

EFFECT OF CERTAIN NAIL CHARACTERISTICS UPON  
RUPTURE RESISTANCE OF SHEET ALUMINUM

by

Connayil Mani Jacob

A Thesis Submitted to the  
Graduate Faculty in Partial Fulfillment of  
The Requirements for the Degree of  
MASTER OF SCIENCE

Major Subject: Agricultural Engineering

---

Signatures have been redacted for privacy

Iowa State College

1952

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION . . . . .	1
The Project, its Purpose and Scope. . . . .	1
Aluminum sheets for roofing and siding . .	1
Nails as fasteners for aluminum sheets . .	2
Fabrication of aluminum on the farm. . . .	2
Justification of the Project. . . . .	3
Objectives of the Present Study . . . . .	4
REVIEW OF LITERATURE . . . . .	6
Aluminum. . . . .	6
History. . . . .	6
Manufacture. . . . .	7
Properties . . . . .	7
Aluminum as a roofing material . . . . .	8
Nails . . . . .	10
Washers . . . . .	15
INVESTIGATION . . . . .	16
Equipment . . . . .	16
Selection of Nails. . . . .	17
Selection of Roofing Sheets . . . . .	22
Neoprene Washers Used in the Experiment . . . .	23
Statistical Planning. . . . .	25

	<u>Page</u>
Randomization for flat sheets . . . . .	26
Randomization for corrugated sheets . . . . .	26
Procedure of Test . . . . .	30
Flat sheets. . . . .	30
Corrugated sheets. . . . .	31
Quantity of Materials Used. . . . .	32
DISCUSSION . . . . .	34
Limitations of Tests. . . . .	34
Rupture Patterns. . . . .	37
Comparison of Flat and Corrugated Sheets. . . . .	42
Comparison of Thicknesses, 0.019, 0.024 and 0.032 inch . . . . .	45
Comparison of Materials, Aluminum and Steel . . . . .	50
Comparison of Nail Points, Diamond and Conical. . . . .	54
Comparison of Shank Types, Ring and Screw . . . . .	57
Comparison of Washers, Neoprene Flat and Wedge Shaped . . . . .	61
Comparison of the Nails Used for the Experiment . . . . .	66
Suggestions for Further Study . . . . .	67
SUMMARY. . . . .	69
CONCLUSIONS. . . . .	72
BIBLIOGRAPHY . . . . .	76
ACKNOWLEDGMENTS. . . . .	78
APPENDIX . . . . .	79

LIST OF FIGURES

	<u>Page</u>
Figure 1. Roofing Nails Tested . . . . .	17
Figure 2. (a) The Nail-Pulling Machine with Baseboard Used to Test Flat Sheet Aluminum. (b) The Nail Pulling Machine as it was Used to Test Corrugated Sheet Aluminum. . . . .	18
Figure 3. Rupture Patterns in Flat Aluminum Sheets with Nail 1 (Aluminum, Diamond Pointed, Ring Shank with Flat Washer). Nails Before and After Test at Left and Right, Respectively. . . . .	38
Figure 4. Rupture Patterns in Flat Aluminum Sheets with Nail 2 (Aluminum, Conical Pointed, Ring Shank with Flat Washer). Nails Before and After Test at Left and Right, Respectively. . . . .	39
Figure 5. Rupture Patterns in Flat Aluminum Sheets with Nail 11 (Steel, Diamond Pointed, Ring Shank with Wedge Shaped Washer). Nails Before and After Test at Left and Right, Respectively. . . . .	40
Figure 6. Rupture Patterns in Flat Aluminum Sheets with Nail 12 (Steel, Conical Pointed, Ring Shank with Wedge Shaped Washer). Nails Before and After Test at Left and Right, Respectively. . . . .	41
Figure 7. Comparison of Flat and Corrugated Aluminum Sheets. . . . .	43
Figure 8. Comparison of 0.019, 0.024 and 0.032 Inch Thick Aluminum Sheets . . . . .	47
Figure 9. Comparison of Steel and Aluminum Nails . .	51
Figure 10. Representative Failures of Nails Which have been Pulled Through 0.032 Inch Flat Aluminum Sheets . . . . .	52



	<u>Page</u>
Figure 11. Comparison of Diamond and Conical Nail Points . . . . .	55
Figure 12. Photograph of Initial Nail Holes Made by the 16 Nails Used in Experiment . . . . .	58
Figure 13. Comparison of Ring and Screw Shanks . . .	59
Figure 14. Comparison of Neoprene Flat and Wedge Shaped Washers. . . . .	62

LIST OF TABLES

	<u>Page</u>
Table 1. Description of Nails Used for Experiment . .	21
Table 2. Description of Aluminum Sheets . . . . .	24
Table 3. Description of Washers . . . . .	24
Table 4. Plan of Randomization for Flat Sheet for One Replication (rep. 1) . . . . .	27
Table 5. Plan of Randomization for Corrugated Sheets for One Replication (rep. 3). . . . .	29
Table 6. Analysis of Variance of Rupture Resistance of Six Different Aluminum Sheets with 16 Different Roofing Nails . . . . .	46
Table 7. Relation Between Per Cent Superiority of Flat Washers and Rupture Resistance of Aluminum Sheets . . . . .	64
Table 8. Experimental Results: Rupture Resistance in Pounds . . . . .	80

## INTRODUCTION

### The Project, its Purpose and Scope

In March, 1947, the Iowa Agricultural Experiment Station opened a new project, Project 1011, called the "Utilization of Aluminum and Aluminum Products in Farm Buildings and Equipment". Since that time the farm structures field of the Agricultural Engineering Department of Iowa State College has been conducting various studies under this project.

The end purpose of the project is to evolve a set of specifications for every aspect of the utilization of aluminum and aluminum products in farm buildings and equipment. A few of these aspects may be listed as below.

- A. Aluminum sheets for roofing and siding
- B. Nails as fasteners for aluminum sheets
- C. Fabrication of aluminum on the farm

Some of the problems met with in these broad aspects which deserve close study may further be listed.

#### Aluminum sheets for roofing and siding

1. What type of sheet is better, corrugated or flat, and under what circumstances should each be used?
2. For corrugated sheets, what is the best type of corrugation?

3. What is the optimum thickness of sheets?
4. What is the most suitable alloy of aluminum for the purpose?
5. The best temper and extent of heat treatment for the alloy used.
6. The corrosion resistance properties of the material.
7. Temperature effects on the sheets.

Nails as fasteners for aluminum sheets

1. Withdrawal resistance.
2. Resistance to creep.
3. The material out of which the nails are manufactured, like steel or aluminum.
4. The type of nail shank, plain, screw, ring or combination ring and screw.
5. Treatment of shank.
6. Diameter of shank.
7. Diameter of head.
8. Thickness of head.
9. Nature of the nail point, diamond, conical or any other type.
10. The type of washer to be used with the nails.

Fabrication of aluminum on the farm

1. Spacing of the rafters.

2. Overlapping of sheets.
3. Type of sheathing.
4. Type of nailing girts, their dimensions and other specifications.
5. Minimum slope of roofing.

It is hoped that in the course of time each of these problems can be studied closely and satisfactory answers obtained.

#### Justification of the Project

The use of aluminum on the American farm, especially as roofing and siding, has increased tremendously since the end of the second world war. During the war, the production of aluminum was stepped up to meet the demands of the war. When the war ended the aluminum industry was forced to seek alternate markets and discovered the farm market as the chief among them. This had mixed results. It gave the farmer an excellent material for roofing, siding and other purposes, a material which not only made up the shortage of other building materials like lumber and iron products, but in many respects was potentially even superior to them. However, the immediate results in many cases were disastrous because of the lack of experience of the farmer with aluminum and because of the lack of any specifications, code or recommendations for its use. Thus the urgent need for a set of

specifications embracing every aspect of the use of aluminum on the farm, in order to help the farmer and the farm building industry, became very pressing. Hence the justification of the project.

### Objectives of the Present Study

It is clear that it will take several years and the efforts of several men to conduct enough experiments to reach the goal set for the project. So a few problems are taken at a time by a few research men, as time and expenses allow, and intense studies are made on them. The accumulated results of such work over a period of years are expected to lead to the stated goal. The objectives of the present study are to determine:

1. the relative merits of corrugated and flat sheet aluminum for roofing of farm buildings;
2. the relative merits of three different thicknesses of aluminum sheets, namely 0.019 inch, 0.024 inch and 0.032 inch;
3. the relative merits of steel and aluminum as material for the manufacture of roofing nails;
4. the relative merits of two different types of nail points, diamond and conical;
5. the relative merits of two different types of nail shanks, screw and ring;

6. the relative merits of two different types of neoprene washers used with roofing nails, flat and wedge shaped.

7. an average rupture resistance for each nail used with each thickness of flat and corrugated aluminum sheets.

The determinations in objectives 1 through 6 are based solely on the rupture resistance of the sheet aluminum used for the particular treatment combination. As for objective 7, since the nail head diameters are reduced for the purposes of this study, the estimates of rupture resistance tend to be lower than what would actually take place under normal conditions.



## REVIEW OF LITERATURE

### Aluminum

Aluminum is the most abundant metallic element, estimated to comprise 8 per cent of the solid portion of the earth's crust. It is an important constituent of clay and practically all common rocks except sandstone and limestone. Yet, despite its prevalence, it was not commercially produced on a large scale until 1888.

### History

The history of aluminum from its isolation to its final commercial production may be briefly summarized as described by Brown (5, pp. 10-12). In 1825 Oersted, a Dane, first isolated aluminum by heating potassium amalgam with aluminum chloride and distilling mercury from the resulting aluminum amalgam. Wohler, a German, in 1845 used potassium instead of potassium amalgam and obtained aluminum as a grey powder. Saint-Claire Deville, a Frenchman, in 1854 changed Wohler's method by substituting sodium for potassium. In 1886, Charles Martin Hall in America and Paul L. T. Heroult in France independently discovered the process of electrolytic reduction of aluminum oxide to the metal. This process, called the

Hall-Heroult process, is basically the same as the one being used today for commercial production of aluminum.

### Manufacture

Brown (5, p. 15) describes the Hall-Heroult process in the following words.

The world's supply of aluminum is produced by the electrolytic reduction of the oxide by the Hall-Heroult process.....For the electrolytic reduction, alumina ( $\text{Al}_2\text{O}_3$ ) is dissolved in a bath of molten cryolite maintained at a temperature of about  $982^\circ\text{C}$ . ( $1800^\circ\text{F}$ .). This molten bath (or electrolyte) is contained in a cell comprising a cast iron shell lined with carbon which serves as a cathode and has carbon anodes suspended therein. The current passing through the electrolyte separates the dissolved aluminum oxide into metallic aluminum, which is deposited at the bottom of the cell, and oxygen, which is deposited on the carbon anodes, gradually consumes them. The cryolite remains substantially unaltered.....Alumina is periodically stirred into the bath and dissolved to maintain the continuous operation of the process. It takes from 10 to 12 kilowatt hours of electricity to product a pound of aluminum.....

### Properties

The great demand for aluminum today--it comes only next to iron in volume of production--is due to certain properties which make it desirable for commercial usage. It is comparatively lightweight; it weighs 168.6 pounds per cubic foot, which is only about one-third of the unit weight of iron, copper, nickel or zinc. It has good resistance to corrosion. Acetic acid and concentrated nitric acid are commonly shipped

and stored in aluminum drums and tanks. Aluminum is an excellent reflector of radiation in ultraviolet, visible, and infra-red regions of the spectrum. It has excellent thermal and electrical conductivity. The electrical conductivity is 61 per cent that of copper by volume and 200 per cent that of copper by weight. Aluminum is soft and ductile, which makes it easier to cold work than some of the harder metals. When used as alloys and by proper heat treatment it can be made to acquire excellent strength properties making it a desirable material for structural work (6, p. 108). As a result of these desirable properties aluminum and its alloys have attained considerable usage in aircraft industry, electrical appliances, engine parts, hulls of ships, cranes, bearings, machinery, cooking utensils, architecture and farm buildings.

#### Aluminum as a roofing material

Aluminum has many good qualities to justify its use as a roofing and siding material. It is light, fire and moisture resistant, comparatively cheap and durable. Weather has little effect on it as evidenced by the aluminum cap on the top of the Washington Monument, which was installed in 1884 and though exposed to all kinds of weather for more than 60 years is still unharmed by the elements (5, p. 3). It is corrosion resistant, although not to the same extent as it is commonly believed to be. If properly used it is strong



enough as a roofing material. However, it has poor heat insulating qualities. Barre and Sammet (3, pp. 78-79) give some recommendations for its use for roofing.

Sheet metal (including aluminum) should not be applied on roofs that slope less than 2.5 to 3.5 inches per foot. The ends of the sheets should be lapped 6 inches. Corrugated sheets should be side-lapped 1.5 to 2 corrugations and flat sheets should be laid with flat or standing soldered seams, or side-lapped with a V-crimp joint..... Aluminum and flat steel sheets should be laid on fairly tight sheathing and the sheathing covered with rosin-sized paper before the metal sheets are laid..... Sheet metal roofing should be well nailed to secure it against wind. Since the nails are exposed, washers of lead or other material that will exclude moisture are necessary under the nail head.

Pandya (14) studied the effects of temperature on aluminum sheet roofing. One of the objectives of his study was to determine whether high temperatures according to the climatic conditions in Iowa would cause any enlargement of the nail hole in the sheet aluminum. If any such appreciable enlargement occurred, the rupture resistance of the sheet would be reduced considerably. So one of the conclusions drawn by Pandya is as follows: (14, p. 67).

If aluminum corrugated sheets are properly applied to a sound roof deck, sheets will not tear round the nail holes if the temperature differential is within 100° F..... The bearing stresses developed in the sheet around the nails are not large enough to enlarge the nail holes to cause leaks in a roof.

Esmay (9), who studied the problem of wind damage to

farm buildings reported that approximately 14 per cent of the total roofing damage in Iowa was caused by wind on roofs covered with sheet metal. The Iowa Mutual Tornado Insurance Association paid about \$32,000 for the damages caused to sheet metal roofing by the single storm of October 10, 1949. These records show not so much the liability of sheet metal roofing to wind damages as the danger of improper usage of the metal. By proper methods of usage, eventually it will be possible to eliminate all wind damages to sheet metal roofing.

#### Nails

The nail, as a fastener for wood, has been known to mankind for several thousands of years. However, there is no record of any serious study on nails earlier than 1893, when Burr experimented with cut and wire nails. He found that the cut nail was superior to the wire nail in direct tensile holding power by about 73 per cent. Since the time of Burr some very careful work has been done on different types of nails, a considerable portion of which has no application to the present study. In this review of literature, it is intended to cover only the work done so far under Project 1011, and that in other places which has a direct bearing on the present study.

In 1939 Reaves (16) conducted some studies on 16

different types of steel roofing nails. These nails differed from one another by shank type, shank treatment and type of head. Some of his conclusions were as follows: (16, p. 49)

The creeping out of roofing nails is caused by a combination of wind action, changes in temperature and changes in moisture content of the wood. All roofing nails (steel) should be galvanized... .. In general the holding power of the common roofing nail may be increased by driving the nail at an angle.

As far as the conclusions drawn from it are concerned, Reaves' study might not have been very valuable. But certainly he made a good start and attracted attention to the very important problem of roofing nails.

In 1948, Boyd (4) investigated the effect of moisture content of wood on withdrawal resistance of roofing nails. He used 33 different types of roofing nails consisting of ring, screw, plain, barbed and combination shanks, different surface treatments, different nail points and different types of nail heads. The nail pulling machine he used was essentially the same as used in the present study. A properly equipped control room was used for varying environmental temperature and humidity. He stated some of his conclusions as follows (4, pp. 115, 118, 119).

Moisture changes in the wood have a definite effect on the withdrawal resistance of roofing nails..... In general plain shank nails lose some of their resistance to withdrawal after the wood has changed in moisture content..... Ring shank nails are



significantly superior to all plain and barb shank nails (as far as withdrawal resistance is concerned). Changes from diamond points to conical points result in no significant increase in withdrawal resistance..... Due to the slight variation of withdrawal resistance of ring shank nails with moisture changes, it appears that they would be relatively unaffected by creep..... Based on withdrawal resistance, deflection, and driving characteristics, ring shank and combination shank nails appear superior, with some screw shank nails also performing satisfactorily..... The flat head with no washer was significantly superior to the flat head with either the wedge type or the flat type washer..... It was observed that anything between the head and the sheet tends to wedge the hole larger and promote failure.

In 1949, Robinson (18) continued the study of the withdrawal resistance. He used the same nails as were used by Boyd and the same equipment and temperature and humidity control device. Some of his conclusions were as follows:

Nails show as much as 95 per cent greater withdrawal resistance when pulled from 2 inch nailing girts than when pulled from 1 inch nailing girts. Galvanized steel nails are superior to aluminum when used with 2 inch nailing girts..... The ring shank nail gives better withdrawal results than nails of other shank types..... The aluminum plain shank and barb shank nails (regardless of surface treatment) are unsatisfactory and should not be used..... The change from diamond point to conical has no material effect on the withdrawal resistance of aluminum nails. The pilot point is a detriment to aluminum screw shank nails..... Galvanized steel nails or aluminum ring or combination shank nails should be used for least splitting..... When using aluminum 0.025 inch thick, the galvanized steel ring, combination, or screw shank nail should be used. (18, pp. 127-129)

In 1951, Kunze (13) studied the resistance of sheet



aluminum to rupture by heads of various types of roofing nails. The present study, in many respects, is a continuation of Kunze's work. He used 16 different types of nails, the variables in which were two different materials, three different types of nail shanks and four different types of washers. He tested the nails on three different thicknesses of plain aluminum sheets and one thickness of corrugated aluminum sheet. The equipment and procedure of test used by Kunze have been followed closely in the present study.

Kunze (13, p. 85) remarked that the diamond and conical nail points deserved close study and comparison. Although he did not study the matter, he thought that a conical point would be superior to a diamond point because of the difference in the form of the initial holes they make on the sheets as they are driven through. In the present study the author has sought to give a definite answer to this question. Some of the conclusions drawn by Kunze, as stated by him are given below (13, pp. 88, 89).

The large bare heads of the steel nails were superior in strength to the large bare heads of aluminum nails..... The large bare heads on aluminum nails are too weak to be used effectively with the 0.032 inch sheet aluminum used in the tests..... The type of rupture which results in aluminum sheet metal is influenced considerably by the type of point on the test nail. The type of shank on the nail has little influence on the final rupture pattern..... All the nails tested show sufficient resistance to rupture to secure one square foot of sheet metal roofing in a 100 mile an hour wind.

Stern (20) who conducted some elaborate studies on several types of nails has the following remarks to make about nail points. (20, p. 46)

The selection of proper type of nail point depends upon the nail use. The point can be of influence on both the nail holding power and the splitting resistance of wood into which the nail is driven.. ... In general, a nail with a long sharp point may have greater holding power than one with a blunt or medium long point. The effect of the point design on the driving resistance and holding properties of nails is, however, relatively small, and thus often practically insignificant from the strength view point.

Giese and Henderson (12, p. 531) make some very pertinent remarks on the problem of nails.

The problems in the use of nails may vary widely with the application. In some cases the load is applied perpendicular to the nail, tending to shear one member from the other. In other instances the load tends to withdraw the nail from its base or results in a combination of the two applications of force. A nail suitable for one purpose may not be well adapted to another.

In the present study only one criterion has been used to judge the nails and that is the rupture resistance of sheet aluminum. The author wishes to emphasize that although this may be valid for the present study, it may not be so for many other applications of the nail.

### Washers

Washers are used with roofing nails primarily as a seal for the hole that the nail makes in the sheet metal when driven through. Only very recently was it discovered that the washers could considerably influence the rupture resistance of the roofing sheet. Boyd (4, p. 115) thinks that the rupture resistance of sheet metal is decreased by the use of any washers. Kunze (13, pp. 89, 90) in his study compared the performance of a few washers on the basis of rupture resistance of sheet aluminum. Some of his conclusions were as follows.

The flat synthetic washers proved to be the best of all washers tested..... In general the nails to which these washers were applied showed a greater resistance to rupture regardless of the characteristics of the individual nail or of the sheet aluminum which was tested. Nails with flat synthetic washers were from 25 to 32 per cent better in tests with the .020 inch sheet aluminum than was the best nail with a wedge synthetic washer. The nail with flat synthetic washers were from 14 to 22 per cent better in test with the .025 inch sheet aluminum.

In the present study only two types of washers were tested, the flat and the wedge shaped neoprene washers. These were among the washers that Kunze (13) used for his study. New and different types of roofing nail washers are coming on the market. Some of them have large diameters while others are manufactured out of neoprene with metal backing. These are developments in the right direction.

## INVESTIGATION

### Equipment

The nail pulling machine that has been in use in Project 1011 was used for the investigation. Figures 1 and 2 show the nail pulling machine testing a flat and a corrugated aluminum sheet respectively. The machine consists of a diaphragm and cell connected by a rubber tubing to a Bourdon gage. Load was applied to the nail through a shaft which was actuated in an upward direction by means of an electric motor. As the shaft moved upward the nail which was rigidly attached to it tried to pull through the aluminum test piece, whose motion was kept restricted. At the same time the upper end of the shaft pushed against the diaphragm putting the fluid in the cell under pressure. This pressure was transmitted hydraulically through the rubber tubing to the Bourdon gage, which was graduated in such a way as to read directly in pounds the load applied to the nail. The machine was calibrated before the investigation was begun. The error in calibration never exceeded two per cent. As the load increased the accuracy of calibration also increased so much that above 100 pounds the calibration was exact for all practical purposes. The smallest graduation on the scale was

Nail Code



Key to code:

1st letter = Material: Aluminum, A; Steel, S.  
2nd letter = Nail point: Diamond, D; Conical, C.  
3rd letter = Shank type: Ring, R; Screw, S.  
4th letter = Washer: Flat, F; Wedge shaped, W.

Figure 1. Roofing Nails Tested.



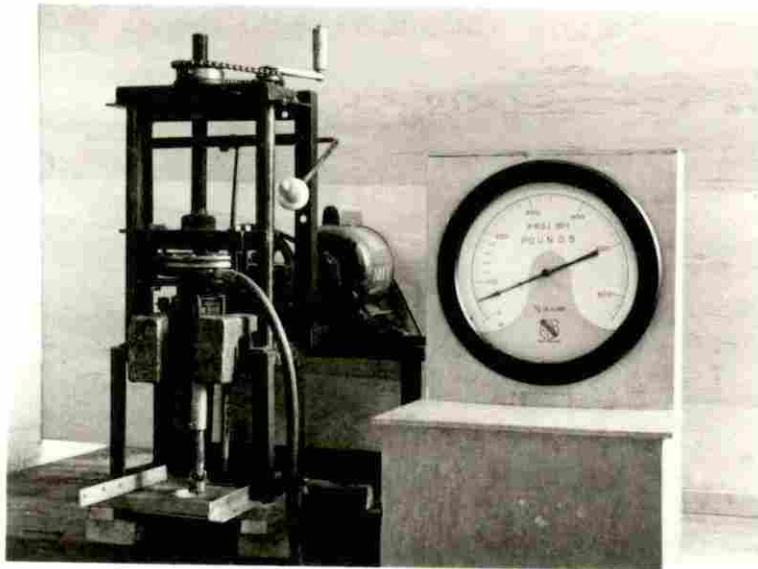


Figure 2. (a) The Nail-Pulling Machine with Baseboard Used to Test Flat Sheet Aluminum.

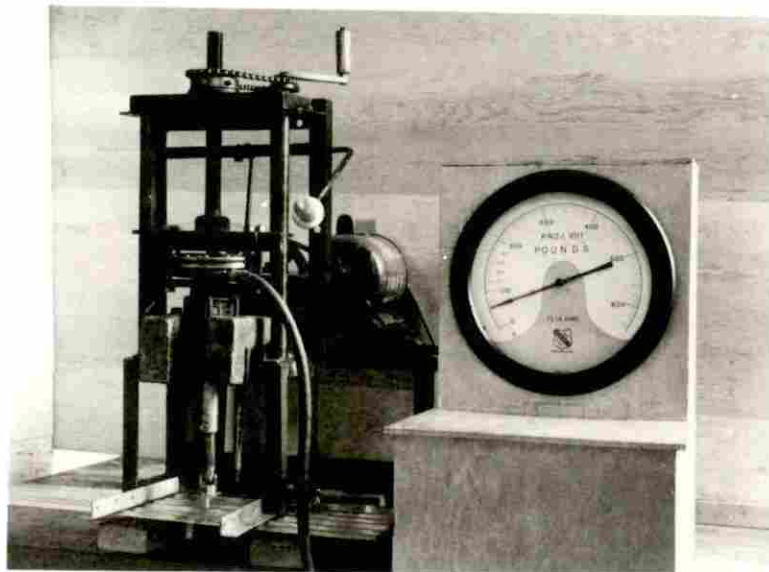


Figure 2. (b) The Nail-Pulling Machine as it was Used to Test Corrugated Sheet Aluminum.

5 pounds, the reading below 5 pounds being ascertained by eye judgment. The calibration was carried out with lead weights of ten pound and twenty pound units.

### Selection of Nails

In the selection of nails, four variables were considered. These variables and the reasons for their selection are as follows.

1. Material of the nail: steel versus aluminum. There are advantages and disadvantages in each of these materials for the nail. In general, steel nails are comparatively stronger, easier to work with in that they do not bend while driving in and their heads remain intact if extracted from wood, and they are cheaper by weight. However there is galvanic action between steel and aluminum, and, even if zinc coated, steel nails are less weather resistant than aluminum nails. Aluminum nails are comparatively light, have better resistance to weather and, being the same material, do not have any galvanic action with aluminum sheets. The need for further comparison of the two materials on the basis of rupture resistance of sheet aluminum was indicated by previous studies.

2. Shank type: ring versus screw. In earlier studies with roofing nails, these two shank types were compared on the bases of withdrawal resistance, splitting qualities, and



resistance to creep. An incomplete study to compare them on the basis of rupture resistance of sheet aluminum has been conducted by Kunze (13), who indicated the need to collect further data in this respect.

3. Nail point: diamond versus conical. Kunze (13) in the course of his study indirectly came to the conclusion that conical points were superior to diamond points on the basis of rupture resistance of sheet aluminum. However, his conclusion was not based on any statistically reliable data. So he made the suggestion that this aspect of the nail be investigated, a suggestion which was followed by the author.

4. Type of washers to be used with roofing nails: neoprene flat versus wedge shaped. Recent studies of roofing nails have made it clear that washers of roofing nails have properties in addition to those of sealing the nail holes. Several different types of washers have made their appearance on the market. Thus it became important that the farmer be given some guidance in the selection of washers. With this object in mind it was decided to compare two common types of roofing nail washers.

These four variables gave a combination of sixteen nails. These nails are shown in Figure 1. Further details and descriptions of these nails are given in Table 1.

It was attempted to eliminate from each nail tested all the variables other than those listed above. Thus the size

Table 1.

Description of Nails Used for Experiment

Nail No.	Code <sup>a</sup>	Material	Point	Shank	Washer	Shank dia. in in.	Head dia. used in exp. in in.
1	ADRF	Alum. <sup>b</sup>	Dmd. <sup>c</sup>	Ring	Flat	0.150	0.350
2	ACRF	"	Con. <sup>d</sup>	"	"	"	"
3	SDRF	Steel	Dmd.	"	"	0.160	"
4	SCRF	"	Con.	"	"	"	"
5	ADSF	Alum.	Dmd.	Screw	"	0.165	"
6	ACSF	"	Con.	"	"	"	"
7	SDSF	Steel	Dmd.	"	"	"	"
8	SCSF	"	Con.	"	"	"	"
9	ADRW	Alum.	Dmd.	Ring	Wedge shaped	0.150	"
10	ACRW	"	Con.	"	"	"	"
11	SDRW	Steel	Dmd.	"	"	0.160	"
12	SCRW	"	Con.	"	"	"	"
13	ADSW	Alum.	Dmd.	Screw	"	0.165	"
14	ACSW	"	Con.	"	"	"	"
15	SDSW	Steel	Dmd.	"	"	"	"
16	SCSW	"	Con.	"	"	"	"

<sup>a</sup> Key to Code:

1st letter = Material: Aluminum, A; Steel, S.  
 2nd letter = Nail point: Diamond, D; Conical, C.  
 3rd letter = Shank type: Ring, R; Screw, S.  
 4th letter = Washer: Flat, F; Wedge shaped, W.

<sup>b</sup> Alum. = Aluminum.

<sup>c</sup> Dmd. = Diamond.

<sup>d</sup> Con. = Conical.

of the nail head was turned down to 0.350 inch in each case. Those nails having conical points had all the same shape and dimensions of the point. The conical points were obtained by taking diamond pointed nails and turning the point on the lathe to a 30 degree cone terminating to a sharp point. There was an appreciable difference in shank diameters between ring and screw shank nails and a slight difference in shank diameters between aluminum ring and steel ring shank nails. The shank diameter can affect the rupture resistance because it determines the size of the original nail hole, which in turn influences the area of the aluminum sheet under the nail head exposed to the load. The difference in shank diameters can confound the comparisons between ring shank nails and screw shank nails and also those between aluminum and steel nails. However, this may not be particularly serious, because the diameter of the nail goes with the make of the nail in ordinary roofing nails. In other words the diameter of the nail may be considered as a property of the particular nail type, aluminum and steel, or ring and screw, as the case may be.

#### Selection of Roofing Sheets

Two different types of sheets, flat and corrugated, and three different thicknesses were used for the experiment. The choice of the sheets was limited by the size of the

experiment and the material supplied by the Aluminum Company of America. The three thicknesses, 0.019 inch, 0.024 inch and 0.032 inch, were selected because they were the ones used by Kunze (13), and uniformity in experimental results was desired. Originally Kunze made his choice on the basis of the fact that these thicknesses are the most prevalent on the market. The two types of sheets and three thicknesses gave six different combinations of sheets for each nail tested. Additional information regarding the sheets is given in Table 2.

#### Neoprene Washers Used in the Experiment

Two different kinds of neoprene washers were used in the experiment, one grey and wedge shaped, the other black and flat. Kunze (13) also used these two types of washers in his experiment. There was some difficulty in obtaining the flat neoprene washer as it was not very common on the market. The grey wedge shaped neoprene washers were taken from the same supply used by Kunze a year ago. More recent makes of such washers have carbon added to the material in order to make them more weather resistant and maintain their qualities for longer periods. The diameter and thickness of the flat washer were approximately 0.50 and .115 inch respectively, and those of the wedge shaped washer were approximately 0.34 and 0.10 inch respectively. (See Table 3.)

Table 2.

Description of Aluminum Sheets

Type of sheet	Thick-ness in in.	Size of corr.	Alloy	Yield point in psi	Ultimate strength in psi	Per cent elonga-tion
Flat	0.019		Alclad XB16SF	35,000	37,000	2.5
"	0.024		"	"	"	"
"	0.032		Alclad 4S-H16	"	40,000	5.0
Corru-gated	0.019	1.50"	Alclad XB16SF	"	37,000	2.5
"	0.024	"	"	"	"	"
"	0.032	1.67"	Alclad 4S-H16	"	40,000	5.0

Table 3.

Description of Washers

Type	Compound	Diameter	Thickness	Color
Flat	Neoprene	0.50	0.115	Black
Wedge shaped	"	0.35	0.10	Grey



### Statistical Planning

A completely randomized factorial design was the statistical plan used for the experiment. The experiment was set up in consultation with the Statistics Department of the Iowa State College. The plan of the experiment may be summarized as follows.

It was desired to use:

- 2 types of aluminum sheets, flat vs. corrugated;
- 3 thicknesses, 0.019 inch, 0.024 inch and 0.032 inch;
- 2 materials for nails, aluminum vs. steel;
- 2 types of nail shanks, ring vs. screw;
- 2 types of nail points, diamond vs. conical;
- 2 types of washers, neoprene flat vs. wedge shaped.

This results in a total of 96 treatment combinations. Using 4 replications and 3 nails in each replication, 12 nails are needed for each treatment combination. Therefore, the total number of nails to be tested was  $12 \times 96 = 1152$ .

Slightly different methods of randomization were used for flat and corrugated sheets. However, this did not confound any results because the statistical plan was still the same for both, i. e., a completely randomized design.

### Randomization for flat sheets

For each thickness, the test pieces were mixed among themselves, and were then assigned at random to four bundles. These bundles were designated by the numbers 1, 2, 3, and 4, giving a total of 12 bundles. Test pieces for each of the four replications were drawn from the corresponding bundles. Then, for each replication, the order of testing of the nails was randomized. Again, for each of these nails, the order of testing the thicknesses was randomized. It is to be noted that the nails, themselves, represented random samples as they were drawn in the first instance from a large supply. Table 4 will further help to explain the scheme of randomization.

### Randomization for corrugated sheets

Table 5 shows the randomization adopted in the case of corrugated sheets. The order of testing the nails was randomized within each thickness for every observation in each replication. This difference in randomization from the flat sheets was necessitated by the difference in the test pieces between the two types of sheets. In the case of flat sheets the test pieces were squares, each taking one nail, while in the case of the corrugated sheets the test pieces were four feet long, each taking six nails. The differences in the two cases will be further clarified in the following section.



Table 4.

Plan of Randomization  
for Flat Sheet for One Replication (Rep. 1)

Observations									
Nail Number									
13			12			8			
C <sup>a</sup>	A <sup>b</sup>	B <sup>c</sup>	C	A	B	A	B	C	
1									
2									
3									
Nail Number									
5			10			1			
B	C	A	C	B	A	B	A	C	
1									
2									
3									
Nail Number									
9			4			3			
A	B	C	B	A	C	A	C	B	
1									
2									
3									
Nail Number									
14			15			2			
B	A	C	B	C	A	A	B	C	
1									
2									
3									

(Continued on next page)

Table 4. (Continued)

Observations	Nail Number								
	7			11			16		
	C	B	A	A	B	C	B	A	C
1									
2									
3									

	Nail Number		
	6		
	A	B	C
1			
2			
3			

<sup>a</sup> C = 0.032 inch sheet.

<sup>b</sup> A = 0.019 inch sheet.

<sup>c</sup> B = 0.024 inch sheet.

Table 5.

Plan of Randomization for Corrugated Sheets for One Replication (Rep. 3)

Sheet	Nail Number															
A <sup>a</sup>	5	15	11	12	3	10	4	7	2	14	8	1	13	9	6	10
	4	6	5	11	13	9	1	10	15	2	3	8	16	14	7	12
	5	11	16	7	3	4	15	2	10	1	13	8	14	6	9	12
B <sup>b</sup>	13	14	8	2	15	6	10	1	5	4	9	12	11	7	3	16
	10	15	1	8	3	5	4	16	6	11	12	7	13	2	14	9
	16	7	3	9	6	13	9	15	4	14	2	11	5	1	10	12
C <sup>c</sup>	14	5	10	13	4	11	3	6	1	8	15	7	16	9	2	12
	5	6	14	15	7	2	13	10	16	4	3	8	9	12	11	1
	6	12	9	7	13	4	11	2	1	14	3	10	5	8	16	15

a A = 0.019 inch thickness.

b B = 0.024 inch thickness.

c C = 0.032 inch thickness.

### Procedure of Test

Once again, with the idea of standardizing the procedures to be used in all similar studies in the project, the same procedure of test that was used by Kunze (13) in his study was adopted. There was some difference in the procedure adopted for flat sheets and corrugated sheets.

#### Flat sheets

Figure 2a shows the testing of a flat sheet. A two inch hole in the baseboard under the nail pulling machine was used for all the sheets. This size of the hole was the largest that could be used without the risk of buckling the sheets when tested.

The 0.024 inch and 0.032 inch test pieces were cut into six inch squares while the 0.019 inch test pieces were cut into seven inch squares. The thinnest sheet was cut into the larger size in order to further insure them against any buckling while being tested. This difference in size of the test pieces is permissible because the load is independent of the size of the test piece.

The specified test piece and the specified nail as given by the randomization plan were taken and the nail was driven through the center of the test piece. Now the test piece was inverted and centered under the baseboard of the nail pulling

machine. The nail was now inserted into the nail shank holder of the machine and held firmly. Load was now applied electrically with a one-fourth horse power motor by pulling the nail in an upward direction through the test piece, whose motion was restricted by the baseboard. The load was applied at a slow constant rate until rupture occurred. The maximum load taken by the test piece as denoted by the attached Bourdon gage was observed. The same procedure was repeated for every other flat test piece.

#### Corrugated sheets

Figure 2b shows the testing of a corrugated sheet. The test pieces were cut into strips of four feet long by 7.5 inches wide. Six specified nails in the order given by the randomization were driven along the top of the central corrugation, equal spaces separating one from the other. Now the sheet was inverted and the first nail attached to the nail shank holder of the nail pulling machine. This time the baseboard under the nail pulling machine was removed. The test piece was restricted from moving by the supports of the nail pulling machine which were at a distance of eight inches from each other. The load was applied as in the case of flat sheets until rupture occurred and the maximum load as given by the Bourdon gage noted. The motor was then shut off and the pulling mechanism lowered by means of the hand crank on



top of the machine. Following the removal of the tested nail, the next nail in order was attached to the nail shank holder and the same procedure repeated.

The question of why the corrugated sheets were tested differently from the flat sheets may now be raised. Preliminary tests were made as in the former case, with the corrugated sheets cut into the same size as flat sheets. But this gave unsatisfactory results because the corrugations flattened out under load. On an actual roof under wind load no flattening of the corrugations takes place because of the large size of the roofing sheets. So it was important to prevent this flattening in the experiment. In order to do this, the size of the test piece had to be increased. Various sizes were tried and finally a size of four feet long and 7.5 inches wide was adopted as the most convenient.

The rupture resistance is independent of the size of the test piece or the spacing of the supports. This is because the failure of the sheets is not due to bending but to combined bearing stresses and tensile stresses in tearing. Thus the size of the test piece and the manner of its support are unimportant as far as resistance to rupture is concerned.

#### Quantity of Materials Used

The total number of nails pulled through was as follows:

- 3 nails per thickness
- 3 thicknesses of material
- 2 types of sheets in each thickness
- 16 different types of nails
- 4 replications

Total: 1156.

The amount of flat sheet aluminum which was used was as follows:

- 3 sheets 28 inches by 12 feet, 0.019 inch material
- 3 sheets 28 inches by 12 feet, 0.024 inch material
- 2 sheets 42 inches by 12 feet, 0.032 inch material.

The amount of corrugated sheet aluminum which was used in the experiment was as follows:

- 3 sheets 26 inches by 12 feet, 0.019 inch material
- 3 sheets 26 inches by 12 feet, 0.024 inch material
- 2 sheets 35 inches by 12 feet, 0.032 inch material.

All of the above material was not necessarily used since a complete sheet had to be secured if any portion of it was to be used. Some additional material had to be used for running a few preliminary tests.

The amount of roofing washers used in the experiment was as follows:

- 578 neoprene flat washers
- 578 neoprene wedge shaped washers

Total: 1156 washers.

Some more washers were used for running the preliminary tests.

## DISCUSSION

### Limitations of Tests

1. The rupture resistance of any test piece with a specified nail was found by applying a steadily increasing load and noting the instantaneous maximum load when rupture occurred. There was no attempt to take into consideration the effects of vibration and of repeated loads. Both vibration and repeated loads can have very significant effects upon the rupture resistance of sheet aluminum. On an actual roof under load (wind load), vibrations in the roofing sheets are set up by the combination of opposing forces of negative pressure due to wind and the restoring force due to the fastener. Again, in nature, it is never a steadily increasing load that is applied to a roofing sheet. Whenever there is a breeze a load is applied to the sheet and at any one spot a breeze is never steady or continuous. The result is the application of varying loads, and aluminum, like most other metals, can fail at a much lower stress than the maximum rupture strength under such an application of repeated loads. The same argument applies to nail heads as well, which are also subjected to the same load as the roofing sheet. It is quite possible that nails tested might have

yielded different results if the effects of vibration and repeated loads were taken into account.

2. Although the calibration of the Bourdon gage did not show any error greater than 2 per cent for lower values and practically no error for values higher than 100 pounds, it is not justifiable, in the opinion of the author, to assume that the measurements are accurate up to any amount less than five pounds. One of the reasons for this is that the lowest graduation on the Bourdon gage is only five pounds. Secondly, the instantaneous maximum load was interpolated within five pounds by eye judgment only, something which is not absolutely reliable. A maximum load indicator needle was tried to overcome this difficulty, but it did not function satisfactorily and so had to be discarded. A third reason is that an error in centering of the nail and test piece may cause an erroneous reading of pressure on the gage. Ordinarily under conditions of the experiment this error is within two pounds, but it may be considerably more if the centering is very poor. Thus the author believes that the results of the experiment are valid only within 5 pounds of the mean values reported. So any difference in the performance of nails which is not more than 5 pounds must be considered as nonsignificant.

3. As has been pointed out earlier, there are differences in the nail diameters:

- a. between ring shank and screw shank nails, and
- b. between aluminum ring shank nails and steel ring shank nails.

The shank diameter will definitely influence the rupture resistance because it determines the size of the original nail hole and the area of sheet under the nail head exposed to the load. The difference in diameter will thus make it impossible to give a true comparison between ring and screw shank types. Similarly it is difficult to get a true comparison between aluminum and steel ring shank nails. However the procedure adopted in the experiment is still justifiable on the ground that the particular size of diameter is a property of the type of shank or the material out of which the nail is manufactured.

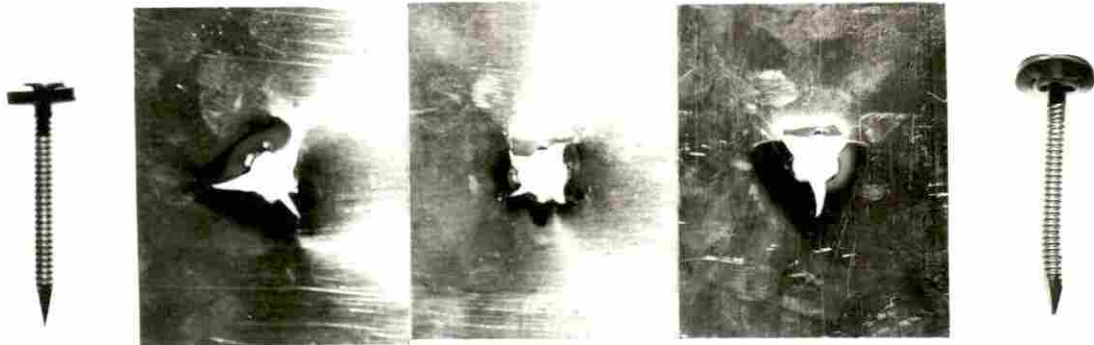
4. The mean value of the maximum resistance to rupture obtained for each nail in each type of sheet is unreliable as a design load. There are several reasons for this. First of all, as referred to earlier, no consideration has been given to effects of vibration or repeated loads in the measurement of rupture resistance. Secondly, the mean value is the mean of the maximum resistance obtained in several observations, while in actual practice, the minimum value among the observations would be more important. Thirdly, the nail heads have been reduced in diameter for the purpose of the experiment, thereby influencing the maximum load. This latter



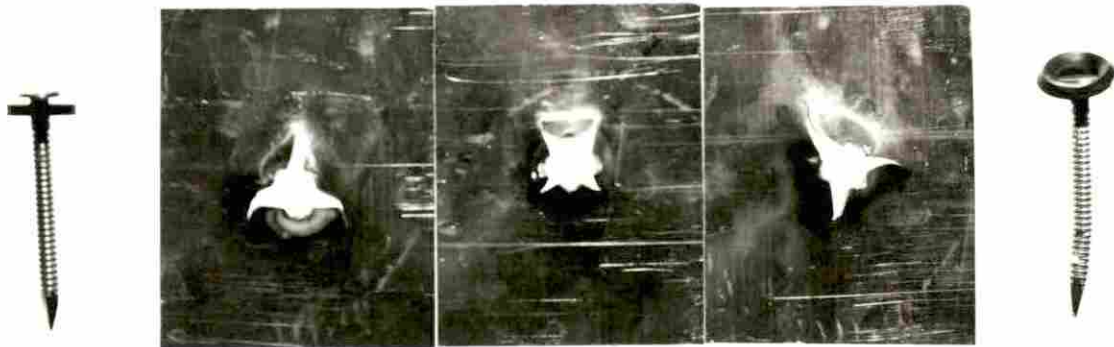
error, however, is on the positive side. Thus the mean values obtained for the different nails with each sheet are justifiable for comparisons rather than estimates of design load.

### Rupture Patterns

The rupture patterns, resulting from two aluminum ring shank nails with flat washers, one with a diamond point and the other with a conical point, and two steel screw shank nails with wedge shaped washers, one with a diamond point and the other with a conical point, are shown in Figures 3 through 6, respectively. The nails before and after the test along with the particular thickness of the sheet tested are also shown in the figures. These combinations of nails were chosen to include both washers, both metals, one shank type and both nail points used in the experiment. Kunze (13, p. 51) advanced the theory that, in general, the four cornered rupture patterns would be associated with a diamond point and a three cornered pattern with a conical point. The author could not find any evidence during his study to substantiate this hypothesis. The rupture patterns obtained, as well as Figures 3 through 6 tell a different story. The particular type of pattern developed seems to be independent of the nail point or any other nail variable under study.



0.019 Inch Flat Aluminum Sheet



0.024 Inch Flat Aluminum Sheet



0.032 Inch Flat Aluminum Sheet

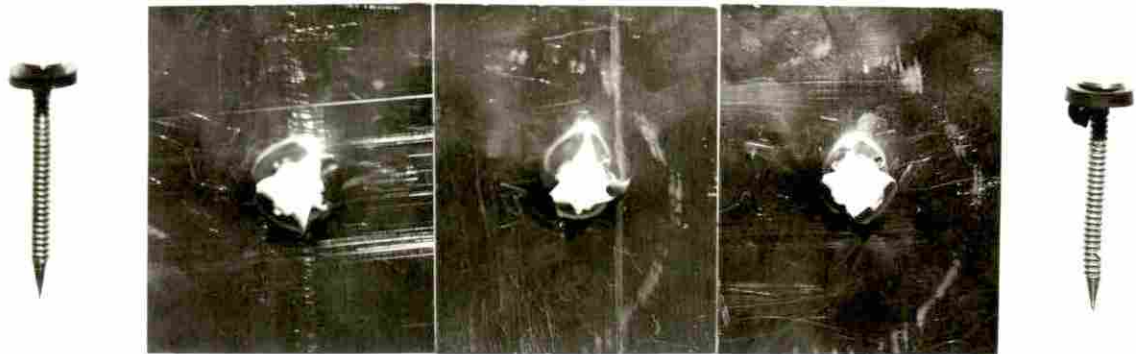
Figure 3. Rupture Patterns in Flat Sheet Aluminum with Nail 1 (Aluminum, Diamond Pointed, Ring Shank with Flat Washer.) Nail Before and After Test at Left and Right Respectively.



0.019 Inch Flat Aluminum Sheet



0.024 Inch Flat Aluminum Sheet



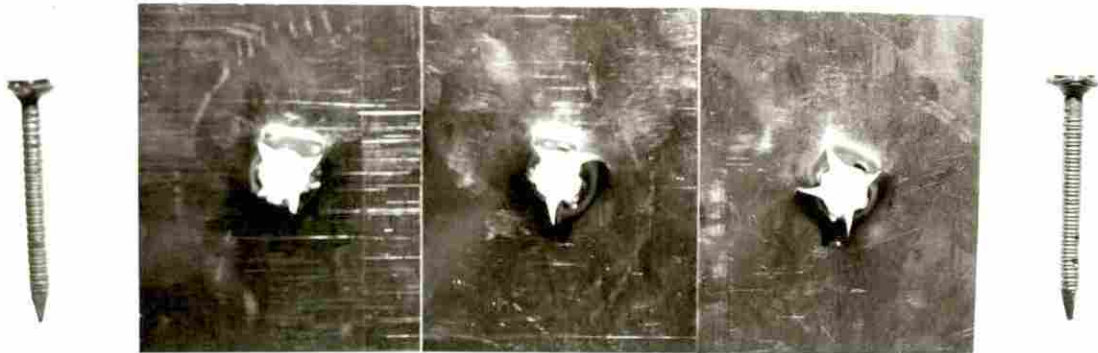
0.032 Inch Flat Aluminum Sheet

Figure 4. Rupture Patterns in Flat Aluminum Sheet with Nail 2 (Aluminum, Conical Pointed, Ring Shank with Flat Washer). Nail Before and After Test at Left and Right, Respectively.





0.019 Inch Flat Aluminum Sheet



0.024 Inch Flat Aluminum Sheet



0.032 Inch Flat Aluminum Sheet

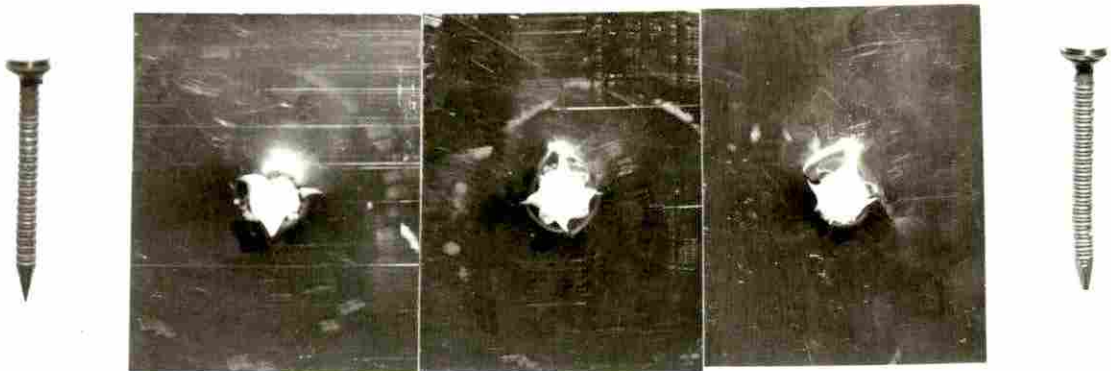
Figure 5. Rupture Patterns in Flat Aluminum Sheets with Nail 11 (Steel, Diamond Pointed, Ring Shank with Wedge Shaped Washer). Nail Before and After Test at Left and Right, Respectively.



0.019 Inch Flat Aluminum Sheet



0.024 Inch Flat Aluminum Sheet



0.032 Inch Flat Aluminum Sheet

Figure 6. Rupture Patterns in Flat Aluminum Sheets with Nail 12 (Steel, Conical Pointed, Ring Shank with Wedge Shaped Washer). Nail Before and After Test at Left and Right, Respectively.



The rupture patterns, however, seem to show some tendency to vary where thickness is concerned. It was noted that the three cornered rupture pattern was most common among the 0.032 inch aluminum sheets. In the 0.019 inch and 0.024 inch flat aluminum the four cornered rupture pattern ran slightly more than the three cornered one. In all the thicknesses of corrugated aluminum sheets, the three cornered rupture pattern predominated. In a few cases of 0.019 inch flat aluminum sheets, the rupture patterns were five and six sided. The author is unable to give any reasons for the development of any particular type of rupture pattern.

Although it is difficult to explain the rupture patterns, it seems there is some relationship between the rupture pattern and the maximum rupture strength. It was observed during the investigation that, in general, when the rupture pattern was three cornered the rupture strength tended to be more. Again, the author is unable to explain this phenomenon.

#### Comparison of Flat and Corrugated Sheets

Figure 7 shows a chart that compares the flat and corrugated aluminum sheets. The figure gives a very true comparison, because the comparison is based solely upon the two types of sheets, all the other variables being held constant. For example, the first set of two bars in the chart gives the

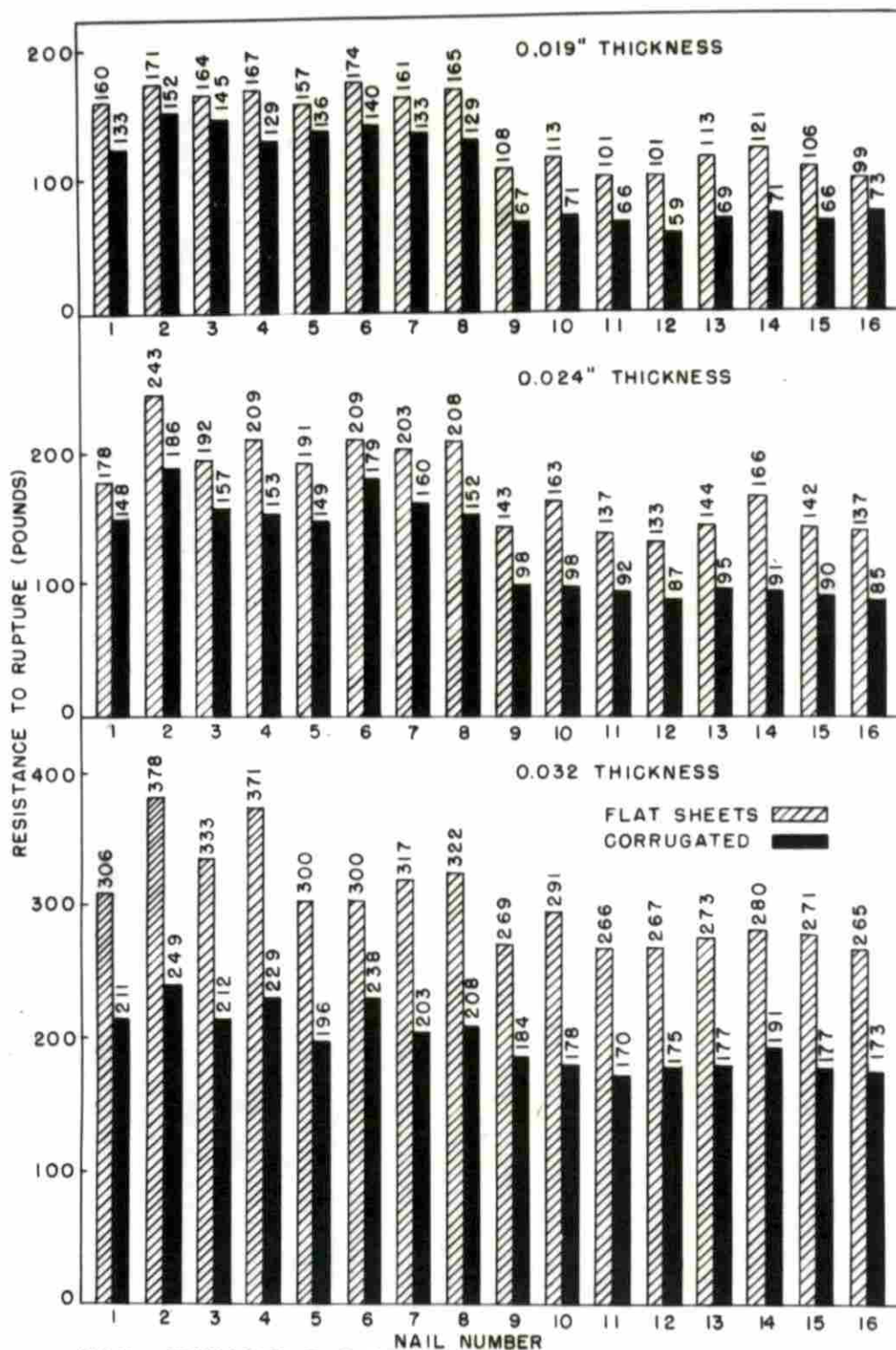


FIG. 7. COMPARATIVE RUPTURE RESISTANCE OF FLAT AND CORRUGATED ALUMINUM SHEETS.

relative values of rupture resistance using the same nail and the same thickness of sheet, but one of them flat and the other corrugated. For every nail and for every thickness the flat sheet exhibited much more resistance to rupture than the corrugated sheet. In the case of the 0.019 thickness the excess of rupture resistance of flat over corrugated sheets ranged from 19 pounds with nails 2 and 3 (aluminum, conical pointed, ring shank with flat washer and steel, diamond pointed, ring shank with flat washer respectively) to 50 pounds with nail 14 (aluminum, conical pointed, screw shank with wedge shaped washer). For the 0.024 inch thickness, the range was from 30 pounds with nails 1 and 6 (aluminum, diamond pointed, ring shank with flat washer and aluminum, conical pointed, screw shank with flat washer respectively) to 95 pounds with nail 14 (aluminum, conical pointed, screw shank with wedge shaped washer). For the 0.032 inch thickness, the range was from 62 pounds with nail 6 (aluminum, conical pointed, screw shank with flat washer) to 142 pounds with nail 4 (steel, conical pointed, ring shank with flat washer). On the average, the flat sheets were 33 per cent, 38 per cent and 52 per cent superior to the corrugated sheets in the 0.019 inch, 0.024 inch and 0.032 inch thicknesses, respectively.

Of all the six different aluminum sheets tested, the 0.032 inch flat one was the best for rupture resistance

qualities. The next in order was the 0.032 inch corrugated, the next the 0.024 inch flat, the next the 0.019 inch flat, the next the 0.024 inch corrugated and the last the 0.0.9 inch corrugated. The average values of rupture resistance, considering all the observations, for these nails were 301.0, 205.0, 174.4, 136.8, 122.4 and 102.5 pounds, respectively. It is remarkable that the 0.019 inch flat aluminum sheet was superior to the 0.024 inch corrugated sheet.

An analysis of variance for the experimental results is given in Table 6. As may be expected, the estimate of expected mean square for the sheets is highly significant.

#### Comparison of Thicknesses, 0.019, 0.024 and 0.032 Inch

Figure 8 shows a comparison, on the basis of rupture resistance, of the three thicknesses of sheets, 0.019, 0.024 and 0.032 inch, that were used for the experiment. As may be expected, the rupture resistance increases as the thickness of the sheet increases. The high significance of thickness in the analysis of variance (Table 6) bears out this fact. In comparison of thicknesses, one is interested in the amount of increase in rupture resistance as the thickness is increased, and in how economical the increase in strength is considering the additional material used.

The amount of material in a given area of sheet is proportional to its thickness. Thus the 0.024 inch thickness

Table 6.

Analysis of Variance of Rupture Resistance of  
Six Different Aluminum Sheets  
with 16 Different Roofing Nails

Source of variation	Degrees of freedom	Sum of squares	Mean squares
Sheets	1	1,081,368	1,081,368 <sup>a</sup>
Thickness	2	3,563,332	1,781,666 <sup>a</sup>
Sheets x thickness	2	256,446	128,223 <sup>a</sup>
Nails <sup>b</sup>	15	1,094,690	72,979 <sup>a</sup>
Sheets x nails	15	21,016	1,401 <sup>a</sup>
Thickness x nails	30	73,332	2,444 <sup>a</sup>
Sheets x thickness x nails	30	17,302	577
Error	1056	427,545	405

<sup>a</sup> Significant at the 1 per cent level.

<sup>b</sup> The breakdown of nails (using the same headings as in the table) is as follows:

Nails

Washers	1	984,789
Point	1	28,134
Material	1	10,774
Shank	1	5,981
Interactions	11	65,012

80-12



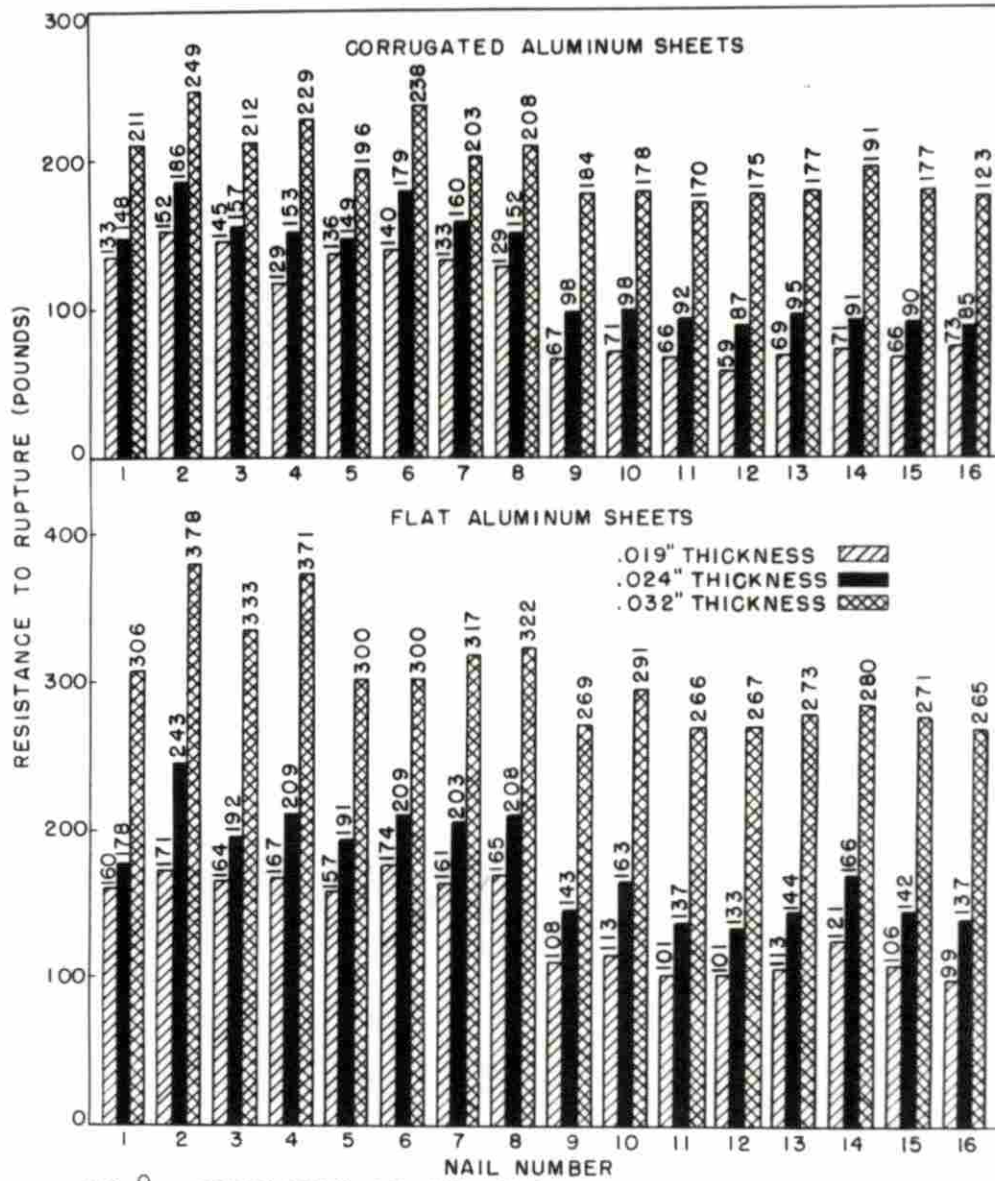


FIG. 8. COMPARISON OF .019, .024 AND .032 INCHES.

sheet has 26.3 per cent more material in it than 0.019 inch thick sheet, and the 0.032 inch thick sheet has 68.5 per cent and 33.3 per cent more material in it than the 0.019 inch and the 0.024 inch thicknesses, respectively. As the thickness of the flat sheet is increased from 0.019 inch to 0.024 inch and 0.032 inch, the rupture resistance, on the average, increases by 27.5 and 121.0 per cent, respectively. As the thickness is increased from 0.024 inch to 0.032 inch the rupture resistance, on the average, increases by 73.5 per cent. As the thickness of sheet changes from 0.019 inch to 0.024, the range of increase in rupture resistance is from 18 pounds with nail 1 (aluminum, diamond pointed, ring shank with flat washer) to 72 pounds with nail 2 (aluminum, conical pointed, ring shank with flat washer). As the thickness of sheet changes from 0.019 inch to 0.032 inch the range of increase in rupture resistance is from 126 pounds with nail 6 (aluminum, conical pointed, screw shank with flat washer) to 207 pounds with nail 2 (aluminum, conical pointed, ring shank, with flat washer). As the thickness changes from 0.024 inch to 0.032 inch the range of increase in rupture resistance is from 91 pounds with nail 6 (aluminum, conical, screw shank with flat washer) to 162 pounds with nail 4 (steel, conical pointed, ring shank with flat washer).

In the case of corrugated sheets, as the thickness is increased from 0.019 inch to 0.024 and 0.032 inch, on the

average, the rupture resistance is increased by 23.5 per cent and 94 per cent respectively. As the thickness increases from 0.024 inch to 0.032 inch, the rupture resistance is increased by 57 per cent. The range of increase in rupture resistance as the thickness increases from 0.019 inch to 0.024 inch is from 12 pounds with nail 3 (steel, diamond pointed, ring shank with flat washer) and nail 16 (steel, conical pointed, screw shank with wedge shaped washer) to 39 pounds with nail 6 (aluminum, conical pointed, screw shank with flat washer). The range as the thickness increases from 0.019 inch to 0.032 inch is from 60 pounds with nail 5 (aluminum, diamond pointed, screw shank with flat washer) to 120 pounds with nail 14 (aluminum, conical pointed, screw shank with wedge shaped washer) and that as the thickness increases from 0.024 inch to 0.032 is 43 pounds with nail 7 (steel, diamond pointed, screw shank with flat washer) to 100 pounds with nail 14 (aluminum, conical pointed, screw shank with wedge shaped washer).

If the values obtained with flat sheets and corrugated sheets are combined, then, on the average, as the thickness of the sheet increases from 0.019 inch to 0.024 inch and 0.032 inch, the rupture resistance is increased by 25.5 per cent and 109 per cent respectively. As the thickness is increased from 0.024 inch to 0.032 inch, the rupture resistance is increased by 66.5 per cent.



### Comparison of Materials, Aluminum and Steel

Figure 9 shows a chart comparing the material of the nail, aluminum and steel, on the basis of rupture resistance of sheet aluminum. In a few cases aluminum nails appear to be superior, while in a few other cases steel nails appear to be superior. This indicates that for the conditions of the experiment there is no significant difference between the steel and aluminum nails on the basis of rupture resistance. If the total rupture load for all the aluminum nails are added up and compared with that for all the steel nails, it is found that aluminum nails are superior to steel nails by 2 per cent and 5 per cent for flat and corrugated sheets, respectively. These values of 2 per cent and 5 per cent should not be considered as showing aluminum nails significantly superior to steel nails.

In testing a nail, failure could occur either by rupture of the sheet or by failure of the nail head or by a combination of both. Figure 10 is a picture of representative failures of nails which have been pulled through 0.032 inch flat aluminum sheets. The heads of aluminum nails are almost invariably damaged, while those of steel nails are practically intact. This shows that the aluminum nails could not have withstood any more load than that to which they were subjected in the experiment, while the steel nails could have

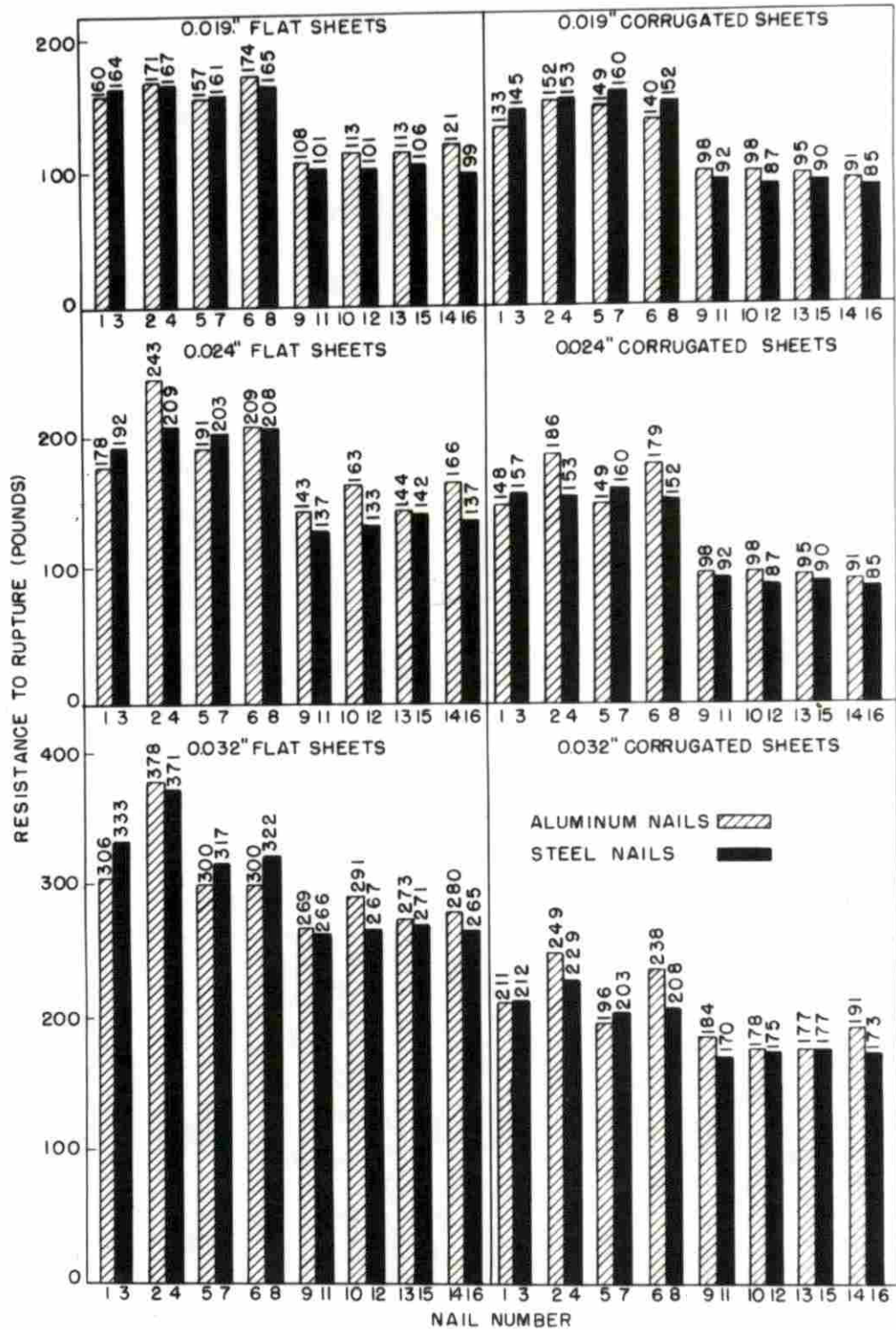


FIG. 9. COMPARISON OF ALUMINUM AND STEEL NAILS.



Nail Code



Key to code:

1st letter = Material of nail: Aluminum, A; Steel, S.  
2nd letter = Nail point: Diamond, D; Conical, C.  
3rd letter = Shank type: Ring, R; Screw, S.  
4th letter = Washer: Flat, F; Wedge shaped, W.

Figure 10. Representative Failures of Nails which have been Pulled Through 0.032 Inch Flat Aluminum Sheets.

taken more load. This is a very important point because the potential ability of steel nail heads to withstand more load has been impaired by reducing their size, which was done for the purposes of the experiment. On the other hand, in the case of aluminum nails the reduction of head size had little effect on their capacity to withstand any load. This point is further substantiated by the fact that although aluminum nails show a small percentage of superiority when all the nails are considered, they are slightly inferior when only 0.032 inch flat sheets are considered. The 0.032 inch flat sheets are the ones that took the maximum rupture load among all the sheets tested. Thus it is quite probable that if the nails were tested as they are sold in the market, which is really more important for the farmer, steel nails might have shown better qualities for rupture resistance.

In general, people who work with nails prefer steel nails to aluminum nails because of the tendency of the latter to bend while being driven in and the chance of their heads being sheared off while being extracted. The results of the present study show that as far as rupture resistance is concerned there is practically no difference between aluminum and steel nails. The probability that steel nails might have taken comparatively higher loads, if the original head size were retained, should also be recognized at the same time. Incidentally, it is interesting to compare the

different shanks of the nails in Figure 10. Shanks of aluminum nails are all bent at the place of support, while the shanks of steel nails remain unaffected by the load. In the light of this discussion the author would state his preference for steel nails over aluminum nails and recommend the use of the former.

#### Comparison of Nail Points, Diamond and Conical

Figure 11 is a chart showing a true comparison of diamond and conical points. For the flat and corrugated aluminum sheets, the conical point, on the average respectively runs about 6.5 and 5 per cent superior to the diamond point. For the 0.019 inch and 0.032 inch flat plates, the conical point is superior for all nails except nails 11 and 15 (steel, diamond pointed, ring shank with wedge shaped washer, and steel, diamond pointed, screw shank with wedge shaped washer, respectively); and for 0.032 inch flat plates, the conical point is superior for all nails except nail 15. In the case of corrugated sheets the results are even less uniform. For 0.019 inch thick corrugated sheets five conical pointed and three diamond pointed are relatively superior; for 0.024 inch thickness the number is three for conical pointed and five for diamond pointed; and for 0.032 inch thickness it is six for conical and two for diamond. Taking the experiment as a whole, conical points seem to show a

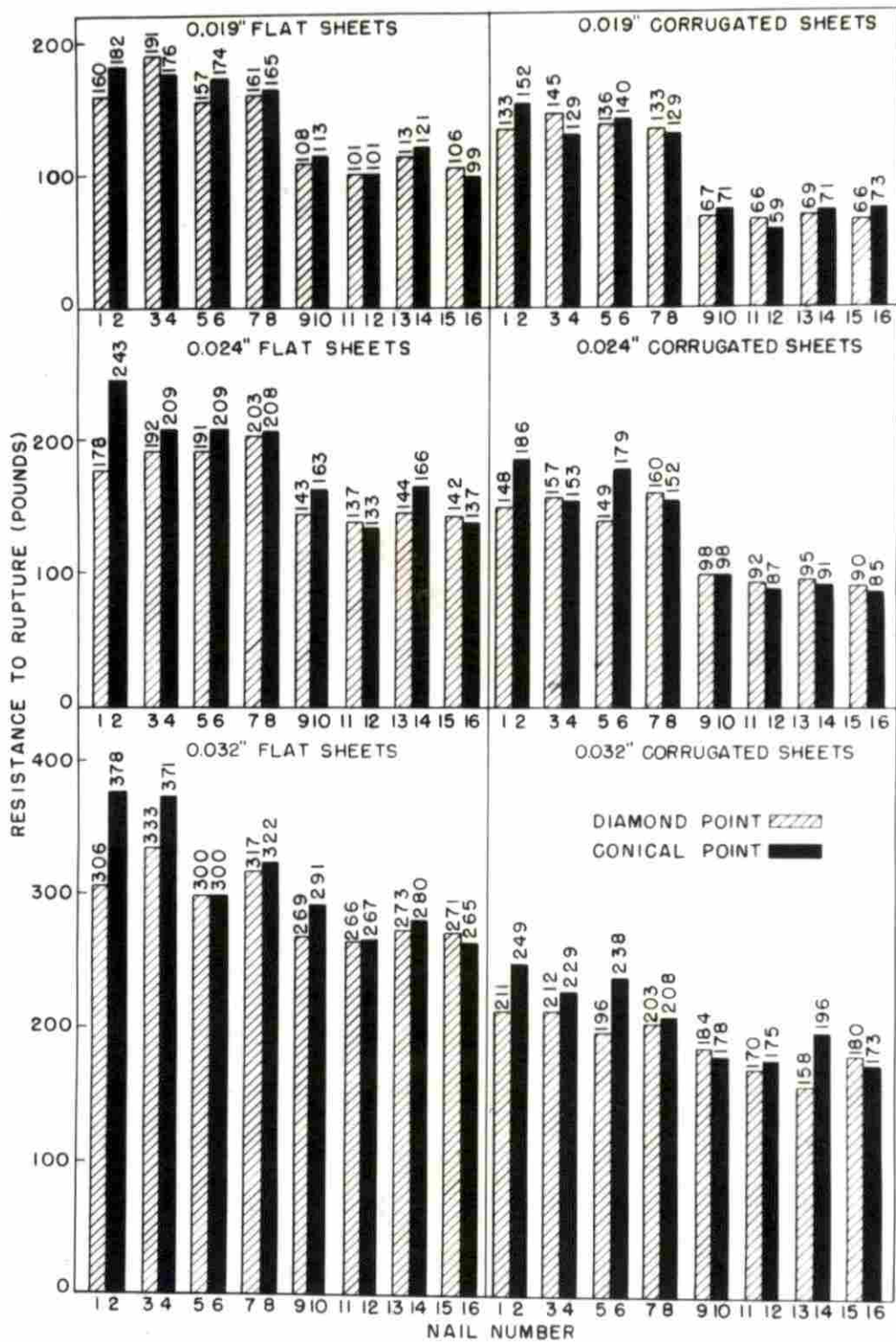


FIG. 11 COMPARISON OF DIAMOND AND CONICAL NAIL POINTS.

slight tendency of superiority over diamond points. However, this tendency is not too well defined. It needs additional verification and more investigation to state conclusively that the conical point is superior to the diamond point.

Kunze (13, p. 89) in his study of diamond and conical points noted some definite tendency for the conical points to be the better of the two. He explained the matter on the basis that the initial nail hole made by a conical point was superior to that made by a diamond point and hence insured a better value of rupture resistance. The initial hole made by a conical point was round, while that made by a diamond point was four cornered. The final rupture pattern, according to him, was more or less determined by the initial hole, this, in the case of the diamond point, being along the four corners it made originally. The author, however, was unable to relate diamond or conical points to any particular type of rupture pattern. Like Kunze, he also made lines on the test piece coinciding with the four corners of a diamond point when making the initial hole. The resulting rupture pattern did not show any tendency to be along those lines. This was surprising because it was in direct conflict to what Kunze got in his experiment. He stated (p. 59, 60) that the rupture pattern almost invariably followed the lines as predicted. It seemed to the author that the shape of the initial hole is determined more by the shank than by the



point, because the shank has the larger size and the last contact with the initial nail hole.

Figure 12 shows a photograph of the initial nail holes made by all the sixteen nails used for the experiment. Each nail hole made by one particular type of nail point is duplicated because the washer, as a variable, cannot possibly affect the initial hole. As an example, the holes made by nails 1 and 9 are duplicates because the only difference between the nails is that one is used with a flat washer and the other with a wedge shaped washer. The photograph also shows that there is practically no difference in the initial holes made by the nails. It must be noted that the nail holes are made by driving the nails through the aluminum sheet without any backing of wood. In actual practice, the restraining effect of the deck below the roofing sheet would further tend to make the initial nail holes uniform.

#### Comparison of Shank Types, Ring and Screw

Figure 13 gives a chart that compares the ring and screw shank nails on the basis of rupture resistance of sheet aluminum. There is no significant difference between shank types as far as rupture resistance is concerned. For the flat sheets the rupture resistance with ring shank nails is more than that of screw shank nails by 3 per cent. Four ring shank nails and four screw shank nails are found to be

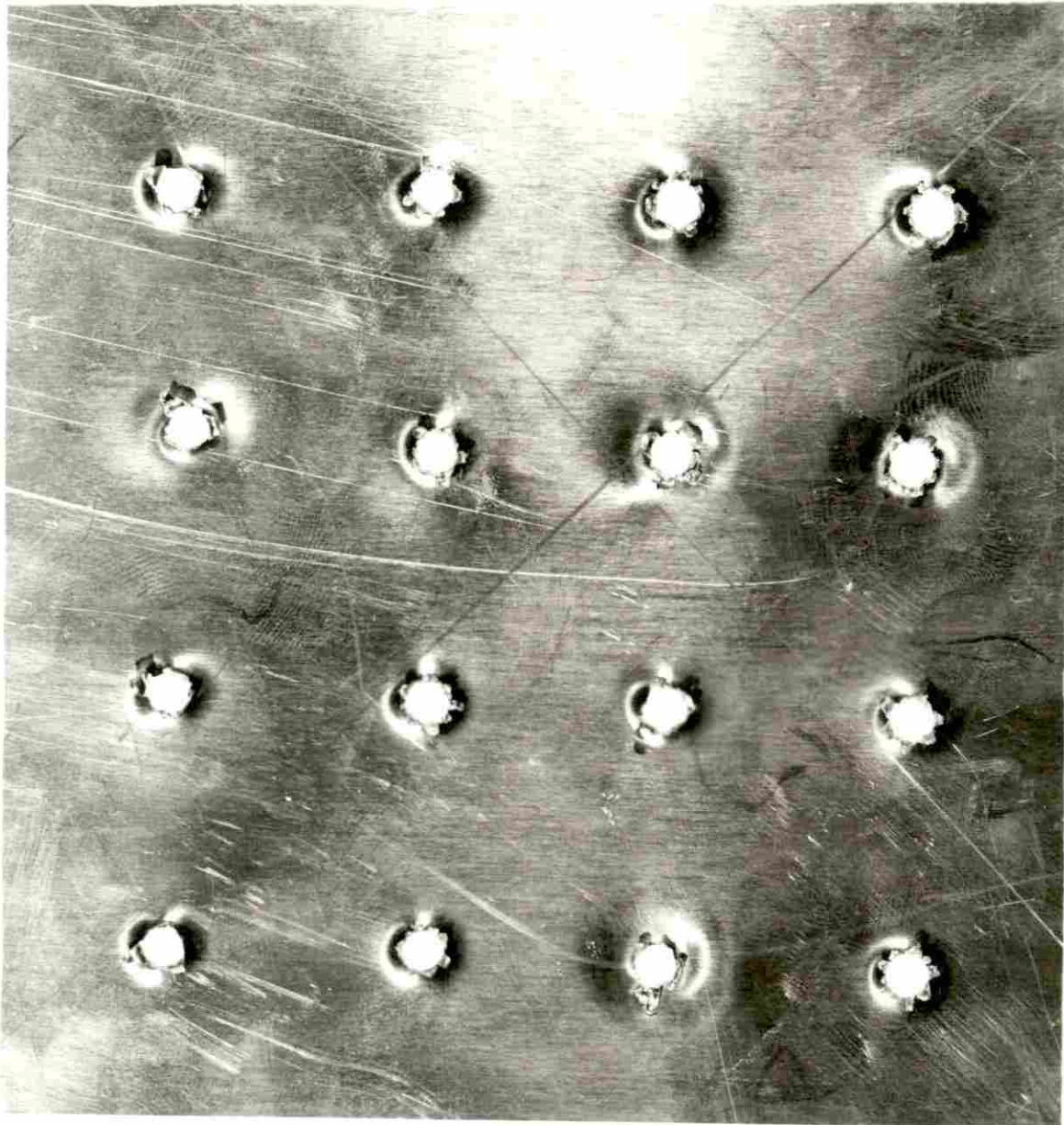


Figure 12. Photograph of Initial Nail Holes Made by the 16 Nails Used in the Experiment. Nail Holes are Arranged According to Nail Number from Nail 1 at Top Left Corner to Nail 16 at Bottom Right Corner.

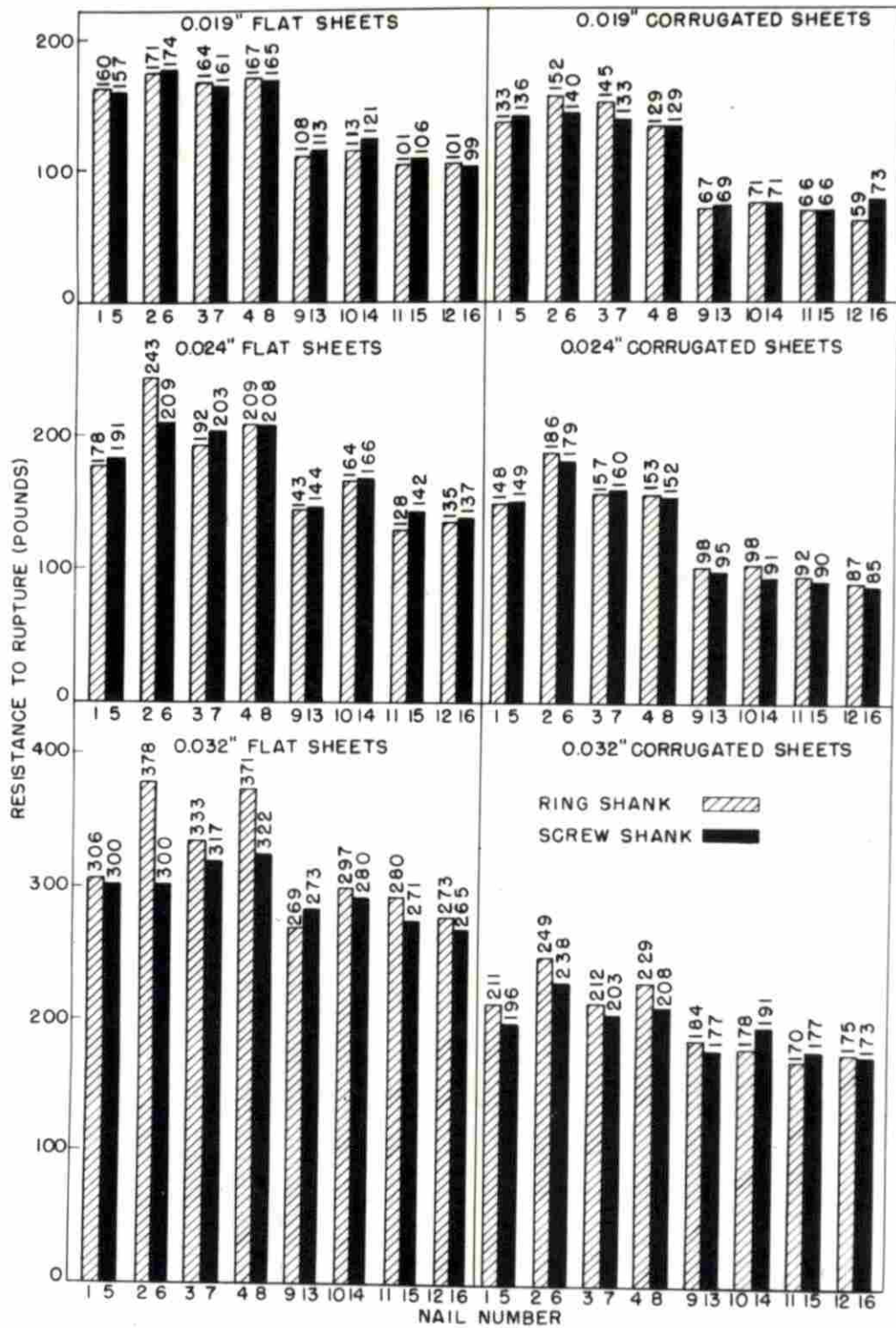


FIG 13. COMPARISON OF RING AND SCREW SHANKS.



relatively superior. The average 3 per cent superiority of the ring shank nails is contributed mostly by nail 2 (aluminum, conical pointed, ring shank with flat washer), which also happens to be the best nail tested. So the 3 per cent superiority of the ring shank nails over the screw shank nails with flat aluminum sheets should not be considered as significant.

In the case of corrugated aluminum sheets, the rupture resistance with ring shank nails is only 1 per cent more than that with screw shank nails. Five ring shank nails and 3 screw shank nails are found to be relatively superior. It has been indicated earlier that the greater diameter of screw shank nails would adversely influence the nails in the amount of load they can take. This disadvantage may be the reason for the slight superiority of the ring shank nails over the screw shank nails as given by the experimental results. However, even disregarding this difference in shank diameters, the difference in the nails in respect to shank type is insignificant.

The theory was advanced by Kunze (13) that a screw shank nail would tend to impart a multi-cornered original nail hole to the sheets and that this would result in a multi-cornered rupture pattern. In the present study, a few five cornered and six cornered rupture patterns for 0.019 inch thickness aluminum sheets with both ring shank and screw shank nails

were obtained. The number of such patterns compared to three cornered and four cornered failures was very few. Further, since such rupture patterns were obtained with both ring and screw shank nails, any positive statement of tendency, on the basis of the present study, is unjustifiable.

#### Comparison of Washers, Neoprene Flat and Wedge Shaped

Figure 14 is a chart that shows a comparison between neoprene flat and wedge shaped washers. For every nail and every thickness, the flat washer is superior to the wedge shaped one. As may be expected, in the analysis of variance table (Table 6) the washers show very high significance. For flat sheets, in 0.019, 0.024 and 0.032 inch thicknesses, the flat washer is superior to the wedge shaped washer by 53.0, 42.2 and 20.1 per cent, respectively. For 0.019 inch thickness the range of superiority of flat washers over wedge shaped ones is from 44 pounds with nail 5 (aluminum, diamond pointed, screw shank with flat washer) to 66 pounds with nails 4 and 8 (steel, conical pointed, ring shank with flat washer and steel, conical pointed, screw shank with flat washer, respectively). For 0.024 inch thickness the range is from 35 pounds with nail 1 (aluminum, diamond pointed, ring shank with flat washer) to 80 pounds with nail 2 (aluminum, conical pointed, ring shank with flat washer). For 0.032 inch thickness it is 12 pounds with nail 6 (aluminum, conical



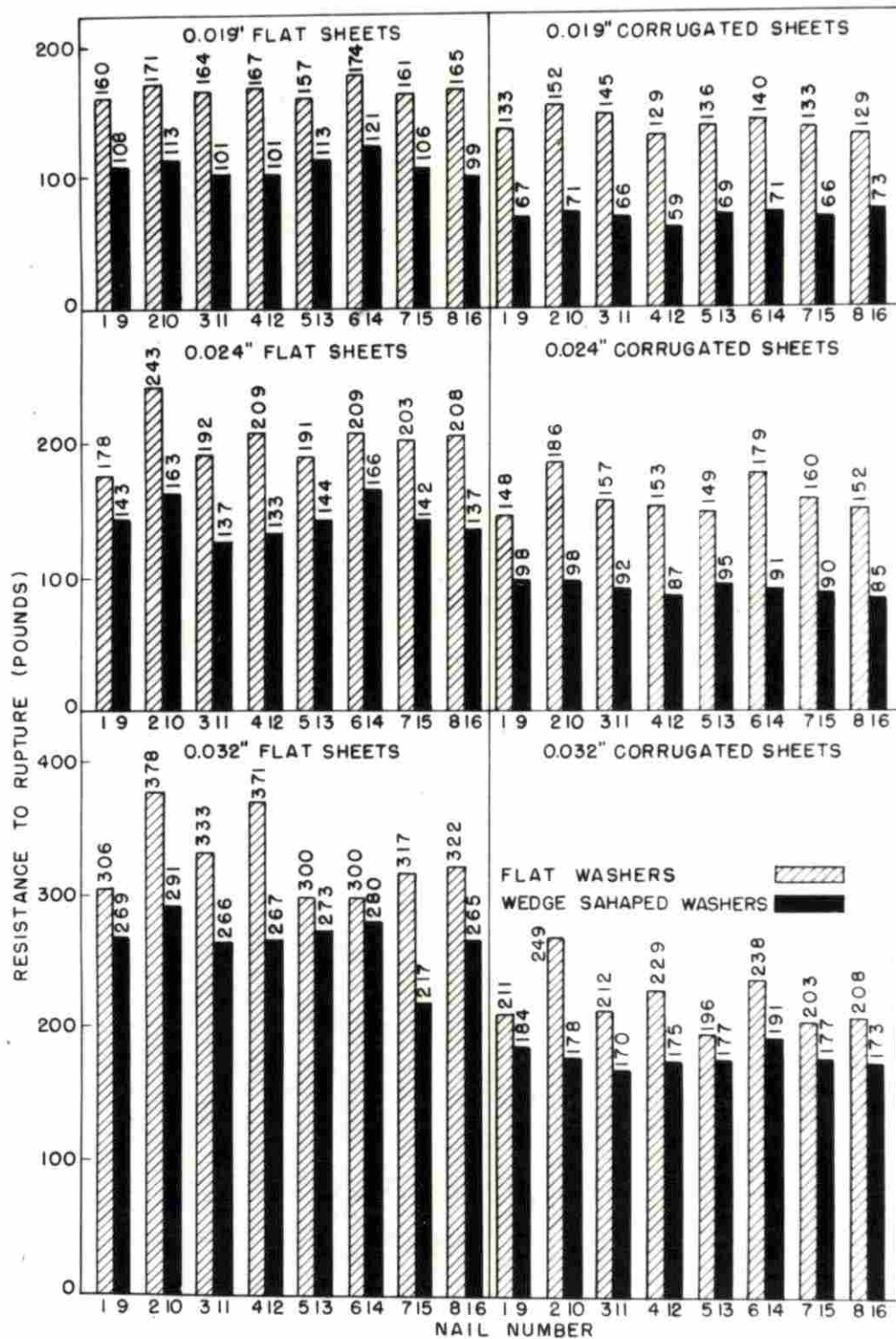


FIG. 14. COMPARISON OF FLAT AND WEDGE SHAPED WASHERS.

pointed, screw shank with flat washer) to 104 pounds with nail 4 (steel, conical pointed, ring shank with flat washer).

In the case of corrugated sheets, for 0.019, 0.024 and 0.032 inch thicknesses, the flat washer is superior to the wedge shaped washer by 102.1, 74.8 and 22.1 per cent, respectively. For 0.019 inch thickness the range of superiority of flat washers over wedge shaped washers is from 56 pounds with nail 8 (steel, conical pointed, ring shank with flat washer). For 0.024 inch thickness it is 54 pounds with nail 5 (aluminum, diamond pointed, screw shank with flat washer) to 108 pounds with nail 2. For 0.032 inch thickness it is from 19 pounds with nail 5 to 71 pounds with nail 2.

For both the flat sheets and corrugated sheets, the percentage of increase in rupture resistance when the washer is changed from wedge shaped to flat is greatest with 0.019 inch thickness, then with 0.024 inch thickness and the least with 0.032 inch thickness. The important point that is made by this fact is that the weaker the aluminum sheet to rupture resistance, the greater the advantage in using a flat washer in preference to a wedge shaped one. This rule holds good even when the flat and corrugated sheets are considered together, as illustrated by Table 7. In this table the six different sheets used for the experiment are arranged according to their mean rupture resistance in ascending order. The corresponding percentage superiority of flat washers over

Table 7.

Relation between Per Cent Superiority of  
Flat Washers and Rupture Resistance of  
Aluminum Sheets<sup>a</sup>

No.	Type of sheet	Thick- ness of sheet (in.)	Ave. value for flat washers (lbs.)	Ave. value for wedge shaped washers (lbs.)	Per Cent superiority of flat washers
1	Corrugated	0.019	137.0	67.9	102.1
2	Corrugated	0.024	160.5	92.0	74.8
3	Flat	0.019	164.8	107.8	53.2
4	Flat	0.024	204.0	143.2	42.2
5	Corrugated	0.032	218.0	177.0	22.1
6	Flat	0.032	328.0	274.0	20.0

<sup>a</sup> Aluminum sheets arranged in order according to  
rupture resistance.

wedge shaped ones is in the reverse order. The inverse relationship between the rupture resistance and the advantage in using a flat washer follows a remarkably uniform pattern.

This rule is important because in actual practice the danger of wind damage to sheet aluminum roofing is greatest when its resistance to rupture is least. Thus in order to guard against wind damage to sheet aluminum roofing, that having the least resistance to rupture must be improved. This is precisely what is done by a good washer.

The present experiment conclusively proves the great influence that washers have on the rupture resistance of sheet aluminum. The flat washer used in the experiment is by no means the best washer that could be made. There are possibilities of improving the quality of this washer several times over. When it is considered that the cost of washers in a sheet roofing is comparatively negligible, and yet the washers can contribute greatly towards the rupture resistance, the great need for improving the quality of the washer becomes quite obvious. The author believes that it may be possible to develop a washer that will insure even the thinnest sheet aluminum now being used for roofing against any wind damage. It must be mentioned in this connection that some excellent types of washers have come on the market recently and that they are very much superior to the washers used in the experiment.



### Comparison of the Nails Used for the Experiment

Table 8 in the Appendix gives all the original data and the average maximum rupture resistance of each nail with each thickness and each type of aluminum sheet. The table also gives the grand total of rupture load for flat and corrugated sheets with each nail. For flat sheets, the order of the nails according to rupture resistance is:<sup>1</sup> 2,4,8,3,6,7,5,1,10,14,13,9,15,11,12 and 16. For corrugated sheets the order is 2,6,3,4,7,1,5,8,14,9,10,13,15,16,11 and 12. Excepting nail 2, which also happens to be the best nail, the order of superiority is different for flat and corrugated sheets.

The best nail for both flat and corrugated sheets is nail number 2 (aluminum, conical pointed, ring shank with flat washer). This nail has the greatest average rupture resistance in each thickness also. For flat sheets, the average maximum rupture resistances with this nail for 0.019, 0.024 and 0.032 inch thicknesses are 171, 243 and 378 pounds respectively. For corrugated sheets with the same nail it is 152, 186 and 249 pounds respectively. The nail showing the least rupture resistance for flat sheets is nail 16 (steel, conical pointed, screw shank with wedge shaped washer), and that for corrugated sheets is nail 12 (steel,

---

<sup>1</sup> For explanation of nail numbers, refer to Table 1 on page 21.



conical pointed, ring shank with wedge shaped washer). For flat sheets the average maximum rupture resistances with nail 16 for 0.019, 0.024 and 0.032 inch thicknesses are 99, 137 and 265 pounds, respectively. For corrugated sheets with nail 12 they are 59, 87 and 175 pounds, respectively.

#### Suggestions for Further Study

1. So far in the study of rupture resistance, no consideration has been given to the effects of vibration and repeated load. It seems to the author that the effects of vibration and repeated load are very important and hence should be investigated.

2. A study should be set up in order to develop the best type of washer for roofing nails. The properties that a roofing washer should have in order to increase the rupture resistance of sheet roofing are:

- a. large bearing area;
- b. elastic properties that will impart a cushioning effect between the sheet roofing and the nail head. This is important in overcoming the effects of vibration;
- c. strength.

The above analysis of the properties of a washer would indicate one with a large diameter and made of a material, such as neoprene, with strong metallic backing. It may be possible to arrive at a rational relationship between these qualities

of the washer and the rupture resistance, and hence develop the best washer that could be used with sheet roofing.

3. Experiments should be set up to determine an estimate of the mean rupture loads that different nails would carry when used with different thicknesses of sheet metal roofing. It would be necessary to consider only those nails which have proved to be the best in the several studies that have been conducted so far. These mean values can then be used as design loads for determining the number of nails to be used for a particular type of sheet roofing.

## SUMMARY

1. After a thorough review of the work done so far under Project 1011 of the Iowa Agricultural Experiment Station ("The Utilization of Aluminum and Aluminum Products in Farm Buildings and Equipment"), it was decided to continue the investigation of sheet aluminum roofing and roofing nails.

2. A review of literature of related material was made.

3. The variables for the study were selected on the basis of order of importance. These variables were:

- a. two types of aluminum sheets, flat and corrugated;
- b. three thicknesses of aluminum sheets, 0.019, 0.024 and 0.032 inch;
- c. two materials for nails, aluminum and steel;
- d. two types of nail shanks, ring and screw;
- e. two types of nail points, diamond and conical; and
- f. two types of roofing washers, neoprene flat and wedge shaped.

The problem was to compare the relative merits of these variables on the basis of maximum rupture resistance of sheet aluminum.

4. It was attempted to eliminate all the variables other than those mentioned above. The size of the nail head

in each case was turned down to 0.35 inch. A conical point was obtained by turning a diamond point on the lathe to a 30 degree cone coming to a sharp point.

5. The experiment was set up in consultation with the Statistics Department of the Iowa State College, the one adopted being called a completely randomized factorial design. There were 96 treatment combinations, four replications and three observations in each replication. Thus the total number of nails to be tested was 1152.

6. Test pieces out of selected aluminum sheets were obtained by cutting the 0.019 inch thick flat sheet into 7 inch squares, the 0.024 and the 0.032 inch thicknesses of flat sheets into 6 inch squares, and all the corrugated sheets into pieces 4 feet long by seven and one-half inches wide.

7. All the treatment combinations were completely randomized according to the advice given the author by the Statistics Department.

8. The nail pulling machine that was being used in the project was selected as the equipment for determining the rupture resistance of sheet aluminum. The machine pulled the nail through the test piece and at the same time indicated the load required to do it.

9. The nail pulling machine was calibrated before the investigation was started.

10. The investigation was made and all the necessary data collected.

11. A statistical analysis of the experimental data was made in consultation with the Statistics Department. The results were further analyzed by other means, also.

12. The attempt was made during the analysis to consider the results together with those obtained in previous studies.

13. The results were discussed and appropriate conclusions were drawn from them.



## CONCLUSIONS

1. For the given thicknesses of 0.019, 0.024 and 0.032 inch, and given alloy and temper, the flat aluminum sheets are superior to the corrugated ones on the basis of rupture resistance (p. 44).

2. For thicknesses of 0.019, 0.024, 0.032 inch, the flat aluminum sheets, on the average, take 33, 38 and 52 per cent respectively more maximum rupture load than corrugated aluminum sheets (p. 44).

3. Out of the six aluminum sheets tested, the best one for rupture resistance qualities is the 0.032 inch flat sheet, then the 0.032 inch corrugated, next the 0.024 inch flat, next the 0.019 inch flat, next the 0.024 inch corrugated and lastly the 0.019 inch corrugated (p. 44).

4. As the thickness is increased the rupture resistance of both flat and corrugated sheet aluminum is increased (p. 45).

5. For flat sheets as the thickness is increased from 0.019 to 0.024 and 0.032 inch, the rupture resistance, on the average, is increased by 27.5 and 121.0 per cent, respectively. As the thickness is increased from 0.024 to 0.032 inch the rupture resistance is increased by 73.5 per cent (p. 48).

6. For corrugated sheets as the thickness is increased from 0.019 to 0.024 and 0.032 inch, the rupture resistance, on the average, is increased by 23.5 and 94.0 per cent, respectively. As the thickness is increased from 0.024 to 0.032 inch the rupture resistance is increased by 57 per cent (p. 48).

7. The rupture resistance of sheet aluminum, for the conditions of the present study, is independent of the material, steel or aluminum, out of which the nail is manufactured (pp. 50-54).

8. The rupture resistance of sheet aluminum is independent of the shape of the nail point, diamond or conical (pp. 54-57).

9. The final rupture patterns of the aluminum sheets are independent of the nail point, diamond or conical (p. 56).

10. The rupture resistance of sheet aluminum is independent of the type of shank of the nail, ring or screw (pp. 57-61).

11. The washer used with a roofing nail exerts considerable influence on the maximum rupture resistance of sheet aluminum. Of the two washers tested, the neoprene flat washer is superior to the wedge shaped washer for every nail and every thickness and for both flat and corrugated aluminum sheets (pp. 61-65).

12. For flat aluminum sheets, in 0.019, 0.024 and 0.032

inch thicknesses, the flat washer is superior to the wedge shaped one in rupture resistance of the sheet by 53.0, 42.2 and 20.1 per cent, respectively (p. 61).

13. For corrugated aluminum sheets, in 0.019, 0.024 and 0.032 inch thicknesses, the flat washer is superior to the wedge shaped one in rupture resistance of the sheet by 102.1, 74.8 and 22.1 per cent respectively (p. 63).

14. The weaker the sheet aluminum to rupture resistance, the greater is the advantage in using a flat washer in preference to a wedge shaped washer (p. 63).

15. Of all the nails tested, nail number 2 (aluminum, conical pointed, ring shank with flat neoprene washer) is the best on the basis of rupture resistance of sheet aluminum. For flat sheets, the average maximum rupture resistance with this nail for 0.019, 0.024 and 0.032 inch thicknesses are 171, 243 and 378 pounds, respectively. For corrugated sheets, with the same nail it is 152, 186 and 249 pounds, respectively (p. 66).

16. The nail showing the least rupture resistance for flat sheets is nail number 16 (steel, conical pointed, screw shank with wedge shaped washer) and that for corrugated sheets is nail number 12 (steel, conical pointed, ring shank with wedge shaped washer). For flat sheets the average maximum rupture resistance with nail 16 for 0.019, 0.024 and

0.032 inch thicknesses are 99, 137 and 265 pounds, respectively. For corrugated sheets with nail 12 they are 59, 87 and 175 pounds, respectively (p. 66).

BIBLIOGRAPHY

1. Aluminum Company of America. Alcoa structural handbook. The Company. Pittsburg. 1950.
2. \_\_\_\_\_. Alcoa aluminum and its alloys. The Company. Pittsburg. 1947.
3. Barre, H. J. and Sammet, L. L. Farm structures. pp. 78-79. New York. John Wiley and Sons. 1950.
4. Boyd, Landis L. The effects of moisture content of wood on withdrawal resistance of roofing nails. pp. 118-119. Unpublished M. S. Thesis. Iowa State College Library. Ames, Iowa. 1948.
5. Brown, Hiram. Aluminum and its applications. pp. 3, 9-15. New York. Pitman Publishing Corporation. 1948.
6. Bugden, N. F. Aluminum and its alloys. p. 108. New York. Pitman Publishing Corporation. 1947.
7. Carter, D. G. and Foster, W. A. Farm buildings. 3rd ed. New York. John Wiley & Sons. 1941.
8. Deniston, A. J., Jr. The development and use of roofing nails. Ag. Eng. Jour. 14: 9-10. 1933.
9. Esmay, Merle L. Wind damage to farm buildings. Unpublished research report. Iowa State College Ag. Eng. Dept. Ames, Iowa. 1950.
10. \_\_\_\_\_ and Giese, Henry. Wind damage to farm buildings. Paper presented at the National meeting of the Amer. Soc. of Ag. Engineers. Chicago, Illinois. December 1950.
11. Giese, Henry. The withdrawal resistance of roofing nails. Ag. Eng. Jour. 28: 445-450. 1947.
12. \_\_\_\_\_ and Henderson, Milton S. The effectiveness of roofing nails for application of metal building sheets. Iowa State College Ag. Exp. St. Res. Bul. 355: 531. November 1947.



13. Kunze, Otto R. Resistance of sheet aluminum to rupture by the heads of various types of roofing nails. pp. 85, 88-89. Unpublished M. S. Thesis. Iowa State College Library. Ames, Iowa. 1951.
14. Pandya, A. C. Some effects of temperature change on aluminum sheet roofing. p. 67. Unpublished M. S. Thesis. Iowa State College Library. Ames, Iowa. 1949.
15. Perry, Josephine. The light metals industry. New York. Longmans, Green & Co. 1947.
16. Reaves, Leon LeRoy. Effectiveness of various types of roofing nails. p. 49. Unpublished M. S. Thesis. Iowa State College Library. Ames, Iowa. 1932.
17. Reynolds Metals Company. Reynolds aluminum alloys and mill products. The Company. Louisville. 1946.
18. Robinson, William T. Factors affecting the withdrawal resistance of roofing nails. pp. 127-129. Unpublished M. S. Thesis. Iowa State College Library. Ames, Iowa. 1949.
19. \_\_\_\_\_. Survey of wind damage to some Iowa farm buildings by the windstorm of October 10, 1949. Unpublished progress report. Iowa State College Ag. Eng. Dept. Ames, Iowa. 1949.
20. Stern, George E. Improved nails for building construction. Virginia Polytechnic Inst. Eng. Exp. Sta. Bul. 76: 46. November 1950.
21. U. S. Forest Products Laboratory. Wood handbook. U. S. D. A. 1935.
22. Vogel, William P. Think you know nails. Pop. Science. 151: 138-143. December 1947.
23. Wooley, J. C. Holding power of nailed joints. Ag. Eng. Jour. 20: 385-386. 1939.
24. \_\_\_\_\_. Farm buildings. 2nd ed. New York. McGraw-Hill Book Co. p. 196.

#### ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Professor Henry Giese, the project leader, for his guidance and helpful suggestions.

The author is grateful to Professor Hobart Beresford and other members of the Agricultural Engineering staff for their assistance and encouragement.

To Professor Huntsburger of the Statistics Department of Iowa State College for his assistance in the statistical analysis of the experimental results, the author is indebted.

The author wishes to express his gratitude to the Aluminum Company of America, whose financial support made this study possible.

APPENDIX

TABLE 8 C. M. Jacob - 1952  
EXPERIMENTAL RESULTS - RUPTURE RESISTANCE IN POUNDS

FLAT SHEETS

Re- plication	Nail Numbers									Nail Numbers									Nail Numbers								
	1			2			3			4			5			6			7			8			9		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	148	201	329	168	214	362	148	192	326	165	197	355	160	185	291	163	208	291	161	251	305	150	204	341	105	146	268
	154	179	321	177	246	422	152	198	346	161	194	386	149	167	286	178	209	305	182	204	316	145	200	294	110	136	236
	160	159	290	171	240	362	160	196	317	163	184	348	155	162	290	178	210	285	162	203	317	190	235	322	111	154	280
2	171	171	342	182	239	362	170	189	326	192	200	397	167	199	284	172	200	296	122	195	312	189	204	321	116	131	265
	142	168	284	181	250	389	150	198	308	181	206	372	148	196	298	174	214	326	159	209	292	142	209	307	98	132	266
	156	172	300	167	249	370	170	201	317	170	242	345	181	219	286	169	218	283	153	190	316	177	196	314	115	142	272
3	164	183	313	148	258	370	153	171	317	160	192	345	144	205	294	165	198	292	161	179	329	166	196	265	98	156	257
	142	183	304	167	252	399	140	203	351	175	199	333	141	183	319	164	198	280	165	202	328	169	211	316	112	145	262
	164	183	299	144	248	364	164	212	346	161	235	358	135	182	325	182	196	314	176	201	309	161	206	316	107	159	267
4	171	192	299	180	220	375	190	170	330	149	203	434	144	210	290	182	222	317	158	186	374	125	210	330	116	141	255
	176	179	296	186	235	402	180	192	346	152	212	403	188	186	315	194	226	300	154	211	301	182	215	335	100	126	272
	166	170	293	182	262	402	191	183	364	176	209	373	162	196	305	170	203	312	183	203	300	184	211	306	106	144	274
Total	1914	2140	3670	2053	2913	4539	1968	2305	3994	2095	2503	4449	1884	2290	3603	2091	2502	3601	1936	2434	3799	1980	2497	3867	1294	1712	3224
Ave.	160	178	306	171	243	378	164	192	333	169	209	371	157	191	300	174	209	300	161	203	317	165	208	322	108	143	269
Grand Total			7724			9505			8267			8957			7777			8194			8169			8344			6230

Re- plication	Nail Numbers									Nail Numbers									Nail Numbers								
	10			11			12			13			14			15			16			17			18		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	102	141	315	100	142	264	103	126	276	109	130	265	137	165	268	120	138	270	116	126	240	89	134	276	101	150	278
	112	161	282	91	131	291	103	113	260	107	135	260	120	152	290	92	140	274	89	134	276	101	150	278	101	150	278
	125	141	319	99	140	281	93	130	235	110	165	263	121	141	266	97	162	270	101	150	278	101	150	278	101	150	278
2	110	168	352	111	141	273	102	141	275	136	142	270	108	159	263	98	142	285	99	130	247	101	132	256	89	132	269
	112	134	316	103	142	263	91	139	299	107	159	275	109	156	270	105	140	242	101	132	256	101	132	256	101	132	256
	116	140	318	112	130	240	102	147	285	105	147	279	129	161	282	100	162	276	99	130	247	101	132	256	101	132	256
3	120	154	275	105	145	270	101	142	259	107	126	272	125	186	309	123	145	250	100	141	280	99	146	264	98	132	268
	106	177	303	96	148	240	94	130	245	109	149	268	108	132	282	104	139	263	99	146	264	98	132	268	98	132	268
	108	149	273	91	139	270	104	126	257	116	144	268	131	177	287	94	124	280	98	132	268	98	132	268	98	132	268
4	119	150	252	94	129	269	117	126	283	125	149	278	112	161	282	111	134	283	95	130	246	102	136	280	97	139	275
	118	172	286	103	132	248	97	137	211	111	140	292	114	152	284	105	136	277	102	136	280	97	139	275	97	139	275
	107	164	297	100	128	280	99	135	273	116	146	282	136	143	279	121	139	282	97	139	275	97	139	275	97	139	275
Total	1357	1851	3583	1210	1647	3189	1210	1592	3208	1358	1732	3272	1450	1835	3362	1270	1701	3252	1186	1628	3179	99	137	265	99	137	265
Ave.	113	163	291	101	137	266	101	133	267	113	144	273	121	166	280	106	142	271	99	137	265	99	137	265	99	137	265
Grand Total			6796			6046			6010			6362			6697			6223			5993						

TABLE 8 C. M. Jacob - 1952  
EXPERIMENTAL RESULTS - RUPTURE RESISTANCE IN POUNDS  
CORRUGATED SHEETS

Re- plication	Nail Numbers									Nail Numbers									Nail Numbers								
	1			2			3			4			5			6			7			8			9		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	131	157	195	160	190	311	111	138	217	120	121	188	120	135	202	127	210	224	175	137	206	121	124	200	60	90	176
	135	120	214	170	310	215	134	140	183	166	175	237	160	142	188	115	173	204	125	155	182	122	125	215	61	86	177
	115	118	300	160	148	225	148	161	227	129	146	365	129	145	185	114	210	285	104	135	210	140	164	224	64	85	184
2	130	115	205	210	196	260	160	140	219	95	148	195	123	134	218	196	145	215	165	174	210	130	207	215	69	176	190
	127	153	215	112	212	198	145	175	215	146	145	218	135	149	204	116	171	215	154	125	205	134	158	204	66	99	184
	155	265	192	165	122	190	180	171	215	110	193	236	125	164	190	180	152	347	106	132	185	171	166	180	80	88	185
3	105	135	210	138	218	235	165	182	226	165	140	226	145	125	210	135	164	208	145	166	210	140	154	208	64	83	192
	175	158	205	162	190	265	130	156	200	118	125	210	150	170	198	156	186	200	168	191	205	115	140	205	77	86	174
	130	145	162	175	136	432	145	165	218	118	137	206	103	166	180	115	213	198	120	172	218	130	146	177	65	96	177
4	160	142	232	112	180	216	155	128	210	135	163	230	135	135	196	125	192	207	82	162	214	104	134	232	72	87	184
	119	145	210	116	168	240	135	145	200	114	161	208	126	155	185	125	138	205	119	215	193	116	177	213	60	104	180
	118	120	193	126	207	185	135	181	211	138	185	233	176	168	198	181	194	350	134	155	193	119	132	224	63	90	211
Total	1600	1773	2533	1826	2237	2992	1743	1882	2541	1554	1839	2752	1627	1788	2394	1685	2153	2858	1597	1919	2431	1542	1827	2497	801	1170	2214
Ave.	133	148	211	152	186	249	145	157	212	129	153	229	136	149	196	140	179	238	133	160	203	129	152	208	67	98	184
Grand Total			5906			7055			6166			6145			5769			6696			5947			5866			4185

Re- plication	Nail Numbers									Nail Numbers									Nail Numbers								
	10			11			12			13			14			15			16								
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C						
1	55	95	191	61	85	177	58	75	168	65	96	174	65	94	211	74	75	180	59	95	159						
	70	90	166	74	85	165	56	73	150	63	94	178	65	103	179	70	90	167	60	75	170						
	73	88	175	70	196	168	59	125	170	60	112	176	65	100	178	67	76	180	56	75	174						
2	75	34	120	60	75	164	58	75	169	60	80	205	60	100	200	76	86	180	75	78	170						
	73	150	180	65	86	166	64	80	170	75	110	165	74	96	205	76	86	168	65	84	174						
	67	87	194	66	91	168	65	115	180	73	118	185	86	83	185	64	85	170	75	88	160						
3	70	89	182	56	85	183	57	89	180	64	85	176	61	84	198	57	84	184	61	78	190						
	65	80	175	63	81	173	57	80	175	84	90	200	72	78	177	62	107	174	71	82	170						
	60	85	165	60	71	166	58	76	170	60	110	153	75	80	164	58	96	162	75	89	180						
4	99	117	180	90	85	180	63	83	193	65	84	180	73	83	217	62	108	202	85	82	185						
	65	85	170	65	85	184	55	85	178	65	86	173	85	102	182	65	92	180	136	82	174						
	87	127	173	65	81	178	62	84	164	87	89	158	75	93	196	60	90	180	62	98	165						
Total	357	1177	2141	790	1106	2042	712	1040	2102	831	1144	2123	851	1096	2292	791	1075	2127	880	1016	2071						
Ave.	71	98	178	66	92	170	59	87	175	69	95	177	71	91	191	66	90	177	73	85	173						
Grand Total			4175			3938			3854			4098			4239			3993			3967						

EFFECT OF CERTAIN NAIL CHARACTERISTICS UPON RUPTURE  
RESISTANCE OF SHEET ALUMINUM

I. Points raised at the final examination.(orals)

A. Non uniformity of test specimens:-

There are wide variations between individual observations with the same nail and same thickness of aluminum sheet. In some cases this variation is as much as 38%. The reasons for this may be listed as

a. Variation in thickness of test specimens although they are cut out from the same sheets and the sheets drawn from the specified thickness of material as supplied by the manufacturer.

b. Variation in alloy and temper of test specimens.

c. Inaccuracy of testing instruments.

d. Errors in testing methods.

e. Variation between individual washers used with the nails. For a nail the variables are

1. Nail head diameter
2. Shank diameter
3. Shank type
4. Material of nail
5. Nail point
6. Washer used with the nail.

When we use the same nail and the same thickness of sheet the first five items in the above list remain constant (These variations are strictly controllable). However the variation between individual washers is not controllable. From the result of the experiment we see that the washer



exerts considerable influence on the rupture resistance. Hence one of the reasons for this wide variation between individual observations may well be due to variation in individual washers.

f. The type of initial rupture - It is quite conceivable that the type of initial rupture may exert considerable influence on the type of final rupture and final rupture resistance. However this can be investigated by making studies with test specimens having drilled holes instead of punctured holes as used in the present experiment. At another part of this report reference is made to a limited study done by the author along these lines.

If out of the reasons listed above we disregard c and d then some further light on the subject may be thrown by studying the following.

1. Examine the thickness of the test specimens.

Elsewhere a discussion is made of the result of such an examination on the specimens tested in the experiments and selected at random.

2. Examine the composition of the test specimens.

3. Examine the physical characteristics of the test specimen like yield point, ultimate strength, etc. This examination, in addition, will be a check on the specifications supplied by the manufacturer.

4. Examine physical properties of the washer.

5. Carry out investigations with drilled holes and compare them with the data already obtained.

Even if variations exist between test specimens, still the conclusions drawn in the thesis are justifiable. This is because complete randomization was expected in the experiment and hence there was equal chance for any one test specimen to be used in any one observation. So the approach made in statistical interpretations are still justified. However the loads obtained are not so good as estimates in contrast to comparisons. If estimates are desired these minimum values obtained among all observations will be more justifiable than average value.

B. Terminology used in the thesis.

a. "Rupture resistance". The use of the term "rupture" seems to be unsatisfactory. Usually by rupture it is meant the initial rupture-hole made in the sheet as the nail is driven through. Even if the final failure of the sheet as the nail is pulled through may be called rupture, then there are two ruptures. Thus the use of the term "rupture" at best is confusing. It is recommended to use "pulling through load" instead of rupture resistance. It may further be mentioned that usually when the word "resistance" is used in a technical sense in books on strength of materials it refers to unit stress and not load. In the present instance the reference is very definitely to load and not unit stress.

b. "Wedge shaped" washer. The use of the expression "wedge shaped" is not appropriate because the shape of the washer is not that of a wedge, rather it is that of a cone. The word was derived from the fact that the behavior of the washer when the nail is pulled is that of a wedge. The usage of the expression "conical shaped" instead of "wedge

shaped" is suggested.

C. Statistical Significance:-

The following is primarily a discussion of the points raised by Prof. Jebe at the time of orals and afterwards.

a. Why nail head diameters were reduced?

The answer is in order to keep down the size of the experiment. By making the size of nail head the same one of the variables was eliminated and hence the size of the experiment reduced to half.

b. Advantages of not reducing nail head sizes:

1. It will afford a study of the effect of nail head diameter on rupture resistance.
2. The statistical analysis will still be possible. A regression analysis may yield even a rational relationship.
3. The tedious and time consuming work of turning down the nail head size on the lathe will be eliminated.
4. An accurate estimate of the rupture resistance characteristics of a particular nail with a given thickness and material as we obtain the nail in the market may be made. The load obtained this way may be used as a design load.

c. "Did turning of heads to 0.350" affect cutting of head or material? Answer - No.

d. The extent of the accuracy of the mean values obtained.

In the thesis the author makes the observation that a difference in the mean value of less than 5 lbs. should not be considered significant. In the light of the discussion the author had with Prof. Jebe, he feels that the statement may be modified. There is no practical significance in

any difference less than 5 lbs. The points involved in this are as given below.

1. There are equal chances for the error to be positive or negative and hence when a number of observations are taken the error tends to cancel out.

2. Even if they do not cancel out still the error is reduced as the number of observations are increased. This may be explained by considering the reasons for variation of individual observations. (Speaking in general terms as understood by statisticians) They are two:

(a) Variation due to individuality of the test specimens - say

(b) Variation due to experimental error - say

Thus total variation is out of which any error in reading will be included only in Again if the number of observations is then when we consider the means the variation is also divided by Hence even if the observations are correct to only 5 lbs, the mean values will be accurate to a much lower figure. The limit of this figure is dependent entirely on the number of observations.

e. The table of means - The author is sorry that the shortage of time at his disposal does not enable him to add here all the mean values of the items listed in table 6. However, the necessary data are included in the table given in the appendix from which the means may be calculated easily.



f. What is the Engineering explanation for flat being better than wedge shaped?

1. The wedge shaped washer acts like a wedge trying to enlarge the initial nail hole, thus rendering the rupture strength.

2. The flat washer on the other hand increases the bearing area of the nail head.

3. The flat washer has bigger diameter than wedge shaped washer.

g. Ref. p.69. The use of the term "eliminated" in connection with variables - The author admits that the choice of the word has not been good. It is admitted that there are always present some variables which can never be eliminated, like time, condition of the operator, etc. All that is possible for the experimenter is to balance the effects of these variables which are beyond this control.

## II. Procedure:

The Statistical Approach:- The author believes in spite of some of his difficulties with statisticians that the method of statistical approach in an experiment is an excellent one. However, the limitations of statistics should be kept in mind while the best use is made of the technique.

a. Extent of statistical application: The most important use of statistical technique can be made when designing the experiment. Serious attention must be paid to the size of the experiment and the number of observation to be taken. If this is done a great amount of work may be reduced. In the opinion of the author it would have been possible to reduce the number of replications in his experiment to half or even



less if he were well advised on the statistical significance of the experiment was known to him at the time of setting it up. The informations required for coming to a decision about the size of the experiment are listed below:

1. Limit of accuracy of the instrument used for investigation.

2. The lowest value which is of any practical significance. In the present study the author would recommend the lowest value as 10 lbs.

3. The number of variables involved in the experiment.

4. The objectives of the experiment, whether it is comparison or estimate or both.

- b. Modification of the present experiment.

The number of replications in the present experiment might have been reduced to half or even less.

- c. Analysis. It is open to question how far the analysis of variance technique could apply to engineering studies advantageously. In engineering we are dealing with standard materials which would conform to rigorous specification. The result is that individual observations tend to be very uniform. In other words the value of experimental error will be very small which in its turn will show significance in most of the items under study. However for an engineer significant difference (in the statistical sense) which is not of any practical use is without value. So it seems to the author that the type of analysis made in the thesis - by means of graphs - may be more beneficial than that by statistical analysis. It must be mentioned here that engineering problems are very much different from problems in crops or soils,

which lend themselves to statistical analysis. The reason is that even a small difference is of practical importance in the latter branches of agriculture.

d. Similitude Approach. The author believes that the technique of dimensional analysis may be used advantageously in similar studies. The experiment in this case should be set up in consultation with the T & AM department (Dr. Murphy). In the present case the relevant variables are

1. Thickness of sheet
2. Temper alloy of sheet
3. Yield point and ultimate strength of the material of the sheet.
4. Diameter of nail head
5. Thickness of nail head
6. Diameter of nail shank
7. Endurance limit of the material of sheet
8. Properties of the washer

By this approach it will be possible to develop a rational expression involving all these variables. However, it must be emphasized that if all these variables are to be taken into account then the experiment may become very complicated.

### III. Further work:-

(1) Carry out some investigations with drilled holes instead of punctured holes.

(2) Design the experiment in such a way as to get accurate estimates of design loads with specific nails and specified aluminum sheets.

(3) Set up experiments to develop better type of washers.

(4) Study the effect of vibration and repeated loads on the rupture resistance. One suggestion is to try the same nail successively for different observations.

(5) Let us experiment to study the effect on the physical properties of the aluminum sheets on its resistance to rupture.

#### IV. Additional investigation carried out by author.

##### 1. Random measurement of thickness of tested specimens.

This is undertaken to get some light on the question of variability between individual observations in the experiment.

The data on previous pages are self explanatory. Although only 6 observations were taken in the case of each nail with the new washer, the result show the new washers are considerably inferior to even the flat washers used in the experiment.

The author believes that by using a metal having higher yield point, ultimate strength and endurance limit for backing the neoprene, a still better washer could be developed.

2. Test with drilled holed. The author is sorry that lack of time prevented him from conducting a few tests along this line. It is requested that a few inch tests be made and the data added to this report.

3. Graphs for the different nails with rupture resistance vs. thickness of metal are shown on the following pages.

Thickness of tested aluminum pieces

No.	A $\bar{x}$ (in) .019"	B $\bar{x}$ (in) .024"	C $\bar{x}$ (in) .032"	<u>N.B.</u> Test pieces selected at random
1	.021	.024	.031	
2	.021	.024	.032	
3	.020	.024	.032	
4	.021	.023	.031	
5	.020	.024	.031	
6	.020	.023	.031	
7	.020	.023	.031	
8	.019	.023	.031	
9	.019	.024	.032	
10	.020	.024	.032	
11	.019	.023	.031	
12	.019	.024	.031	
13	.019	.024	.031	
14	.019	.023	.031	
15	.020	.024	.031	
16	.019	.023	.032	
17	.019	.024	.031	
18	.019	.023	.031	
19	.020	.024	.032	
20	.019	.024	.031	

Test of .019" flat aluminum sheet with new washer

Description of washer:-

Diameter = .625"  
Thickness = .010"

Alumin = .025"  
Neoprene = .075" } .010"  
(double material)

No.	Nail Al. diamond ring	Thickness of sheet (in.)	Type of failure
1	201 lbs.	.020	3 corner
2	200 "	.021	"
3	203 "	.020	"
4	219 "	.020	"
5	206 "	.020	"
6	208 "	.019	"

Total 1237  
Ave. 206

Considering conical washer as 100,

With flat  
washer 160

flat washer - 148

new " -191

With  
conical 108

1	194 "	.020	4 corner
2	221 "	.020	3 "
3	187 "	.019	"
4	214 "	.019	"
5	224 "	.020	"
6	176 "	.019	4 corner

Total 1226  
Ave. 204

Considering conical washer as 100,

With flat 164

flat washer - 162.5

" con 101

new " - 202