0.0001	Reject
Moisture	2	33997.33	1986.75	0.0001	Reject
Velocity	3	36336.13	1415.62	0.0001	Reject
Surface	2	50762.00	2966.45	0.0001	Reject
A*M	2	689.28	40.28	0.0001	Reject
A*V	3	159.58	6.22	0.0006	Reject
A*S	2	3271.51	191.18	0.0001	Reject
M*V	6	1218.73	23.14	0.0001	Reject
M*S	4	1438.29	42.03	0.0001	Reject
V*S	6	697.69	13.59	0.0001	Reject
A*M*V	6	420.53	8.19	0.0001	Reject
A*M*S	4	507.37	14.83	0.0001	Reject
A*V*S	6	528.85	10.30	0.0001	Reject
M*V*S	12	1716.75	16.72	0.0001	Reject
A*M*V*S	12	559.64	5.45	0.0001	Reject

1 This decision is based in the null hypothesis that the group means for each effect are equal.

the results for the breakage data, the ANOVA table for urethane reveals that moisture content and kernel velocity were by far the most significant factors accounting for the differences in total damage due to impact of corn kernels against a urethane surface. Angle of impact, on the other hand, was not significant at all.

The ANOVA results for concrete show the same pattern found in the analysis of breakage for concrete. Moisture content and kernel velocity were the leading factors, with all main factors and interactions being significant except for the interaction associated with angle and kernel velocity.

The analysis of variance for steel corroborates the belief that moisture content and kernel velocity may be the key factors to be considered when dealing with damage due to impact during corn harvesting, handling and processing operations. Table 5 is a summary of the statistical computations perfomed on the breakage and the total damage data. There were 72 observations for each surface for each type of damage (24 different points, 3 replications each). As observed in this table, results for concrete and steel were very similar, even for the minimum and maximum values, and there were no significant differences in the means of steel and concrete for total damage.

TABLE 5. Statistical Computations for Breakage and Total Damage Data.

Type of Damage	Surface	Obser-tions	Mean (%)	Standard Deviation	Minimum Value	Maximum Value
	Urethane	72	2.01	1.70	0.16	8.57
Breakage	Concrete	72	5.03	5.79	0.64	30.12
	Steel	72	6.17	7.16	0.75	30.84
	Urethane	72	42.35	16.69	10.82	74.75
Total	Concrete	72	74.61	21.40	27.93	100.00
	Steel	72	75.12	22.04	22.72	100.00

Multiple Regression Analysis

Based on the results obtained by the analysis of variance methods, Multiple Regression analysis was used in order to select predictive models estimating corn damage as a function of kernel velocity, moisture content and angle of impact for each surface used in the experiment and for both types of damage: total and breakage.

Many different models involving data rearrangement, transformations, polynomials and cross products were tried in order to find simple, but useful models that could be used to truly predict corn damage within a given range of operating conditions. A complete second-order model with three predictor variables was finally selected as the starting general model to which Multiple Regresion analysis would be applied:

$$D = \beta_0 + \beta_1 V + \beta_2 M + \beta_3 A + \beta_{11} V^2 + \beta_{22} M^2 + \beta_{33} A^2 + \beta_{12} V{*}M + \beta_{13} V{*}A + \beta_{23} M{*}A + \beta_{123} V{*}M{*}A + \epsilon$$

where

$\beta_0 \cdots \beta_{123}$ = predicting parameters

V = kernel Velocity, m/s

M = corn moisture content, percent wet basis

A = angle of impact, degrees

- all other terms are cross products of the above variables

ϵ = deviation of the individual observations from the regression equatio

For the urethane surface, a complete second order model with two predictor variables was employed, due to the fact that angle of impact was not a significant factor for this surface.

The regression procedures applied to the above model to select the best regression equation for each surface and type of damage were:

1. Stepwise Regression
2. Maximum R^2 Improvement (MAXR)
3. Backward Elimination
4. Forward Selection

While a main goal of the analysis was to keep the regression equations as simple as possible, several criteria would also have to be met by them in order to be selected. They were:

1. The final regression equations should explain more than 80 percent of the variation about the mean ($R^2 > 0.80$).

2. The standard error of estimate should be less than 10 percent of the average total damage by impact and less than 30 percent for broken kernels (Coefficient of Variation Criterium, C_v).

3. All estimated coefficients in the final models should be statistically significant at the $\alpha = 0.05$ level.

4. The number of predictor variables (or cross products) should be no more than three (four parameters).

5. There should be no discernible pattern in the residuals.

6. The observed F-value for the regression equations should be at least five times the usual percentage point (table value) at a significant level of $\alpha = 0.05$ (γ_m Criterium; Drapper and Smith, 1981).

7. Mallows C_p Statistic should be close to the number of parameters in the final regression equations.

The regression equations that best fit for total damage and breakage damage resulting from the Multiple Regression analysis are given in Table 6.

TABLE 6. Regression Equations of Best Fit Resulting from the Multiple Regression Analysis.

BREAKAGE DATA

Urethane

$$D_b = 0.809 + 0.019V^2 + 0.026M^2 - 0.045M*V \qquad (1)$$

Concrete

$$D_b = -36.937 + 3.474V + 0.107M^2 - 0.183M*V \qquad (2)$$

Steel

$$D_b = 0.905 + A*(0.001V^2 + 0.002M^2 - 0.003M*V) \qquad (3)$$

TOTAL DAMAGE DATA

Urethane

$$D_t = -15.739 + V*(0.496M - 0.021M^2) \qquad (4)$$

Concrete

$$D_t = 147.143 + M*(-10.693 + 0.214V + 0.013A) \qquad (5)$$

Steel

$$D_t = 147.831 + M*(-10.924 + 0.187V + 0.026A) \qquad (6)$$

where

D_b = corn breakage, percent by weight

D_t = corn total damage, percent by weight

V = kernel velocity, m/s

M = corn moisture content, percent wet basis

A = angle of impact, degrees

Regression Analysis for Urethane

Equation 1, shown in Table 6, expresses corn breakage in percentage by weight as a function of the square of moisture content (M), the square of kernel velocity (V) and the cross product of these two veriables. Figure 7 shows the plotting of the data and the regression equation for corn breakage versus kernel velocity for different moisture content levels.

While as mentioned before, a main purpose of the analysis was to kept the regression equations as simple as possible, no meaningful linear relationship of velocity or moisture was found to satisfactorily explain breakage resulting from impact of corn kernels against a urethane surface. While corn breakage for 19 percent moisture content could have been expressed as a linear function of velocity, the same relationship could have not be used to explain breakage for the other moisture levels without having a significant lack of fit or insignificant parameters. In the analysis of variance results grain moisture content and kernel velocity were found to be significant effects on damage. However, no single function of either moisture or velocity could explain satisfactorily the variation in the extent of broken kernels during impact. Moisture alone accounted for only 24.1 percent of the variation ($R^2 = 0.241$), while kernel velocity alone explained 38.2 percent of the variation ($R^2 = 0.382$).

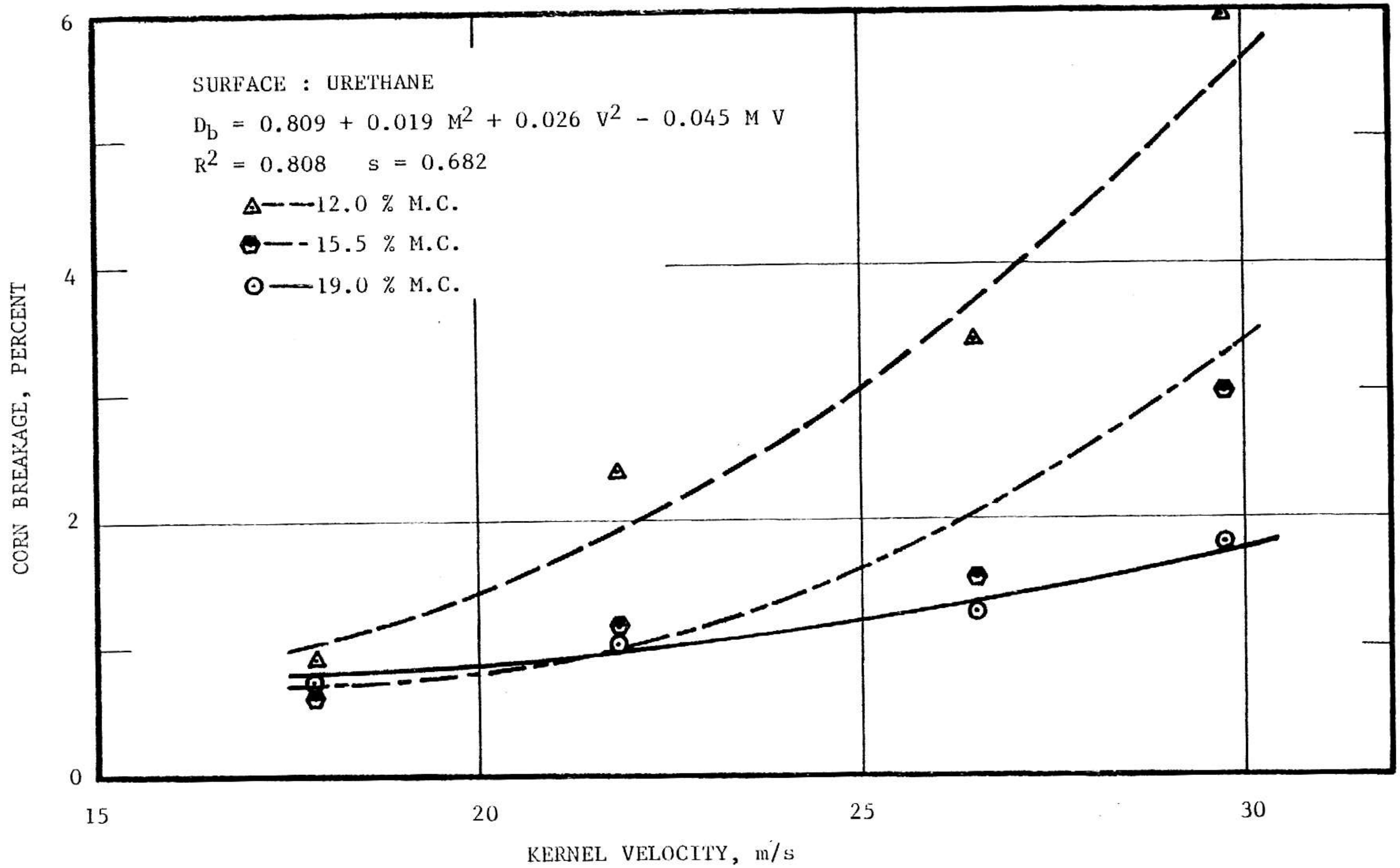

Figure 7. Corn Breakage due to Impact Against a Urethane Surface vs Kernel Velocity at Different Moisture Contents.

In general, of all the data analyzed, the breakage data for urethane seemed to be the most scattered, the least uniform and least related to the main effects. Equation 1 was by far the simplest-best fitting equation found, explaining 80.8 percent of the variation about the mean of broken kernels ($R^2 = 0.808$), and satisfying all the criteria required by the selection procedure. Table 25 in Appendix C shows the results of Multiple Regression analysis for the breakage data-urethane surface. As seen in this table, the regression equation is highly significant ($\alpha = 0.0001$), as are all the parameters in the equation.

Figure 8 shows the plotting of values predicted by the regression equation versus the experimental points of breakage damage for urethane. A good correlation was observed for the lower values, but as the damage increased, the deviation of the predicted values from the experimental points also increased. However, most of the observations points are located in the lower part of the plot. Thus, the deviation found for larger values is not significant, as predicted by the results of the Multiple Regression analysis.

Equation 4 expresses corn total damage (in percentage by weight) as a function of the product of moisture content and kernel velocity and the product of the square of moisture times velocity. Figure 9 shows the plotting of the total damage data (each point is the average of 6 observations) and the resultant regression equation at three different moisture content levels. This figure shows that the predicted total damage for urethane can be plotted as a linear function of kernel velocity for each level of moisture. Damage at 19 percent moisture was relatively

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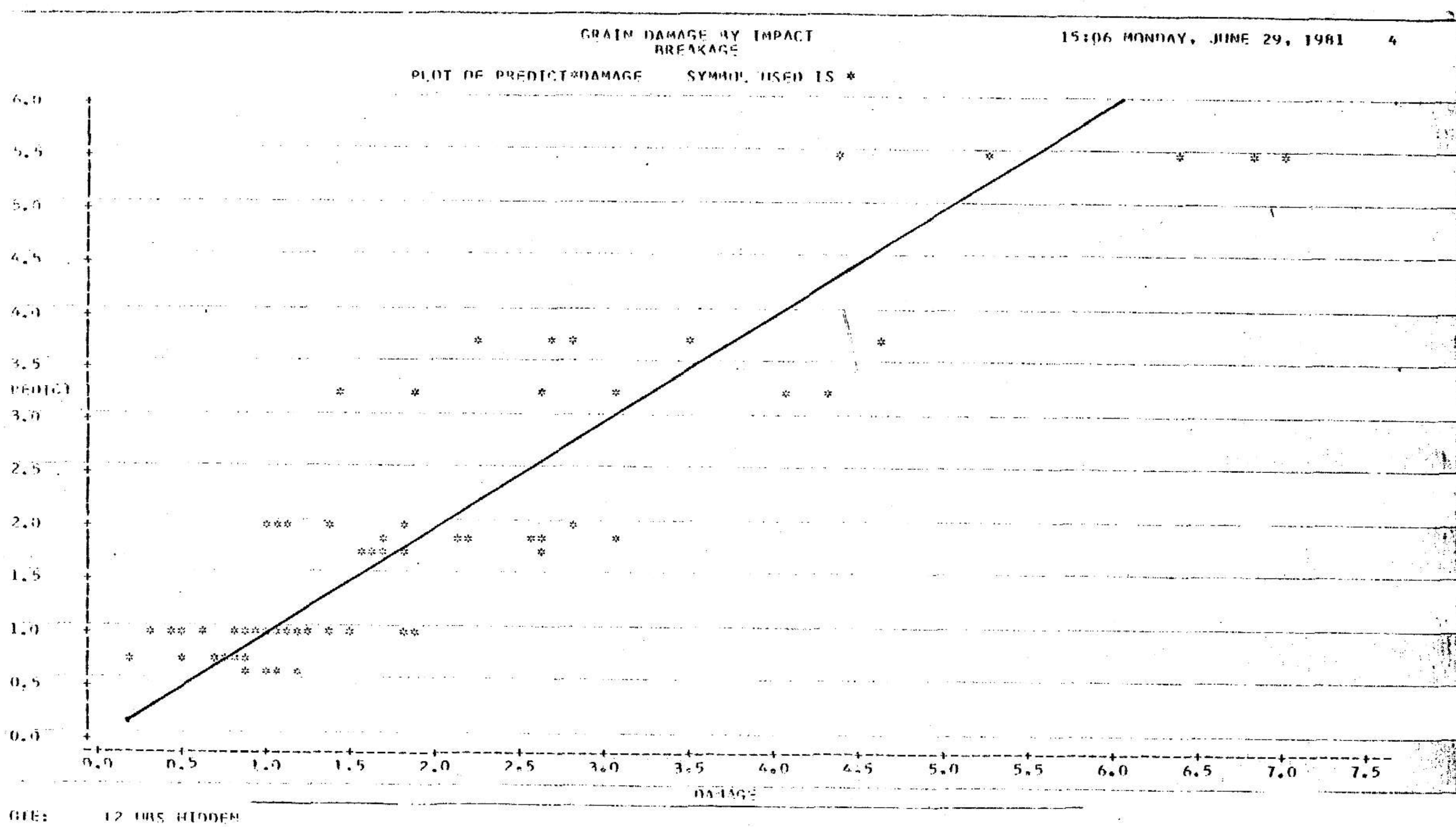


Figure 8. Predicted Values vs Breakage Data for Urethane.

small as compared to damage at the 15.5 percent and 12 percent levels (about 54 percent of the damage at 15.5 moisture and 48 percent of the damage at 12 percent moisture).

Equation 4 accounted for 93.6 percent ($R^2 = 0.936$) of the variation about the mean of total damage due to impact of corn kernels against a urethane surface. Moisture content alone accounted for 45.5 percent of such variation and kernel velocity also explained the same amount of variation (as compared to 24.1 percent and 38.2 percent respectively, for the breakage data.

Table 28 in Appendix C is the result of the Multiple Regression analysis for total damage- urethane surface. As shown in this table, the regression equation is highly significant, as well as all the parameters in the equation. All the criteria required by the selection procedure are also satisfied by this equation. Figure 10 shows the values predicted by the regression equation plotted against the experimental data. As expected from the results obtained by the regression analysis, the correlation between the predicted values and the experimental observations was very significant all along the entire plot.

Regression Analysis for Concrete

Equation 2, shown in Table 6, expresses corn breakage (in percentage by weight) due to impact against a concrete surface as a function of kernel velocity, the square of moisture content and the product of these two variables. Figure 11 shows the plotting of the breakage data (each point is the average of six observations) and the resultant regression equation versus kernel velocity at three levels of moisture

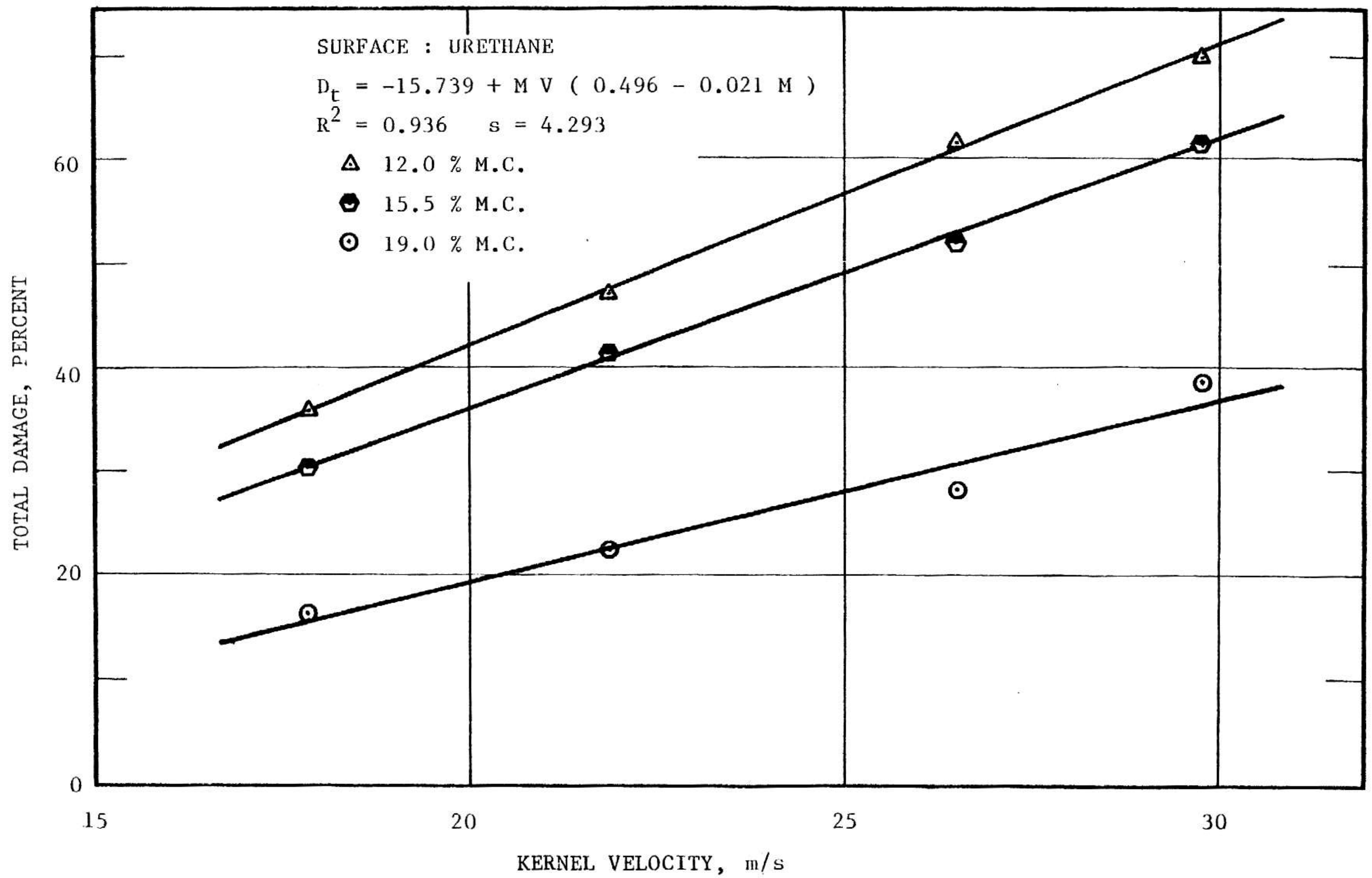


Figure 9. Corn Total Damage due to Impact Against a Urethane Surface vs Kernel Velocity at Different Moisture Contents.

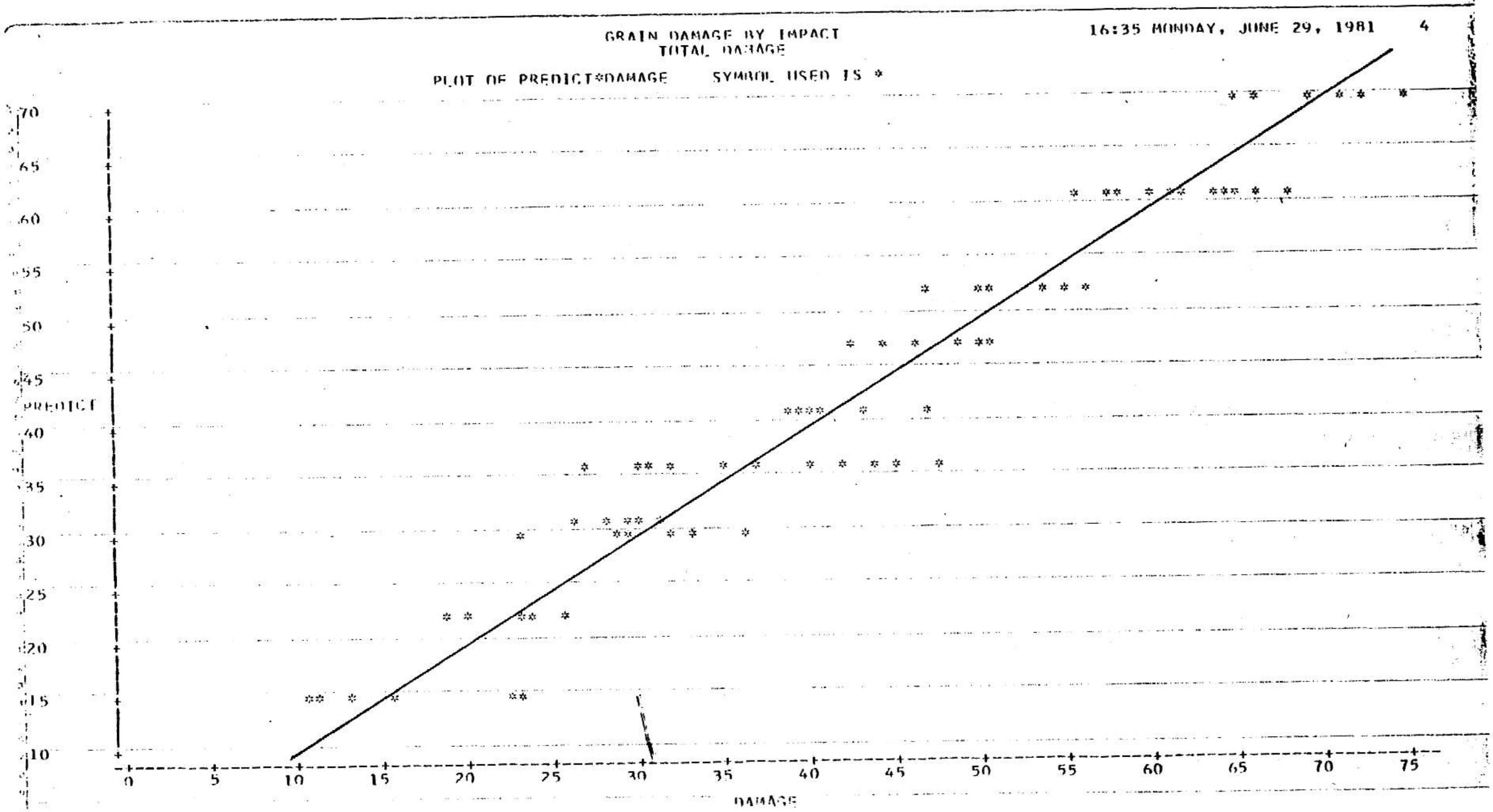


Figure 10. Predicted Values vs Total Damage Data for Urethane.

content. Predicted breakage is plotted here as a linear function of kernel velocity for each level of moisture. The breakage data for concrete clearly followed a more defined pattern with respect to the main factor than it did for the urethane surface. As observed in the graph, corn breakage rapidly increased as kernel velocity increased and moisture content decreased. At the higher moisture content level, breakage did not seem to change as kernel velocity increased, but as the moisture content decreased the extent of broken kernels became more correlated to kernel velocity.

Equation 2 accounted for 90.3 percent (R^2 = 0.903) of the variation about the mean of broken kernels for concrete, and at the same time, satisfied all the selection criteria required by the regression analysis, as shown in Table 26 in appendix C. Figure 12 is a plotting of the values predicted by the regression equation versus the experimental points for the breakage data-concrete surface. A good correlation throughout the entire range of damage is observed here.

Equation 5 expresses corn total damage (in percentage by weight) due to impact against a concrete surface as a function of moisture and the products of moisture and kernel velocity and moisture and angle of impact (A). Figure 13 shows the plotting of the total damage data (each point represent the average of three replications) and the resultant regression equation at three moisture content levels for an impact angle of 90 degrees. Figure 14 is a plot of total damage data and equation 5 at three different moisture levels for an impact angle of 45 degrees. As seen in these graphs, total damage could be plotted as a linear function of kernel velocity for each level of moisture and for each impact angle.

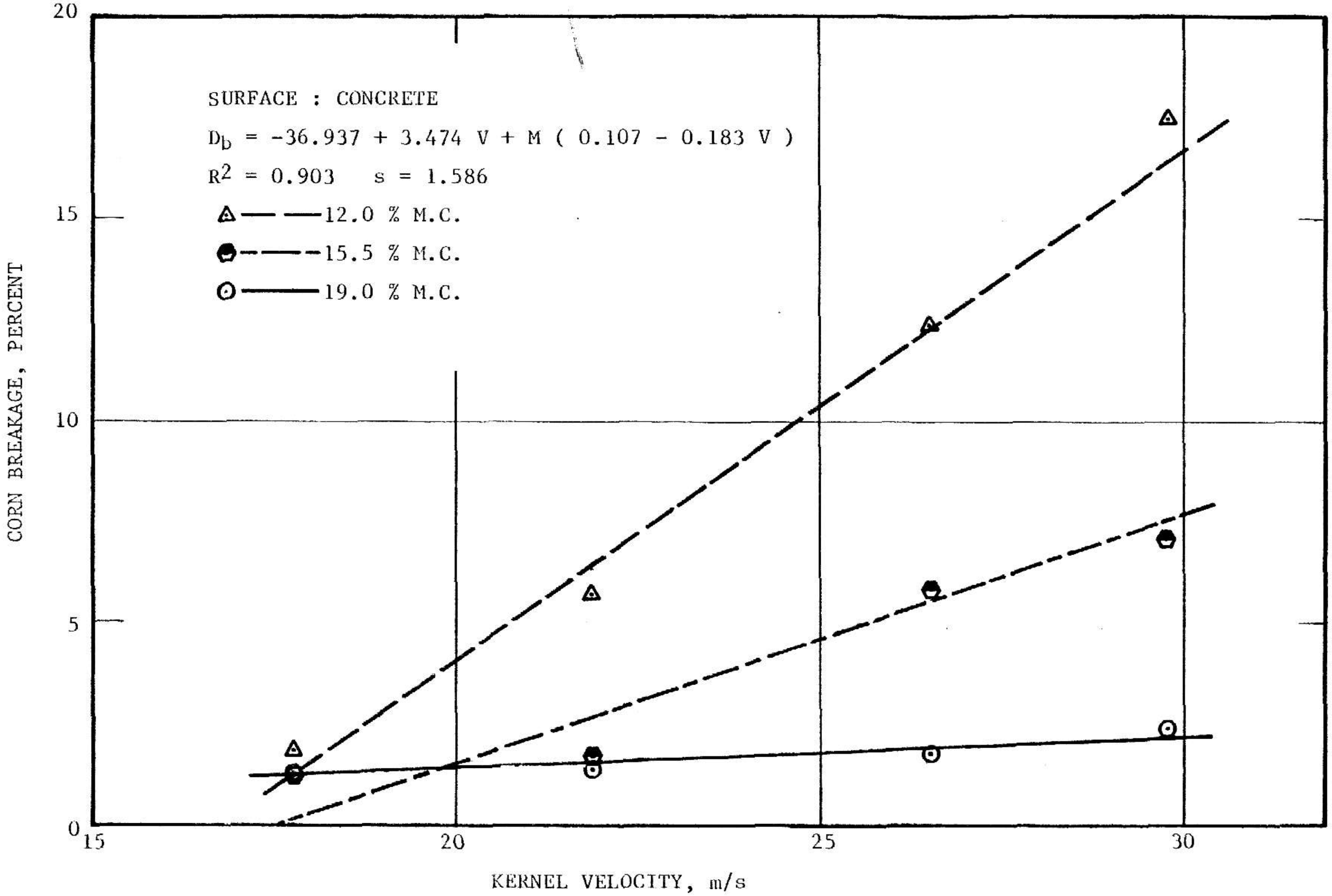
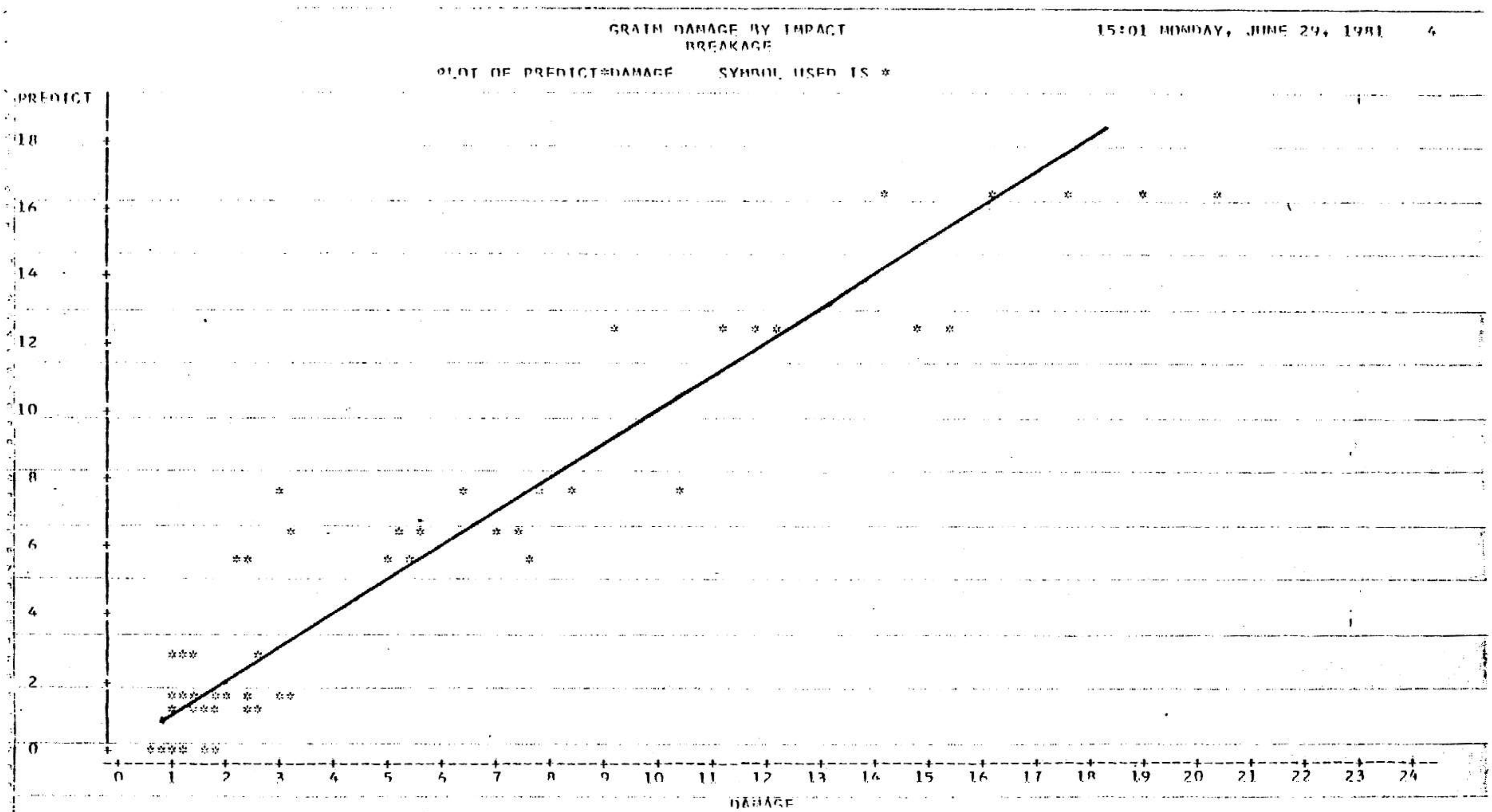


Figure 11. Corn Breakage due to Impact Against a Concrete Surface vs Kernel Velocity at Different Moisture Contents.



NOTE: 20 OBS HIDDEN

Figure 12. Predicted values vs Breakage Data for Concrete.

The extent of total damage for the 90 degree impact angle was greater than for the 45 degree angle. Damage under the same operating conditions also increased at a faster rate for the 90 degree impact angle. On the other hand, the rate of increase of total damage diminished as moisture content decreased, i.e. the slope of the linear equation became smaller as the moisture content increased, as noted in Figures 13 and 14.

Equation 5 was an exceptionally good fit for the experimental data (C.V. only 5.8 percent), accounting for 96.0 percent (R^2 = 0.960) of the variation about the mean of total damage for concrete. Although moisture content and kernel velocity were highly significant effects, alone they only accounted for 39.7 percent and 49.1 percent of such variation, respectively (as compared to just 35.6 percent and 30.0 percent,respectively, for the variation of the breakage mean for concrete). Table 29 in appendix C, shows the results of the regression analysis for Equation 5. Figure 15 is a plotting of the predicted values versus the experimental observations. As expected, an excellent correlation is observed through the entire range of damage.

Regression Analysis for Steel

Equation 3, shown in Table 6, expresses corn breakage (in percentage by weight) due to impact against a steel surface as a function of impact angle times the square of velocity, the square of moisture content, and the product of moisture and velocity. Figure 16 shows the plotting of the breakage data (each point represents the average of three replications) and the resultant regression equation, at three different misture content levels for and impact angle of 90 degrees. Fig-

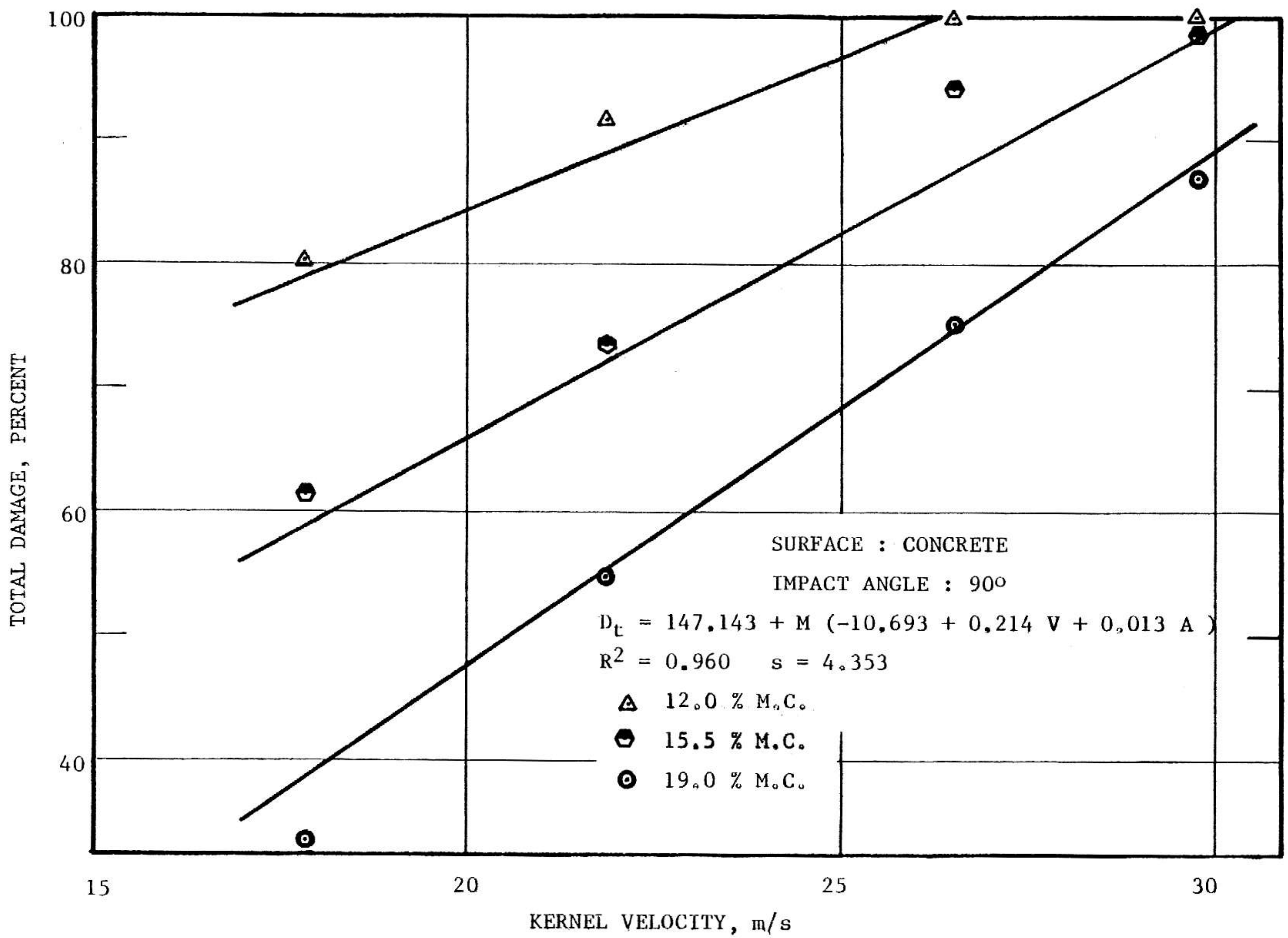


Figure 13. Corn Total Damage due to Impact Against a Concrete Surface vs Kernel Velocity at Different Moisture Contents and Impact Angle of 90°.

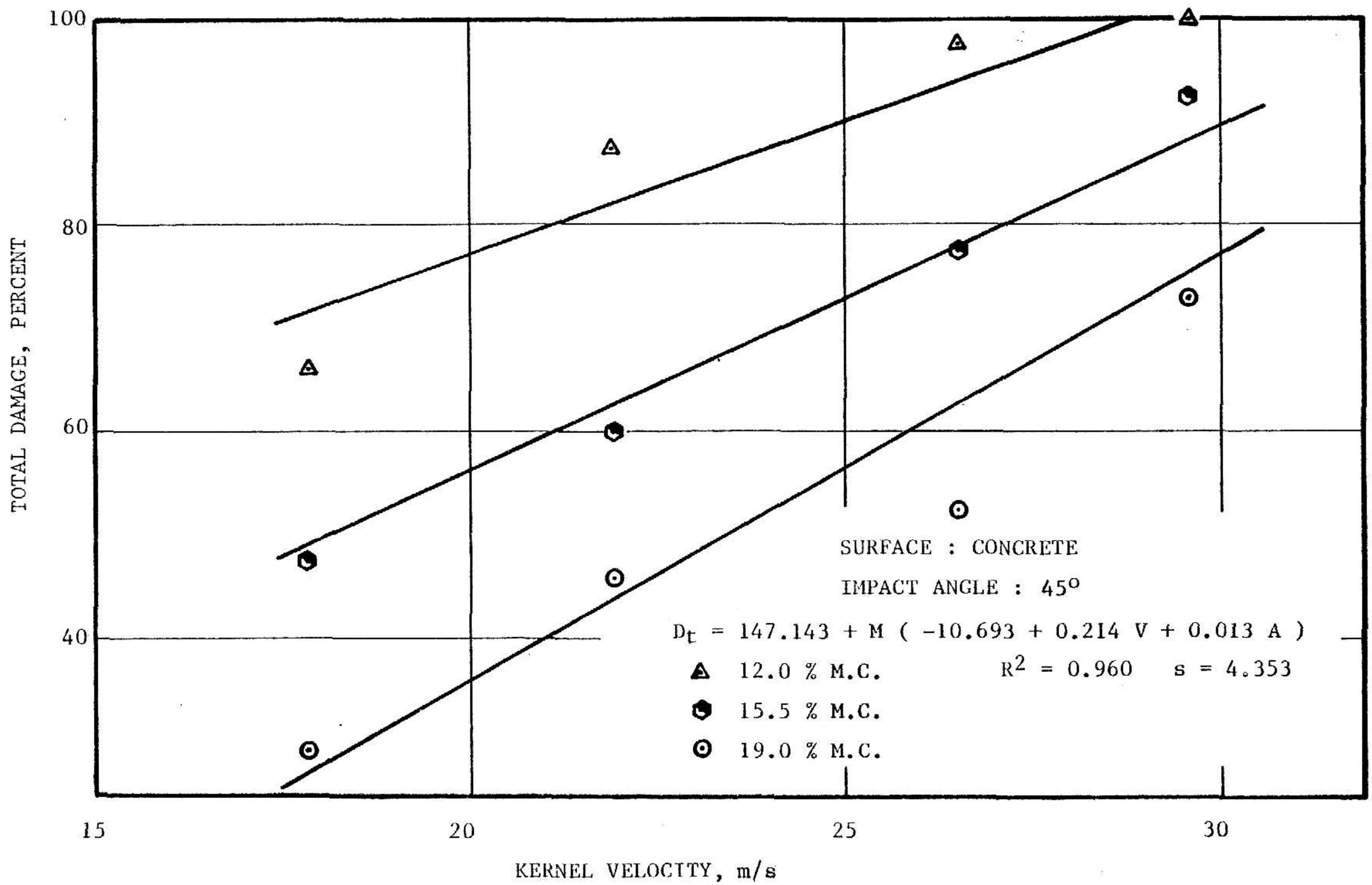


Figure 14. Corn Total Damage due to Impact Against a Concrete Surface vs Kernel Velocity at Different Moisture Contents and Impact Angle of 45°.

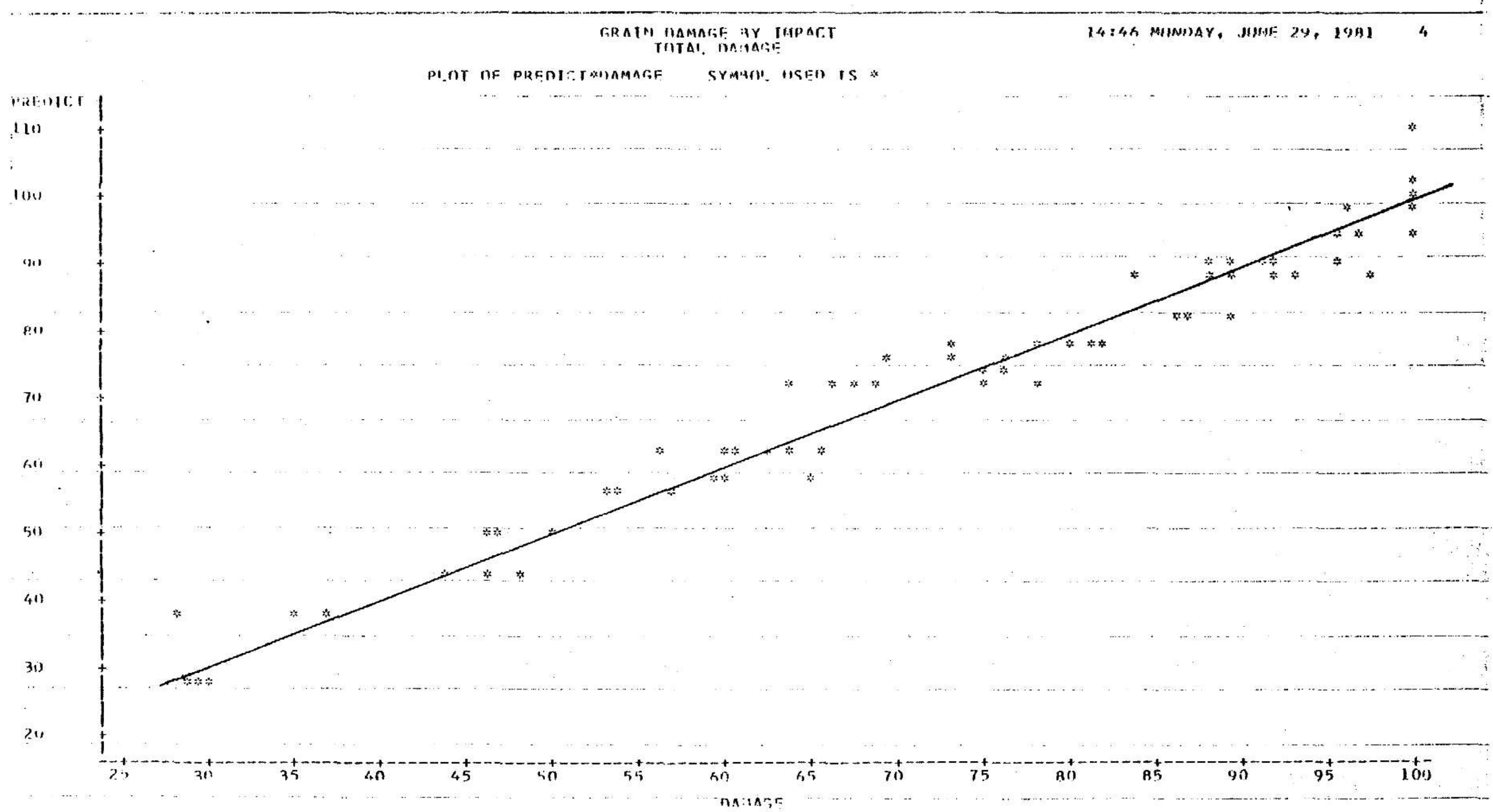


Figure 15. Predicted Values vs Total Damage Data for Concrete.

ure 17 is a plot of corn breakage data and Equation 3 at three levels of moisture and impact angle of 45 degrees.

As seen in these graphs, the extent of corn broken kernels did not vary significantly at the lower kernel velocities. However, as kernel velocity was increased during the experiment, the amount of corn breakage increased as moisture content decreased. The lower the moisture content level, the greater the rate of damage increase. The opposite seemed to be valid in the case of impact angle. As angle of impact was decreased, the amount of breakage resulting from the impact decreased. Reducing the angle of impact from 90 degrees to 45 degrees decreased the corn breakage mean by 54 percent.

Equation 3 accounted for 94.0 percent ($R^2 = 0.940$) of the variation about the breakage mean, providing an exceptionally good fit for a four parameter equation. The best five parameter equation found explained 94.5 percent ($R^2 = 0.945$) of the variation about the mean. However, an improvement of just 0.05 in R^2 did not really justify the extra parameter in the equation (this extra parameter was not significant). On the other hand, moisture content alone explained 30.9 percent of the variation about the breakage mean, kernel velocity 28.3 percent and angle of impact accounted for only 9.7 percent of such variation.

As seen in Table 27 in Appendix C, the regression equation of best fit (Equation 3), as all the parameters involved, is significant, satisfying all the criteria required in the selection procedure. Figure 18 shows the plotting of the predicted values versus breakage data for the steel surface. A high correlation is observed in the lower range of dam-

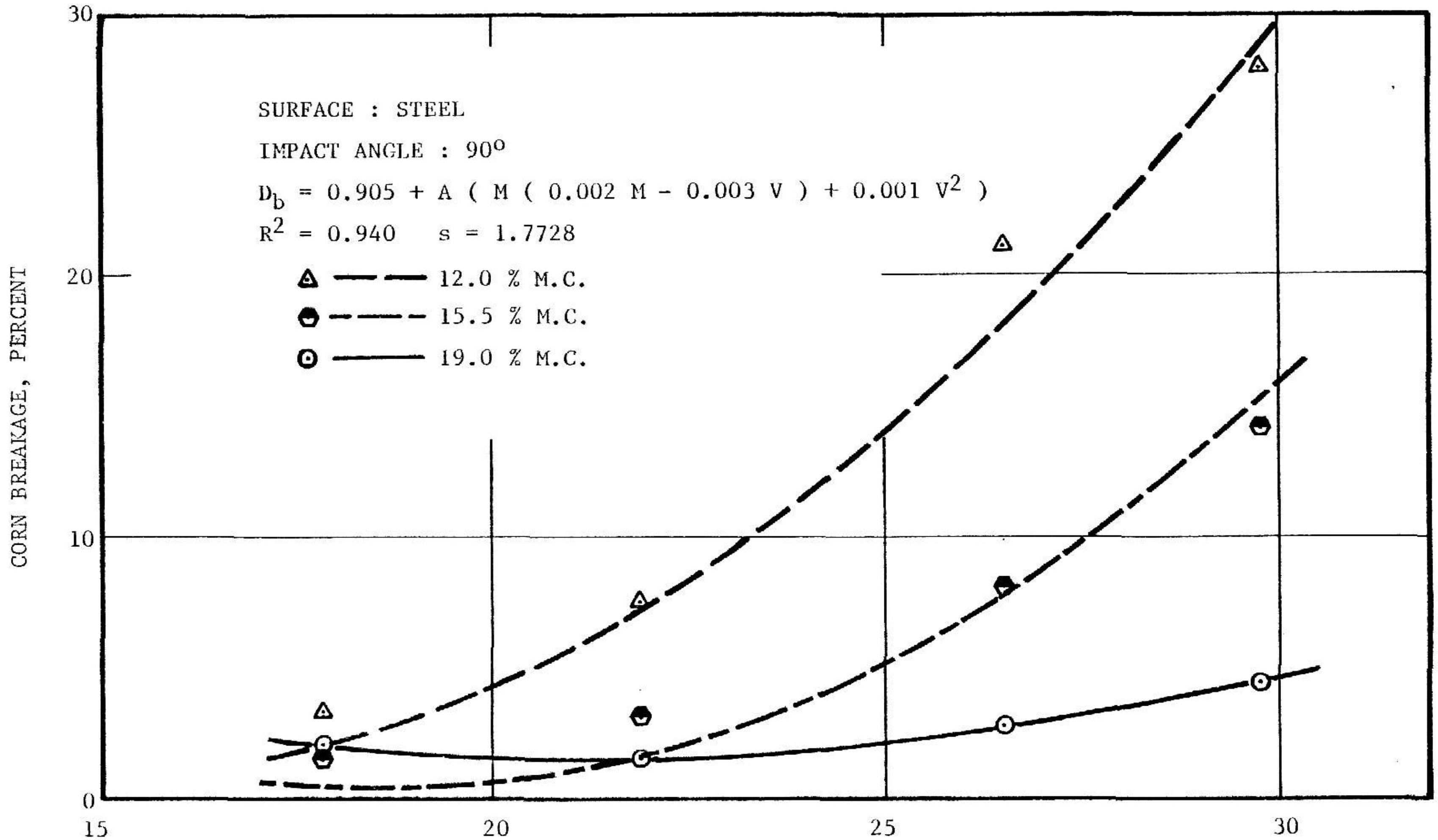


Figure 16. Corn Breakage due to Impact Against a Steel Surface vs Kernel Velocity at Different Moisture Contents and Impact Angle of 90°.

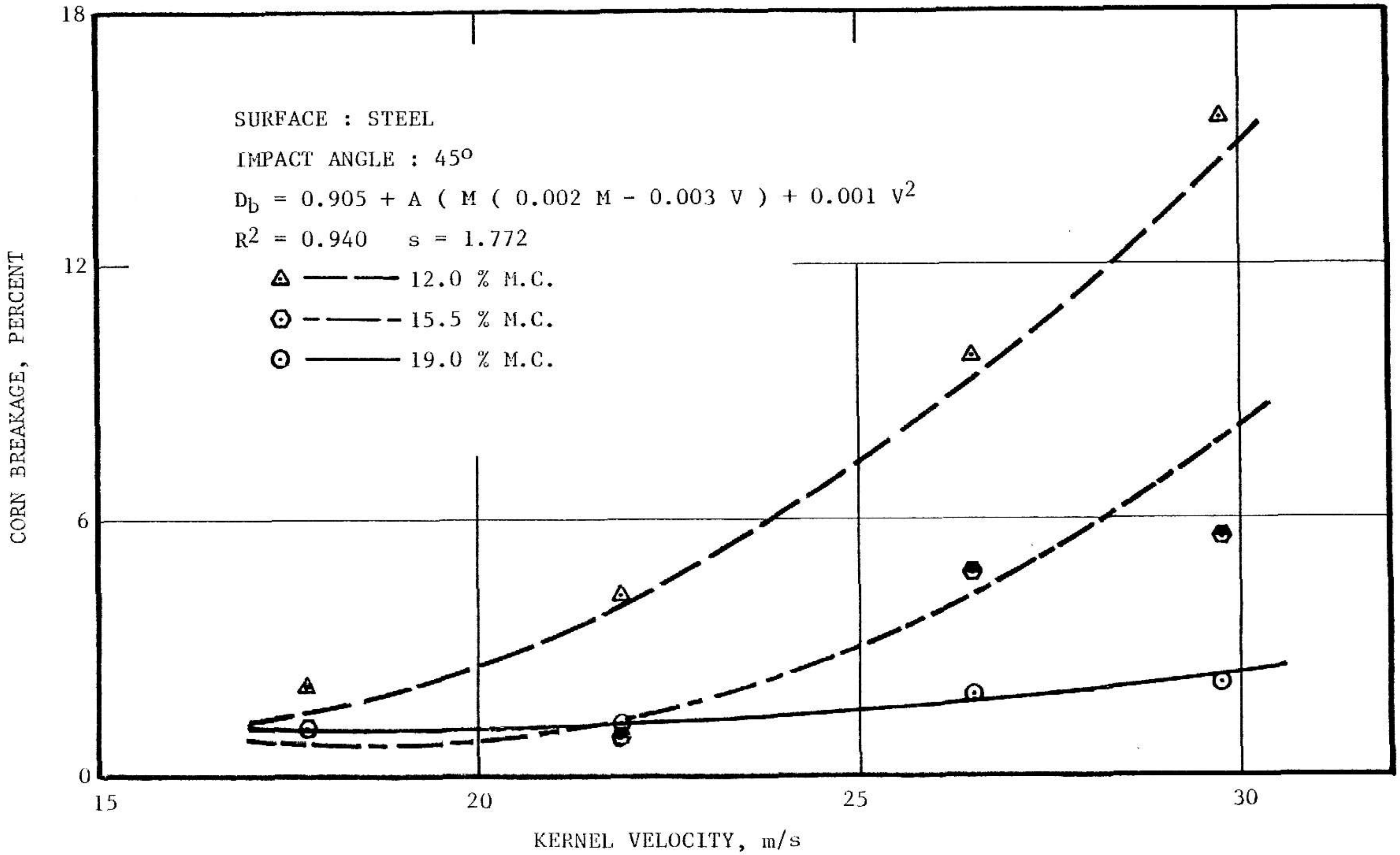


Figure 17. Corn Breakage due to Impact Against a Steel Surface vs Kernel Velocity at Different Moisture Contents and Impact Angle of 45°.

age, where most of the observations are found. A deviation, which is not significant (as shown by the regression analysis results), in found in the upper range of damage. This might mean that the regression equation does not fit that well for higher kernel velocities and/or lower corn moistures, which at any rate, are the ranges that should be avoided in corn handling and processing operations.

Equation 6, shown in Table 6, expresses corn total damage (in percentage by weight) due to impact against a steel surface as a function of grain moisture content and the products of moisture and kernel velocity and moisture and angle of impact. Figure 19 is a plot of the total damage data (each point represents the average of three replications) and the corresponding regression equation of best fit at three different levels of moisture content and at impact angle of 90 degrees. Figure 20 shows the plot of total damage and the regression equation at three different levels of corn moisture and at impact angle of 45 degrees. As shown in these graphs, total damage could be plotted as a linear function of kernel velocity for each level of corn moisture content and angle of impact, as opposed to breakage damage for steel, whose best fit regression equation was not linear respect to kernel velocity.

Total damage at the 90 degrees impact angle was greater than at the 45 degrees angle. Reducing the impact angle from 90 to 45 degrees decreased the total damage mean by 40.7 percent. As kernel velocity was increased, total damage also increased at a faster rate for the higher impact angle. However, as moisture content was decreased in the experiment, the rate at which damage increased became smaller, that is, decreasing moisture content did not accelerate the rate of damage, even

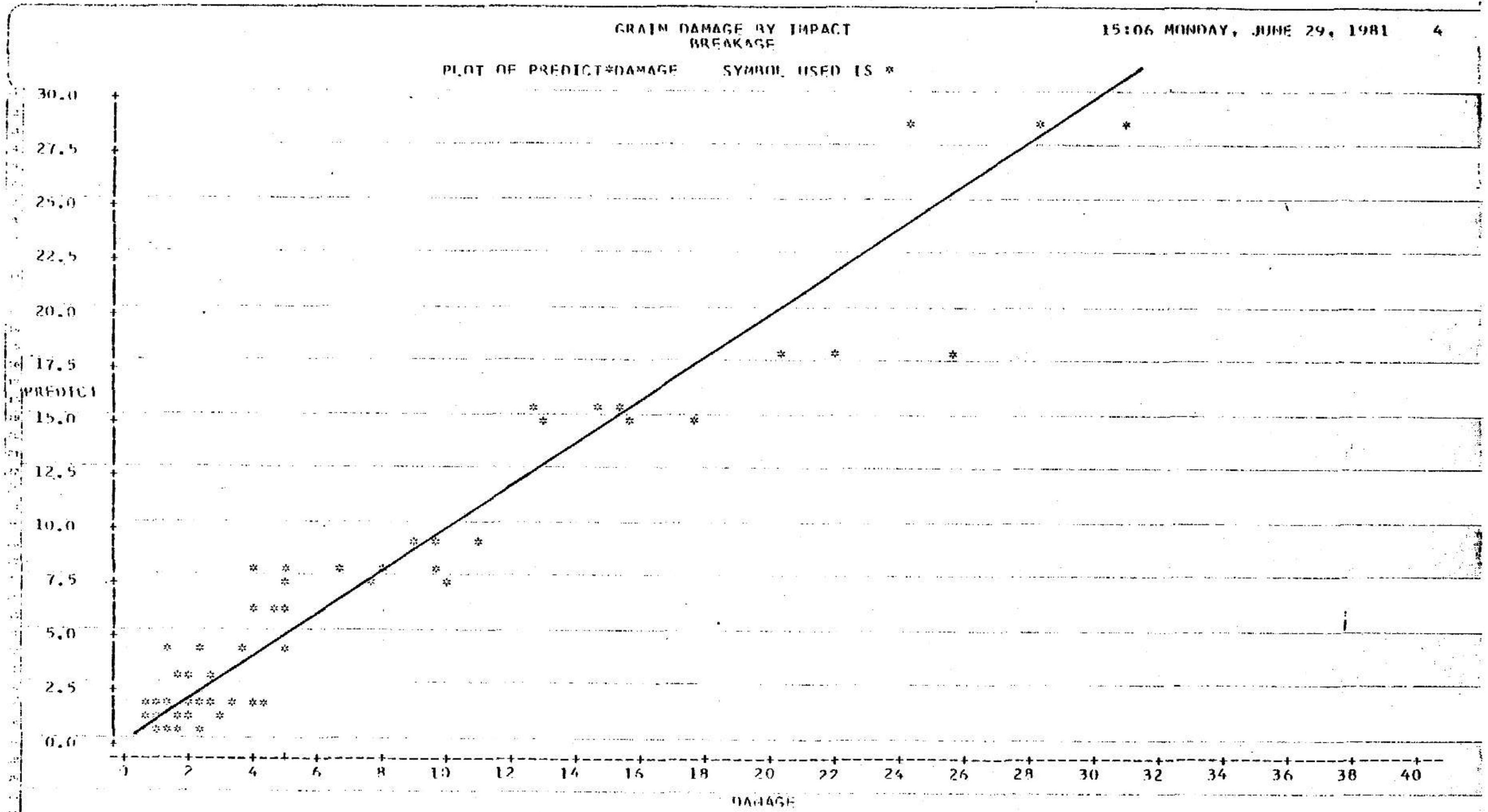


Figure 18. Predicted values vs Breakage Data for Steel.

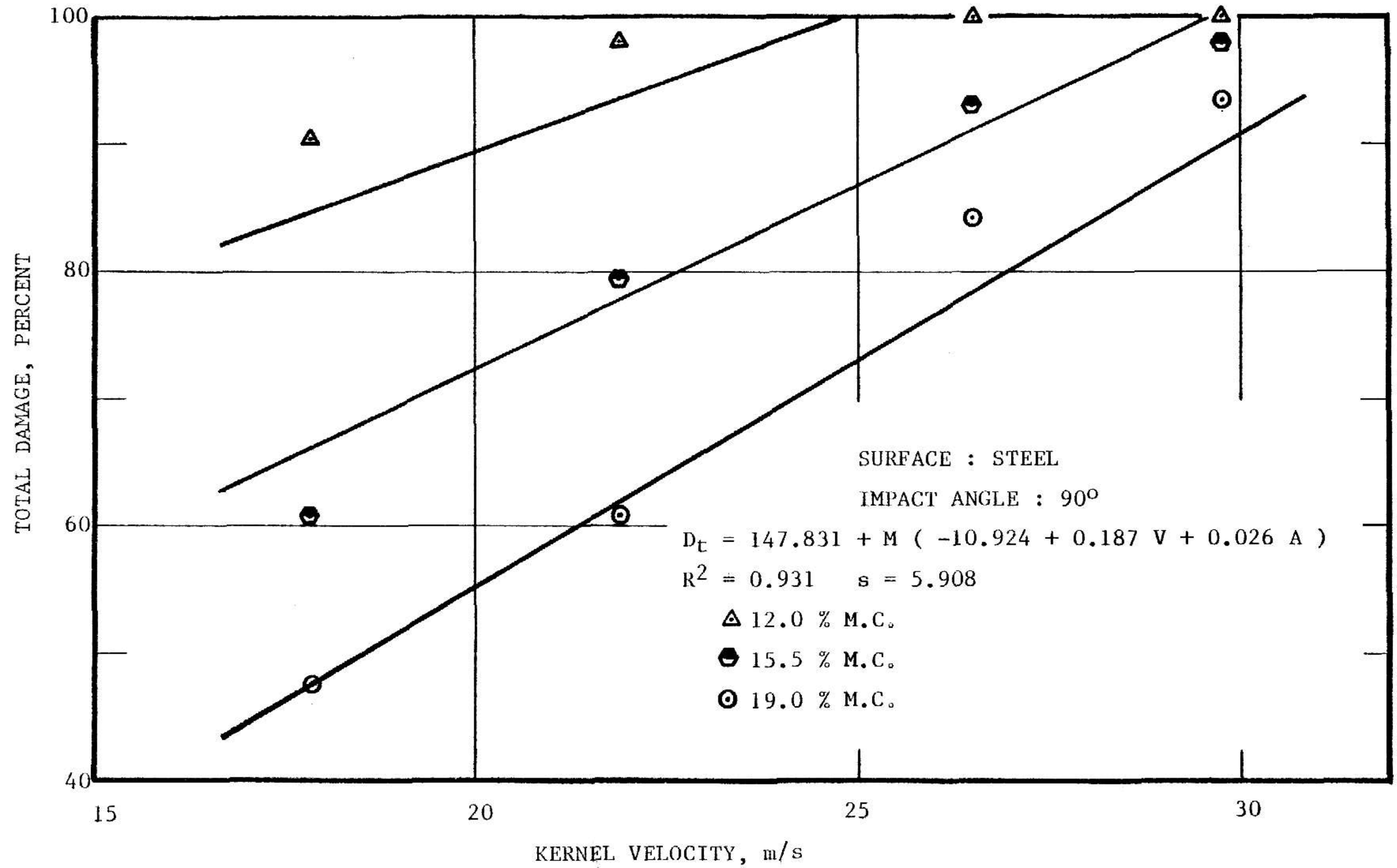


Figure 19. Corn Total Damage due to Impact Against a Steel Surface vs Kernel Velocity at Different Moisture Contents and Impact Angle of 90°.

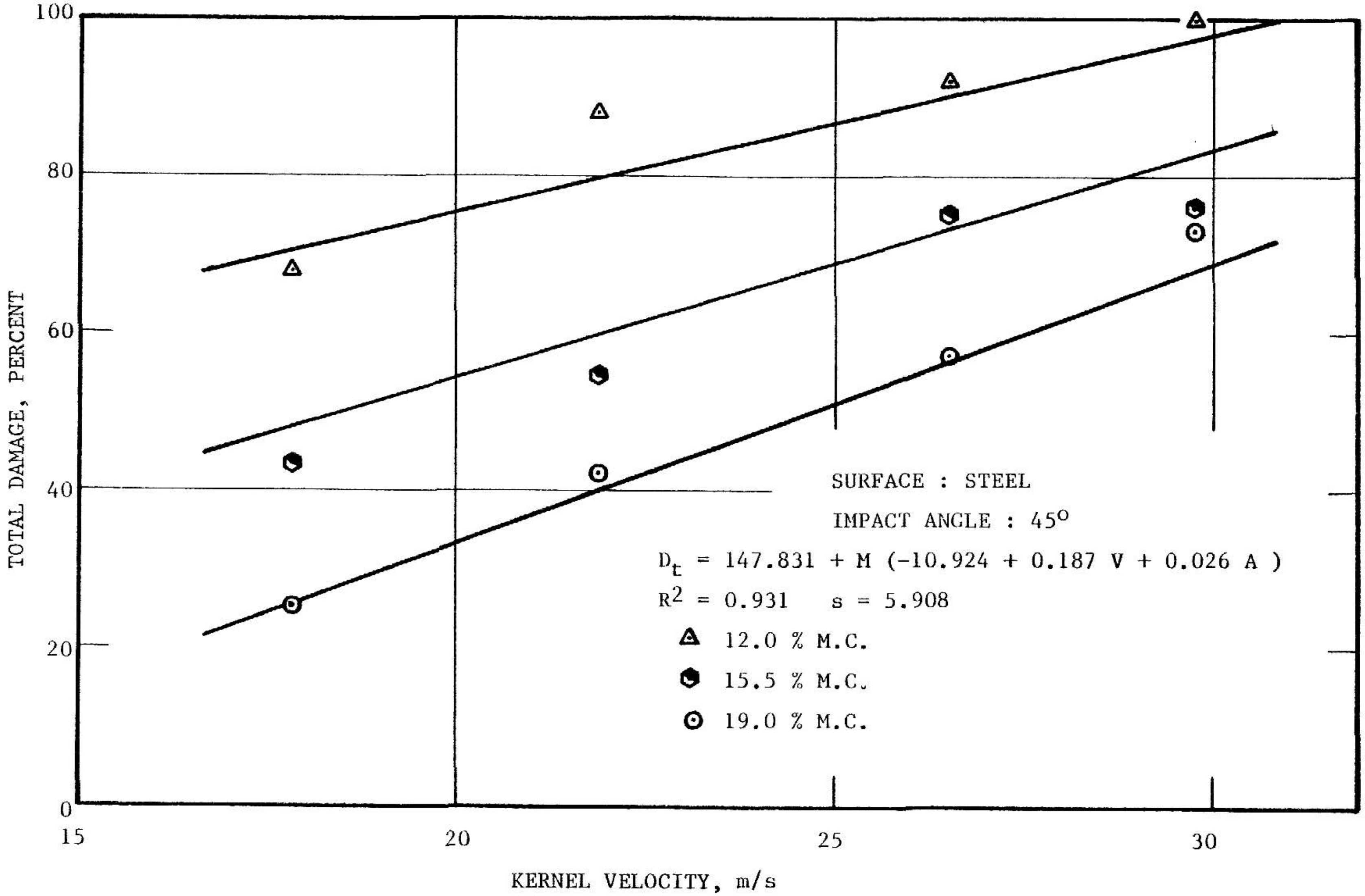


Figure 20. Corn Total Damage due to Impact Against a Steel Surface vs Kernel Velocity at Different Moisture Contents and Impact Angle of 45°.

though damage was higher at lower grain moistures. Equation 6 accounted for 93.1 percent (R^2 = 0.931) of the variation about the mean of total damage for steel. Moisture content, on the other hand, explained 38.3 percent of such variation, kernel velocity 33.8 percent and impact angle just 15.8 percent (as compared to 30.9 percent, 28.3 percent and 9.7 percent, respectively, for broken kernels).

Table 30 in Appendix C shows the regression analysis results for equation 6. As seen on this table, the regression equation, as are all the regression parameters, is significant, satisfying all the criteria required by the selection procedure. Figure 21 shows the plotting of the predicted values versus total damage data for the steel surface. A good correlation is observed in the lower and middle range of damage, but a deviation is found in the upper range of the observations. However, this is not significant, as confirmed by the results in Table 30 in Appendix C.

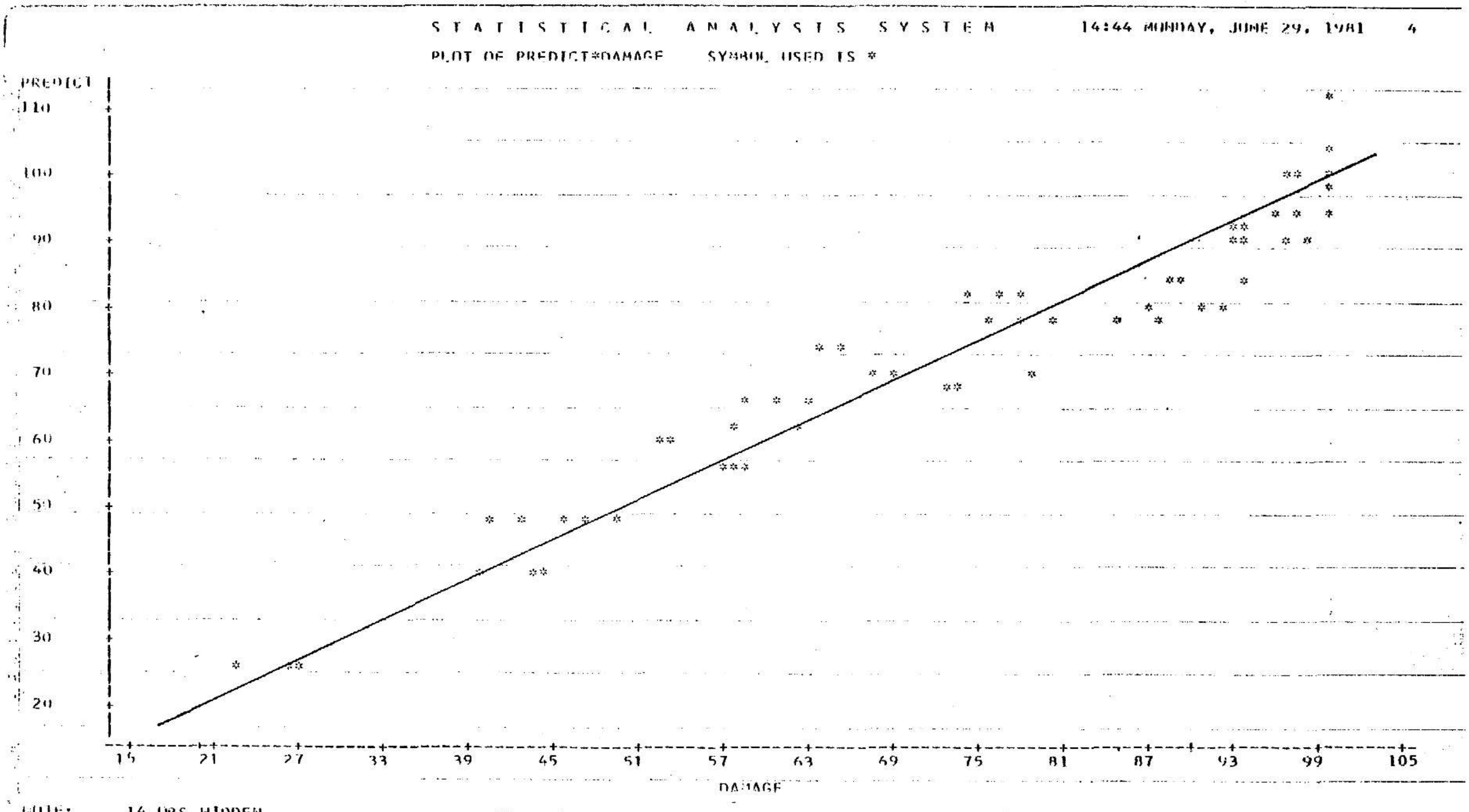


Figure 21. Predicted Values vs Total Damage Data for Steel.

CONCLUSIONS

Within the limits of the investigation, the following conclusions were drawn from this study:

1. Corn moisture content, kernel velocity, surface material and angle of impact were all found to significantly affect the extent of damage caused by impact to artificially dried and mechanically shelled corn. Angle of impact was not a significant factor in causing damage to corn kernels when impacting against a urethane surface.

2. Moisture content and kernel velocity were by far the most significant factors accounting for the variation in the extent of damage to corn due to impact.

3. For all observations, moisture content alone accounted for 30.2 percent of the variation about the mean of broken kernels, and for 41.2 percent of the variation in total damage. Reducing grain moisture content from 19.0 percent to 15.5 percent increased the amount of breakage 1.9 times and the total damage 1.3 times. Decreasing the moisture content from 15.5 percent to 12.0 percent increased the amount of broken kernel damage 2.6 times and the total damage 1.2 times.

4. For all observations, kernel velocity alone accounted for 32 percent of the variation about the mean of breakage damage, and for 42.7 percent of the variation in total damage. In general,increasing kernel velocity increased corn damage.

5. The urethane surface reduced corn breakage by 3/5 times (60 percent) as compared to concrete, and by 2/3 times (67 percent) as compared to steel. Replacing the steel surface with a concrete surface reduced the amount of breakage due to impact by 18 percent. No significant reduction was observed in the average total damage.

6. Turning the impact surface from 90 degrees (perpendicular to the grain stream) to a 45 degree impact angle reduced the average amount of breakage by 3/8 times (37.4 percent) and the total damage by 1/8 times (12.5 percent).

7. As seen from the conclusions above, as moisture content was decreased and kernel velocity increased, corn material classified as total damage became broken to a greater extent, i.e. corn kernels that would break into fewer pieces at higher moistures and lower kernel velocities, broke into a greater number of pieces whose size was smaller than 4.76 mm (12/64 in), when subjected to impact at lower moisture contents and/or higher kernel velocities. This would explain the fact that total damage did not increase as fast as breakage damage did.

8. Corn damage due to impact can be satisfactorily explained as a function of grain moisture content, kernel velocity, angle of impact and impact surface characteristics.

SUGGESTIONS FOR FUTURE RESEARCH

1. Futher investigation to study impact damage to mechanically shelled- artificially dried corn should be conducted along the same lines as was this research. However, drying temperature should be considered as a main factor in any new study about grain damage by impact.

2. Further work is needed to determine the optimum moisture content and kernel velocity levels that would minimize impact damage to corn. Thus, higher levels of moisture content, as well as intermediate values within the range used in this investigation should be tested.

3. Research in grain damage due to impact should be extended to other cereal grains. However, others techniques would have to be used or developed to conduct the experimental tests and damage evaluations.

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APPENDICES

APPENDIX A

Analysis of Variance of Breakage and Total Damage for Urethane, Concrete and Steel

TABLE 7. Analysis of Variance for Breakage Data for the Urethane Surface.

Source of Variation	Degrees of Freedom	Sum of Squares	F	Level of Significance	Decision1]
Angle	1	0.07	0.12	NS	Accept
Moisture	2	58.41	55.08	0.0001	Reject
Velocity	3	84.59	53.18	0.0001	Reject
A*M	2	0.59	0.56	NS	Accept
A*V	3	1.01	0.64	NS	Accept
M*V	6	33.31	10.47	0.0001	Reject
A*M*V	6	2.06	0.65	NS	Accept

1] This decision is based in the null hypothesis that the group means for each effect are equal.

NS : Non Significant.

TABLE 8. Analysis of Variance for Breakage Data for the Concrete Surface.

Source of Variation	Degrees of Freedom	Sum of Squares	F	Level of Significance	Decision 1/
Angle	1	56.87	19.15	0.0001	Reject
Moisture	2	882.98	148.68	0.0001	Reject
Velocity	3	727.56	81.67	0.0001	Reject
A*M	2	21.16	3.56	0.03	Reject
A*V	3	23.63	2.65	0.06	Accept
M*V	6	510.13	28.63	0.0001	Reject
A*M*V	6	14.87	0.87	NS	Accept

1/ This decision is based in the null hypothesis that the group means for each effect are equal.

NS : Non significant.

TABLE 9. Analysis of Variance for Breakage Data for the Steel Surface.

Source of Variation	Degrees of Freedom	Sum of Squares	F	Level of Significance	Decision[1]
Angle	1	339.08	181.40	0.0001	Reject
Moisture	2	1223.79	327.34	0.0001	Reject
Velocity	3	1035.37	184.63	0.0001	Reject
A*M	2	108.16	28.93	0.0001	Reject
A*V	3	179.13	31.94	0.0001	Reject
M*V	6	589.06	52.52	0.0001	Reject
A*M*V	6	83.04	7.40	0.0001	Reject

1| This decision is based in the null hypothesis that the group means for each effect are equal.

TABLE 10. Analysis of Variance for Total Damage Data for the Urethane Surface.

Source of Variation	Degrees of Freedom	Sum of Squares	F	Level of Significance	Decision1]
Angle	1	27.26	2.44	NS	Accept
Moisture	2	9014.22	403.53	0.0001	Reject
Velocity	3	9083.61	271.09	0.0001	Reject
A*M	2	15.47	0.69	NS	Accept
A*V	3	545.97	16.29	0.0001	Reject
M*V	6	312.65	4.67	0.0008	Reject
A*M*V	6	242.00	3.61	0.0049	Reject

1] This decision is based in the null hypothesis that the group means for each effect are equal.

TABLE 11. Analysis of Variance for Total Damage Data for the Concrete Surface.

Source of Variation	Degrees of Freedom	Sum of Squares	F	Level of Significance	Decision1/
Angle	1	1489.12	189.32	0.0001	Reject
Moisture	2	12921.22	821.39	0.0001	Reject
Velocity	3	16092.30	681.98	0.0001	Reject
A*M	2	160.00	10.17	0.0002	Reject
A*V	3	43.47	1.84	NS	Accept
M*V	6	1058.29	22.42	0.0001	Reject
A*M*V	6	311.22	6.59	0.0001	Reject

1/ This decision is based in the null hypothesis that the group means for each effect are equal.

NS : Non Significant.

TABLE 12. Analysis of Variance for Total Damage Data for the Steel Surface.

Source of Variation	Degrees of Freedom	Sum of Squares	F	Level of Significance	Decision[1]
Angle	1	5711.13	860.99	0.0001	Reject
Moisture	2	13500.18	1017.61	0.0001	Reject
Velocity	3	11857.91	595.88	0.0001	Reject
A*M	2	1021.19	76.98	0.0001	Reject
A*V	3	98.99	4.97	0.0044	Reject
M*V	6	1564.54	39.31	0.0001	Reject
A*M*V	6	426.95	10.73	0.0001	Reject

[1] This decision is based in the null hypothesis that the group means for each effect are equal.

APPENDIX B

Breakage and Total Damage Data for Each Type of Surface

TABLE 13. Percentages (by Weight) of Total Damage on Corn Kernels due to Impact Against a Urethane Surface at 90 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%)		
	12.0	15.5	19.0
	26.96	31.78	13.27
17.84	31.72	22.88	11.17
	30.60	29.44	10.82
	42.56	38.71	18.50
21.86	44.63	39.16	23.46
	46.13	39.92	19.96
	65.00	54.90	31.01
26.50	63.60	56.33	28.06
	68.01	49.93	26.51
	69.29	66.26	44.00
29.75	71.02	58.01	53.80
	72.73	57.27	44.93

TABLE 14. Percentages (by Weight) of Total Damage on Corn Kernels due to Impact Against a Urethane Surface at 45 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	36.87	29.05	22.76
17.84	41.64	32.93	15.93
	47.48	36.2	23.40
	50.12	47.04	23.36
21.86	50.48	40.66	23.18
	48.86	43.29	25.88
	55.83	50.39	26.25
26.50	57.51	53.72	29.09
	59.78	47.05	29.74
	66.09	61.97	29.77
29.75	74.75	64.31	40.28
	64.69	61.30	34.91

TABLE 15. Percentages (by Weight) of Total Damage on Corn Kernels due to Impact Against a Steel Surface at 90 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	89.05	60.92	49.59
17.84	93.92	63.01	45.78
	98.13	58.62	47.25
	97.83	76.06	57.73
21.86	96.05	77.78	63.54
	100.00	84.65	62.20
	100.00	100.00	80.30
26.50	100.00	92.96	84.88
	100.00	93.42	87.56
	100.00	97.39	92.99
29.75	100.00	100.00	93.82
	100.00	96.63	93.82

TABLE 16. Percentages (by Weight) of Total Damage on Corn Kernels due to Impact Against a Steel Surface at 45 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	78.97	42.74	26.73
17.84	67.22	46.93	22.72
	68.63	40.40	26.60
	92.43	52.77	39.44
21.84	87.09	52.41	43.21
	90.69	53.28	44.28
	96.96	63.93	57.38
26.50	97.88	65.38	56.70
	98.18	64.10	58.27
	100.00	77.84	73.09
29.75	100.00	76.63	73.21
	100.00	74.02	73.52

TABLE 17. Percentages (by Weight) of Total Damage on Corn Kernels due to Impact Against a Concrete Surface at 90 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	78.09	59.88	36.73
17.84	81.85	59.37	34.72
	81.40	64.89	27.93
	95.63	77.82	53.32
21.86	88.29	75.27	53.65
	91.12	67.50	56.99
	100.00	97.31	74.76
26.50	100.00	92.03	74.71
	100.00	92.99	76.05
	100.00	100.00	89.35
29.75	100.00	100.00	83.57
	100.00	96.25	88.15

TABLE 18. Percentages (by Weight) of Total Damage on Corn Kernels due to Impact Against a Concrete Surface at 45 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%)		
	12.0	15.5	19.0
	63.47	49.72	28.92
17.84	66.21	46.45	22.72
	68.77	46.98	30.13
	89.31	56.03	46.23
21.84	86.46	63.83	43.85
	87.07	60.80	48.86
	95.58	73.05	60.15
26.50	97.10	79.98	65.62
	100.00	79.97	64.10
	100.00	95.84	69.46
29.75	100.00	91.92	73.37
	100.00	89.44	76.52

TABLE 19. Percentages (by Weight) of Broken Kernels due to Impact Against a Urethane Surface at 90 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	0.79	0.67	0.60
17.84	0.52	0.87	0.30
	0.89	0.16	0.45
	2.12	0.88	0.99
21.86	2.20	0.94	1.06
	3.06	0.91	0.98
	2.69	2.82	1.51
26.50	4.62	1.84	1.09
	2.79	0.97	1.80
	4.40	4.31	2.61
29.75	6.98	1.89	1.69
	6.35	3.07	1.59

TABLE 20. Percentages (by Weight) of Broken Kernels due to Impact Against an Urethane Surface at 45 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	1.05	0.81	1.13
17.84	1.19	0.72	1.08
	0.99	0.47	0.83
	1.67	1.86	1.03
21.86	2.65	1.07	0.89
	2.58	1.36	1.18
	4.61	1.09	1.19
26.50	2.26	1.40	0.84
	3.51	1.13	1.23
	5.24	4.07	1.60
29.75	8.57	1.46	1.63
	6.83	2.61	1.81

TABLE 21. Percentages (by Weight) of Broken Kernel due to Impact Against a Steel Surface at 90 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	4.23	0.97	1.64
17.84	3.44	2.41	1.55
	2.37	1.15	2.79
	9.98	3.39	1.55
21.86	4.99	3.89	1.72
	7.69	2.26	1.57
	25.56	8.09	2.62
26.50	22.15	6.74	3.93
	20.24	9.65	1.85
	30.84	14.79	4.06
29.75	28.47	12.72	4.86
	24.41	15.26	4.50

TABLE 22. Percentages (by Weight) of Broken Kernels due to Impact Against a Steel Surface at 45 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	2.89	0.88	1.39
17.84	1.59	1.02	0.97
	1.64	1.47	0.82
	8.04	0.75	1.09
21.86	3.50	0.98	1.13
	4.92	0.81	1.26
	10.97	1.21	1.62
26.50	9.72	2.18	2.13
	9.04	2.34	1.83
	17.58	4.08	2.55
29.75	15.70	4.02	2.13
	13.16	4.95	1.72

TABLE 23. Percentages (by Weight) of Broken Kernels due to Impact Against a Concrete Surface at 90 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	1.35	0.83	1.49
17.84	2.33	1.66	1.49
	2.65	1.73	1.16
	7.34	2.68	1.17
21.86	5.26	2.68	1.61
	7.08	1.45	1.53
	15.38	5.05	2.48
26.50	14.72	5.45	1.94
	11.29	7.66	1.28
	17.60	7.85	3.17
29.75	30.12	10.33	1.59
	20.32	8.35	3.15

TABLE 24. Percentages (by Weight) of Broken Kernels due to Impact Against a Concrete Surface at 45 Degree Impact Angle.

Kernel Velocity (m/s)	Moisture Content (%) 12.0	15.5	19.0
	0.97	1.30	1.20
17.84	1.84	0.64	1.30
	1.64	0.90	0.98
	5.58	1.22	1.05
21.86	5.60	1.22	1.54
	3.29	0.96	1.27
	12.17	2.26	1.87
26.50	9.15	2.47	1.37
	11.74	2.14	1.62
	14.17	6.49	1.69
29.75	16.24	3.04	1.69
	19.08	6.49	3.05

APPENDIX C

Regression Analysis Results

Table 25. GRAIN DAMAGE BY IMPACT BREAKAGE — 15:06 MONDAY, JUNE 29, 1981 1

GENERAL LINEAR MODELS PROCEDURE

SURFACE : URETHANE

DEPENDENT VARIABLE: DAMAGE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	130.79396844	43.59798948	93.79	0.0001	0.807675	35.4557
ERROR	67	31.14491043	0.46484941		STD DEV		DAMAGE MEAN
CORRECTED TOTAL	70	161.93887887			0.68179866		1.92295775

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEL2	1	63.14895359	135.85	0.0001	1	46.64537719	100.35	0.0001
M2	1	39.24981773	84.44	0.0001	1	15.43121047	33.20	0.0001
MV	1	28.39519722	61.08	0.0001	1	28.39519722	61.08	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	0.80887274	2.42	0.0182	0.33397720
VEL2	0.01903033	10.02	0.0001	0.00189976
M2	0.02564539	5.75	0.0001	0.00445108
MV	-0.04450430	-7.92	0.0001	0.00569424

Table 26. GRAIN DAMAGE BY IMPACT BREAKAGE   15:01 MONDAY, JUNE 29, 1981   1

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: DAMAGE

SURFACE : CONCRETE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	1573.18903662	524.39634554	208.66	0.0001	0.903317	33.8686
ERROR	67	168.38082817	2.51314669		STD DEV		DAMAGE MEAN
CORRECTED TOTAL	70	1741.56986479			1.58529073		4.68070423

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VELOCITY	1	521.85962950	207.65	0.0001	1	615.65369916	244.97	0.0001
M2	1	619.41189985	246.47	0.0001	1	241.37017139	96.04	0.0001
MV	1	431.90750726	171.86	0.0001	1	431.90750726	171.86	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-36.93698227	-12.66	0.0001	2.91762087
VELOCITY	3.47390564	15.65	0.0001	0.22195181
M2	0.10694404	9.80	0.0001	0.01091249
MV	-0.18320411	-13.11	0.0001	0.01397490

Table 27. GRAIN DAMAGE BY IMPACT BREAKAGE   16:47 MONDAY, JUNE 29, 1981   1

GENERAL LINEAR MODELS PROCEDURE

SURFACE : STEEL

DEPENDENT VARIABLE: DAMAGE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	3062.12379113	1020.70793038	341.99	0.0001	0.939559	29.7270
ERROR	66	196.98533601	2.98462630		STD DEV		DAMAGE MEAN
CORRECTED TOTAL	69	3259.10912714			1.72760710		5.81157143

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
AMV	1	134.90945043	45.20	0.0001	1	770.15987703	258.04	0.0001
AV2	1	2461.08705863	824.59	0.0001	1	1264.07068593	423.53	0.0001
AM2	1	466.12728208	156.18	0.0001	1	466.12728208	156.18	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	0.90523630	1.70	0.0932	0.53146389
AMV	-0.00313865	-16.06	0.0001	0.00019539
AV2	0.00130397	20.58	0.0001	0.00006336
AM2	0.00187089	12.50	0.0001	0.00014971

Table 28. GRAIN DAMAGE BY IMPACT
TOTAL DAMAGE

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GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: DAMAGE

SURFACE : URETHANE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	2	18391.24772164	9195.62386083	499.03	0.0001	0.936214	10.1757
ERROR	68	1253.02444453	18.42683007		STD DEV		DAMAGE MEAN
CORRECTED TOTAL	70	19644.2721662			4.29264837		42.18535211

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
MV	1	0.65298585	0.04	0.8512	1	16474.08033712	894.03	0.0001
MV21	1	18390.59473581	998.03	0.0001	1	18390.59473581	998.03	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	-15.73878551	-5.77	0.0001	2.72599159
MV	0.49567235	29.90	0.0001	0.01657751
MV21	-0.02122010	-31.59	0.0001	0.00067170

Table 29. GRAIN DAMAGE BY IMPACT
TOTAL DAMAGE

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GENERAL LINEAR MODELS PROCEDURE

PENDENT VARIABLE: DAMAGE

SURFACE : CONCRETE

URCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
DEL	3	31164.50449027	10388.16816342	548.16	0.0001	0.960292	5.8348
ROR	68	1288.65742084	18.95084442		STD DEV		DAMAGE MEAN
RRECTED TOTAL	71	32453.16191111			4.35325676		74.60888889

URCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ISTURE	1	12876.64557500	679.48	0.0001	1	30276.91290408	1597.66	0.0001
	1	16739.83172349	883.33	0.0001	1	16739.83172349	883.33	0.0001
	1	1548.02709178	81.69	0.0001	1	1548.02709178	81.69	0.0001

RAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
TERCEPT	147.14335317	52.01	0.0001	2.82954096
ISTURE	-10.69271276	-39.97	0.0001	0.26751392
	0.21388182	29.72	0.0001	0.00719636
	0.01307525	9.04	0.0001	0.00144669

S T A T I S T I C A L   A N A L Y S I S   S Y S T E M   14:44 MONDAY, JUNE 29, 1981   1

Table 30. GENERAL LINEAR MODELS PROCEDURE

TOTAL DAMAGE   SURFACE : STEEL

PENDENT VARIABLE: DAMAGE

URCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
DEL	3	31533.05460168	10511.01820056	301.16	0.0001	0.930962	7.9015
ROR	67	2338.42663776	34.90189012		STD DEV		DAMAGE MEAN
RRECTED TOTAL	70	33871.48123944			5.90778217		74.76774648

URCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
ISTURE	1	12982.99867500	371.99	0.0001	1	31372.87754703	898.89	0.0001
	1	12561.54217423	359.89	0.0001	1	12692.59183752	363.66	0.0001
	1	5989.51385245	171.61	0.0001	1	5989.51385245	171.61	0.0001

RAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
TERCEPT	147.83071585	38.49	0.0001	3.84086038
ISTURE	-10.92395387	-29.98	0.0001	0.36435703
	0.18663828	19.07	0.0001	0.00978701
	0.02589688	13.10	0.0001	0.00197686

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CORN DAMAGE BY IMPACT

by

RONALD JIMENEZ

B. S., University of Costa Rica, 1976

AN ABSTRACT OF A MASTER'S THESIS

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MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

ABSTRACT

The objectives of this investigation were: (1) to study damage to corn due to impact as affected by kernel velocity, grain moisture content, impact surface characteristics and angle of impact, and (2) to develop a relationship between corn damage by impact and these variables for each surface under study.

Four main factors were studied: (a) kernel velocity (17.84 m/s, 21.86 m/s, 26.50 m/s and 29.75 m/s); (b) corn moisture content (12.0 percent, 15.5 percent and 19.0 percent); (c) impact surface (urethane,concrete and steel); and (c) angle of impact (45 degrees and 90 degrees).

Tests were carried out using a modified pneumatic conveying system located in the Agricultural Engineering laboratory at KSU. Single kernels of mechanically shelled corn dried at an average temperature of 180 ^{o}F were dropped into the system and impacted against the different surfaces under investigation. Corn damage by impact was then visually inspected and classified in two categories: (1) Breakage, which included all broken material passing through an official 4.76 mm round hole sieve, (2) total damage, which included any visible damage on kenels as coat damage, small and large cracks and any broken material.

The results showed that all main factors significantly affected the extent at which corn kernels were damaged during the impact. Kernel velocity and moisture content accounted for most of the differences observed in corn breakage, and impact surface, kernel velocity and moisture content accounted for most of the variation found in corn total

damage. In general, as kernel velocity was increased corn damage increased, and decreasing moisture content resulted in a greater amount of impact damage. Moisture content also greatly influenced the effect of kernel velocity on corn damage.

Urethane succesfully reduced the extent of damage as compared to concrete and steel: 60 percent less breakage and 43 percent less total damage were observed when concrete was replaced by urethane, and 67 percent less breakage and 44 percent less total damage resulted when steel was replaced by urethane as the impacted surface. Turning the impact surface from 90 degrees to 45 degrees with respect to the kernel flow reduced the average amount of breakage 37.4 percent (3/8 times) and the total damage 12 percent (1/8 times).

Analysis of Variance and Multiple Regression analysis were also performed to test the significance of the main factors and to establish relationships between corn damage and these variables. It was found that corn damage by impact could satisfactorily be explained in terms of grain moisture content, kernel velocity and angle of impact for each of the different surfaces tested in the experiment.