THE EFFECT OF MOISTURE CONTENT OF WOOD ON WITHDRAWAL RESISTANCE OF ROOFING NAILS

by

Landis L. Boyd

A Thesis Submitted to the Graduate Faculty
for the Degree of

MASTER OF SCIENCE

Major Subject: Agricultural Engineering
(Farm Structures)

Approved:

Henry Giese (signed)
In Charge of Major Work

Hobart Beresford (signed)
Head of Major Department

R. M. Hixon (signed)
Dean of Graduate College

Iowa State College
1948

TABLE OF CONTENTS

Page

LIST OF FIGURES

Figure | Page

LIST OF TABLES

INTRODUCTION

The Project

History

Project 1011, entitled "The Utilization of Aluminum and Aluminum Products in Farm B u ildings and Equipment", was iriginaged at the Iowa Agricultural Experiment Station on March 1, 1947. It was made possible as a result of a grant in aid by the Aluminum Company of America for a three year program to further research in the field of Farm Structures.

Purpose

This project, as the title suggests, was set up for the purpose of determining, through research, those uses for which aluminum might be suitable in farm buildings and equipment. The major outlet for aluminum in farm buildings use at the time the project originated was its use as roofing sheet. Many lumber dealers stocked aluminum roofing reluctantly and only because galvanized steel was not available. The question seemed to be whether aluminum was merely a substitute, or did it have suitable qualities which would merit its use even if steel again became plentiful.

Certainly if aluminum roofing were to be successful, considerable information was needed in regard to the proper method of application. Could it be applied as steel, or were there precautions which had to be taken? This lack of knowledge of the proper methods of application led to the beginning of one part of the investigations to determine the suitability of aluminum for use in farm structures.

The proper method of application of aluminum roofing involved study of nailing girts and roof deck requirements, end lap requirements, side lap requirements, and nail requirements.

Nail requirements of aluminum were thought to approximate those of steel, but no definite information was available. Nail manufacturers had tried aluminum for making nails, but no information concerning their relative merits as compared with steel nails was available. Possible electrolytic action between steel nails and the aluminum roofing sheet might demand the use of the aluminum nail provided it was suitable.

Since no data on the aluminum nail were available, it was decided to set up a series of tests on nails. Previous investigation on steel nails at the Iowa Station had brought to light several important facts regarding roofing nail withdrawal resistance. This work, which was carried on by Professors Henry Giese and S. Milton Henderson and by Leon LeRoy Reaves, will be covered in the review of literature.

Review of Literature

General

No one knows just how long nails have been in existence, but it is reported in Steel Facts (22) that Biblical reference indicated their use as early as 1100 B.C. It is possible that these nails were made of iron, but nothing definite is known.

The evolution of the nail from the "old" cut nail and hand-forged nail to the present day types of nails is indeed interesting. Hand-forged nails were made in Colonial times primarily during the winter months when little other work could be accomplished. Merchants sold "nail rods" to farmers from which to make the nails, and then bought the nails after they had been produced or took them in trade for other products which the Colonial people needed. Nails, being quite precious in Colonial times, were often hoarded and sometimes used as money. Considerable controversy has arisen over whether the cut nail or the wire nail was first made by machine. Clay (3, page 22) reports:

> The first nail machines on record were constructed in 1790, and made wire nails, probably on account of the ease with which wire could be made and its cheapness. . . . . Though it is a quite general impression that the wire nail is a new invention that is about to replace the "old" cut nail, the fact is that while wire nails were made in 1790, the first cut nail machines only came into use in 1812, ...

However, an article in Steel Facts (22, page 6) states that:

> The first of the cut nail machines was built in 1777 by Jeremiah Wilkinson of Rhode Island. . . . . Wire nails were first manufactured in 1834 by a nail-maker in France. In 1850 the first wire nail machines was built in the United States.

The cut nail was generally considered to be superior to the wire nail, but nevertheless has practically passed out of existence. Burr (1) concluded that the cut nail was superior to the wire nail in tension by approximately 73 per cent. Clay (3, page 22) states:

> The probable reason for growth in popularity of the wire nail is that it is clean, regular in size, looks well, is easily driven, and as a rule, is apparently not so liable to split the wood. For real utility, however, the cut nail seems to be far in advance of the wire nail.

Evinger (7) further substantiates the popularity of the wire nail by his statements and adds that wire nails are considerably cheaper, particularly the smaller sizes.

No doubt the economic factor has been a predominant one in promoting the change from the "old" cut nail to the present day wire nails made of steel, aluminum and monel metal.

Many variables are included in the nails used today. Vogel (29, page 139) says, "Increasing mechanization has made nails more highly specialized, until today more than 1200 species of nails are produced for as many different distinct uses." The types varying from shingle nails to marking nails, include common nails, roofing nails, slating nails, finishing nails, casing nails and many others. Variations within each distinct type include differences in shank, point, surface, and material from which manufactured. Also affecting nail performance are the depth to which they are driven, moisture conditions of the wood used, and many other factors.

<u>Species of wood</u>

Probably the greatest single variable affecting the withdrawal resistance of any nail is the species of the wood into which it is driven. Langlands (12) indicates that the holding power of the wood increases with an increase in density, and that porous timbers generally have greater holding power than non-porous timbers.

The Wood Handbook (28) suggests that the withdrawal resistance of a nail in the direction of its length is closely related to the density or specific gravity of the wood. For nails driven into the side grain of seasoned wood, the equation for the withdrawal force is given as $P= 6900\ G^{2.5}D$, where P represents the ultimate load per lineal inch of penetration; G, the specific gravity based on oven dry weight and volume when oven dry; and D, the diameter of the nail in inches. For Douglas Fir (specific gravity = .51) the equation becomes approximately $P = 1283\ D$.

As a result of the great variation in the wood, it is impossible to get any exact value of the withdrawal resistance of a specific nail. Only comparable values can be obtained and even then moisture conditions within the wood are a contributing factor.

Moisture conditions

Neubrech (24, page 49) states, "The dimensions of wood, regardless of species, are not affected by changes in temperatures." Other references indicate that this is not quite true, but that changes in dimensions due to temperature are quite negligible in comparison with those resulting from variations in moisture content.

The Wood Handbook (28) tells that nails driven into green wood which is later seasoned lose a large percent of their holding power. Evidently this reference is made of plain shank nails since it further denotes that barbed and screw nails will retain a majority of their holding power if driven into green wood which is subsequently dried.

Steel Facts (22) further substantiated statements by the Wood Handbook and adds that nails driven into properly seasoned wood gain in holding power as time passes. This in effect, means an increase in moisture, since Giese and Henderson (10) found that t ime had little effect on withdrawal resistance except as it affected the moisture conditions.

Shank type

Probably the next most important factor aiding or contributing to the withdrawal resistance is the shank of the nail. Certainly the shank is important, because the holding power of the nail in a specific species of wood at an established moisture content is partially dependent upon shank variations.

The holding power of the nail is described by Lammey (11, page 145) as:

> Fibers are bent downward; some are severed and others forced aside. The wood fibers act as a wedge (only those severed act as a true wedge); those forced aside act on the body of the nail in much the same way as a wire or rope looped tightly about a dowel or broom handle and then twisted tightly.

Clay (3) also indicates that wedging is a factor in nail holding power as in friction between the wood and the nail. Langlands (12, page 258) states:

> Attempts have been made throughout the world to improve holding power by increasing the frictional resistance to withdrawal, or substituting (at least in part) mechanical for frictional holding.

Langlands (12) mentioned the process of barbing done overseas and reported that barbed nails, being tested by the United States Forest Products Laboratory, were inferior to plain nails when driven into dry wood and superior if driven into green lumber which was dried before the withdrawals were made. In Australia the special hails used were the twisted (or spiral) and the barbed (or jagged) nails. The spiral nail is similar to the screw nail in America and it is believed that the so-called jagged nails having depressions rather than barbs were like the present day barb nail in America.

The Scientific American (26) reports that a ring shank nail of monel metal outheld the wood screw in a special demonstration for naval architects. The rings were sharp and did not disrupt the wood fibers in driving.

Markwardt and Gahagan (15), after making tests of longitudinally grooved nails, found that there was a resultant increase in withdrawal resistance of approximately 10 per cent. This increase was attributed primarily to an increase in perimeter due to the deformation of the shank in grooving. This nail is not to be confused with the spirally grooved nail which is commonly known as the screw shank nail. After several months had elapsed the longitudinally grooved nail exhibited less resistance to withdrawal than did the plain shank nail. It was noted that the grooved nail had less tendency to split the wood than did the plain shank nail.

Giese (9) says that screw shank nails improve in performance if driven into wet wood which is later dried. He also credits the screw shank nail with small lead with having attained an effectiveness of more than 7 times that of a plain shank nail of equal perimeter. Ring shank nails neither gain nor lose appreciably in withdrawal resistance due to changes in moisture content of the wood. Giese concluded that all nails are probably satisfactory when first driven and that the main advantage of nails with deformed shanks is the fact that they retain most of or improve their resistance to withdrawal after the wood has been subjected to moisture changes.

Point types

Point shapes on nails seem to be highly significant. McHugh (14, page 119) states, "The point of the nail, more than the shank, determines splitting and holding qualities, ..." It is agreed that if the point does or does not cause splitting it is the determining factor, but assuming no splitting it hardly seems logical that the point has a greater effect than does shank type. Nails with sharper and longer taper points tend to give greater holding power, because of less multilation of the fibers. However, more splitting occurs due to the fact that the fibers are merely forced aside and not destroyed. Blunt points shear off and multilate fibers and as a result cause less splitting, but also cause a loss in holding power.

Langlands (12, page 258) states:

> In general, the sharper the point of the nail, the greater the holding power, provided splitting does not occur; but, on the other hand, the sharper the point, the greater the tendency for the wood to split, with consequent loss in holding power.

He indicates that the point of the common nail has about the right degree of sharpness for most woods. If this were not true there would probably be more attempts made to alter it.

The use of beeswax on nail points to prevent splitting of hard woods has been suggested. In addition bending is reduced as is the amount of force required to drive the nail. Apparently over a long period of time there will be no reduction or only aslight reduction in holding power as a result of this practice. Even if some loss is experienced, the gain in reduction of splitting, bending and driving force undoubtedly outweighs the loss in withdrawal resistance.

Prebored holes have been suggested to reduce splitting and are credited by McHugh (14) as giving the best results for the prevention of splitting. Marten (19) indicates that the resistivity of the wood when force is applied parallel to the grain is greater when nails are driven through pre-drilled holes due to the reduction in splitting. However, it seems highly impractical to attempt to prebore the nail holes for the application of roofing.

An article in Steel Facts (22, page 7) makes this statement:

> The type of nail which causes the least distortion in the fibers of the wood will have the greatest holding power. The point of a nail has a direct relation to the amount of distortion produced in the wood fiber, but a nail which produces little distortion produces splitting which is also objectionable. Therefore, for general purposes, a moderately shaped point which causes a minimum amount of both distortion and splitting is ideal.

Clay (3, page 24), who ran several tests on points of both wire nails and cut nails, emphasizes:

> An important point in the shape of nails is the form of its driving end. . . . . From this (his tests) it appears that the pointing of the wire nail increases its holding power by 122%, and even the slight wedging accomplished by having beveled edges increases it by 78%.

He also indicates that the tendency to split the wood is not a detriment, but an advantage as that tendency is actually the holding power.

Marten (19, page 941), after making several tests of nails in Germany, concludes: "It is possible to diminish the splitting action of a nail with special nail shapes (points) and thus improve the resistivity of the hole."

Markwardt and Gahagan (16) made extensive studies of nail points at the Forest Products Laboratory at Madison, Wisconsin. Their investigations included both plain and deformed shank nails to determine the best type of nail point for different conditions. Tests were made immediately and also after time and moisture changes had occurred. Their tests included plain round shank nails with common, cruciform, blunt, blunt-taper and spherical taper points; grooved shank nails with common, cruciform and blunt points; and a cut shank nail with a blunt point.

The results of the Markwardt and Gahagan (16) experiments show that upon immediate withdrawal the greatest withdrawal resistance is obtained with nails having the sharpest points and the least with nails having blunt untapered points. When time and moisture changes took place before withdrawal, the variation followed a like pattern, but the extent of variation was not necessarily of equal magnitude. The Wood Handbook (28), which uses Markwardt and Gahagan (16) along with others as a reference, verifies previous statements relating to the higher withdrawal resistance of nails with long sharp points.

In summarizing the findings of others, it seems that the following statements could be made:

1. Sharp, long tapered points result in greater holding power if no splitting is induced.
2. In woods which split easily use points with less taper and sharpness, thus sacrificing some holding power, but not as much as would be lost if splitting occurred.

Surface

Surface coatings are applied to nails for two widely different reasons. One is to protect the nail from corrosion; the other, to increase its resistance to withdrawal. It has been generally agreed, as of late, that steel nails need some type of coating to protect them from the elements of weather which start and accelerate rusting. The method most commonly used is galvanizing or zinc coating. This process consists of an immersion of the nails in a bath of hot zinc, generally maintained at a temperature of approximately 900° F. They generally remain in the bath of hot zinc from three to five minutes and are then vibrated to remove any excess. This coating of zinc offers excellent protection from rust for steel nails.

Deniston (4) attributes longer service life of some galvanized sheet steel roofs to the use of galvanized nails and recommends that galvanized nails be used in all roofing applications. Carter and Foster (2, page 81) state, "Galvanized or zinc coated nails are recommended for roofing or for structural work subject to moisture." The Wood Handbook (28) asserts that zinc coating is applied to nails for the primary purpose of reducing or preventing corrosion, but an evenly applied coating may increase withdrawal resistance. However, extreme roughening resulting from an uneven application may even impair the withdrawal resistance. It can be seen that the express purpose of a zinc coating is corrosion resistance with any increase in withdrawal resistance, if any, also an asset.

It is not definitely known if aluminum nails require a coating for corrosion resistance. Monel nails do not rust and it may be assumed that they are not in need of a protective coating. Alcoa (The Aluminum Company of America) has tried the "Alrok" treatment on aluminum nails and has found that it results in an increase in withdrawal resistance. It is not known if this was the original objective of the application to nails, but it is believed that the greater resistance to withdrawal was discovered while trying the "Alrok" process for corrosion resistance.

In speaking of the patented "Alrok" treatment Lloyd (13, page 103) relates:

> This chemical dip changes the characteristics of the shank surface of the nail, and in doing so increases the holding power between 200 and 300 per cent. (It is believed that the reference made here is only to plain shank nails.) There are various surface treatments that can be used for Aluminum nails, but the Alrok treatment has been found the best.

In addition to the plain surface and "Alrok" surface, aluminum nails are also manufactured with an etched surface. The etching is done by dipping in an alkaline solution, neutralizing with acid and then rinsing. This process is quite often employed to cleanse the nails and remove the lubricant used in the forming process. Some aluminum nails have been observed which seem to have been shipped prior to and without removing the lubricant. It is expected that this will greatly impair the withdrawal resistance. Other coatings are used to improve the withdrawal resistance of steel nails. Foremost of these is the cement coating process.

Vogel (29, page 142) asserts:

> Cement coated nails (which are not really cement-coated) are made by tumbling nails in a mixture of pitch and resins in solution . . . . The heat caused by driving a coated nail melts the mixture enough to 'glue' the nail to the wood.

Steel Facts (22) supports this theory to the extent that the heat generated in driving fuses the mixture slightly and forms a bond between the wood and the nail, which results in an increased resistance to withdrawal. The increase may be as much as 85 to 100 per cent upon immediate withdrawal, but the increase partially disappears in softer woods after a time, reports the Wood Handbook (28). The softer woods often retain only about one half of the increase resulting from cement-coating after a month's time has elapsed. Langlands (12) asserts that the cement coated nail is widely used in both England and America, and that it is probably the most popular variety having increased holding power.

Markwardt and Gahagan (18) in tests conducted at the Forest Products Laboratory found that variations in the ingredients used in cement coatings resulted in improved withdrawal resistance of from 25 to 125 per cent. Moreover, they found that chemical etching of the nail gave greater resistance to withdrawal than cement coating.

The surface on the chemically etched nail is a pitting which is practically invisible to the naked eye. At least there is not apparent roughening. In tests using lowland white fir, Gahagan and Beglinger (8) show the chemically processed nail superior by 307 per cent to the plain nail as opposed to a superiority of 279 per cent by the cement coated nail. In ponderosa pine the values were respectively 288 per cent and 187 per cent.

The sandblast treatment also shows an increase in holding power as opposed to the plain nail, but it has not received any broad commercial attention. As reported in Steel (21) findings show an increase in withdrawal resistance of from 91 to 207 per cent for nails treated by the sandblast treatment. It is declared that the roughening can be accomplished on the wire before forming of the nail. Also that the nail can be galvanized without destroying the roughened quality. However, it is doubtful if the full benefit of the roughening would be available after galvanizing. Roughening of nail surfaces tends to produce the same effect in nail holding power, regardless of how the roughening is effected.

Blued nails were used in early times, but being very susceptible to rust, they have not become popular. Also the process softened the metal and the nails bent easily resulting in a high percentage of waste.

Heads

It is the function of the head to hold the roofing sheet in place and to seal the nail hole from the passage of moisture. Many variations are used for the purpose of sealing including lead heads, washers, and cup heads in addition to the ordinary large flat heads.

Probably the important factor is that the head be large enough so that it will not pull through the roofing easily, since this would result in damage to the sheet. Whether or not the head should be sufficiently large to withdraw the nail before pulling through the sheet is still a question. Certainly the strength of the head should be important since it is subjected to what is more or less a repeated stress.

While the head is generally considered to contribute very little to withdrawal resistance of the nail, Maze (20) indicates that it is a factor in the case of screw shank nails, because the head should lock the screw in place. The result is that the screw cannot turn in the reverse direction and work out. He states that he does not believe the lead head to be satisfactory, since it becomes loose on the steel head and does not function as a lock to keep the screw shank nail in place.

He advocates the use of the cup or umbrella head to lock the screw in place.

Maze (20), Deniston (4) and others recommend the use of the lead head for sealing the hole in the roofing sheet. Deniston (4), however, believes that the head should be of the washer type so that it will not absorb the blow of the hammer. Perhaps this is true, because in many cases the lead is loosened or knocked from those nails with encased lead heads.

Lead heads may be a party to electrolytic action when used with aluminum roofing. To overcome this, if it does occur, washers have been made, generally from some synthetic product. The washer keeps the nail from touching the roofing and also aids in sealing the hole to restrict the passage of moisture. An article in the Sheet Metal Worker (23, page 67) states: "It is also purported that the give-and-take of the washer tends to keep the nail from pulling out of the wooden members into which it is driven".

Depth of Driving

The depth to which the nail is driven has a definite influence upon the withdrawal resistance. Many people undoubtedly assume that the withdrawal resistance varies directly as the depth to which the nail is driven. Clay (3) gives reference to work at Cornell University by Professor Bevans which indicated that the variation of withdrawal resistance was approximately 1.5d, where "d" is the depth.

Slant driving

Slant driving or driving the nail at an angle other than 90° to the wood's surface has proven to be a means of increasing withdrawal resistance. However, slant driving cannot be used with satisfactory results with roofing, as the roofing is likely to be damaged in driving the nail "home". In addition the head will probably not seal the hole adequately. Markwardt and Gahagan (17) found advantages to slant driving especially if moisture changes took place in the wood before withdrawal. However, difficulties in starting the nails, loss of depth of penetration, destruction and multilation of fibers, and damage to the wood by the hammer was found almost to overshadow the advantages of slant driving. The author believes that slant driving is not practical in the nailing of roofing.

Summary

The species of the wood, the moisture condition of the wood, the shank type, the surface condition, the point type, and the depth to which driven; these and other factors contribute to the performance of the nail. Nails perform differently under varied conditions, and certainly improvements are still to be made. Markwardt and Gahagan (18) state: "Nails are and very likely will continue to be the simplest fastening for wood, and hence their improvement offers inducements toward promoting greater efficiency in wood use."

One problem on which much work could be done is the isolation, if possible, of the causes of nail creep. Giese (9) expresses great concern over this phenomenon, advancing the opinion that the ring shank nail will not creep. In explaining his theory of creep, Giese (9, page 446), after assuming moisture changes in wood to begin at the outside and progress inward, states:

> As the wood near the outside dries, the grip on the nail at that point relaxes while it still remains firm near the point of the nail. This means that as the wood shrinks, the nail is not pulled inward with the shrinking wood. As the wood takes up moisture, however, the grip on the nail is increased near the outside while it is relaxed deeper in the wood. As the wood swells then, the nail tends to follow. Movements are small and considerable time is required to produce a marked movement.

Reaves (25) lists wind action, changes in temperature and changes in moisture content of the wood as causes of creep. Undoubtedly there are others.

Just what nail is the best will probably always be a question for debate. However, Vogel (29) says: "The best nail for the job is the type with greatest holding power that causes the least distortion of the wood fibers.

Justification

Annual roofing losses

Annual roofing losses to farm buildings in Iowa in 1946 were given by Esmay (5) as totaling $73,416. This is a large amount, yet it only represents those losses on which claims were paid by the Iowa Mutual Tornado Insurance Association. The number and value of uninsured losses and those covered by other companies are not known. The total roofing losses due to wind are also given by Esmay (5) and total $44,788. Of this amount, $12,851 (28.7 per cent) was the loss to barns, and $23,277 (52 per cent) was the loss to dwellings. Based on a study of approximately 38 per cent of the 1947 claims, Esmay (6) estimates the 1947 roofing losses to reach $211,000. This is almost three times as great as the 1946 losses and further accentuates the need for better methods of applying roofing.

A portion of this damage was no doubt due to improper and insufficient nailing. The use of plain shank nails, whereas the deformed shank types generally have greater holding power, may have been a factor. It is a known fact that poor construction results in many large losses annually.

Demand on the roofing nail

The use of the metal roof has undoubtedly placed greater demands on the roofing nail. Whereas it takes approximately 30 pounds to pull a roofing nail head through asphalt shingles, it requires approximately 100 pounds to pull the head through 26 gauge (.019" in thickness) corrugated aluminum. The greatest use for metal roofing is the machine shed with many applications making their appearance on barns, hog houses and cribs and granaries. Reasons for the increase in use of metal roofing are its ease of application and the relative scarcity of wood shingles. In addition the wood shingle has become quite expensive.

An excellent example of the maximum pull on roofing nails is the use of machine sheds and stock sheds which are left open on one side. Both suction and direct pressure may result when the wind is in the right direction.

Creeping of nails

With this increase in demand on the roofing nail it is essential to know which nails will perform satisfactorily. In addition the problem of creep again must be overcome if possible. Creep is defined as that movement of the nail due to no apparent reason. It can be witnessed in boxes, in siding, on metal roofs and on asphalt roofs. Certainly creep must be associated with withdrawal resistance. In other words, it seems that a nail having high resistance to withdrawal should not be affected as much by the forces causing creep as one having low resistance to withdrawal.

Many property owners take creep as a matter of fact, and plan an annual excursion to the roof to renail those nails which have crept upward. In addition to being time consuming, continued renailing tends to flatten the corrugations and produce a bulging effect which is unsightly and in extreme cases may result in leakage.

Little advance has been made in the design of nails in general. Probably more has been done with roofing nails than others, but certainly any new development in roofing nails might be used to improve common ordinary nails. It is probably that construction could be improved by changes in the ordinary nail.

Variables affecting withdrawal resistance

A review of previous investigations reveals that the greatest variable in the withdrawal resistance of nails which could not be controlled by man was moisture changes of the wood. It was mentioned that the species of wood was also important, but in times when wood is more plentiful than it is today, it may be selected. Hence, it seems essential to gain more knowledge of the effects of moisture changes. Cyclic changes from high to low to high to determine the loss or gain in withdrawal resistance seem in order.

Under various conditions which might be expected, how do various nail variables such as shank type, variations within shank type, surface condition and point type contribute to or deduct from the withdrawal resistance?

What can be expected of nails driven into wood 1" in thickness as opposed to those driven into wood 2" in thickness? It was stated that the variation of withdrawal resistance with depth was 1.5d. Does this hold true in 1" and 2" lumber; if not what can be expected?

A general overall evaluation of each specific nail is needed so that carpenters, farmers and others may use the nail in the proper way and for the proper purpose so that the performance shown will be a maximum.

Objectives of the Study

The objectives of these investigations are:

1. To define as nearly as possible the variations in withdrawal resistance of roofing nails that are associated with moisture changes of the wood into which they are driven.

2. To define the variations that are associated with shank types.

3. To define the variations that are associated with surface conditions.

4. To define the variations that are associated with point types.

5. To determine the effect of 1" and 2" material on items 1, 2, 3 and 4.

6. To obtain a general overall evaluation of the various types of nails as related to driving, withdrawal, etc.

7. To associate, if possible, withdrawal resistance with creep.

THE INVESTIGATION

Nails Tested

Variations and changes

In beginning the investigation of roofing nails it was necessary to determine the extent of variability within this group of special purpose nails. The best method of approach seemed to be the contacting of several of the prominent nail manufacturers. Those companies which were contacted were asked what they had available and where the types which they couldn't provide might be obtained. Several samples of both roofing nails and common nails were received from the various nail companies all of whom seemed quite willing to cooperate. Many of the nails were shipped gratis.

After all purchases and gratis shipments had arrived, 33 different nails shown in Figure 1 and listed in Table I were available for testing. This group included 8 plain shank nails, 2 barb shank nails, 10 ring shank nails, 2 combination ring and screw shank nails and 11 screw shank nails. Variations in ring shank nails are shown by the longitudinal sections, Figures 2 through 11. Variations in the combination shank and screw shank nails are shown by both longitudinal sections and cross sections, Figures 12 through 37. Actually there was one

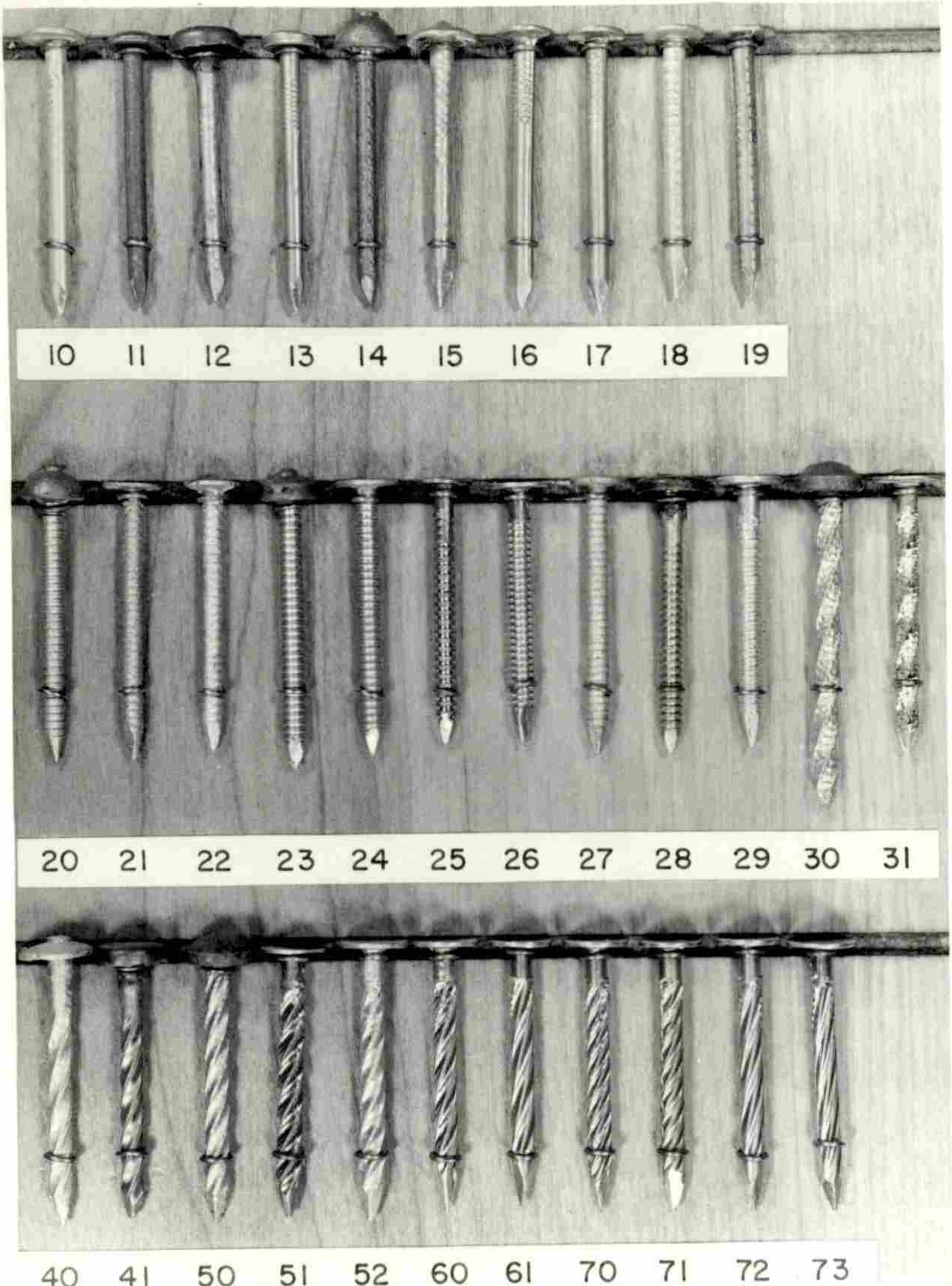

Fig. 1. Roofing nails tested (actual size).

Table I

Roofing Nails and Variations Used in Moisture Content Investigations

I.D. No.	1" No.	2" No.	Shank Type	Shank Dia.	Mat.	Surface Treat.	Point Type	Rgs Thr	Pitch	Lead	Lgth.	Depth Dr.	Head Type
103		10	Plain	0.1342	Al.	Etched	Diamond				1.75	1.42	Com.
104p		33	Plain	0.1342	Al.	Etched	Conical				1.71	1.38	Com.
105s		1	Plain	0.1342	Al.	Alrok	Diamond				1.75	1.42	Com.
115	1	11	Plain	0.1345	Al.	Alrok	Diamond				1.71	1.38	Hood
127		12	Plain	0.1345	St.	Gal.	Diamond				1.65	1.32	L.W.
131	2	13	Plain	0.1350	Al.	Plain	Diamond				1.74	1.41	Hood
147		14	Plain	0.1376	St.	Gal.	Diamond				1.69	1.36	L.B.
157		15	Plain	0.1394	St.	Gal.	Diamond				1.71	1.38	Cup.
161		16	Plain	0.1447	Al.	Plain	Diamond				1.76	1.43	Com.
171		17	Plain	0.1451	Al.	Plain	Diamond				1.76	1.43	Com.
183	3	18	Barb	0.1409	Al.	Etched	Diamond				1.74	1.41	Com.
185s		2	Barb	0.1409	Al.	Alrok	Diamond				1.74	1.41	Com.
191		19	Barb	0.1464	Al.	Plain	Diamond				1.77	1.44	Com.

Continued on the next page

Table I (Cont'd)

I.D. No.	1" No.	2" No.	Shank Type	Shank Dia.	Mat.	Surface Treat.	Point Type	Rgs Thr	Pitch	Lead	Lgth.	Depth Dr.	Head Type
2080		20	Ring	0.1321	St.	Gal.	Conical	20			1.72	1.39	L.B.
2119	4	21	Ring	0.1330	Al.	Plain	Diamond	19			1.75	1.42	Com.
2159[s]		3	Ring	0.1330	Al.	Alrok	Diamond	19			1.75	1.42	Com.
2279		22	Ring	0.1343	St.	Gal.	Diamond	19			1.74	1.41	Com.
2310		23	Ring	0.1429	Al.	Plain	Diamond	20			1.78	1.45	Lead
2410	5	24	Ring	0.1438	Al.	Plain	Diamond	20			1.74	1.41	Com.
2420[p]		34	Ring	0.1438	Al.	Plain	Conical	20			1.74	1.41	Com.
2450[s]		4	Ring	0.1438	Al.	Alrok	Diamond	20			1.74	1.41	Com.
2597		25	Ring	0.1480	Mo.	Plain	Diamond	17			1.69	1.36	Com.
2613	6	26	Ring	0.1510	Al.	Plain	Diamond	23			1.72	1.39	Com.
2623[p]		35	Ring	0.1510	Al.	Plain	Conical	23			1.65	1.32	Com.
2653[s]		5	Ring	0.1510	Al.	Alrok	Diamond	23			1.72	1.39	Com.
2770		27	Ring	0.1513	St.	Gal.	Diamond	20			1.77	1.44	Com.
2870		28	Ring	0.1523	St.	Gal.	Diamond	20			1.70	1.37	L.W.

Continued on the next page

pencilled figures calculated from photomicrographs 5/16/57

Table I (Cont'd)

I.D. No.	1" No.	2" No.	Shank Type	Shank Dia.	Mat.	Surface Treat.	Point Type	Rgs Thr	Pitch	Lead	Lgth.	Depth Dr.	Head Type
2977	7	29	Ring	0.1618	St.	Gal.	Diamond	17			1.74	1.41	Com.
3079	15	30	Comb.	0.1606	St.	Gal.	Diamond	4	0.281	1.12	2.00	1.42	Lead
3177	16	31	Comb.	0.1607	Al.	Plain	Diamond	4	0.250	1.00	1.78	1.45	Com.
3127^p		32	Comb.	0.1607	Al.	Plain	Conical	4	0.250	1.00	1.78	1.45	Com.
3157^s		6	Comb.	0.1607	Al.	Alrok	Diamond	4	0.250	1.00	1.78	1.45	Com.
4076	13	41	Screw	0.1489	St.	Gal.	Diamond	4	0.234	0.94	1.74	1.41	L.W.
4179		40	Screw	0.1560	St.	Gal.	Diamond	4	0.281	1.12	1.70	1.37	Cup
5075		42	Screw	0.1616	St.	Gal.	Diamond	5	0.219	1.10	1.71	1.38	Lead
5115	8	43	Screw	0.1680	Al.	Plain	Diamond	5	0.203	1.02	1.74	1.41	Com.
5125^p		47	Screw	0.1680	Al.	Plain	Conical	5	0.203	1.02	1.74	1.41	Com.
5155^s		7	Screw	0.1680	Al.	Alrok	Diamond	5	0.203	1.02	1.74	1.41	Com.
5275	14	44	Screw	0.1761	St.	Gal.	Diamond	5	0.203	1.02	1.74	1.41	Com.
6015	9	45	Screw	0.1555	Al.	Plain	Diamond	6	0.203	1.22	1.74	1.41	Com.
6055^s		8	Screw	0.1555	Al.	Alrok	Diamond	6	0.203	1.22	1.74	1.41	Com.

Continued on the next page

Table I (Cont'd)

I.D. No.	1" No.	2" No.	Shank Type	Shank Dia.	Mat.	Surface Treat.	Point Type	Rgs Thr	Pitch	Lead	Lgth.	Depth Dr.	Head Type
6100		46	Screw	0.1589	Al.	Plain	Pilot	6	0.312	1.87	1.72	1.39	Com.
7012	10	36	Screw	0.1554	Al.	Plain	Diamond	7	0.141	0.98	1.73	1.40	Com.
7022p		48	Screw	0.1554	Al.	Plain	Conical	7	0.141	0.98	1.71	1.38	Com.
7052s		9	Screw	0.1554	Al.	Alrok	Diamond	7	0.141	0.98	1.73	1.40	Com.
7112	11	37	Screw	0.1568	Al.	Plain	Diamond	7	0.156	1.09	1.72	1.39	Com.
7200		38	Screw	0.1589	Al.	Plain	Pilot	7	0.312	2.19	1.72	1.39	Com.
7310	12	39	Screw	0.1594	Al.	Plain	Diamond	7	0.312	2.19	1.76	1.43	Com.
7350s		49	Screw	0.1594	Al.	Alrok	Diamond	7	0.312	2.19	1.76	1.43	Com.

I.D. No. - Identification number

p - point change of original nail

s - surface change of original nail

1"No. - Randomization number assigned when driven in one inch lumber

2"No. - Randomization number assigned when driven in two inch lumber

Shank Dia. - Shank Diameter

Material - Metal from which the nail is made. Al. - Aluminum, St. - Steel, and Mo. - Monel

Table I (Cont'd)

Surface Treat. - Type of surface on the nail. Gal. - Galvanized

Rgs, Thr - Rings per inch for ring shank nails and the number of threads for screw shank and combination shank nails

Pitch - Distance between threads measured along the axis of the nail

Lead - Advance of the threads in one revolution. Equal to pitch times the number of threads.

Lgth. - Length of nail from base of the head to the tip of the point

Depth Dr. - Depth to which the nail was driven

Head Type:

- Com. - Common flat head
- Hood - Small hood type head
- L.W. - Lead washer head
- L.B. - Encased bell type lead head
- Lead - Ordinary encased lead head
- Cup - Large cup type head

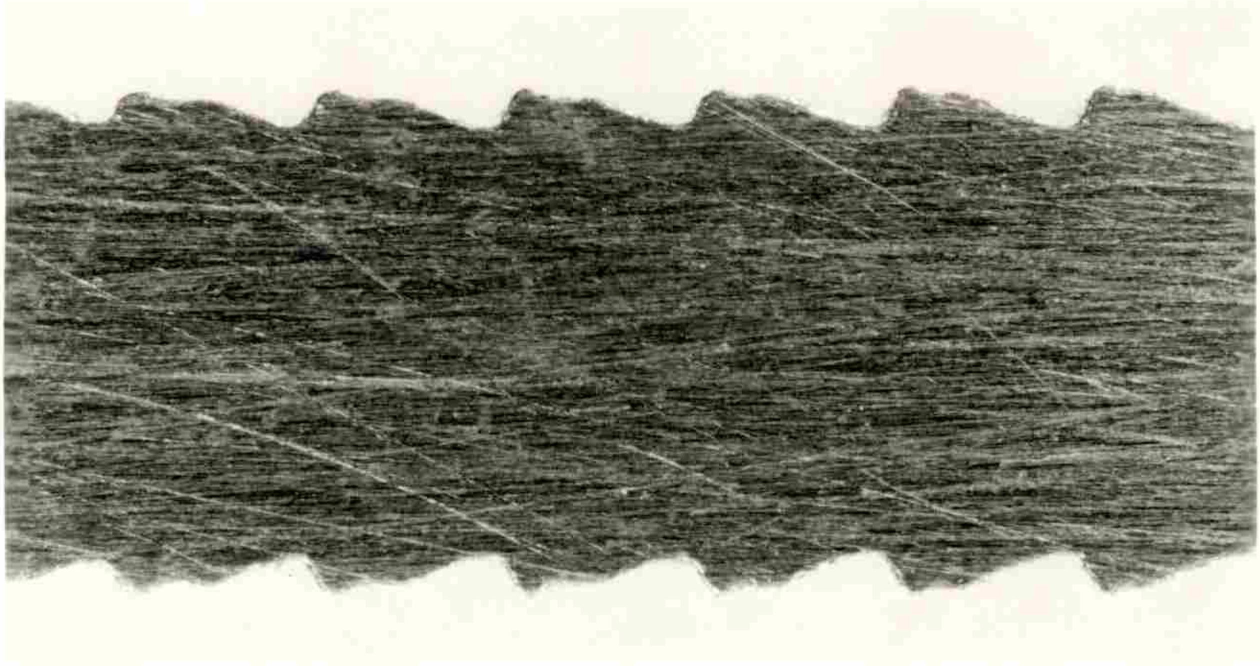

Fig. 2. Longitudinal section of nail No. 2080 (x20d).

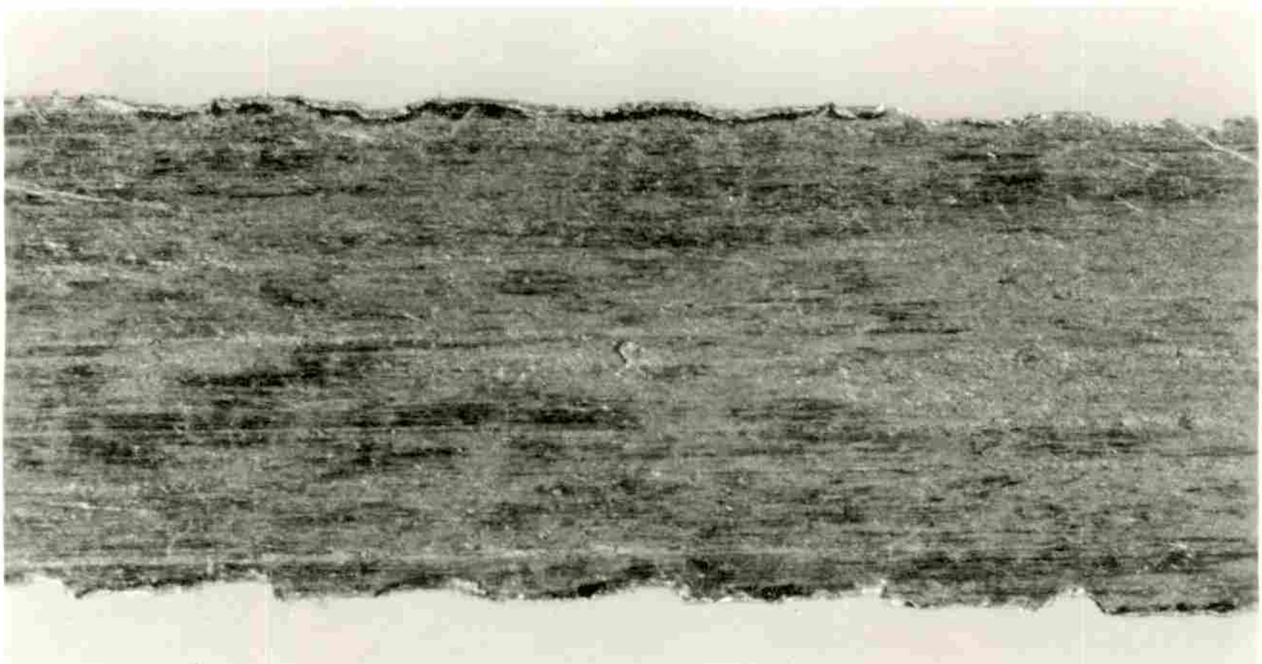

Fig. 3. Longitudinal section of nail No. 2119 (x20d).

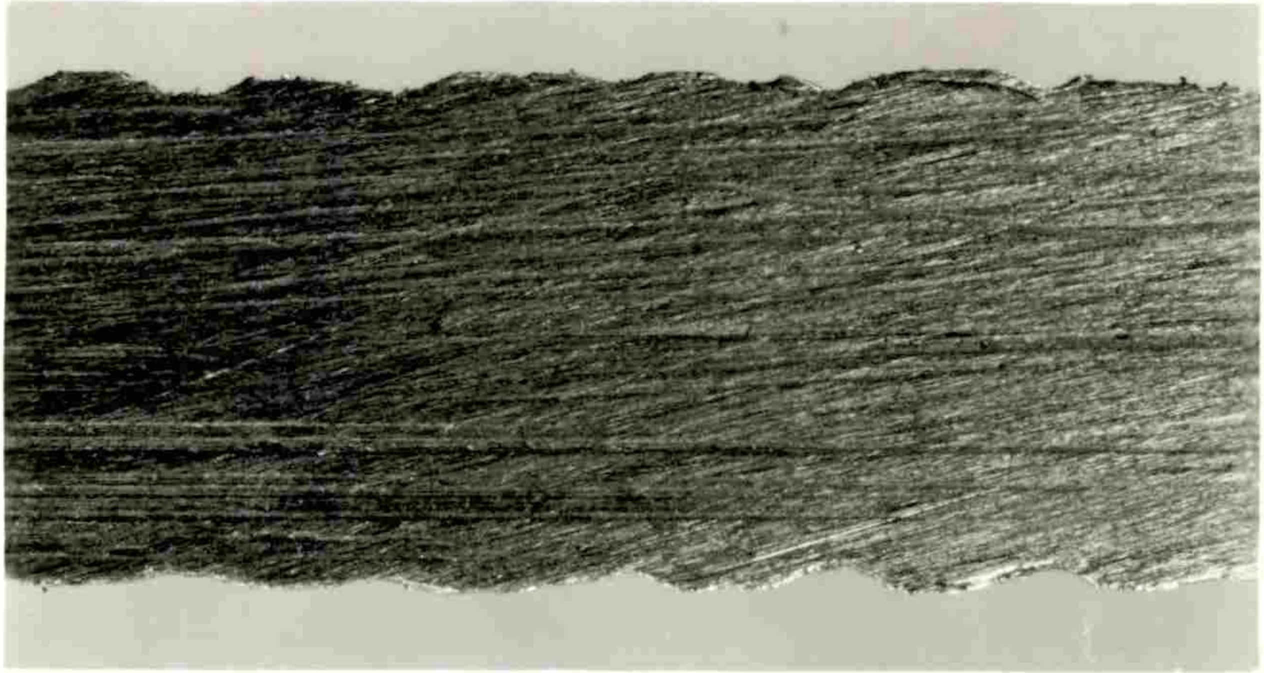

Fig. 4. Longitudinal section of nail No. 2279 (x20d).

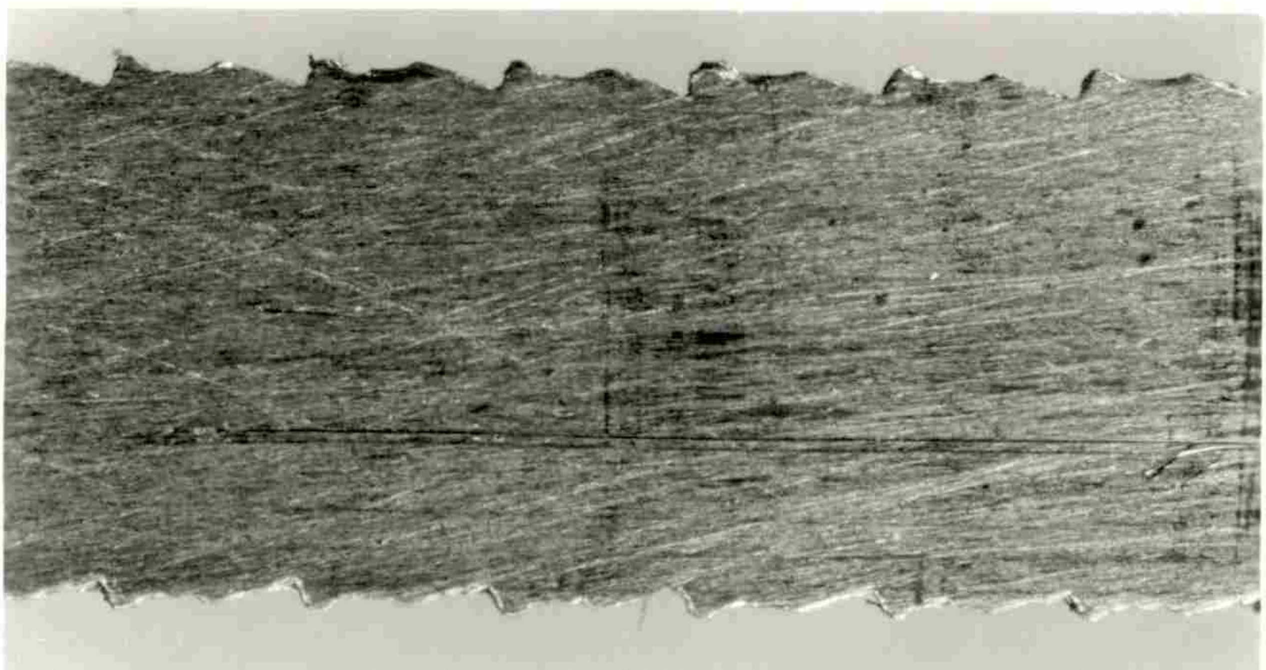

Fig. 5. Longitudinal section of nail No. 2310 (x20d).

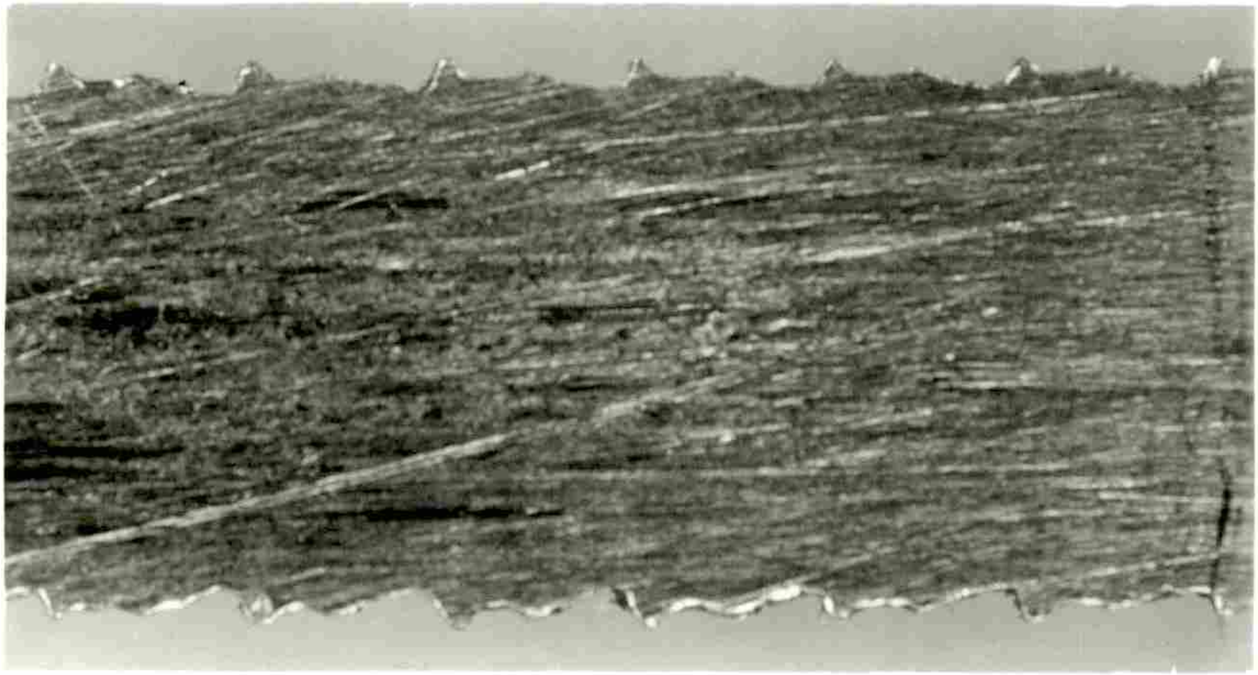

Fig. 6. Longitudinal section of nail No. 2410 (x20d).

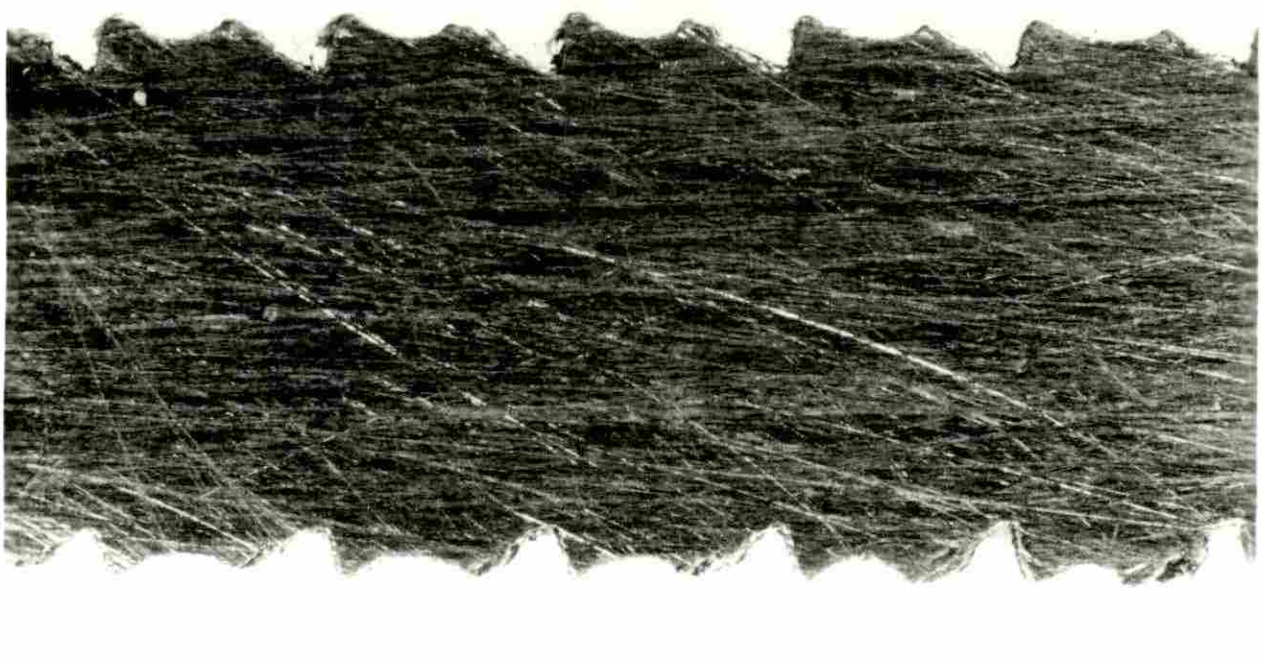

Fig. 7. Longitudinal section of nail No. 2597 (x20d).

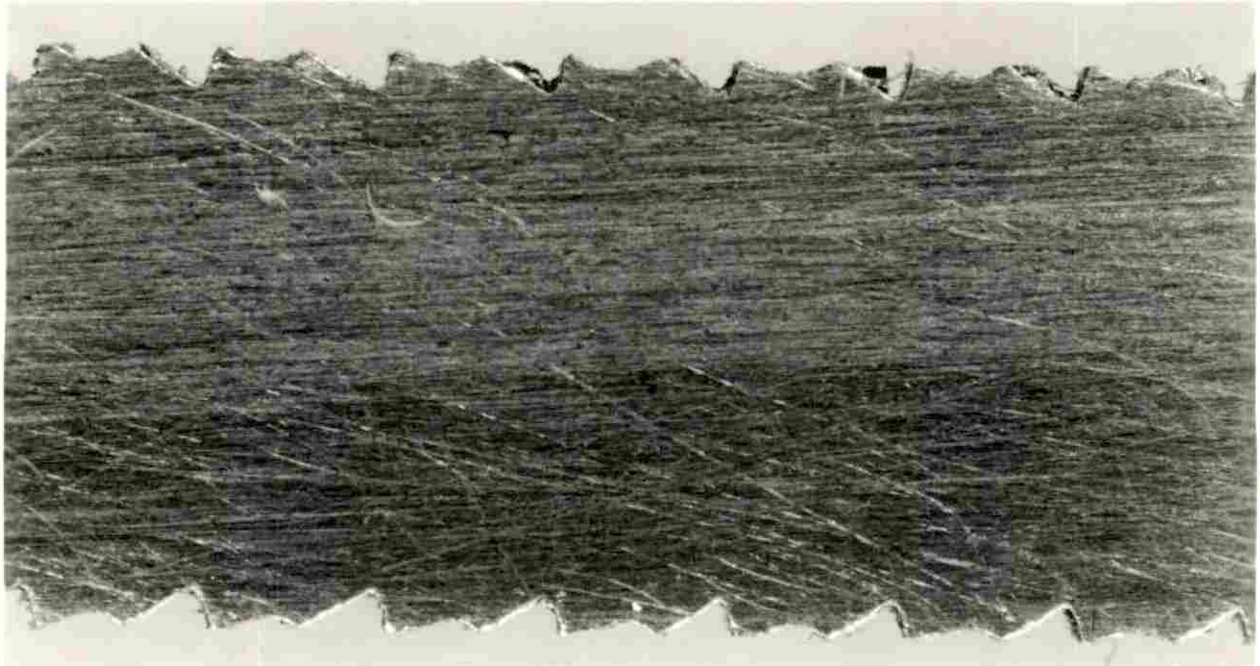

Fig. 8. Longitudinal section of nail No. 2613 (x20d).

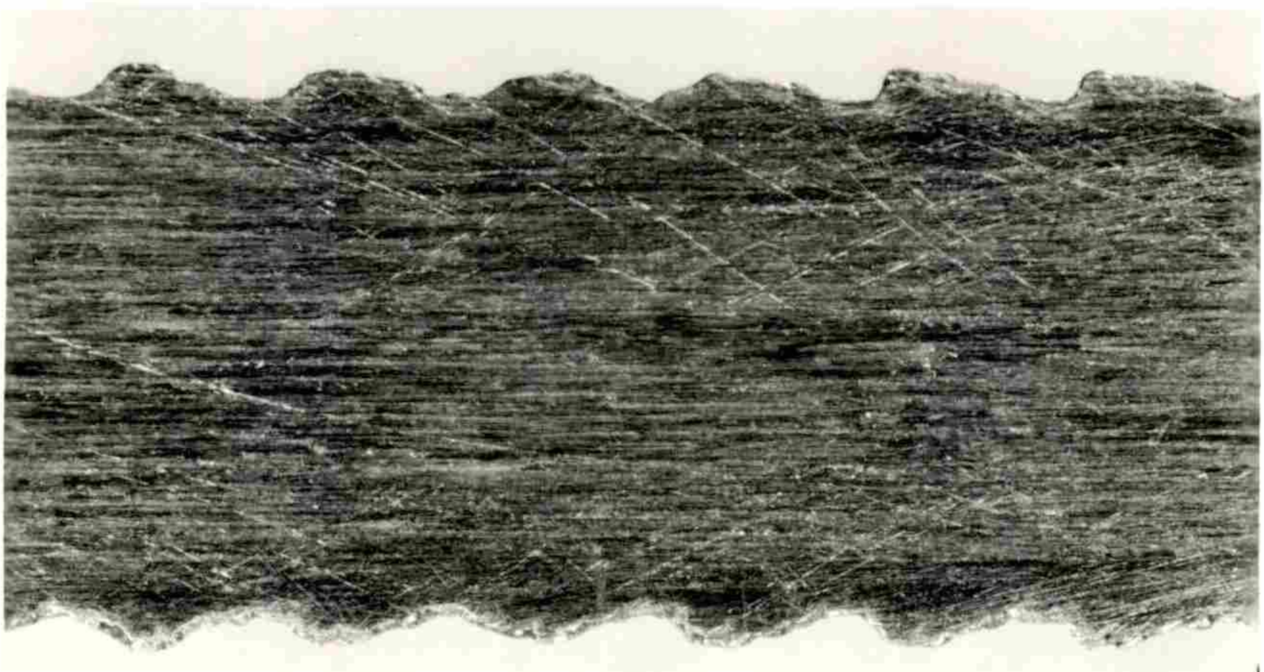

Fig. 9. Longitudinal section of nail No. 2770 (x20d).

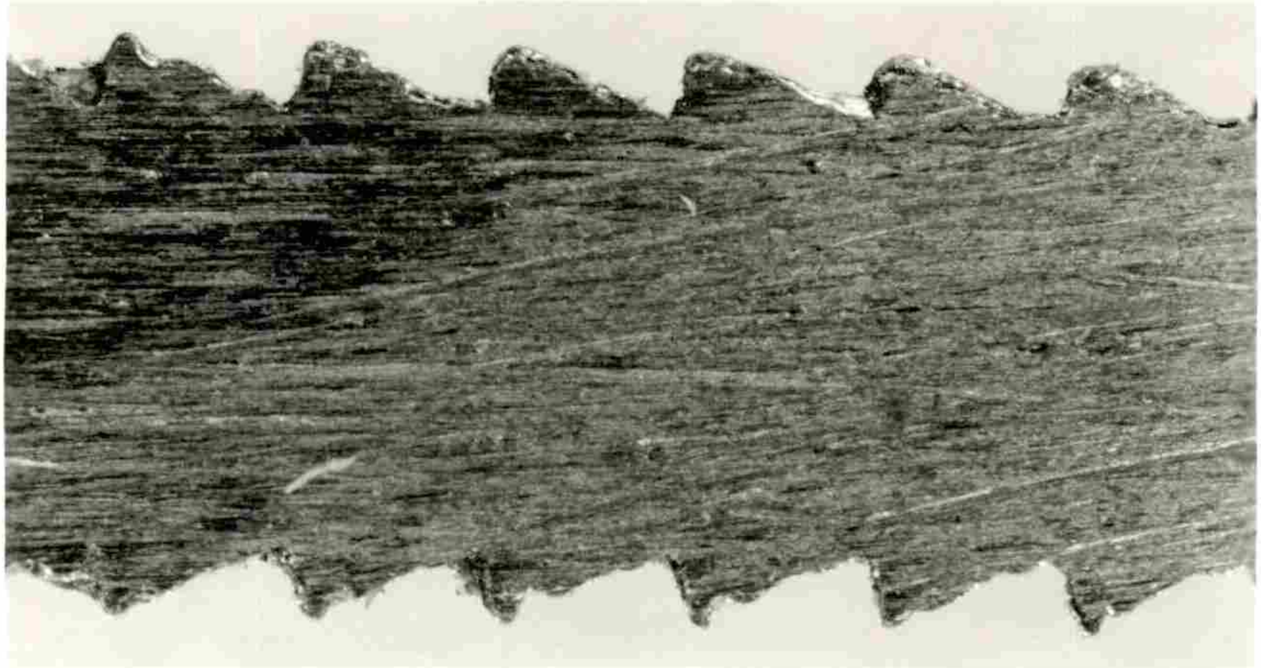

Fig. 10. Longitudinal section of nail No. 2870 (x20d).

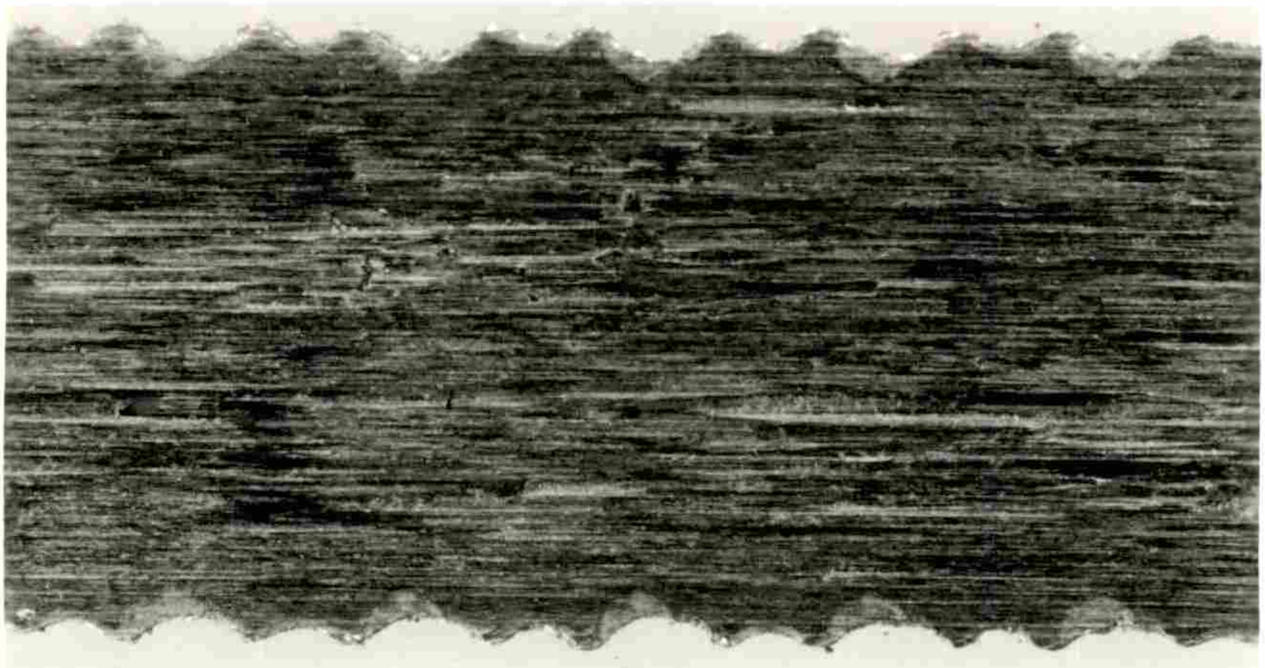

Fig. 11. Longitudinal section of nail No. 2977 (x20d).

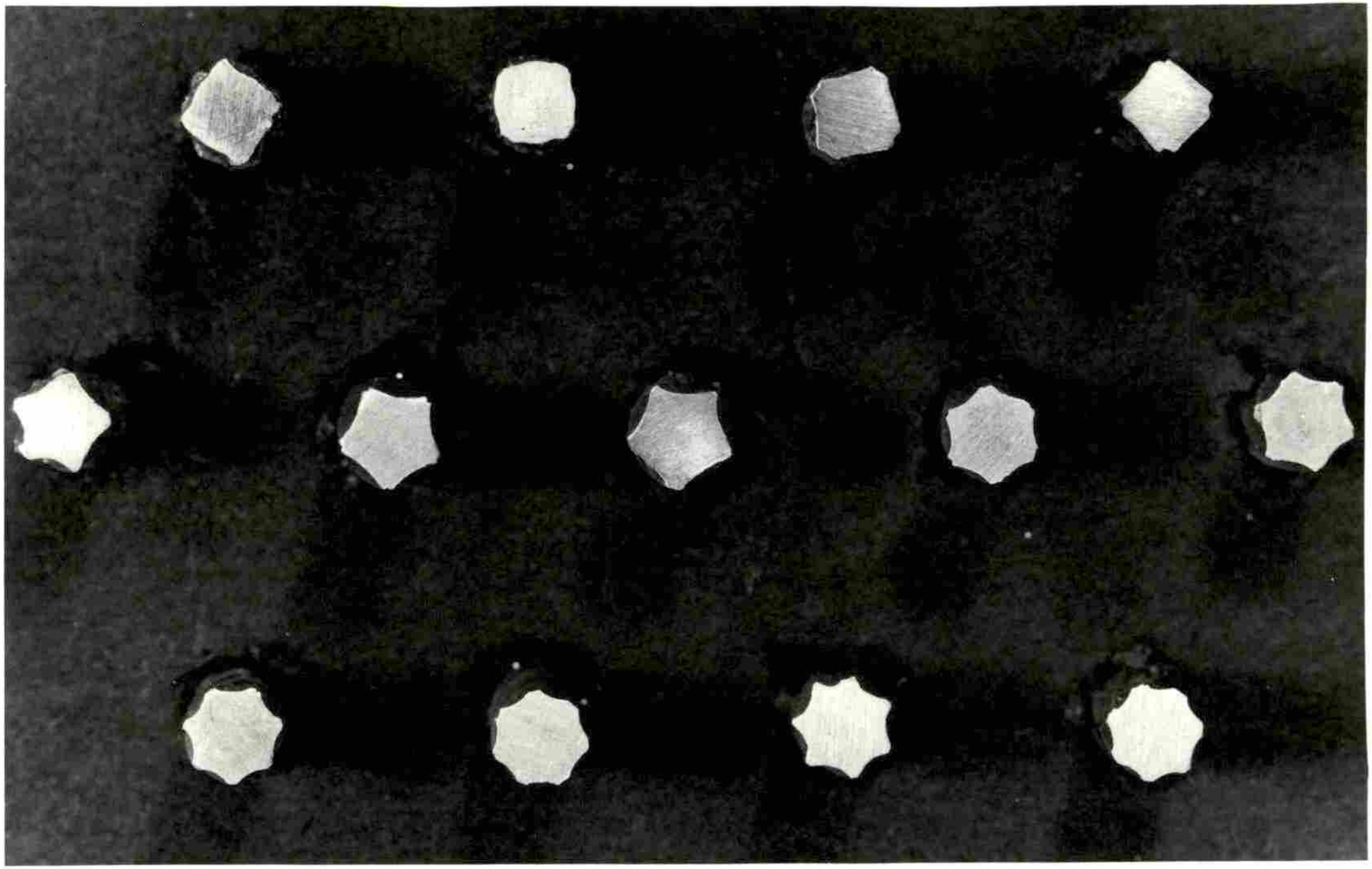

Fig. 12a. Cross sections of combination and screw shank nails (x approx. 4d).
Left to right, top row - 3097, 3117, 4179, 4076
Left to right, middle row - 5075, 5115, 5275, 6015, 6100
Left to right, bottom row - 7012, 7112, 7200, 7310

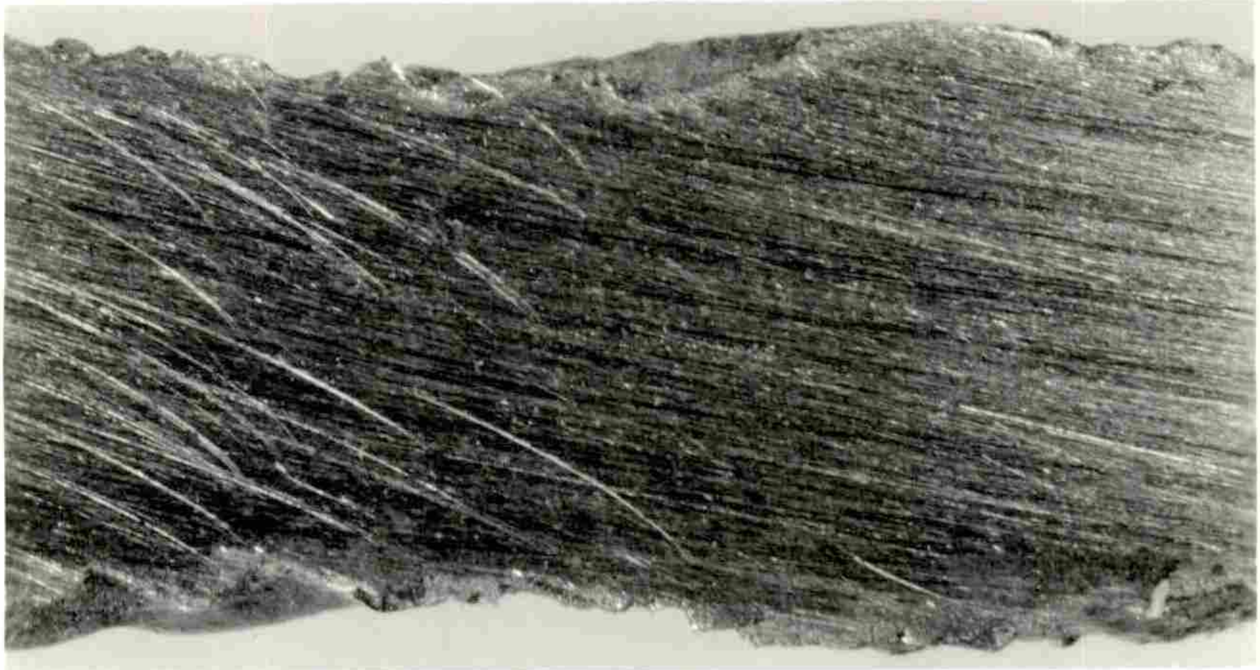

Fig. 12b. Longitudinal section of nail No. 3079 (x20d).

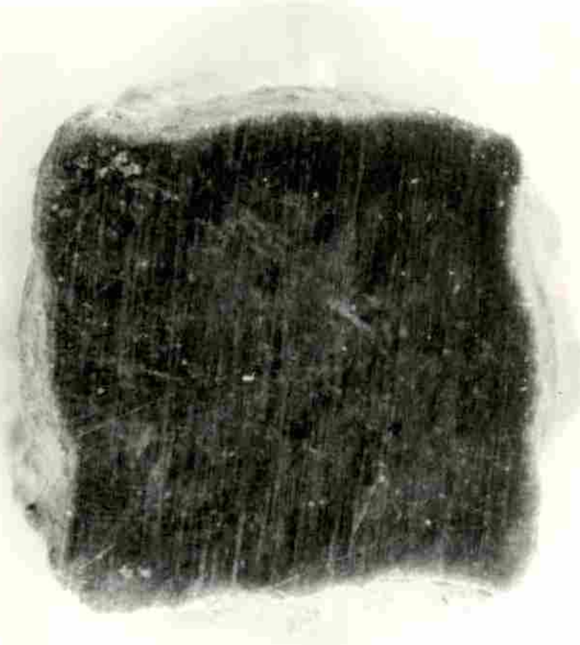

Fig. 13. Cross section of nail
No. 3079 (x20d).

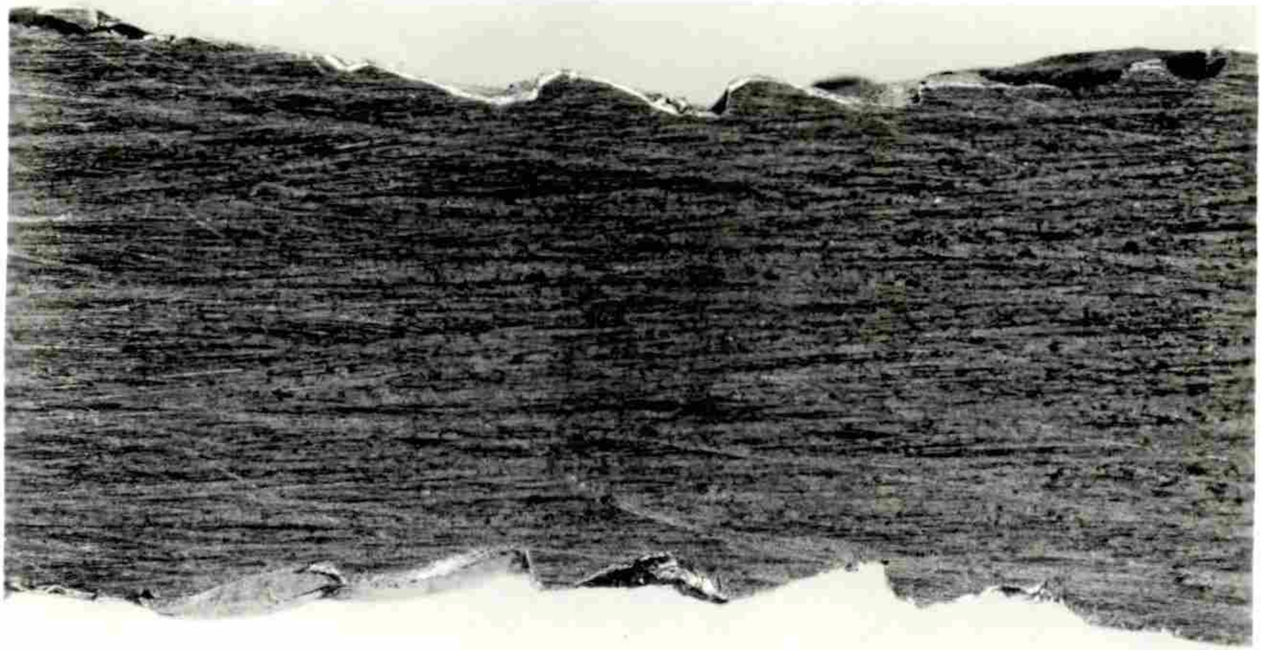

Fig. 14. Longitudinal section of nail No. 3117 (x20d).

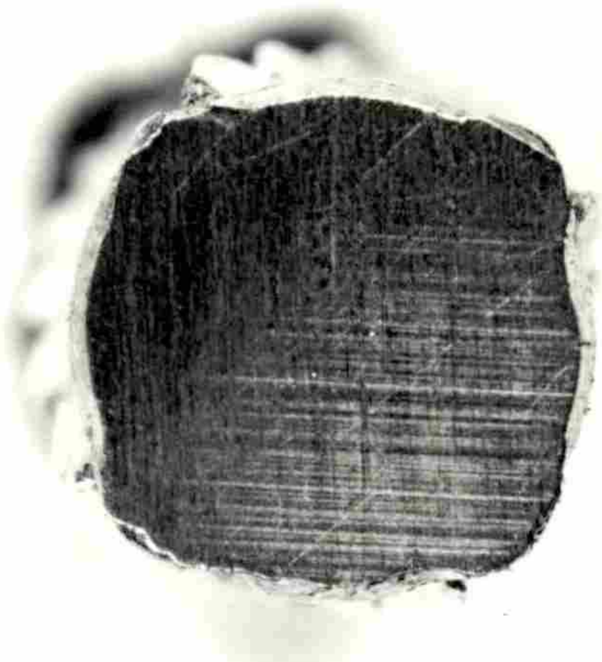

Fig. 15. Cross section of nail
No. 3117 (x20d).

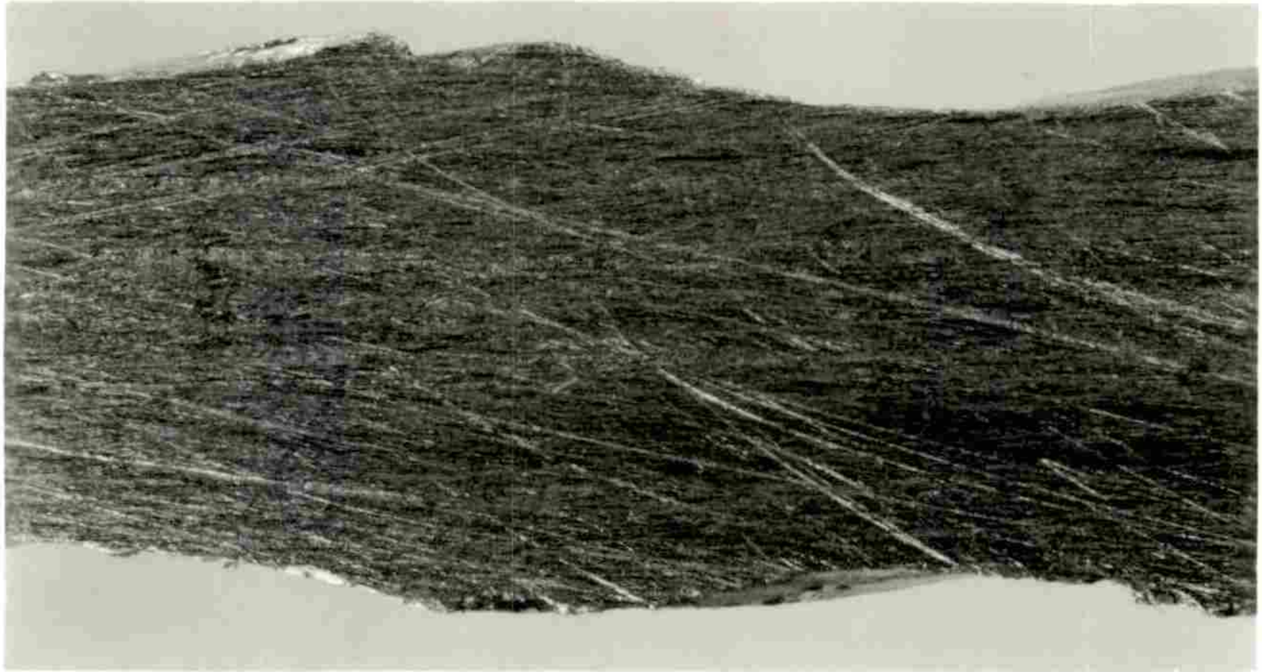

Fig. 16. Longitudinal section of nail No. 4076 (x20d).

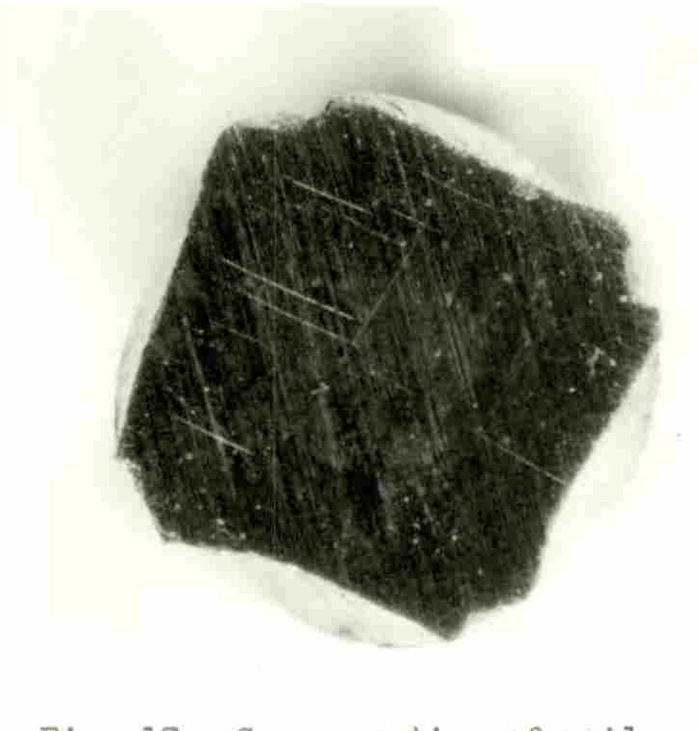

Fig. 17. Cross section of nail
No. 4076 (x20d).

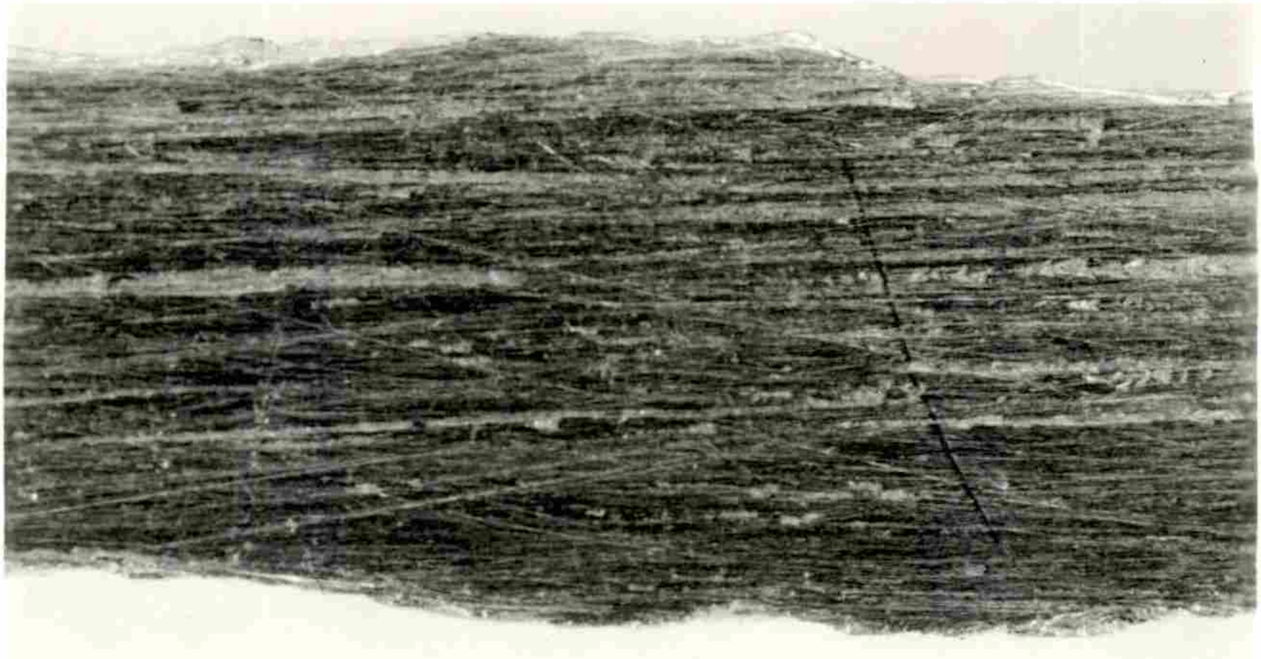

Fig. 18. Longitudinal section of nail No. 4179 (x20d).

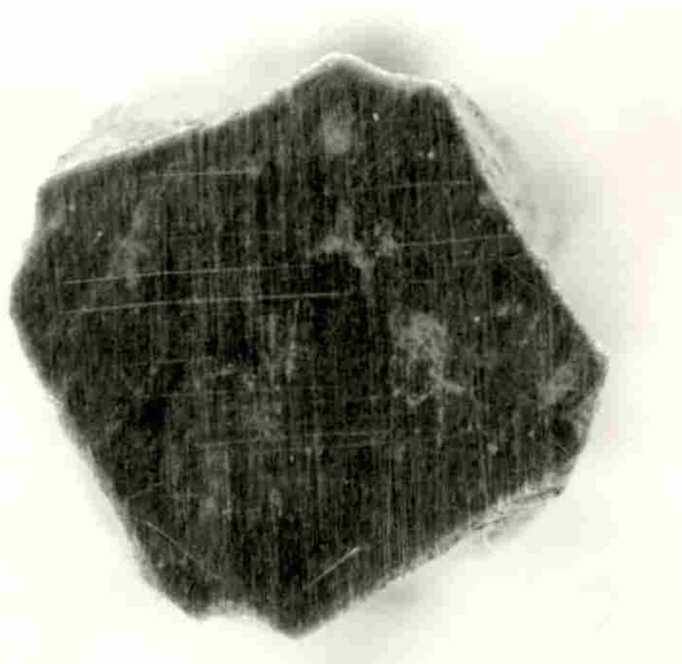

Fig. 19. Cross section of nail No. 4179 (x20d).

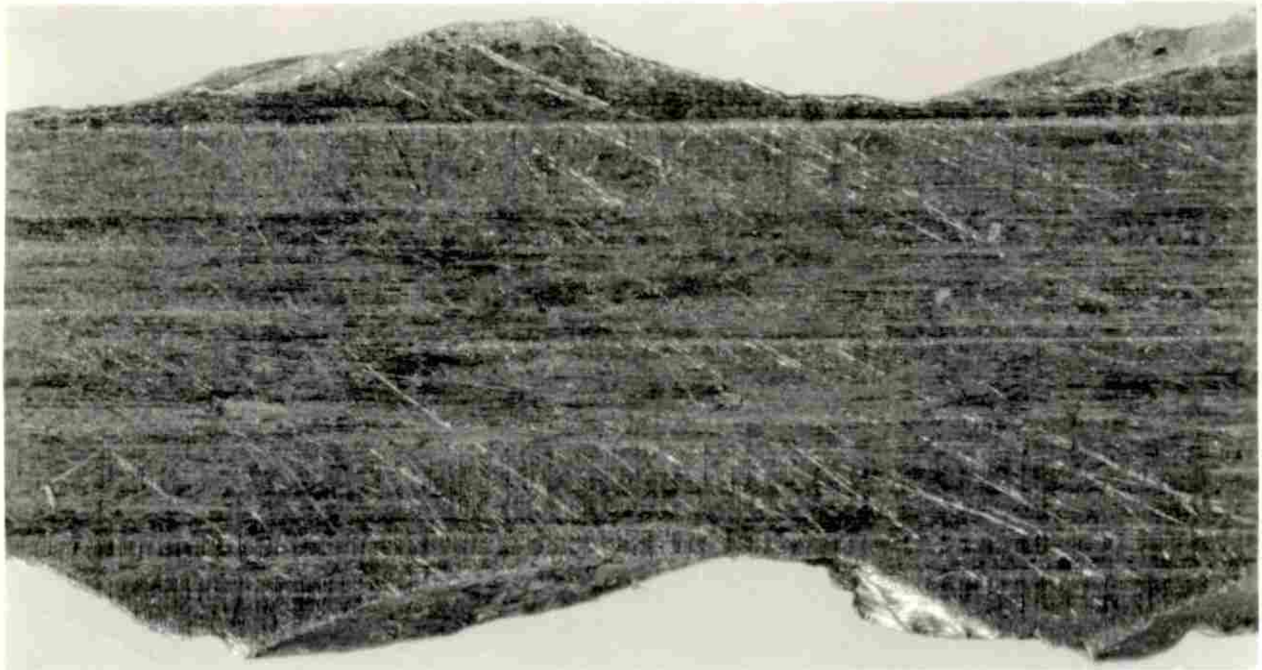

Fig. 20. Longitudinal section of nail No. 5075 (x20d).

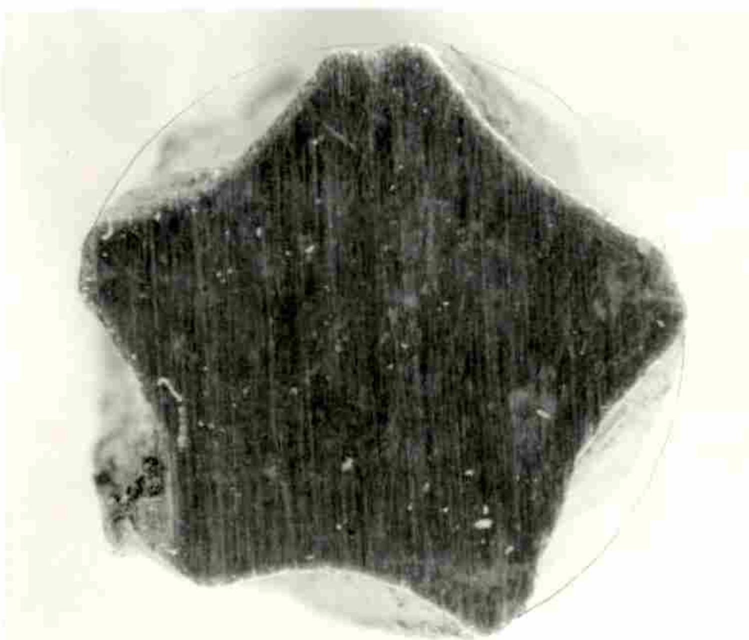

Fig. 21. Cross section of nail No. 5075 (x20d).

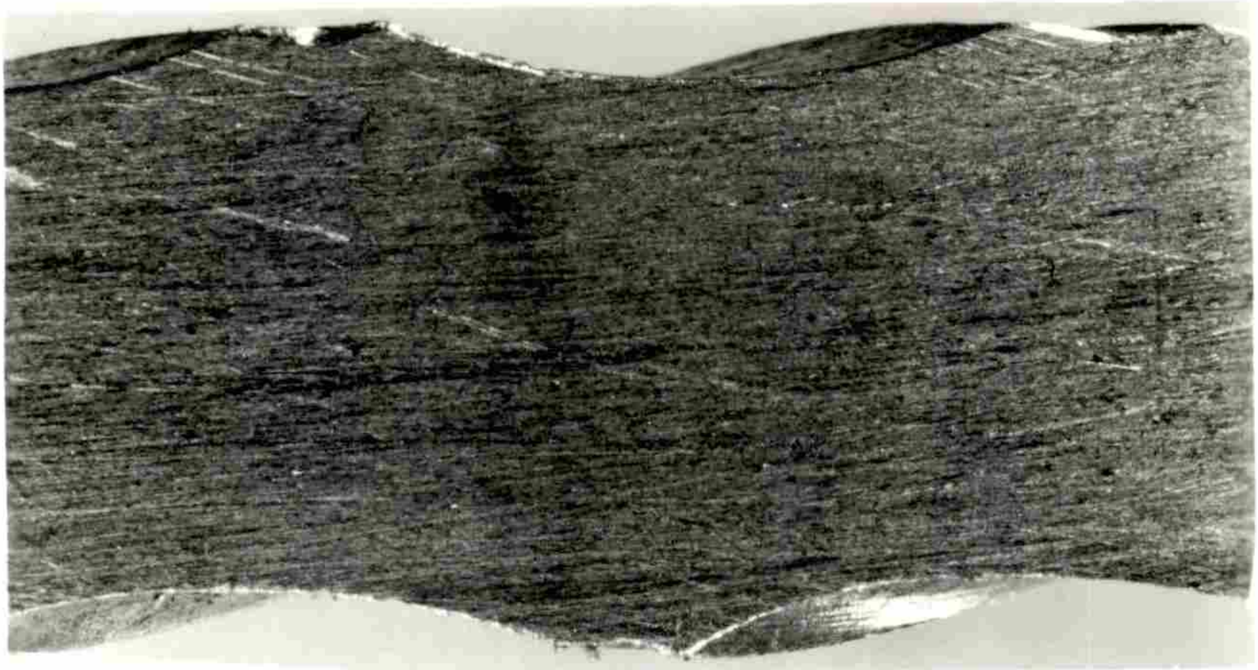

Fig. 22. Longitudinal section of nail No. 5115 (x20d).

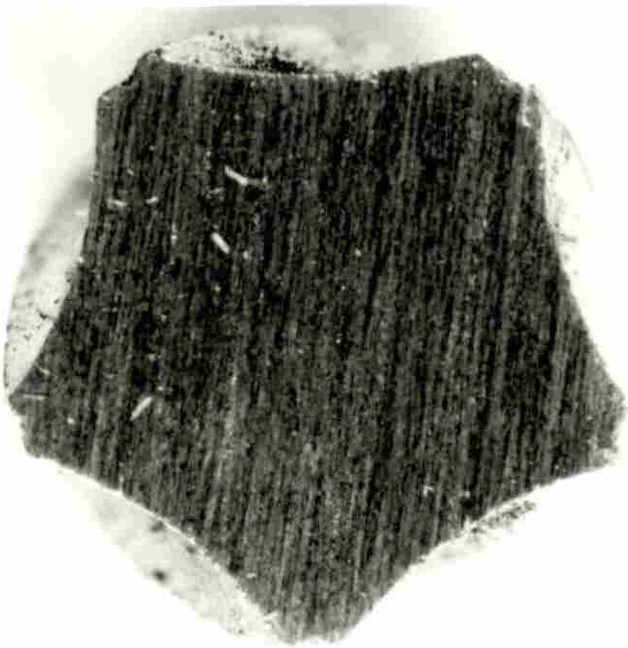

Fig. 23. Cross section of nail No. 5115 (x20d).

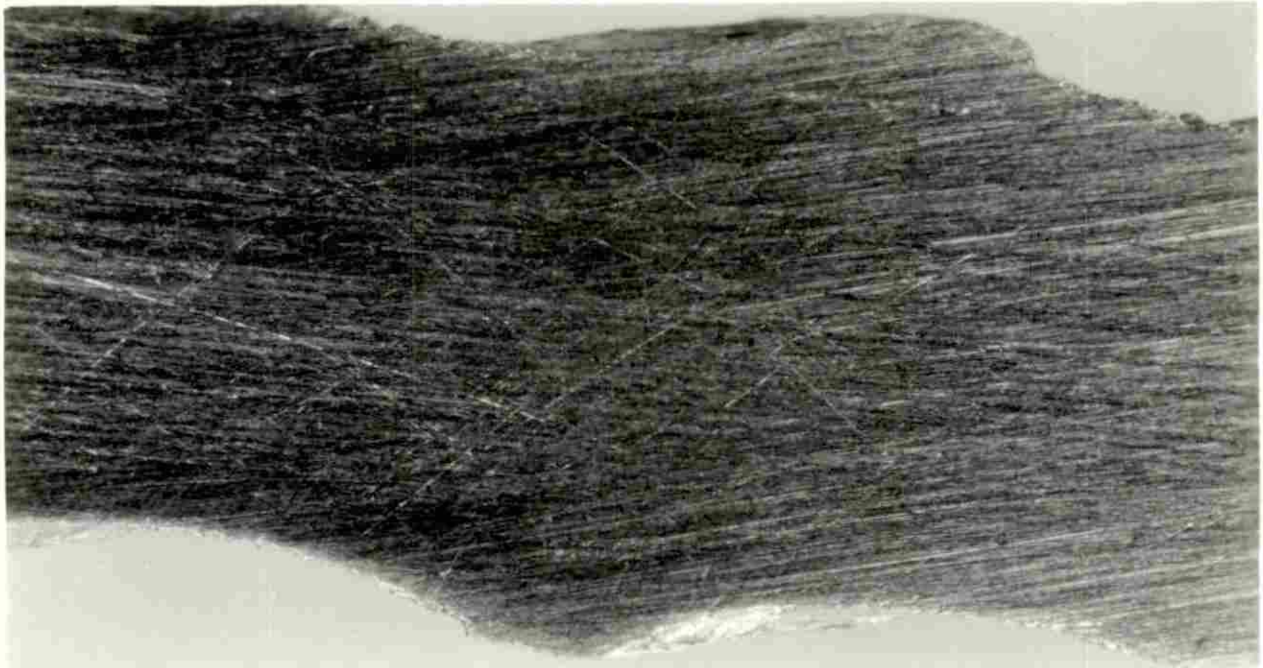

Fig. 24. Longitudinal section of nail No. 5275 (x20d).

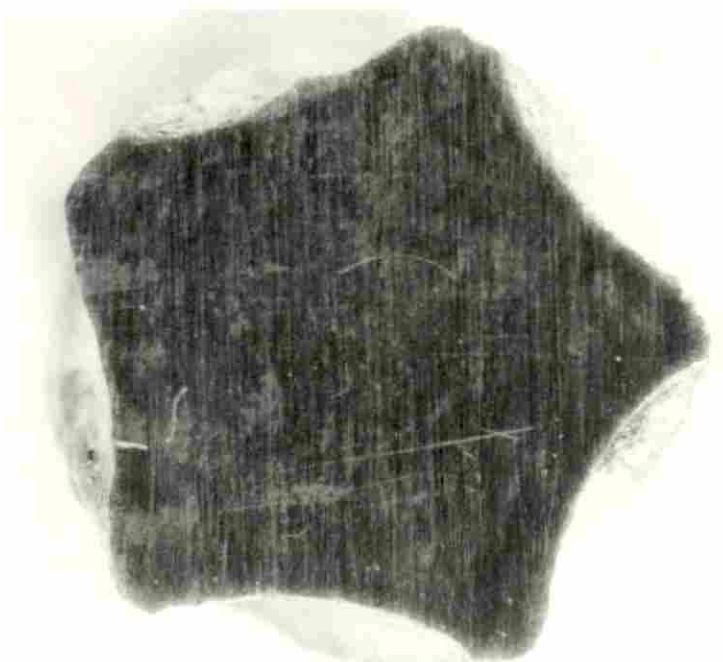

Fig. 25. Cross section of nail No. 5275 (x20d).

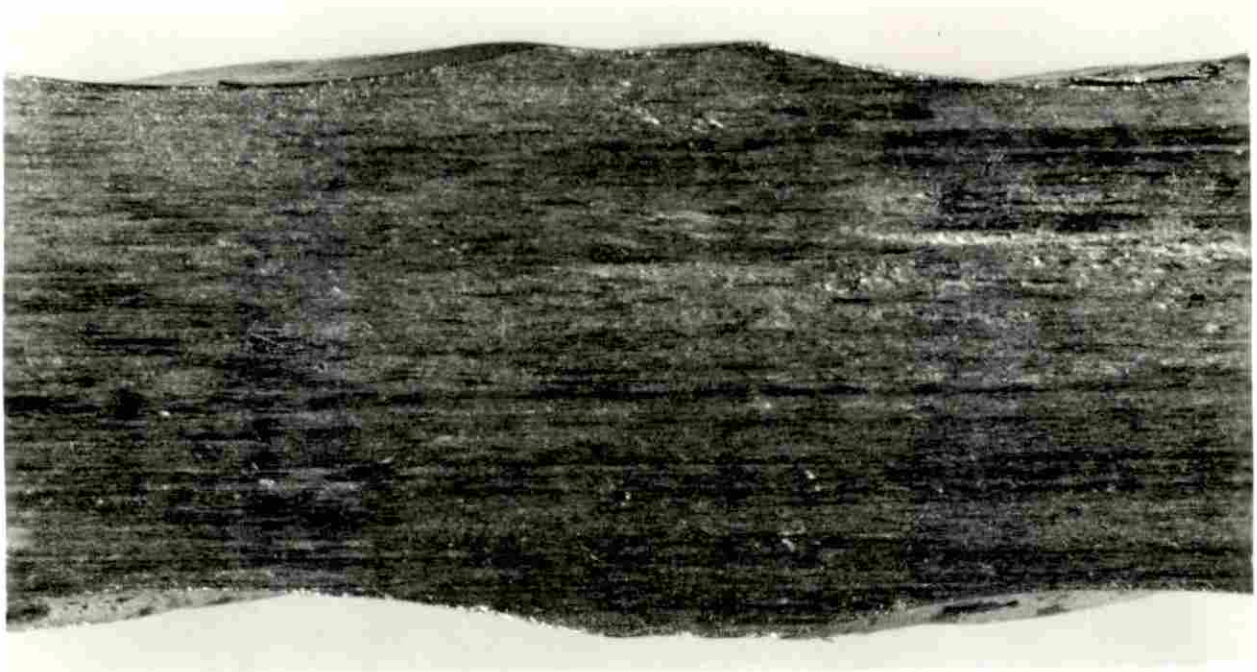

Fig. 26. Longitudinal section of nail No. 6015 (x20d).

Fig. 27. Cross section of nail No. 6015 (x20d).

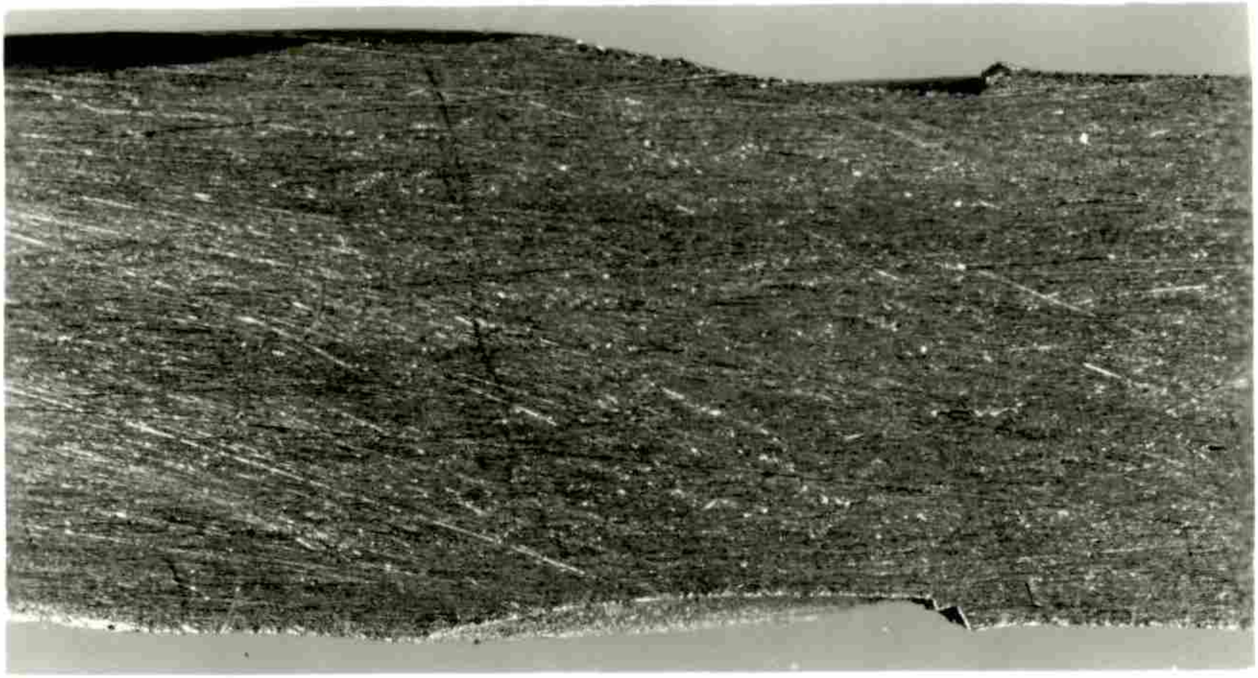

Fig. 28. Longitudinal section of nail No. 6100 (x20d).

Fig. 29. Cross section of nail
No. 6100 (x20d).

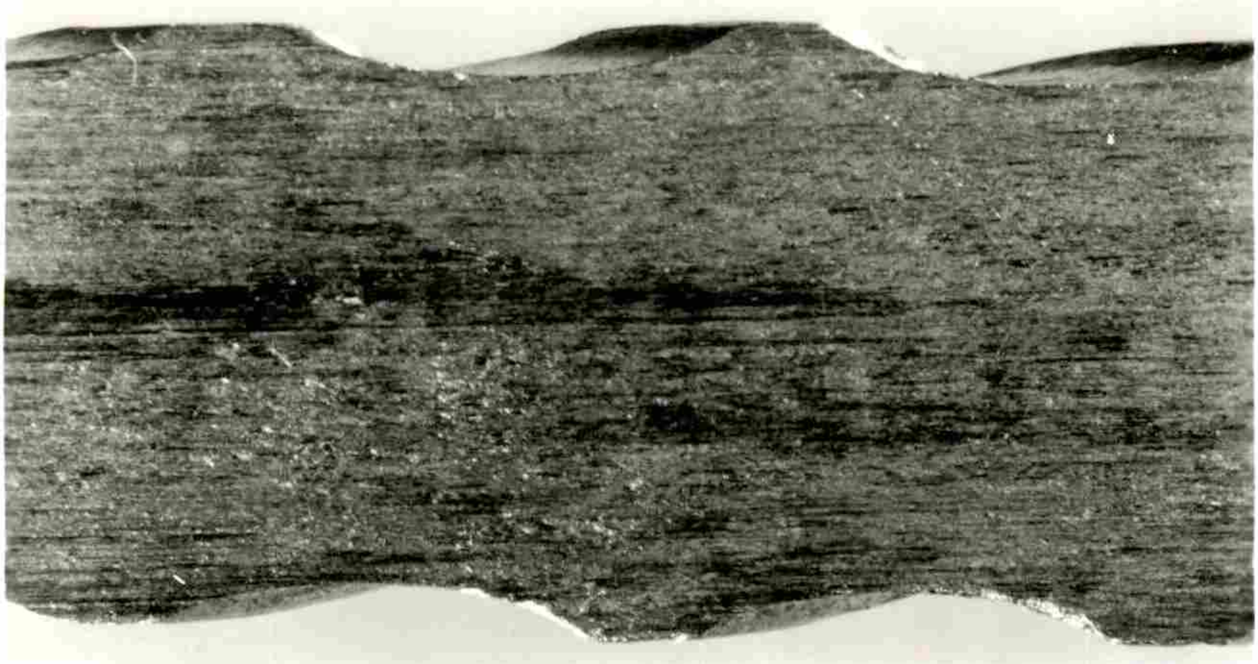

Fig. 30. Longitudinal section of nail No. 7012 (x20d).

Fig. 31. Cross section of nail No. 7012 (x20d).

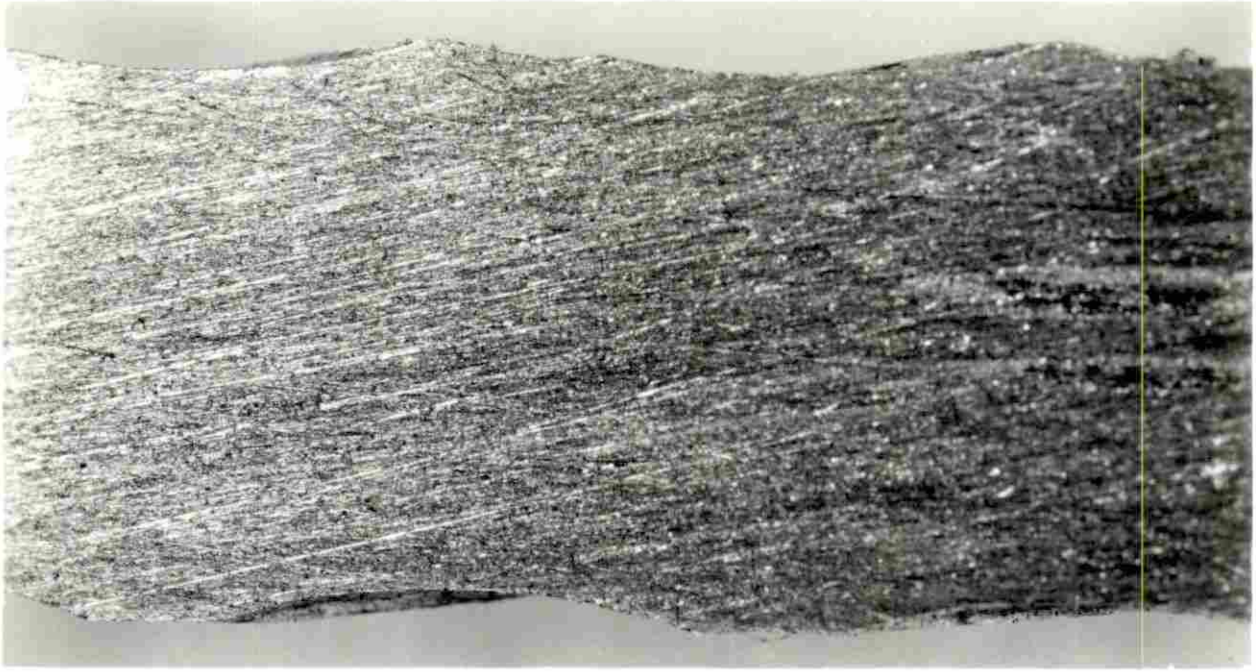

Fig. 32. Longitudinal section of nail No. 7112 (x20d).

Fig. 33. Cross section of nail
No. 7112 (x20d).

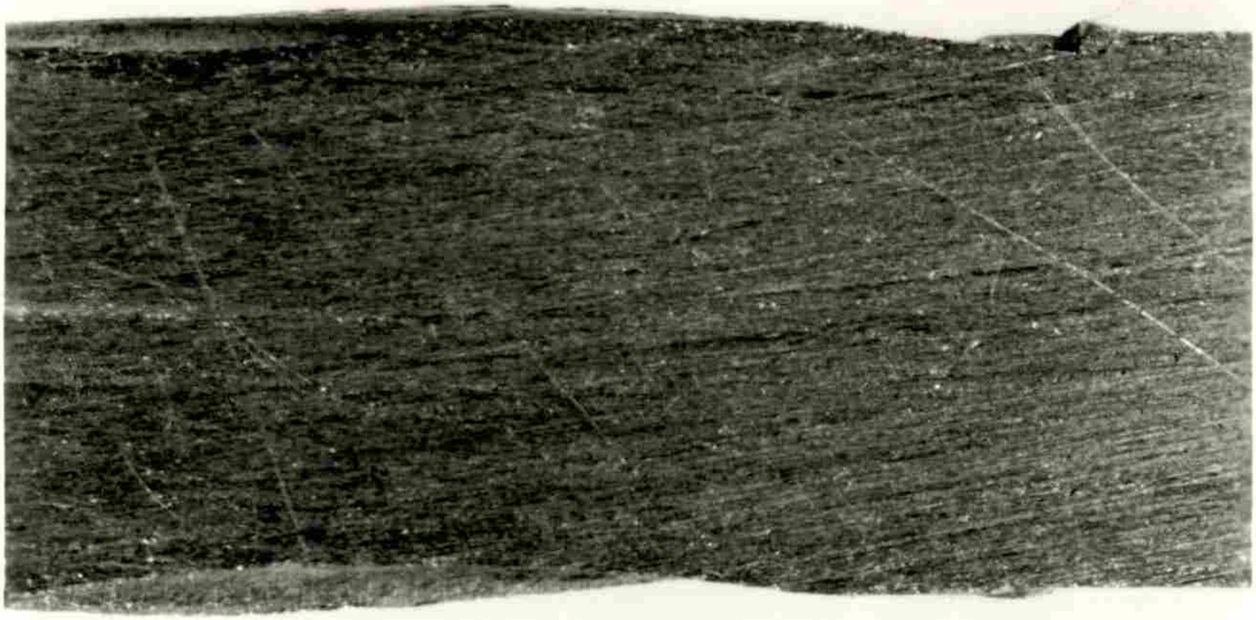

Fig. 34. Longitudinal section of nail No. 7200 (x20d).

Fig. 35. Cross section of nail No. 7200 (x20d).

Fig. 36. Longitudinal section of nail No. 7310 (x20d).

Fig. 37. Cross section of nail No. 7310 (x20d).

additional ring shank and one additional plain shank, but the use of the identification system adopted made it necessary to eliminate them from the tests.

Since no record had been found of studies of aluminum nails and since aluminum roofing was becoming prominent, a special effort was made to secure several aluminum nails. An effort also was made to secure some of the nails used in previous investigations so that these tests could be used as a check besides providing additional information. As a result 19 aluminum nails, 13 steel nails and 1 monel metal nail were selected for testing.

Head variables of the nails were many with the following types represented: (1) common flat, (2) cup, (3) lead washer, (4) lead bell, (5) lead encased, and (6) hood. There were variables within the different types of heads with the common flat head varying in both diameter and thickness.

Little point variability was present with 30 nails having the ordinary diamond point; 1, a conical point; and 2, pilot points. However, there was considerable difference in the length and taper of the various diamond points. The pilot point on the nails tested is really just like the tip of the plain shank nail with a diamond point. This pilot point is approximately 0.35 inch in length above which the threads begin. Due to the shortage of conical points it seemed advisable to make alterations and thus attempt to compare their resistance to withdrawal with that of the diamond pointed nails. Several methods were given trials and considerable difficulty was experienced. It was not possible to set up a jig to give a constant slope. However, this was approximated by fastening each nail in the lathe by means of a collet and then filing as the nail revolved. If the lathe was turning at approximately 300 r.p.m., the point could be filed rather easily to about the same slope as was originally present on the diamond point. Considerable care was necessary in the case of the ring shank since too much pressure applied to the point would turn the nail in the collet and result in damage to the rings.

Only aluminum nails were used for making the point changes since they would respond to the filing more rapidly. The use of the lathe and the file was very slow and tedious so only six point changes were made. The nails changed included 1 plain shank, 1 barb shank, 2 ring shanks, 1 combination shank and 3 screw shanks.

Several different surface conditions were represented. Included were etched, plain and "Alroked" aluminum nails; galvanized steel nails; and the plain monel nail. The reports of others and observations from some trial immediate withdrawal tests, made it apparent that the "Alroked" aluminum plain shank nail possessed much greater resistance to withdrawal than did either the plain aluminum nail or etched aluminum nail. However, no nails other than plain shank had been "Alroked". It seemed desirable to subject other shank types to the "Alrok" treatment to determine whether or not their resistance to withdrawal could also be increased. It was not expected that the percentage increase would be as great for deformed shank nails since a large portion of their resistance to withdrawal is mechanical rather than frictional as in the case of the plain shank nail. The change in surface condition was not likely to result in any increase in mechanical resistance. Ten nails were given the "Alrok" treatment so that determinations on deformed shank nails could be made as well as on plain shank nails. Those nails included one plain shank, one barb shank, three ring shanks, one combination shank and four screw shanks which gave a fairly representative sample of each shank type. It was possible that the increase resulting from the "Alrok" surface would not appear after moisture changes had occurred in the wood.

Identification system

After adding six point changes and ten surface changes to the original 33 nails, the number of nail variations reached 49. It appeared advisable to devise some sort of an identification system which would make each nail easily identified. The system followed the plan of previous investigations with the first digit indicating the shank type and the second digit, the relative diameter of the nails within the shank type group. A third digit was added to differentiate among the material, the surface and point. A fourth digit was also added for use with ring shank, combination ring and screw shank, and screw shank.

In the case of the ring shank it denoted the number of rings per inch, and for combination shank and screw shank, the fourth digit indicates the pitch. The pitch is the distance between threads measured along the axis of the nail. The identification system will permit the dropping of the last digits in many cases. The system is outlined below:

First digit - shank type

1 - Plain shank or barb shank

2 - Ring shank

3 - Combination ring and screw shank

4 - Screw shank having 4 threads

5 - Screw shank having 5 threads

6 - Screw shank having 6 threads

7 - Screw shank having 7 threads

Second digit - relative diameter. The numbers will run from 0 through 9, when necessary, with 0 denoting the nail having the smallest diameter within a specific shank type group. (Table I gives the exact diameter based on an average of 20 nails measured with a micrometer.) No differentiation is made between aluminum and steel nails in respect to relative diameter.

Third digit - material, surface and point. Numbers 1 through 0 will be used to designate material, surface and point type according to the code given below:

1 - Aluminum, plain surface, diamond point

2 - Aluminum, plain surface, conical point

3 - Aluminum, etched surface, diamond point

4 - Aluminum, etched surface, conical point

5 - Aluminum, Alrok surface, diamond point

6 - Aluminum, Alrok surface, conical point

7 - Steel, galvanized surface, diamond point

8 - Steel, galvanized surface, conical point

9 - Monel, plain surface, diamond point

0 - Aluminum, plain surface, pilot point

Fourth digit - pitch for screw shank; rings per inch for ring shank.

	Pitch	Rings/inch
1 -	.120" to .139"	21
2 -	.140" to .159"	22
3 -	.160" to .179"	23
4 -	.180" to .199"	24
5 -	.200" to .219"	25
6 -	.220" to .239"	16
7 -	.240" to .259"	17
8 -	.260" to .279"	18
9 -	.280" to .299"	19
0 -	.300" to .320"	20

The variations in the nails will be shown by the changes in the third digit. This probably can best be explained by the use of an example. An aluminum ring shank nail having the smallest diameter, 18 rings per inch, a plain surface and a conical point would be identified as 2028. After "Alroking" it would become 2068.

Wood

The selection of the wood to be used was a major problem in planning the investigation. The variation in moisture content and density in wood is quite great with some woods varying as much or more from end to end of a piece as from piece to piece. The use of randomized patterns in driving was used to minimize the variability remining after the wood had been carefully selected. The basis for selection was the grain. It was decided that flat grain would be the most satisfactory since all nails would penetrate each layer of spring wood and summer wood. If edge grain had been used, some of the nails would have been driven into summer wood; others, into spring wood. Since the density of these two kinds of wood varies greatly the withdrawal resistance would probably also vary and the true representation would not be shown.

It was finally determined that Douglas Fir should be used since it is the wood most commonly used for roof sheathing. In addition it was probably more plentiful than any other species.

Another question was whether or not kiln dried or air dried lumber should be used. Granting that in normal times most lumber used would be kiln dried, it was decided to use air dried for the following reasons:

1. It was thought kiln drying changes wood structure which might affect the results of the investigation.
2. It was reported by Dr. D. W. Bensend of the Department of Forestry that air dried lumber would change in moisture content more rapidly than kiln dried lumber. This would facilitate an acceleration of the desired changes.

Conditions to be Varied

Moisture cycles

A search of literature revealed the moisture content of wood to have an approximate range of from 7 per cent to 19 per cent under normal weather conditions. The moisture content is intimately related to the relative humidity, thus making it possible to control moisture. An equilibrium moisture content of 19 per cent results with a relative humidity of 87.5 per cent at a temperature of 80° F. The relative humidity must be lowered to 36.5 per cent at a temperature of 80° F to give an equilibrium moisture content of 7 per cent.

Since the moisture seemed to range from 7 per cent to 19 per cent, these points were chosen as the outside limits of the moisture cycle. Withdrawals were made at these points in addition to the intermediate point of 13 per cent. Three cycles composed of 14 withdrawals seemed to be a sufficient number to show trends in withdrawal resistance.

Nails are driven into both green and well seasoned lumber. To approximate these extremes in addition to the average condition, the 25 per cent, the 16 per cent and the 7 per cent points were selected for driving the nails. However, great difficulty was experienced in reaching the 25 per cent point, so that group of nails was finally driven at approximately 21 per cent. All pieces of lumber in the 7 per cent group did not reach that point, but were slightly above when the nails were driven.

Considerable time is needed to make changes in the moisture content of wood. Due to this fact the predetermined points were not always attained. However, in Iowa the maximum and minimum points probably have less range than those used.

Use of metal

In the application of all roofing, the nail must penetrate the sheet or the shingle in order to serve its purpose and hold the roofing in place. Generally the nail must make the hole through which it passes. As a result the points are blunted and in the case of the ring shank nail, the rings are often damaged. The result is a reduction in holding power, which is not desirable.

Previous investigations show the reduction in withdrawal resistance of the ring shank nail resulting from driving through metal to be as great as 25 per cent. This value was obtained for steel nails driven through galvanized steel roofing sheet. No data were available for aluminum nails, so ten replicas of each of the five aluminum ring shank nails, of the monel ring shank nail, and of the aluminum combination shank nail, were driven through aluminum and ten replicas of each directly into the wood. All were driven to the same depth in 2 inch Douglas Fir at a moisture content of approximately 16 per cent. Table II shows the reduction in withdrawal resistance of the nails resulting from their being driven through 26 gauge (0.019 inches in thickness) aluminum roofing sheet. The maximum reduction was 11.2 per cent. The damage, which results in less withdrawal resistance, is shown by Figures 38 through 49. These are photomicrographs showing the nails both before and after their being driven through the roofing sheet. Other photomicrographs show no apparent damage to plain, barb and screw shank aluminum nails. Hence, no reduction in withdrawal resistance was expected.

It was not probable that aluminum nails would be used in the application of steel roofing sheet. As a result, no attempt was made to determine the extent of damage resulting from driving aluminum nails through steel. In addition it was felt that steel nails would be undamaged by their passage through aluminum so no data were taken under those conditions. The above findings and beliefs, plus the fact that the 26 gauge aluminum was the thickness most commonly used, made it seem wise to drive all nails through this material. The aluminum was cut into small pieces so that each nail penetrated an

Table II

Reduction in Withdrawal Resistance Resulting From Driving Through 26 Gauge Aluminum

Replica No.	Withdrawal Force in lbs.[a]											
	Nail No. 21		Nail No. 23		Nail No. 24		Nail No. 25		Nail No. 26		Nail No. 31	
	No. Metal	Metal	No Metal	Metal	No Metal	Metal	No Metal	Metal	No Metal	Metal	No. Metal	Metal
1	387	334	570	535	465[b]	455	477	478	510	405	405	333
2	318	315	480	453	420[b]	404	514	465	454	398	387[b]	353
3	238	302	523	487	429	435[b]	478	576	501	450	394[b]	426[b]
4	350	358	489	462	410[b]	420	524	498	549	407	396[b]	395
5	299	324	509	460	459[b]	421	477	449	436	455	400[b]	330
6	333	350	477	509	395[b]	385[b]	483	489	465	422	365	377[b]
7	345[b]	295	505	406	382	385	419	509	480	389	408[b]	415[b]
8	355	355	506	505	419[b]	435	469	445	459	444	437	394
9	328	353	585	497	460	412	529	524	464	421	362[b]	299
10	342	358[b]	505	462	455	397	512	574	473	462	388	376[b]
Total	3295	3344	5149	4776	4294	4149	4982	5007	4791	4253	3942	3698
Average	329.5	344.4	514.9	477.6	429.4	414.9	498.2	500.7	479.1	425.3	394.2	369.8
% Reduction		-4.5		7.3		3.5		-0.5		11.2		6.2

[a]Immediate withdrawals from 2" Douglas Fir. Moisture content approximately 16 per cent. Depth of driving approximately 1.4 inches.

[b]head failure before maximum withdrawal resistance reached.

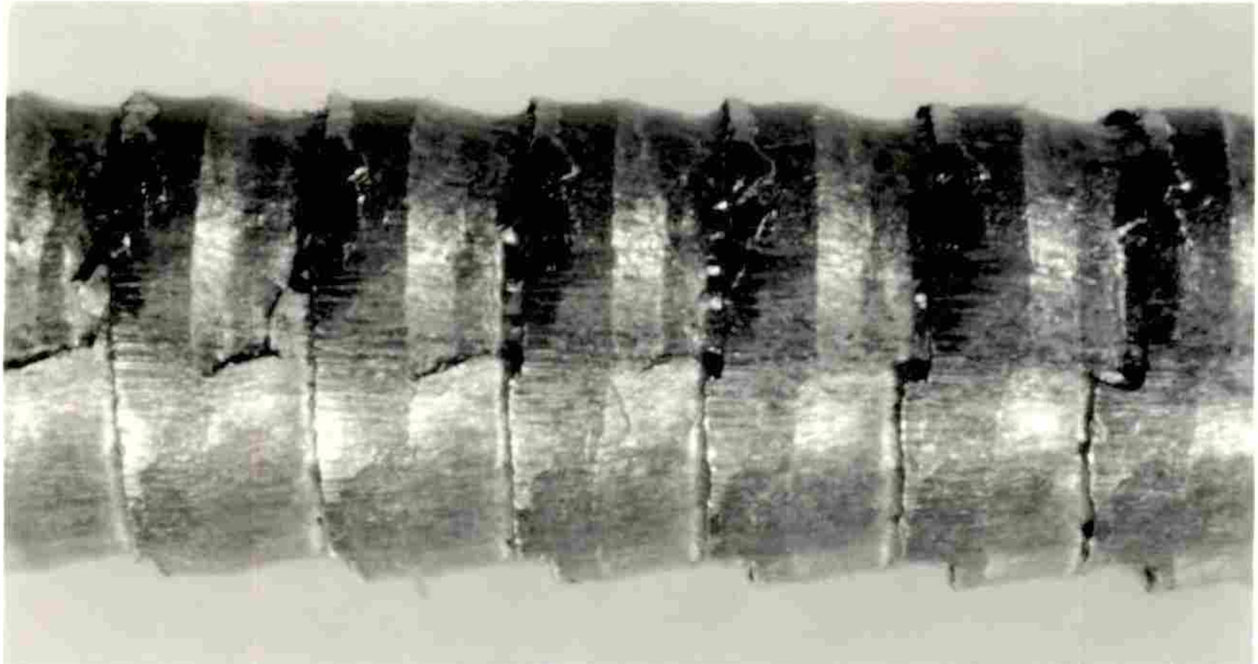

Fig. 38. Nail No. 2119 before driving through 26 gauge aluminum (x20d).

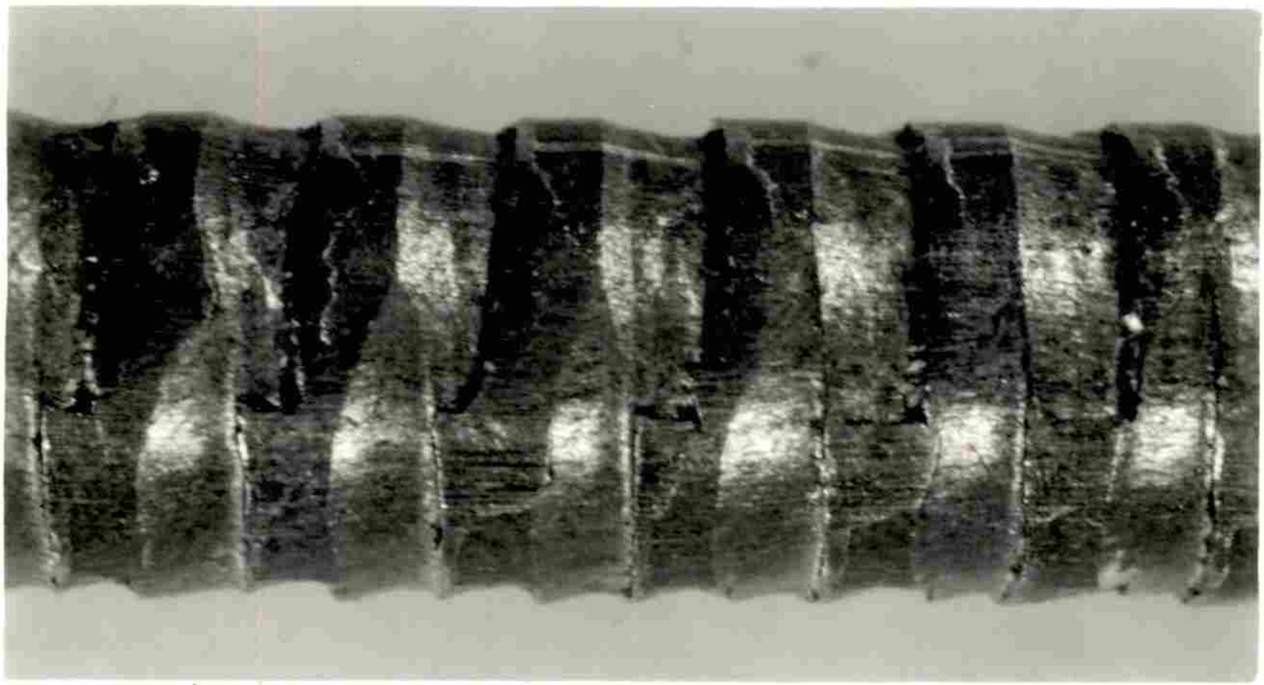

Fig. 39. Nail No. 2119 after driving through 26 gauge aluminum (x20d).

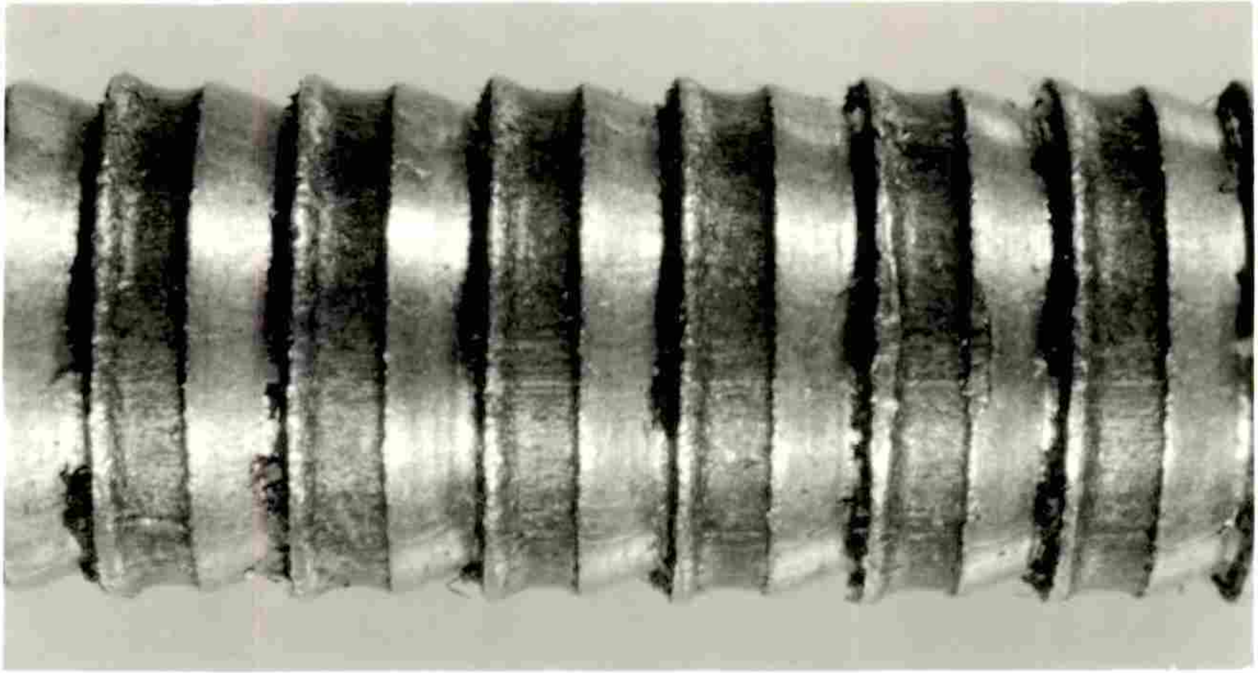

Fig. 40. Nail No. 2310 before driving through 26 gauge aluminum (x20d).

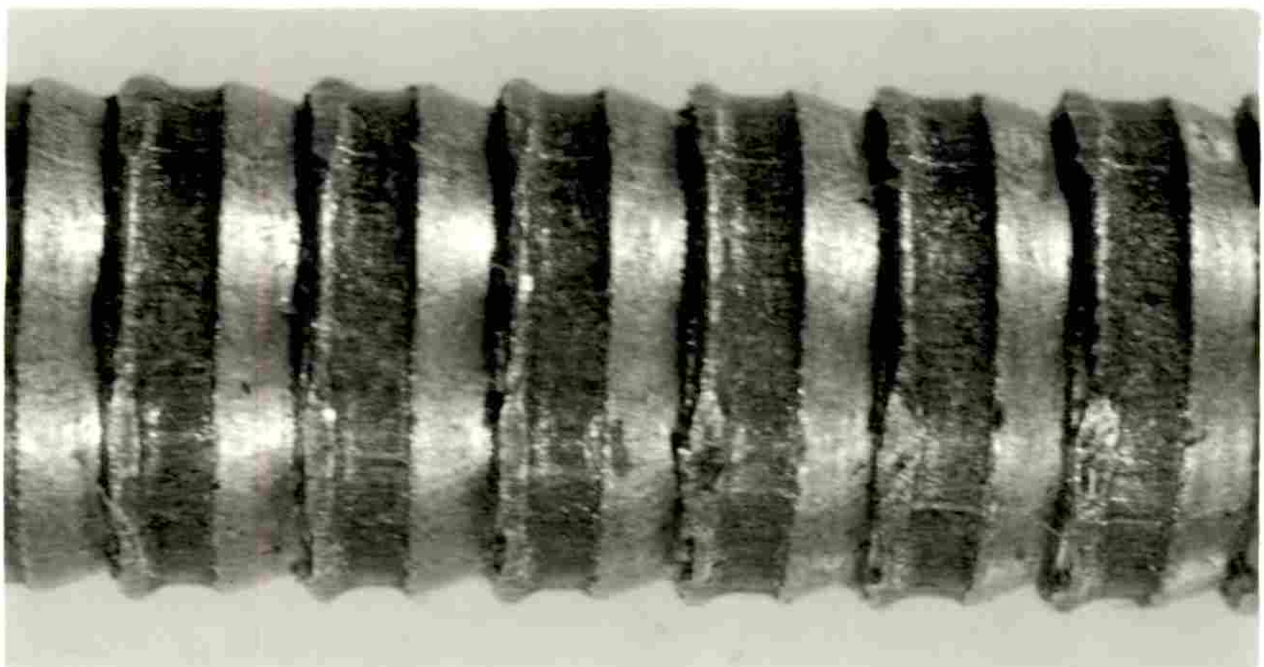

Fig. 41. Nail No. 2310 after driving through 26 gauge aluminum (x20d).

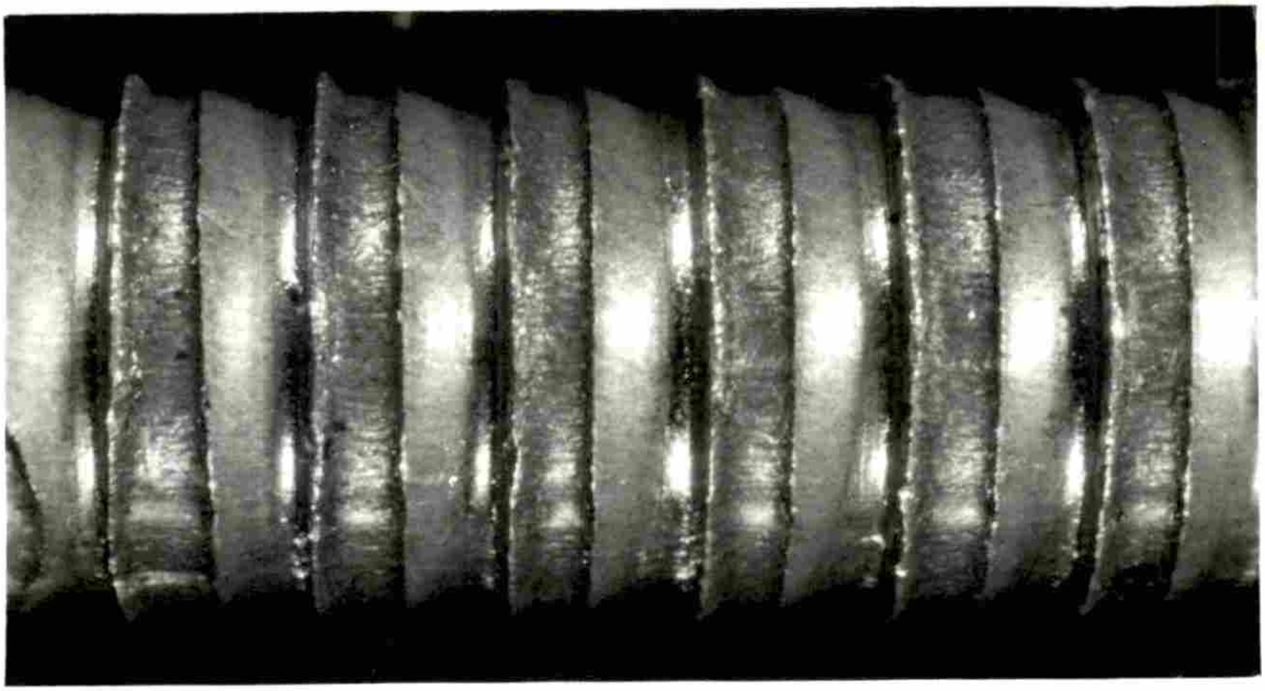

Fig. 42. Nail No. 2410 before driving through 26 gauge aluminum (x20d).

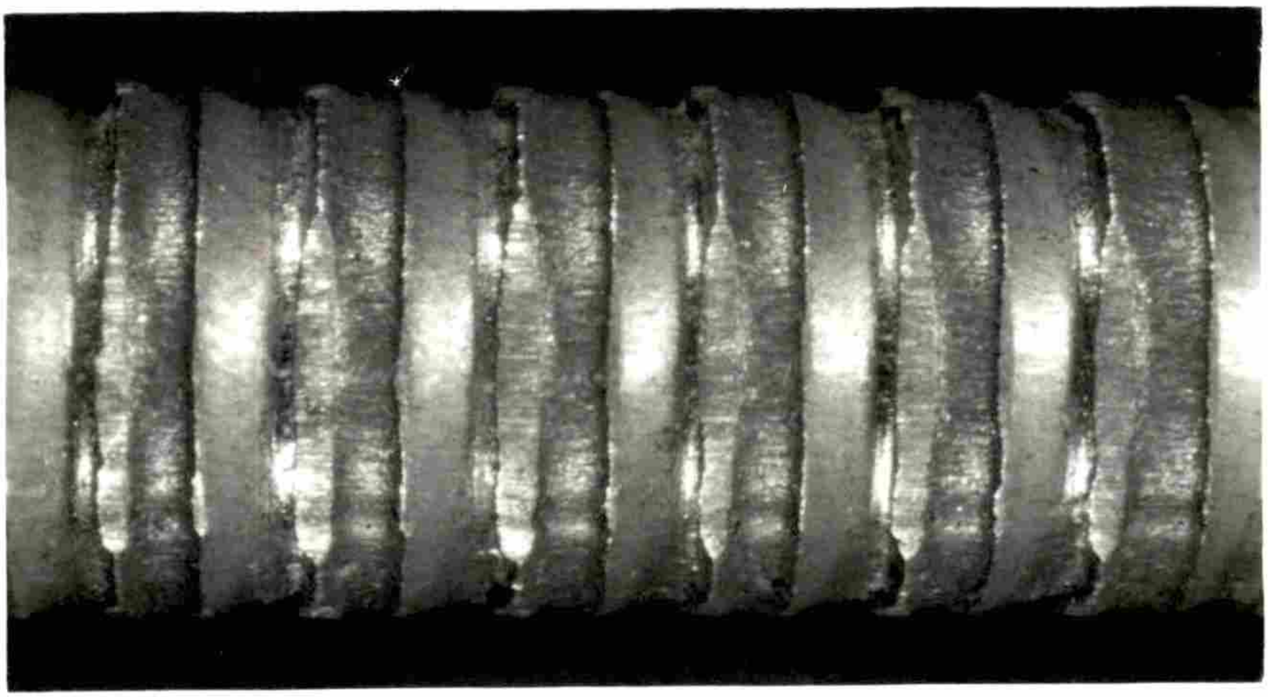

Fig. 43. Nail No. 2410 after driving through 26 gauge aluminum (x20d).

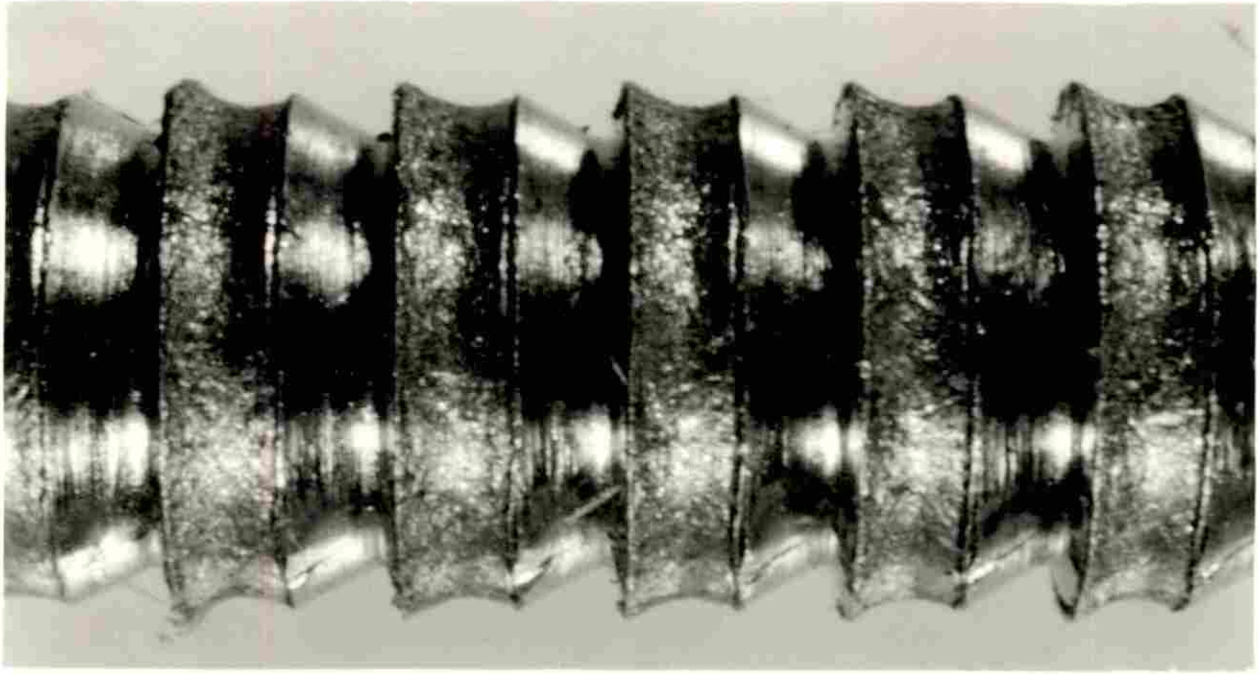

Fig. 44. Nail No. 2597 before driving through 26 gauge aluminum (x20d).

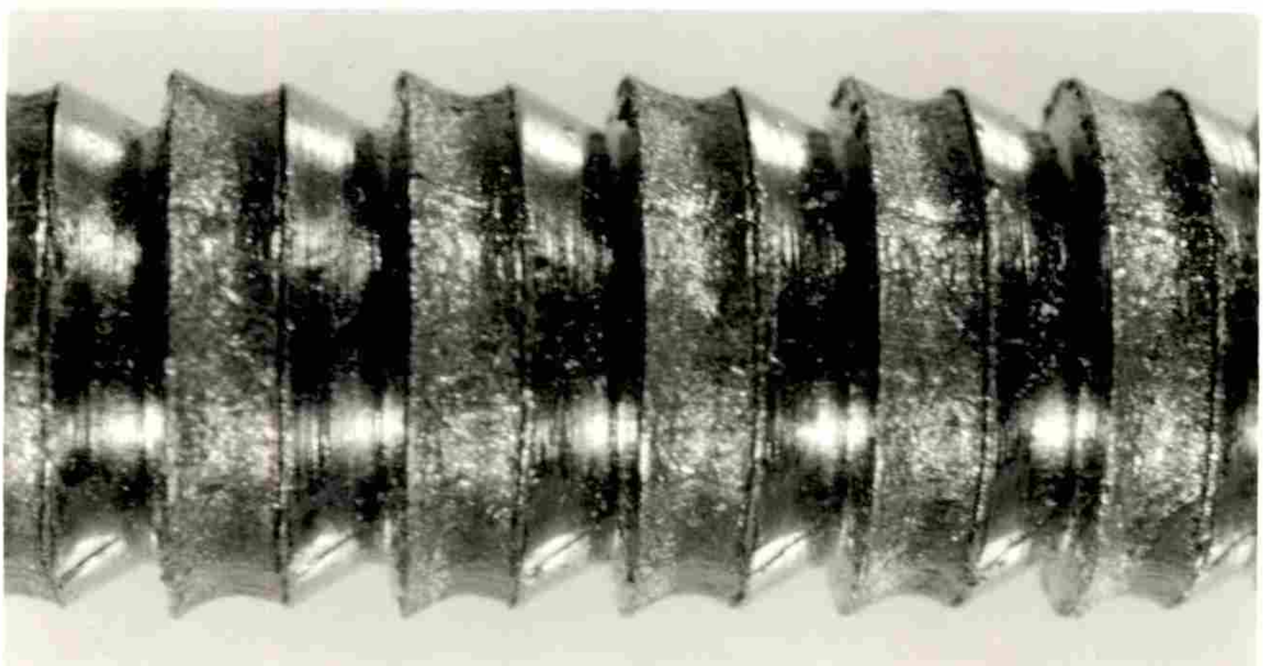

Fig. 45. Nail No. 2597 after driving through 26 gauge aluminum (x20d).

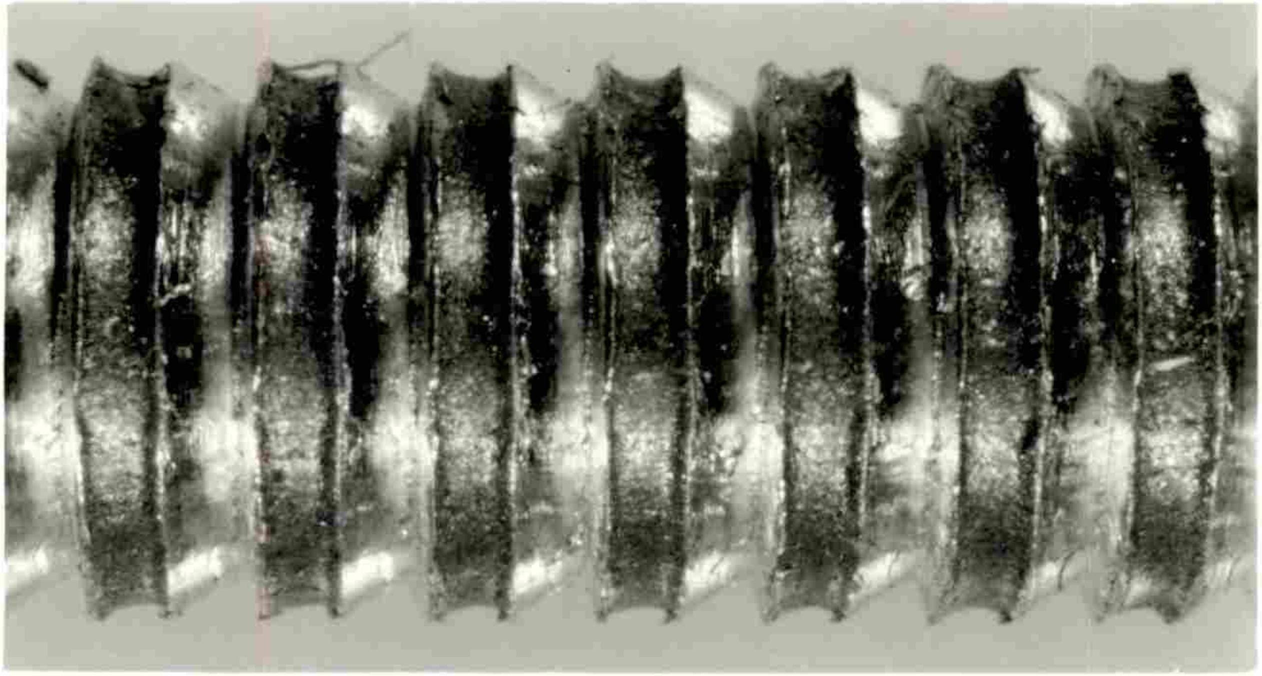

Fig. 46. Nail No. 2613 before driving through 26 gauge aluminum (x20d).

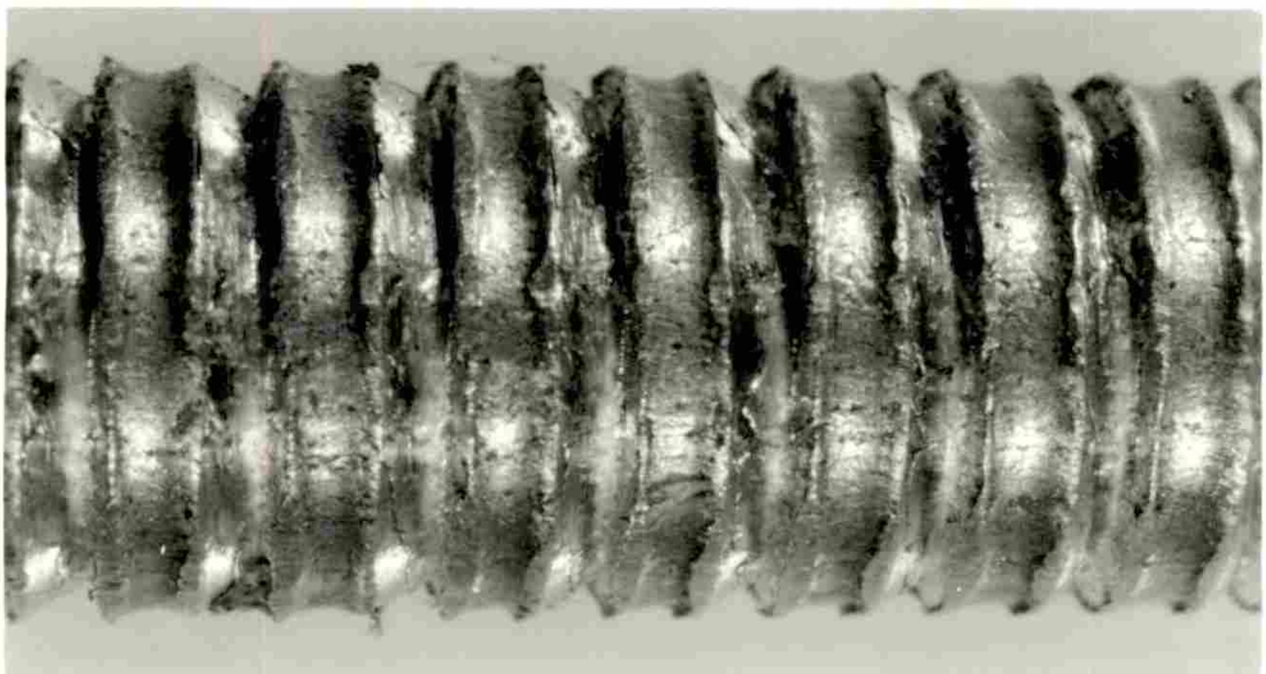

Fig. 47. Nail No. 2613 after driving through 26 gauge aluminum (x20d).

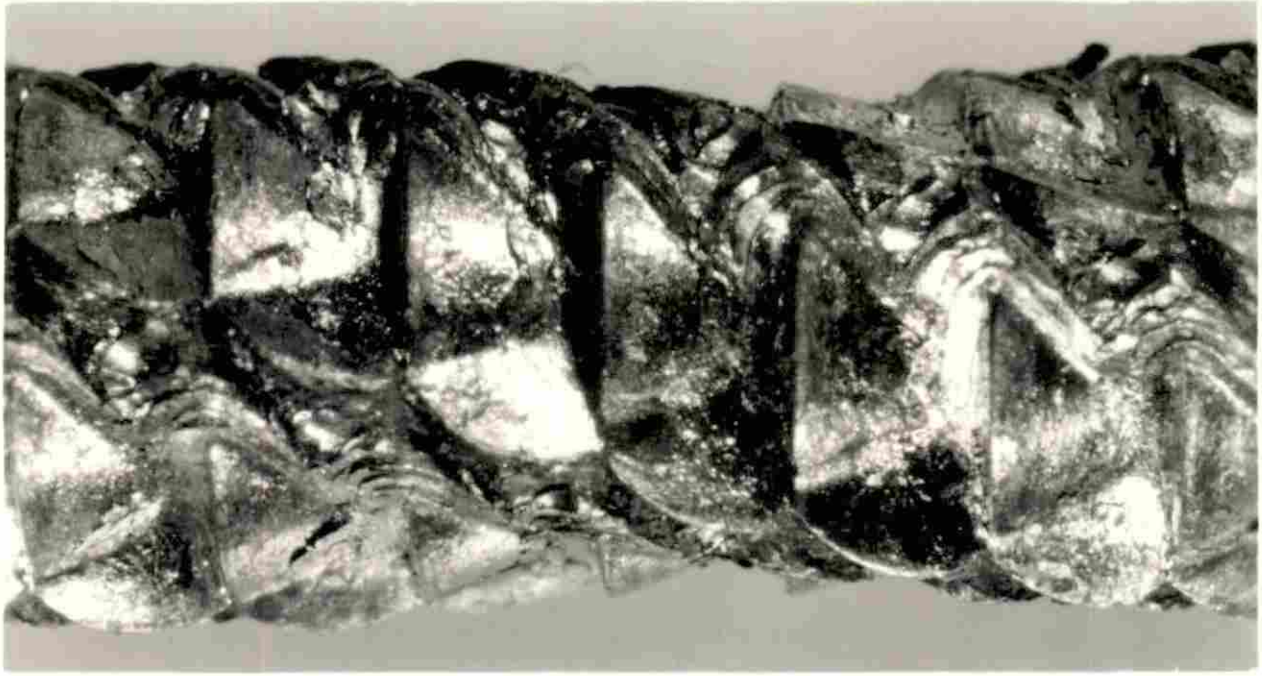

Fig. 48. Nail No. 3117 before driving through 26 gauge aluminum (x20d).

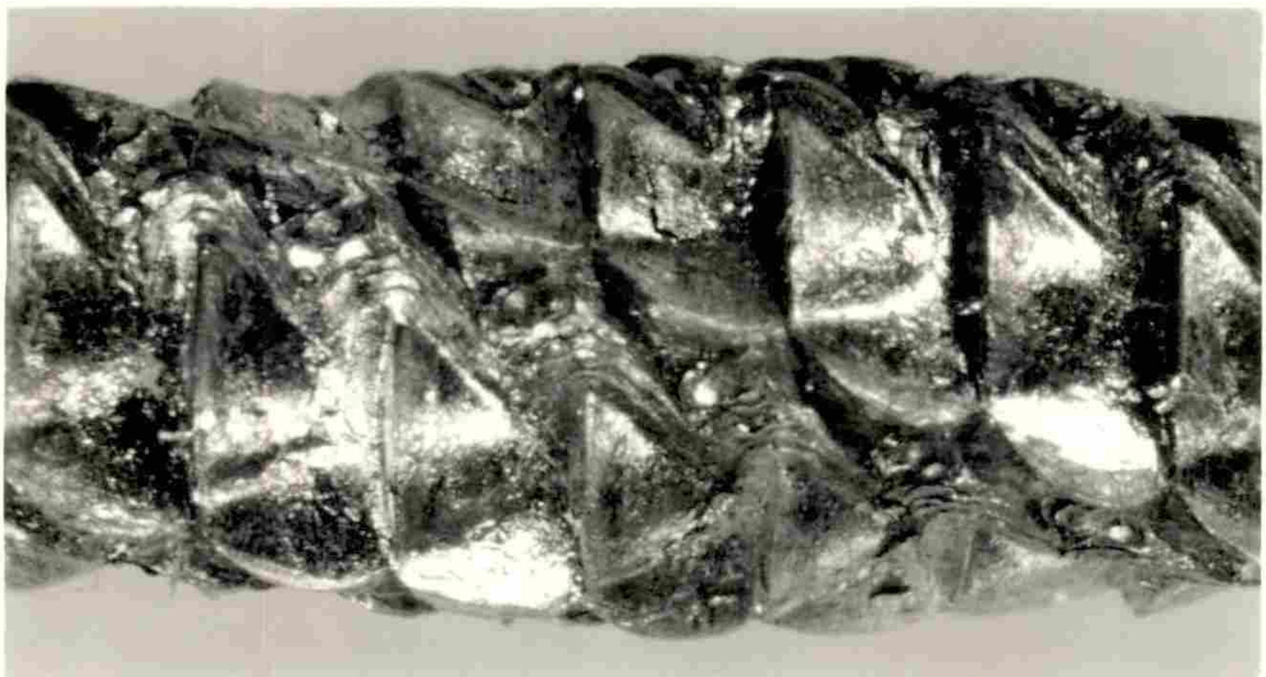

Fig. 49. Nail No. 3117 after driving through 26 gauge aluminum (x20d).

individual piece. When the nail was pulled, the metal was lifted with the nail. This eliminated the possibility of increased withdrawal resistance which could result from the nail passing back through metal which was not free to move.

Nailing girts

For many years one inch lumber has been commonly used for the sheathing or nailing girts in the application of all roofing, regardless of whether or not the deck were solid. Recently, two inch lumber has been recommended, especially for use with metal roofing. Thicker sheathing results in greater withdrawal resistance of the nails thus permitting a greater spacing. With the two inch lumber and the greater spacing, costs can be kept equal to or less than that of 1" sheathing and undoubtedly result in a more securely fastened roof.

Comparative data for one inch and two inch sheathing were lacking; therefore, it seemed wise to include both in the investigation. Sixteen nails were selected from the original 33 for driving into one inch lumber.

Since both one inch and two inch lumber were used, it was not thought necessary to drive the nails to different depths. For this reason an attempt was made to drive all nails to a uniform depth which approximated actual conditions. Most of the roofing used was the 1-1/4 inch corrugation for which the corrugation height is about 5/16 (.3125) inches. Irons shaped like a corrugation were used to provide the correct depth of driving.

Since all nails except No. 30 were approximately 1.75 inches in length, the irons simulating corrugations and the 26 gauge aluminum through which the nails were driven, resulted in a depth of penetration of approximately 1.4 inches. The actual effective depth of penetration was probably somewhat less since in some cases the sloping part of the point is as much as 0.28 inches in length. This leaves an effective depth of slightly more than 1.1 inches.

Keeping the depth driven constant made it possible to compare the results of this investigation with those carried on previously. Also it permitted less difficulty in analyzing the results, since many variables had already been introduced.

Statistical Planning

Randomizations

Separate randomization plans were used for the 1 inch and 2 inch lumber. This was necessary since a different number of nails were driven into each one.

A four by four lattice square plan was used to randomize the placing of the nails in the 1 inch lumber and a seven by seven lattice square plan in the 2 inch lumber.

Figure 50 shows the method of dividing the pieces of lumber and includes the first replica of the randomization plan for nails driven into 2 inch lumber at high moisture content. The ends of the boards were also numbered. The first two digits

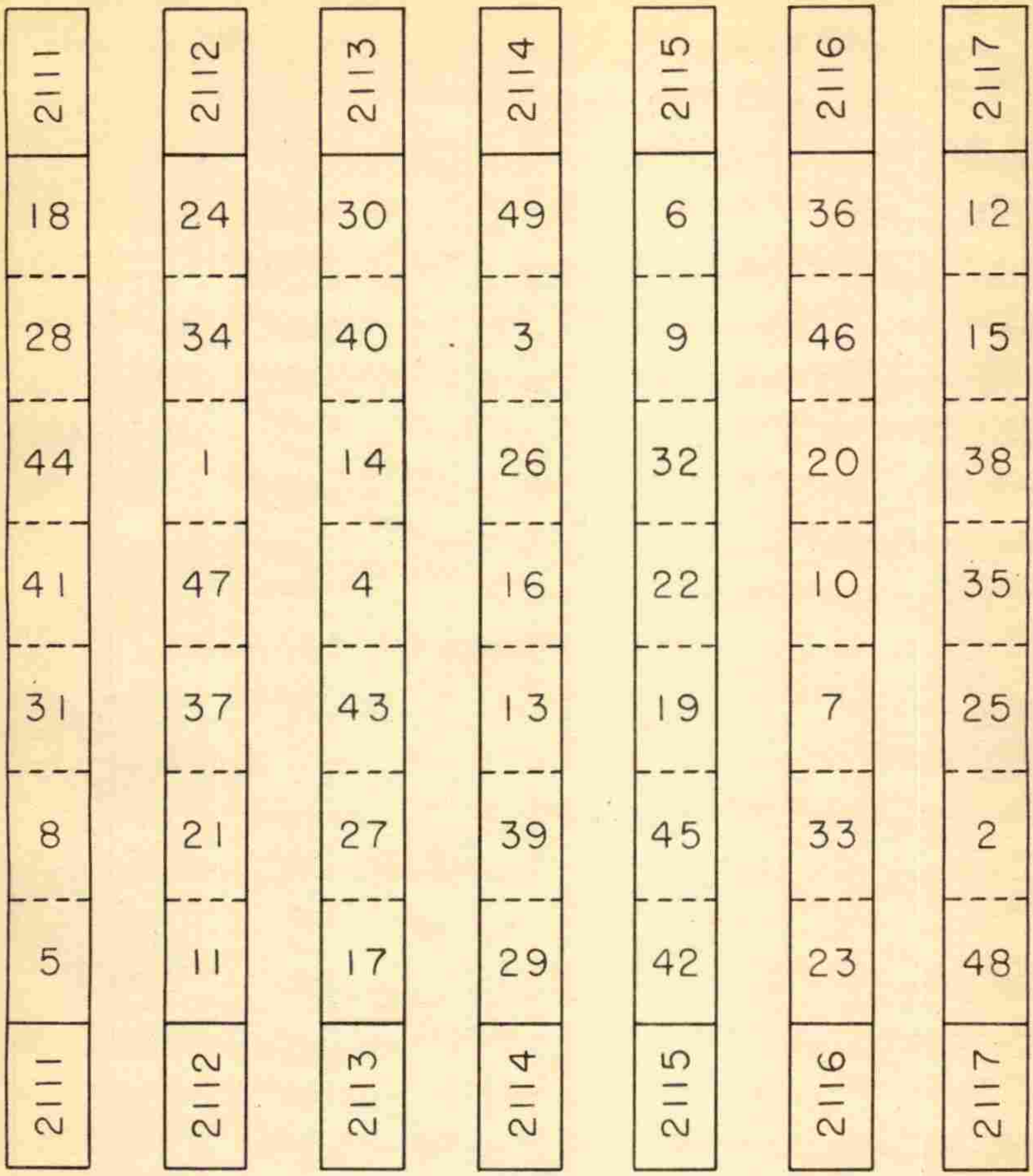

Fig. 50. Division of 2" lumber for driving with first replica of the randomization for driving at high moisture content.

indicate the moisture content at driving; the third digit, the replication number; and the fourth digit, the board number within the replication group. This number was used for recording the moisture content of each piece of lumber.

Replicas necessary

The Statistics Department of the Iowa State College determined that 8 replicas were necessary when using the seven square lattice randomization and 10 replicas when using the four square lattice randomization. The number of replicas was the number of times each nail had to be pulled to eliminate the effect of the variability of the wood by giving each nail an equal chance to appear at any particular place in the group. Figures 51 through 56 show the randomization patterns which were used in this investigation.

Quantity of nails

Using the number of replicas necessary and predetermined number of withdrawals (14), the number of nails to be driven was computed. One extra nail was driven. The number of nails driven were:

2" lumber - (14 withdrawals + 1 extra)(8 replicas)
(49 variations)(3 driving points)
= 17,640 nails.

The number of nails driven into one inch lumber was:

1" lumber - (14 withdrawals + 1 extra)(10 replicas)
(16 variations)(3 driving points)
= 7,200 nails.

Replica No. 1

Board Number			
1	2	3	4
8	3	14	9
11	16	1	6
13	10	7	4
2	5	12	15

Replica No. 2

Board Number			
1	2	3	4
8	11	13	2
10	5	3	16
1	14	12	7
15	4	6	9

Replica No. 3

Board Number			
1	2	3	4
2	9	7	16
10	1	15	8
14	5	11	4
6	13	3	12

Replica No. 4

Board Number			
1	2	3	4
16	8	12	4
13	5	9	1
14	6	10	2
15	7	11	3

Replica No. 5

Board Number			
1	2	3	4
10	12	11	9
4	2	1	3
13	15	16	14
7	5	6	8

Replica No. 6

Board Number			
1	2	3	4
9	1	13	5
12	4	16	8
10	2	14	6
11	3	15	7

Replica No. 7

Board Number			
1	2	3	4
9	8	3	14
4	13	10	7
6	11	16	1
15	2	5	12

Replica No. 8

Board Number			
1	2	3	4
4	9	15	6
5	16	10	3
14	7	1	12
11	2	8	13

Replica No. 9

Board Number			
1	2	3	4
4	1	3	2
13	16	14	15
7	6	8	5
10	11	9	12

Replica No. 10

Board Number			
1	2	3	4
1	8	10	15
9	16	2	7
5	4	14	11
13	12	6	3

Fig. 51. Randomizations for nails driven in 1" lumber at high moisture content.

Replica No. 1

Board Number						
1	2	3	4	5	6	7
18	24	30	49	6	36	12
28	34	40	3	9	46	15
44	1	14	26	32	20	38
41	47	4	16	22	10	35
31	37	43	13	19	7	25
8	21	27	39	45	33	2
5	11	17	29	42	23	48

Replica No. 2

Board Number						
1	2	3	4	5	6	7
6	44	25	21	40	10	29
23	19	49	38	8	34	4
15	11	41	30	7	26	45
47	36	17	13	32	2	28
39	35	9	5	24	43	20
31	27	1	46	16	42	12
14	3	33	22	48	18	37

Replica No. 3

Board Number						
1	2	3	4	5	6	7
46	35	8	37	26	6	17
41	23	3	32	21	43	12
19	1	30	10	48	28	39
14	45	25	5	36	16	34
24	13	42	15	4	33	44
2	40	20	49	31	11	22
29	18	47	27	9	38	7

Replica No. 4

Board Number						
1	2	3	4	5	6	7
17	19	18	21	15	20	16
31	33	32	35	29	34	30
45	47	46	49	43	48	44
38	40	39	42	36	41	37
3	5	4	7	1	6	2
24	26	25	28	22	27	23
10	12	11	14	8	13	9

Replica No. 5

Board Number						
1	2	3	4	5	6	7
16	23	37	2	44	9	30
20	27	41	6	48	13	34
18	25	39	4	46	11	32
17	24	38	3	45	10	31
15	22	36	1	43	8	29
19	26	40	5	47	12	33
21	28	42	7	49	14	35

Replica No. 6

Board Number						
1	2	3	4	5	6	7
39	29	26	16	3	13	49
33	23	20	10	46	7	36
2	48	38	35	15	25	12
45	42	32	22	9	19	6
8	5	44	41	28	31	18
21	11	1	47	34	37	24
27	17	14	4	40	43	30

Replica No. 8

Board Number						
1	2	3	4	5	6	7
17	39	44	7	12	34	22
6	28	33	38	43	16	11
35	1	13	18	23	45	40
26	48	4	9	21	36	31
46	19	24	29	41	14	2
8	30	42	47	3	25	20
37	10	15	27	32	5	49

Replica No. 8

Board Number						
1	2	3	4	5	6	7
39	31	6	15	23	14	47
24	16	40	7	8	48	32
43	42	10	26	34	18	2
35	27	44	11	19	3	36
20	12	29	45	4	37	28
5	46	21	30	38	22	13
9	1	25	41	49	33	17

Fig. 52. Randomizations for nails driven in 2" lumber at high moisture content.

Replica No. 1

Board Number			
1	2	3	4
13	9	1	5
15	11	3	7
16	12	4	8
14	10	2	6

Replica No. 2

Board Number			
1	2	3	4
16	1	11	6
5	12	2	15
10	7	13	4
3	14	8	9

Replica No. 3

Board Number			
1	2	3	4
12	3	13	6
8	15	1	10
4	11	5	14
16	7	9	2

Replica No. 4

Board Number			
1	2	3	4
14	13	15	16
8	7	5	6
3	4	2	1
9	10	12	11

Replica No. 5

Board Number			
1	2	3	4
7	14	12	1
16	5	3	10
9	4	6	15
2	11	13	8

Replica No. 6

Board Number			
1	2	3	4
8	14	9	3
11	1	6	16
2	12	15	5
13	7	4	10

Replica No. 7

Board Number			
1	2	3	4
3	15	11	7
1	13	9	5
4	16	12	8
2	14	10	6

Replica No. 8

Board Number			
1	2	3	4
6	9	15	4
13	2	8	11
3	16	10	5
12	7	1	14

Replica No. 9

Board Number			
1	2	3	4
11	10	9	12
1	4	3	2
6	7	8	5
16	13	14	15

Replica No. 10

Board Number			
1	2	3	4
5	11	4	14
1	15	8	10
9	7	16	2
13	3	12	6

Fig. 53. Randomizations for nails driven in 1" lumber at intermediate moisture content.

Replica No. 1

Board Number						
1	2	3	4	5	6	7
27	39	33	8	45	2	21
43	13	7	31	19	25	37
4	16	10	41	22	35	47
40	3	46	28	9	15	34
30	49	36	18	6	12	24
14	26	20	44	32	38	1
17	29	23	5	42	48	11

Replica No. 2

Board Number						
1	2	3	4	5	6	7
43	9	20	39	35	5	24
10	25	29	6	44	21	40
18	33	37	14	3	22	48
42	1	12	31	27	46	16
34	49	4	23	19	38	8
2	17	28	47	36	13	32
26	41	45	15	11	30	7

Replica No. 3

Board Number						
1	2	3	4	5	6	7
46	35	8	37	26	6	17
41	23	3	32	21	43	12
19	1	30	10	48	28	39
14	45	25	5	36	16	34
24	13	42	15	4	33	44
2	40	20	49	31	11	22
29	18	47	27	9	38	7

Replica No. 4

Board Number						
1	2	3	4	5	6	7
18	20	17	15	19	21	16
4	6	3	1	5	7	2
32	34	31	29	33	35	30
46	48	45	43	47	49	44
39	41	38	36	40	42	37
11	13	10	8	12	14	9
25	27	24	22	26	28	23

Replica No. 5

Board Number						
1	2	3	4	5	6	7
15	22	29	36	43	1	8
21	28	35	42	49	7	14
17	24	31	38	45	3	10
18	25	32	39	46	4	11
19	26	33	40	47	5	12
20	27	34	41	48	6	13
16	23	30	37	44	2	9

Replica No. 6

Board Number						
1	2	3	4	5	6	7
8	18	31	5	41	28	44
21	24	37	11	47	34	1
27	30	43	17	4	40	14
45	6	19	42	22	9	32
2	12	25	48	35	15	38
33	36	7	23	10	46	20
39	49	13	29	16	3	26

Replica No. 7

Board Number						
1	2	3	4	5	6	7
3	47	42	25	8	30	20
43	38	33	16	6	28	11
41	29	24	14	46	19	2
12	7	44	34	17	39	22
32	27	15	5	37	10	49
23	18	13	45	35	1	40
21	9	4	36	26	48	31

Replica No. 8

Board Number						
1	2	3	4	5	6	7
47	23	14	31	15	6	39
13	38	22	46	30	21	5
28	4	37	12	45	29	20
36	19	3	27	11	44	35
17	49	33	1	41	25	9
32	8	48	16	7	40	24
2	34	18	42	26	10	43

Fig. 54. Randomizations for nails driven in 2" lumber at intermediate moisture content.

Replica No. 1

Board Number			
1	2	3	4
12	9	11	10
8	5	7	6
4	1	3	2
16	13	15	14

Replica No. 2

Board Number			
1	2	3	4
9	8	14	3
12	5	15	2
10	7	13	4
11	6	16	1

Replica No. 3

Board Number			
1	2	3	4
11	13	8	2
16	10	3	5
6	4	9	15
1	7	14	12

Replica No. 4

Board Number			
1	2	3	4
11	14	5	4
13	12	3	6
2	7	16	9
8	1	10	15

Replica No. 5

Board Number			
1	2	3	4
9	13	5	1
2	6	14	10
16	12	4	8
7	3	11	15

Replica No. 6

Board Number			
1	2	3	4
14	15	13	16
10	11	9	12
2	3	1	4
6	7	5	8

Replica No. 7

Board Number			
1	2	3	4
6	13	12	3
15	8	1	10
4	11	14	5
9	2	7	16

Replica No. 8

Board Number			
1	2	3	4
9	8	3	14
12	5	2	15
11	6	1	16
10	7	4	13

Replica No. 9

Board Number			
1	2	3	4
10	14	2	6
15	11	7	3
1	5	9	13
8	4	16	12

Replica No. 10

Board Number			
1	2	3	4
14	12	1	7
8	2	11	13
9	15	6	4
3	5	16	10

Fig. 55. Randomizations for nails driven in 1" lumber at low moisture content.

Replica No. 1

Board Number						
1	2	3	4	5	6	7
37	13	7	43	19	25	31
47	16	10	4	22	35	41
11	29	23	17	42	48	5
34	3	46	40	9	15	28
21	39	33	27	45	2	8
24	49	36	30	6	12	18
1	26	20	14	32	38	44

Replica No. 2

Board Number						
1	2	3	4	5	6	7
41	26	7	15	11	45	30
49	34	8	23	19	4	38
9	43	24	39	35	20	5
33	18	48	14	3	37	22
17	2	32	47	36	28	13
25	10	40	6	44	29	21
1	42	16	31	27	12	46

Replica No. 3

Board Number						
1	2	3	4	5	6	7
30	39	1	28	48	10	19
47	7	18	38	9	27	29
25	34	45	16	36	5	14
42	44	13	33	4	15	24
3	12	23	43	21	32	41
8	17	35	6	26	37	46
20	22	40	11	31	49	2

Replica No. 4

Board Number						
1	2	3	4	5	6	7
24	25	22	23	28	26	27
38	39	36	37	42	40	41
10	11	8	9	14	12	13
31	32	29	30	35	33	34
17	18	15	16	21	19	20
3	4	1	2	7	5	6
45	46	43	44	49	47	48

Replica No. 5

Board Number						
1	2	3	4	5	6	7
8	36	15	29	1	22	43
10	38	17	31	3	24	45
11	39	18	32	4	25	46
12	40	19	33	5	26	47
14	42	21	35	7	28	49
13	41	20	34	6	27	48
9	37	16	30	2	23	44

Replica No. 6

Board Number						
1	2	3	4	5	6	7
14	27	17	40	43	30	4
1	21	11	34	37	24	47
20	33	23	46	7	36	10
44	8	5	28	31	18	41
38	2	48	15	25	12	35
26	39	29	3	13	49	16
32	45	42	9	19	6	22

Replica No. 7

Board Number						
1	2	3	4	5	6	7
46	19	2	14	29	24	41
8	30	20	25	47	42	3
6	28	11	16	38	33	43
17	39	22	34	7	44	12
35	1	40	45	18	13	23
37	10	49	5	27	15	32
26	48	31	36	9	4	21

Replica No. 8

Board Number						
1	2	3	4	5	6	7
43	2	26	18	42	34	10
24	32	7	48	16	8	40
5	13	30	22	46	38	21
9	17	41	33	1	49	25
20	28	45	37	12	4	29
39	47	15	14	31	23	6
35	36	11	3	27	19	44

Fig. 56. Randomizations for nails driven in 2" lumber at low moisture content.

Quantity of lumber

Previous tests showed that the nails could be placed as close as one inch laterally and three inches longitudinally in the lumber. Lumber six inches in width was used instead of lumber four inches in width which was used in previous tests. Since 5 rows of nails could be placed across the six inch width to three rows across the four inch width, 67 per cent more nails could be driven into 50 per cent more lumber.

Seven foot pieces of 2" by 6" were used for the two inch lumber. Eight foot pieces of 1" by 6" were used for the one inch lumber and two groups of nails driven into it. The amount of lumber was computed as:

2"x6" - (7 ft. long)(1 bd.ft./ft.)(7 bd./group)
(8 replicas)(3 driving points)
= 1176 bd. ft.

1"x6" - (8 ft. long)(0.5 bd.ft./ft.)(4 bd./group)
(10 replicas)(3 driving points)
= 480 bd. ft.

Equipment Used

Pulling apparatus

The apparatus used for pulling the nails shown in Figure 57 was a modification of the one used for previous tests. It was found that a large error was possible if the diaphragm which was previously used had a low oil level. The diaphragm was replaced by a 4 inch hydraulic cylinder to which was

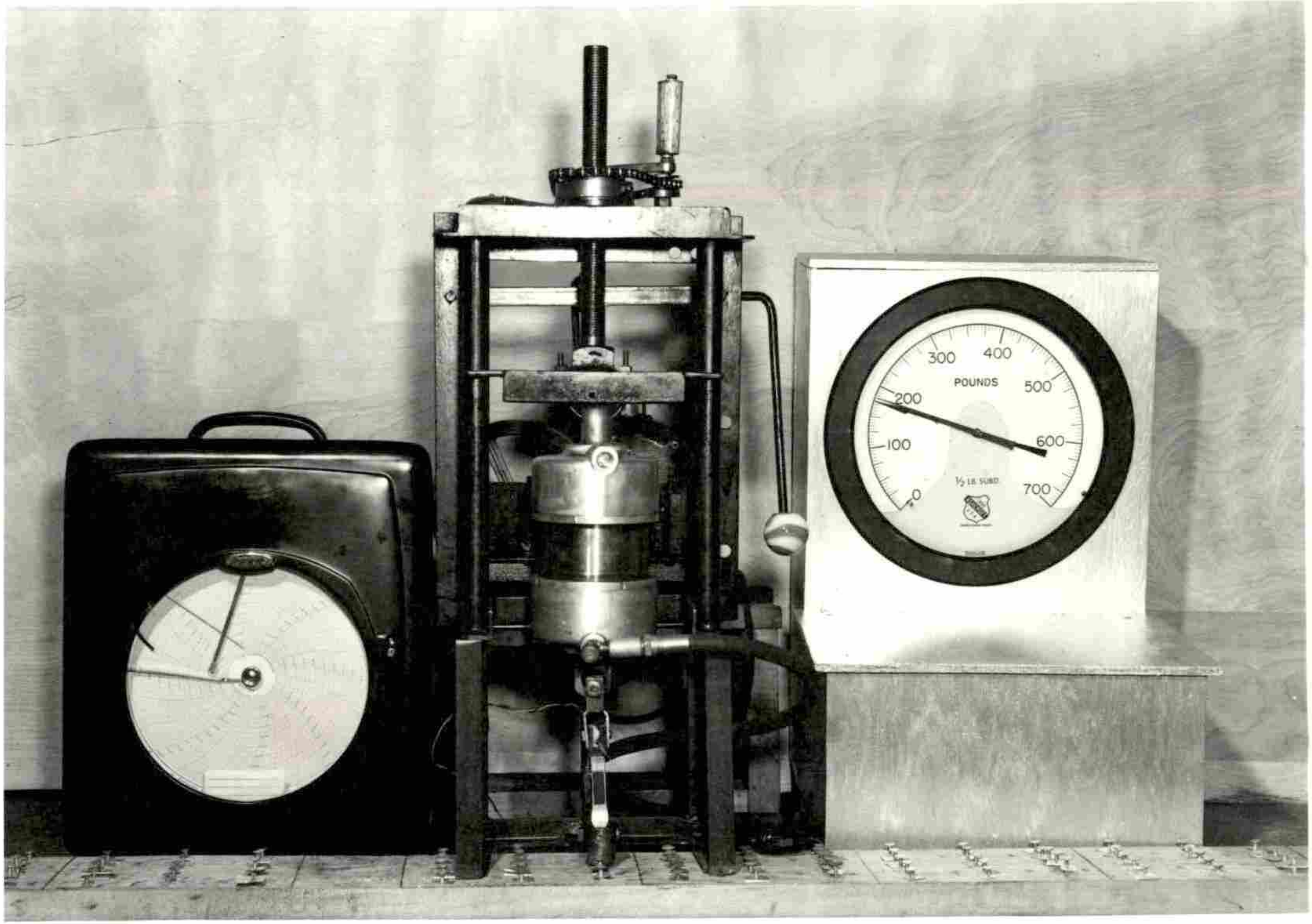

Fig. 57. Nail pulling machine with pressure gauge and strain gauge.

attached a 12 inch bourdon tube pressure gauge. The pressure gauge which was calibrated directly in pounds, was equipped with a maximum reading indicator. This, in addition to the large size dial, made reading easier and no doubt resulted in greater accuracy. At no time was the error greater than 2 per cent during calibration by lead weights.

The hook with which to pull the nails was made to simulate, as nearly as possible, an actual corrugation. This was accomplished by welding a curved section of pipe into the end of another piece of pipe. This was then slotted along the axis of the simulated corrugation to allow the nail to slide in with the head above the curved portion. The free swivel which was used previously was not used since it was felt that the nail hook more nearly approached actual conditions.

An attempt was made to utilize the electric strain gauge to record the force required for withdrawal. After considerable time and thought, it was found that a piece of aluminum machined to the proper dimensions might be used as a base for which to fasten the strain gauges.

Since the Strain Gauge Recorder had a minimum range of from 0 to 2000 microinches and the maximum force was expected to be less than 1000 pounds, a relationship of one pound of pull resulting in two microinches of strain was used for determining the size of the piece of metal to be used. Aluminum was chosen since a piece of steel small enough to give the required force-strain relationship was stressed above the elastic limit. The aluminum used was found to have a modulus of elasticity lower than the 10,600,000 p.s.i. generally accredited to it. The value determined was 8,160,000 p.s.i. Using this value and some basic mechanics relationships obtained from Seeley (27), the cross sectional area was computed. A minimum thickness was decided to be 0.10 inches so that the width might be determined. Use was made of the relationship of one pound of force resulting in two microinches of strain and the following formulas: (1) $s = \frac{P}{A}$ and (2) $E = \frac{S}{\epsilon}$ where P is the axial load; s, the unit stress; A, the cross sectional area; ϵ, the unit strain; and E, the modulus of elasticity in tension.

$$S = \frac{P}{A} \qquad E = \frac{S}{\epsilon} \qquad \therefore S = \epsilon E$$

$$\frac{P}{A} = E\epsilon$$

$$A = \frac{P}{\epsilon E} = \frac{1 \text{ lb.}}{2(10^{-6})(8.16)(10^{6})} = \frac{1}{16.32}$$

$$= 0.0612 \text{ square inches}$$

Assume thickness, t = 0.10 then width, $w = \frac{.0612}{.10} = 0.612$ inches.

The piece of aluminum was machined to 0.10 inches in thickness and 0.63 inches in width leaving the rest to be removed after the gauges have been applied and subjected to load. It was necessary to apply gauges to each side of the metal to eliminate bending stress since having the pivot points as little as 10 per cent off the axis would double the bending stress if a gauge were not applied to each side. Two gauges must also be attached to the compensating piece of metal. The compensating piece is used to correct for temperature changes.

Extensive tests of the strain gauge indicated that it was not as satisfactory as the pressure gauge. However, it was valuable as a check and also for making the deflection diagrams. Figure 58 shows a chart taken from the strain gauge recorder. The strain gauge records time and force. The time can be changed to the upward movement of the screw which is constant and the deflection in the linkage at all loads was determined and is shown in Figure 59.

Moisture control and measurement

Both humidifying and drying were necessary to make the desired moisture changes in the wood. For the purpose of raising the moisture content, a temporary structure was built of aluminum and a humidifier installed. Figure 60 shows the humidifier, the water storage tank, a blower for air circulation and pans filled with water to further aid in increasing the relative humidity which largely controls the moisture content of the wood.

Drying was accomplished by placing the wood in an insulated room, placing calcium chloride in pans under it and raising the temperature to approximately 110^{o} F. A fan was used to circulate the air and aid in drying. Figure 61 shows the drying room.

A Tag-Heppenstall moisture meter, Figure 62 was used to check the changes in moisture content. While not as precise as

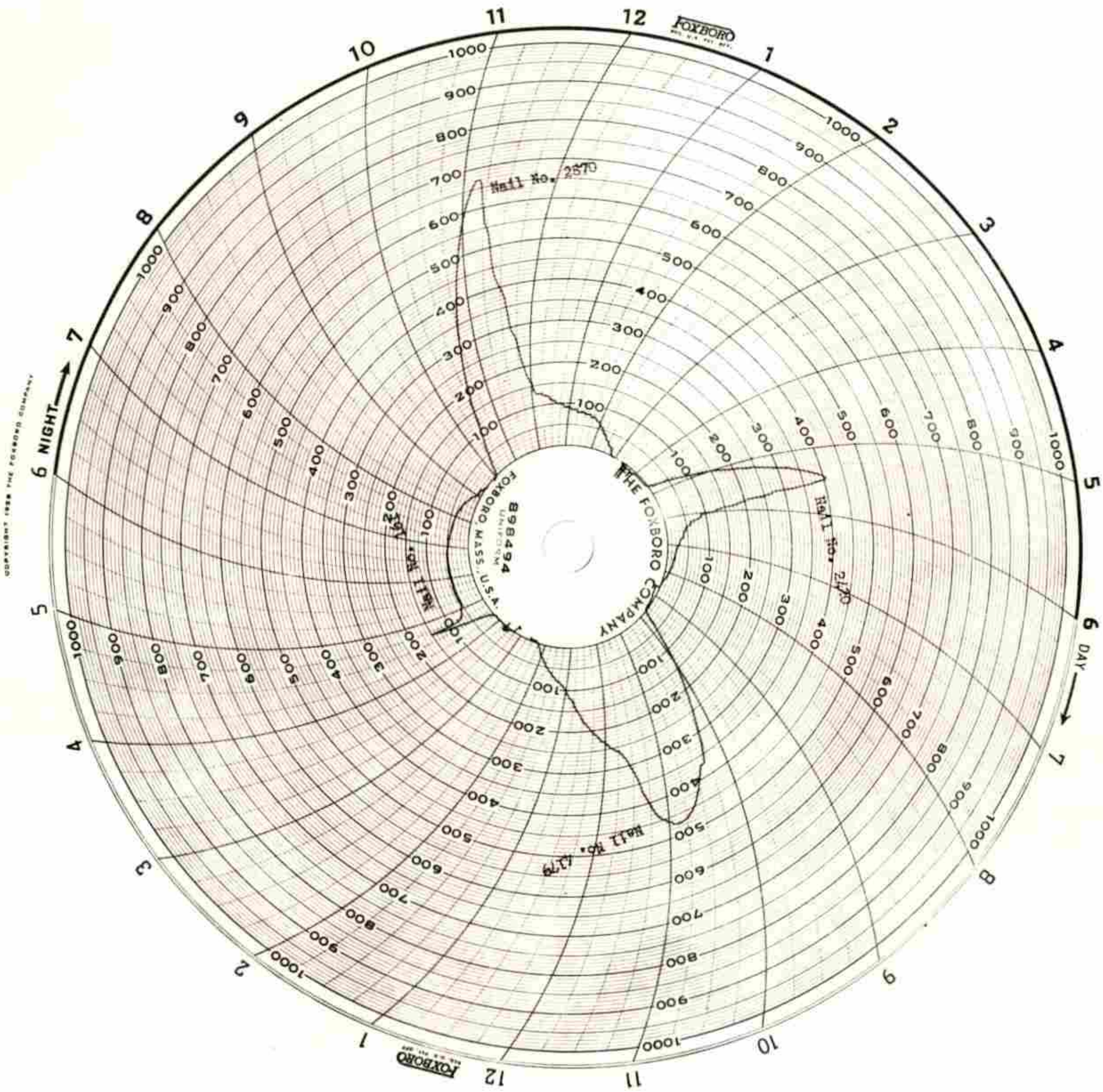

Fig. 58. Chart taken from the strain gauge recorder.

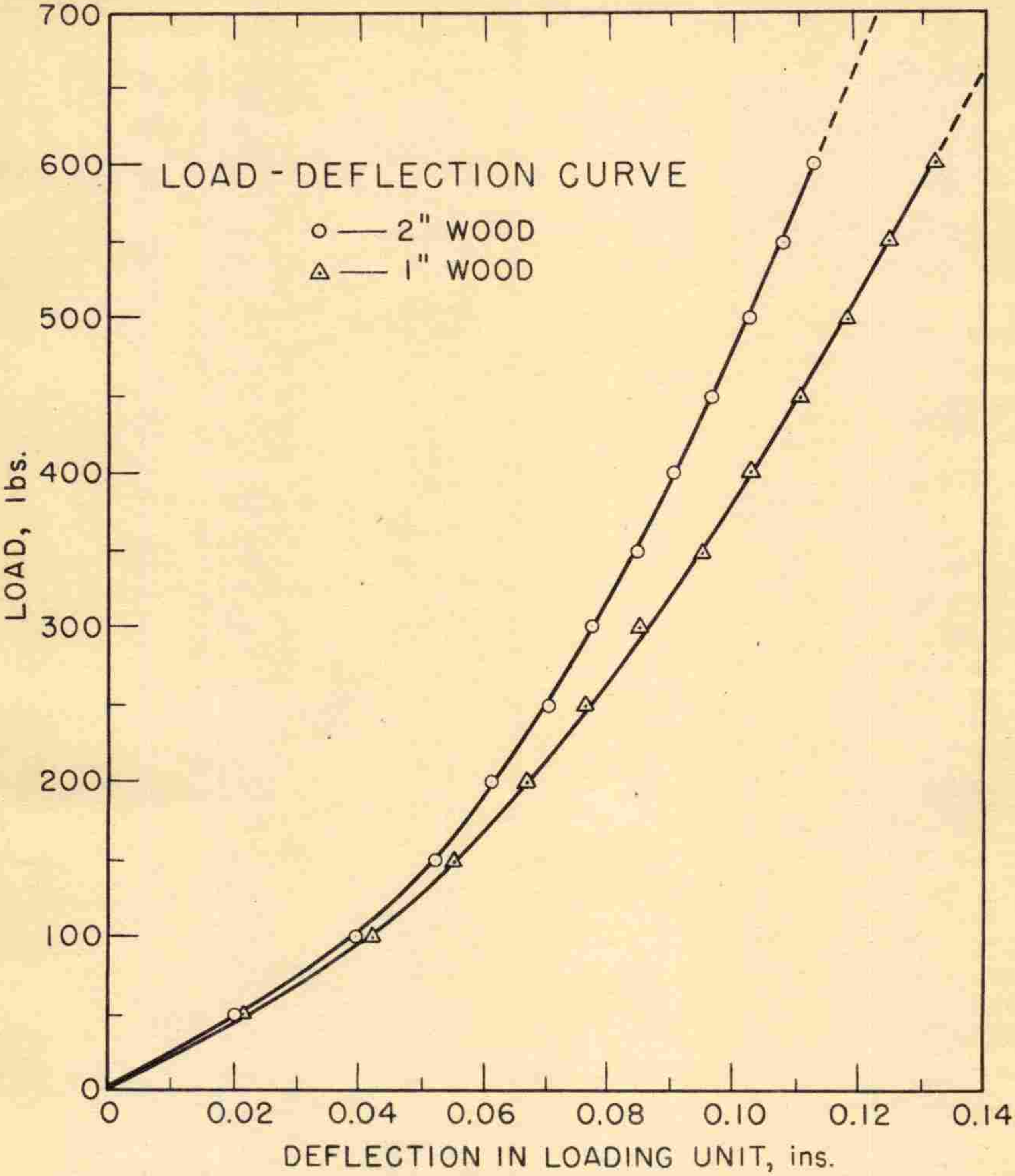

Fig. 59. Load-deflection curves showing the deflection in the linkage of the nail pulling machine.

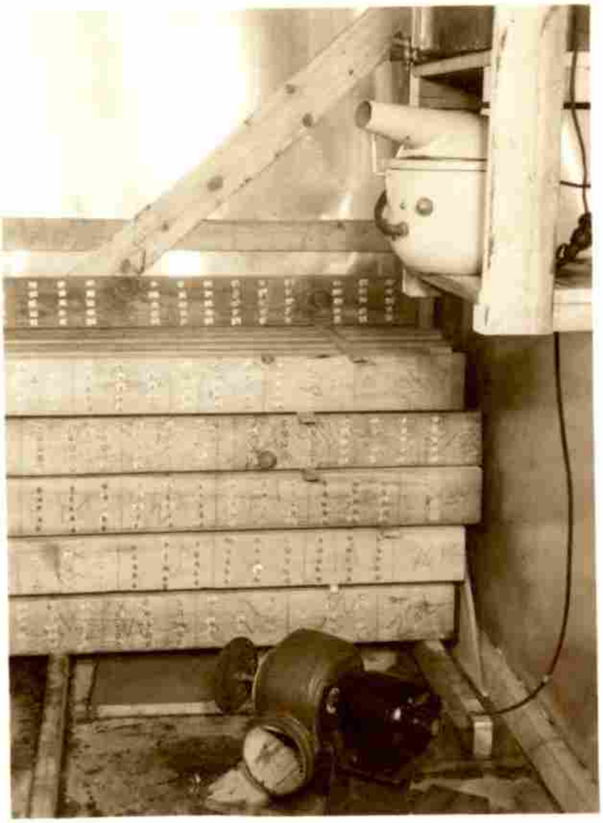

Fig. 60. Humidifying room.

Fig. 61. Drying room.

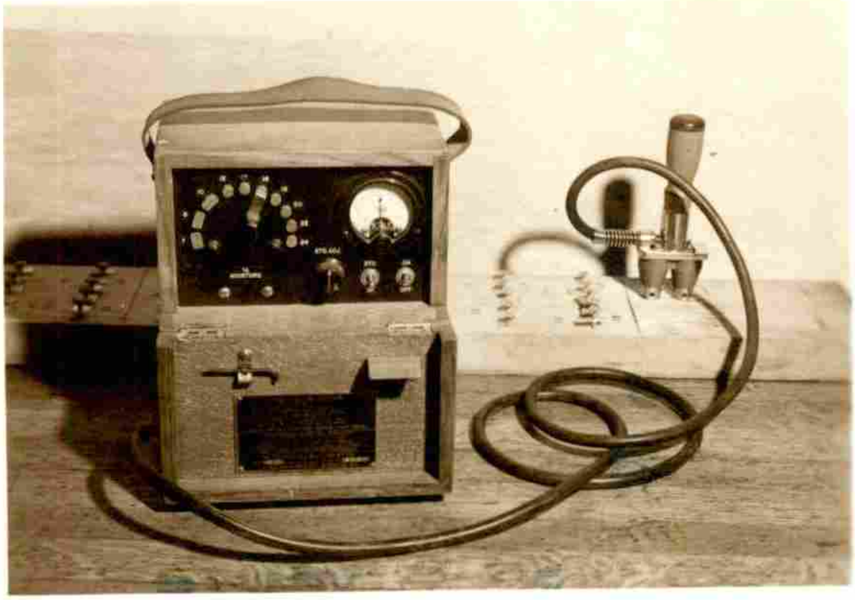

Fig. 62. Tag-Heppenstall moisture meter.

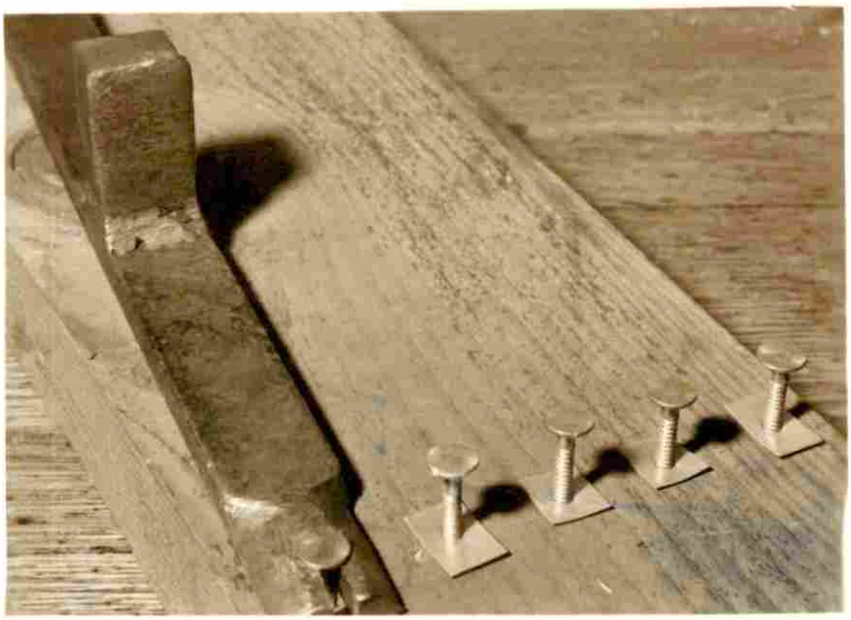

Fig. 63. Corrugation shaped iron used to keep the depth of driving constant.

checking the weight, the moisture meter has proven quite satisfactory. Since there were 168 pieces of lumber, it was impractical to weigh them. However, a group of seven 2 inch pieces of lumber was checked and gave results in agreement with the electric moisture meter.

Simulation of roofing and corrugations

Figure 63 indicates the use of the iron which simulates the corrugations and also the use of the metal. The part of the iron which extends upward is used to remove the iron from the nail after it has been driven down tightly.

Data sheet

Figure 64 shows the form used for recording data and is filled out for nail number 2597 when driven into wood of high moisture content.

Observation Made During Research

Characteristics of wood

It was found that the nails drove quite easily into wood of high moisture content. However, as the wood became drier, more force was required to drive the nails. Little splitting occurred during driving into two inch lumber, and most of what did occur was at the low moisture content driving point.

In one inch lumber splitting occurred at all driving points.

DATA SHEET FOR NAIL WITHDRAWAL TESTS

OBSERVER Boyd NAIL NUMBER 2597

DATE OF DRIVING 6-24-48 WOOD 2" Douglas Fir MOISTURE 21%

DRIVING CONDITIONS 26 gauge al. DEPTH OF DRIVING 1-7/16 inches

TEST NAIL NUMBER	WITHDRAWAL FORCE IN POUNDS													
	IMMEDIATE AT 21.1 %	1st CYCLE					2nd CYCLE				3rd CYCLE			
		MOISTURE CONTENT AND WITHDRAWAL DATE					MOISTURE CONTENT AND WITHDRAWAL DATE				MOISTURE CONTENT AND WITHDRAWAL DATE			
		15.0 %	8.6 %	14.8 %	17.2 %	%	%	%	%	%	%	%	%	%
	7/24	7/30	8/7	8/16	8/26									
1.	470	536	480	608	495									
2.	313	370	402	353	359									
3.	424	445	481	498	400									
4.	385	435	470	440	430									
5.	429	450	498	527	470									
6.	418	432	552	575	393									
7.	446	555	550	540	535									
8.	388	418	420	390	396									
9.														
10.														
TOT.	3273	3641	3853	3931	3478									
AV.	409	455	482	491	435									

REMARKS

Fig. 64. Data sheet

It was not appreciable at the high moisture driving point, but became disturbing at the medium moisture driving point. It became so serious at the low moisture driving point that the spacing had to be increased.

Considerable time is required for changing moisture content. In general the less dense pieces of lumber tend to make the changes more rapidly than do the more dense. Moisture readings depend to some extent upon how firmly the points of the moisture meter are driven into the wood.

Characteristics of nails

Generally speaking the plain shank nails tend to drive more easily than the other types.

Ring shank nails bend more easily than do the other types and if an attempt is made to straighten them they quite often break. This is true of both aluminum and steel nails. Bending is also affected by the head type, since the hammer tends to slide off of curved heads. Flat heads give less trouble and result in less bending during driving.

Screw shank nails often turn in the hook during withdrawal. Those with the greatest resistance attain a major portion of it before beginning to turn. Screw shanks with long leads tend to begin turning almost immediately after the force is applied.

Considerable head failure was experienced with some aluminum nails. In most cases of head failure the head was not as thick as the heads of those not failing. If the head is properly designed it will not fail at loads less than that required to withdraw the nail.

ANALYSIS

Withdrawal Resistance - 2" Lumber

General

The results of the withdrawal tests of the nails driven at 21 per cent moisture content are shown in Figure 65. The moisture contents used in the graph are an average of the moisture contents at withdrawal of the 49 nail variations and approximate the actual withdrawal conditions. Complete data for all three of the driving points are available in the appendix.

The graph shows a rather general superiority for the ring shank group. However, some of the screw shank nails exceeded some of the ring shanks, so certainly they must be considered. The nail exhibiting the greatest holding power was the monel ring shank, No. 2597.

The graph gives a general indication of the capabilities of the various nails. However, screw shank and combination shank nails have greater perimeters resulting from the deformation of the shank. Was the increase in withdrawal resistance attributable to the increase in perimeter, or did the threads add some mechanical resistance to the frictional resistance? What was the effect of increased cross sectional area? Certainly more wood was displaced by a nail with a greater cross

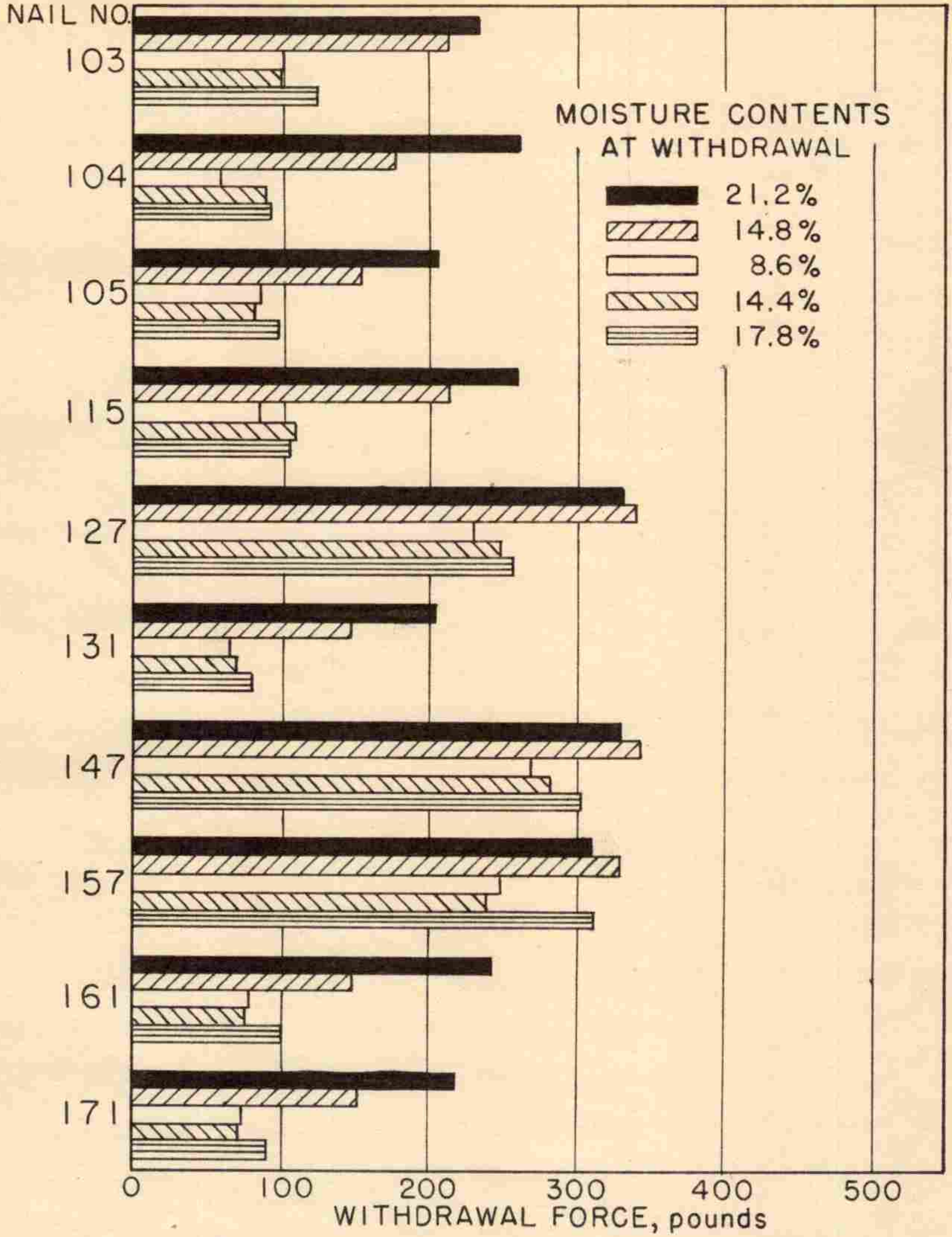

Fig. 65a. Withdrawal resistance of roofing nails driven into 2" lumber at 21 per cent moisture content.

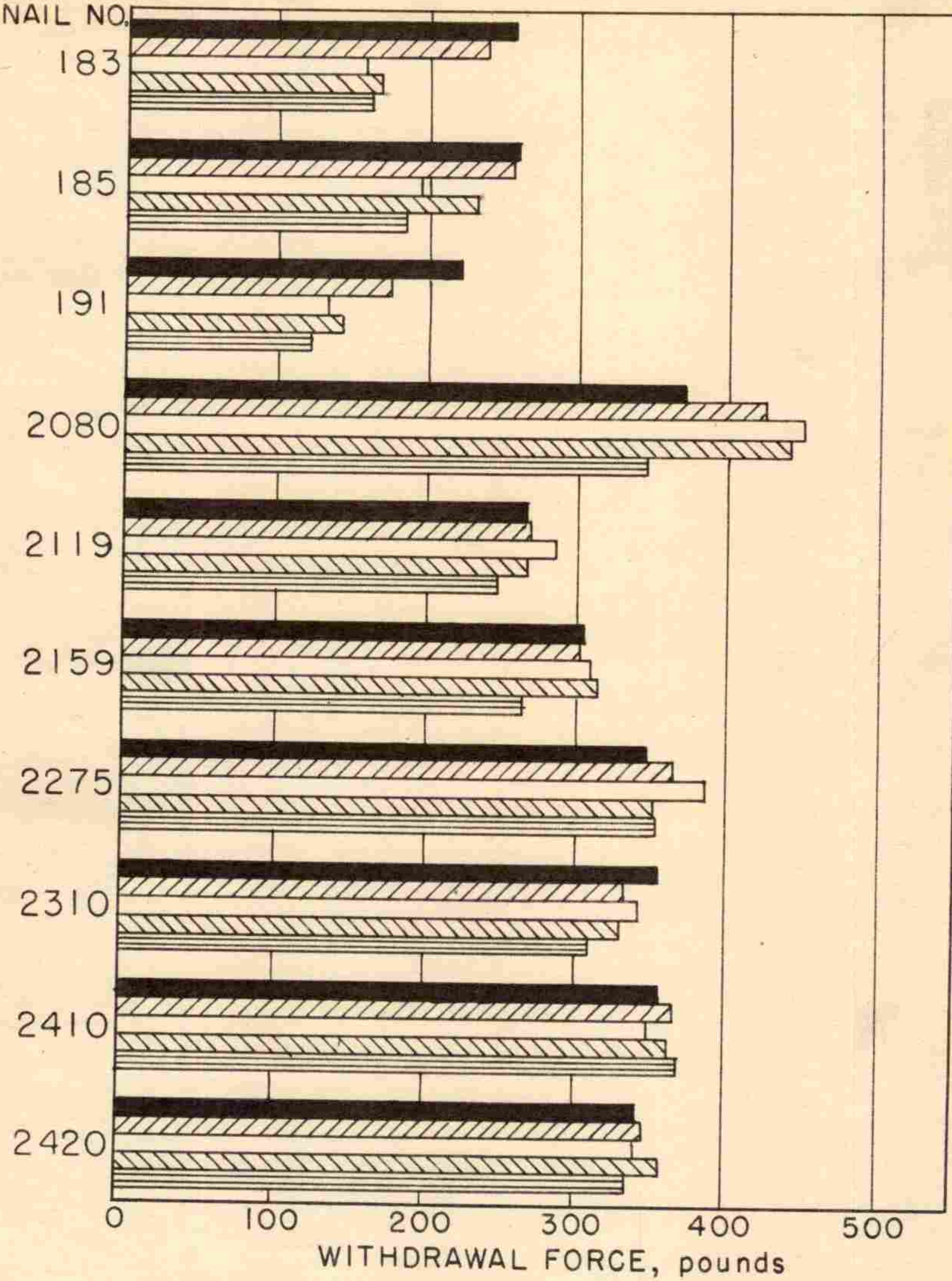

Fig. 65b. Withdrawal resistance of roofing nails driven into 2" lumber at 21 per cent moisture content.

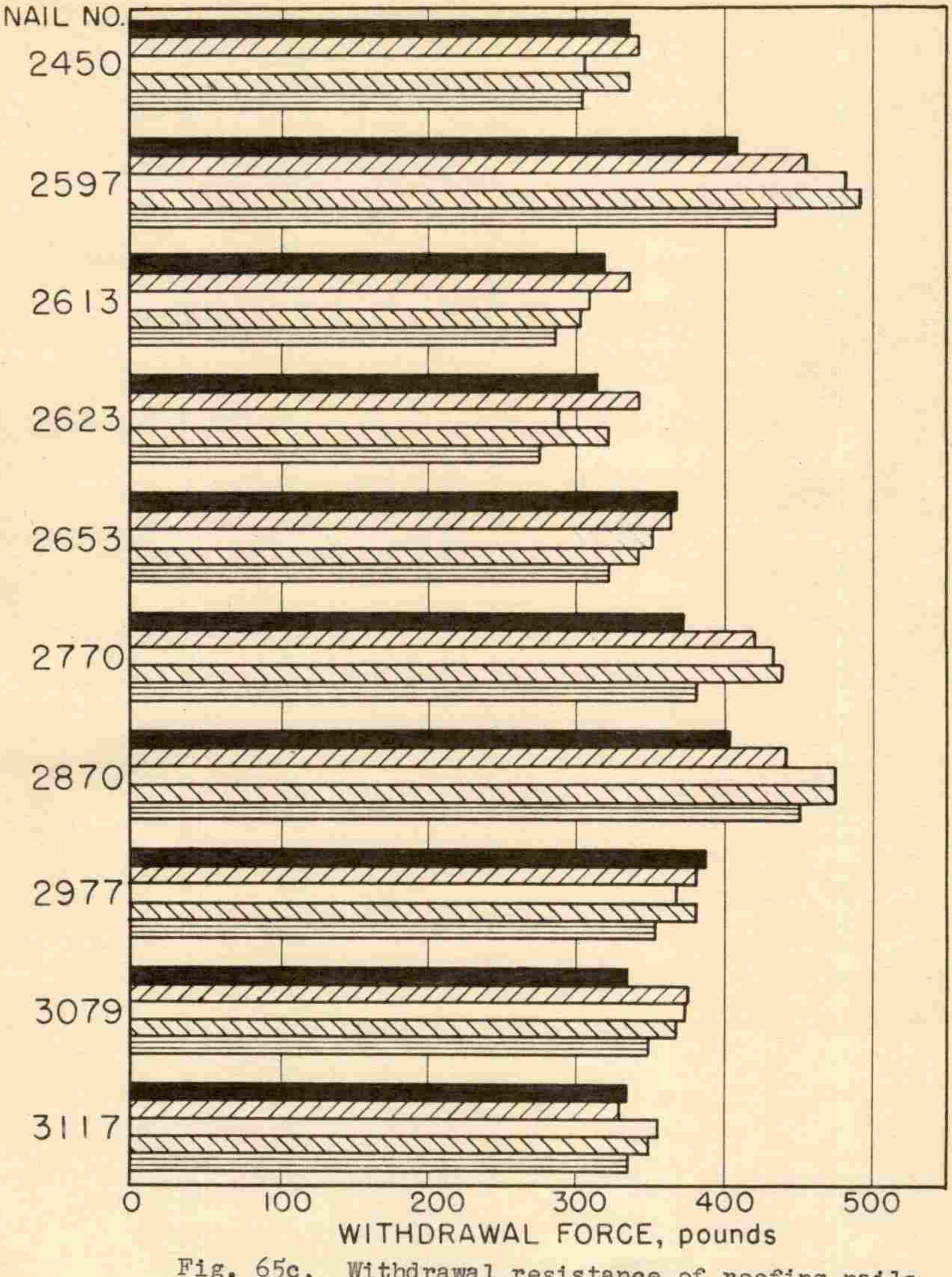

Fig. 65c. Withdrawal resistance of roofing nails driven into 2" lumber at 21 per cent moisture content.

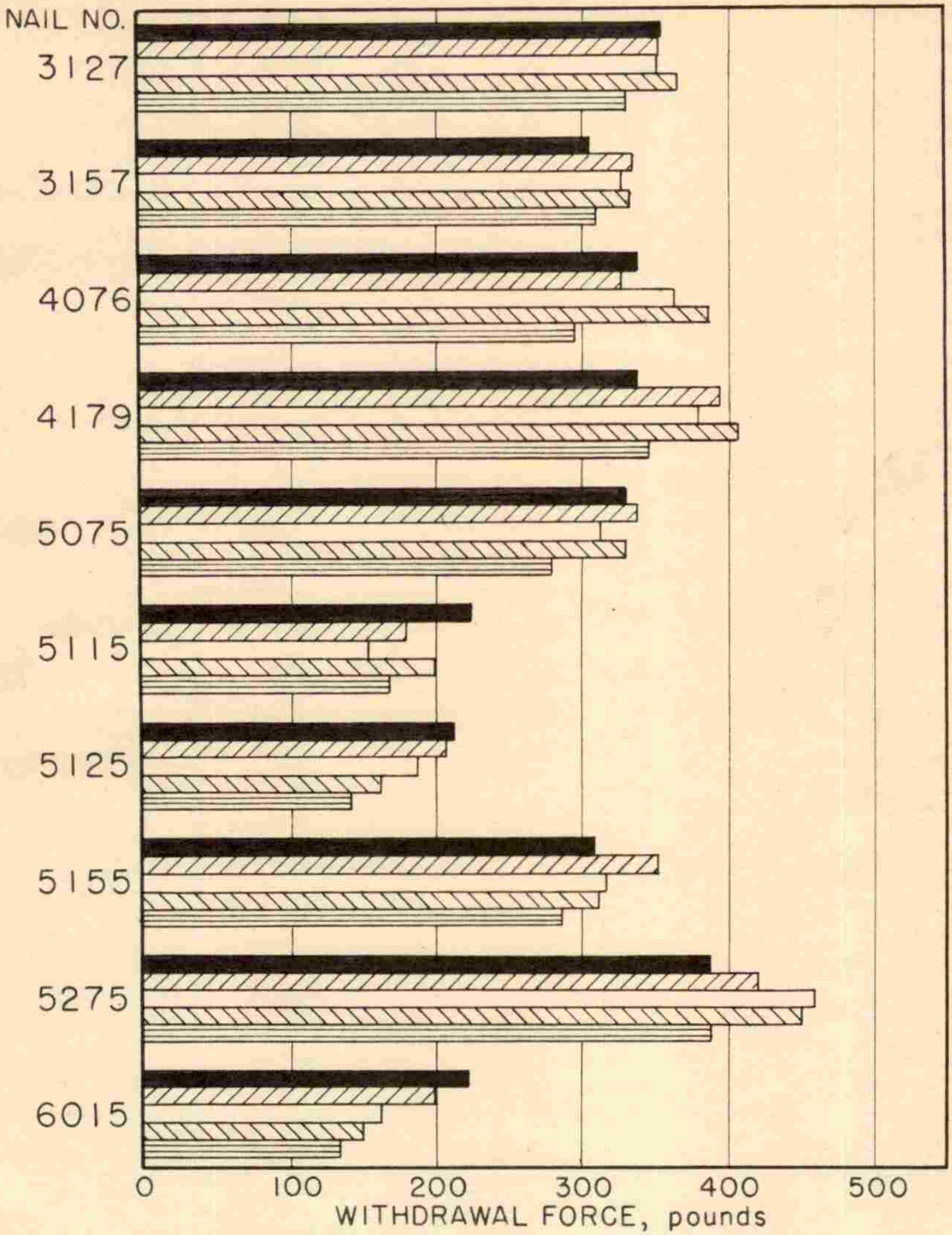

Fig. 65d. Withdrawal resistance of roofing nails driven into 2" lumber at 21 per cent moisture content.

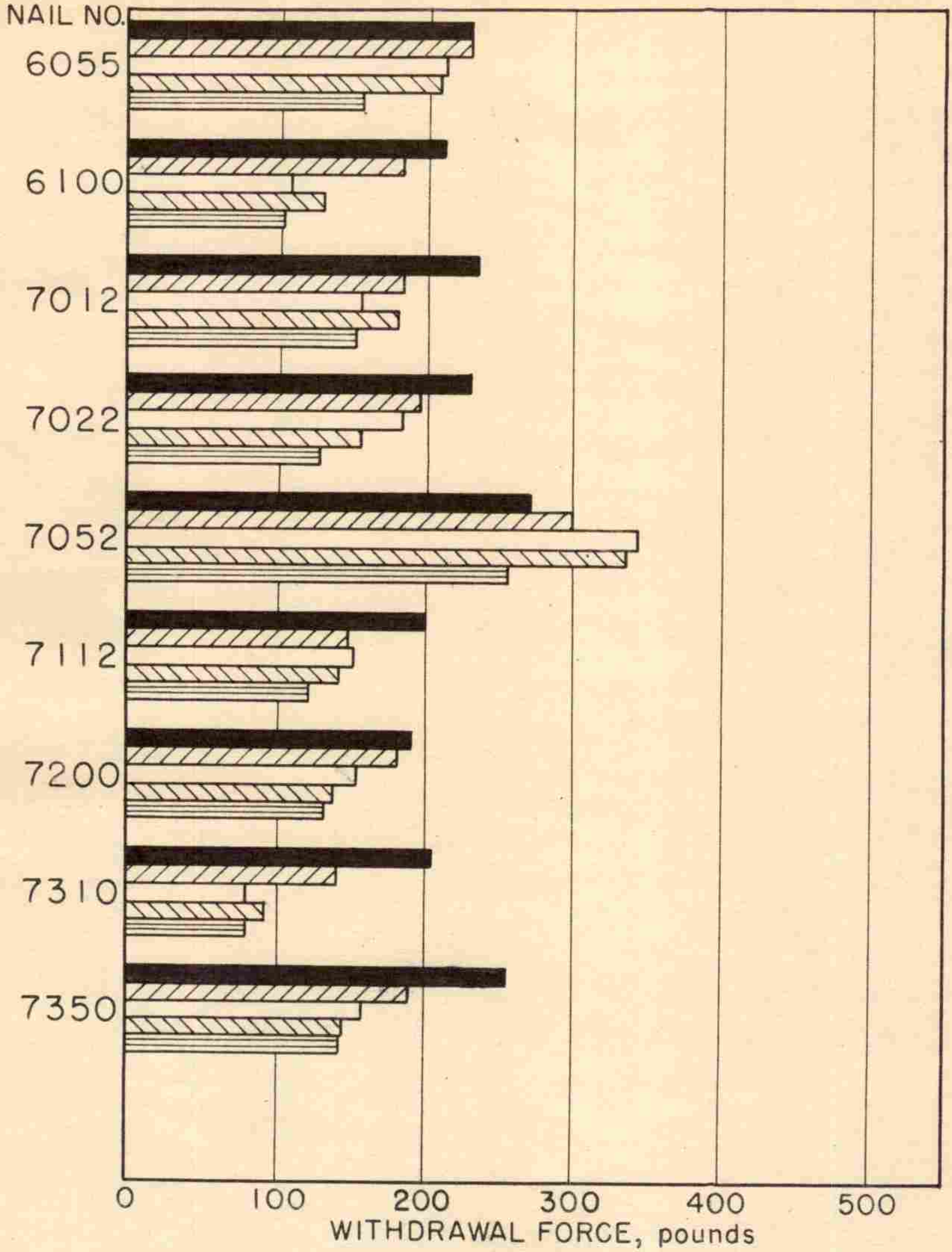

Fig. 65e. Withdrawal resistance of roofing nails driven into 2" lumber at 21 per cent moisture content.

sectional area. Perhaps this affected the withdrawal resistance.

Table III was made to facilitate a comparison of the various nails based on perimeter and cross sectional area. Relative perimeters and areas were computed. Nail No. 2080, having the smallest diameter, was chosen as the basis of this computation and was assigned a relative area and perimeter of 1.0. For plain, barb and ring shank nails, the relative perimeter was obtained by merely dividing the diameter of the nail by the diameter of nail No. 2080; the relative area, by dividing the diameter squared by the diameter square of nail No. 2080. The area and perimeter of the combination shank and screw shank nails were obtained from the photomicrographs (x20d). These values were then divided by the area and perimeter of nail No. 2080.

Some question may arise as to why the minimum withdrawal resistance was chosen instead of the maximum. It was felt that the minimum resistance to withdrawal was certainly the limiting factor since it was impossible to predict what the moisture content of the wood might be at the time the greatest demand was placed on the nail. Table III does not indicate the moisture content of least withdrawal resistance, but this can be obtained from the table of complete data found in the appendix.

<u>Plain shank nails</u>

In considering the plain shank group of nails, it was found that all steel nails exhibited greater resistance to withdrawal

Table III

Relative Minimum Withdrawal Force of
Nails Driven in 2" Lumber

			Withdrawal Force in lbs.							
			Based on Perimeter				Based on Area			
Nail No.	Relative Perimeter	Relative Area	Moisture Content at Driving				Moisture Content at Driving			
			21%	16%	7%	Av.	21%	16%	7%	Av.
103	1.02	1.03	96	82	175	118	95	82	174	117
104	1.02	1.03	61	78	177	105	60	78	175	104
105	1.02	1.03	81	102	186	123	81	101	184	122
115	1.02	1.04	89	106	164	120	88	104	161	118
127	1.02	1.04	226	95	177	166	221	93	174	163
131	1.02	1.05	64	57	111	77	62	55	108	75
147	1.04	1.08	260	111	219	197	250	106	211	189
157	1.06	1.11	235	129	186	183	224	123	176	174
161	1.10	1.20	67	61	144	91	62	56	132	83
171	1.10	1.21	64	64	158	95	58	58	144	87
183	1.07	1.14	146	150	202	166	137	140	189	155
185	1.07	1.14	171	155	186	171	161	146	175	161
191	1.11	1.23	110	108	170	129	99	98	154	117
2080	1.00	1.00	344	299	297	313	344	299	297	313
2119	1.01	1.02	242	246	251	246	239	243	249	244
2159	1.01	1.02	262	253	296	270	259	251	293	268
2279	1.02	1.04	340	236	266	281	334	232	261	276
2310	1.08	1.17	286	303	320	303	264	280	295	280

Continued on Next Page

Table III (Cont'd)

Nail No.	Relative Perimeter	Relative Area	Withdrawal Force in lbs. Based on Perimeter, Moisture Content at Driving 21%	16%	7%	Av.	Based on Area, Moisture Content at Driving 21%	16%	7%	Av.
2410	1.09	1.18	320	272	284	292	296	252	263	270
2420	1.09	1.18	308	253	300	287	285	234	277	265
2450	1.09	1.18	279	297	334	303	258	275	309	281
2597	1.12	1.25	365	392	397	385	327	351	356	345
2613	1.14	1.31	251	283	284	273	218	247	248	238
2623	1.14	1.31	243	280	270	264	212	244	235	230
2653	1.14	1.31	283	267	293	281	247	232	255	245
2770	1.15	1.31	324	301	263	296	285	264	231	260
2870	1.15	1.34	351	296	354	334	302	254	304	287
2977	1.22	1.44	291	271	249	270	246	230	211	229
3079	1.21	1.14	278	228	167	224	295	242	177	238
3117	1.08	1.05	306	278	300	295	314	286	309	303
3127	1.08	1.05	308	264	287	286	317	271	295	294
3157	1.08	1.05	284	246	234	255	292	252	241	262
4076	1.09	.98	272	244	209	242	303	272	233	269
4179	1.15	1.17	295	245	217	252	290	241	213	248
5075	1.20	1.11	234	202	165	200	253	218	178	216
5115	1.24	1.24	125	119	137	127	125	119	137	127
5125	1.24	1.24	118	126	161	135	118	126	161	135
5155	1.24	1.24	224	206	194	208	224	206	194	208

Continued on Next Page

Table III (Cont'd)

Nail No.	Relative Perimeter	Relative Area	Withdrawal Force in lbs. Based on Perimeter, Moisture Content at Driving 21%	16%	7%	Av.	Based on Area, Moisture Content at Driving 21%	16%	7%	Av.
5275	1.32	1.35	294	285	205	261	288	279	201	256
6015	1.20	1.20	111	107	146	121	111	107	146	121
6055	1.20	1.20	131	146	152	143	131	146	152	143
6100	1.22	1.22	84	89	100	91	84	89	100	91
7012	1.22	1.22	125	109	115	116	125	109	115	116
7022	1.22	1.22	107	117	125	116	107	117	125	116
7052	1.22	1.22	211	202	188	200	211	202	188	200
7112	1.17	1.22	103	110	115	109	99	106	111	105
7200	1.27	1.22	103	99	96	99	107	103	100	103
7310	1.21	1.23	65	76	94	78	64	75	93	77
7350	1.21	1.23	117	112	134	121	115	111	132	119

than any of the aluminum nails. Nail 147 possessed the greatest withdrawal resistance. Close observation of Figure 1 reveals small indentations on the shank of nail 147. Perhaps it should have been considered a barb shank, but the indentations of 181 and 191 are much deeper. These tests showed that the poorest galvanized steel plain shank nail was not significantly superior to the best aluminum plain shank nail which was No. 105, but did possess about 28 per cent greater withdrawal resistance. There appeared to be no significant difference between the "alroked" nail and the etched nail, but there was a significant difference between both the "alroked" and etched nails and the plain surface aluminum nail. The plain shank steel nails were slightly superior to all aluminum barb shank nails, but the difference was not significant.

Plain shank nails driven into lumber at 21 per cent moisture content lost a large per cent of their withdrawal resistance as the wood dried. The lowest point was either at 8.6 per cent, or at 14.4 per cent as the moisture was being increased. All nails driven at 16 per cent exhibited the least resistance at the low point in the moisture cycle, 8.4 per cent. The withdrawal resistance of those driven at 7 per cent generally decreased as the moisture content increased, but the reduction was much less than that of the other driving points.

<u>Barb shank nails</u>

In reviewing the barb shank group it was found there was no significant difference between etching and "alroking", but that both "alroked" and etched nails were significantly superior to the plain surface nail.

Barb shank nails driven at 21 per cent displayed the least resistance after the low point in the cycle had been reached and the moisture increased to 17.8 per cent. Barb shanks driven at 16 per cent showed the least resistance at the low point in the cycle, 8.4 per cent. Barb shank nails driven at 7 per cent moisture content decreased in withdrawal resistance as the moisture content increased.

Ring shank nails

The ring shank group exhibited considerably greater holding power than any other group. Based on equal perimeter, only four nails of other shank types exceeded the lowest ring shank which is No. 2119. Actually this nail and No. 2279 are not true ring shanks as the rings are formed on the wire prior to forming the nail.

Monel ring shank No. 2597 was significantly superior to some but not all other ring shank nails. Figure 7 showing the longitudinal section of No. 2597 denotes clean-cut sharp rings indicating that they were probably an important factor.

In reviewing the steel nails, it was again found that sharp rings gave the greatest withdrawal resistance. Nail No. 2870, Figure 10, was superior to the nail with next greatest withdrawal resistance, No. 2080, by only 6 per cent.

"Alroked" nail No. 2450 was apparently a significant improvement over the same nail not "alroked", No. 2410. Nails No. 2159 and 2653 were not significant over their counterparts, nails No. 2119 and 2613.

Changes from diamond to conical points resulted in less resistance to withdrawal possibly because of a slight decrease in length, but the difference was not significant.

At the 21 per cent driving point, the minimum resistance for ring shank nails occurred at the high points in the cycle, either at the first or the last withdrawal. There appeared to be no particular pattern at the 16 per cent driving point. At the 7 per cent driving point, the ring shank nails decreased in withdrawal resistance as the moisture content was increased. The variation was slight at all driving points.

Combination shank nails

Combination shank nails performed well. The aluminum nail was significantly superior to the steel nail, probably because of the sharper serrations on the shank. The point change from diamond to conical resulted in a reduction in withdrawal resistance, but not to a significant degree. "Alroking" did significantly lower the withdrawal resistance probably because it tended to fill the small serrations but not to the degree that galvanizing does in the case of the steel nail.

In general the withdrawal resistance of combination shanks driven at 21 per cent moisture content increased as the wood dried, but the reverse was true at the 16 per cent driving point. All nails driven at the 7 per cent point displayed less resistance as the moisture content was increased.

Screw shank nails

Five thread screw shank nail No. 5275 was the superior nail on the basis of perimeter, with four thread screw shank nail No. 4076 the leader on the basis of area. The differences between these and four thread screw No. 4179 were not significant.

"Alrok" nails Nos. 5155, 6055, 7052, and 7350 proved to be a significant improvement over the same nail which was not "alroked".

In general the aluminum screw shank nails with shorter lead were more effective than those with longer lead. This of course refers to nails having comparable surfaces.

In general all screw shank nails driven at the 21 per cent point displayed greatest resistance at the low point in the moisture cycle, and the least at the high point. The same is more or less true at the 16 per cent driving point. All the nails driven at the 7 per cent point decreased in withdrawal resistance as the moisture content was increased.

Withdrawal Resistance - 1" Lumber

General

Figure 66 shows the results of the withdrawal tests for nails driven into 1" lumber at 21 per cent moisture content. The moisture contents for this graph are an average of the moisture contents at withdrawal of the 16 nails that were driven into one inch lumber. Again as in the case of the two inch lumber, the ring shank group of nails appeared to be superior, with screw shank nail No. 5275 possessing the greatest resistance to withdrawal. No doubt much of this can be accredited to its greater perimeter.

Table IV gives the minimum withdrawal resistance based on equal perimeter and equal area. The nail with greatest withdrawal resistance based on both perimeter and area was the combination shank No. 3117. Ring shank nail No. 2410 was a close second based on perimeter.

Plain and barb shank nails

"Alrok" nail No. 115 was significantly superior to plain surface nail No. 131, but possessed less withdrawal resistance than did etched barb shank nail No. 183; this difference is not significant.

The withdrawal resistance for those nails driven at high moisture was greatest at the first withdrawal and least at the

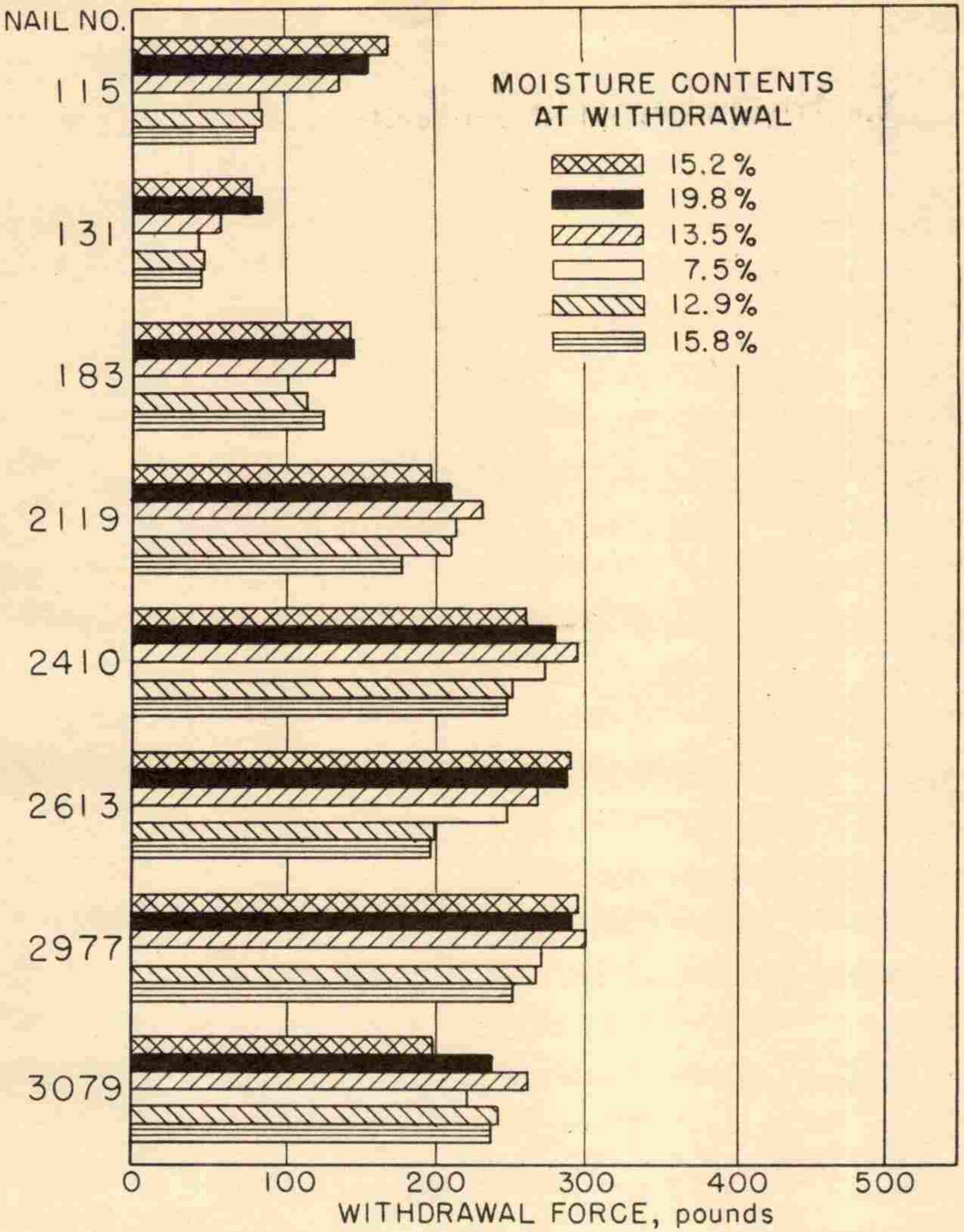

Fig. 66a. Withdrawal resistance of roofing nails driven into 1" lumber at 21 per cent moisture content.

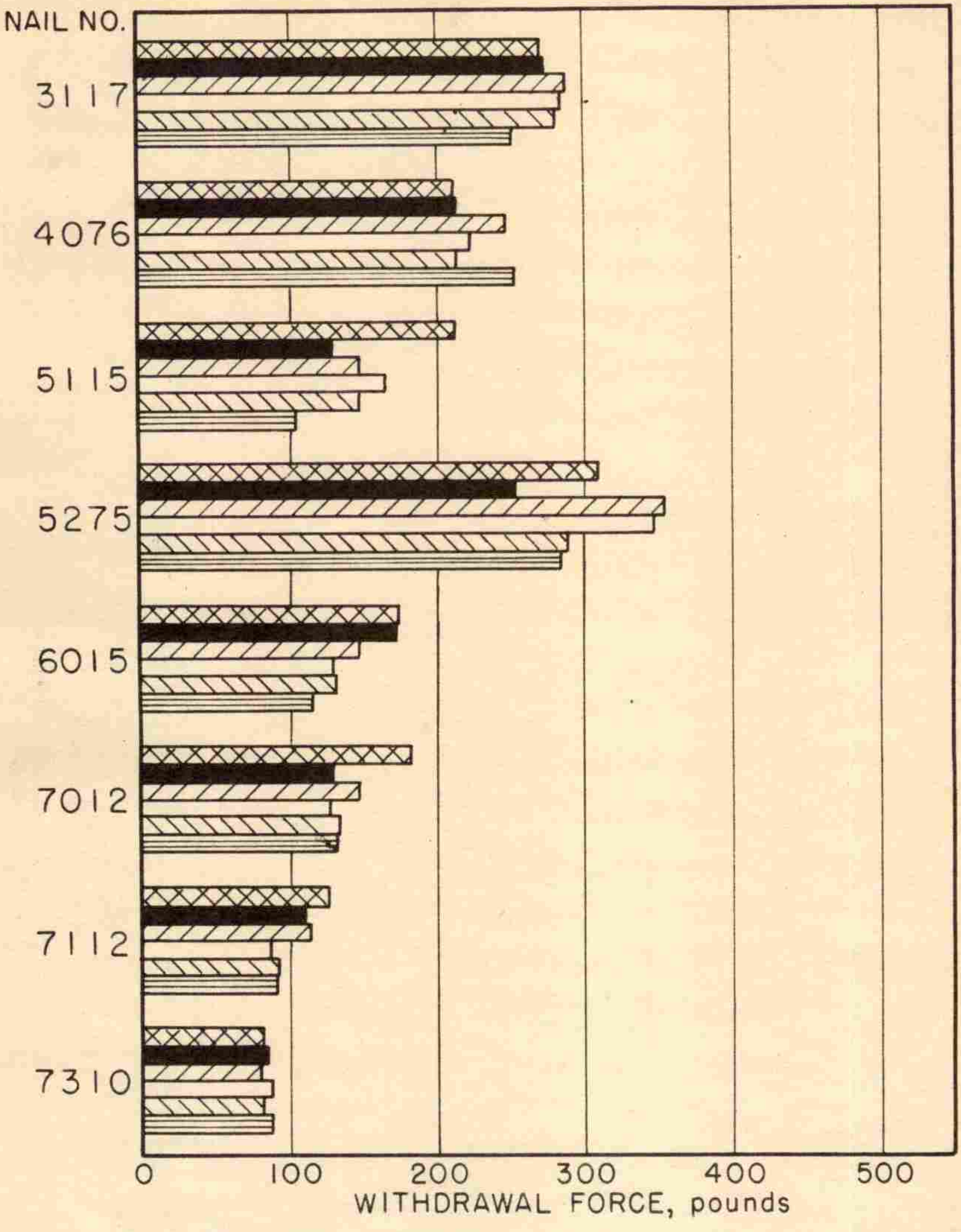

Fig. 66b. Withdrawal resistance of roofing nails driven into 1" lumber at 21 per cent moisture content.

Table IV

Relative Minimum Withdrawal Force of
Nails Driven in 1" Lumber

Nail No.	Relative Perimeter	Relative Area	Withdrawal Force in lbs. Based on Perimeter, Moisture Content at Driving 21%	15%	7%	Av.	Based on Area, Moisture Content at Driving 21%	15%	7%	Av.
115	1.02	1.04	79	94	87	87	78	92	86	85
131	1.02	1.05	42	42	50	45	42	41	49	44
183	1.07	1.14	97	90	101	96	91	84	95	90
2119	1.01	1.02	177	177	148	167	175	175	146	165
2410	1.09	1.18	230	200	177	202	210	185	164	186
2613	1.14	1.31	174	201	175	183	151	175	152	159
2977	1.22	1.44	208	148	139	165	176	126	118	140
3079	1.21	1.14	166	119	112	132	176	126	118	140
3117	1.08	1.05	240	200	183	208	234	206	189	210
4076	1.09	0.98	194	159	144	166	216	177	160	184
5115	1.24	1.24	85	89	74	83	85	89	74	83
5275	1.32	1.35	208	195	157	187	203	190	153	182
6015	1.20	1.20	97	91	78	89	97	91	78	89
7012	1.22	1.22	104	100	74	93	104	100	74	93
7112	1.17	1.22	74	63	70	69	71	61	67	66
7310	1.21	1.23	67	57	46	57	66	53	46	55

low point in the cycle. The same was true at the 15 per cent driving point. Those driven at low moisture content decreased in withdrawal resistance as the moisture content was increased.

Ring shank nails

Ring shank nail No. 2410 exhibited a greater resistance to withdrawal than any of the other ring shank nails. Nail No. 2119, on which the rings are placed on the wire prior to forming the nail, had the least withdrawal resistance of the ring shanks, but was significantly superior to the plain shank and barb shank nails.

The greatest withdrawal resistance for the 21 per cent driving point occurred at the low point in the cycle. At the 15 per cent driving point, the least withdrawal resistance occurred at the low point. There was a decrease in withdrawal resistance of the nails driven at 7 per cent as the moisture content was increased.

Combination shank nails

Aluminum nail No. 3117 exhibited 50 per cent greater resistance to withdrawal than did steel nail No. 3079. This is significant and much of the greater resistance can be attributed to the sharper serrations of the aluminum nail and the longer lead of the steel nail.

The variation of withdrawal resistance with moisture content presents a varied picture and can hardly be defined.

Screw shank nails

Nail No. 5275 displayed approximately 12.7 per cent greater resistance to withdrawal than did nail No. 4076. Perhaps this variation can be credited to the greater lead of No. 4076. In general the nails with longer leads possess less resistance to withdrawal.

For the screw nails driven into one inch lumber, the withdrawal resistance generally was a minimum at higher moisture content withdrawals.

Deflection Versus Load

Figures 67 and 68 show load-deflection curves for various nails driven into both one inch and two inch lumber. These curves were chosen randomly and converted from the strain gauge recorder charts to rectangular coordinates.

Plain and barb shank nails

Figure 67a, showing plain and barb shank deflection curves for two inch lumber, indicates that most of these nails were withdrawn only 0.1 inches or less before reaching their maximum resistance. All reached the maximum before 0.16 inches movement had taken place. Plain shank nails in one inch lumber, Figure 68a, performed similarly, but the magnitude of the withdrawal resistance was somewhat less.

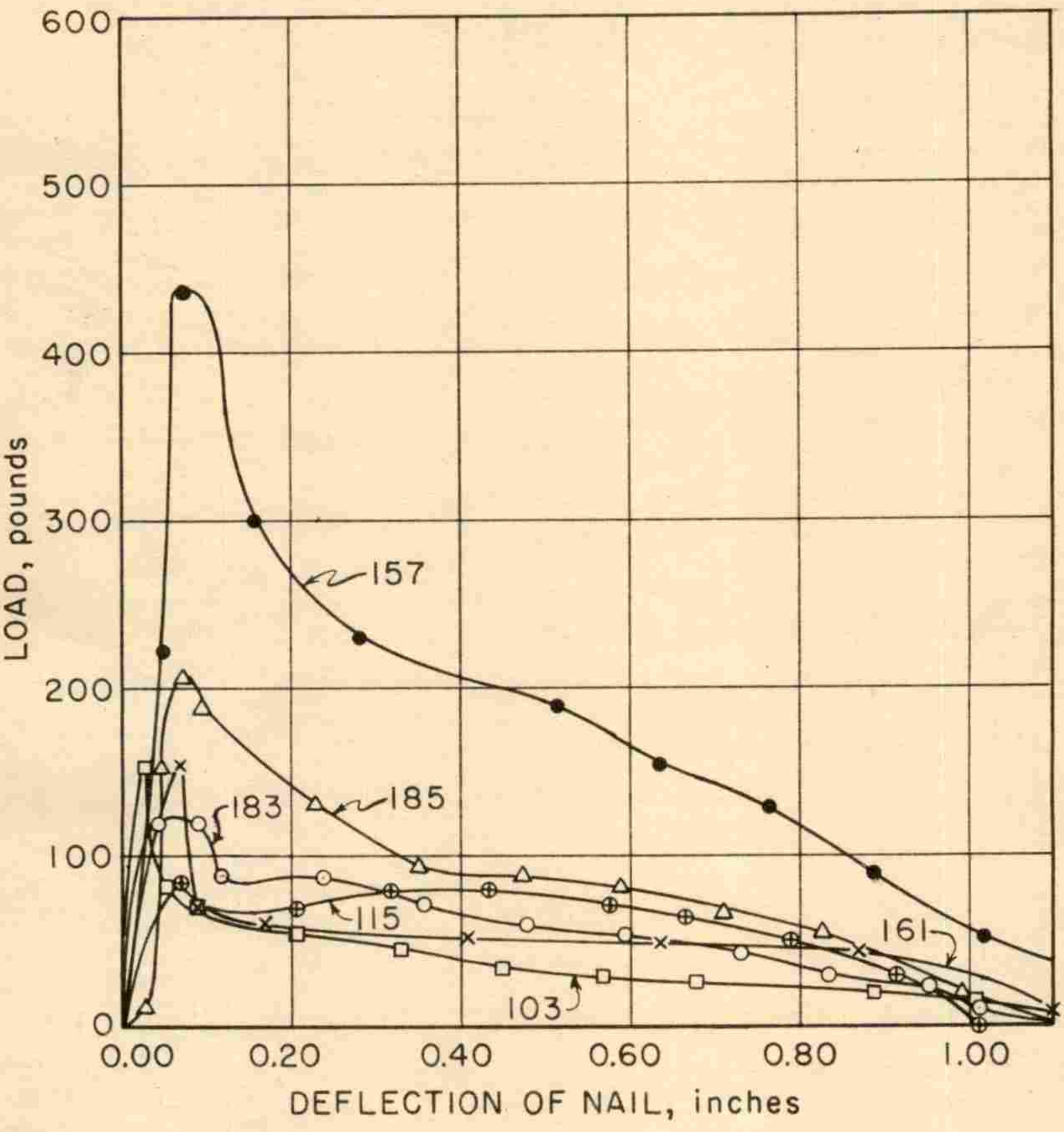

Fig. 67a. Load-deflection curves of plain shank and barb shank nails driven into 2" lumber.

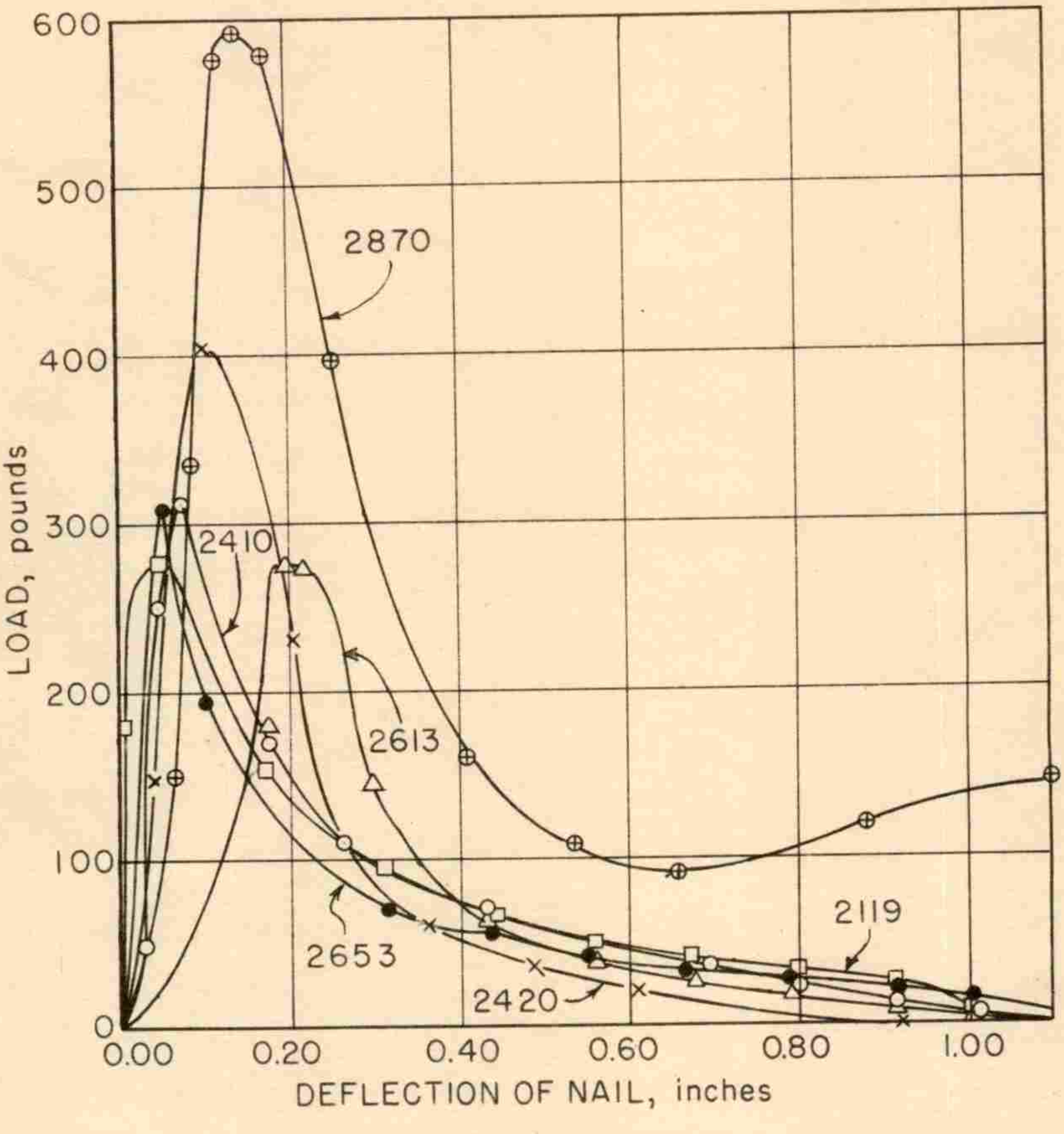

Fig. 67b. Load-deflection curves of ring shank nails driven into 2" lumber.

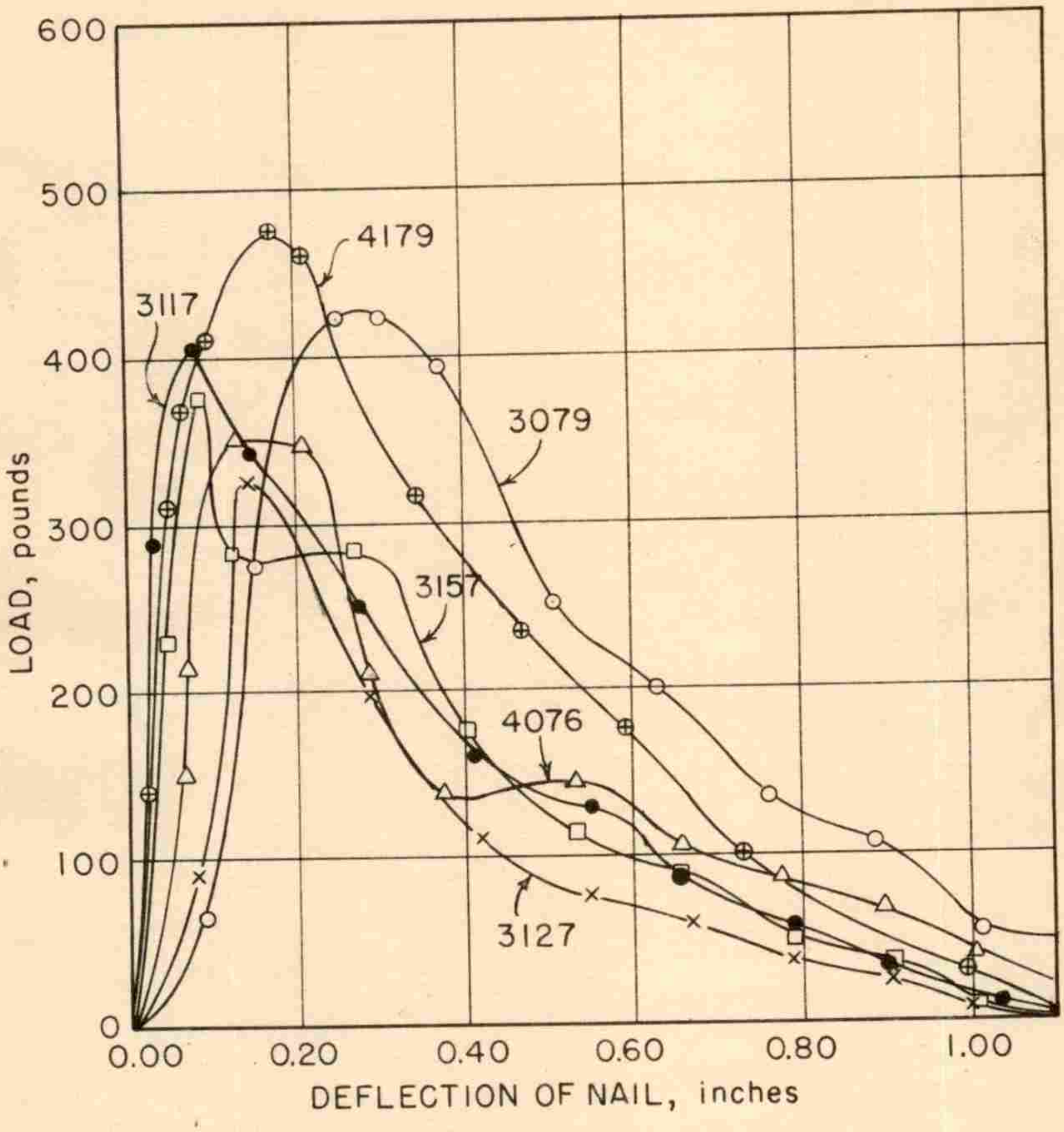

Fig. 67c. Load-deflection curves of combination shank and four thread screw shank nails driven into 2" lumber.

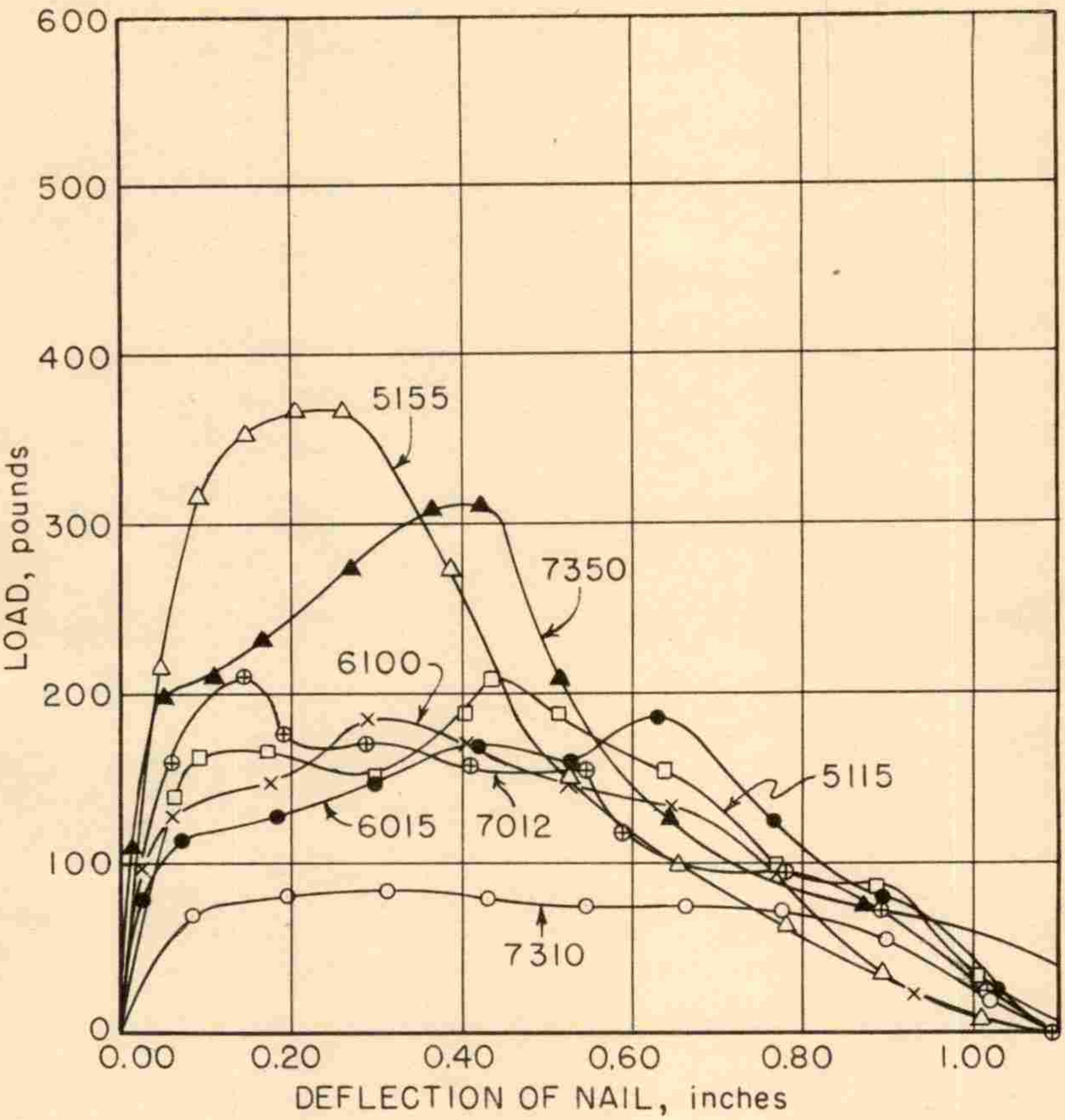

Fig. 67d. Load-deflection curves of five, six and seven thread screw shank nails driven into 2" lumber.

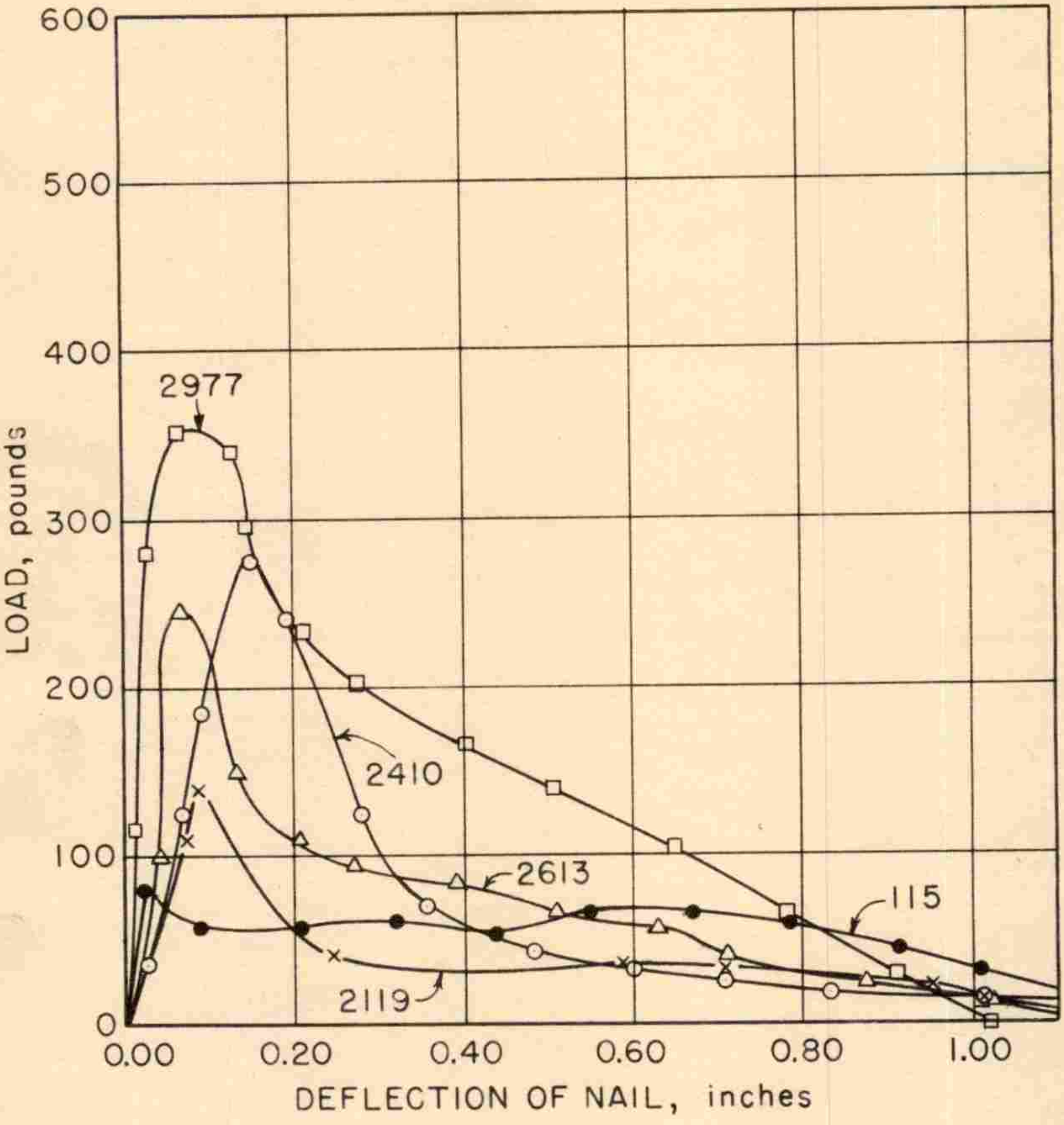

Fig. 68a. Load-deflection curves of plain and ring shank nails driven into 1" lumber.

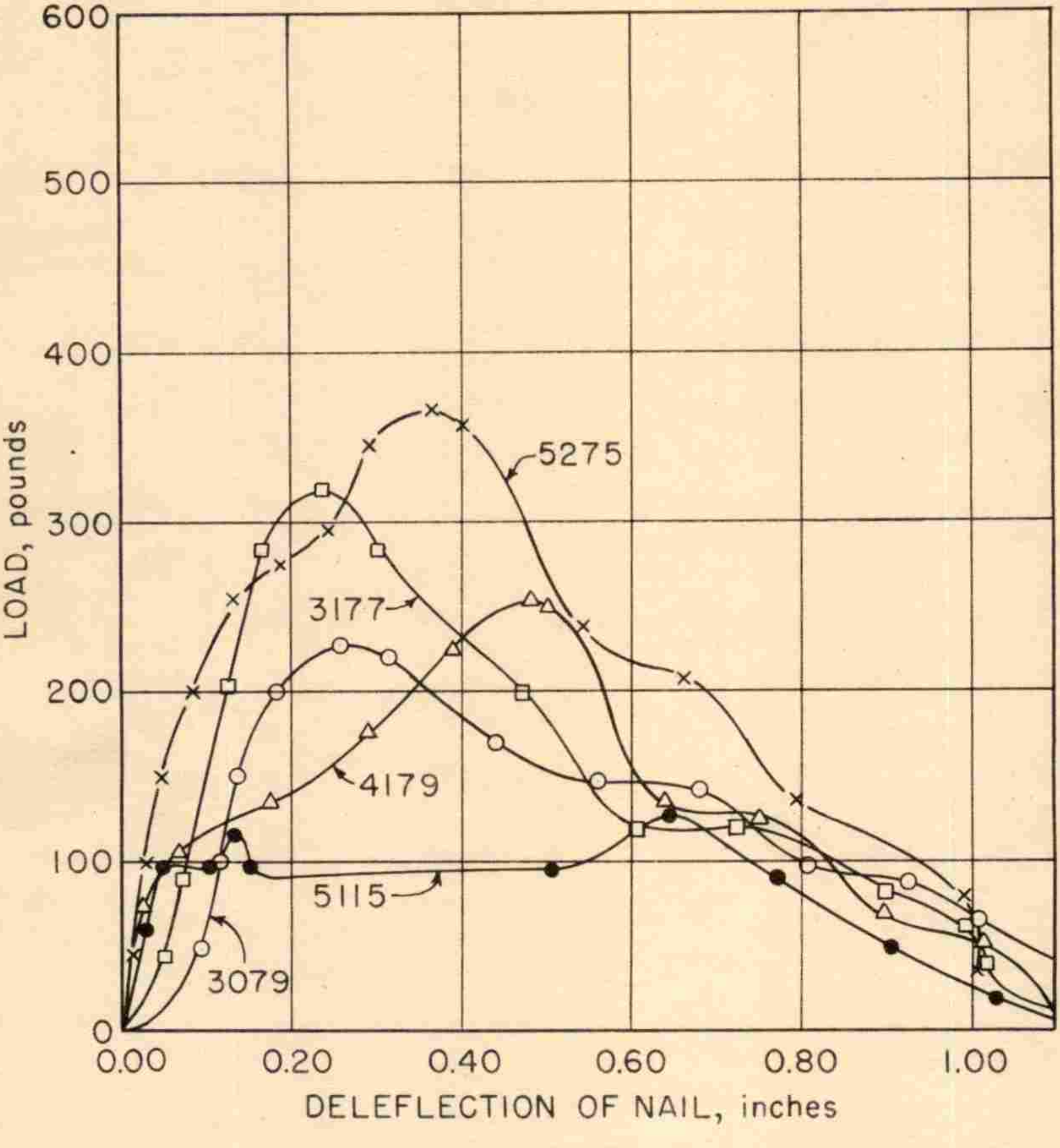

Fig. 68b. Load-deflection curves of combination shank and screw shank nails driven into 1" lumber.

Ring shank nails

Ring shank nails in two inch lumber, Figure 67b, reached their maximum resistance to withdrawal before being withdrawn more than 0.2 inches and most of them by the time the 0.1 inch point was reached. All ring shank nails in one inch lumber, Figure 68a, had reached a maximum resistance when it was withdrawn 0.15 inches. Whenever the maximum was reached there was an abrupt decrease in the load. This resulted from the rings shearing the wood fibers and leaving an enlarged hole with little frictional resistance to promote holding. Wood fibers were found in the rings after the nail had been withdrawn.

Combination and screw shank nails

Screw and combination shank nails in two inch lumber, Figures 67c and 67d, tended to withdraw a greater distance before reaching a maximum. This was particularly true of those with a large number of threads. The extreme was nail No. 6015 which reached its peak after being withdrawn 0.63 inches. Nail No. 3117, performed as well as ring shank nails and reached its maximum after moving slightly over 0.08 inches. In one inch lumber, Figure 68b, no nail reached a maximum withdrawal resistance before moving 0.24 inches.

Summary

The curves show the various characteristics of withdrawal. Most of them are fairly representative and are similar to other curves which have been taken.

It seems that deflection is a very important item in nail performance, since a nail which deflects before reaching a maximum will allow the roofing sheet to be subjected to vibration. In the case of aluminum it is highly undesirable because cracking may occur. In addition it may promote leakage if the nail which deflects is near the edge or the end of the sheet.

Head Performance

Several variations with heads were tried to determine the force necessary to pull the head through corrugated 26 gauge (0.019") aluminum. The head variations can be seen in Figure 1.

The flat head, nail No. 10, was tried as is and with both a wedge shape and a flat synthetic washer. Other heads used were: (1) The lead washer, nail No. 28; (2) the lead bell, nail No. 20; (3) the lead encased, nail No. 50; (4) the cup, nail No. 40; and (5) the hood, nail No. 13. Table V gives the results of four determinations.

Table V

Force in Pounds Required to Pull Nail Heads Through Aluminum

	Flat Heads			Lead Heads			Other	
	No Washer	Wedge	Flat	Washer	Bell	Encased	Hood	Cup
1.	110	77	103	75	100	70	100	170
2.	115	68	87	88	100	84	102	150
3.	135	90	93	73	95	82	97	155
4.	120	77	98	95	115	85	115	180
Av.	120	78	95	83	103	80	104	164

A statistical analysis indicates that four observations are sufficient if the variation between means is approximately twenty pounds. On this basis 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.

SUMMARY

1. Previous investigations of nails were reviewed.

2. This study was justified by: (a) the need for more information concerning withdrawal force-moisture content relationships; (b) the very large annual roofing losses in Iowa: (c) no information on aluminum nail performance; (d) greater demand on nails used for the application of metal roofing; and (e) the need for a nail not subject to creep.

3. Nails were obtained, the variations determined and an identification system devised.

4. Desired variations which were not already present were effected.

5. The wood was selected for uniformity, flat grain being selected. Both one and two inch lumber were to be used.

6. The driving conditions were determined to be 21 per cent, 16 per cent and 7 per cent moisture content. Withdrawals were to be made at the 19 per cent, 13 per cent and 7 per cent points in the moisture cycles.

7. All nails were driven through 26 gauge aluminum. Reduction factors for some of the nails driven through aluminum were computed.

8. The nails were placed randomly in the lumber and were hand driven to a uniform depth. An iron, shaped like a corrugation and 5/16 inches in thickness, was used for this purpose.

9. Eight replicas were necessary for the seven square lattice randomization for two inch lumber; ten for the four square lattice for one inch lumber.

10. Moisture changes were made in the lumber. Raising was done by means of a humidifying room and lowering by means of a drying room. A humidifier was used in the humidifying room and calcium chloride was used in the drying room. Air was circulated by a blower or fan in both rooms.

11. The nails were pulled at the predetermined points in the cycle when possible and the data recorded. Difficulties were experienced in bringing about moisture changes.

12. Observations were made during the investigations.

13. The data were condensed and analyzed. The primary basis for analysis was equal perimeter and area.

14. Deflection-load curves were taken with the strain gauge recorder.

15. Head characteristics were discussed.

CONCLUSIONS

1. Moisture changes in the wood have a definite effect on the withdrawal resistance of roofing nails, but there are not sufficient data to define the relationship.

2. In general plain shank nails lose some of their resistance to withdrawal after the wood has changed in moisture content. If the moisture content is increased the loss is much less than if it is decreased.

3. Plain shank nails regain only a small portion of the loss, when the wood returns to the moisture content of driving.

4. Barb shank nails perform similarly to plain shank nails, but the loss is of lesser magnitude.

5. Ring shank nails are significantly superior to all plain and barb shank nails. Little variation in withdrawal resistance can be associated with changes in moisture content, but the tendency is for the greatest withdrawal resistance to occur at the lower moisture contents. The monel ring shank nail exhibits superior performance, but is rather expensive. Clean cut rings provide the greatest withdrawal resistance.

6. Combination shank nails perform similarly to ring shank nails. This is especially true of the aluminum nail which has the sharper serrations and which is significantly superior to the steel nail.

7. Screw shank nails with shorter leads tend to increase

in withdrawal resistance as the moisture content decreases. Those with longer leads perform like the plain shank nails.

8. "Alroking" and etching of plain shank and barb shank aluminum nails are a significant improvement over the plain surface nail.

9. "Alroking" does not significantly improve ring shank and combination shank nails and may even result in a decrease in holding power.

10. "Alroking" significantly increases the withdrawal resistance of plain surface aluminum screw shank nails.

11. Plain surfaced plain, barb and screw shank aluminum nails are not satisfactory and should be either etched or "alroked."

12. Changes from diamond points to conical points result in no significant increase in withdrawal resistance.

13. All nails perform similarly in one inch lumber as in two inch lumber, but the magnitude of withdrawal resistance is not as great, being approximately 2/3 that of the two inch lumber.

14. Deflection curves show that ring and plain shank nails move very little before reaching their maximum resistance.

15. Based on withdrawal resistance, deflection, and driving characteristics ring shank and combination shank nails appear superior, with some screw shank nails also performing satisfactorily.

16. Due to the slight variation of withdrawal resistance

of ring shank nails with moisture changes, it appears that they would be relatively unaffected by creep. This is also true of the aluminum combination shank with sharp serrations.

LITERATURE CITED

1. Burr, W. R. Experiments on holding power of nails. Abstracted by Clay, F. W. Eng. News 31:22. 1894.

2. Carter, D. G. and Foster, W. A. Farm Buildings. 3d ed. p 81. New York. John Wiley & Sons, Inc. 1941.

3. Clay, F. W. Experiments to determine the holding power of nails and drift bolts. Eng. News 31:22-5. 1894.

4. Deniston, A. J., Jr. The development and use of roofing nails. Agr. Eng. 14:9-10. 1933.

5. Esmay, Merle L. An analysis of wind losses to Iowa farm buildings. Unpublished M. S. Thesis. Ames, Iowa, Iowa State College Library 1947.

6. ________. Unpublished report. Ames, Iowa, Agr. Eng. Dept., Iowa State College. February 5, 1948.

7. Evinger, M. I. Holding power of nails in single shear. Iowa State College Eng. Exp. Sta., Bul. No. 11. 1908.

8. Gahagan, J. M. and Beglinger, E. New nail treating process increases holding power. Barrel and Box and Packages 37:21. July 1932.

9. Giese, Henry. The withdrawal resistance of roofing nails. Agr. Eng. 28:445-50. Oct. 1947.

10. Giese, Henry and Henderson, S. Milton. The effectiveness of roofing nails for application of metal building sheets. Iowa Agr. Exp. Sta. Bul. 355. Nov. 1947.

11. Lammey, W. Clyde. Use of the right nail. Pop. Mech. 76:145-9. Dec. 1941.

12. Langlands, I. The holding power of special nails. Australia, Council for Scientific and Industrial Research, Pam. No. 46. Melbourne, Australia. 1933.

13. Lloyd, T. E. Aluminum seen new factor in special purpose field. Iron Age 159:102-3. March 27, 1947.

14. McHugh, F. D. Pointers on nails. Sci. Am. 145:119. Aug. 1931.

15. Markwardt, L. J. and Gahagan, J. M. The grooved nail. Barrel and Box 34:16-8. Aug. 1929.

16. ________ and ________. Report on tests to determine the effects of nail points on resistance to withdrawal. Timberman. 31:107-08, 110. 1930.

17. ________ and ________. Slant driving of nails! Does it pay? Packing and Shipping 56:7-9, 23, 25. Jan. 1930.

18. ________ and ________. How surface conditions of nails affects their holding power in wood. Barrel and Box and Packages. 37:7-8. Sept. 1932.

19. Marten, I. G. Kraftuebertragung. VDI Zeit. 84:940-1. Berlin, Germany. Nov. 30, 1940.

20. Maze, James S. New developments in roofing nails. Agr. Eng. 18:405-6. 1937.

21. Nails given sandblast treatment show increase in holding power. Steel 91:26. Nov. 28, 1932.

22. Nails have 3,000 years of history; are important steel product. Steel Facts, No. 34. American Iron and Steel Institute. June 1939.

23. Neoprene-washered nails for fastening aluminum roofing and siding. Sheet Metal Worker. 39:66-8. Feb. 1948.

24. Neubrech, W. LeRoy. American hardwoods and their uses. U. S. Bur. Foreign and Dom. Com. Trade Prom. Ser. No. 178. G. P. O. 1938.

25. Reaves, Leon LeRoy. Effectiveness of various types of roofing nails. Unpublished M. S. Thesis. Ames, Iowa, Iowa State College Library. 1932.

26. Rust proof nail for boats made of monel. Sci. Am. 163:55. Dec. 1941.

27. Seely, Fred B. Resistance of materials. 3d ed. p. 5, 23. New York, John Wiley & Sons, Inc. 1947.

28. U. S. Forest Products Laboratory. Wood Handbook, U.S.D.A. 1935.

29. Vogel, William P. Think you know nails? Pop. Sci. 151:138-43. Dec. 1947.

30. Wooley, John C. Farm buildings. 2d ed. p. 167-70. New York, McGraw-Hill Book Co., Inc. 1946.

ACKNOWLEDGMENTS

The writer wishes to express his sincere appreciation to Professor Henry Giese, the project leader, for the invaluable guidance and counsel.

To Professor Hobart Beresford, Head of the Agricultural Engineering Department, to Professor Alvin Dale, and to other members of the Agricultural Engineering staff, the writer is deeply grateful for the suggestions, criticisms and assistance.

The writer also wishes to express his appreciation to the Aluminum Company of America whose support made this investigation possible.

APPENDIX

Average Withdrawal Resistance in lbs. of Nails Driven into 2" Lumber

Nail	21% Driving Point										16% Driving Point								7% Driving Point					
No.	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %
103	229	20.8	211	14.4	98	8.5	98	14.5	122	18.2	185	15.5	84	8.0	109	13.2	118	15.5	268	8.6	224	13.0	179	16.9
104	264	21.3	180	14.9	62	8.8	84	14.3	91	18.1	194	15.9	80	8.5	100	13.4	99	15.3	245	8.9	222	13.2	180	16.9
105	205	21.1	152	14.4	86	8.6	83	14.6	97	18.2	198	15.5	104	8.2	123	13.0	133	15.5	303	8.4	234	13.1	190	17.3
115	263	21.5	219	15.3	91	8.8	109	14.1	101	17.8	240	15.8	108	8.6	129	13.4	131	15.9	354	8.3	266	13.6	167	17.6
127	331	21.2	341	14.9	230	8.8	248	14.3	257	18.0	184	15.4	97	8.2	124	13.4	155	15.4	193	8.5	181	13.2	209	17.6
131	209	21.6	143	14.3	65	8.7	67	14.3	79	18.1	129	16.0	58	8.6	68	13.7	77	16.1	203	8.3	149	13.4	113	17.1
147	331	21.3	349	15.0	270	8.6	283	14.1	303	18.3	226	15.0	115	8.4	180	13.1	156	15.7	228	8.1	241	13.1	238	17.2
157	309	21.0	340	15.2	257	8.9	249	14.8	306	17.6	213	16.1	137	8.8	174	13.4	186	15.3	250	8.9	195	13.4	213	17.9
161	221	19.5	146	14.4	74	8.3	75	14.8	98	18.0	152	16.2	67	8.8	79	13.5	86	15.8	229	8.7	208	13.3	158	17.8
171	219	21.1	154	14.9	73	8.5	70	14.6	87	17.8	170	15.9	70	8.3	89	13.3	91	15.8	238	8.3	249	13.4	174	17.2
183	257	21.6	243	15.1	156	8.6	165	14.4	157	17.8	240	15.9	160	8.0	195	12.9	185	15.8	283	8.4	226	13.4	216	17.3
185	257	21.3	258	15.0	189	8.4	227	14.2	183	18.2	210	15.8	166	8.3	181	13.3	167	15.6	329	8.8	273	13.8	199	17.8
191	221	21.2	174	14.4	137	8.9	143	14.3	122	17.7	168	15.8	120	7.9	132	12.8	141	15.0	235	8.6	208	13.6	189	17.2
2080	371	20.8	422	14.9	448	8.6	440	14.5	344	18.0	359	15.9	299	8.4	350	13.4	335	15.5	358	8.4	311	13.4	297	17.3
2119	264	21.8	267	14.8	287	8.4	267	14.1	244	18.0	308	15.4	248	8.1	304	13.3	319	15.0	317	8.5	293	13.4	254	17.4
2159	305	21.6	302	14.8	309	8.4	314	14.3	264	17.8	293	16.3	256	8.7	266	13.9	293	15.7	360	8.8	305	13.5	299	17.5
2279	347	21.1	365	14.9	387	8.5	352	14.0	354	17.4	267	15.5	260	8.1	265	13.3	241	15.2	298	8.4	279	13.3	271	17.9
2310	355	21.0	333	14.7	342	8.4	332	14.6	309	18.3	395	15.8	327	8.2	344	13.0	333	15.6	482	8.3	389	13.4	345	17.1
2410	357	21.1	366	14.5	349	8.4	363	14.8	368	18.0	345	15.3	297	7.9	322	13.1	313	15.2	362	8.6	345	13.4	310	17.8
2420	342	20.8	346	14.9	342	8.3	358	14.2	336	18.0	320	15.9	300	8.2	300	13.1	276	15.4	372	8.5	376	13.6	327	16.9
2450	336	21.4	342	14.1	306	8.4	337	14.0	304	18.0	372	15.9	324	8.3	380	13.2	357	15.6	375	8.5	368	13.3	364	17.3
2597	409	21.1	455	15.0	482	8.6	491	14.8	435	17.2	482	16.0	484	8.8	479	13.1	439	15.6	562	8.1	483	13.6	445	17.3
2613	320	22.1	337	15.0	310	8.9	303	14.7	286	18.4	363	16.2	323	8.3	328	13.3	323	15.8	444	8.3	381	13.7	324	17.4
2623	315	20.9	344	14.4	289	8.3	323	13.6	277	17.9	352	15.9	319	8.1	341	13.1	326	15.4	416	8.6	361	13.9	308	17.0
2653	368	20.9	365	14.9	352	8.6	343	14.7	323	17.8	366	16.3	304	8.6	319	13.3	322	15.6	440	8.7	384	13.6	334	17.9
2770	373	21.1	421	14.5	434	8.9	440	14.7	382	18.0	357	15.8	346	8.4	383	13.5	362	15.4	426	8.3	320	13.8	302	17.0
2870	404	21.3	442	15.1	476	8.7	476	14.2	452	17.9	369	16.3	384	8.8	340	13.4	351	15.7	538	8.8	482	13.6	407	17.3
2977	393	21.8	382	15.3	369	8.8	382	14.0	355	17.8	393	15.5	331	8.5	398	13.2	345	15.7	405	8.2	343	13.1	304	17.4
3079	336	21.1	377	14.6	375	8.6	368	14.6	354	17.6	319	16.0	276	8.6	294	13.4	289	15.6	250	7.9	204	13.3	202	18.4
3117	336	20.9	330	14.9	357	8.5	350	14.9	337	18.1	319	15.9	307	7.9	300	13.1	322	15.5	348	8.9	339	13.8	324	17.5
3127	355	21.4	354	14.7	351	8.7	367	14.1	333	17.8	311	15.8	302	8.1	351	13.4	285	15.9	375	8.3	348	13.7	310	17.4
3157	307	21.1	336	14.9	329	8.7	335	14.4	312	17.7	266	15.8	265	8.3	301	13.1	314	15.6	333	8.1	300	13.4	253	17.3
4076	340	21.1	329	14.7	365	8.6	389	14.7	297	17.5	295	15.8	266	8.4	315	13.4	306	15.4	228	7.7	249	13.6	231	17.9
4179	339	20.9	396	14.6	381	8.4	409	14.2	344	17.5	309	15.8	314	8.1	333	13.1	282	15.6	371	8.4	288	13.7	249	17.5
5075	332	21.3	339	14.8	314	8.6	332	14.8	281	18.6	242	15.7	251	7.9	277	13.3	272	15.6	209	8.3	198	13.8	200	17.0
5115	225	21.6	180	14.6	155	8.8	200	13.8	168	17.7	181	15.6	149	8.8	180	13.2	148	15.0	217	8.4	170	13.8	173	17.2
5125	213	20.9	207	14.3	188	8.6	162	14.8	146	17.3	168	15.3	156	8.2	194	13.0	173	15.3	290	9.1	241	13.6	200	16.5
5155	309	21.2	353	14.1	318	8.4	312	14.8	287	18.0	255	15.4	300	8.4	284	13.0	282	14.3	290	8.4	282	13.1	240	17.0
5275	388	20.4	421	15.0	458	8.8	450	14.1	388	17.4	382	16.3	407	8.8	436	13.9	376	15.9	332	8.6	294	13.7	271	17.9
6015	222	20.9	199	15.0	161	8.9	150	14.3	133	17.7	178	16.2	132	8.3	145	13.4	128	15.8	222	8.5	184	13.3	175	17.2
6055	229	21.3	229	14.9	212	8.7	208	14.8	157	17.8	215	15.9	193	8.4	205	13.3	175	15.2	287	8.5	212	13.4	182	17.8
6100	211	21.6	184	15.2	111	8.6	130	13.8	103	18.0	141	15.3	108	8.3	118	13.0	113	15.4	192	8.1	139	13.6	120	17.8
7012	235	21.3	184	15.0	156	8.7	181	13.9	152	17.6	146	16.4	137	8.3	133	13.5	142	15.9	214	8.0	177	13.7	140	18.3
7022	230	21.3	196	15.3	184	8.8	156	14.8	131	17.7	175	15.8	143	8.5	172	13.1	163	15.3	245	8.5	174	13.4	153	17.4
7052	271	20.9	300	16.1	343	8.7	336	14.1	257	17.5	246	15.5	300	8.1	261	13.2	252	15.6	355	8.7	301	13.7	229	17.4
7112	200	21.2	147	14.6	152	8.9	142	14.4	121	17.5	149	15.4	133	8.3	129	13.1	149	15.5	217	8.7	142	13.7	135	17.4
7200	190	20.4	181	14.4	154	8.3	138	14.0	131	17.3	150	15.7	126	8.3	139	13.0	129	15.7	200	8.3	153	14.0	122	18.1
7310	205	21.3	140	14.8	80	8.7	92	14.1	79	17.9	149	16.3	92	9.0	93	13.9	119	15.8	180	8.2	114	13.9	132	17.6
7350	257	21.0	190	14.8	158	8.3	144	14.0	142	17.6	207	15.9	172	8.4	142	13.6	136	15.6	310	8.3	218	13.5	162	17.6

49 x 13

Average Withdrawal Resistance in lbs. of Nails Driven into 1" Lumber

Nail No.	21% Driving Point W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	15% Driving Point W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	7% Driving Point W.F. lbs.	M.C. %	W.F. lbs.	M.C. %	W.F. lbs.	M.C. %
115	168	15.1	156	19.9	137	13.1	84	7.3	85	13.3	81	15.8	166	15.3	96	8.0	113	11.3	110	15.9	174	7.6	141	12.9	89	15.3
131	78	14.6	85	19.3	58	13.2	44	7.4	47	12.5	46	15.6	68	15.8	43	8.3	52	11.5	56	16.2	119	7.4	72	12.5	51	15.7
183	144	15.4	147	19.6	135	13.7	104	7.5	117	12.5	127	15.7	138	15.2	99	8.3	140	11.4	95	15.9	161	7.1	128	12.9	108	15.4
2119	199	14.6	213	19.6	234	13.4	215	7.5	212	13.0	179	15.8	197	15.1	179	8.0	200	11.2	199	15.8	227	7.7	191	12.4	149	15.1
2410	263	15.1	281	19.8	297	13.5	277	7.7	254	13.1	250	16.0	247	15.3	236	7.7	265	10.9	218	16.2	232	8.0	193	13.1	198	15.4
2613	292	15.7	290	20.1	271	13.7	250	7.5	200	13.1	198	15.9	291	15.1	244	7.7	265	11.1	229	16.1	302	7.7	243	13.0	199	15.4
2977	297	15.1	292	19.3	302	13.3	274	7.5	269	12.7	254	15.7	255	15.2	205	7.9	226	11.2	181	15.9	250	8.0	228	12.7	170	15.7
3079	201	14.1	240	19.6	263	13.8	223	7.5	244	13.1	239	15.8	149	15.4	144	8.2	174	11.4	170	16.2	135	8.0	145	12.5	141	14.9
3117	271	15.5	274	20.2	288	13.6	286	7.6	278	13.2	252	15.9	234	15.2	216	8.1	236	11.0	220	15.7	257	7.9	226	12.9	198	15.4
4076	212	15.1	213	20.0	248	13.2	224	7.5	214	13.1	254	16.1	199	15.4	197	8.1	231	11.3	173	16.2	170	7.7	167	12.8	157	15.6
5115	214	16.0	129	20.0	149	13.6	166	7.5	148	13.3	105	16.1	180	15.2	133	8.2	133	11.3	110	16.1	126	7.8	92	13.1	92	15.6
5275	311	15.2	274	19.8	355	13.6	348	7.5	285	12.6	281	15.7	316	15.4	257	8.3	319	11.5	325	16.0	261	8.0	253	13.2	207	15.5
6015	174	14.5	172	19.9	147	13.5	129	7.4	131	13.1	116	15.9	161	15.7	128	8.2	146	11.4	109	16.0	138	7.5	94	12.4	95	15.3
7012	183	16.0	129	19.6	147	13.5	127	7.8	134	12.6	132	16.0	147	15.4	122	8.1	131	11.5	128	16.3	123	7.8	90	12.9	97	15.4
7112	126	14.6	109	19.9	114	13.5	87	7.5	92	12.7	91	15.6	108	15.1	86	8.0	87	11.2	82	16.1	107	7.6	77	12.9	74	15.4
7310	82	15.9	85	20.2	81	13.5	87	7.5	82	12.9	87	15.8	95	15.8	69	8.4	77	11.3	85	16.2	82	7.7	63	12.7	56	15.1

16 × 13 × 8
13
48
16
208
8
1664