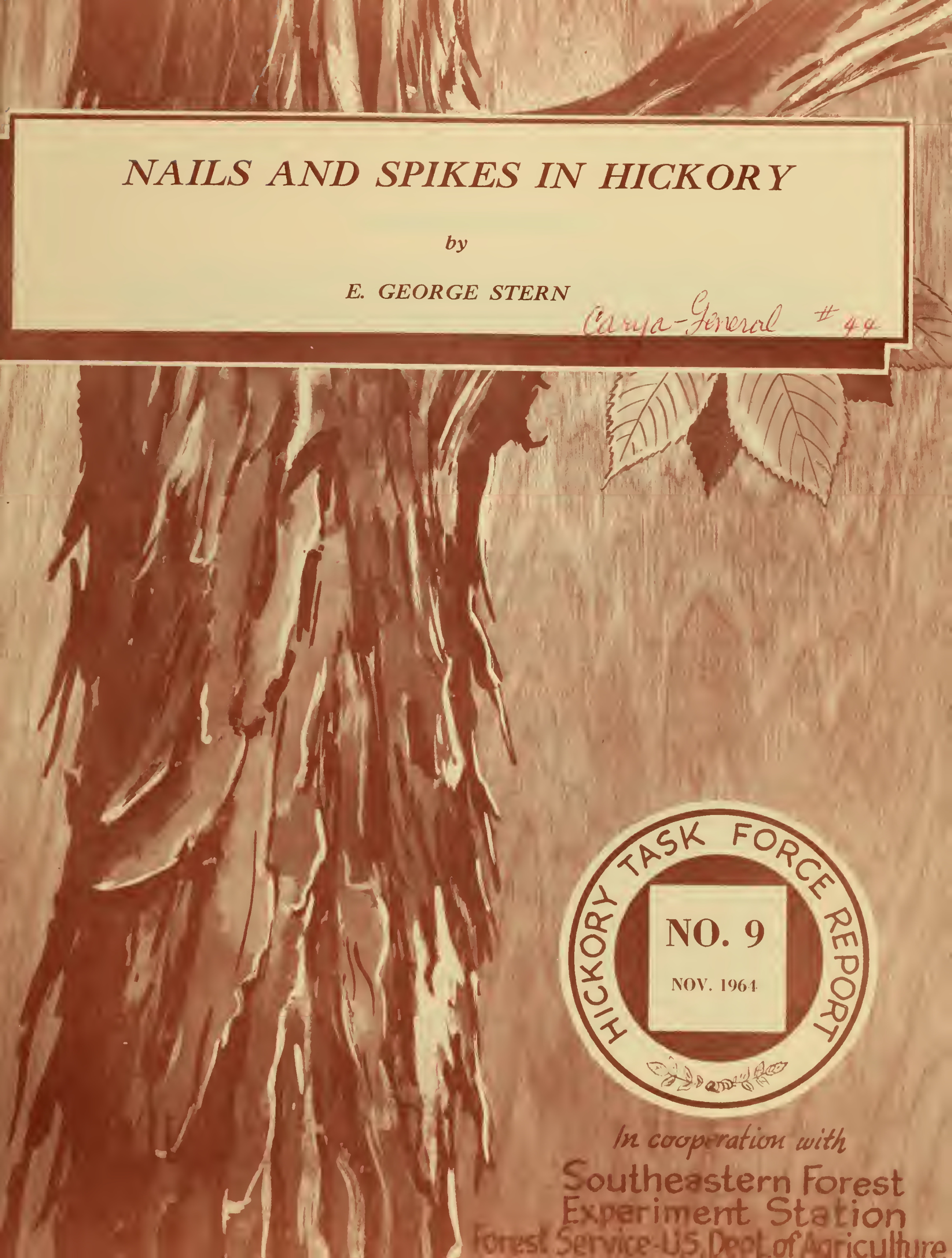

NAILS AND SPIKES IN HICKORY

by

E. GEORGE STERN

Carya-General # 44

HICKORY TASK FORCE REPORT
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In cooperation with
Southeastern Forest
Experiment Station
Forest Service-U.S. Dept of Agriculture

FOREWORD

Hickory (Carya spp.) has earned the reputation of being one of the world's toughest woods. In shock resistance it has no equal. The reputation earned by hickory is based on the performance of high-quality material in products requiring a high degree of strength and toughness.

Today, a limited quantity of high-grade hickory is available and its value and scarcity are well recognized by the wood-using industries. There is, however, a large volume of low-grade hickory that was bypassed when loggers cut our hardwood forests, and many land managers are troubled by the increasing amount of growing space occupied by it. Although this low-grade hickory does not possess the quality or properties required in many products, it is a potentially valuable wood for many uses.

A conference of federal, state, university, and industrial representatives was held in Clemson, S. C., in April 1953, and the Hickory Task Force was organized to promote the utilization of hickory. Accomplishment of this objective will be reached through research and publication of known information.

The Southeastern Forest Experiment Station has assumed the responsibility to edit, publish, and distribute reports containing information which will be developed under this program.

Full acknowledgment is due the many cooperating agencies and individuals who are making the project possible. Subject Matter Committee Chairmen are:

Robert L. Youngs, Forest Products Laboratory, Madison, Wisconsin
Growth and Properties of Hickory.
Roger Anderson, Duke University, Durham, North Carolina
Enemies of Hickory.
Roy M. Carter, N. C. State College, Raleigh, North Carolina
Manufacturing and Seasoning of Hickory.
Woodrow W. King, Tennessee Valley Authority, Norris, Tennessee
Products from Hickory.
Eric L. Ellwood, N. C. State College, Raleigh, North Carolina
Hickory for Fiber and Fuel.
Monie S. Hudson, Spartanburg, South Carolina
Treating Hickory.
Kenneth C. Compton, Central States Forest Experiment Station,
Columbus, Ohio. Marketing of Hickory.

Walton R. Smith, Chairman
Hickory Task Force

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The cooperation and assistance of the Independent Nail Corporation of Bridgewater, Mass., manufacturer of the threaded nails used in this study, and of the Auto-Nailer Company of Atlanta, Ga., manufacturer of the special automatic stationary nailing machines employed, are gratefully acknowledged.

The cooperators are indebted to the Poinsett Lumber and Manufacturing Company of Pickens, S. C., for providing the nontreated hickory planks, and to the Norfolk & Western Railway Company of Roanoke, Va., for providing the creosote-pressure-treated hickory used for testing purposes.

Detailed test data for this report are presented in an Appendix which is available upon request to the Southeastern Forest Experiment Station, P. O. Box 2570, Asheville, N. C. 28802.

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NAILS AND SPIKES IN HICKORY

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E. GEORGE STERN
Research Professor of Wood Construction
Virginia Polytechnic Institute, Blacksburg, Virginia

INTRODUCTION

Hickory, a beautiful, native, dense hardwood of somewhat higher density and hardness than beech, birch, hard maple, and white oak, can provide even greater nailing problems than these other hardwoods. In nail-holding ability hickory ranks high, but its resistance to nail driving is also high. It has an even greater tendency to split during nailing than many other dense hardwoods (15).

Recent technological developments permit the hickory user to overcome many of the fastening problems with which he was previously confronted. It is the purpose of this report to provide all available information on nailing procedures that are especially suitable for properly fastening hickory.

Since hickory has been avoided in many fields because of the lack of applicable information on effective and economical fastening methods, the solving of this problem should result in a more extensive use of this desirable wood. It is visualized that the use of improved slender nails, which can be driven into dry hickory either with or without suitable nailing machines, may make it feasible to employ even relatively low-grade hickory for such assemblies as skids, picture frames, window sashes, bed rails, drawers and drawer guides, and pallets, to mention just a few applications where nailing problems previously made the use of hickory impractical or undesirable.

When green, hickory can be nailed relatively easily. Yet the use of green hickory has many disadvantages and is usually limited to rough lumber. Use of green dressed hickory for pallets is one of the noteworthy exceptions.

In the case of dry hickory, the most slender nail which can be driven may be the most effective nail, since this slender nail avoids splitting of the wood. In order to reduce splitting, the nail should be spaced away from the end cut, and the spacing along the grain between nails should be greater than is normally the case with softer woods.

Medium and blunt-pointed nails are more effective than sharp-pointed nails in reducing splitting. Consequently, the use of nails with long-tapered points is generally not recommended for nailing dry hickory (14).

It is an old practice to wax the points of nails to facilitate driving them into hard woods. Test data indicate that even small amounts of wax materially decrease the force required in nail driving and can reduce nail buckling as well as lumber splitting. However, such application of wax can reduce the nail-holding power (14). In light of this potential loss in holding power, preference may be given to the use of especially slender, improved nails instead of waxing the heavier common wire nail.

Under certain conditions, particularly when large nails and spikes have to be used, predrilling of hickory may be necessary. It can be relatively time-consuming, and hence expensive. For this reason, predrilling should be employed only in cases where no other more satisfactory nailing procedure can be used.

EFFICIENT NAILING OF HICKORY

Because hickory is so extremely hard, the use of aluminum-alloy, copper, and similar soft-metal nails is out of place unless pilot holes are drilled.

Common low-carbon-steel nails have to be of fairly large diameter to be sufficiently stiff for satisfactory driving; thus, they may require predrilling in order to eliminate lumber splitting during nailing. Because of the high nail-holding ability of hickory, such nails can in many cases be relatively short--particularly if the stubby nails are properly threaded along part of the shank. On the basis of drivability, it may be possible to select short, large-diameter, bright low-carbon-steel, helically threaded nails to best advantage. The manufacture of such stubby nails was standardized recently. In fact, $1\frac{1}{2}$'' x 0.135'', $1\frac{3}{4}$'' x 0.135'', 2'' x 0.148'', and $2\frac{1}{2}$'' x 0.148'' helically threaded nails are mass-produced items today.

Another method of satisfactorily driving very slender, low-carbon-steel nails into hickory without predrilling is with nailing machines which laterally support each nail during driving and thus eliminate nail buckling. Once machine-driven into hickory, a short slender nail may provide better holding power than a heavier nail which splits the wood.

Another practical approach to nailing hickory is that of using bright high-carbon-steel nails, commonly referred to as "stiff-stock" nails. Especially in the case of long nails, these hardened, heat-treated and tempered, high-carbon-steel nails are best for fastening hickory. They resist shank buckling during driving because of their extraordinary stiffness and the drivability resulting from their slenderness. The hardened nails can usually be one gauge smaller than the same-length low-carbon-steel nails. Recent advances in the manufacture of hardened nails have eliminated the brittleness which in the past often proved to be both annoying and dangerous. As a result of improved techniques, a properly hardened, slender nail neither breaks nor buckles if properly driven.

Effectiveness of Common Wire Nails in Hickory

The ultimate axial withdrawal resistance of bright plain-shank common wire nails and spikes in pounds per inch of shank penetration immediately after being driven into the side grain of seasoned wood that will remain dry, or into green wood that will remain wet, is given by the U. S. Forest Products Laboratory formula (16):

$$p = 6900\ G^{5/2}D$$

in which D represents the nail-shank wire diameter in inches, and G represents the ovendry specific gravity of the wood. The average specific gravity of true hickory is 0.74. Hence, for common wire nails in such hickory, the withdrawal resistance per inch of shank penetration in pounds may be an amount equal to 3240 shank diameters, and the design load one-sixth thereof, or 540 shank diameters.

The delayed withdrawal resistance of common wire nails driven into wood that is subject to changes in moisture content may be as little as one-quarter of the above values (16, 6). On the other hand, the delayed withdrawal resistance of properly threaded nails amounts to approximately the same as their immediate withdrawal resistance (6).

The immediate ultimate lateral load-carrying capacity of bright common wire nails and spikes in pounds, driven through one member into the side grain of another member of seasoned dense hardwood, to a depth of not less than ten shank diameters, is given by the U. S. Forest Products Laboratory formula (16):

$$p = 11\ K\ D^{3/2}$$

in which D represents the nail-shank wire diameter in inches, and K is a constant amounting to approximately 1700 for true hickory. The suggested design load may amount to one-eleventh of this ultimate load. This results in a factor of safety of only 1.6 for the proportional-limit load (16). These values apply for conditions where both members to be fastened are of approximately the same density. Where metal is fastened to wood, a 25% load increase is allowable (16).

Lateral loads for end-grain nailing should be restricted to values only slightly higher than 60% of those determined for side-grain nailing in the dense wood species (16).

Nails driven into the side grain of green wood provide, immediately after driving, approximately the same lateral load-carrying capacities as nails driven into seasoned wood. However, the proportional-limit loads for nails in green wood are somewhat smaller than for nails in seasoned woods. Therefore, design loads for nails in green wood that will remain wet, or which will be loaded before seasoning takes place, may have to be reduced as much as 25% below those for seasoned wood (16).

RESULTS OF RECENT RESEARCH

Effectiveness of Plain, Knurled, and Helically Fluted Auto Nails in Hickory

Slender auto nails (8) cut and driven by a special automatic stationary nailing machine readily penetrate such dense hardwoods as hickory, since they are prevented from buckling during driving by the guiding mechanism of the nailing machine. Because of their slenderness, and as a result of the extraordinary speed with which these nails are driven--as many as three per second--they are not apt to split hickory even if driven adjacent to each other or in clumps. Such machine-nailing of hickory with auto nails should find many applications, since hickory's energy-consuming high resistance to nail driving is of no influence on the operational effectiveness of the nailing machine.

Immediate Withdrawal Resistance of 15- and 16-Gauge Auto Nails

In order to shed light on the comparative effectiveness of 15- and 16-gauge plain and knurled low-carbon-steel auto nails, fully comparative, matched sextuple tests were performed on the immediate static axial withdrawal resistance of a number of $1\frac{1}{2}''$ (4d) bright steel nails. They were selected for their drivability, without predrilling, into dry side-grain hickory of 0.76 ovendry specific gravity and 10% moisture content. The nails were withdrawn with a 600/3000-lb. capacity testing machine at a constant rate of loading of 0.100 inch per minute, immediately after being driven to a shank penetration of 1 inch.

The 13-gauge common wire nail, 15- and 16-gauge plain and knurled auto nails, 15-gauge helically fluted medium-carbon-steel nail, and $12\frac{1}{2}$-gauge helically threaded and 12-gauge annularly threaded nails under test observation are shown in figure 1. The average test results are graphically presented in figure 2.

As previously indicated, these nails were selected for drivability into dry hickory. It would have been difficult to drive under given conditions identical common wire, fluted, and threaded nails of smaller diameters without predrilling.

In comparison with the immediate withdrawal resistance per inch of penetration of the 0.091'' common wire nail, that of the

0.061'' plain auto nail was 23% lower

0.061'' knurled auto nail was 4% higher

0.070'' plain auto nail was 14% lower

0.070" knurled auto nail was 10% higher

0.075" helically fluted nail was 21% lower

0.098" helically threaded nail was 33% higher

0.105" annularly threaded nail was 113% higher

On a uniform weight basis, the 16- and 15-gauge plain auto nails were 200% and 180% more effective, and the knurled auto nails 270% and 220% more effective than the common wire nail. The medium-carbon-steel fluted nail was quite similar in effectiveness to the common wire nail. The helically and annularly threaded nails were 120% and 180%, respectively, more effective than the common wire nail.

In making these comparisons, consideration must be given to the fact that the auto nails are headless, although under certain conditions a bradded head is formed by the machine plunger which forces the nail into the wood. Hence, the above comparisons of immediate withdrawal resistance are limited by the shorter penetration when two pieces of wood are fastened together, if such penetrations are unequal. Since a bradded or clinched point of the auto nail can serve as its head, this fact has also to be given consideration in the application of the test data.

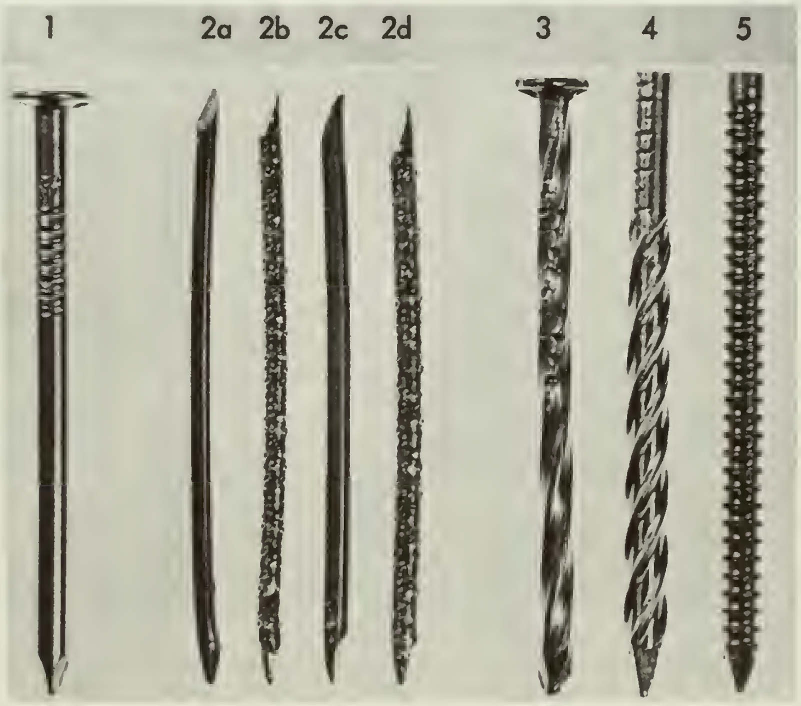

Figure 1.--Bright-steel $1\frac{1}{2}$" nails selected for their drivability into dry hickory without predrilling, and tested for their immediate withdrawal resistance. From left to right:

1) 13-gauge common wire nail
2) 16- and 15-gauge plain and knurled auto nails
3) 15-gauge medium-carbon-steel helically fluted nail
4) $12\frac{1}{2}$-gauge helically threaded nail (illustrated without head)
5) 12-gauge annularly threaded nail (illustrated without head)

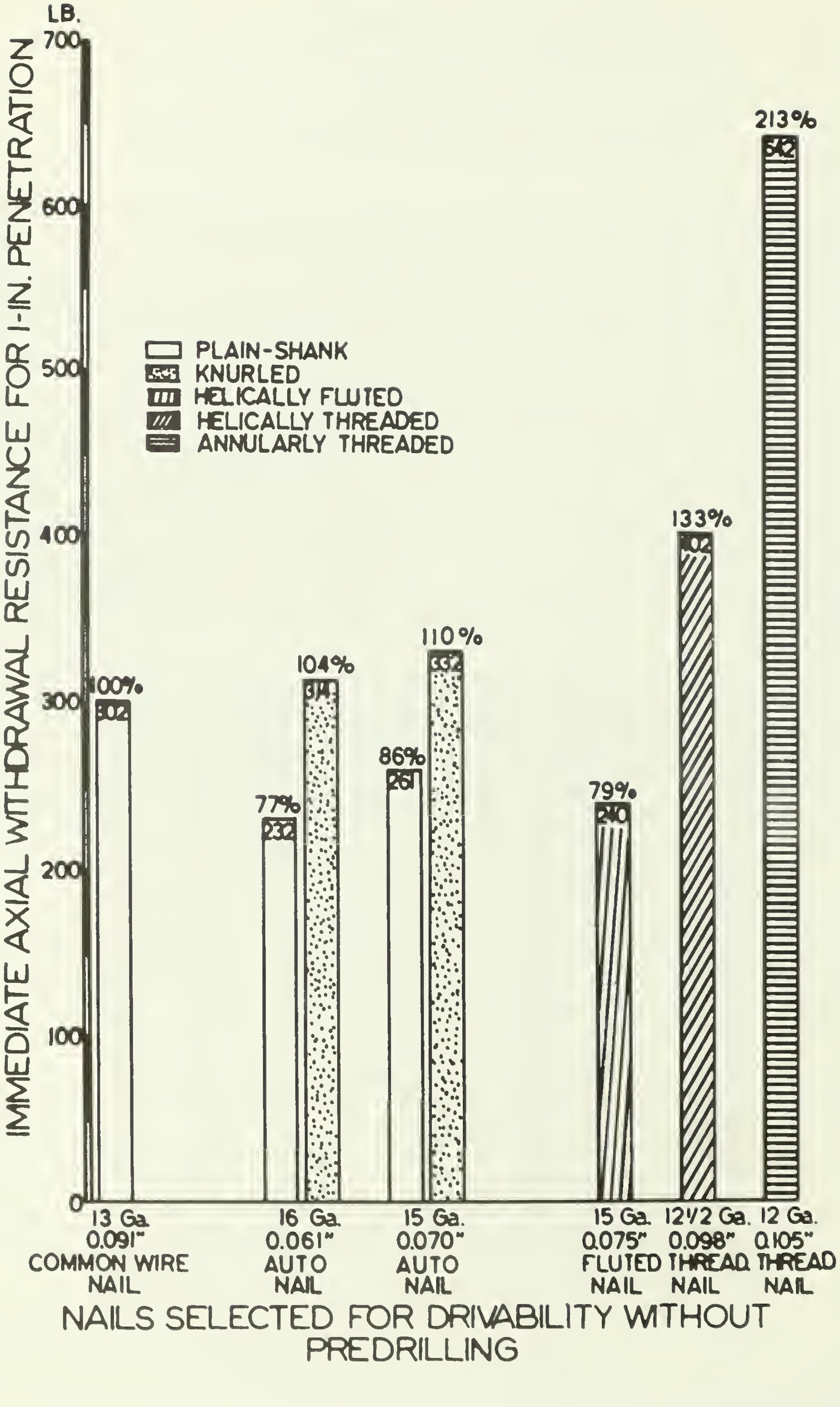

Figure 2.--Withdrawal resistance of $1\frac{1}{2}$" (4d) bright-steel nails, immediately after being driven to depth of 1" into side-grain hickory of 0.76 specific gravity and 10% moisture content, and tested at constant rate of loading of 0.100 inch per minute.

Immediate and Delayed Withdrawal and Pull-Through Resistance of 13- and 13½-Gauge Auto Nails

Information was needed on 13-gauge knurled low-carbon-steel auto nails and on 13½-gauge helically fluted medium-carbon-steel auto nails with regard to the influence of time as well as exposure after nailing. For this reason, matched quintuple tests were performed. Pull-through resistance and static axial withdrawal resistance were tested at three time intervals: immediate, after 3 weeks, and after 6 weeks. The 1½" (4d) bright nails were driven without predrilling into dry side-grain hickory of 0.84 ovendry specific gravity and 9% moisture content. For the withdrawal test, the shank penetration amounted to 1" and, for the pull-through test, the shank penetration amounted to ½". The 6-week delayed test was performed after 3-week storage of the nailed hickory in conditions of equilibrium moisture content, followed by 2-day water soaking and subsequent 19-day air drying. The nails were tested at a constant rate of loading of 0.100 inch per minute with a 600-lb. capacity testing machine of the lever type with double-torque bar and differential-transformer signal transmitter.

All auto nails were held by friction grips and could not turn during testing. Such a testing procedure may result in more favorable data for the helically fluted auto nail than a procedure which would allow the nail to turn during withdrawal. In the field, any loss in rigidity of the auto-nailed wood assembly may allow the nail to turn. Consequently, the data for the helically fluted auto nails presented in this report are optimum.

The 13-gauge knurled and 13½-gauge helically fluted auto nails under observation are shown in figure 3. The average test results are graphically presented in figure 4 and may be summarized as follows:

The pull-through resistance of the knurled and fluted auto nails in ½" hickory is considerably (24% to 52%) lower than their withdrawal resistance in 1" hickory, except for the 6-week delayed pull-through resistance of the knurled nail which is slightly (13%) higher. Consequently, depending principally on the amount of shank penetration of the auto nail in the pieces to be fastened to each other, either the withdrawal or head pull-through resistance of knurled or fluted auto nails can be governing factors for joint effectiveness.

On the basis of all test data obtained, the fluted medium-carbon-steel auto nail appears to be 29% less effective and, on a uniform weight basis, 15% less efficient than the knurled low-carbon-steel auto nail. The somewhat stiffer fluted medium-carbon-steel auto nail may, however, be preferred where narrow members are to be assembled with long auto nails, since this stiffer nail may deviate less from the intended driving direction, especially during its penetration into bastard-sawn wood.

Figure 3.--Knurled $1\frac{1}{2}''$ x 13-gauge (left) and helically fluted $1\frac{1}{2}''$ x $13\frac{1}{2}$-gauge (right) auto nails with sheared needle points, prior to driving.

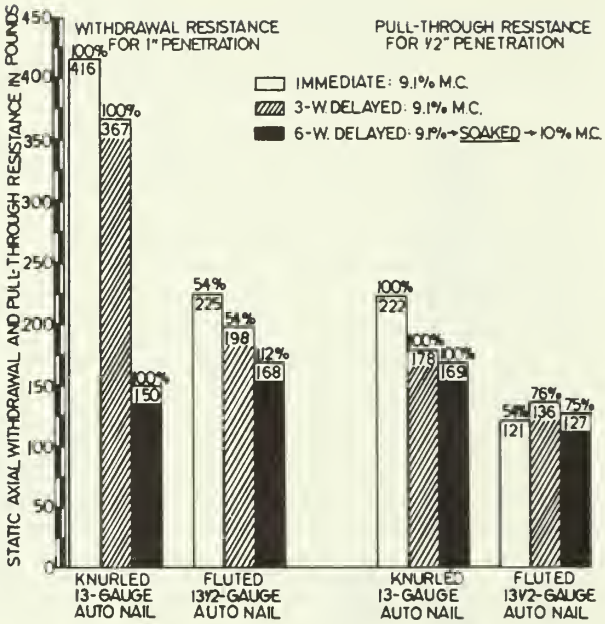

Figure 4.--Immediate and delayed static withdrawal resistance and head pull-through resistance of $1\frac{1}{2}''$ x $13\frac{1}{2}$-gauge helically fluted and 13-gauge knurled auto nails with sheared needle points, driven without predrilling into side-grain dry hickory of 0.84 specific gravity and 9% moisture content, and tested at constant rate of loading of 0.100 inch per minute.

Immediate and Delayed Withdrawal Resistance of 13-, 15-, and 16-Gauge Auto Nails

Directly comparative information on the immediate and delayed static axial withdrawal resistance of 13-, 15-, and 16-gauge plain and knurled low-carbon-steel "crating wire" and medium-carbon-steel "furniture wire" auto nails as well as a number of other steel nails was obtained immediately and 6 weeks after they were driven, without predrilling, to a depth of 1" into green hickory of 0.77 ovendry specific gravity and 73% moisture content. During the 6-week storage of the nailed test plank in 50% relative humidity at 70° F. temperature, its average moisture content decreased to 20%. The same testing procedures were followed as were used for the tests described previously.

Samples of the nails under test observation are shown in figure 5. The average test results are presented graphically in figure 6 and may be evaluated as follows:

In comparison with the immediate and delayed withdrawal resistance of the 0.091" common wire nail in 1" hickory, the corresponding value for the

0.061" plain low-carbon-steel auto nail	was	29% lower	and	29% higher
0.061" knurled low-carbon-steel auto nail	was	14% lower	and	83% higher
0.061" knurled medium-carbon-steel auto nail	was	20% lower	and	69% higher
0.070" plain low-carbon-steel auto nail	was	27% lower	and	19% lower
0.070" knurled low-carbon-steel auto nail	was	6% lower	and	36% higher
0.070" knurled medium-carbon-steel auto nail	was	7% higher	and	22% higher
0.092" plain low-carbon-steel auto nail	was	28% higher	and	16% higher
0.092" knurled low-carbon-steel auto nail	was	31% higher	and	56% higher
0.092" knurled medium-carbon-steel auto nail	was	48% higher	and	56% higher
0.075" helically fluted medium-carbon-steel nail	was	10% higher	and	53% higher
0.098" helically threaded low-carbon-steel nail	was	76% higher	and	205% higher
0.105" annularly threaded low-carbon-steel nail	was	144% higher	and	284% higher

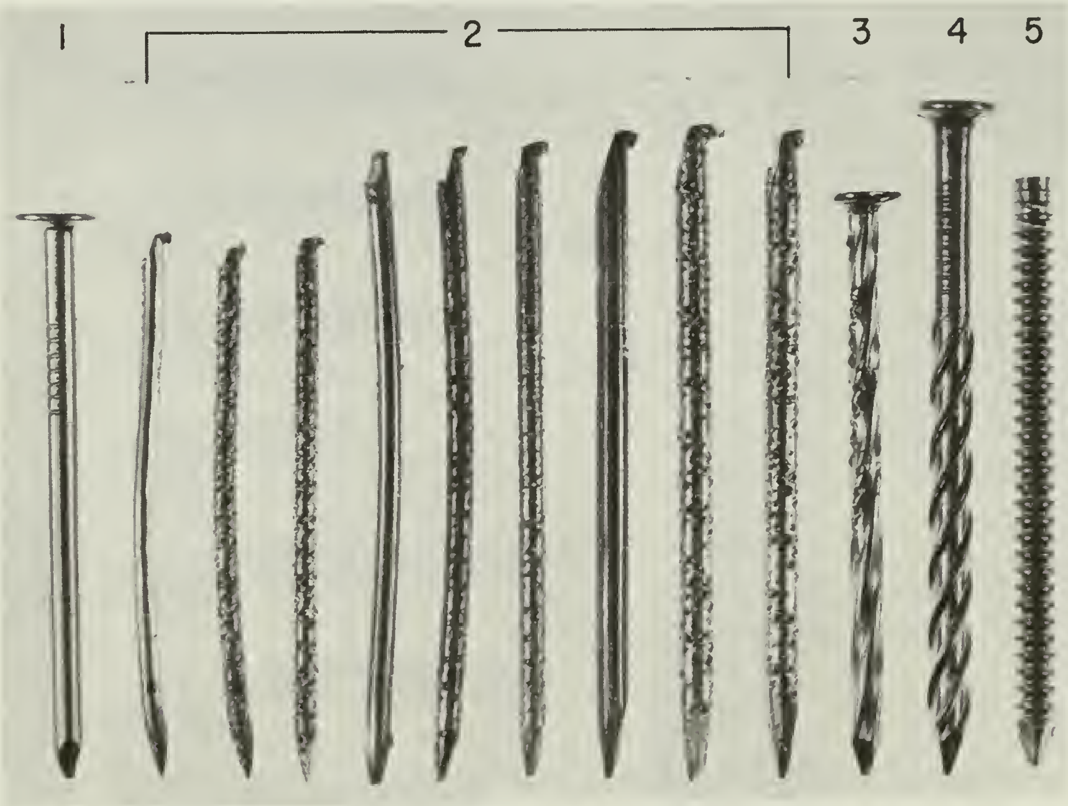

Figure 5.--Various types of steel nails after being driven, without predrilling, to depth of 1" into green hickory. From left to right:

1) 13-gauge plain-shank common wire nail
2) 16-, 15-, and 13-gauge plain and knurled auto nails, with knurled auto nails shown from two sides
3) 15-gauge fluted nail
4) $12\frac{1}{2}$-gauge helically threaded nail
5) 12-gauge annularly threaded nail (illustrated without head)

Note slight head on auto nails formed while they were driven into wood by machine plunger.

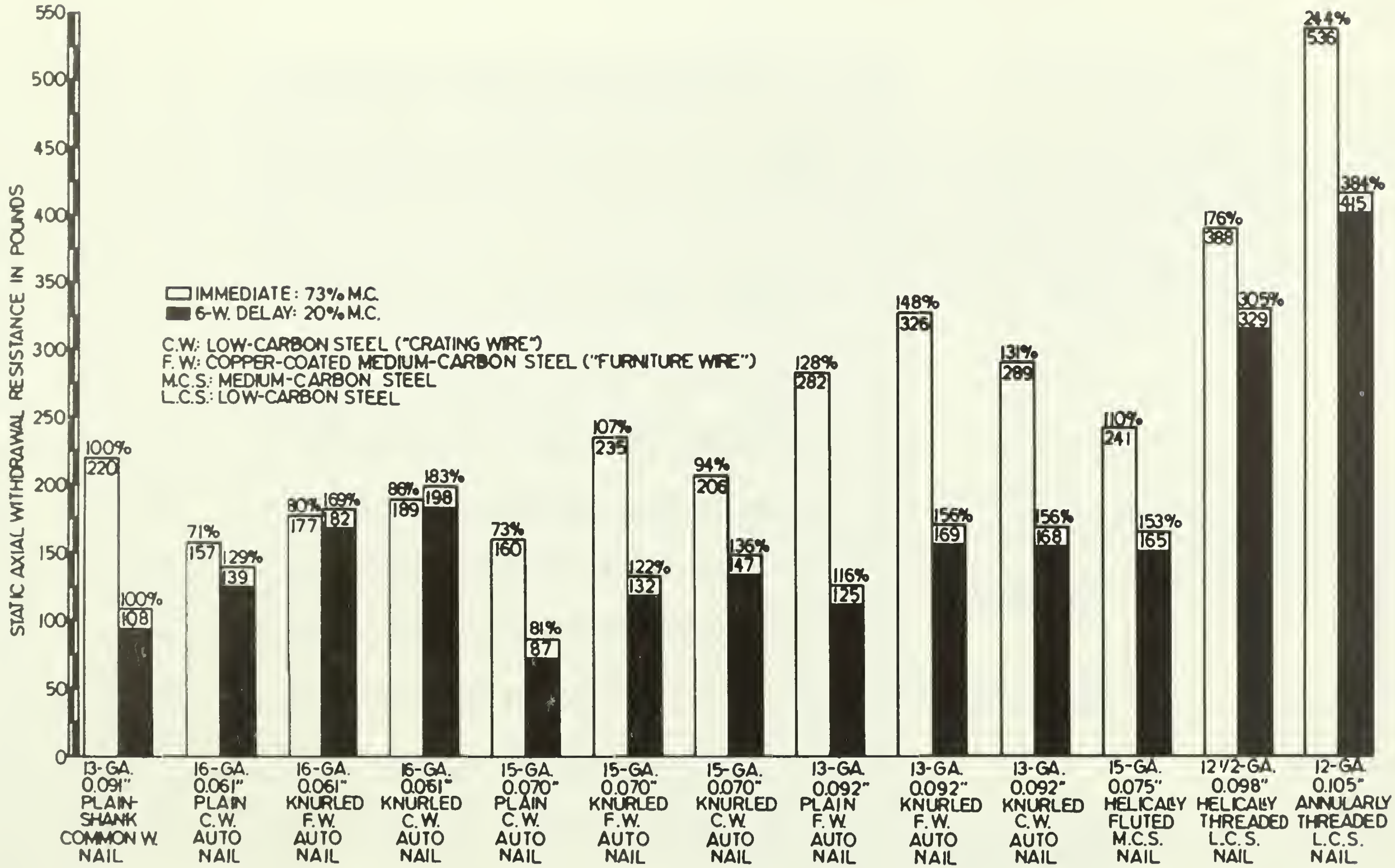

Figure 6.--Immediate and delayed static withdrawal resistance of various types of steel nails, driven without predrilling to depth of 1" into side-grain green hickory of 0.77 specific gravity and 73% moisture content, and tested at constant rate of loading of 0.100 inch per minute.

After 6-weeks' seasoning of the green-nailed plank to 20% moisture content, the effectiveness of the

13-ga.	plain-shank common wire nail	decreased	51%
16-ga.	plain low-carbon-steel auto nail	decreased	11%
16-ga.	knurled low-carbon-steel auto nail	increased	5%
16-ga.	knurled medium-carbon-steel auto nail	increased	3%
15-ga.	plain low-carbon-steel auto nail	decreased	46%
15-ga.	knurled low-carbon-steel auto nail	decreased	29%
15-ga.	knurled medium-carbon-steel auto nail	decreased	44%
13-ga.	plain low-carbon-steel auto nail	decreased	56%
13-ga.	knurled low-carbon-steel auto nail	decreased	48%
13-ga.	knurled medium-carbon-steel auto nail	decreased	42%
15-ga.	helically fluted medium-carbon-steel nail	decreased	32%
12½-ga.	helically threaded low-carbon-steel nail	decreased	15%
12-ga.	annularly threaded low-carbon-steel nail	decreased	23%

In comparison with the immediate and delayed average effectiveness of the plain low-carbon-steel auto nails, that of

the knurled low-carbon-steel auto nails was 17% and 48%, respectively, more effective;
the knurled medium-carbon-steel auto nails was 25% and 39%, respectively, more effective.

On a uniform weight basis and in comparison with the immediate and delayed efficiency of the 13-gauge plain-shank common wire nail,

the 16-ga.	plain low-carbon-steel auto nail	was 83%	and	232%	more efficient
the 16-ga.	knurled low-carbon-steel auto nail	was 59%	and	373%	more efficient
the 16-ga.	knurled medium-carbon-steel auto nail	was 106%	and	334%	more efficient
the 15-ga.	plain low-carbon-steel auto nail	was 48%	and	64%	more efficient
the 15-ga.	knurled low-carbon-steel auto nail	was 90%	and	177%	more efficient
the 15-ga.	knurled medium-carbon-steel auto nail	was 117%	and	149%	more efficient
the 13-ga.	plain low-carbon-steel auto nail	was 32%	and	20%	more efficient
the 13-ga.	knurled low-carbon-steel auto nail	was 35%	and	61%	more efficient
the 13-ga.	knurled medium-carbon-steel auto nail	was 52%	and	62%	more efficient
the 15-ga.	helically fluted medium-carbon-steel nail	was 35%	and	90%	more efficient
the 12½-ga.	helically threaded low-carbon-steel nail	was 65%	and	61%	more efficient
the 12-ga.	annularly threaded low-carbon-steel nail	was 102%	and	220%	more efficient

The 13-gauge knurled auto nails were, on the average,

40% more effective and 44% more efficient immediately 56% more effective and 62% more efficient six weeks	after nail driving than the same-size common wire nail
28% more effective and 6% more efficient immediately 2% more effective and 15% more efficient six weeks	after nail driving than the 15-ga. helically fluted nail
21% less effective and 13% less efficient immediately 49% less effective and 44% less efficient six weeks	after nail driving than the 12½-ga. helically threaded nail
43% less effective and 29% less efficient immediately 60% less effective and 49% less efficient six weeks	after nail driving than the 12-ga. annularly threaded nail

It should be noted that the delayed tests were performed when the green-nailed hickory plank was only partially seasoned and that different test data would have been obtained if further drying of the plank had taken place prior to delayed testing. In light of the observations, the following conclusions appear to be warranted:

> Two-thirds as many knurled auto nails can replace a given number of the same-size common wire nails; also, knurled auto nails can in certain applications replace 17% lighter helically fluted auto nails effectively and efficiently.

On the other hand, twice as many knurled auto nails might be required to replace the 10% heavier helically threaded and the 24% heavier annularly threaded nails. But such a replacement may not be efficient.

Effectiveness of Helically and Annularly Threaded Nails and Spikes

The notable loss in holding power of the plain-shank nail during seasoning of green-nailed lumber (6), which can amount to as much as three-quarters of its initial withdrawal resistance,[1] limits the effectiveness of the plain-shank nail as a permanent or semipermanent fastener when driven into green or partially seasoned lumber or into wood with a fluctuating moisture content. Thus, even in a wood as dense as hickory the use of the more effective threaded nail can be of considerable advantage when large holding power is a prime consideration, particularly under adverse service conditions.

Helically fluted nails (10) having continuous symmetrical deformations formed onto the steel wire before the nails are made should be differentiated from truly threaded nails; that is, nails which pass between threading dies during the thread-rolling process. Generally, fluted nails are made of stiffer, higher-carbon-steel wire than the common wire nails, to compensate for the reduced cross-section of the nails, to decrease the driving resistance, and to reduce wood splitting during nailing. Since the holding power of a nail decreases as the diameter of the nail decreases, the more slender nail should be provided with a relatively effective shank deformation. The grooves of fluted nails, however, are necessarily of simple design and not of an engineered profile, as is the case for the most effective threaded nails. Furthermore, the crests of the flutes are rounded, in line with the limitations of the manufacturing process involved. Additionally, the angles of the flutes which can be attained are limited for fluted nails. Thus, it is often impractical to impress the most effective lead angles on fluted nails. By contrast, wedging crests of properly threaded nails introduce strong lateral pressure against the wood fibers along the threads and result in the high

[1] Borkenhagen, E. H. Tests of Group IV Hardwood Joints Assembled with Several Types of Grooved-Shank Nails. U. S. Forest Prod. Lab. Prog. Rpt. 1949.

friction between the threaded shank and the wood surrounding it. The fluted nails are of necessity deformed all the way from head to point. Furthermore, their heads are not uniformly round. These two characteristics can be helpful in identifying fluted nails.

In dense hardwoods such as hickory, properly helically threaded, hardened nails can be more effective than annularly threaded hardened nails. The helically threaded nails offer greater bending resistance during nail driving; hence, can be driven faster than the annularly threaded nails with their greatly reduced cross-section at the root of the thread. When nails are helically threaded with medium-long pitch, they turn as they are driven; the shank threads displace wood fibers and form threads in the wood. Thereby, the surrounding fibers are compressed and the frictional resistance between wood and nail shank is increased. In addition, there is a mechanical gripping between wood fibers and nail thread. These nails can grip hickory so tightly that during forced nail extraction even the hardened nail shank may be counter-twisted in a reverse direction.

The annularly threaded nails, with their reduced thread root diameter, are held in place by the wood fibers forced over the thread shoulder into the annular grooves like wedges, to be released only when the wood is destroyed. The strength of hickory fibers, however, can offer such resistance to movement of the hardened annularly threaded nails that nail-shank failure in tension or flexure at the reduced cross-section may be the factor which limits their effectiveness, especially in dry hickory under impact withdrawal load and under static lateral load.

The slender hardened helically threaded nail made of high-carbon steel is probably most effective for assembling hickory because of its drivability, its resistance to static and impact withdrawal, and its lateral load-carrying capacity.

Plain-Shank, Fluted, and Threaded Nails in Green Hickory

In consideration of the fact that a slender nail can be more effective in hickory than a heavy nail, fully comparative, matched, sextuple, immediate and 6-week delayed tests were performed on plain-shank, fluted, and threaded nails shown in figure 7. They were driven according to standardized procedures (4) and without predrilling to a depth of $1\frac{5}{8}$" into green side-grain hickory of 0.65 ovendry specific gravity and 46% moisture content. During 6-week storage of the green-nailed test plank in 50% relative humidity at 70° F. temperature, its average moisture content decreased to 21%.

The fasteners were statically loaded in a 600/3000-lb. capacity testing machine at a constant rate of loading of 0.100 inch per minute. The impact withdrawal tests were performed with a Forest Products Laboratory Toughness Tester, with the pendulum initially at the 60° angle and the weight at Position 2.

The average test results are presented graphically in figures 8-10 and may be evaluated as follows:

In comparison with the immediate and delayed effectiveness of the $2\frac{1}{2}''$ x 0.129'' (8d) common wire nail, the corresponding values for given properties were found to vary as shown in the following tabulation:

Size	Finish	Carbon steel	Shank	Style	Static withdr. Immed.	Static withdr. Del.	Impact withdr. Immed.	Impact withdr. Del.	Static lateral Immed.	Static lateral Del.
					Percent resistance					
0.097''	bright	Low	plain-shank	sinker	-37	-52	-19	-25	-49	-50
0.097''	bright	Low	helically threaded	sinker	-25	-2	-25	+110	-44	-41
0.097''	bright	Low	annularly threaded	sinker	+16	+133	-26	+61	-45	-41
0.115''	bright	Low	helically threaded	nail	+29	+153	+24	+222	+6	+8
0.120''	bright	Low	annularly threaded	nail	+58	+217	+9	+128	+12	+7
0.119''	bright	High	plain-shank	nail	-18	-12	-2	+8	-6	-4
0.110''	bright	Med.	helically fluted	nail	-26	+33	-15	+129	-6	+7
0.120''	bright	High	annularly threaded	nail	+55	+200	-8	+103	-39	-32
0.120''	hardened	High	plain-shank	nail	-0	+56	-23	+21	+23	+50
0.120''	hardened	High	helically threaded	nail	+49	+173	+28	+161	+52	+101
0.119''	hardened	High	annularly threaded	nail	+46	+216	-10	+99	-23	-18

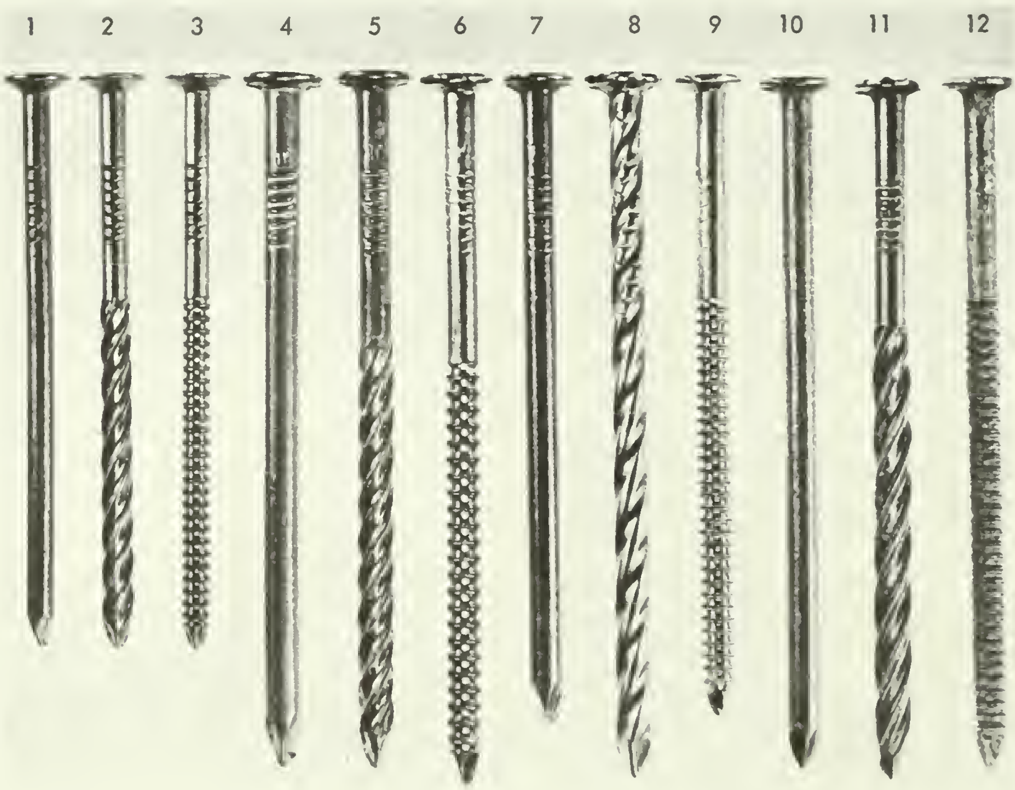

Figure 7.--Various nails driven to uniform depth of penetration of $1\frac{5}{8}''$ into green hickory, and tested for immediate and 6-week delayed static and impact axial withdrawal resistance and static lateral load-carrying capacity. From left to right:

1-3) low-carbon-steel, plain-shank and helically and annularly threaded $2\frac{1}{8}''$ sinkers
4-6) low-carbon-steel, plain-shank and helically and annularly threaded $2\frac{1}{2}''$ nails
7) high-carbon-steel, plain-shank $2\frac{1}{4}''$ nail
8) medium-carbon-steel, helically fluted, $2\frac{1}{2}''$ nail
9) high-carbon-steel, annularly threaded, $2\frac{1}{4}''$ nail
10-12) hardened high-carbon-steel, plain-shank and helically and annularly threaded $2\frac{1}{2}''$ nails

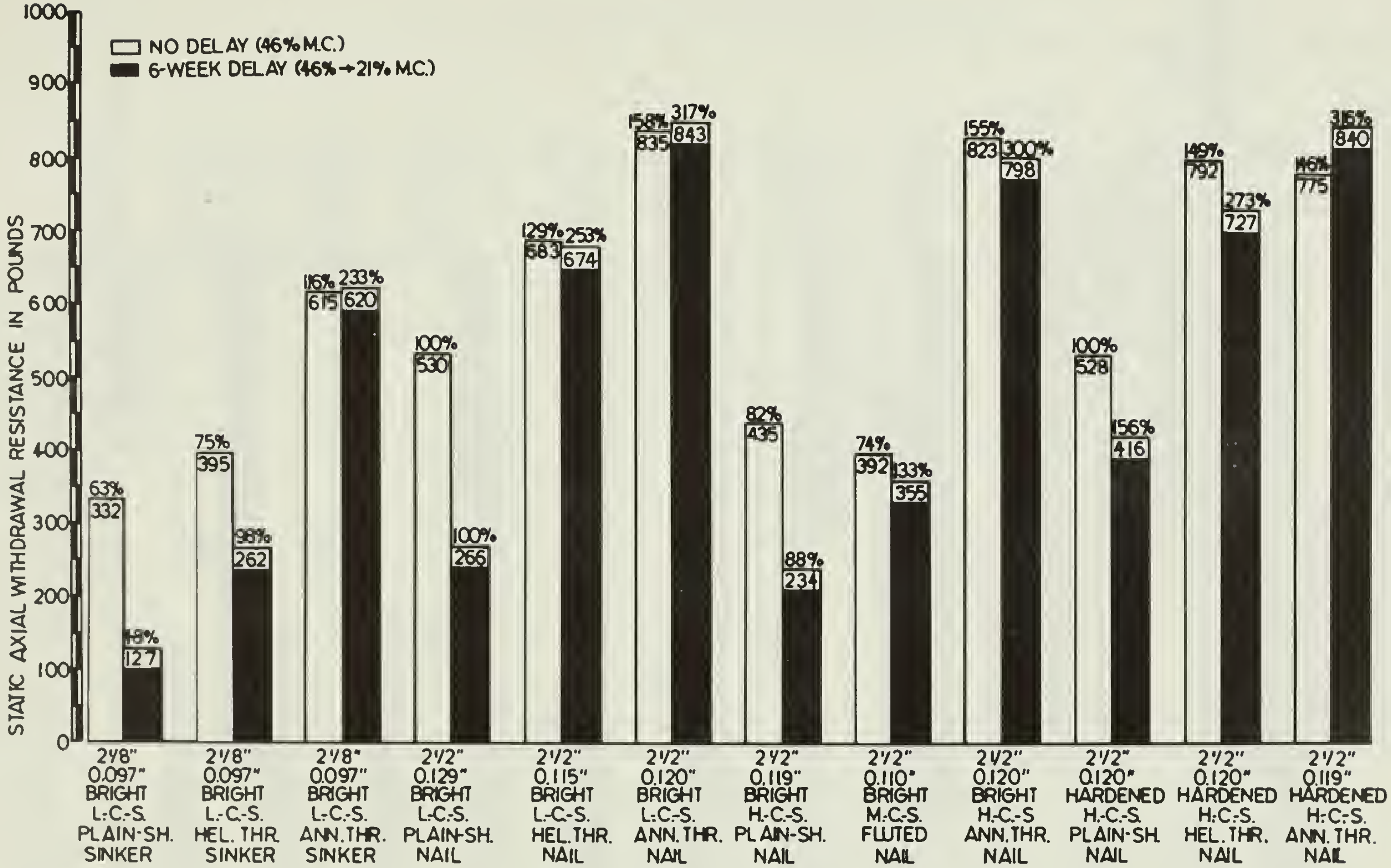

Figure 8.--Immediate and delayed static withdrawal resistance of various steel nails driven without predrilling to depth of $1\frac{5}{8}''$ into side-grain hickory of 0.65 specific gravity.

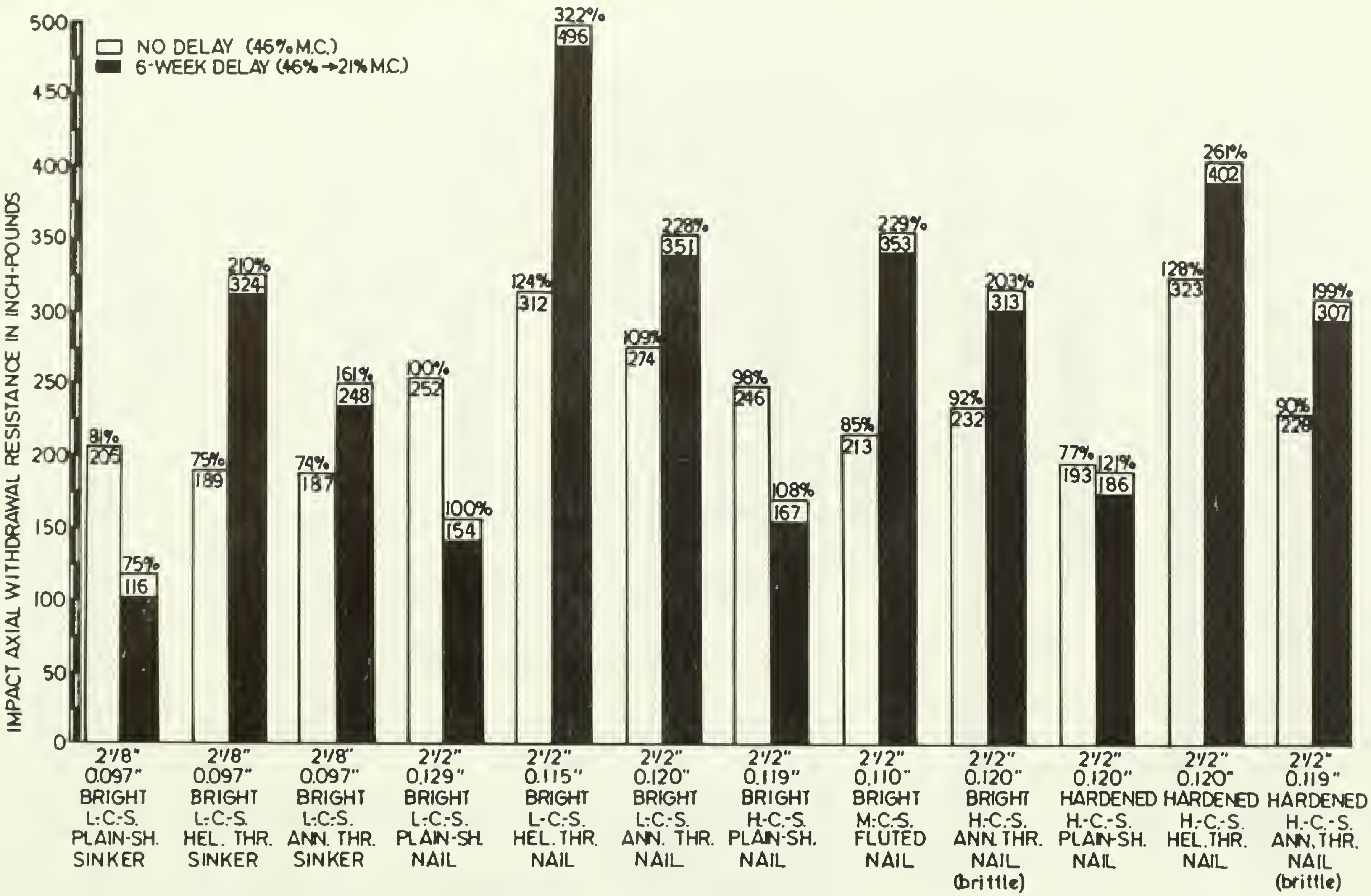

Figure 9.--Immediate and delayed impact withdrawal resistance of various steel nails driven without predrilling to depth of $1\frac{5}{8}$" into side-grain hickory of 0.65 specific gravity.

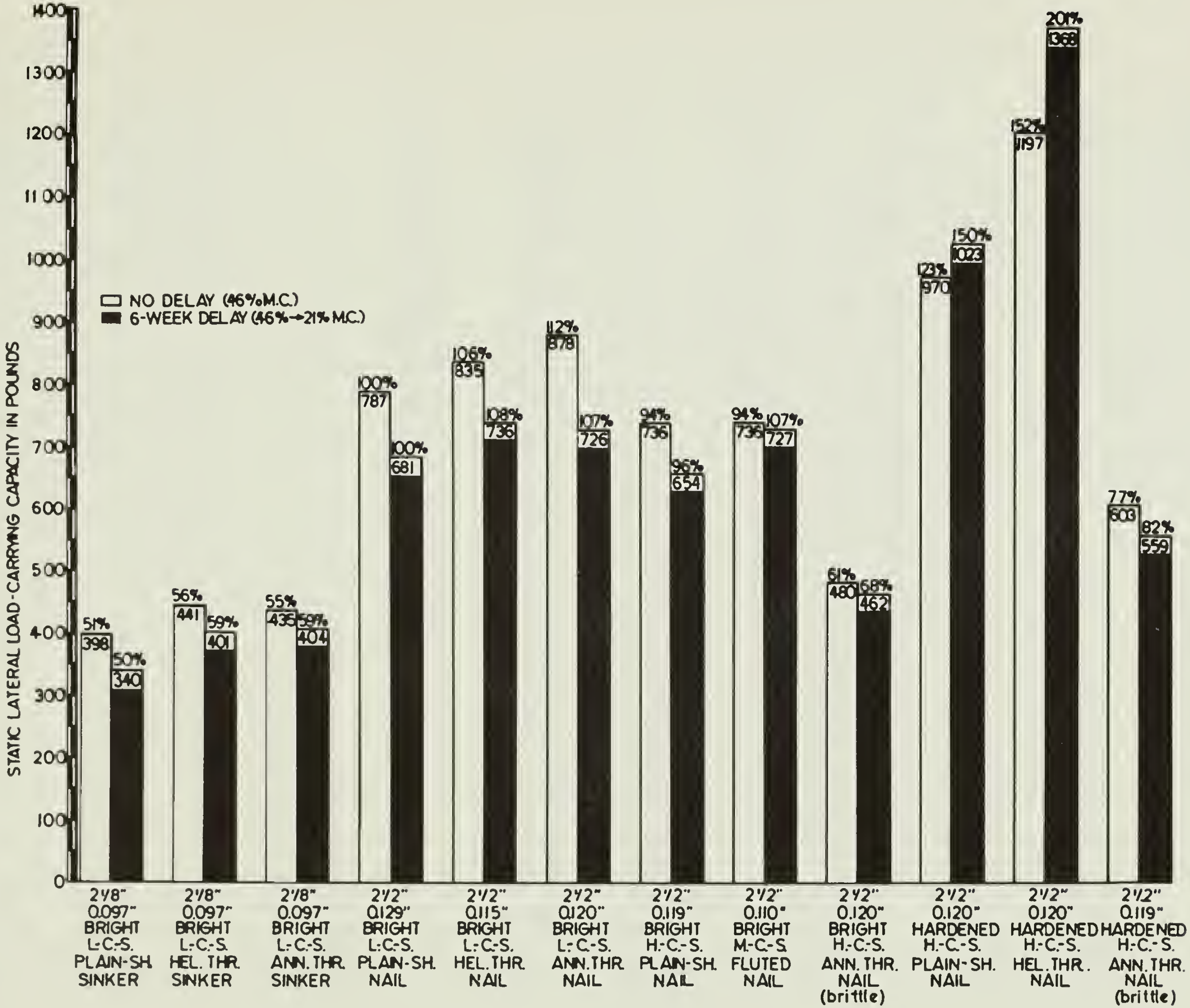

Figure 10.--Immediate and delayed static lateral load-carrying capacity of various steel nails driven without predrilling to depth of 1$\frac{5}{8}$" into side-grain hickory of 0.65 specific gravity and 46% moisture content.

In comparison with the immediate and delayed effectiveness of the respective plain-shank fasteners of same size, the corresponding values for given properties were found to vary as shown below:

	Static withdr.		Impact withdr.		Static lateral	
	Immed.	Del.	Immed.	Del.	Immed.	Del.
	Percent resistance					
helically fluted nail	-3	+64	-6	+129	+13	+26
helically threaded fasteners	+38	+122	+33	+185	+21	+31
annularly threaded fasteners	+72	+142	+5	+102	+17 to -36	+19 to -38

The lateral resistance of the annularly threaded nails varied because of different reductions in cross-section at the thread roots and variations in brittleness of the steel.

In comparison with the immediate and delayed effectiveness of the respective bright low-carbon-steel nails of same size, the corresponding values for given properties were found to vary as shown below:

	Static withdr.			Impact withdr.			Static lateral		
	Immed.	Del.	Avg.	Immed.	Del.	Avg.	Immed.	Del.	Avg.
	Percent resistance								
bright high-carbon-steel plain-shank nail	--	--	-8	--	--	+12	--	--	+9
bright high-carbon-steel annularly threaded nail	--	--	-3	--	--	-13	--	--	-40
hardened high-carbon-steel plain-shank nail	+7	+68	--	+11	+30	--	+38	+68	--
hardened high-carbon-steel helically threaded nail	--	--	+7	--	--	-6	+33	+72	--
hardened high-carbon-steel annularly threaded nail	--	--	-2	--	--	-14	--	--	-26

During 6-week seasoning of the green-nailed plank to 21% moisture content, the average nail effectiveness under given loading conditions was found to have decreased or increased as is shown below:

	Static withdr.	Impact withdr.	Static lateral
	Percent resistance		
plain-shank fasteners	-41	-26	-7
helically fluted nail	-9	+66	-1
helically threaded fasteners	-13	+44	+2
annularly threaded fasteners	+2	+33	-7

It should be noted that the delayed tests were performed when the green-nailed hickory was only partially seasoned. On the basis of previously published information (6), more favorable test data would have been obtained for the threaded fasteners if further drying of the lumber had taken place prior to delayed testing.

These tests indicate that annularly threaded fasteners provide maximum static withdrawal resistance in green-nailed hickory. In comparison with the effectiveness of these fasteners, the average immediate and delayed static withdrawal resistance of same-size helically threaded fasteners in green-nailed hickory is only 17% lower and 30% lower, respectively, while their impact withdrawal resistance is 20% higher and 36% higher and their lateral load-carrying capacity may be 2% or 94% and 4% or 140% higher. Consequently, preference may be given to the helically threaded nails and sinkers wherever green-nailed hickory will be subjected to large impact withdrawal and static lateral forces.

The use of hardened high-carbon-steel helically threaded nails, instead of similar bright low-carbon-steel nails, does not significantly change the effectiveness of the green-nailed hickory joint with respect to withdrawal resistance. On the other hand, the immediate and delayed lateral load-carrying capacity of such a joint can be increased 33% and 72%, respectively.

Hardened High-Carbon-Steel Plain-Shank and Threaded Nails, Spikes, and Staples in Dry Hickory

Hardened high-carbon-steel nails are generally manufactured of one gauge smaller wire than low-carbon-steel nails of equivalent lengths because of the inherent stiffness of hardened steel and the resulting good drivability of the hardened nails. These slender fasteners easily penetrate dense dry hickory. If, however, long nails and spikes with large shank diameters are required, predrilling of the dry hickory is necessary.

To determine the effectiveness of hardened steel nails, spikes, and staples in dry hickory, fully comparative matched tests were performed on plain-shank and threaded fasteners shown in figures 11 and 12. They were driven into dry side-grain hickory of 0.76 ovendry specific gravity and 10% moisture content and tested immediately with a 3000/12000-lb. capacity testing machine at a constant rate of loading of 0.100 inch per minute.

Withdrawal resistance.--Axial withdrawal tests were performed according to previously established testing procedures (4). The average test results are graphically presented in figure 13.

Predrilling was employed whenever necessary. In such cases, the drill diameter chosen varied from 77% to 88% of the nail diameter.[2] The drill diameter measured 3/32" for the 0.112" annularly threaded nail; 1/8" for the 0.148" plain-shank and helically threaded nails; 9/64" for the 0.148" helically threaded nail with short pitch (screwnail), for the 0.160" annularly threaded nail, and for all 0.177" nails; 5/32" for the 0.203" plain-shank spike; and 11/64" for all 0.203" threaded spikes.

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[2] Nail diameter as defined here is that of the wire from which a nail is made; the crest diameter of the thread is somewhat larger.

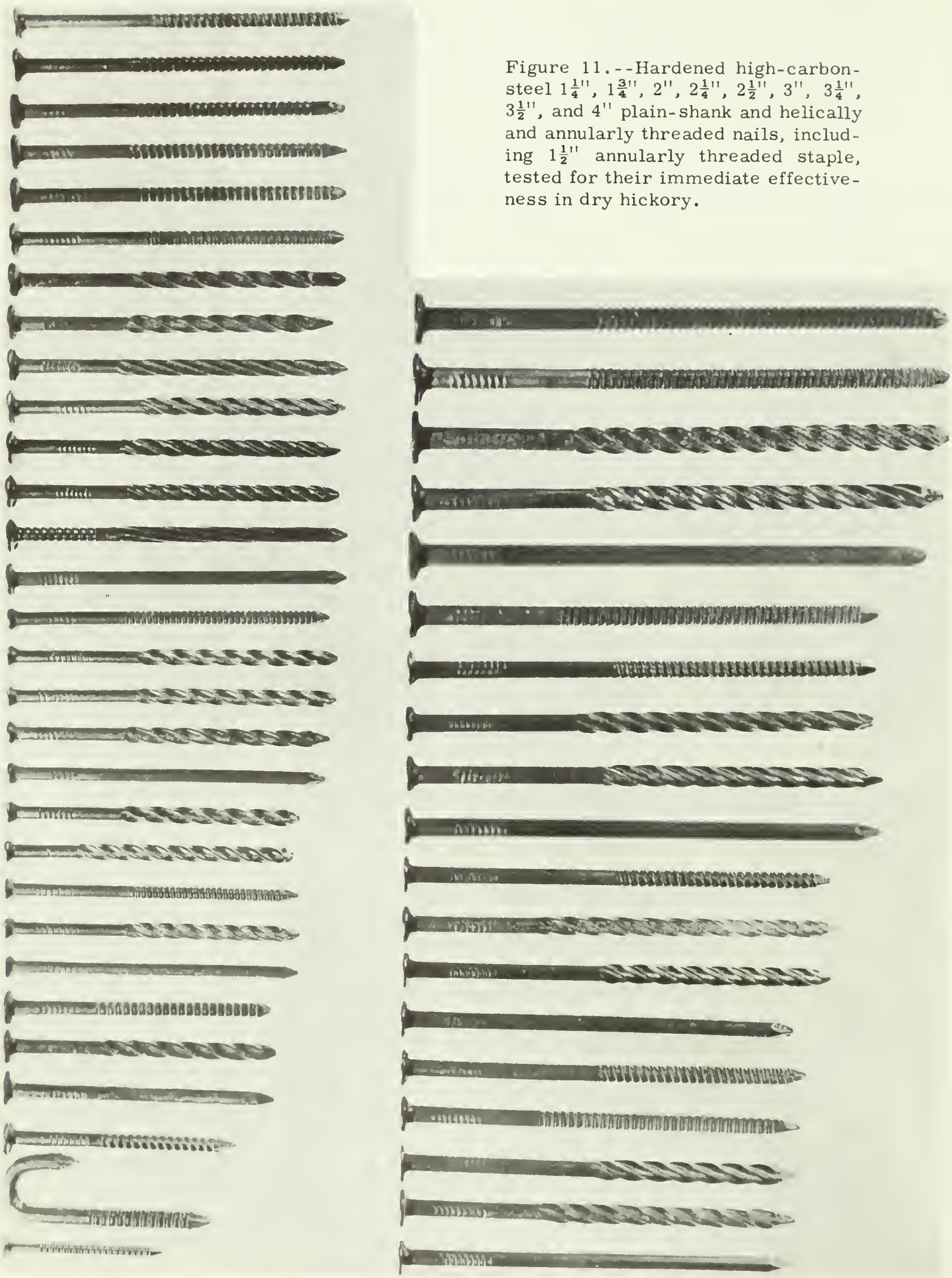

Figure 11.--Hardened high-carbon-steel $1\frac{1}{4}''$, $1\frac{3}{4}''$, $2''$, $2\frac{1}{4}''$, $2\frac{1}{2}''$, $3''$, $3\frac{1}{4}''$, $3\frac{1}{2}''$, and $4''$ plain-shank and helically and annularly threaded nails, including $1\frac{1}{2}''$ annularly threaded staple, tested for their immediate effectiveness in dry hickory.

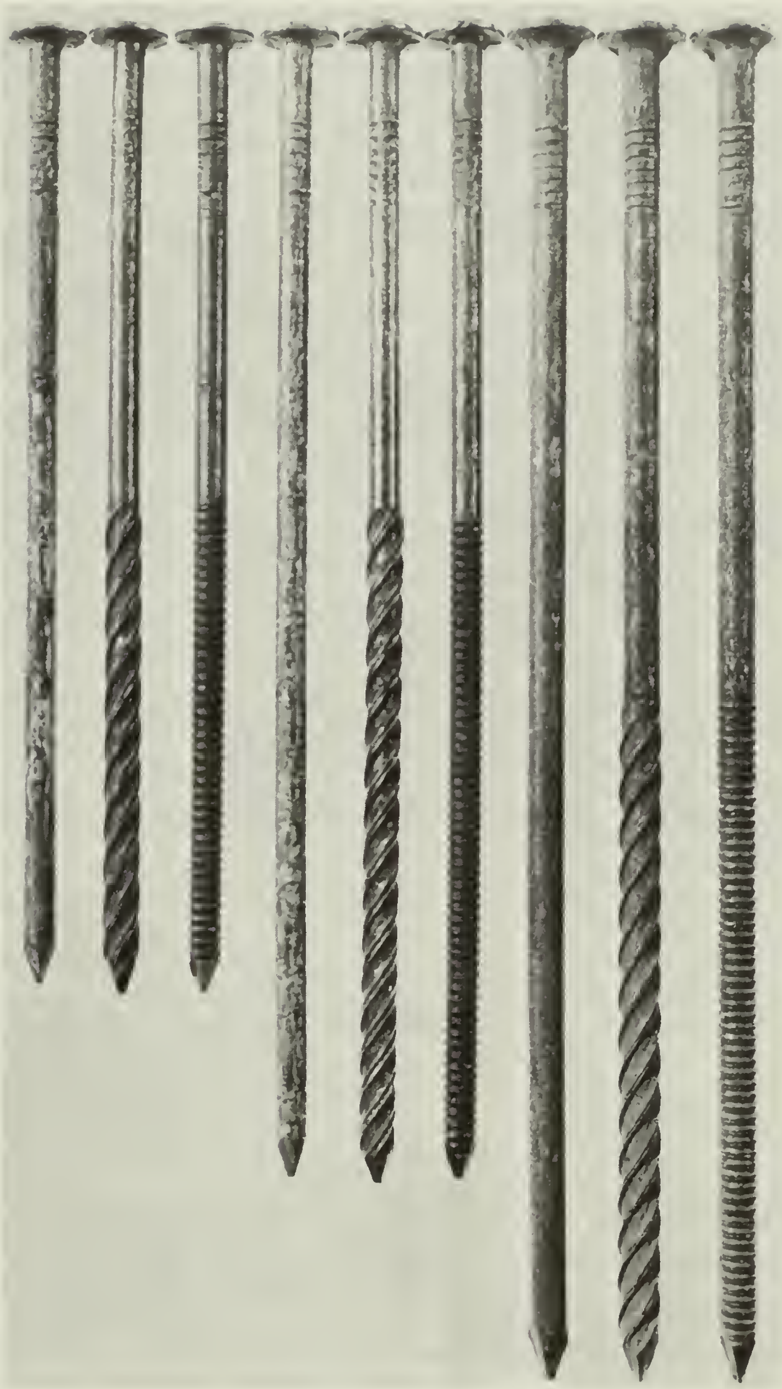

Figure 12.--From left to right, hardened high-carbon-steel 5", 6", and 7" plain-shank helically threaded and annularly threaded nails and spikes tested for their immediate effectiveness in dry hickory.

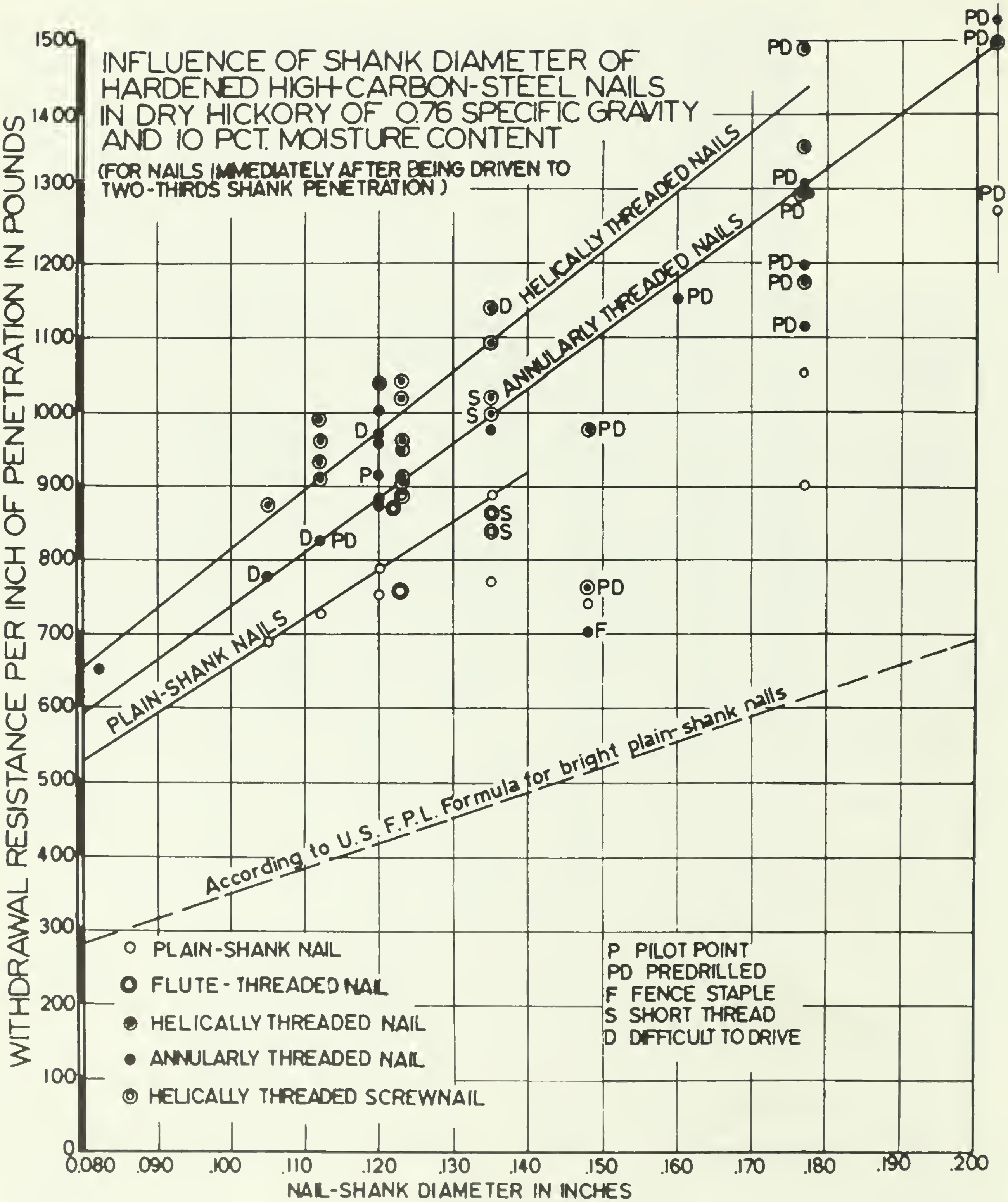

Figure 13.--Immediate withdrawal resistance of hardened high-carbon-steel plain-shank and threaded nails in dry hickory.

As shown in figure 13, the hardened nails and spikes, with slightly roughened surface resulting from the heat-treating process, provided considerably greater holding power than would be expected from bright plain-shank nails of same diameters according to the general formula for nail-holding power. On the average, the hardened plain-shank nails may offer 73% greater immediate withdrawal resistance in dry hickory than the bright plain-shank nails, if such a comparison is justified with no directly comparable test data available for this wood species.

The hardened flute-threaded nail--thus labeled because its thread-pitch is markedly longer than any of the other nails--provided the same withdrawal resistance as the hardened plain-shank nail. The hardened helically threaded nails with medium-long pitch offered on the average 25% higher, and the hardened annularly threaded nails offered on the average 20% higher immediate withdrawal resistance than the hardened plain-shank nails of same diameters.[3] The data for helically threaded nails with short pitch (screwnails) are too limited to allow a valid direct comparison. The superior drivability and holding power of helically threaded nails with medium-long pitch suggests their preferred use in hickory.

Considerable benefit has been derived from use of L-shaped, annularly threaded[4] fence staples in fastening wires and wire fences, particularly to posts that have been pressure treated with creosote. Special hardened high-carbon-steel staples of this type are manufactured for use with dense posts such as hickory (7). The immediate average withdrawal resistance of such a hardened annularly threaded staple in the tested dry hickory amounted to as much as 874 lbs.

Lateral load-carrying capacity.--Nails tested for their immediate lateral load-carrying capacity were loaded by steel blocks which fitted snugly around the protruding nail shanks (4). The direction of load application was perpendicular to the grain of the hickory plank. In most cases, the test load was limited by shear failure of the nail at the edge of the steel loading block along the plank surface. Thus, it is evident that the testing procedure employed had a direct influence on the test data.

Load-deformation curves for plain-shank, flute-threaded, and helically threaded nails--incorporating the deformation of the complete assembly--were automatically recorded. Slopes of load-deformation curves for different nails of same size proved to be similar. A definite proportional limit was not observed despite the continuous automatic record of load-deformation data.

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[3] Had tests been performed on nails driven into green hickory, this difference could have been considerably larger, because of the expected loss in holding power of plain-shank nails during lumber seasoning to dry condition.

[4] Helical threads should not be used on an L-shaped fastener, since they would cause shank rotation during driving.

The averages of the ultimate test data are graphically presented in figure 14. The hardened plain-shank nails and spikes offered, on the average, approximately $2\frac{1}{2}$ times the immediate lateral load-carrying capacity of bright plain-shank nails of same size in the tested hickory, which would be expected, according to the general formula developed for the lateral load-carrying capacity of common wire nails.

As in the case of withdrawal resistance, the flute-threaded nail with annular threads below the nail head provided the same immediate lateral load-carrying capacity as the plain-shank nail of same size. The helically threaded nails with medium-long pitch offered, on the average, 16% greater immediate lateral load-carrying capacity than the same-size plain-shank nails. The relatively poor performance of the annularly threaded nails and short-pitch helically threaded nails (screwnails) indicates that these nails are not the best choice. The reduction in cross-section along the threaded part of the nail shank is a disadvantage when nailing such hard woods as hickory.

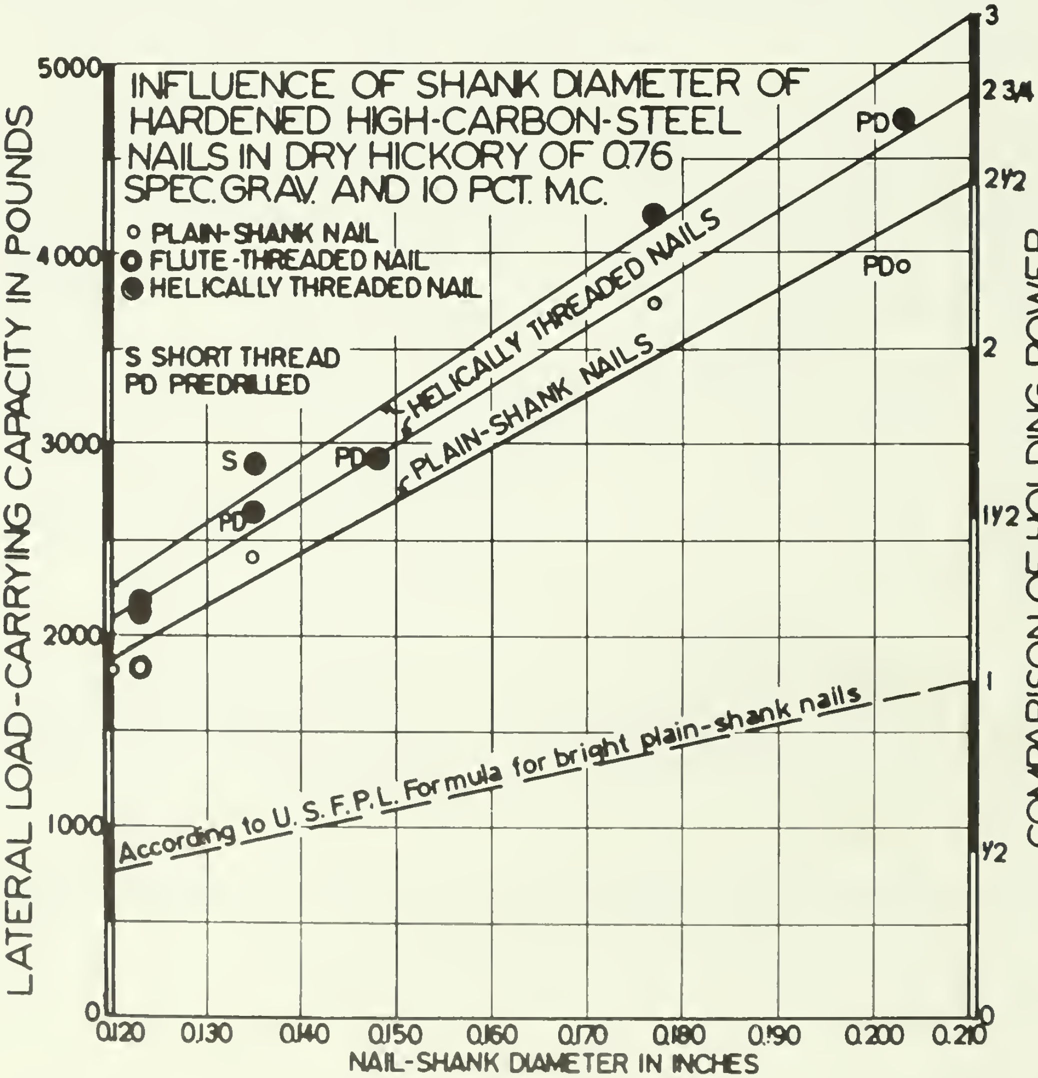

Figure 14.--Immediate lateral load-carrying capacity of hardened high-carbon-steel plain-shank and threaded nails in dry hickory.

Low-Carbon-Steel Plain-Shank and Threaded Nails and Spikes in Dry Hickory

Since predrilling is necessary for satisfactorily driving any large nails and spikes into dry hickory--whether they are the slender hardened high-carbon-steel or the heavy-gauge bright low-carbon-steel fasteners--the use of low-carbon-steel nails and spikes can be desirable under certain conditions.

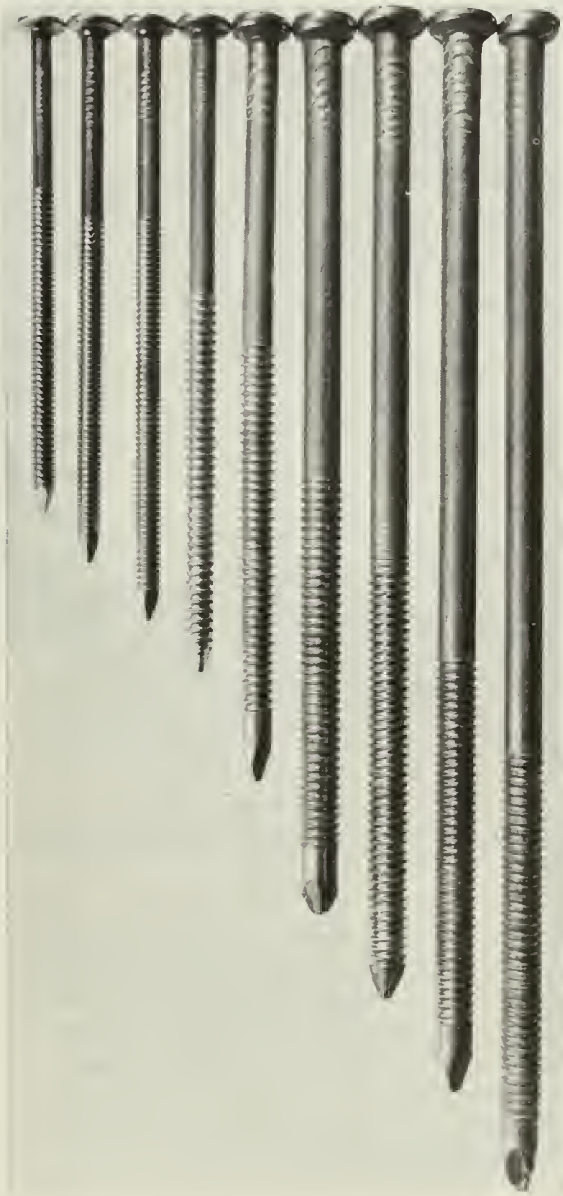

Figure 15.--Bright low-carbon-steel $4\frac{1}{2}''$ to 11'' annularly threaded nails and spikes tested for their withdrawal resistance in dry hickory.

In order to obtain information on the effectiveness of bright low-carbon-steel nails and spikes in hickory, identical static withdrawal tests, as described in the previous chapter, were performed with the plain-shank and annularly threaded fasteners shown in figure 15. The average test results are graphically presented in figure 16.

Predrilling had to be employed throughout. The influence of the diameter of the predrilled hole on the test data is indicated in figure 16. Too small a hole (83% of nail diameter) made it difficult to drive the nail, although the holding power of the nail in such a small hole proved to be greater than that for an identical nail in a larger hole. Too large a hole (97% and 99% of nail diameter) eased nailing but reduced holding power. A predrilled hole of a diameter amounting to 90% of the wire diameter proved to be desirable. For the tested plain-shank and annularly threaded nails, such predrilling resulted in, respectively, 36% and 16% larger holding power than predrilling of a larger hole. Hence, predrilled nail holes with diameters ranging from 89% to 93% of the wire diameters were used for most of the tests and can be recommended for large bright low-carbon-steel fasteners in dry hickory.

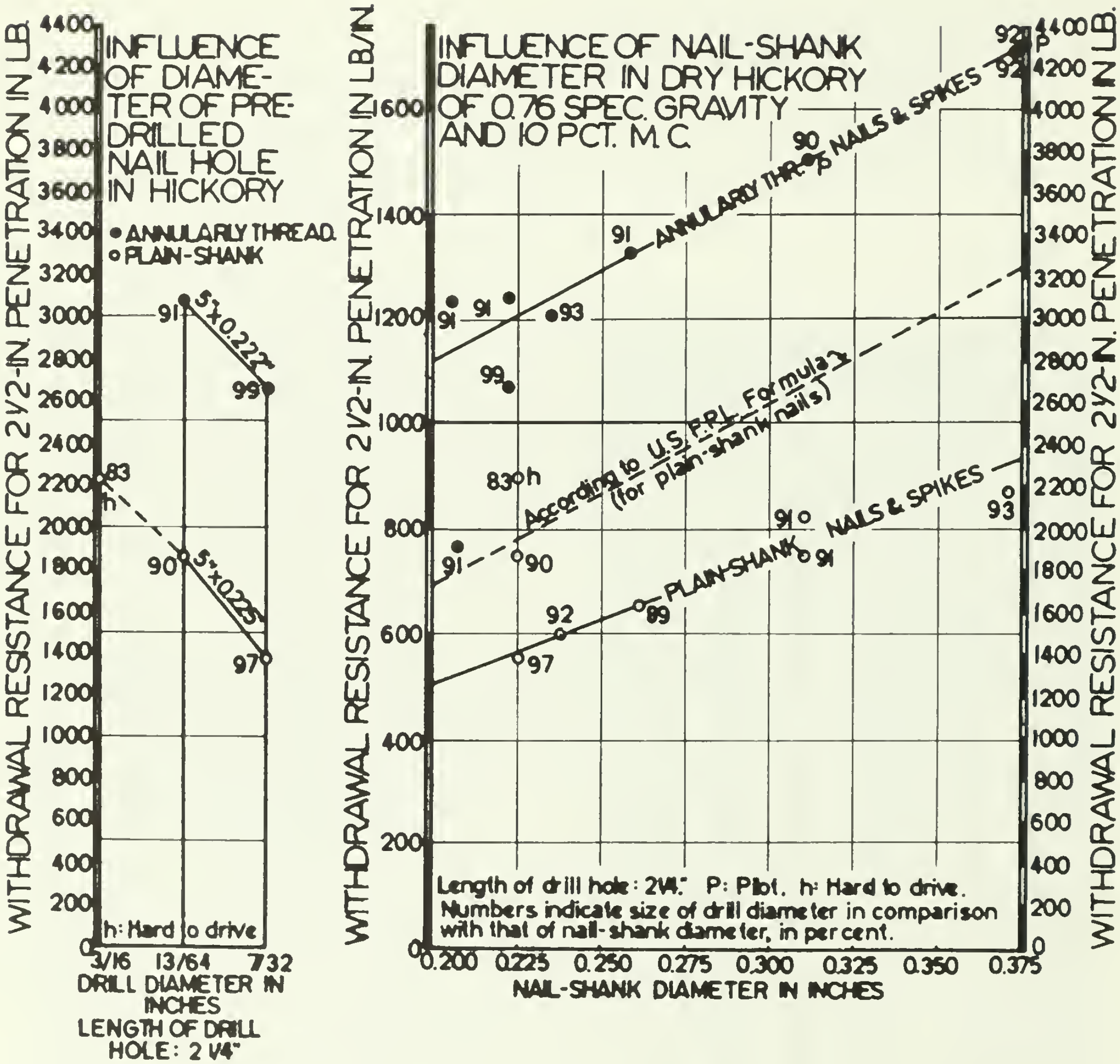

Figure 16.--Immediate withdrawal resistance of plain-shank and threaded nails and spikes in hickory.

As shown in figure 16, the withdrawal resistance of the $4\frac{1}{2}$'' x 0.207'' and the 5'' x 0.225'' plain-shank nails driven into predrilled holes of recommended diameters is in excellent agreement with the values computed according to the general formula for nail-holding power. On the other hand, the withdrawal resistance of the larger nails and that of the spikes driven into predrilled holes of recommended diameters was on the average 28% smaller than would be expected according to this formula.

The annularly threaded nails and spikes, on the average, provided 89% greater immediate withdrawal resistance than the plain-shank fasteners of same diameters if driven into predrilled holes of identical sizes. The relatively uniform test data for the threaded fasteners follow a parallel trend to that suggested by the above-mentioned formula. Thus, one may compute the holding power of large-diameter, bright low-carbon-steel annularly threaded nails and spikes in pounds per inch of shank penetration in predrilled hickory by the expanded formula:

$$p' = 440 + (6900\ G^{5/2}D)$$

or

$p' = 440 + 3240\ D$ for average hickory of 0.74 specific gravity.

A comparison of the withdrawal resistance of bright low-carbon-steel and hardened high-carbon-steel plain-shank and annularly threaded nails and spikes of similar diameters driven into predrilled hickory is made in the following tabulation of the average test values for immediate static withdrawal resistance, in pounds per inch of shank penetration:

Plain-shank		Annularly threaded	
Bright	Hardened	Bright	Hardened
4½" x 0.207"	7" x 0.203"	4½" x 0.205"	7" x 0.203"
760	1271	1228	1526

Thus, the hardened plain-shank spike offered 67% higher and the hardened threaded spike offered approximately 25% higher immediate holding power per inch of shank penetration than the respective bright nail of similar diameter.

Hardened High-Carbon-Steel Plain-Shank and Threaded Spikes in Green Hickory

Since slender, hardened high-carbon-steel spikes show a definite economic advantage (12), it is appropriate to consider their use in hickory.

Fully matched, duplicate, immediate and 6-week delayed, static axial withdrawal tests were performed according to standardized procedures (4) and at a constant rate of withdrawal of 0.100 inch per minute on the 7" x 0.177" plain-shank and helically threaded, hardened high-carbon-steel spikes shown in figure 17. They were driven without predrilling to a depth of 2½" into green side-grain hickory of 0.77 ovendry specific gravity and 73% moisture content. During 6-week storage of the green-nailed plank in 50% relative humidity at 70° F. temperature its average moisture content decreased to 20%.

The average test results are presented graphically in figure 18 and may be evaluated as follows:

In comparison with the respective withdrawal resistance of the plain-shank spike, the helically threaded spike provided 30% higher immediate and 124% higher delayed holding power. During 6-week seasoning of the green plank to 20% moisture content, the plain-shank spike lost 47% and the hardened spike lost 8% of the initial holding power.

While the number of tests performed was small, the better performance of the threaded spike is significant.

Threaded Nails in Creosote-Treated Hickory

Because of the presence of oil in lumber pressure-treated with creosote, the holding power of plain-shank nails is only a fraction of that in non-treated lumber. For this reason, the use of threaded nails has been suggested when nailing to pressure-treated lumber (9).

Especially for low-cost assemblies, there is a tendency to use ineffectively threaded nails. They are driven relatively easily, but offer small holding power.

In order to demonstrate the effectiveness of various types of threads along nail shanks in hickory that had been pressure-treated with creosote, fully matched, sextuple, immediate and delayed, static axial withdrawal tests were performed on seven types of $2\frac{1}{4}''$ and $2\frac{1}{2}''$ bright and hardened, high-carbon-steel, helically threaded, flooring and pallet nails shown in figure 19.

Without predrilling, these nails were driven to 13/16'' from nail head into side-grain, pressure-treated hickory of 0.92 ovendry specific gravity[5] and 23% total moisture content. The nails were withdrawn immediately after being driven or after 12-week storage of the nailed test plank in 50% relative humidity at 70° F. temperature. During this period, the total moisture content of the hickory plank decreased to 13%.

These tests were performed at a constant rate of withdrawal of 0.060 inch per minute with a 1500-lb. capacity testing machine according to the standardized testing procedure (4).

The average test results are graphically presented in figure 20. A comparison of the lead angles of the threads along the nail shanks and an

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[5] The specific-gravity value was affected by the creosote treatment.

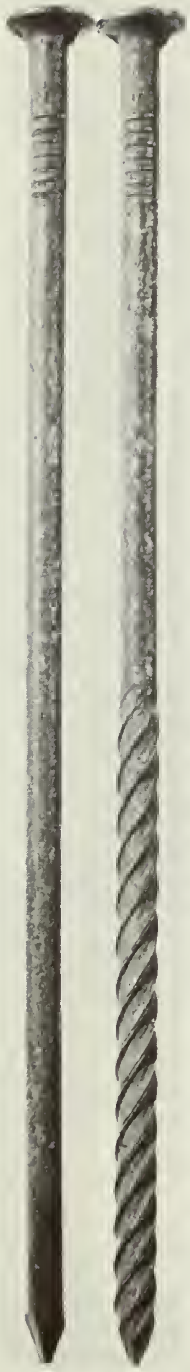

Figure 17.--Slender, hardened high-carbon-steel 7" x 0.177" plain-shank and helically threaded spikes driven into green hickory and tested for their immediate and delayed withdrawal resistance.

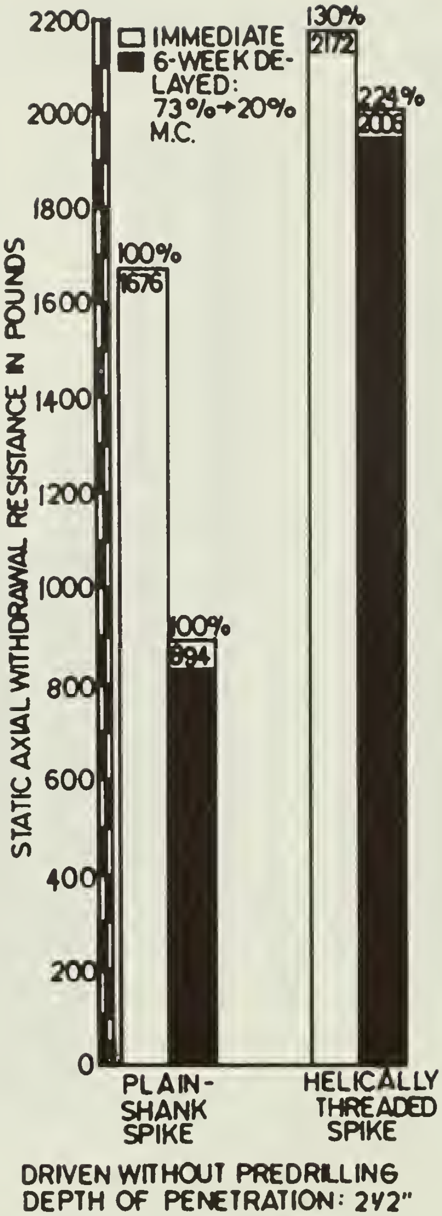

Figure 18.--Immediate and delayed static withdrawal resistance of 7-gauge hardened high-carbon-steel spikes driven to depth of $2\frac{1}{2}$" into side-grain green hickory of 0.77 specific gravity and 73% moisture content and tested at constant rate of loading of 0.100 inch per minute.

analysis of the test results indicate that the tested nails can be divided into three groups of effectiveness:

Nail group	Nail No.	Nail diameter (Inch)	Lead angle of thread (Degrees)	Withdrawal resistance Immediate (Pounds per inch of shank penetration)	Withdrawal resistance Delayed (Pounds per inch of shank penetration)	Gain or loss (Percent)
1	1	0.122	81	346 (100%)	247 (100%)	-29
2	2	0.122	70	379 (110%)	377 (153%)	-1
2	5	0.106	72	327 (95%)	351 (142%)	+7
2	6	0.120	70	414 (120%)	475 (192%)	+15
3	3	0.122	60	526 (152%)	611 (247%)	+16
3	4	0.114	68	661 (191%)	811 (328%)	+23
3	7	0.122	59	612 (177%)	680 (275%)	+11

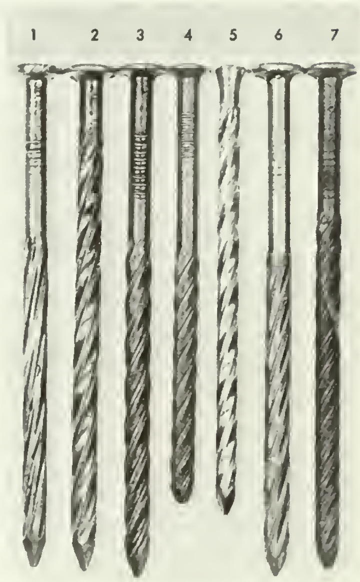

Figure 19.--Bright and hardened high-carbon-steel $2\frac{1}{4}$'' and $2\frac{1}{2}$'' helically threaded nails. From left to right:

1-2) cement-coated, bright $2\frac{1}{2}$'' x 0.122'' pallet nails
3) cement-coated, hardened $2\frac{1}{2}$'' x 0.122'' pallet nail
4) non-coated, hardened $2\frac{1}{4}$'' x 0.114'' flooring nail
5) non-coated, bright $2\frac{1}{4}$'' x 0.106'' flooring nail
6) lightly cement-coated, bright $2\frac{1}{2}$'' x 0.120'' pallet nail
7) lightly cement-coated, hardened $2\frac{1}{2}$'' x 0.122'' pallet nail

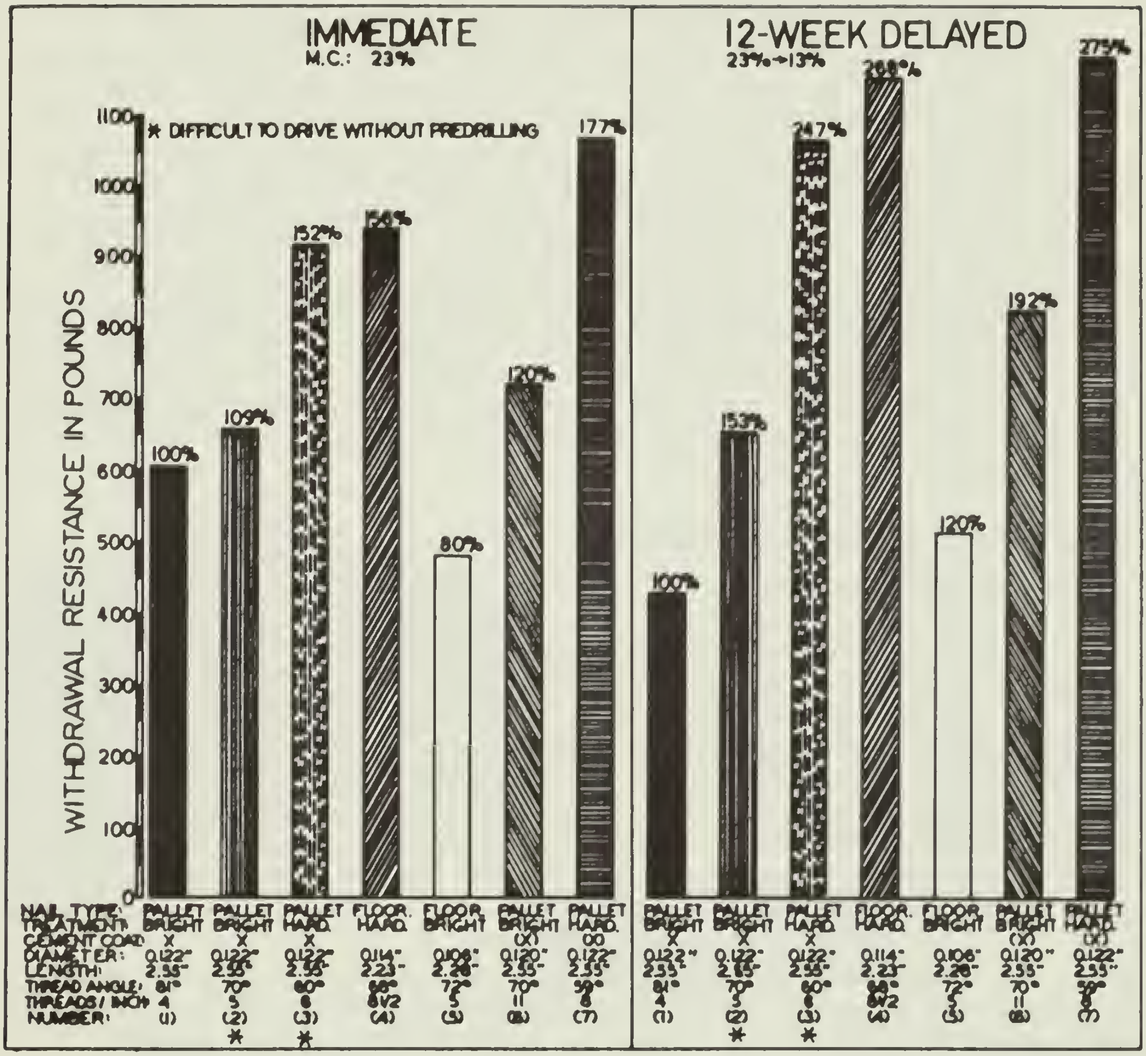

Figure 20.--Immediate and delayed withdrawal resistance of high-carbon-steel helically threaded nails driven to depth of 13/16" from nail head into creosote-pressure-treated hickory.

As compared to the effectiveness of the flute-threaded nail with large lead angle, the immediate and delayed withdrawal resistance of the second group of nails with medium-large lead angles was on the average 8% and 62% higher, respectively; and that of the third group of nails with recommended lead angles was on the average 74% and 183% higher, respectively. This third group included the nail which offered maximum immediate and delayed holding power despite its 7% smaller shank diameter.

During 12-week drying of the nailed plank from 23% to 13% moisture content, the flute-threaded nail lost as much as 29% of its relatively small initial holding power. On the other hand, the second and third groups of nails gained on the average 7% and 17%, respectively, in holding power.

Manufacturing variables other than lead angle and type of thread, such as cement coatings of varying thicknesses, were of relatively little effect on nail-holding power in the creosote-pressure-treated hickory, which is in agreement with previous findings for dense woods (4).

Exceedingly effective types of threads can be applied economically to nail shanks on a mass-production basis. It is thus possible to use relatively slender and short nails with highly effective threads along their shanks for the efficient assembly of treated and nontreated hickory without decreasing the joint effectiveness attained with larger nails having less effective threads along their shanks. A small but effectively threaded nail can be the most efficient fastener, especially in such dense woods as hickory and particularly in pressure-treated hickory, where the treating material acts as a lubricant and adversely influences the holding power of plain-shank fasteners.

Effectiveness of Helically Threaded Nails in Studding Hickory

Despite the high load-carrying capacity of hickory perpendicular to its grain--allowing a design load of 720 psi, which is a higher design load than for any other commercial U. S. wood species (2)--it is possible to increase its bearing capacity by studding it with nails. This procedure can be particularly advantageous where high-strength materials of the resilience and damping capacity of wood are required, such as for foundations on which heavy machinery is to be mounted. Such an improvement in the bearing capacity of softwood was studied elsewhere (1) and may be adapted to hickory.

Studding of hickory can also increase its wear resistance, which is a particularly important feature in railroad crossties. Studding with nails can reduce mechanical wear, abrasion, and the cutting of the crossties by the plates--principal causes of failure in preservatively treated ties.

To increase the useful service life of crossties, the train load carried by each tie plate should be transmitted through the tie plate directly into the interior of the tie, instead of onto its top surface as is the present practice. This load transmission is accomplished by studding the tie below the tie plate with a relatively large number of properly threaded nails of large diameter, as shown in figure 21 (5, 11).

Fully matched tests were performed on the bearing capacity of an 8'' x 13½'' tie plate placed on 7'' by 9'' conventional, plain and studded, creosote-pressure-treated hickory crossties. The same slopes of the load-penetration curves and approximately the same proportional-limit compressive load-carrying capacities as for the corresponding surface-bearing ties were observed for ties studded with forty-six 3'' x 0.250'' threaded nails with 2½'' shank penetration. On the basis of a 35000-lb. wheel load distributed over three tie plates (3), the static design load amounts to only 12% to 13% of the proportional-limit bearing capacity of the studded ties immediately after nail driving.

Full shank penetration of the nails, with the nail heads flush with the top surface of the tie, results in a considerably larger bearing capacity of studded ties than is attained by the partial shank penetration. Such a procedure provides (a) additional shank penetration, and hence greater load-carrying capacity per nail; (b) deeper shank penetration, and hence better load distribution within the tie cross-section; and (c) simultaneous load distribution to top surface and interior of the tie.

In light of the exploratory tests performed, the wearing of the surface of a crosstie can be delayed, if not prevented, by properly studding the tie below the tie plate.

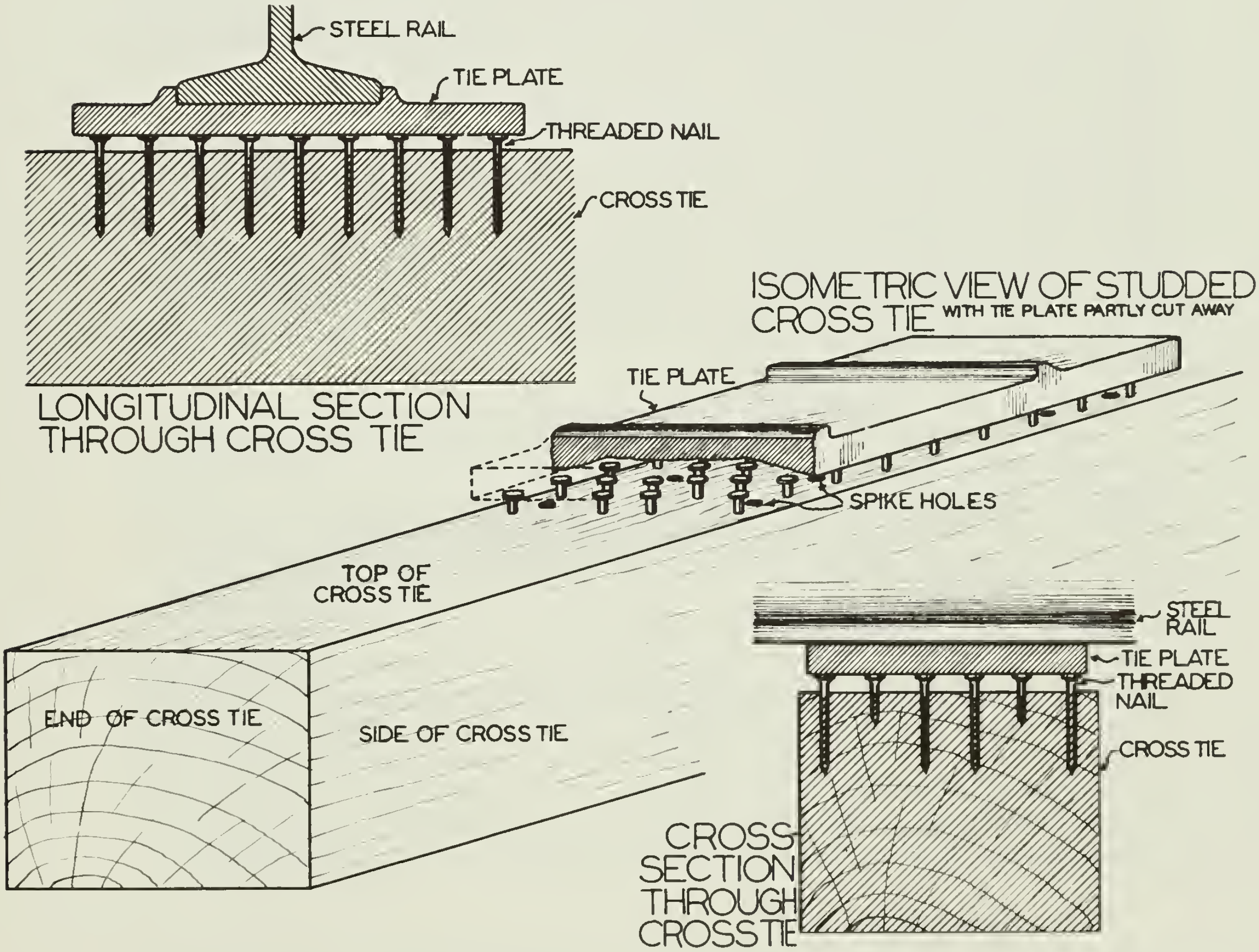

Figure 21.--Studded cross tie.

SUMMARY AND RECOMMENDATIONS

To provide most effective, efficient nailing and at the same time avoid splitting, use slender nails, which can if properly handled be driven without predrilling.

Outstanding effectiveness and efficiency in nailing dry hickory without predrilling is feasible with machine-driven knurled auto nails, since the auto-nailers allow the use of more slender nails than is possible for hand-nailing into dry hickory.

For such hand-nailing into dry hickory as well as for machine-nailing, slender, properly hardened, high-carbon-steel nails and spikes are recommended. The hardened nails may offer approximately 75% higher holding power than same-size bright low-carbon-steel nails immediately after being driven into dry hickory. If driven into green hickory, the hardened nails may provide at least 67% higher delayed static withdrawal resistance, 33% higher delayed impact withdrawal resistance, and 67% higher delayed static lateral load-carrying capacity than same-size, bright low-carbon-steel nails. Especially in the case of long nails and spikes, the saving in steel required for the slender, hardened, high-carbon-steel fasteners, in comparison with that required for the heavier low-carbon-steel common wire nails, is considerable (12). For this reason, in a comparison of the cost of nonhardened and hardened nails the number of nails per pound must be given particular consideration.

Recommended for maximum effectiveness in hand-nailing and machine-nailing green, partially seasoned, and dry hickory are helically threaded, hardened, high-carbon-steel nails with medium (approximately 60°) lead angle of the threads. Plain-shank nails may lose 67% and more of their initial holding power during seasoning of green-nailed hickory. Properly threaded nails retain or even increase their initially higher holding power. Immediately after being driven into dry hickory, such hardened helically threaded nails provide, on the average, 25% higher withdrawal resistance and 16% higher lateral load-carrying capacity than same-size hardened plain-shank nails. Immediately after being driven into green hickory, the benefit derived from proper helical threads along the shanks of hardened nails amounts to a 50% increase in static withdrawal resistance, 67% increase in impact withdrawal resistance, and approximately 25% increase in static lateral load-carrying capacity.

The advantage of hardened threaded nails over hardened plain-shank nails is considerably greater after the seasoning of green-nailed hickory. Thus, after partial seasoning of green-nailed hickory to 20% moisture content, the hardened helically threaded nail driven without predrilling provided 75% higher static withdrawal resistance, 116% higher impact withdrawal resistance, and 33% higher lateral load-carrying capacity than the same-size hardened plain-shank nail; and the hardened helically threaded spike provided approximately 125% higher static withdrawal resistance than the same-size hardened plain-shank spike. In a comparison of the effectiveness of same-size hardened and bright helically threaded nails, the corresponding increases in effectiveness amounted to 61%, 38%, and 71% immediately after driving and to 194%, 182%, and 125% after partial seasoning of the hickory.[6]

If predrilling is necessary for satisfactory nail driving into hickory, the drill should have a diameter approximately 90% of the wire diameter of the bright low-carbon-steel nail, and 80% to 85% of the wire diameter of the hardened high-carbon-steel nail.

Properly threaded and hardened high-carbon-steel nails, spikes, and staples of the following standard sizes will provide optimum performance:

Structural hickory and hickory framing, poles, formwork, and scaffolding

2" and 2½" x 0.120"
3" and 3¼" x 0.135"
3½" x 0.148"
4" to 6" x 0.177"
7" to 9" x 0.207"[7]

Hickory and other lumber sheathing of 1" nominal thickness to hickory framing

1¾" x 0.120"

Plywood and hardboard sheathing to hickory framing

1¼" and 1½" x 0.083"

Hickory and other subflooring to hickory joists, and hickory and other flooring to hickory subflooring and joists

2¼" x 0.110"
2" and 2¼" x 0.115"

Underlayment to hickory sleepers and joists, and panelling to hickory framing

1" and 1¼" x 0.083"

Gypsumboard and lath to hickory framing

1¼" x 0.098"

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[6] After seasoning of green-assembled hickory from 38% to 9% moisture content, a hardened helically threaded nail driven without predrilling provided approximately a 567% higher static withdrawal resistance per inch of penetration than a bright low-carbon-steel plain-shank box nail having a 20% smaller wire diameter and having been driven into a predrilled hole. Consequently, the holding power attributable to the surface-roughened helical shank deformations actually amounted to approximately 433% (see footnote 1).

[7] Spikes longer than 9" have to be of ⅜" bright low-carbon steel because of present manufacturing limitations for hardened high-carbon-steel spikes.

<u>Electrical conduit to hickory framing and sheathing</u>

$1\frac{1}{2}$'' x 0.162'' (annularly threaded L-shaped conduit staple)

<u>Fence wire to hickory posts</u>

$1\frac{1}{2}$'' x 0.148'' (annularly threaded L-shaped fence staple)

<u>Hickory boxes, crates, and pallets</u>

2'' x 0.105''
$2\frac{1}{4}$'' x 0.110''
$2\frac{1}{2}$'' x 0.120''

The selection of the lengths of these fasteners is governed by the thickness of the members to be fastened, to allow a minimum penetration into hickory of six to seven nail diameters for properly threaded nails and of ten nail diameters for other nails.

BIBLIOGRAPHY AND REFERENCES

(1) HOPPE, C. J.
1949. Increasing the load-carrying capacity perpendicular to grain of softwoods by nailing. Der Bauingenieur 24(3): 90-93.

(2) NATIONAL LUMBER MANUFACTURERS ASSOCIATION
1962. National design specification for stress-grade lumber and its fastenings. Natl. Lumber Mfrs. Assoc. Bul., 64 pp.

(3) PERLMAN, A. E.
1951. Prevention of mechanical wear in cross-ties. Amer. Wood Preservers' Assoc. Proc. 47: 206-211.

(4) STERN, E. G.
1950. Improved nails, their driving resistance, withdrawal resistance, and lateral load-carrying capacity. Amer. Soc. Mech. Engin. Trans. 72(7): 987-998.

(5) ________
1952. Some yields of wood research at V.P.I. Va. Polytech. Inst. Wood Res. Lab. Bul. 7.

(6) ________
1952. Immediate vs. delayed holding power of nails. Va. Polytech. Inst. Wood Res. Lab. Bul. 8.

(7) ________
1953. Improvements in the L-shaped fence staple. Agr. Engin. 34(11): 782.

(8) ________
1953. Strength of auto-nailer assembled skids of green and dry lumber. Va. Polytech. Inst. Wood Res. Lab. Bul. 12.

(9) ________
1956. Nails and spikes in creosote-pressure-treated southern pine poles and timbers. Va. Polytech. Inst. Wood Res. Lab. Bul. 26.

(10) ________
1956. Plain-shank vs. fluted vs. threaded nails. Va. Polytech. Inst. Wood Res. Lab. Bul. 27.

(11) ________
1956. Studded cross ties. Cross Tie Bul. 37(12): 45-50.

(12) ________
1957. Holding power of large nails and spikes in dry southern pine. Va. Polytech. Inst. Wood Res. Lab. Bul. 30.

(13) ________
1960. Recent yields of wood research laboratory of Virginia Engineering Experiment Station. Va. Polytech. Inst. Wood Res. Lab. Bul. 41.

(14) U. S. FOREST PRODUCTS LABORATORY
1941. Nailing dense hardwoods. U. S. Forest Serv. Forest Prod. Lab. Tech. Note 247, 3 pp.

(15) U. S. FOREST SERVICE
1945. Hickory. In American Woods. U. S. Dept. Agr. Leaflet, 10 pp., illus.

(16) ________
1955. Wood handbook. U. S. Dept. Agr. Handb. 72, 528 pp., illus.

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