Resistance of sheet aluminum to rupture by the heads of various types of roofing nails

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RESISTANCE OF SHEET ALUMINUM TO RUPTURE BY THE HEADS OF VARIOUS TYPES OF ROOFING NAILS

by

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## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>The Project</td>
<td>1</td>
</tr>
<tr>
<td>History</td>
<td>1</td>
</tr>
<tr>
<td>Purpose</td>
<td>1</td>
</tr>
<tr>
<td>Review of Literature.</td>
<td>3</td>
</tr>
<tr>
<td>History of aluminum.</td>
<td>3</td>
</tr>
<tr>
<td>Manufacture of aluminum.</td>
<td>6</td>
</tr>
<tr>
<td>Developments in recent years</td>
<td>7</td>
</tr>
<tr>
<td>History of the nail.</td>
<td>9</td>
</tr>
<tr>
<td>Development of the roofing nail.</td>
<td>10</td>
</tr>
<tr>
<td>Ideal sheet metal roofing nail</td>
<td>12</td>
</tr>
<tr>
<td>New and experimental types of nail heads</td>
<td>13</td>
</tr>
<tr>
<td>Synthetic washers.</td>
<td>14</td>
</tr>
<tr>
<td>Aluminum roofing nails</td>
<td>15</td>
</tr>
<tr>
<td>Economics of aluminum and steel nails</td>
<td>16</td>
</tr>
<tr>
<td>General</td>
<td>17</td>
</tr>
<tr>
<td>Characteristics of aluminum</td>
<td>17</td>
</tr>
<tr>
<td>Galvanic action</td>
<td>18</td>
</tr>
<tr>
<td>Wrought alloy designations</td>
<td>19</td>
</tr>
<tr>
<td>Wind pressures</td>
<td>20</td>
</tr>
<tr>
<td>Effects of temperature change</td>
<td>21</td>
</tr>
<tr>
<td>Previous nail and sheet metal tests</td>
<td>21</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Justification</td>
<td>23</td>
</tr>
<tr>
<td>Roofing investment</td>
<td>23</td>
</tr>
<tr>
<td>Wind damage</td>
<td>24</td>
</tr>
<tr>
<td>Wind records</td>
<td>27</td>
</tr>
<tr>
<td>Permanence of aluminum</td>
<td>27</td>
</tr>
<tr>
<td>Limitations of aluminum</td>
<td>28</td>
</tr>
<tr>
<td>Inadequacies of previous tests</td>
<td>30</td>
</tr>
<tr>
<td>Objectives of the Study</td>
<td>30</td>
</tr>
<tr>
<td>THE INVESTIGATION</td>
<td>32</td>
</tr>
<tr>
<td>Selection of Equipment</td>
<td>32</td>
</tr>
<tr>
<td>Preliminary Tests</td>
<td>33</td>
</tr>
<tr>
<td>Selection of Nails</td>
<td>34</td>
</tr>
<tr>
<td>Nail Head Changes</td>
<td>36</td>
</tr>
<tr>
<td>Nail Code Numbers and Designations</td>
<td>39</td>
</tr>
<tr>
<td>Synthetic Washers</td>
<td>41</td>
</tr>
<tr>
<td>Statistical Planning</td>
<td>42</td>
</tr>
<tr>
<td>Standard Procedure</td>
<td>43</td>
</tr>
<tr>
<td>Tests - flat sheets</td>
<td>43</td>
</tr>
<tr>
<td>Tests - corrugated sheets</td>
<td>46</td>
</tr>
<tr>
<td>Identification of Sheet Aluminum</td>
<td>47</td>
</tr>
<tr>
<td>Quantity of Materials</td>
<td>49</td>
</tr>
<tr>
<td>ANALYSIS</td>
<td>51</td>
</tr>
<tr>
<td>Rupture Patterns - Flat Sheet Aluminum</td>
<td>51</td>
</tr>
<tr>
<td>Nail Head Performance with Flat Sheets</td>
<td>58</td>
</tr>
<tr>
<td>Comparison of steel and aluminum heads</td>
<td>58</td>
</tr>
<tr>
<td>Influence of nail shank diameters</td>
<td>59</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------</td>
<td>------</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>88</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>91</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>94</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>95</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Fig. no.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Losses paid by the Iowa Mutual Tornado Insurance Association on wind damage to sheet metal roofing on Iowa farm buildings</td>
<td>25</td>
</tr>
<tr>
<td>2.</td>
<td>Iowa farm building sheet metal roofs on which wind damages were paid by the Iowa Mutual Tornado Insurance Association</td>
<td>26</td>
</tr>
<tr>
<td>3.</td>
<td>Nails which ruptured the 0.019 inch corrugated sheet aluminum while it was being applied. Picture was taken of a newly constructed corn bin at Cedar</td>
<td>29</td>
</tr>
<tr>
<td>4.</td>
<td>Fasteners that have ruptured the corrugated 0.019 inch aluminum sliding on a machine shed in Pocahontas County</td>
<td>29</td>
</tr>
<tr>
<td>5.</td>
<td>Roofing nails tested (actual size)</td>
<td>37</td>
</tr>
<tr>
<td>6.</td>
<td>Randomizations of the order in which the various nails were pulled through the different thicknesses of sheet aluminum</td>
<td>44</td>
</tr>
<tr>
<td>7.</td>
<td>The nail-pulling machine with baseboard used to test flat sheet aluminum</td>
<td>48</td>
</tr>
<tr>
<td>8.</td>
<td>The nail-pulling machine as it was used to test corrugated sheet aluminum.</td>
<td>48</td>
</tr>
<tr>
<td>9.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 17(\frac{3}{4}) before and after test with 0.025 inch sheet</td>
<td>52</td>
</tr>
<tr>
<td>10.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 17(\frac{3}{4}) before and after test with 0.025 inch sheet</td>
<td>52</td>
</tr>
<tr>
<td>11.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 27(\frac{1}{4}) before and after test with 0.025 inch sheet</td>
<td>52</td>
</tr>
<tr>
<td>Fig. no.</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2733 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>13.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 1738 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2738 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2748 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>16.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2738 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2525 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>18.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2626 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>19.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 1214 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>20.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2111 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>21.</td>
<td>Rupture patterns in 0.020, 0.025 and 0.032 inch flat sheet aluminum, respectively. Nail 2312 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>22.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2418 before and after test with 0.025 inch sheet.</td>
<td></td>
</tr>
<tr>
<td>Fig. no.</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>23.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2217 before and after test with 0.025 inch sheet</td>
<td>56</td>
</tr>
<tr>
<td>24.</td>
<td>Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2317 before and after test with 0.025 inch sheet</td>
<td>57</td>
</tr>
<tr>
<td>25.</td>
<td>Representative head failures resulting from tests with flat 0.032 inch sheet aluminum</td>
<td>57</td>
</tr>
<tr>
<td>26.</td>
<td>Nail point puncture patterns resulting from nails 2312 and 2111 in 0.020-inch sheet aluminum (x6.5D)</td>
<td>61</td>
</tr>
<tr>
<td>27.</td>
<td>Nail point puncture patterns resulting from nails 2312 and 2111 in 0.025-inch sheet aluminum (x6.5D)</td>
<td>61</td>
</tr>
<tr>
<td>28.</td>
<td>Nail point puncture patterns resulting from nails 2312 and 2111 in 0.032-inch sheet aluminum (x6.5D)</td>
<td>62</td>
</tr>
<tr>
<td>29.</td>
<td>The wedge synthetic washer after being subjected to a compressive force of 325 pounds (x6.5D)</td>
<td>62</td>
</tr>
<tr>
<td>30.</td>
<td>Rupture resistance of specified thicknesses of flat sheet aluminum with indicated nails</td>
<td>64</td>
</tr>
<tr>
<td>31.</td>
<td>Rupture resistance of specified thicknesses of flat sheet aluminum with indicated nails</td>
<td>65</td>
</tr>
<tr>
<td>32.</td>
<td>Pounds rupture resistance of specified thickness of flat sheet aluminum with indicated nails</td>
<td>66</td>
</tr>
<tr>
<td>33.</td>
<td>Pounds rupture resistance of specified thickness of flat sheet aluminum with indicated nails</td>
<td>68</td>
</tr>
<tr>
<td>34.</td>
<td>Nail 2743 being tested with 0.025-inch sheet aluminum. Pictures are successive.</td>
<td>69</td>
</tr>
<tr>
<td>35.</td>
<td>Nail 2733 being tested with 0.025-inch sheet aluminum.</td>
<td>69</td>
</tr>
<tr>
<td>36.</td>
<td>Rupture resistance of specified sheet aluminum with indicated nails</td>
<td>78</td>
</tr>
<tr>
<td>Table no.</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>I. Variations and Code Numbers of Roofing Nails</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>
INTRODUCTION

The Project

History

"The Utilization of Aluminum and Aluminum Products in Farm Buildings and Equipment", Project 1011, has been an active program at the Iowa Agricultural Experiment Station since March 1, 1917. At that time the Aluminum Company of America made a grant-in-aid to the station for a three-year research program in the field of farm structures.

In 1948 and 1949 the study of the withdrawal resistance of roofing nails was carried on as a part of this project, and during the past year work on the resistance of aluminum sheet metal to rupture by various types of roofing nails was carried on under this same program.

Purpose

Project 1011 was started with the objective in mind of determining the most effective ways of utilizing aluminum and aluminum products on the farm. Prior to the second world war, aluminum was on the market only in a limited number of products. During and after the war, the production of aluminum increased to the extent that it now is one
of the most important metals used in the nation.

Aluminum finds its greatest use in rural areas as a roofing and siding material for farm buildings. In many cases, immediately after the war, farmers purchased aluminum only because steel was not available. If aluminum is to become a permanent product on the market, it will have to render service which is comparable or superior to other competing materials.

It is with this thought in mind that the study of determining the rupture resistance of sheet aluminum to various types of roofing nail heads was undertaken. Intensive studies by Landis L. Boyd (4) and William T. Robison (22) have been conducted on the withdrawal resistance of different roofing nails. Obviously the withdrawal resistance of a roofing nail does not have to exceed the resistance of the sheet aluminum to rupture by the nail head. This statement is made with the assumption that the problem of nail creep does not demand a higher withdrawal resistance. The ideal condition would be one in which the withdrawal resistance and rupture resistance would be equal. Such a condition can be created in two ways. The first of these is by increasing the thickness of the sheet aluminum or improving its composition until it has the desirable rupture resistance and the second is to keep the thickness and composition of the sheet metal constant while determining
the desirable characteristics of a nail head which will give the sheet aluminum a maximum resistance to rupture. The latter of these received primary consideration in this study.

Review of Literature

History of aluminum

The first use of heavy metals, other than the precious metals, dates back several thousands of years. According to Reynolds (21, p. 15), man used heavy metal in making weapons, cooking pots, implements for working the soil, and other tools to help him live in his crude environment many centuries before the year 1 A.D. No one seems to know exactly when the first heavy metal was discovered or produced, but the traces left by man during the Middle Ages indicate that heavy metals have been in use almost since antiquity.

The story of aluminum, one of the light metals, is not shrouded in history since it was first discovered and produced less than a century and a half ago by a Danish scientist named Hans Christian Oersted. The scientists of that time were aware of the existence of aluminum, but no one was able to isolate the metal until Oersted made his discovery in 1825. The procedure used was that of heating a mixture of aluminum chloride with potassium amalgam.

This process did not prove to be very successful since several years later a German scientist, Frederick Wöhler, attempted
to produce aluminum by this same method but failed. By using metallic potassium as a substitute for the amalgam used by Oersted, Wöhler discovered another way of producing aluminum.

Although Wöhler and Oersted had discovered the secrets for aluminum production, the amounts which could be produced were very small and the cost of production was high. It was not until the time of Napoleon III that the manufacture of aluminum took another step forward. Reynolds (21, p. 15) states that Napoleon saw in aluminum a metal from which to make lighter more easily transported equipment for his armies. As a result he employed Henri Sainte-Claire Deville to find a way of producing large quantities of aluminum at a low cost.

Deville was not successful in finding a new method, but he did improve on the one used by Wöhler and managed to greatly reduce the cost of aluminum production. Concerning Deville's accomplishments, Hobbs (12, p. 5) states as follows:

Deville improved upon Wöhler's method by substituting metallic potassium. Bars of his metal (aluminum) were exhibited at the Paris Exposition in 1855, and commercial production was begun at Glacière, a suburb of Paris, in 1856. The price of aluminum was dropping. In 1852, it had been quoted at $5.45 a pound. Four years later it sold for $3.41 a pound, and in 1859, for $1.7 a pound. That year the world's production of the metal was exactly two tons.

The modern electrolytic process was discovered simultaneously in 1886 by an American scientist, Charles Martin Hall, and by a French Scientist, Paul Louis Toussaint.
Héroult. Although the two men did not know of each other's work, they seemed to have had a lot in common. Both were born in the year 1863, each made his discovery in 1886, and both died in the year 1914. Their discovery cheapened the process of making aluminum to such an extent that within a few years the metal began to sell for less than one dollar per pound.

Hall's success in discovering the electrolytic process can be accredited to his untiring efforts. After trying many types of purely chemical tests, he finally turned to electrolysis. But even after the first of these tests failed, Hall's determination moved him on.

The success of Hall's discovery is described by Hobbs (12, p. 7) as follows:

His will to succeed finally resulted in success, and on February 10, 1886, he found that cryolite, a sodium aluminum fluoride mineral, when molten, would dissolve aluminum oxide, or alumina, and that the resulting solution would conduct electricity. With this accomplished, he tried to electrolyze the solution, but failed to obtain any aluminum. He tried again, this time using a carbon crucible. It worked! The aluminum oxide had been broken down into its component parts of aluminum and oxygen by means of the electric current. It was on February 23, 1886, that he succeeded in making aluminum by a new process.

It was not until two years later that Hall was able to interest someone in his discovery. In 1888, the Pittsburgh Reduction Company was organized to exploit Hall's new process. This small organization later became the Aluminum Company of America.
Heroult also had difficulty in exploiting the discovery which he had made. Unfortunately, he did not fully realize the value of his process and was further discouraged by M. Péchiney to whom Héroult looked for advice. Hobbs (12, p. 10) states as follows:

Unfortunately, one of the producers of aluminum to whom the young man (Héroult) looked for counsel, M. Péchiney, advised Héroult against attempting to manufacture pure aluminum saying: 'Aluminum is a metal with limited market and should you sell it for 10 francs or 100 francs per kilo, you would not sell one more kilo. Should you make aluminum bronze, that would be a different matter, for substantial quantities of the latter are used.'

As a result, Héroult did not follow up his discovery of the electrolytic process but instead tried to find a method for making aluminum bronze.

Reynolds (21, p. 20) sums up the history of aluminum in the following words:

The aluminum industry as we know it today was founded not by accident and with no reasonable amount of facility, but through the steady perseverance of Charles Martin Hall and Paul Louis Héroult who laid the cornerstone for an industry which has put aluminum among the five leading metals today, reduced the price to approximately 14 cents per pound, and inaugurated the light metal age.

Manufacture of aluminum

Aluminum as it is found in nature composes about one-twelth of the earth's surface. Even though it exists in such abundance, it is never found in its pure state. Man had discovered and was using many metals which are much
more scarce long before aluminum was even known to exist.

Although aluminum is found in many clays and silicates, bauxite is the principal ore mined for the production of aluminum. Deposits are located in numerous states in the nation, but Hobbs (12, p. 13) states that the mining of the ore is carried on principally in Arkansas. Because of the international situation and the limited natural deposits of high quality ore in this nation, most of the bauxite ore now being used is imported from Suriname, South America.

After mining, the ore is purified by the use of a sodium hydroxide solution which dissolves the aluminum hydrate and forms an aluminum hydroxide. A calcining process follows in which all remaining impurities are removed and the final product is aluminum oxide, or alumina as it is often called. Hobbs (12, p. 17) explains that approximately two pounds of bauxite ore are required to produce one pound of aluminum oxide, and for the production of one pound of pure aluminum, two pounds of aluminum oxide and about 12 kilowatt-hours of electricity are necessary.

**Developments in recent years**

During the second world war, the aluminum companies were called upon to produce large quantities of this metal which was so vital for the production of our aircraft. The aluminum companies were successful in meeting this production challenge and in a few years were producing record-breaking quantities.

Besides for the production of aircraft, aluminum alloys were used for many other purposes in the armed forces.
Since the metal was relatively light, it was given preference in the production of materials which had to be shipped to our overseas forces. Its low specific gravity permitted greater volumes of the manufactured materials to be hauled on our trucks, shipped on trains, and moved on our ships.

Because of its desirable characteristics, aluminum was selected for the construction of many military installations. The aluminum sheet used was rolled 0.019 inches thick. This material was not very strong but it did serve the purpose if handled with care.

When the war ended, the aluminum companies had to find other markets to consume their aluminum output. This problem was quite simple since the farmers in the United States were very much in need of roofing materials for their buildings. The result was that the production of 0.019-inch sheet aluminum was continued. Many farmers who were in need of roofing materials purchased aluminum not because they preferred it, but instead because they had no other choice.

The introduction of 0.019-inch sheet aluminum on American farms has shown that aluminum, if properly used, can become one of our most common roofing materials. The only prerequisite for this possibility to become a reality is that sheet aluminum must give equal if not superior service under the same weather conditions as other competitive roofing materials.
History of the nail

History indicates that man first began to use nails 3000 or more years ago. How these first nails were made and for what they were used, is not exactly known; but it is known that nails have been serving man for many ages.

The history of the manufacture of nails in this country can be traced back to the eighteenth century. Undoubtedly nails were manufactured before then but not on such a large scale. Although nails today are made by mass production, the manufacturing of nails in the eighteenth century was a very slow and tedious process. Each individual nail had to be processed by hand until it had the desired shape. This occupation employed many farmers during the cold winter months.

Swank (24, p. 133) gives the following description of the manufacture of nails in the early history of this country.

The manufacture of nails was one of the household industries of New England during the eighteenth century. In a speech in Congress in 1789 Fisher Ames said, 'It has become common for the country people in Massachusetts to erect small forges in their chimney corners; and in winter, and in evenings, when little other work can be done, great quantities of nails are made, even by children. These people take the rod iron of the merchant and return him the nails, and in consequence of this easy mode of barter the manufacture is prodigiously great.'

Vogel (27, p. 138) describes the early production of nails in a very similar manner.
Colonial farmers hand forged their nails during the long winters. Nails then were prized possessions, hoarded and straightened for re-use, often spent as money. Later, cut nails were made by machine and since 1850 wire nails have been cold drawn. Increasing mechanization has made nails more highly specialized, until today more than 1200 species of nails are produced for as many different purposes.

The first nail-cutting machine was invented by Jacob Perkins of Newburyport, Massachusetts, in about 1750, according to Swank (24, p. 133). The machine was not patented until 1795. Other similar inventions followed, and the cutting of nails soon displaced the slow process of hand forging.

The nail-cutting machines proved to be of valuable service for only a half century before they were displaced by machines making wire nails. The first of these was invented during the middle of the nineteenth century by William Hassall of New York. Although the wire nail was not immediately accepted, the ease and speed with which it could be made caused the wire nail to finally displace the old cut nails. With the development and perfection of the wire nail machine came the process of mass production which put nails on the market in large quantities.

**Development of the roofing nail**

Roofing nails are manufactured for the specific purpose of applying roofing materials. This adaptation of the ordinary nail requires that some minor changes be made in
order that the nail will be most useful for the purpose which it is to serve.

The first metal roofing nail was simply an ordinary nail supplied with a cone-shaped lead washer to seal the hole made in the metal by the nail and to cover the breaks in the galvanization around the nail hole. The lead washers could be purchased in bulk and were then attached to whatever size nail was desirable.

The task of applying the lead washers proved so tedious that many farmers refused to use them and consequently applied their roofs with plain nails. This problem of properly using the lead washers presented a challenge to the nail manufacturers, and as a result they began to produce nails with a lead encased head. These nails gave good service and are still on the market, but the greatest objection to their use is the ease with which the lead heads can be knocked off when the nail is driven. This weakness in the heads is especially prevalent when attempting to drive the nail through several thicknesses of sheet metal at the various laps.

The most recent of the lead head nails is a new adaptation of the lead washer. The nail has a large head which is semi-encased with lead. The washer is attached to the nail in the factory by pressing the lead firmly around the bottom of the nail head. In driving this nail, the lead remains unharmed because the hammer never strikes the lead
but instead makes direct contact with the bare steel nail head.

**Ideal sheet metal roofing nail**

The lead head roofing nail has proven to be quite successful if its services are compared to those that were rendered by the roofing nails which preceded it. However, when the services of a lead head nail are compared with those which would be expected of an ideal sheet metal roofing nail, much is left to be desired. This ideal nail is still to be manufactured. If and whenever such a nail is made, it should have the following characteristics.

1. The nail must be manufactured strong enough so that it may be driven without bending or breaking of the shank.
2. The head must be strong enough so that the nail, after it is fully driven, can be withdrawn from the girt without breaking the nail head.
3. The characteristics of the nail shank must be such that the nail will never creep.
4. The material from which the nail is made must be resistant to corrosion or must have a permanent coating of some non-corroding material.
5. The material from which the nail is made must not produce galvanic action with any sheet metal roofing.
6. The nail head must permanently seal the hole made by the nail shank.

7. The nail head must protect the sheet metal surrounding the punctured hole. This is especially true when galvanized sheet metal is used.

New and experimental types of nail heads

Roofing nail manufacturers are constantly striving to improve their products and as a result new and experimental nails are appearing on the market. Much work has been done to improve the nail shank. But since this study is not particularly concerned with nail shank types, that subject will not be discussed. For information on the holding power of different nails, the works of Boyd (4) and Robison (22) may be consulted.

Just as different shank types may be used on roofing nails to give them desirable holding characteristics, likewise different types of heads may be used to obtain better sealing qualities. As a result the cup or umbrella type, the hood type, and the large plain head with synthetic washers have appeared on the market.

One manufacturer has produced a washer with a metal top and a layer of synthetic materials beneath it. The claims made for this product are that the synthetic material will
stick to the roof after the nail is driven. In this case
nail creep would not materially affect the sealing qualities
since the washer would adhere to the roofing material and
still maintain a seal with the nail shank.

**Synthetic washers**

Washers made from plain rubber, neoprene, and certain
types of mastic have been on the market in limited quanti-
ties during recent years. The manufacturers make very favorable claims for their products, but whether the products will live up to these claims is another question. The production of at least one type of mastic washer has already been dis-
continued because the material proved unsatisfactory after
aging.

Neoprene seems to be the most satisfactory material for
roofing nail washers. The Sheet Metal Worker (17, p. 67)
makes the following claims for the synthetic washer.

Neoprene was selected for the application as the
composition most able to retain high tensile
strengths and resiliency, without cracking, after
long exposure to radical alternations between heat
and cold, exposure to sunlight, and oxidizing in-
fluences. This characteristic of neoprene persists
even when the material is under stress—a difficult
specification for any rubber to meet.

The author is somewhat doubtful of the above claims be-
cause some neoprene washers which have been in storage for
several years in the Agricultural Engineering Department at
Iowa State College are so brittle that a person has difficulty
in placing them on screw-shanked nails. These definitely do not show very much resiliency or tensile strength. It is, of course, possible that the neoprene washers on the market today are of a better quality.

**Aluminum roofing nails**

The introduction of aluminum sheet roofing on the farm required that some roofing nail be manufactured which would not react with the sheet aluminum. The most logical answer was to produce an aluminum roofing nail. The aluminum companies did that but encountered some difficulty in making their nails substantial enough to give good service. This difficulty is only natural, since any new product placed on the market will more than likely have some weaknesses.

Some aluminum nails were manufactured with a lead encased head, but the permanence of this nail was questioned because galvanic action could occur between the aluminum and the lead. Because of this possibility, the lead head aluminum nail is no longer produced. Today only synthetic washers are recommended with aluminum nails.

The aluminum alloys used for producing nails immediately after the second world war were 17S and 24S. These nails were probably satisfactory, but the method by which they were produced was rather expensive. After the heading and forming processes, these nails had to be heat treated before they were ready for the market.
Continued research by the aluminum companies soon overcame this difficulty. The progress made is stated by Lloyd (14, p. 103) in the following manner.

Alcoa continuing its early investigation, developed a special aluminum wire from the alloy 61S-T61, a standard specification that is cold worked between solution heat treatment and artificial aging. The wire has a tensile strength of about 55,000 psi and a yield strength of 51,000 psi, whereas straight 61S-T has a tensile strength of about 45,000 psi and a yield strength of 40,000 psi. This alloy, according to Aluminum Co. of America experiments, provides the best corrosion resistance and can be heat treated in wire form, yet easily formed in nail making machines without head cracking of the nail itself.

The aluminum nail has made reasonable progress during the few years in which it has been on the market. Much research, however, remains to be done before it will be able to render services equal to those rendered by competitive nails now on the market.

**Economics of aluminum and steel nails**

The price of the aluminum nail is still not such that it can compete favorably with other nails on the market. Lloyd (14, p. 103) sums up the situation with the following statements.

While aluminum nails generally cost about 12 time more per lb. than steel nails, there are about three times as many nails per unit weight, bringing the nail for nail price ratio to about 3:1 in favor of steel nails. However, compared with stainless and other nonferrous type nails, the price is appreciably lower.

As long as the price ratio between steel and aluminum
nails does not become more favorable, the latter will not grow in popularity. At the present this condition is not objectionable since much research remains to be done with the aluminum nail before it will give equal or superior service to the other nails on the market. Whenever the aluminum nail is developed to this extent, improvements in the manufacturing process may be advanced to such a stage that a more favorable price ratio will exist between the aluminum and the ferrous nails.

General Characteristics of aluminum

Sheet aluminum has very desirable characteristics for construction purposes. The material is light, durable, strong, fire resistant, and has a high reflectivity. It is non-sparking and non-magnetic as well as non-toxic to food or water with which it may come into contact. Aluminum has a specific gravity of 2.7 which is approximately one-third that of most ferrous metals. Its melting point is approximately 1217°F Fahrenheit, and its atomic number and atomic weight are 13 and 26.97 respectively.

Aluminum is very resistant to weathering and corrosion under ordinary conditions. Although great quantities of this metal were not used for farm structures prior to a half decade ago, several instances can be cited where
sheet aluminum has been in service for many years. Reynolds Farm Institute (20, p. 7) cites the Chief Secretary's Office building in Sydney, Australia, which had an aluminum roof applied in 1895. After 40 years of service, the roof was still in sound condition.

Aluminum has an inherent characteristic which makes it very resistant to deterioration. Upon exposure, a thin film of aluminum oxide quickly forms to cover the sheet. This formation, which is permanent and non-soluble in water, continues to become thicker for several years at a progressively slower rate until the weather conditions finally have no further effect on the underlying aluminum.

Although the metal is very resistant to deterioration, it is subject to corrosion by some acids and practically by all alkalies. Concrete should never be placed in direct contact with aluminum since serious corrosion will result. Reynolds Farm Institute (20, p. 60) recommends that a liberal coating of asphalt or mastic compound be applied between sheet aluminum and concrete.

Galvanic action

Aluminum ranks rather high in the electromotive series and hence is subject to galvanic action by numerous other metals. This type of electrolytic action is especially prevalent when aluminum is in contact with copper. The detrimental effects of steel and lead are somewhat
questionable but aluminum manufacturers recommend that mastic compounds or asphalt be used between surfaces of aluminum and other metal parts.

**Wrought alloy designations**

Wrought alloys are those metals which are ductile and malleable enough to be formed into desirable shapes without cracking or breaking when the common metal working processes are employed. Most of the wrought alloys of aluminum are produced by rolling, extruding, drawing, and forging. They are designated by combinations of numbers and letters which indicate the alloy, temper, and heat treatment. A simple example from the Alcoa Structural Handbook (1, p. 9) is a good illustration.

The alloy most widely used in aluminum structures is 61S-T6. The first number, "61", identifies the chemical composition; the letter "S" distinguishes this as a wrought, rather than a cast product; the letter "T" shows that the metal has been heat treated to increase strength; and the final "6" defines the method of heat treatment.

The letter "0" in a wrought alloy designation indicates that the metal was annealed, i.e., 52S-0. The letter "H" is used to indicate the extent to which the material has been hardened, i.e., 52S-1H. Most other aluminum companies in the nation follow a similar system of identifying their products.
Wind pressures

Investigations by Test (25, p. 36) indicate that a maximum negative wind pressure of 70.2 pounds per square foot may occur on a gothic roof in a 125 mile an hour wind. Fenton and Otis (9) at Kansas State College conducted wind tunnel tests on model barns with gambrel, gothic, and gable roofs. They found that the maximum pressure which could occur was a negative one which would result if a large barn door facing the wind were left open. According to their method of calculation, the maximum possible pressure which could occur in a 125 mile an hour wind would be 74.4 pounds per square foot. This figure is obtained by multiplying a negative force coefficient of 1.9 by the velocity pressure of the design wind.

Dryden and Hill (6, p. 730) conducted some similar research on mill buildings and found the maximum negative force coefficient to be 1.5. The resulting pressure for a wind of 120 miles an hour on a mill building completely enclosed and without a monitor is 55.2 pounds per square foot. By using the 1.9 negative force coefficient of Fenton and Otis (9), a 120 mile an hour wind, and an open door in the windward side of the building, a 68.5 pound pressure results. For a building with all doors closed under the same conditions the maximum negative coefficient for a gable type roof was found to be minus 0.9. This occurred on the roof
when the wind was perpendicular to the end of the building. Using this coefficient, a maximum pressure of 32.5 pounds per square foot is obtained.

The results of the several investigators mentioned above show quite a disparity. A person can readily see that much work remains to be done in the field of wind pressures on farm buildings. At the present, a person can probably use the results of any of the above with reasonable success.

**Effects of temperature change**

Some research has been conducted by Pandya (18) on the effects of temperature change on aluminum sheet roofing. The object of his study was to determine if thermal stresses in sheet aluminum are sufficient to cause an elongation of the hole through which the nail is driven. If such an elongation did occur, the sheet metal would be more subject to rupture by the nail head. In his conclusions, however, Pandya (18, p. 67) makes the following remarks.

1. If aluminum corrugated sheets are properly applied to a sound roof deck, sheets will not tear around the nail holes if the temperature differential is within 100° F.

2. 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.

**Previous nail and sheet metal test**

Several people who have done research to determine the
withdrawal resistance of various types of roofing nails have also done some work in determining the resistance to rupture of sheet metal to various types of roofing nail heads.

The first work of this type was done by Reaves (19, p. 20). The process used by him is described below.

To find the rupture point a roofing nail was driven through a piece of sheet steel and a force (to extract the nail) was applied perpendicular to the sheet. At 78 pounds the metal began to bend and at 192 pounds the sheet pulled off leaving the nail in place.

Several years later additional work was done by Giese and Henderson (10, p. 549). They used only three types of nails with 28 gage sheet steel and then noted when the metal deformed as well as when it finally ruptured. The nail heads used were of the plain lead encased type, the semi-lead encased or washer type, and the cup or umbrella type.

The nails deformed the metal when a load range of 185 to 220 pounds was applied. The range of the metal rupture was between 210 and 495 pounds.

In 1946, Boyd (4, p. 114) tested numerous nails with various types of heads on 0.019 inch corrugated aluminum. He did not state the size of corrugation tested nor the composition and treatment of the sheet metal. His observations showed that the cup head was significantly superior to all other heads. He states as follows:

On the basis (statistical analysis) the cup head was significantly superior to all other heads. 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. Lead washer and lead encased heads sheared from the steel heads. This was also true of some of the lead bell heads.

In 1949, Robison (22, p. 112) did some similar testing with a group of roofing nails and 0.025 and 0.032 inch sheet aluminum. Information on his tests is also incomplete in that he does not state whether corrugated or flat sheets were tested, nor does he specify the composition and the treatment of the material that was used. He concludes that the cup type head fitted with the neoprene washer is by far superior to other head types.

Justification

Roofing Investment

The investment which American farmers have in their farm building roofs is sufficient to justify much research to make these roofs more permanent. Nearly two decades ago, Deniston (5, p. 9) stated that the estimated cost of reroofing all the buildings in this country would be five billion dollars. Several years later Maze (15, p. 405) stated that the bill for excessive roof depreciation on farms due to improper nails amounted to about 20 million dollars annually. If the depreciation in roofing was already this staggering
sum two decades ago, it is certainly no smaller today.

Wind damage

Studies of wind damage to the roofs of Iowa farm buildings for the past 20 years show no tendency that wind damage is decreasing. The amount of damage occurring with any one roofing material may be changing somewhat but the overall trend shows an inconsistent rise. Studies made by Esmay (7) show that approximately 14 percent of the total roofing damage in Iowa each year is inflicted by wind on roofs covered with sheet metal. This loss may not seem very significant until a person begins to question the fact as to why there should be any wind loss. Sheet metal when properly applied is practically immune to wind damage. Figure 1 shows the dollar damage to sheet metal roofing which was paid by one Iowa insurance company during the years indicated. Figure 2 shows the number of roofs on which damages were paid during the respective years. The information for the graphs was secured from the studies made by Esmay (7).

The primary problem which must be overcome to secure a reduction in the percent of total wind damage to metal roofing is an educational one. The farmers must be taught the importance of proper methods of construction and application or all the improvements in design and materials of roofing nails and sheets will never prove their value. Before the farmer can be educated, however, someone must
FIG. 1. LOSSES PAID BY THE IOWA MUTUAL TORNADO INSURANCE ASSOCIATION ON WIND DAMAGE TO SHEET METAL ROOFING ON IOWA FARM BUILDINGS.
FIG. 2. IOWA FARM BUILDING SHEET METAL ROOFS ON WHICH WIND DAMAGES WERE PAID BY THE IOWA MUTUAL TORNADO INSURANCE ASSOCIATION.
first determine the correct specifications for applying the sheet metal. These tests of the resistance of aluminum sheet metal to rupture by various types of roofing nail heads which were conducted in this project should help to determine what the eventual specifications will be.

Wind records

Records of the U.S. Department of Commerce (26) show that the maximum gust velocities of wind recorded in Iowa to date are in the range of 90 to 95 miles an hour. Hence, the engineer must design for a minimum wind of 100 miles an hour, and in order to have a larger factor of safety the design for a 125 mile an hour wind would not be out of order.

Robison (23) reported a particular case in which sheet aluminum was blown from the roof of a building during the October 10, 1949, wind storm. The incident occurred on the Howard County Experimental Farm. Residents who witnessed the storm stated that the lead heads from the combination shank nails fastening the material sheared off, and the aluminum then easily pulled over the small sub-head. The nailing pattern which had been used to fasten the aluminum sheets was not specified.

Permanence of aluminum

The many good qualities of aluminum as a roofing and siding material justify the research which is necessary to
determine its proper utilization. Available information on sheet aluminum indicates that the material may last indefinitely. This statement certainly cannot be made for any other metal roofing or siding material. A good example of the permanence of aluminum sheet roofing is found in Reynolds Farm Institute (20, p. 6). It relates the following:

Aluminum's durability is such that time has not yet affected it. One of the earliest domestic applications, the aluminum cap on top of the Washington Monument, was installed in 1884. When examined fifty years later by metallurgists of the Bureau of Standards, it was found substantially unchanged.

Because aluminum is a relatively new metal from which roofing and siding materials are made, many questions remain unanswered in making recommendations for its application. The farmers are not aware of the limitations of this sheet metal and as a consequence much of the material is applied improperly.

**Limitations of aluminum**

A limited survey of farm buildings was conducted by the author in Northwestern Iowa before this project was begun. Other trips also were made to various localities to see specific buildings which had aluminum applied to them. The observations made on these trips proved very definitely that aluminum has limitations, and if they are not respected the results may be quite costly. Figure 3 shows a case in which nail heads ruptured 0.019 inch corrugated sheet aluminum
Fig. 3. Nails which ruptured the 0.019 inch corrugated sheet aluminum while it was being applied. Picture was taken of a newly constructed corn bin at Cedar.

Fig. 4. Fasteners that have ruptured the corrugated 0.019 inch aluminum siding on a machine shed in Pocahontas County.
during application. Either the carpenter who applied the material was very careless or the sheet aluminum was not strong enough to give the required stability. The holes which resulted are not only undesirable but the nails adjacent to the hole must carry an extra load to secure the sheet. This additional pressure under certain conditions may be sufficient to cause the adjacent nail heads to rupture the material also. As a consequence a very minor defect in the building could very easily lead to major damage. Figure 4 shows a case in which the fasteners ruptured the 0.019 inch sheet aluminum on a machine shed.

Inadequacies of previous tests

The limited information available on previous tests with sheet aluminum is further reason for this investigation. The methods used by previous investigators to test the sheet aluminum are probably as good as any that have been devised, but the roofing material was never properly identified nor were the synthetic washers that were used. The adequacy of the number of tests from a statistical standpoint is also very questionable.

Objectives of the Study

The study of the resistance of sheet aluminum to rupture by the heads of various types of roofing nails was
undertaken with the following objectives in mind.

1. To set up a program by statistical methods for testing various types of sheet metal roofing with as many different types of nails as possible.

2. To determine the nail head characteristics that are least likely to induce rupture in the sheet metal which the nail is supposed to hold.

3. To determine the relative merits of aluminum nails as compared to steel nails in relation to their strength and rupture-inducing characteristics.

4. To compare the relative merits of lead encased heads, lead washers, and synthetic washers in relation to their rupture-inducing characteristics.

5. To compare the merits of wedge and flat shaped synthetic washers.

6. To determine the effects of nail head size on rupture resistance of sheet aluminum.
THE INVESTIGATION

Selection of Equipment

A nail pulling machine originally designed and built by Milton S. Henderson (11) was selected as being the most suitable for running the rupture resistance tests. The machine, as originally constructed, consisted of a pressure cell enclosed on one end by a diaphragm. The load was applied directly to the diaphragm which put the fluid in the cell under pressure. A suitable hose from the cell transmitted this pressure to a properly calibrated Bourdon gage which allowed a direct reading to be made of the applied load.

In 1948 a hydraulic cylinder was installed to replace the diaphragm and cell. Calibration checks made with the cylinder before conducting the rupture resistance tests proved that the cylinder was unsatisfactory below the 200 pound range. The same type of checks were run with the original cell and diaphragm. This combination showed less error in the range below 200 pounds as a result this system was used.

The Bourdon pressure gage was tested before any rupture resistance tests were run. Results showed that the gage was inconsistent before it reached the 100 pound mark. The
amount of error in pounds steadily decreased as the load was increased. After the 100 pound mark was passed, the error was consistently less than 1.5 percent.

All sheet aluminum was anticipated to have a rupture resistance of 60 pounds or over. Two lead weights weighing 41 pounds were applied as a dead load in order that all readings would be in the range above 100 pounds.

Preliminary Tests

The investigation of the project was begun by running some preliminary tests on both flat and corrugated sheet aluminum. These trial runs were made in an attempt to simplify and improve on the procedures used by previous investigators. As a result a nail shank holder was devised and subsequent tests were run by pulling the nail head through the material instead of pulling the sheet metal over the nail head. The eventual results of the rupture resistance are the same. These modifications simplified the procedure and also lead to the method of testing the corrugated sheets in long strips instead of small squares.

Preliminary tests were run by using only one type of nail with both flat and corrugated sheet aluminum. Base-boards having holes from one-half to four inches in diameter were used for the different tests as a foundation for the aluminum test strips. The hole variations showed little difference in the rupture resistance of the flat and
corrugated sheet metal. The tendency of the 0.019 inch flat aluminum strips to buckle and pull through the hole proved to be the limiting factor in determining the largest size of hole that could be used. The corrugated and flat sheets showed very little variation in rupture resistance as the size of hole in the baseboard was changed.

Selection of Nails

To limit the field somewhat, all nails with smooth shanks were eliminated. This was done because previous investigations have shown that smooth shank nails are very subject to creep and have a low withdrawal resistance. These characteristics make the nail generally unsatisfactory as a roofing fastener. Consequently, even if a smooth shank nail had an ideal head, it would still be unsatisfactory for its intended purpose.

The selection of the nails to be tested was one of the most difficult problems encountered. The first group which was chosen consisted of 12 roofing nails commonly found on the market. These were to be tested with the three most common thicknesses of aluminum. A statistical analysis was made and the number of tests required to get reliable results were determined.

Such a test program would have shown (1) which nail was better than another nail, (2) which group of nails was better
than another group, and (3) which sheet aluminum was the most effective in relation to its thickness. Investigation of this program revealed that it did not achieve the objectives for which the study was intended. There was no way to determine the characteristics of a particular nail head which made it less probable to induce rupture. As a result this program was abandoned and another selection of nails was made.

The second group was chosen on the basis of nail head characteristics. This method of selection did not prove completely satisfactory since several roofing nails on the market today had to be eliminated because their head characteristics were not comparable to the head characteristics of any other nail.

A simple illustration may be the best explanation of the above statement. Suppose that an aluminum and a steel nail with identical characteristics had been selected for the tests and that after the experiment had been run one nail proved consistently better than the other. The superior performance of the one nail could then have been attributed directly to the fact that it was made of aluminum or steel. Now if two other similar nails would have been selected, but neither had the same diameter head or head configuration, the superior performance of the one nail could not have been attributed to any particular nail characteristic. The
better performance could have been due to the different metal types, the different diameter heads, the different head configurations, or perhaps because of all three. Nails which fell into this category were eliminated from the tests.

The nail head characteristics were given primary consideration in making the selection while the shank and point characteristics were considered as secondary. Several attempts were made to limit the characteristics to the head only. But since various nails have different shank diameters, the importance of the original hole punctured by the nail point and shank obviously could not be overlooked. The nails which were used are shown in Figure 5 and additional information concerning them is listed in Table I.

**Nail Head Changes**

Head changes were effected on eight of the nails having comparatively large diameter heads in order to make the final comparisons of the nails as valid as possible. In general the bare-head diameters of the entire group of nails fell into two categories which may be considered as large and small. All nails having small bare-head diameters had lead encased heads. All nails having large bare-head diameters were fitted with either a lead or a neoprene washer. The heads of the nails with the lead washers were partially encased, thus preventing any head changes. These nails had the smallest heads in the large diameter group and were
Fig. 5. Roofing nails tested (actual size)
Table I
Variations and Code Numbers of Roofing Nails

<table>
<thead>
<tr>
<th>No.</th>
<th>Mat.</th>
<th>Dia.</th>
<th>Head</th>
<th>Casing</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al.</td>
<td>0.350</td>
<td>0.146</td>
<td>0.411</td>
<td>0.398 Ring</td>
</tr>
<tr>
<td>2</td>
<td>Al.</td>
<td>0.350</td>
<td>0.146</td>
<td>0.411</td>
<td>0.339 Ring</td>
</tr>
<tr>
<td>3</td>
<td>St.</td>
<td>0.350</td>
<td>0.138</td>
<td>0.372</td>
<td>0.398 Ring</td>
</tr>
<tr>
<td>4</td>
<td>St.</td>
<td>0.350</td>
<td>0.138</td>
<td>0.372</td>
<td>0.339 Ring</td>
</tr>
<tr>
<td>5</td>
<td>Al.</td>
<td>0.350</td>
<td>0.169</td>
<td>0.430</td>
<td>0.398 Screw</td>
</tr>
<tr>
<td>6</td>
<td>Al.</td>
<td>0.350</td>
<td>0.169</td>
<td>0.430</td>
<td>0.339 Screw</td>
</tr>
<tr>
<td>7</td>
<td>St.</td>
<td>0.350</td>
<td>0.169</td>
<td>0.440</td>
<td>0.398 Screw</td>
</tr>
<tr>
<td>8</td>
<td>St.</td>
<td>0.350</td>
<td>0.169</td>
<td>0.440</td>
<td>0.339 Screw</td>
</tr>
<tr>
<td>9</td>
<td>St.</td>
<td>0.340</td>
<td>0.150</td>
<td>0.340</td>
<td>0.468 Screw</td>
</tr>
<tr>
<td>10</td>
<td>St.</td>
<td>0.345</td>
<td>0.152</td>
<td>0.345</td>
<td>0.468 Ring</td>
</tr>
<tr>
<td>11</td>
<td>Al.</td>
<td>0.281</td>
<td>0.146</td>
<td>0.281</td>
<td>0.375 Ring</td>
</tr>
<tr>
<td>12</td>
<td>St.</td>
<td>0.277</td>
<td>0.133</td>
<td>0.277</td>
<td>0.409 Ring</td>
</tr>
<tr>
<td>13</td>
<td>St.</td>
<td>0.284</td>
<td>0.136</td>
<td>0.284</td>
<td>0.376 Ring</td>
</tr>
<tr>
<td>14</td>
<td>St.</td>
<td>0.285</td>
<td>0.169</td>
<td>0.285</td>
<td>0.375 Comb.</td>
</tr>
<tr>
<td>15</td>
<td>St.</td>
<td>0.281</td>
<td>0.164</td>
<td>0.284</td>
<td>0.437 Screw</td>
</tr>
<tr>
<td>16</td>
<td>St.</td>
<td>0.284</td>
<td>0.164</td>
<td>0.284</td>
<td>0.436 Comb.</td>
</tr>
</tbody>
</table>

*Syn., Synthetic; F., flat; W., wedge; Wa., washer; En., encased*
subsequently used as a basis for cutting down the heads of the other nails having large diameter heads. The heads were cut down to a diameter of 0.350 of an inch with a tolerance of plus or minus 0.005 of an inch. The head reductions were made with a lathe. In most cases the aluminum heads required a greater reduction than the steel nails.

No head changes could be made on any of the small diameter bare-head nails since they were all lead encased. The preliminary tests as well as previous investigations showed that the lead heads sheared from the nail before rupture of the sheet material occurred. This indicated that the size of the lead head actually has very little effect on the pull required to rupture the sheet material. The respective bare-head diameters of the nails with lead encased heads are indicated in Table I.

Nail Code Numbers and Designations

A code system was devised to show comparative characteristics of the various nails. Since all of the nails tested were made from either aluminum or steel, the first digit of the code number includes only 1 and 2 as is indicated below.

<table>
<thead>
<tr>
<th>First digit</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aluminum</td>
</tr>
<tr>
<td>2</td>
<td>Steel</td>
</tr>
</tbody>
</table>
The second digit of the code number represents the relative head diameters of the various nails. The numbers are from 1 to 7 and indicate heads of increasing diameters. The digits designate diameters as shown.

<table>
<thead>
<tr>
<th>Second digit</th>
<th>Bare-head diameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dia. of 0.277 inches, small head</td>
</tr>
<tr>
<td>2</td>
<td>Dia. of 0.281 inches, small head</td>
</tr>
<tr>
<td>3</td>
<td>Dia. of 0.284 inches, small head</td>
</tr>
<tr>
<td>4</td>
<td>Dia. of 0.285 inches, small head</td>
</tr>
<tr>
<td>5</td>
<td>Dia. of 0.340 inches, large head</td>
</tr>
<tr>
<td>6</td>
<td>Dia. of 0.345 inches, large head</td>
</tr>
<tr>
<td>7</td>
<td>Dia. of 0.350 inches, large head</td>
</tr>
</tbody>
</table>

The third digit indicates the type and material of the washers or encasings on the nail.

<table>
<thead>
<tr>
<th>Third digit</th>
<th>Encasing or washer, material and type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lead encased head</td>
</tr>
<tr>
<td>2</td>
<td>Head with a lead washer</td>
</tr>
<tr>
<td>3</td>
<td>Head with a wedge synthetic washer</td>
</tr>
<tr>
<td>4</td>
<td>Head with a flat synthetic washer</td>
</tr>
</tbody>
</table>

The fourth digit indicates the comparative shank diameter of the nails in the test. The numbers are from 1 to 8 and are in the order of increasing diameters.

<table>
<thead>
<tr>
<th>Fourth digit</th>
<th>Shank diameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indicates diameter of 0.133 inches</td>
</tr>
<tr>
<td>2</td>
<td>Indicates diameter of 0.136 inches</td>
</tr>
<tr>
<td>3</td>
<td>Indicates diameter of 0.138 inches</td>
</tr>
</tbody>
</table>
Indicates diameter of 0.146 inches
5 Indicates diameter of 0.150 inches
6 Indicates diameter of 0.152 inches
7 Indicates diameter of 0.164 inches
8 Indicates diameter of 0.169 inches

The nail with the code number 1744 can thus be readily identified as an aluminum nail having a large diameter bare head with a flat synthetic washer and the fourth smallest shank diameter of all the nails in the test group. The code numbers of all the nails are listed in Table I and can be interpreted in a similar manner.

Synthetic Washers

Two different synthetic washers were used. One was gray and wedge shaped while the other was black and flat. Both were identified by their respective manufacturers as washers made from a neoprene compound.

The gray synthetic washers have an approximate diameter and thickness of 0.339 and 0.1 inches, respectively. This same type of washer is still on the market, but the color has been changed to black. The addition of carbon black, which is to make the washer more resistant to weather and give it longer aging properties, is responsible for the change in color.
The black and flat neoprene washers have never appeared on the market to a great extent. The diameter and thickness of the washer are 0.398 and 0.1 inches, respectively. They consist of the same type of neoprene compound that is commonly used on electric refrigerator doors.

Statistical Planning

Bernard Ostle, assistant professor in the Department of Statistics at Iowa State College, was consulted in an effort to set up a program which would give reliable results on a statistical basis. After much consideration, a plan was evolved which required that for each experiment three nails be used with the same thickness of material. Since 16 nails were to be used, 48 tests were required for one thickness of material. With three thicknesses of material one complete experiment included the pulling of 144 nails. According to the Statistical Department, four replications were necessary. Consequently, a total of 576 nails had to be pulled for the complete testing of any one particular type of material involving three thicknesses. If only one thickness was tested, the total was decreased by two-thirds.

Various randomizations were used to determine the order in which the thicknesses of materials were to be tested. The thicknesses were codified to eliminate any bias during the analysis of the results. The letters A, B, and C were
used to represent the thicknesses of 0.020, 0.025, and 0.032 inches, respectively.

Randomizations of a similar nature were used to determine the order in which the nails were to be tested with each thickness of material. The randomizations used in the different replications are shown in Figure 6.

Standard Procedure

Tests - flat sheets

The same nail-pulling machine used for running the preliminary tests was used to run the tests for making the final analysis of the problem. Before the tests were begun, the diaphragm and cell were filled with kerosene. The calibration of the Bourdon gage was checked by applying lead weights to the pull-bar attachment on the diaphragm. Slight variations of readings could be obtained by adjusting the position of the diaphragm and cell as well as the individual bars to which the pull was applied. The adjustments could be made by turning the nuts on the bolts which were used to hold the pressure cell and bars in place. Following the necessary adjustment, the calibrations on the Bourdon gage proved to be within 2 percent of the actual weight at the 100 pound mark and were accurate to within 1 percent for all weights applied thereafter. The weights were applied in 10 and 20-pound increments.
Replication No. 1

<table>
<thead>
<tr>
<th>Sheet</th>
<th>Nail no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>14 12 13 2 7 16 3 8 15 9 5 1 10 6 4 11</td>
</tr>
<tr>
<td>C</td>
<td>15 9 7 5 14 6 11 13 12 4 1 16 8 3 2 10</td>
</tr>
<tr>
<td>A</td>
<td>16 3 7 9 8 11 12 6 14 10 13 4 5 1 2 15</td>
</tr>
</tbody>
</table>

Replication No. 2

<table>
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<th>Sheet</th>
<th>Nail no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15 5 6 16 8 7 14 11 12 4 13 3 10 9 1 2</td>
</tr>
<tr>
<td>B</td>
<td>5 10 6 11 14 12 3 1 13 8 2 15 16 4 7 9</td>
</tr>
<tr>
<td>C</td>
<td>3 2 14 15 10 16 12 6 9 1 5 11 13 8 7 4</td>
</tr>
</tbody>
</table>

Replication No. 3

<table>
<thead>
<tr>
<th>Sheet</th>
<th>Nail no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>13 6 16 10 9 1 12 2 4 5 3 11 7 15 8 14</td>
</tr>
<tr>
<td>A</td>
<td>8 16 13 14 1 4 7 10 9 3 2 6 11 4 15 12</td>
</tr>
<tr>
<td>C</td>
<td>8 1 4 12 13 16 5 15 14 11 10 7 3 2 9 6</td>
</tr>
</tbody>
</table>

Replication No. 4

<table>
<thead>
<tr>
<th>Sheet</th>
<th>Nail no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>6 8 11 2 13 7 14 15 9 3 1 5 16 12 10 4</td>
</tr>
<tr>
<td>A</td>
<td>11 16 4 3 15 1 13 12 2 6 10 8 5 7 14 9</td>
</tr>
<tr>
<td>B</td>
<td>12 5 15 3 8 13 9 7 14 2 4 1 16 11 6 10</td>
</tr>
</tbody>
</table>

Fig. 6. Randomizations of the order in which the various nails were pulled through the different thicknesses of sheet aluminum
The maximum reading indicator on the gage was not used because it proved to be unreliable. Besides better readings could be obtained if the gage indicator was free to move without having to push the maximum reading indicator. This arrangement, although considered the best for the equipment available, was not ideal. The person running the tests was restricted to watching the gage only and hence could not observe the manner in which each individual nail pulled through the sheet. In general, however, the movements of the gage indicator as well as the resulting rupture pattern gave a good indication as to how the rupture occurred.

Flat sheet aluminum having thicknesses of 0.020, 0.025, and 0.032 inches was the first to be tested. The preliminary tests had shown that a three-inch hole in the baseboard under the nail-pulling machine was the largest that could be used without encountering difficulties of buckling in the 0.020-inch material.

The 0.025 and 0.032 inch test sheets were cut into six-inch squares while the 0.020 inch test sheets were cut into squares of seven inches. The latter material was cut larger since it was still inclined to buckle if cut in smaller squares. The size of the test sheets did not affect the rupture resistance because the circumference of a three-inch hole was used as a bearing area for all of the thicknesses tested.

The tests were begun after the necessary preparations
had been made. Figure 7 shows the nail-pulling machine and
the pressure gage as they were used for testing the flat
sheets. The procedure was to take the specified test square
and center it over a board with a two-inch hole. The
specified nail was then driven through the small test sheet
before both were inverted and centered under the baseboard
of the nail-pulling machine. The nail shank holder on the
pulling mechanism was attached to the nail and an electric
motor supplied the power for pulling the nail in an upward
direction at a constant rate until rupture occurred.

The motor was then shut off and the pulling mechanism
was lowered by means of the hand crank on top of the nail-
pulling machine. Following the removal of the test nail,
the same procedure was repeated for the next test.

Tests - corrugated sheets

The preliminary tests with the corrugated sheets were
conducted with baseboards having holes of varying sizes.
Test sheets were cut into pieces about five inches square.
The observation was made that the corrugation through which
the nail was driven would flatten out through the entire
length of sheet as the pull on the nail began. An attempt
was made to counter this action by restricting the sides of
the sheet. Some success was achieved but the test procedure
was not satisfactory because it did not simulate actual
conditions. On a building the sheets would be applied in
long lengths and the corrugations would not flatten out as readily. Additional preliminary tests were run without the baseboard. The test sheets were made sufficiently long to span the eight inches between the supports of the nail-pulling machine. The width of the sheet was made sufficient to prevent buckling across the corrugations. This procedure worked very well and was adapted for running the tests on the corrugated sheets.

Only the 0.019 inch thickness of material was available for testing. Sheet aluminum with 1.26-inch corrugations is also made in the 0.025 inch thickness but none of this material could be purchased locally nor could it be secured from the manufacturers.

The test sheets were cut into strips four feet long and five corrugations or six and one-quarter inches wide. Figure 8 illustrates the manner in which the tests were conducted. The rupture tests on the sheet were spaced at six-inch intervals along the length of the corrugation. This spacing was sufficient to allow a perfect undamaged section of the test sheet to span the distance between the supports of the nail-pulling machine for each test that was conducted.

Identification of Sheet Aluminum

The sheet aluminum for the tests was secured locally. Samples of the sheets were sent to the Aluminum Company of
Fig. 7. The nail-pulling machine with baseboard used to test flat sheet aluminum

Fig. 8. The nail-pulling machine as it was used to test corrugated sheet aluminum
America for identification of the alloy and temper. The materials were identified as shown.

**Flat Sheet Aluminum**

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Alloy</th>
<th>Temper</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020-in.</td>
<td>2S</td>
<td>H18</td>
</tr>
<tr>
<td>0.025-in.</td>
<td>3S</td>
<td>H14</td>
</tr>
<tr>
<td>0.032-in.</td>
<td>Alclad 4S</td>
<td>H38</td>
</tr>
</tbody>
</table>

**Corrugated Sheet Aluminum**

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Alloy</th>
<th>Temper</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.019-in.</td>
<td>Alclad XB16S</td>
<td>---</td>
</tr>
</tbody>
</table>

Tests could not be made of the temper of the 0.019-inch corrugated sheets because the material was too thin.

**Quantity of Materials**

The total number of nails pulled was as follows:

*Flat sheets*

- 3 nails per thickness
- 3 thicknesses of material
- 16 different types of nails
- 4 replications
- Total - 576 nails
Corrugated sheets

- 3 nails per thickness
- 1 thickness of material
- 16 different types of nails
- 4 replications
- Total - 192 nails
- Sum total of nails - 768

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

- 4 sheets 3'-0" x 8'-0" 0.020" material
- 3 sheets 3'-0" x 8'-0" 0.025" material
- 2 sheets 3'-7" x 12'-0" 0.032" 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.

The amount of 1.26-inch corrugated sheet aluminum which was used is shown below:

- 4 sheets 2'-2" x 8'-0" 0.019" material

Some additional material was used in running the preliminary tests.
ANALYSIS

Rupture Patterns - Flat Sheet Aluminum

The rupture patterns resulting from the various nails gave some indication of how well the nail heads performed. The type of rupture which occurred was directly influenced by the initial hole punctured by the nail point. In most cases the rupture was four-cornered. In some instances the rupture pattern was triangular while in others it was pentagonal or even hexagonal in shape.

The four-cornered rupture pattern was most common in the 0.020 and the 0.025-inch test sheets when a diamond pointed nail was used. In some cases the screw shanks changed the initial holes enough so that the final ruptures had five or six corners.

The triangular rupture pattern was most prevalent in the 0.032-inch sheet aluminum. This pattern often resulted when the aluminum nail heads failed before complete rupture occurred. Another reason for this type of rupture was the hardness of the material which resisted the cutting action of the nail point. Sample rupture patterns from each type of nail in each thickness of material are shown in Figures 9 through 24. A picture of each respective nail before and after a rupture test with the 0.025-inch sheet aluminum is also shown in the figures.
Fig. 9. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 1744 before and after test with 0.025 inch sheet.

Fig. 10. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 1734 before and after test with 0.025 inch sheet.

Fig. 11. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2743 before and after test with 0.025 inch sheet.
Fig. 12. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2733 before and after test with 0.025 inch sheet.

Fig. 13. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 1748 before and after test with 0.025 inch sheet.

Fig. 14. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 1738 before and after test with 0.025 inch sheet.
Fig. 15. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2748 before and after test with 0.025 inch sheet.

Fig. 16. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2738 before and after test with 0.025 inch sheet.

Fig. 17. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2525 before and after test with 0.025 inch sheet.
Fig. 18. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2626 before and after test with 0.025 inch sheet.

Fig. 19. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 1214 before and after test with 0.025 inch sheet.

Fig. 20. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2111 before and after test with 0.025 inch sheet.
Fig. 21. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2312 before and after test with 0.025 inch sheet.

Fig. 22. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2418 before and after test with 0.025 inch sheet.

Fig. 23. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2217 before and after test with 0.025 inch sheet.
Fig. 24. Rupture patterns in 0.020, 0.025, and 0.032 inch flat sheet aluminum, respectively. Nail 2317 before and after test with 0.025 inch sheet.

Fig. 25. Representative head failures resulting from tests with flat 0.032 inch sheet aluminum.
Comparison of steel and aluminum heads

Nail 1214 was the only aluminum nail tested with a small lead encased head. The test results showed that it performed third best of all the nails with lead encased heads when tested with the 0.020 and the 0.025-inch material. In tests with the 0.032-inch sheet aluminum, however, its position dropped to fifth among the six nails with lead encased heads. This drop is not as great as it may seem since the third best nail in the tests with the heavy material had a resistance to rupture which was only nine pounds greater than that of nail 1214.

A similar comparison may be made between the aluminum and steel nails having large bare heads. The aluminum nails performed equally as well as the steel nails in tests with the 0.020 and 0.025-inch sheet aluminum. In the 0.032-inch material the heads of the aluminum nails failed by bending or breaking before rupture in the sheet metal occurred. Even with these head failures, the aluminum nails performed remarkably well in comparison to the steel nails. If the aluminum nails had not failed, it is quite probable that their performance in the heavy sheet aluminum may have been better than that of the steel nails.
Influence of nail shank diameters

The Statistical Department was consulted for an analysis of all the data in order to determine if the number of tests run with each type of nail was sufficient for reliable results. In making this analysis, a correction factor was introduced for the different shank diameters of the respective nails. The objective was to judge all the nails on the basis of having equal diameter shanks. The analysis showed that only about one-eighth of the difference in the performance of the nails could be attributed to the difference in shank diameters. This was considered as very small and hence was not investigated any further.

Comparison of nail point types

All of the nails tested, with the exception of 2111, had diamond points which pierced a square hole when the nail was driven through the sheet aluminum. Some of the points had long tapers while others were somewhat shorter. The type of hole punctured by each was very much the same.

Several minor studies were made to determine if there is any correlation between the hole initially punctured by the nail point and the final shape of the rupture by the nail head. To make these studies any diamond pointed nail was driven through a test square of sheet aluminum. Then before subjecting it to the rupture test, a study was made
of the initial hole. In an effort to establish some correlation, a pencil was used to mark the predicted manner in which the test square would rupture. The prediction lines were an extension of the four incisions made by the nail point.

This method of predicting the rupture patterns was surprisingly accurate in the 0.020 and the 0.025-inch sheet aluminum. It did not work so well in the 0.032-inch sheets because the initial hole was usually not so well defined. The rupture lines were also more jagged because the 0.032-inch material was hard and had a tendency to break more readily than to tear.

Some photomicrographs were made to get a better concept of the original nature of the hole. These are shown in Figures 26 through 28. Since the pictures were taken from directly above the test square, they do not show the characteristics of the punctured hole very well. In general, however, the edges around the holes are bent back far enough to show the incisions made by the nail points. The holes on the left were made with the diamond point on nail 2312 while those on the right were made with the conical point on nail 2111.

The pictures show that the conical point does not pierce the metal, but instead it acts as a punch. The punched-out sections are still attached to the edges of the ruptured sheet metal. The holes resulting from the conical
Fig. 26. Nail point puncture patterns resulting from nails 2312 and 2111 in 0.020-inch sheet aluminum (x6.5D)

Fig. 27. Nail point puncture patterns resulting from nails 2312 and 2111 in 0.025-inch sheet aluminum (x6.5D)
Fig. 28. Nail point puncture patterns resulting from nails 2312 and 2111 in 0.032-inch sheet aluminum (x6.5D)

Fig. 29. The wedge synthetic washer after being subjected to a compressive force of 325 pounds (x6.5D)
point of nail 2114 were round and did not have any particular pattern. The holes which resulted from the diamond point of nail 2312 were initially square, but the nail shank changed them to a circular shape.

**Wedge synthetic washers**

The nails to which the wedge synthetic washers were applied are 1734, 1738, 2733, and 2738. These nails performed better with the 0.025 and 0.032-inch sheet aluminum than they did with the 0.020-inch material. The slope of the performance lines in Figure 32 is greater for the interval between the heavier sheets. Three of the nails, 1734, 1738, and 2738, were consistent in their performances relative to each other. The rupture resistances among these varied only 11 pounds for the 0.020-inch material, 17 pounds for the 0.025-inch material, and 20 pounds for the 0.032-inch material.

Nail 2733 showed faster improvement as the thickness of the test materials was increased. Consequently, its performance line is somewhat divergent from the others. Investigation of this nail shows that it was made of steel and had the smallest diameter shank of all the nails tested with wedge synthetic washers. Since the nail was made of steel, there was no tendency of the head to bend or break before rupture occurred in the sheet metal. These characteristics undoubtedly had some influence on the performance of the
FIG. 30. RUPTURE RESISTANCE OF SPECIFIED THICKNESSES OF FLAT SHEET ALUMINUM WITH INDICATED NAILS.
FIG. 31. RUPTURE RESISTANCE OF SPECIFIED THICKNESSES OF FLAT SHEET ALUMINUM WITH INDICATED NAILS.
FIG. 32. POUNDS RUPTURE RESISTANCE OF SPECIFIED THICKNESS OF FLAT SHEET ALUMINUM WITH INDICATED NAILS.
nail. Figure 35 shows a picture of this nail being pulled through 0.025-inch sheet aluminum.

The wedge synthetic washers in general seemed to have had more influence on the rupture resistances than the characteristics of the individual nails. The washers were rather hard and non-resilient. In the tests with the 0.020-inch sheet metal, they were never compressed enough to lose their wedge shape, but instead they ruptured the sheet material with ease. As the 0.025-inch sheet aluminum was tested, the washers were compressed considerably and their original wedge shape was less effective. Compression of the washer set up tensile forces which, if great enough, caused the washer to fail at its outer perimeter. In tests with the 0.032-inch sheet aluminum, the wedge shape was still less effective. The compression of the washer was considerably greater and the tensile failure around the outer perimeter was much more evident. A good example of how the washers failed is shown in Figure 29. Figure 35 shows the wedge washer on nail 2733 in the process of rupturing a 0.025-inch aluminum test square.

The failure of the wedge synthetic washer helps to explain the performance of the nails on which it was used. If the nail punctured a small hole in the sheet, the wedge shape of the washer was initially less effective. Thus the washer had to be compressed more before rupture in the sheet started. The more the washer was compressed, the greater
FIG. 33. POUNDS RUPTURE RESISTANCE OF SPECIFIED THICKNESS OF FLAT SHEET ALUMINUM WITH INDICATED NAILS.
Fig. 34. Nail 2743 being tested with 0.025-inch sheet aluminum. Pictures are successive.

Fig. 35. Nail 2733 being tested with 0.025-inch sheet aluminum.
was the extent to which it failed. The greater the extent of failure, the less effective was the wedge shape and the greater was the pull required to induce rupture.

**Flat synthetic washers**

The flat synthetic washers in general proved to be far superior to any other type of washer that was used. The nails to which these washers were applied are 1744, 1748, 2743, and 2748. These nails as a group were superior to all the others tested with the exception that nail 2733 performed equally well in tests with the 0.032-inch material. Figure 32 shows their relative performances.

Nail 1744 proved best in the tests with 0.020-inch material. It was made of aluminum and had the second smallest diameter shank of this particular group. It ranked first together with nail 2743 in the tests with the 0.025-inch aluminum but showed a sharp decline in performance with the 0.032-inch material. This decline in the heavy material can be attributed to the fact that the nail head failed by bending or breaking. Figure 25 shows the manner in which the nail heads failed.

Nail 1748 was another aluminum nail but it was consistently the poorest nail in this group. Investigation shows that it and nail 2748 had the largest shanks of the nails tested with flat synthetic washers. The slope of its performance line is also somewhat less between the 0.025
and 0.032-inch thicknesses of sheet metal. This can be attributed to failure of the head as is shown in Figure 25.

Nail 27\#3 is the only nail of all the nails tested whose performance line has a constant slope throughout, thus indicating that it performed equally well for all three thicknesses of flat sheet aluminum.

The nail with the smallest shank in this group was 27\#3. It did not perform the best in the 0.020-inch material but it shared first place with nail 17\#4 in the 0.025-inch material. In tests with the 0.032-inch aluminum it was the best nail. Although its performance line has a slightly smaller slope between the 0.025 and 0.032-inch material, the nail head cannot be criticized for this fact.

The flat synthetic washer was very resilient and able to resist the tensile forces which resulted when it was subjected to compression. Since the washer was somewhat larger in diameter than the nail head, it prevented direct contact between the nail head and the sheet metal. The washer remained intact after tests with the 0.020 and the 0.025-inch material. Figure 34 shows two successive pictures of nail 27\#3 in the process of rupturing a 0.025-inch test square. The resiliency and cushioning effect of the washer are well illustrated.

In tests with the 0.032-inch sheet aluminum the washer was often damaged by the shearing forces between the sheet
metal and the nail head. In case of partial head failure, the washer was generally pulled apart as the remaining portion of the nail head pulled through the test sheet. Figure 25 shows the condition of the washers after tests with some 0.032-inch material.

**Lead washers**

Only two of the nails tested, 2525 and 2626, had lead washers. The head characteristics of both nails were very similar, but one nail had a screw shank while the other had a ring shank. The type of shank was of little importance because both nails had diamond points which punctures square holes in the sheet metal. The nature of these holes was changed only slightly by the shanks of the respective nails. The ring shank on nail 2626 rounded the original hole somewhat while the screw shank on nail 2525 did not alter the hole at all.

Above the ring and screw shank sections of these nails, the shanks were enlarged for a very short distance. The lead washer under the nail head extended down to this enlarged section on the shank. The purpose of this lead projection was to establish a seal between the nail shank and the metal sheet. These nails may have desirable characteristics as far as sealing qualities are concerned, but they are not very effective in preventing rupture of the sheet metal which they are supposed to hold.
The pull required to rupture the sheet aluminum with nails having lead washers was approximately the same as for nails 1214, 2418, 2217, and 2317. Figure 33 shows the respective rupture resistances in the form of a line graph. When nails 2525 and 2626 were compared to other nails having large diameter heads and synthetic washers, the nails with the lead washers in general were inferior. The only favorable comparison which could be made existed with the nails having wedge shaped synthetic washers in the tests with the 0.020-inch sheet aluminum. The nails with wedge synthetic washers had a rupture resistance which ranged between 101 and 120 pounds while that of the nails with lead washers ranged between 105 and 113 pounds. Both the wedge and the flat synthetic washers were superior to the lead washer for all other tests with the exception that nail 2626 had a rupture resistance which was three pounds greater in the 0.025-inch material than the rupture resistance of nail 2738.

**Lead encased heads**

Six nails with lead encased heads were tested. One was made of aluminum and the other five of steel. Their code numbers are 1214, 2111, 2312, 2418, 2217, and 2317. Nails 2111 and 2312 proved to be superior to the other four nails. The performances of nails 1214, 2418, 2217, and 2317 were rather consistent for all of the thicknesses of sheet
aluminum tested. The rupture resistances of this group varied only ten pounds in the 0.020 and 0.025-inch material and 11 pounds in the 0.032-inch material. The graphs in Figures 31 and 33 show this information very well. None of the nails was consistently superior for all thicknesses of material. Since the rupture resistance variations were so small, the nails could not be ranked according to performance. Instead each individual nail in the group was considered to be equally good.

Nail 2111 proved to be definitely superior to any other nail with a lead encased head. It was unique in that it was the only nail with a conical point. It had the smallest bare head as well as the smallest diameter shank. The small diameter shank may have been an asset, but the small head probably offset the initial advantage of the small shank.

The lead heads on all of the nails sheared off before rupture of the sheet metal occurred. This indicates that the bell head on nail 2111 was not responsible for its superior performance. From all available evidence, the conical point was the factor which made nail 2111 superior to the other nails with lead encased heads.

Nail 2312 was inferior to nail 2111 but superior to nails 1214, 2418, 2217, and 2317. In appearance nail 2312 was almost identical to nail 1214. The two respective code numbers indicate that the former was made of steel while the latter was made of aluminum. A further comparison shows
that the steel nail had the larger bare-head diameter and the smaller shank. These characteristics of nail 2312 must be credited with its superior performance.

The fact that one nail was aluminum and the other steel did not influence the rupture resistance because in either case the nail head was strong enough to rupture the sheet metal before damage occurred to the head itself.

A comparison with nail 2111 shows that nail 2312 had the larger bare head and shank. But as far as rupture resistance is concerned, these two characteristics have a tendency to eliminate each other. The characteristics of the original hole punctured by the nail point seem to have influenced the rupture resistance more than the respective diameters of the head and shank.

All nails having lead encased heads seemed to rupture the sheet metal in a similar manner. As the pull was applied to the nail, all of the lead extending beyond the perimeter of the bare nail head sheared off. The lead under the nail head formed a cone which acted as a wedge and caused the sheet metal to rupture sooner than it would have if the head had not been encased.

A study of Figures 32 and 33 shows that most nails with lead washers or lead encased heads performed similarly to the nails with wedge synthetic washers. This indicates that the lead wedges were also less effective in the thicker sheet materials.
Rupture Patterns - Corrugated Sheet Aluminum

The rupture patterns in the 0.019-inch sheet aluminum with 1.26-inch corrugations were not consistent for any particular nail. The hardness of the material could not be determined since the sheets were too thin after the necessary processing. The configurations of the lines along which the metal ruptured were similar to those which resulted in the 0.032-inch flat sheets. This does not indicate that this material was treated to a full hard temper because the corrugations undoubtedly had some effect on the rupture patterns which resulted.

The nails to which flat synthetic washers had been applied occasionally produced a rather unusual rupture in the corrugated sheets. The tests were conducted as usual, but the corrugation through which the nail was driven flattened out completely before the sheet ruptured. In such a case the resistance to rupture was much greater because the initial corrugation was no longer effective and the synthetic washer became more efficient on the flat surface. After enough pressure was applied, the sheet would fail by splitting perpendicularly to the corrugations for about an inch on either side of the nail.

The directions in which rupture would occur in the corrugated sheets could not be predicted as was the case with the 0.020 and 0.025-inch flat sheets. However, the final
riiptur© in most cases was still influenced by the original incisions made by the four corners of the nail point. The lines along which the rupture occurred were ordinarily not straight but curved in almost any direction.

The corrugations in the sheet influenced the rupture pattern because the pressure applied by the nail head was more along the length of the corrugation than perpendicular to it. However, if the corrugation flattened out, as it did in some cases, the pressure of the nail head was equally distributed.

Nail Head Performance with Corrugated Sheets

The resistance to rupture of the various nail heads was much smaller in the corrugated sheets than it was in the flat sheets which had approximately the same thickness. Figure 36 shows the difference in rupture resistance which resulted for the respective nails. A true comparison, however, cannot be made because the sheet materials were not tested under the same conditions. The alloys for the sheets were not the same and the flat sheets were rolled 0.001 of an inch thicker than the corrugated sheets. Because of these differences, Figure 36 cannot be used to compare the performance of the two sheet materials. Instead it shows a comparison of performance for the respective nails in each thickness of material.
FIG. 36. RUPTURE RESISTANCE OF SPECIFIED SHEET ALUMINUM WITH INDICATED NAILS.
The author is not completely satisfied that the results obtained from the tests with the corrugated sheets are conclusive. Original plans were to run tests with at least two thicknesses of corrugated materials. The 0.025-inch aluminum sheets with the 1.26-inch corrugations, however, never became available so those tests were not run. If a study is made of the collected data in the Appendix, the range of rupture resistance for most nails can be seen to be quite great. Before any definite conclusions can be reached, the tests with the 0.025-inch corrugated material should be run and an analysis should be made by the Statistical Department to determine if sufficient data have been collected. A preliminary analysis of the collected data indicates the results which are stated in the following paragraphs.

Wedge synthetic washers

Nails 1734, 1738, 2733, and 2738 were supplied with wedge synthetic washers as their code numbers indicate. These nails as a group showed the smallest resistance to rupture of all the nails tested with corrugated material. The steel nails, 2733 and 2738, performed the best regardless of the nail characteristics. Their average resistance to rupture was 74 pounds while that of the aluminum nails varied between 68 and 69 pounds.
Flat synthetic washers

The test results of the nails with flat synthetic washers showed some correlation between the characteristics of the nail and its resistance to induce rupture. Nail 1744 performed the best and was followed by nail 2743. Each had a comparatively small shank. Nails 1748 and 2748 had large shanks and showed a smaller resistance to rupture.

Lead washers

Nails 2525 and 2626 were consistently better than the nails with wedge synthetic washers. This consistent superiority indicates that the characteristics of the individual nails were not responsible for the better performances but instead the washers which were used with the respective nails. The lead wedges resulting from the lead washers were not as effective in inducing rupture as were the wedge synthetic washers.

Lead encased heads

Nails 2111 and 2312, which were the best in the flat sheet aluminum, were also the best in tests with the corrugated material. The aluminum nail 1214, which ranked third in tests with the 0.020-inch flat sheets, was the poorest nail with a lead encased head in tests with the corrugated sheet metal. The remaining nails with lead encased heads...
performed equally well relative to each other as they did in the flat sheet aluminum.
DISCUSSION

Suggestions for Improving the Aluminum Nail

In tests with the 0.032-inch sheets, the large aluminum nail heads proved to be too weak. The head failures would have been even more evident if the nails had been used as they are sold on the market. For the rupture tests, the large diameter aluminum nail heads were reduced in size by amounts varying from 0.061 to 0.080 of an inch. Several tests were run with nails on which the head size had not been reduced. Almost invariably the complete head sheared from the nail shank. This weakness of the head is also obvious when a person attempts to withdraw a deformed shank nail from a girt. The tests further indicated that a conical point would give the aluminum nails a greater resistance to rupture. (See pages 57-62).

Limitations of Tests

Simulation of wind action

The tests were not an exact simulation of wind action on a sheet metal roof. Under actual conditions the sheet metal is subjected to tensile as well as vertical shearing stresses. The tensile forces were not considered because they could not be worked into the test procedure without
Increasing the complexity of the problem considerably. The
tensile forces may be significant in that they may cause
the nail holes in the sheet metal to elongate and thus make
the sheet metal more subject to rupture by the nail head.

**Conditions of lead encasings**

The lead encasings on the nails having lead encased
heads were in excellent condition when the rupture tests
were conducted. The only deformation in the lead head
occurred when the nail was driven through the sheet aluminum.
If the nail were used to actually fasten sheet metal, the
lead head would be deformed considerably more as a result
of the nail being driven into the girt. Hence there is a
possibility that the lead encased heads would perform some-
what differently on an actual roof.

**Alloys and Tempers of Test Materials**

All of the tests run in this project were originally
planned with one alloy and one temper of sheet aluminum.
If these plans could have been followed, the test results
would have shown the effectiveness of each thickness of
sheet aluminum. Thereafter determinations could have been
made to see which thickness of sheet material was the best
to use relative to its thickness.

Since the sheet aluminum could not be secured in one
alloy and one temper, the tests were run with materials secured locally. The most effective thickness or temper cannot be determined from the tests run because both the alloys and the tempers changed for each thickness of aluminum which was used. (See page 47.)

Suggestions for Further Study

Sheet steel

Tests similar to those which were run with the flat sheet aluminum could be run with flat sheet steel. By using various gages of sheet steel with the most common temper, the most effective thickness for farm use could be determined. If the temper proved to be an important factor, tests could be run with one thickness of sheet steel with various tempers to determine which is best. Similar tests could be run with sheet steel having 1.26 and 2.66-inch corrugations.

Sheet aluminum

Further tests could be run with 1.26 and 2.66-inch corrugated sheet aluminum. If the problem of thickness and tempers becomes important, the tests with the flat sheets could be repeated; first, with only one temper and various thicknesses of material and second, with only one thickness of material and various tempers.
Nails rejected

A study could be made of the nails which were rejected for these tests. Even if the head characteristics are not comparable, the nails could be tested and the performance of one nail could be compared to that of another. (See pages 34-36.)

Nail points

The diamond and conical nail points deserve further study. The conical nail point seems to have very definite possibilities as far as increasing rupture resistance qualities of the nail. All tests which have been conducted show the conical point to be superior. None of the tests, however, were based on a statistical analysis of the problem. (See pages 59-62.)

Lateral resistance to rupture of sheet metals

A series of tests could be conducted to determine the lateral resistance to rupture of both sheet aluminum and sheet steel by various types of nail shanks. Some correlation may be established between the lateral resistance to rupture of the sheet metals and the lateral stresses caused by certain wind velocities.
SUMMARY

1. The problem was selected and considered important enough to merit an investigation.

2. Several field trips were made to determine the extent to which the problem existed on the farm.

3. A review of literature concerning the problem was made.

4. The study was justified by the existence of the problem and by the losses which are annually inflicted by wind damage.

5. The objectives of the problem were set forth.

6. The testing mechanism was selected and tested for accuracy of measurement.

7. Preliminary tests were run to determine the conditions and procedures to be used in the standard tests.

8. The nails were selected and the large diameter heads were cut down to a standard size.

9. The flat and synthetic washers were applied to the respective test nails.

10. A statistical analysis was made of the problem to determine the number of tests necessary with each nail for each thickness of material.

11. The test materials were secured locally since the desired sheet aluminum could not be obtained from the manufacturers.
12. A test strip from each type of sheet aluminum was sent to the Aluminum Company of America for an analysis of the alloy and its temper.

13. Samples of the neoprene washers were sent to the nail and synthetic washer producers for proper identification.

14. Tests were run with all three thicknesses of flat sheet aluminum.

15. Tests were run with only one thickness of corrugated sheet aluminum.

16. An analysis was made of the collected data.
CONCLUSIONS

1. The flat synthetic washers proved to be the best of all the 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 the type of sheet aluminum which was tested.

2. Nails with flat synthetic washers were from 25 to 32 percent better in tests with the 0.020-inch sheet aluminum than was the best nail with a wedge synthetic washer. The nails with flat synthetic washers were from 14 to 22 percent better in tests with the 0.025-inch sheet aluminum.

3. No true comparison of performance between the nails with flat synthetic washers and with wedge synthetic washers can be made in tests with the 0.032-inch sheet aluminum because the wedge washers failed before rupture occurred.

4. The nails with wedge synthetic washers performed equally well with nails having lead encased heads or lead washers in the 0.020-inch flat sheet aluminum. Nail 2111 was an exception to the above statement since it performed 13 percent better than the next best nail with a lead encased head, 14 percent better than the best nail with a wedge synthetic washer, and 21 percent better than the best nail with a lead washer.
5. The conical point on nail 2111 must be credited with the superior performance of that nail.

6. The characteristics of the lead encased heads, the lead washers, or the synthetic washers have more influence on resistance to rupture than do the characteristics of the individual nails.

7. 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.

8. Lead from the lead washers and the lead encased heads, as well as the synthetic material of the wedge shaped washers, acted as a wedge under the nail head and aided the nail to induce rupture.

9. The size of lead head or lead washer on a nail has no effect on the rupture resistance qualities of the nail since the lead head or washer will shear off before rupture occurs.

10. The wedge synthetic washer used in these tests is generally unsatisfactory on a roofing nail because of its shape and aging properties.

11. The large bare heads of the steel nails were superior in strength to the large bare heads of the aluminum nails. The steel and aluminum nails with small encased heads performed equally well as far as the respective metals are concerned.

12. If the nail heads do not fall, the size of rupture
resulting in the sheet aluminum is much greater for the nails having flat synthetic washers than it is for any other washer and nail head combination.

13. The Al clad X168 alloy of the corrugated sheet aluminum was much less resistant to rupture than was the 28-H18 alloy of the flat sheet aluminum.

14. 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.

15. 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.
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ACKNOWLEDGMENTS

The author wishes to express his most sincere appreciation to Professor Henry Giese of the Iowa State College Agricultural Engineering Department for his helpful suggestions and constructive criticisms of the project.

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APPENDIX
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**Rupture Resistance Data**

**Flat Sheets**

- Indicates material thickness.
- Indicates sum total of individual nails.

A | Indicates a sheet thickness of 0.020 inches.
B | Indicates a sheet thickness of 0.025 inches.
C | Indicates a sheet thickness of 0.030 inches.
### Rupture Resistance Data

(1.26-in. corrugated sheets - 0.019 in. thick)

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