AN HISTORICAL STUDY OF WOOD FASTENERS USED IN WOODWORK

THESIS

Presented to the Graduate Council of the
North Texas State College in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

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Jonesboro, Texas

January, 1953

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CHAPTER I

INTRODUCTION

Wood has been used by man for the construction of dwellings, furniture, and for many other purposes since the time of recorded history. Wood is one of the oldest substances known to man, and long before man was civilized, he had learned to use wood. After the dawn of civilization the woodworkers acquired skill and recognition.

The primitive club, rudely shaped to increase its effectiveness, was probably the earliest form of woodworking. A stick sharpened into a spear with a jagged piece of flint or stone gave early man a wider range in his assault upon his enemy or his animal quarry. The range and power of his attack was steadily enlarged thereafter as craftsmen in wood whittled, shaped, and expertly fashioned such lethal weapons as the catapults which hurled heavy missiles into the walls of Troy. The earliest human habitations, caves and mud huts, gave way to rude frame structures, and the earliest carts had wheels and spokes of hand-whittled wood. Wooden plows furrowed the ground in ancient times, as they still do in the backward areas.

Purpose of the Study

The purpose of this study is to determine how early man fastened wood together in order that it might be utilized to a greater extent and to trace the improvements and additions which have been made in these original fasteners of wood in the ensuing years.

Delimitations

Although there are many wood fasteners, this study deals primarily with the historical development of nails, screws, glue, hinges, woodjoints, corrugated fasteners, and other modern timber connectors. These fasteners were chosen because they are the most frequently used in industrial arts; they are by no means all the fasteners used in woodwork. A detailed description will not be given of the manufacture of these fasteners, nor will the installation and proper use of each be discussed in detail.

Definitions

The term wood fasteners is defined as any material or device used to joint together two or more pieces of wood.

Nails are defined as slender, usually pointed, and headed pieces of metal designed for driving into or through wood. The length of nails ranges from less than one inch to six inches.

Glue is an adhesive used to join wooden materials together to form a strong joint. Some of the glues are slightly water-resistant only; some are water-resistant, and some are completely waterproof. Glue is made of a variety of materials;

hence the various glues possess a variety of characteristics which will be discussed in detail in Chapter III.

The <u>screw</u> is a metal cylinder with a spiral ridge winding around it in a uniform manner so that the successive turns are all exactly the same distance from each other.

The <u>hinge</u> is a moveable joint usually employed to attach a door or lid and is a device used to join two parts together which will allow them to move upon each other. Hinges are usually made of metal, but other materials have been and can be used.

A <u>wood joint</u> is the joining point of two or more pieces of wood. Joints may be made in such a manner that no other fastener is needed to keep the joint firmly in place, but nails, glue, or screws are often employed to insure the strength of the joint.

The <u>corrugated fastener</u> is a piece of corrugated mild steel sharpened on one edge and used to join two or more pieces of wood together. The sizes range from one-half inch to two inches in length and from one-fourth to three-fourths inch in width.

Source of Data

In conducting this investigation it was found that a comprehensive study dealing with wood fasteners was not obtainable and that pertinent information concerning the historical development of wood fasteners appears to be very limited. A publication by Thomas entitled Register of American Manufactures[1] was consulted, and the names and addresses of some of the leading manufacturers of these fasteners were obtained. Letters were sent to these concerns asking for any available literature concerning the history and development of wood fasteners. Sixty-six pamphlets, catalogs, and brochures were received in response to the request, and most of the information contained in this study was obtained from these.

Organization of Study

The introduction to the study is presented in Chapter I. Chapter II, Chapter III, and Chapter IV present the development of nails, screws, and glues, respectively. In Chapter V the development of hinges, wood joints, corrugated fasteners, and other timber connectors is treated in the same manner. A summary and some conclusions are presented in Chapter VI.

Related Studies

E. George Stern, Research Professor of Wood Construction and Director of Wood Research Laboratory at Virginia Polytechnic Institute, and the United States Department of Agriculture Forest Products Laboratory of Madison, Wisconsin, have made a number of tests to determine the holding power of many varieties of nails and screws when they are driven

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[1]Thomas' Register of American Manufacturers and First Hands in All Lines, Buyers' Guide, 1949, Vols. I and II.

into a wide variety of the woods used in construction. The Forest Products Laboratory has also made a number of tests testing the various glues under many conditions. The results of all these tests have been recorded and are available for use; however, they do not contain any pertinent information concerning the discovery and development of the common wood fasteners used by man. In this investigation the writer failed to find a recent study which treated in detail the development of wood fasteners.

CHAPTER II

THE DEVELOPMENT OF NAILS

For centuries nails have been one of the most important fasteners used in woodwork. In framing any wooden structure the strength of the structure is dependent on how well the parts and elements are fastened together. In general, nails are of two kinds, namely, cut nails and wire nails, the difference between the two kinds being in the material and the method of manufacture. The quality of a nail depends upon the quality of the steel, on the straight drawing of the wire used in its manufacture, on the shaping of its head, and on the cutting of its point. Where hard steel is used to increase the stiffness of the nail, the shaping of the head and cutting of the point are more difficult and more expensive. If a softer quality of steel is used, the nail is easier to make and is cheaper. A good nail has a sharp point, a firm head, well-punched barbing, and will not bend easily when driven.

Nails afford the simplest and quickest way of fastening together two pieces of wood. Not all nailed joints are as strong as some of the other methods used to join two pieces of wood, but nailed joints are used extensively in rough and inexpensive work such as house-framing and the making of packing boxes, crates, or other wood construction where a finished surface is of minor importance.

Sizes and Types of Nails

The sizes and types of nails in production and their uses are numerous. Nails are made of low-carbon, high-carbon, or stainless steel, of aluminum, copper, brass, bronze, chromium, nickel, and silver alloys. Nails are manufactured with points which are pointless, or with blunt, medium or long diamond, needle, chisel, duckbill, and side or V points. They are made headless, or they may have heads which are described as follows: standard, medium, or large; flat round, oval cupped, checkered, or slotted; cone, countersunk, brad, hook, double, or spiral-wire heads. The round, triangular, square, or rectangular-shank nails may be either smooth, barbed, etched, twisted or spiral, helical, or annularly grooved. Grooved-shank nails may be provided with a clearance and/or a pilot. Special-purpose nails may be blued, annealed, tempered, and may have a coating of hot or electro-galvanized copper, nickel, tin or cadmium plate, phosphate or resin. Altogether, more than one thousand different sizes and types of nails are made on request by the numerous nail users.[1]

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[1]E. George Stern, "The Nail: An Indispensable Fastener," Paper presented at the 1951 Spring Meeting of the American Society of Mechanical Engineers in Atlanta, Georgia, April 2-5, 1951, p. 3.

Most nails are classified by what is known as the penny system. The penny system of naming nails originated in England. Two explanations have been offered as to how this curious system came about. One explanation is that the six-penny, eight-penny, and ten-penny nails received their names from the fact that one hundred of the nails cost six pence, eight pence, and ten pence, respectively. The other explanation, which is probably more reasonable, is that one hundred ten-penny nails weigh ten pounds. The ancient as well as the modern abbreviation for penny is "d."[2]

To make the nail even more competitive with the wood screw, the manufacturers of nails have been using special steels and non-ferrous metals to give their products a combination of lightness and corrosion-resistance. Although a little more expensive than the ordinary nails, the aluminum-type nails have recently cornered a healthy market in the building trades, because they will not corrode and streak the sides of buildings. Stainless steels are used in nails which are employed in contact with corrosive chemicals in the processing and metal-working industries. One company has even gone so far as to manufacture experimental nails made from titanium metal with the hope of making the nails still more resistant to chemical attack.[3]

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[2]Leo C. Schultz and Louis J. Schultz, School and Home Shopwork for Junior High Grades, p. 64.

[3]"The Humble, Ancient Nail Gets Fancier," Business Week, May 5, 1951, p. 46.

Early History of Nails

Eons ago a prehistoric man, an exceptionally bright one, hammered the first wooden peg into a piece of wood and said, "This is the greatest thing until the invention of the wheel!" And no doubt he was right. His peg may have fastened the wheel on the axle hub of a crude wagon. Today the peg is called the nail.[4] The only resemblance, however, between the original peg and the modern nail is the point. The head and shank of the present-day product are highly technical parts that do much more than hold a couple of boards together.[5] "Nails appear to have been among the earliest inventions in the use of metals, preceded here and there by thorns taken from convenient trees and by wooden pins for which the material to be fastened was suitably pierced in advance."[6]

The earliest mention of the common nail is found in the Bible and is recorded as follows: "And David prepared iron in abundance for the nails, for the doors of the gates, and for the couplings."[7] This was thirty centuries ago, and it is reasonable to assume that nails were wrought by hand some ten centuries earlier. John Hassall believes it is possible to produce evidence to show that the nail in one form or

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[4]Ibid.

[5]Ibid.

[6]Jones and Laughlin Steel Corporation, Nails and Wire Products, Catalog No. N-7, 1951, p. 1.

[7]Holy Bible, King James Version, "Chronicles," 22:3.

another was used to fasten together the tools and weapons of prehistoric man.[8]

Excavations in the tombs of Egypt have yielded many examples of Egyptian furniture and woodwork. Due to the nature of the structure of these tombs, many of these articles have been wonderfully preserved. They indicate that the Egyptians were skilled craftsmen and employed many of the tools and methods used by the present-day woodworkers. The furniture taken from the tomb of Tut-Ankh-Amen shows the use of wooden pegs and metal rivets which were employed to fasten the lid of the wooden coffin to the body of the coffin.[9] Howard Carter stated as follows: "The lid of the inner coffin, which was of solid gold, was fastened to the shell by means of eight gold tennons, which were held in their corresponding sockets by nails."[10] Nails were not used as extensively in Egyptian woodwork as in later times, but their use was well known. When nails were used where they were exposed, they had ornamental heads.

In some of the early Egyptian and Polynesian boats, wooden pegs and treenails were used to fasten together the various pieces of the hull. Earlier and in more primitive

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[8]John Hassall, Inc., Catalog No. 50, p. 2.

[9]A. Lucas, Ancient Egyptian Materials and Industries, p. 394.

[10]Howard Carter, The Tomb of Tut-Ankh-Amen, p. 129.

regions, the various parts of boats were fastened together with thongs of leather or cords.

Paul B. DuChaillu stated that "nails have been found in graves dating back to the Iron Age in the Baltic Region."[11] In just the same way as in Egypt, man has learned much of what is known of the craftwork of the North from the burial places of these people. These burial places disclose that the Northern woodworker had attained a great measure of skill, both in construction and in certain forms of decorative carving. The Veneti, a tribe who inhabited Brittany and whose power on the sea was described by Caesar, were in all probability the advance guard of the tribes of the North; their ships were built of oak and fastened together with iron nails, just as those of the Northmen.[12] In Oseberg an old Viking ship was found whose wooden parts were fastened together by iron nails which are still bright and beautifully preserved. This ship, which is now preserved in the National Museum of Oslo, was examined by Gustafson, who could not, however, ascertain the reason for the absence of rust. This absence of rust was found, by a special commission appointed later for the purpose, to be due to the purity of the iron.[13]

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[11]Paul B. DuChaillu, The Viking Age, p. 129.

[12]Ibid., p. 8.

[13]Albert Neuberger, The Technical Arts and Sciences of the Ancients, p. 21.

Iron nails were commonly used during the Roman occupation of Britain, and large numbers have been found in the places where they were wrought by the Romans. There is a striking similarity between the forged Roman nail and the type which is manufactured at the present time. The forging of nails was an industry of some importance in Great Britain up to the end of the Seventeenth Century and only gave way to the advent of machinery and the cut and machine-headed nail.[14]

During the Twelfth Century, five hewn planks were spiked or pegged together and often banded with iron for strength to form a chest. A demand for chests arose for use in the homes, churches, and for other purposes. As a result, a special kind of woodworker, known as a "cofferer," appeared who made chests only. His tools were improved and also his method of construction.[15]

Nails were used as early as the Twelfth Century in China. It has been reported that "Genghis Khan had prisoners nailed to a wooden ass."[16] If nails were used for this purpose, in all probability they were also used in joining together pieces of wood in other woodworking.

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[14]"Nails," Encyclopaedia Britannica, Vol. XVI, 1946 ed., p. 61.

[15]Donald Smith, Woodwork, p. 12.

[16]Will Durant, "Our Oriental Heritage," The Story of Civilization, Vol. I, p. 763.

During the Fifteenth Century a number of the nails used in Europe were made by Monks. Due to the fact that nails were hand-made, they were no doubt very expensive and rather limited in number. When some other means of fastening could be employed, it was probably used in place of nails. There was an ample supply of iron ore, but the refining process was very crude; consequently there were instances where there were shortages of wrought iron.[17]

Only the wealthy people of Europe could afford furniture made by a skilled carpenter. The first drawers had thick sides which were grooved and which ran on "bearers," and the fronts and sides of the drawers were nailed together. This type of construction was bad, and by the end of Queen Elizabeth's reign one large dovetail joint was used. The workman referred to as a "carpenter" joined wood by nailing and pegging the materials together, and the "joiner" joined two or more pieces of wood together by means of joints.[18]

A notable early development of quantity production is the record concerning a manufacturing establishment planned and directed by Christopher Polhem at Stiernsund, Sweden. Polhem was a distinguished scientist and engineer whose plans were a direct result of substantial practical experience and keen realization of the economic advantages to be achieved by

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[17]"The Humble, Ancient Nail Gets Fancier," Business Week, May 5, 1951, p. 46.

[18]Smith, op. cit., p. 20.

general application of mechanism to industry with an elaborate division of labor. Among the machines invented was a slitting mill for nail making, a shearing mill for cutting bars, and power machinery for polishing rolls of wire for the rolling mill. From Stiensund, Sweden, the use of the power-driven shears spread to the rest of Sweden and ultimately to other countries. These shears became the basis of considerable increase in the export of finished and partly-finished nails from Sweden.[19]

Nails in the Colonial United States

In 1622, the Plymouth pilgrims made a fine strong fort which five years later excited the admiration of a visitor from New Netherlands who described it as a "large square house made of thick planks, stayed with oak beams." It served also as a meeting house and must have done something for the morale of its builders. It started them, too, on their own dwellings, for in 1623, Governor Bradford tells of "building great houses" in "pleasant situations."[20]

These "great houses" were flimsy affairs, and the split clapboards were nailed directly to the hewn studding. The roofs were of straw thatch, which was an agricultural product and an old-world invention. The chimneys were made of wood

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[19]Abbott Payson Usher, A History of Mechanical Invention, p. 339.

[20]Roger Burlingame, March of the Iron Men, p. 40.

and daubbed with clay. This combination was highly inflammable, and in 1621 a court decreed that henceforth every chimney should be made of brick and should extend "above the roof of the house four feete and a halfe."[21]

The houses which the English people built in the United States were usually cold, because the hewn planks did not fit together well enough to keep out the cold winds. The people who were able plastered their houses with clay so that their houses would be warmer. Nails were a luxury, and when a house burned, a careful search was made of the ashes in order to recover all of the nails. Nail-making was an important household industry during the Colonial period in American history. The making of nails required simple equipment of anvil tools, and during the winter evenings the entire family took part in this occupation, making great quantities of nails.[22]

While the English colonists were building their houses of hewn clapboards nailed to hewn studding, the Swedish people were building log cabins for their homes. The entire trunks of trees were either split through the middle or squared out of the rough and placed in the form of a square. The ends of these timbers were "let" into each other about a foot from each end. Burlingame stated that the whole structure

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[21] Ibid.

[22] Victor S. Clark, History of Manufactures in the United States, Vol. I, p. 161.

was made without the use of nails or spikes and that the houses were quite tight and warm. Four or five days were required for two men to construct a house in this manner.[23]

In 1716, an act was passed granting to Ebenezer Fitch and Company the exclusive right to erect a slitting mill at Stony Brook, Connecticut, to slit and draw out iron rods for nail makers. There is no evidence of any earlier proposition to erect such a mill in any of the colonies.[24] These iron rods were sold to the farmers who made nails from them in their homes during the evenings and winters. Due to the short growing season in New England, these farmers spent much of their spare time making nails. There was an ample supply of iron ore in the early American Colonies, but the crude methods of smelting it limited its use to absolute necessities. In 1721, Governor Belcher of Massachusetts reported that "there are several forges for making of bar iron, and some furnaces for cast iron, or hollow ware; and one slitting mill, the undertaker whereof carries on the manufacture of nails."[25]

It is well known that England's colonial theory was a commercial one. The colony existed for the benefit of the mother country, and England became greatly disturbed when

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[23]Burlingame, op. cit., p. 43.

[24]J. Leander Bishop, History of American Manufacturers, Vol. I, p. 507.

[25]Clark, op. cit., Vol. I, p. 204.

she received the news that the American Colonies were not only reducing their own iron ore, but that they were also making articles of the iron after it was reduced. In 1750, a law was passed forbidding the erection of slitting mills, rolling mills, tilt hammers, and steel furnaces in the American Colonies. This law temporarily reduced the manufacture of nails in the American Colonies, and some furnaces were closed and others had to be moved to the interior of the country in order to escape detection by the English.

Even during the Revolutionary War, local makers of iron and steel products began to supply, to a greater extent than previously, many minor articles of iron and steel hitherto imported. Slitting mills and forges could be erected freely, and nail rods came from domestic sources. The making of nails had occupied many winter hours by the fireside of the colonial farmers, but small nails and tacks were generally made in England where labor was cheaper. Shortages of small nails and tacks during the Revolution suggested to a Rhode Island mechanic the expediency of cutting them from plates of metal with heavy shears, and from this developed the cut-nail industry which soon became one of the most important, as well as the most characteristic, branches of metal manufacture in America.[26] It is claimed that the first cold-cut nail in the world was made in 1777 by Jeremiah Wilkinson, of Cumberland,

[26] _Ibid._, p. 222.

Rhode Island. He made tacks by cutting the forms with shears from an old chest lock and headed them in a vise.[27]

Besides the power bellows there was the rolling and slitting of iron and the grinding of tools by power. When the iron bars were rolled into thin strips, they were slit with shears into small bits and fashioned into nails. Gras reported that a furnace, a forge, and a slitting mill belonging to one firm would be situated on different water falls in the same district.[28] These plants were so located that full use could be made of the water power.

The first man to invent a nail-making machine was Eziekiel Reed, a Massachusetts man, who received a patent in 1786. His machine in an improved form is still used for making cut nails. Strips of metal the thickness of the nail are fed into the machine, and a "slicer" cuts them into square-sided nail lengths which are firmly clutched at the neck until the upper end is hammered into a head. These cut nails taper but are not pointed.[29]

By 1789, neither spikes nor nails used in shipbuilding were imported, because they were large and heavy. They were made in this country according to the builder's order. Between 1790 and 1800, twenty-three patents were granted in the

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[27]William B. Weeden, Economic and Social History of New England, p. 793.

[28]N. S. B. Gras, Industrial Evolution, p. 72.

[29]"Nails," Compton's Pictured Encyclopedia, Vol. X, p. 2.

United States for nail-making machinery.[30] Hand-made nails were known as wrought or forged nails and were made from metal plates rolled to the required thickness and then slit by slitting machines. Various sizes of rods, corresponding to the required size and character of the nails to be forged, were sold to the nail-makers in bundles. The hand-nailers' outfit consisted of a forge for heating the nail rods, an anvil, a hammer resembling that of a file-cutter, and a few swages. In England the center of this household industry was Birmingham, whereas New England was the center of this industry in the United States.[31]

Nail-making was partly a fireside industry until power machinery supplemented hand labor in this employment. The government was informed, in 1791, that most "nailers" were farmers and followed this trade only in the winter, except in the towns of Bridgewater, Norton, and Taunton, where there were regular and steady establishments affording constant employment to a great number of people.[32] This industry grew and by 1798, some of the nails manufactured in the United States were superior to those made in England and sold for 20 per cent less.[33]

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[30]Bishop, _op. cit._, Vol. I, p. 500.

[31]"Nails," _Encyclopedia Americana_, Vol. XIX, 1942 ed., p. 682.

[32]Clark, _op. cit._, Vol. I, p. 441.

[33]Bishop, _op. cit._, Vol. I, p. 492.

The Development of Nails from 1800 to 1952

Square-cut nails came into general use early in the Nineteenth Century. They were made in machines by shearing each nail from a strip of iron or iron plate and were more uniform in size and shape than the old hand-wrought ones. Soon after the introduction of machinery, small factories for the manufacture of nails were built all over the country to supplant household forging in their respective neighborhoods. The commercial manufacture of nails was centered in eastern Massachusetts, northern New York, eastern Pennsylvania, Pittsburgh, Pennsylvania, and Wheeling, West Virginia.

The nail maker and the iron puddler whose furnace supplied the raw materials were the aristocrats of their day. Both trades were carefully guarded secrets. Although the manufacture of the nail was close to mass production, the machine used was still crude enough to require a degree of skill on the part of the operator. The chance of error in the adjustment of the machine was so great that adjustments made by the worker determined the quality of the product. To make the trade even more aristocratic, nail makers kept their craft within their own families and passed the "tricks of the trade" from father to son.[34]

The machines manufactured by Perkins and Reed for the cutting and heading of nails in one operation were regarded

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[34]"The Humble, Ancient Nail Gets Fancier," Business Week, May 5, 1951, p. 46.

in England as possessing merit. They were adapted to use either steam, water, or horse power and were soon employed abroad. Within a few years the use of these machines enabled England not only to supply an enormous demand for tacks and nails in England, but also to export vast quantities.[35]

The wire nail was a French invention of the 1830's and was known for many years as "Points de Paris."[36] Originally the nail was headless, but in a few years the upset head was added, and in that form it was imported to America in the late 1840's. The first wire nail produced in the United States was made in 1851 by Morton and Bremmer of New York City. The machine was devised by William Hassall.[37]

It is a tradition that at the Crystal Palace Exhibition, in 1851, American wire-making machinery was admittedly better than that used abroad.[38] With the introduction of the Bessemer converter for use in the manufacture of steel and the nail-making machinery, each more or less supplementing the other, nails were manufactured in actual mass production.[39]

Two important changes occurred in the nail-making industry between 1880 and 1890, namely, the substitution of steel

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[35]Bishop, op. cit., Vol. I, p. 498.

[36]John Hassall, Inc., op. cit., p. 3.

[37]Ibid.

[38]Clark, op. cit., Vol. I, p. 518.

[39]"The Humble, Ancient Nail Gets Fancier," Business Week, May 5, 1951, p. 47.

for iron and the rapid introduction of wire nails for uses previously monopolized by cut nails. No radical changes in the manufacture of nails occurred between 1893 and 1914, although the manufacture of cut nails steadily declined and the manufacture of wire nails more than correspondingly increased. America also began to export wire nails in quantities during the period of low prices in the middle nineties. Nails could be manufactured at such a low cost that a computation made in 1895 showed that if a carpenter dropped a nail, it was considerably cheaper for him to let it lie than to take time to pick it up.[40] The manufacturers of cut nails formed an association as late as 1897, with a membership of twenty-one firms, for the purpose of advancing prices, but wire nails were displacing cut nails so rapidly that the latter already controlled the market.[41]

During the past several years many improvements have been made in the shape of the nail shank, but the basic methods of manufacturing have remained the same. Nails are now manufactured with shanks which are twisted or spiral and which are hellically or annularly grooved. Tests have proven that their holding power is greater than that of nails which have smooth shanks.

Various alloys and metals other than steel are being used in the manufacture of nails. Nails made of these materials

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[40] Clark, <u>op</u>. <u>cit</u>., Vol. III, p. 126.

[41] <u>Ibid</u>.

have desirable qualities and characteristics which enable them to be used successfully where the ordinary steel nail would not meet the requirements satisfactorily. Every nail used in the manufacture and assembly of wood products has a specific purpose. In numerous cases it may be possible to improve the effectiveness and efficiency of construction by taking advantage of specially-designed nails which are available.

In 1948, 750,000 tons of steel-wire nails were produced in the United States. More than 560 pounds of nails are needed to build a standard-design fifty foot by twenty-four foot five-room house with an attached garage.[42] The cost of this quantity of nails amounts to two-thirds of 1 per cent of the total construction costs if plain-shank nails are used and to 1 per cent if the nails with plain shanks are replaced with nails which have grooved shanks. The use of grooved nails may improve, for example, the strength of the conventional unsheathed, framed house as much as four to six times. Greater strength in construction may be attained if advantage is taken of some of the recent developments in the manufacture of nails and their uses.[43]

The development of a new nail, referred to as a "joint nail," is probably the latest innovation in the manufacture of

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[42]Stern, *op. cit.*, p. 16.

[43]*Ibid.*

nails. These nails are designed to exert on the joint a uniform, drawing action during the entire driving operation and hold the joints permanently and securely in a forced and fixed relation in such a manner as not to be affected by temperature or climatic changes. Manufacturers employing joint nails in construction have entirely eliminated losses heretofore suffered because of the failure of joints resulting from insecure fastening. In many instances manufacturers have dispensed with the use of glue when joint nails are used; where glue is used, however, these nails take the place of the clamping process because the nails themselves act as clamps. It is needless to say that a direct result of the use of joint nails is a substantial saving in investment for floor space, labor, and clamping equipment and materials.[44]

Joint nails are presently used by cabinet, casket, furniture, and radio cabinet manufacturers, as well as by pattern makers, planing mills, and the building trades. Joint nails are used extensively on all kinds of mitre joints, such as door panels, screens, blinds, picture frames, table trims, sewing cabinets, chests, boxes, and a multitude of kindred items, as well as for repairs around the house.

The length, shank diameter, and approximate number of nails per pound follow definite standards as are given in Table 1.

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[44]Wash Company, Inc., Mac's Joint Nails, p. 4.

TABLE 1

COMMON NAILS[45]

Penny Size	Length in Ins.	Wire Gauge No.	Wire Diam. in Inches*	Approx. No. to Lb.*
2d	1	15	0.0720	874
3d	1 1/4	14	0.0800	543
4d	1 1/2	12 1/2	0.0938	294
5d	1 3/4	12 1/2	0.0938	254
6d	2	11 1/2	0.1130	167
7d	2 1/4	11 1/2	0.1130	150
8d	2 1/2	10 1/4	0.1314	101
9d	2 3/4	10 1/4	0.1314	92
10d	3	9	0.1438	66
12d	3 1/4	9	0.1438	61
16d	3 1/2	8	0.1620	47
20d	4	6	0.1920	29
30d	4 1/2	5	0.2070	22
40d	5	4	0.2253	17
50d	5 1/2	3	0.2437	13
60d	6	2	0.2625	10

*For American Steel and Wire Company's Steel-Wire Gauge

[45]Stern, _op. cit._, p. 4.

The nail which is most often used for most common construction is the common nail. This nail has a round and plain shank and is made of low-carbon steel.

Summary

Many improvements have been made in the design of nails so that today they have a wider range of practical application, and when used in the conventional manner, their holding power has been greatly increased. Automatic machinery for the manufacture of nails has greatly reduced the cost of nails so that nails are now the most used of all wood fasteners.

CHAPTER III

THE DEVELOPMENT OF GLUES

Glue is an adhesive prepared generally from complex organic compounds containing nitrogen and derived from various sources. Glue is normally marketed in a solid or powder form, although sometimes, especially for household use, it is marketed in a liquid form by adjusting its acidity.

Glue frequently offers the most satisfactory method of fastening wood together. It is used almost to the exclusion of nails and screws in fine cabinet, furniture, and pattern work. Glued joints involving the side and edge grain of two pieces of wood can be made stronger than the wood itself. Glue does not hold well on end grain, however, for it is drawn into the wood by the open cells of the end grain before it has a chance to set.

The process of gluing consists essentially of applying liquid glue to the surfaces to be fastened together and then applying a clamping pressure which holds the surfaces together until the glue has set. It requires several hours for glue to set, and its holding power depends on the bonding action. While in a liquid state, the glue penetrates the wood by passing into the tiny pores or spaces between the wood fibers and clinging there to join the two pieces of wood firmly together.

One of the oldest and most widely accepted theories about the adhesiveness of glue is that the glue sticks to wood because it gains access, while fluid, to the cavities in the wood structure and then solidifies. The resulting strength of the joint is credited to the intertwining or interlocking of the two strong solids, wood and glue. This theory can be explained somewhat differently by stating that the glue gets its initial grip as it flows from a surface coating into the subsurface openings of the wood, and in a brief period it begins to jell and to become semi-solid before it has an opportunity to penetrate too deeply or to diffuse; finally, the surface coating or film, as well as the prongs or fingers extending into the wood, sets or hardens and forms a solid of sufficient strength to retain its shape and hold unbroken its many fingers or prongs. This behavior is termed "mechanical adhesion."[1]

Thomas Perry is of the opinion that the above theory is a correct statement of fact but that it is less than the whole truth. Consideration must be given to the type of glue, its ash, acid, alkaline, and grease contents, and the processing methods, as all have a bearing on the finished product. It is well known that smooth materials can be made

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[1]Thomas D. Perry, Modern Plywood, second edition, p. 67.

to adhere with certain types of glue. It is conceivable that the surface of a dense hardwood, such as ebony, can be made approximately as smooth as glass, with a minimum of cavities for the accommodation of the prongs of the adhesive previously mentioned. It is a well known fact that such smooth wood surfaces can be satisfactorily glued together; it can be demonstrated also that a glue joint between two smooth surfaces can have a much greater tensil strength than an independent film of the same glue. This behavior indicates quite clearly that there is another form of adhesion, which is termed "specific adhesion." This may be described as surface adhesion, independent of any protrusions or adhesive branches into the surfaces that are glued together. Specific adhesion is again divisible into physical and chemical phenomena.[2]

In the case of adhesion between two pieces of wood, there is known to be a definite combination of both mechanical and specific adhesion. The combination is stronger than either type singly, if it were possible to isolate them entirely. It is interesting to note that the theory of mechanical adhesion is responsible for the use of the toothing planes and scrapers, a long-established practice by some woodworkers in gluing such hardwoods as maple.

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[2]Ibid., p. 68.

Animal Glues

Animal glues, manufactured from hide, skin, bone, or sinew, have been used throughout the ages. Animal glue is the oldest known type of glue, its use as an adhesive dating back to antiquity. Stone carvings more than thirty centuries old, found in the ancient city of Thebes, indicate that the Egyptians were familiar with the preparation and application of animal glue. Such woodworking functions as veneering and inlaying are pictured on these old carvings, and furniture removed from the tombs of the Egyptian Pharoahs reveals that joints were dovetailed and assembled with glue.[3] Tustison and Brown also believe that glue is probably the oldest fastener used in woodwork.[4]

A specimen of glue of an early Eighteenth Dynasty date was found by Howard Carter in a rock chamber over the mortuary temple of Hatshepsut at El-Deir el-Bahari. Even though it had dried and shrunk, this specimen could not be distinguished from modern glue and responded to the usual tests.[5] From examinations of the objects in the tombs it is evident that glue was employed in Ancient Egypt exactly in the same manner as by the modern woodworker.[6]

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[3]National Association of Glue Manufacturers, Inc., _Animal Glue in Industry_, p. 1.

[4]F. E. Tustison and Arthur G. Brown, _Instruction Units in Hand Woodwork_, p. 135.

[5]Lucas, _op. cit._, p. 31.

[6]Carter, _op. cit._, p. 238.

The ancient Greeks and Romans used glue in their woodwork in a like manner. Tustison and Brown report that "cabinets of the Ancient Greeks and Romans, made with joints held together with glue, are still preserved in the museums of today."[7]

Animal glue has been mentioned in the literature since 200 A. D., but it was not until 1690, in Holland, that the first commercial glue plant was erected. Ten years later a factory was established in England. Fifty years later patent literature began to register the improvement of glue.[8] The increased production of glue caused an increase in the use of glue instead of dowel pins in mortise and tenon joints, and forms of wood construction became infinitely more varied.[9]

Glue was used in applying veneer in the Seventeenth and Eighteenth Centuries. Wood that would not glue satisfactorily could not be used. Because the common dovetail joint used in such details as drawer fronts presented too much end-grain for veneering, the lap dovetail joint was substituted by about 1695.

The glue industry in the United States was founded by Peter Cooper in 1827, when he established a factory in Brooklyn, New York. About the same time Charles Boeder and William

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[7]Tustison and Brown, op. cit., p. 135.

[8]National Association of Glue Manufacturers, Inc., op. cit., p. 1.

[9]Therle Hughes, Old English Furniture, p. 25.

Adamson started a factory in Philadelphia, Pennsylvania.[10] Since that time the manufacture of glue has been one of the nation's basic industries. Despite its long history, however, animal glue did not realize its maximum potentialities until certain fundamentals about its technical nature were fully developed. These fundamentals, clarified by progress in protein and colloid chemistry, and accompanied by the development of definitive testing methods, have established animal glue as a fully developed material holding continued promise for research and practical applications in broad industrial fields. Due to its long lineage, animal glue has become the accepted standard by which the qualities of all other glues are measured. Some of the older schools of traditional woodworkers refuse to admit that any other adhesive is its equal.

In the last quarter of the century, the animal glue industry has spent great sums for research in improving the manufacturing processes and in devising techniques for producing the enormously increased amount of glue required in American manufacturing. Research and refined industrial techniques have, in turn, required still greater mechanization of manufacturing, so that by 1950, thirty-six plants operated by twenty-six companies were capitalized at more than one hundred million dollars. The present wide trade

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[10]"Glue," Encyclopedia Americana, Vol. XII, 1942 edition.

acceptance of animal glue in industry is reflected in the sale of one hundred and fifty million pounds annually, and the demand is constantly increasing.[11]

Glue does not exist as such in the raw material from which it is made. The glue-bearing substance in the raw material is called collagen. This collagen in the presence of hot water breaks down into glue which promptly dissolves in the surrounding water. Although essentially the process of manufacturing glue is extremely simple, its actual production is highly technical and requires the services of many trained chemists. It consists of heating the glue-bearing raw material in hot water; the water, which contains a small amount of dissolved glue, is then passed through evaporators and other drying devices until the dried, concentrated product, glue, is recovered. All classes of glue stock require some preparation prior to the actual extraction process; this preparation is necessary in order to insure the proper yield and quality from the raw material.

The early animal glues were probably made from the hides of animals only. At the present time there is much diversity in the raw materials which are divided into two general classifications, namely, hide glue stock which consists of hide trimmings from cattle, sheep, goats, and horses, fleshings, tails, ears, pates, sinews, and other similar parts, and bone

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[11]National Association of Glue Manufacturers, Inc., <u>op. cit.</u>, p. 2.

glue stock which consists of green bones secured direct from the packing houses and dry bones which have been either processed by drying quickly or by being allowed to dry slowly by exposure to the elements. Hide glue is stronger and of higher quality than either of the bone glues and commands a higher price.[12]

Extracted bone glue is of better quality than green bone glue. Although there is some overlapping between the lower grades of hide glue and the better grades of extracted bone glue, the average quality of hide glue is superior to the best quality of extracted bone glue. Hide and extracted bone glues are seldom, if ever, sold in the forms in which they are first produced, but they are blended into dry state to conform with standards maintained by the producer or specified by the purchaser. Green bone glue, on the other hand, does not come in standard grades, because each producer makes his own particular quality which is maintained by blending individual lots of glue. Hide glue is used to the practical exclusion of the other animal glues in the manufacture of furniture.[13]

Animal glue is a hard, horn-like substance, somewhat transparent, and ranges in color from a light tan or amber to dark brown. It is sold in several forms; cake, flake, and ground glue are the most common. Shredded and pearl are two

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[12]Perry, op. cit., p. 72.

[13]U. S. Tariff Commission, Glues, Gelatins, and Related Products, Report No. 135, second series, p. 10.

new forms of animal glue recently developed. There is no distinguishable difference in the strength or other properties among these several forms, but they vary considerably in the time required for preparation.

Animal glue is readily soluble in water, and in hot water it dissolves slowly and without much swelling. In cold water it does not dissolve, but begins immediately to absorb the water and swells to form a jelly, and in doing so, it may absorb ten or even more times its weight of water. Swollen glue is very pliable, but retains its original shape. When swollen glue is heated to 105 degrees fahrenheit, it melts into a slow-running liquid. Viscosity, the reverse of fluidity, is a distinct quality of glue solutions. When heated glue is cooled to 70 or 80 degrees fahrenheit, it will solidify into a jelly again. In adhesive preparations this gelatinizing point depends more on the grade than on the ratio of water. Animal glue has been described as a reversible colloid, and this flexibility adapts it admirably to many industrial uses.[14]

After animal glue has become hardened by evaporation or by cooling, it becomes a reversible colloid, but it can be regarded in no sense as an adhesive that is durable under severe moisture exposure. On most wood products which are exposed to ordinary atmospheric conditions and even to high

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[14]Perry, op. cit., p. 72.

humidity, however, the better grades of animal glue will give long and enduring service. Resistance to moisture of animal glue can be substantially increased by the addition of various chemical preservatives.

The high cost of the better grades of animal glue precludes its extensive use in veneer and plywood operations, but it is still the favored adhesive among skilled artisans for the applications of high grade and highly-figured veneer. In the average plywood factory it is largely used for incidental operations, such as edge gluing, repairs, and the like.[15]

In mass production woodworking plants, part or all of the gluing process is done by machinery. The glue is applied to the wood by glue-spreading machines, and the parts are clamped together in special fixtures or presses. In small shops and schools and in the household, gluing is a hand operation. The glue is spread on the wood with a brush or with a small wooden paddle, and the joints are pressed together with hand screws and clamps.[16]

The preferred method of converting a dry glue into a liquid for woodworking is to weigh both the glue and the water, maintaining a proper ratio, and to stir the glue slowly into pure cold water for a few minutes. This mixture

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[15]*Ibid.*, p. 74.

[16]Alfred P. Morgan, *Tools and How to Use Them for Woodworking and Metal Working*, p. 165.

should be allowed to soak for two hours when ground glue is used and for six hours or more when flake glue is used. Overnight soaking is desirable, however, when possible. This soaking period should be long enough to soften each piece or particle of glue to its core. Too long a period of soaking requires artificial cooling because bacterial growth is encouraged. Tests should be made to determine the best standard procedure for any desired glue combination.

If the glue has been properly and completely softened, it will go into solution with the minimum of heat and within the shortest period of time. Melting temperatures should not exceed 140 degrees fahrenheit, and slightly lower temperatures are better. Excessive heat, either in temperature or excessive time, will weaken the glue; therefore, much care must be taken to guard against this occurrence. The melting should be done with moderate stirring in a water-jacketed or electrically-heated glue pot. Almost all grades of animal glue are properly defoamed and will not be harmed by such moderate agitation. If not defoamed, they may tend to deteriorate. Automatic regulators designed to keep the temperatures below 140 degrees fahrenheit are desirable.

No more glue than the requirement for one day should be prepared, and fresh mixes should never be added to old mixtures. Fresh glue preparations are always desirable, and several separate mixtures a day are preferable when practicable. While a mixture of glue is in use, it should be maintained at the regular temperature; in the case of certain types of bone glue, lower temperatures may be necessary to maintain the desired viscosity. Mold and bacterial growth may develop if the proper heat is not maintained.

Since animal glue thickens rapidly as it comes in contact with cool or cold veneer or wood, it is customary to preheat the wood members before the glue is applied. In fact, where animal glue is used extensively, the workrooms are commonly maintained at temperatures of eighty degrees fahrenheit or slightly higher.[17]

Animal glues are commonly graded on the basis of comparative jelly and viscosity values, following standards adopted by the National Association of Glue Manufacturers. While this system of grading serves a good purpose in establishing a relatively simple basis for evaluating glues and provides a rough guide for its use in most applications, it should be noted that such tests do not always accurately measure their working qualities. Consideration must be given to the type of glue, its ash, acid, alkaline, and grease contents, and the processing methods, as all have a bearing on the finished product. Because of such factors, most producers market their glues under brand names or numbers and furnish a uniform type of glue best suited as to the working qualities for the specific application. The hide glues

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[17]Perry, op. cit., p. 73.

range from the low-medium to the highest testing grades; extracted bone glues range from low to medium, and green bone glues range from low to low-medium.[18]

Casein Glues

The use of casein as an adhesive in the gluing of wood is believed to be an ancient art. Craftsmen of China and the ancient Mediterranean Countries and the European artisans of the Middle Ages have left some evidence of the use of a crude casein used in wood gluing. It was probably the curd of soured milk mixed with quick lime.[19]

The technical utilization of casein, however, as an industrial product did not occur until more recent times. The manufacture of casein glue as a separate industry seems to have started in Switzerland or Germany in the early years of the Nineteenth Century.[20] European cabinet makers used it in the construction of wooden joints.[21]

The existence of this type of glue has been known in the United States since 1873, and the first commercial production of casein is generally considered to have started about 1900 when the Casein Company of America was formed. Casein glues

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[18]National Association of Glue Manufacturers, Inc., *op. cit.*, p. 4.

[19]Perry, *op. cit.*, p. 77.

[20]*Ibid.*

[21]Francis E. Tustison, *Forests, Trees, and Wood*, p. 87.

did not become commercially important, however, until around 1916, when the need for water-resistant glues for airplane construction in World War I led to their development. Casein and blood-albumin glues, the two principal adhesives used for the aircraft of that era, filled an important place in the growth of the domestic airplane industry.[22]

Casein glue is made from milk from which the cream has been separated. This milk is soured, usually with the aid of a small amount of dilute acid, and the temperature is raised to approximately ninety-eight degrees fahrenheit. This temperature quickly separates the curd and the whey. The whey, used by farmers for stock feeding, is drained off, and the curd, or crude casein, is washed thoroughly and then pressed to remove the excess water. The pressed curd is broken into small particles and dried and ground into a powder which is sifted through a suitable mesh screen. Raw caseins vary much with respect to quality, and certain types are more useful as glues than others.[23]

The strength of casein glue depends chiefly on the quality of the casein used in its manufacture and to a smaller extent on the quantity and kind of chemical base used as a dispersing agent. Water-resistance qualities are said to be dependent on the quantity and kind of the chemical base.

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[22]Perry, *op. cit.*, p. 77.

[23]*Ibid.*, p. 78.

Ordinary casein when dispersed with a mild base such as ammonia yields an adhesive less water-resistant than when a strong base such as calcium hydroxide is used. If a high lime content is used to obtain high water-resistance, a glue with a tendency toward staining often results.[24] When a high lime content is used in the manufacture of casein glue, the working life is very short, but some selected chemical may be added which will lengthen the useful spreadable life of the glue mixture. A number of minor ingredients may also be added for special objectives.

Casein glue is made in many strengths which are broadly classified as veneer, joint, and universal in order that each strength may be made to meet specific individual requirements. It is possible to blend casein glues, but according to certain producers better results are obtained if instead of blending the finished glues, different grades of casein are blended before they are processed into glue.

The glue trade distinguishes between two types of casein glue--the wet-mix and the dry-mix--and the dry-mix predominates. The type of glue referred to as dry-mix is prepared by the manufacturer from casein and certain chemicals; this compound is mixed with the proper amount of water by the consumer. The wet-mix type of glue is prepared by the consumer by dissolving ground casein in cold water and adding such chemicals as are

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[24] U. S. Tariff Commission, _op. cit._, p. 55.

required to produce a glue with the desired qualities. In either case, mixing is necessary to bring the glue to the proper consistency. Casein glue is sold by producers in the dry form only, because the fully-prepared liquid casein glue must be used within a short time, since it begins to thicken in four to twelve hours, and when once it becomes thick, it must be discarded.

Casein glue has one serious disadvantage not shared by other adhesives, namely, that it forms an extremely hard glue line. When such glued parts pass through woodworking machines, the glue line dulls the knives of the machines.

It has been suggested that the occasional user of glue buy the ready-prepared glues on the market rather than attempt to mix the ingredients himself. There are a number of good ready-prepared glues on the market, and they can be purchased in convenient packages at the hardware stores. These glues contain the proper ingredients already in correct proportions to be mixed with water. Directions for mixing and using these glues are always furnished by the manufacturers, and they suggest that the strictest adherence to the directions be followed for obtaining satisfactory results.

Casein glue is used extensively in woodworking plants. The amateur craftsman will find it superior to liquid and animal glues for home repairs and many other purposes. While not waterproof, casein glue is much more resistant to moisture and heat than is animal glue. The latter must be applied quickly while it is hot, as it sets rapidly. Speed is not necessary in using casein glue, because it is used cold and does not begin to set until ten to fifteen minutes after application.[25]

Casein glue is used extensively as a primary glue in the manufacture of plywood where substantial water-resistance is required and where hot presses are not available, but its wider adoption has been somewhat retarded by its relatively higher costs as compared with the costs of some of the other glues. Casein glue is used extensively in the manufacture of plywood used in concrete form work where water-resistance is essential and where its cost can be justified because of the durability required. It is ordinarily used also as a cold-press glue when the plywood is clamped in bundles for setting.

Casein glue also has wide applicability as a secondary or assembly glue, since it is less sensitive to temperature changes than most other glues and can be used in places where other adhesives would not work. This glue can be mixed and used in most any temperature in which men can work, provided the temperature is not too near freezing.

In the construction industry the versatility of the casein glues provides a wide range of applications. The use of laminated arches, trusses, beams, and other structural members is growing rapidly, and its water-resistance has been demonstrated

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[25]Morgan, <u>op. cit.</u>, p. 167.

by inspections of casein-glued building arches and bridges in Europe which are still in good condition after thirty or more years of service.[26]

The alkalinity of casein glue, though below that which will weaken the wood, often facilitates the gluing of oily woods, such as teak, pitch, pine, and yew. The alkali content breaks down the oily film which may prevent neutral or acid glues from giving the proper results.

Casein is a protein material and, as such, is subject to deterioration when exposed to mold and fungus growths. The incorporation of a suitable preservative in a highly water-resistant casein glue will overcome to a certain extent this condition and will result in no more than slight weakening of the glued joint under conditions favorable to the growth of molds and fungi.

Casein glue is produced commercially in the United States by at least seventeen different companies which operate twenty plants. In addition to this number of commercial producers, an indeterminate number of concerns make casein glue for their own use. The commercial production of casein glue is concentrated in the Middle Atlantic and North Central States. In 1938, approximately 50 per cent of the total output of casein glue was produced in the Middle Atlantic States and roughly 40 per cent in the North Central States. The remainder of the

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[26]Perry, op. cit., p. 79.

casein glue was produced chiefly in the Pacific Coast States and to a lesser extent in the New England States.[27]

Liquid Glues

Liquid glues are those glues which are liquid at ordinary temperatures and can be spread without heating or other preparation. They are commonly referred to as fish glue, because practically all liquid glue is made from the waste materials of several species of fish. Such glues are used to some extent to make regular joints in wood construction, but their main use is for general repair and other miscellaneous jobs. This type of glue is handy for general work, and the better grades will make joints which compare favorably in strength with hot animal glue.

While the ancient Greeks and Romans actually produced an adhesive from fish skins and used it for such exacting duty as setting precious stones in jewelry, they had no means of preserving it and made it only when needed. The fish glue or "ichthyocholl," as they called it, disappeared with the other lost arts, and it was not regained until 1873, when Isaac Stanwood, of Gloucester, Massachusetts, began the experiments which gave birth to the now world-famous LePage's glue.[28]

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[27]U. S. Tariff Commission, op. cit., p. 57.

[28]LePage's, Inc., "LePage's Glue and Other Adhesives," p. 1.

Fish glue is a liquid adhesive made from waste materials of several species of fish and, like animal glue, is obtained by a process of boiling properly prepared glue stock in hot water. This process is followed by filtration and evaporation to attain a desired consistency and finally by the addition of certain deodorizing chemicals. Fish glue is produced in several grades or strengths. Fish glue made from different raw materials may be blended by the producer, but the different grades sold by the producers are seldom blended by the purchaser. It has been reported that fish glue is occasionally blended with animal glue.[29]

The finished product is marketed almost exclusively in the liquid state, a very small percentage being sold in sheet form. Producers usually market it in barrels, casks, small sealed bottles, cans, and tubes. A large part of the fish glue purchased from producers by distributors is repackaged in small containers for resale to the general public through hardware chain stores.

Fish glue is used extensively in the woodworking arts, particularly on alignment and inlay work. Large quantities are sold for household use, for fish glue is especially adapted for minor repairs because of its ease of application and because it may be bought in small quantities.

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[29]U. S. Tariff Commission, op. cit., p. 59.

The process of manufacturing liquid fish glue, while not complex, requires skill and experience to bring about a uniformly good product. The salt skins received from the producers of food fish are first washed to remove the salt and any other foreign matter which may have become mixed with the stock. Then the skins are cooked very slowly in specially constructed apparatus where the gelatin contents are extracted in their purest form. After cooking and settling in the cookers, this thin gelatin liquid is pumped to an evaporating apparatus where it is concentrated under vacuum to remove the excess water which was used in extracting the gelatin from the original raw material. When the glue has reached the proper concentration, preservatives and scent are added under proprietary formulas so that the resulting glue will retain its qualities indefinitely. When the highest adhesive strength is required, nothing has been found to equal the glue made from the properly salted skins of the cod and cusk fish. These are the raw materials which go into the manufacture of the fish glue known to the carpenter and woodworker.[30]

Table 2 is a comparison of animal, casein, and cold liquid glue. These three types are the most frequently used in the home and school, and the items of comparison are source, area covered per pound, how mixed, how applied, water-resistance, and chief shop uses.

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[30]Perry, op. cit., p. 100.

TABLE 2

COMPARISON OF THREE COMMON GLUES[31]

Item of Comparison	Animal Glue	Casein Glue	Cold Liquid Glue
Source	Hides, bones, skins, etc.	Casein of milk	Animal or fish parts
Area covered per pound	25-35 sq. ft.	35-55 sq. ft.	No data
How mixed	Soaked in cold water and melted	Mixed with cold water by stirring	Ready mixed
How applied	Warm--on warmed stock	Cold--on cold stock	Cold or warm
Water resistance	Low	High	Low
Shearing strength	Best grades stronger than any wood	Equal to medium grades of animal glue	Good grades equal to medium grades of animal glue
Chief shop use	For joint work (not exposed to water)	For water-resistant joint work	For repair work and odd jobs

Producers sell fish glue either in bulk or in small packages. Bulk sales, which account for about half of the total output, go either to industrial manufacturers, especially

[31]Tustison and Brown, op. cit., p. 135.

in the paper, upholstery, and shoe industries, or to wholesale distributors who may resell part of it in bulk or put part of it in small packages for sale to household consumers. The producers of fish glue estimate that about half of the total ultimate consumption is by industries and about half by household consumers. The retail market for fish glue is far greater than that for any other kind of glue.[32]

Vegetable Glues

The two principal types of vegetable glues are tapioca and soybean glue, with soybean glue being used more extensively at this time in the woodworking industry. At one time tapioca glue was used by the plywood industry almost exclusively, but its wide use has been discontinued because soybean glue is water-resistant and yet is in the price range of tapioca glue. Soybean glue, however, has a tendency to stain and is therefore not well suited for use with hardwoods or on fancy thin veneer.[33]

All vegetable glues are referred to as cold glues, because they need not be applied at high temperatures nor need the article for gluing be warmed to facilitate spreading. Being odorless, vegetable glues are preferred to other glues, particularly animal glues. With the exception of soybean glue, which has great adhesive power, vegetable glues do not

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[32]U. S. Tariff Commission, *op. cit.*, p. 61.

[33]*Ibid.*, p. 51.

have the adhesive strength of animal glues and consequently cannot be used in applications where a strong bond is important.

Wood glues extracted from the soybean were brought to the attention of the plywood manufacturers of the Pacific Northwest about 1923. These glues made good bonds and had a reasonable degree of water resistance, and since the plywood from this area was mostly made from Douglas fir and used for structural purposes, a high degree of moisture resistance was important. It was not, however, until 1926 that soybean glue became commercially important in the fir plywood industry. Soybean glue has now become one of the standard adhesives, not only in the Douglas Fir and Pine Industry, but also in the manufacture of industrial and box-grade plywood in other parts of the United States.[34]

At first the soybean base from which soybean glue is manufactured was imported into the United States from the Orient and refined here. The raw-material base was obtained from the soybeans by first extracting the oil and then refining the resultant cake or meal, using only that part which had the proper water-absorptive capacity and which met the desired adhesive requirements.[35] During this pioneer period the foresight of I. F. Laucks was largely responsible for furthering

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[34] Perry, op. cit., p. 93.

[35] Ibid.

the development of suitable wood glues from soybean extracts. His developments have continued so that now his company is the leading producer of soybean glues for the plywood industry. About 1928, it became possible to give substantial encouragement to the domestic production of the soybean, and the first factory to manufacture soybean derivatives was established in Bloomington, Illinois. There are now other important producers of a wide variety of soybean products.[36]

Soybean glue is claimed to be the lowest priced water-resistant glue base available. There are a number of different grades ranging from the minimum-cost glue base in the box-shook industry to a highly-refined, chemically-extracted soybean protein material which is not unlike casein in its physical and adhesive qualities.

It has been found that soybean glues can be used successfully on hardwood veneers with as high as 15 per cent moisture content, as contrasted with the requirements of many other glues which average approximately 5 per cent moisture content. The handling of the veneer at the higher moisture content reduces breakage and results in greater useful yield ratios.

Soybean glue mixtures have rather high caustic requirements and have a tendency to discolor thin-face veneers. As a consequence, soybean glues are used little with decorative

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[36] Ibid.

face veneers, as in the piano and furniture industries. Some authorities claim that soybean glues should not be used where the veneers are thinner than one-twelfth of an inch.

Soybean glue, as it is manufactured and delivered to consumers, is in dry powder form, somewhat yellow in color, and not unlike flour. This base, however, has been treated by the supplier with certain chemicals, such as caustic soda, silicate of soda, lime, and waterproofing agents which aid in its dispersion when mixed with water and other ingredients.

Synthetic-Resin Adhesives

There are three important classes of synthetic resins that are recognized in the adhesive field. They are vinyl and acrylic compounds, phenol-formaldehyde, and urea-formaldehyde, and each has some individual characteristics which make it applicable to various situations.

The adhesive qualities of certain synthetic resins were noted in the laboratory about 1920, but their cost seemed prohibitive; presses for plywood were almost unknown, and little encouragement could be found from the study of a practical production technique. In the early 1930's a phenol-formaldehyde resin film was introduced into the European plywood program, and the unusual durability of the plywood resulting from its use attracted widespread attention on both sides of the Atlantic. Moderate amounts were imported into the United States and proved to be of distinct interest to the plywood industry, although the high cost and lack of hot presses required for manufacturing plywood were still serious handicaps. In the latter part of 1935, phenol-formaldehyde became commercially available in the United States.[37]

After the development of the hot presses used in the manufacture of plywood, resin-bonded plywood came into prominence. Probably another reason why the idea of this type of plywood became so popular was because of the considerable interest which has developed in the idea of using plywood in building construction. It has been said also that resin plywood came along at the psychological moment, as the plywood consuming public was "ripe" for the suggestion.[38]

While the extreme durability of resin-bonded plywood soon gained distinct recognition, and its cost proved to be no serious deterrent where severe service was required, there remained an obvious need for a lower cost resin adhesive which would be more durable than the conventional glues and still have ultimate serviceability. About 1937, this need led to the introduction of urea-formaldehyde resin adhesives which would cure at lower temperatures, would be compatible with other extenders used, and would thus reduce costs

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[37]Ibid., p. 81.

[38]I. F. Laucks, "Resin-Bonded Plywood," Modern Plastics, XV (October, 1937), 294.

substantially. In fact, this adjustable cost factor reduces the cost at a more rapid rate than it lessens the quality of the bond. It was also found that the durability of these generously extended urea resins was greater than that of most of the conventional glues, whereas the costs closely approached those of the earlier and cheaper glues.[39]

The urea-formaldehyde resin glues were the first synthetics capable of setting or polymerizing at normal room temperatures. The action of acids or an acid which forms salts upon the resin affects polymerizing at room temperatures. Increased profits are made through the use of this phenomenon by harnessing this reaction so that it will occur in the glue joint by applying the liquid solution of resin and acid-salt to the wood surfaces to be glued, placing the assembly under pressure at room temperature, and allowing the setting of the resin glue to occur.[40]

The urea-formaldehyde bond, after polymerization, is insoluble, and because it lacks protein elements, it is not susceptible to fungus. It does not stain wood, which is important to the manufacture of fine cabinet work and delicate veneers. Although the bond becomes strong a few hours after gluing and the glued wood can be machined, the glue line does

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[39]Perry, op. cit., p. 81.

[40]Arthur P. Dowling, "Wood Aircraft Assembly Glues," Modern Plastics, XXIII (September, 1945), 157.

not attain its maximum strength and water resistance for several days.

Like the urea type, the first of the phenol types of resin glues required the use of acid substances for catalyzing the polymerization. Unlike the urea type, however, the phenolics required much stronger acids and an elevated temperature to aid setting. While some of the acid-phenolics possessed much better resistance to adverse conditions of heat and moisture than did the urea types, conservative manufacturers in the gluing field have looked with disfavor upon their use because of their high acidity and possible adverse effects of this acidity upon the strength of the wood. Probably a more deterring factor which has accounted for the somewhat limited use of the acid-phenolics has been the fact that cumbersome heating arrangements are needed to supply the heat necessary for properly setting the glue. A later development in phenolic assembly glues has been the alkaline-catalyzed type. This type of resin glue also requires an elevated temperature if its curing is to be accomplished in a practical length of time. However, since the acidic and alkaline components of the new type are near the neutral point, the factor of attack on the wood does not have to be reckoned with, and its use has become more widespread than the acid-phenolic variety. Although the alkaline-phenolics have the same limitations as the acid-phenolics, they do yield glue joints which have excellent durability characteristics, and their development has marked a departure from the conventional thinking which has seemed to characterize the researcher's concern with the phenolic-assembly glue problem.[41]

The use of phenol-formaldehyde resin adhesives under heat is used in the manufacture of flat and curved plywood. Such phenolic bonds when properly made are of maximum durability and are stronger than wood itself. Plywood manufactured with the use of phenol-formaldehyde resin adhesives will withstand heat and cold, hot and cold water, and mold and fungus growths to the extent that the wood deteriorates.

The use of extenders is limited with phenolic-resin adhesives. In some cases excessive flow and penetration are better regulated when moderate ratios of walnut-shell flour are used. Another type of extender used in phenolic-resin adhesives, which can be used in substantial ratios, is dried blood which partially supplements by coagulating the adhesive quality of the resin. Some other advantages of using dried blood as an extender are the regulation of the excessive flow of the phenolic resin and the reduction of the temperature requirements.[42]

The vinyl resins used as adhesives are dissolved in an organic solvent, such as ethyl acetate, alcohol, or acetone, and supplied to the user in the solution form. Thinners may

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[41]Ibid.

[42]Perry, op. cit., p. 85.

also be supplied to adjust the consistency. The principal use of thermoplastic resins has been in the manufacture of molded plywood made by the flexible-bag process. Since thermoplastic materials remain soft while under heat, this characteristic is practically adaptable to operations which involve curved shapes which require appreciable time to attain final configuration. On the other hand, this continuous-flow quality can be terminated only by cooling the work while it is still under pressure.[43]

An adhesive with a reversible bond, like a thermoplastic, may have definite advantages in the preparation of models and mock-ups, since bonds can be released and reset at will. As a production adhesive its limitations are considered serious.

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[43]*Ibid.*, p. 87.

CHAPTER IV

THE DEVELOPMENT OF WOOD SCREWS

Next to nails, screws are the most common fasteners used in woodwork. Wood screws are more expensive than nails, and more time and effort are required to insert them, but they hold better and if it becomes necessary to do so, the assembled material may be taken apart by removing the screws without splitting or marring the pieces of materials. If the threads of the screw are not stripped in the pilot hole, joints fastened together with wood screws can be tightened simply by turning the screw. Screws are now used in general construction which involves the use of wood to a much greater extent than ever before; this partially accounts for the decrease in cost in the manufacture of screws. There are a great many different kinds of wood screws, and they vary as to the shape of the head, the size of the shank, and length.

The holding power of a wood screw is dependent on the anchorage which the screw has in the wood fibers. The holding power is also in proportion to the amount of surface area of the screw in contact with the wood and to the pressure exerted against the surface of the screw. This pressure is caused by the compression of wood fibers and their tendency to spring back to their original position before the screw displaced them. The wood screw has a maximum amount of surface area, because the fins spread out beyond the root diameter of the screw; this gives a better grip in the wood than the smooth surface of a nail.

There appears to be no evidence available which indicates that iron wood screws were used by the ancient people. The use of the plane was introduced by Archimedes, and it has been assumed that it was used in pump work in the first mines. Vitruvius described the first screws as being made of wood and as being first used exclusively for drawing water. Later the screw was used in the construction of the single-screw olive-presses and in the construction of the double-screw cloth-presses.[1] Although it is not possible to date any of the inventions or improvements with even approximate accuracy concerning the development of screws and though the names of all the inventors appear to be lost, it is evident that some improvements were made during the last two centuries of the pre-Christian era.[2]

Another line of thought concerning the development of screws was given by David D. Davis. Davis stated as follows:

> Although fasteners are almost as old as civilization, little is known about their early development. But we do know that even in the earliest ages man was trying to fasten things together. No

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[1]Albert Neuburger, The Technical Arts and Sciences of the Ancients, p. 208.

[2]Ibid., p. 78.

> doubt, the first fastener was a screw, but its origin is a mystery. There is no evidence from the relics and paintings found in Egyptian tombs that the screw was known, but what may have been the predecessor of the screw was known as early as the Bronze Age, 3000 years ago. These were copper and bronze pins found in the ruins of prehistoric Swiss lake dwellings. They have a screw form, part of the distance below the head, which kept the pin in place and made it more ornamental. This screw-form has also been found on prehistoric Eskimo bone arrow points to fasten them to the shafts more securely.[3]

In the ruins of ancient Rome, a screw designed for wood was discovered. Although the principle of the spiral or endless screw was first used for raising water in the ancient Mediterranean world, the use of screws for wood and metal was negligible. This was because of the great difficulty in making them. The early lathe, in which screws were made, was a bow and string affair. The metal from which a screw was made was revolved by a string, and a file or cutter was held against it with one hand. The forming of a spiral thread by this method was a difficult task.[4] Probably some of the first screws made by this method were used in the construction of Roman ships. A vivid description of the work involved in building a ship was given by Homer in the Odyssey in which mention is made concerning the use of screws.[5]

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[3]David D. Davis, The Evolution of the Fastener Industry, reprinted from Hardware Age, p. 1.

[4]Ibid.

[5]Neuburger, op. cit., p. 482.

In the Middle Ages both lathes and dies were used in making screws. Feldhaus stated that Leonardo da Vinci's design for a screw-cutting machine stood alone for a considerable period and that other attempts which were made to improve a screw machine were clumsy and unskillful. Da Vinci's machine embodied all the essential elements of modern mechanisms for cutting long screw spindles. Beck infers that this apparatus was used for cutting screws in pieces of bronze or iron and that it marks the beginning of the use of metal screws which prior to this period were cast and finished with a file or cut directly from the metal.[6]

About 1569, Besson improved the lathe for turning screws by employing the use of the treadle and weights. These permitted the operator to use both hands. These first lathes were used primarily for turning large screws from wood. The same principle involved in them was later used in turning screws from metal.[7]

For many years ordinary screws which were used in wood were made by hand. They were forged on an anvil with a hammer and tongs, and the rods were cut off to the right lengths by a chisel. A head was forged on the shank, and the slot was cut in by a hand saw. The head was formed with a file, and of course the result was very crude and expensive.

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[6]Usher, op. cit., p. 192.

[7]Davis, op. cit., p. 2.

The first English patent concerning the improvement of screw machines was granted in 1760 to the Wyatt brothers. They attempted an improvement on the principle used by Besson in 1569. The screw blank was clamped in a lathe and was moved forward by a screw at one end of the spindle as the screw blank revolved. This motion forced the blank between tools that cut the threads.[8]

There appears to be some evidence, as in the case of many other apparently modern inventions, that the gimlet-pointed screw was made as far back as 1755.[9] The first wood screws in Colonial America were blunt on the end, and before they could be inserted into the wood, a hole had to be bored.

The first American patent in connection with machinery for making screws was granted in 1790 to David Wilkinson, and the first enterprise for the manufacture of screws in America was undertaken in 1810.[10] The next important step in the early manufacture of screws did not occur in America, but in Germany. In 1817, an automatic screw-making machine was patented by Colbert, a German clockmaker. He introduced the use of drawn wire to replace forged rods for screw blanks, and through gradual improvements wire became much

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[8]Edward C. Simmons, "The Hardware Trade," <u>One Hundred Years of American Commerce</u>, Vol. II, edited by Chauncey M. Depew, p. 639.

[9]<u>Ibid</u>.

[10]Davis, <u>op</u>. <u>cit</u>., p. 2.

cheaper and far more uniform than forged rods for screw making. This machine must have been lacking in serviceability, because it was not until 1854 that a practical and serviceable machine, the result of further American improvements, gave the first impulse to the screw industry.[11] The screw machinery which was in operation in this country in 1810 was known as French machinery, and it originated in Eastern France. Some of this machinery was in use as far back as 1798 in the state of New York.[12]

A machine used for making a screw with a point was patented in 1842, and a machine used for making a wood screw with a gimlet point was patented in 1846. In the same year a gimlet screw was patented and soon became practical. Perhaps this is the greatest improvement which has been made in the wood screws. Although several patents were issued between 1830 and 1840 concerning the manufacture of a wood screw which would not require the boring of a hole as large as the solid cylinder of the screw before it could be inserted, the first products resulting from these early patents were not completely satisfactory. American screw manufacturers recognized the great advantage of screws with a gimlet point and quickly adopted the methods to produce them.[13]

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[11]"Screw," Nelson's Perpetual Loose-Leaf Encyclopaedia, Vol. XI, 1926 edition.

[12]Simmons, op. cit., Vol. II, p. 640.

[13]Davis, op. cit., p. 3.

About 1850, machines were developed with automatic feed hoppers which held a quantity of screw blanks and which fed them continuously into the machine. One hopper-fed machine turned the heads of the screws, sawed the slots, and shaved off the burrs left by the sawing operation. Another hopper-fed machine was used to complete the operation by forming the point and cutting the thread. These screw machines were automatic to the point where one operator could attend to several machines, and by 1854 the use of these machines made it possible to cut the cost of screws in half. With this great reduction in price and increase in production, the complex screw machine of today was made possible.[14]

A new type screw head called the recessed head screw, or more commonly called the Phillips screw, has rather recently been made available. This improvement is the first major change made in the design of screws in more than half a century. A four-winged recess tapered at the bottom replaces the conventional slot in the screw head. A mated screw driver is used which exactly fits the recess, and because it does not slip or slide out when turned, the screw can be driven safely by power, even on finished work. It has been claimed that this type of head is stronger than the regular type of screw head. A special type of screw driver is recommended to be used in driving Phillips screws,

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[14] Ibid.

although the conventional type of screw driver may be used for this purpose.[15]

Some special wood screws are the screw eye, curved screw hook, the right-angled hook, and the lag screw. The screw eye is often used for hanging picture frames, for screen door hooks, and as an anchor for wire, cord, and small ropes. The curved screw hook and the right-angled screw hook are used chiefly as anchors on which articles are hung. These three special kinds of screws may be obtained in a large variety of sizes at hardware stores and at some variety stores. The lag screw is essentially a large screw with a square head and is driven in place with a wrench instead of a screw driver. Because of the size of a lag screw, a lead hole is required before the screw can be inserted into wood. Lag screws are used to fasten heavy timbers used in rough construction work and for fastening benches and machinery to a floor.[16]

Wood screws vary in the materials from which they are made, the shape of the head, and in the size and finish. Most wood screws are made of steel, but they are also made of brass, copper, and bronze. Screws may have special finishes; they may be blued, galvanized, nickel-plated, or tinned.

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[15]H. H. Douglass and R. H. Roberts, Instruction and Information Units for Hand Woodworking, revised edition, p. 52.

[16]Howard J. Hansen, Modern Timber Design, second edition, p. 73.

The three most common shapes of heads of wood screws are the flathead, round head, and oval head. About 80 per cent of the wood screws manufactured have flat heads; about 15 per cent have round heads, and about 5 per cent have an oval head or some other special type of head.[17]

Screws which are used on visible surfaces where the head of the screw will show are usually blued or nickeled and have round heads. They are not countersunk, and the screw should be left in final position so that the slot in the screw head is parallel with the grain of the wood. The blued finish on screws is obtained by dipping them in oil while they are hot. The screw with an oval head is usually used in fastening hinges and other hardware to wood. Flat head, bright screws are made to be used where they will not show on a finished surface. This type of screw should be countersunk so that the head of the screw is level or slightly below the adjoining surface. In case screws which have flat heads are used on a visible surface, they should be countersunk with an auger bit and a plug placed over them.

The length of screws which have round heads is measured from the bottom of the slot in the head to the point, and the length of screws with oval heads is measured from the edge of the countersunk portion of the screw to the point. The length of screws which have flat heads includes an over-all

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[17]Verne C. Fryklund and Charles H. Sechrest, <u>Materials of Construction</u>, p. 60.

measurement. Common wood screws range in length from one-fourth inch to five inches. The diameter of the shanks of wood screws ranges from gauge number, zero, through number twenty-four, as measured by the American screw gauge. As measured by the American screw gauge, zero refers to a screw which is approximately one-sixteenth inch in diameter, and gauge number twenty-four refers to a screw which is approximately three-eighths inch in diameter. Table 3 shows the common lengths of wood screws, and the various gauges in which they are made.

TABLE 3

LENGTHS AND GAUGES OF WOOD SCREWS[18]

Length in Inches	Gauge	Length in Inches	Gauge
1/4	0 to 4	1 3/4	6 to 20
3/8	0 to 8	2	6 to 20
1/2	1 to 10	2 1/4	6 to 20
5/8	2 to 12	2 1/2	10 to 24
3/4	2 to 14	2 3/4	12 to 24
7/8	3 to 14	3	14 to 24
1	3 to 16	3 1/2	14 to 24
1 1/4	4 to 18	4	6 to 20
1 1/2	4 to 20	4 1/2	8 to 20
		5	8 to 24

When wood screws were first manufactured with the aid of machinery, the metal was cut out between the threads. This method of manufacture tended to weaken the screws, and they

[18] *Ibid.*

frequently broke when they were driven into wood. The modern manufacturing process consists of raising the thread by a system of rolling and compression. Screws are packed in kegs when shipped in large quantities, but they are packed in pasteboard boxes containing one gross when shipped to retailers.

In choosing a wood screw, the following factors should be considered: first, the length of the screw is determined by the thickness of the materials to be joined together; second, the diameter of the screw is determined by the kind of material and the strength of the joint needed; and third, the type of screw head is determined by the finish of the surface of the product in which the screw is to be used.

Screws were not in prominent use until the middle of the Nineteenth Century, because they were made by hand or made in crude machines, had a blunt point, and were too expensive for general use. After practical screw-making machinery was developed, well-made screws became available at a moderate cost, and their use increased immediately. Screws are now the second most common fastener used in woodwork.

CHAPTER V

THE DEVELOPMENT OF HINGES, WOOD JOINTS, TIMBER CONNECTORS, AND CORRUGATED FASTENERS

Hinges

Rare indeed is the piece of old furniture, constructed of any wood, other than chairs, which does not have some piece of hardware, either open to view or concealed, used in its construction. The hinges were considered as an important item in the building of early household furniture.

Hinges are made in different forms and of different materials, such as brass, iron, galvanized iron, nickel, and brass-plated iron. The most common hinge is the butt hinge, which consists of two rectangular leaves which are bent and held together with a steel pin. If the steel pin can be removed, the hinge is called a loose-pin hinge. The butt hinge is commonly used for hanging doors, and the removable pin makes it possible to take a door from its frame without removing the hinges. The strap hinge is another common type of hinge. It is made with two long leaves which are screwed to the flat surfaces of the door instead of to the edge of the door. Today, this hinge is more frequently used on gates, bulkheads, and storm doors. There are many other types of hinges manufactured, but they are not as widely used as the common strap and butt hinges.

Ancient doors did not turn on hinges like those of today, but they swung around on pivots fixed in the threshold and the lintel. These pivots on which the door swung were made of hard wood, and later they were cast from bronze.[1]

The very early makers of chests which had lids, and even later the makers who did not have iron hinges or screws at hand, used the ancient cotter-pin hinge. Leather was oten used as a substitute for the iron hinge.[2] Later the lids of chests which were often canted opened on a pin hinge which revolved on a horizontal pivot fastened into the uprights. This method of fastening the lids of chests continued until the fifteenth century, although it was largely replaced after the thirteenth century by the strap hinge. Iron hinges were used in connection with iron bandings.[3]

In the first years of the Seventeenth Century, there were two types of hinges used in the construction of chests. One type was the hardware dowel, but more common was the bent wire or staple hinge. The staple hinge was made on the link principle, and its ends were driven through the lid of the chest and through the back board of the chest and then clinched. For attaching the lids of chests, these two types of hinges were used for a century or more, but for attaching

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[1]Neuburger, op. cit., p. 335.

[2]Raymond F. Yates, Antique Reproductions for the Home Craftsman, p. 73.

[3]Hughes, op. cit., p. 40.

doors where the swinging plane was vertical, other types of hinges were required. If the principle of the link is retained and the staples made into flat surfaces that can be nailed to the door and post, the butterfly hinge is the result.[4]

The butterfly type of hinge is excellently suited for use on light and narrow cupboard doors and desk lids. For attaching wider and heavier doors and lids, the strap hinge was made with a longer iron arm in order to get a wider distribution of the nail holes. This type of hinge can be traced back to the Roman Empire. As used by the Romans, the strap hinge often hung from a gudgeon or pintail and a vertical finger in the end of a heavy spike driven into the side of the doorway.

Door hinges invented in the early Seventeenth Century were of the "H" type, and usually the two vertical plates and the ends were silhouetted in the outline of Eastern domes. Generally, however, the hinges were of the curving twin "cock's head" design, but many variations have been noted. Hinges of the mid-seventeenth-century were frequently of the small butt type and were attached inside the door. They were necessitated by the use of doors which were the full width of

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[4]Russell Hawes Kettell, The Pine Furniture of Early New England, p. 9.

[5]*Ibid.*, p. 10.

the cupboard front. These hinges were hand-made and were not countersunk for screws.[6]

The foregoing type of hinge was not the typical hinge used in America. The workmanship on these hinges was a little too exacting for the early settler's equipment and tools. In order for the hinge to operate efficiently the pin must be round, quite smooth, and carefully fitted. At first, this was beyond the powers of the settlers; consequently, many of the first "H"-hinges to appear in this country were imported from England. Before the end of the Seventeenth Century, American blacksmiths were making pin hinges, not only of the strap and butterfly types, but also of the "H," "HL," and "LHL" patterns as well.[7]

The idea of concealing the plates of the hinge by setting them into the door and its frame was experimented with first in wrought iron and brass just before the Revolution. In 1775 came the English-patented invention of cast butt hinges. This new type of hinge, imported at first, then manufactured in America, completely supplanted all other types of hinges for interiors, once the war was over. On outside doors the use of the strap hinge was long continued, and for barn doors it has never been entirely replaced.[8]

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[6]Hughes, op.cit., p. 130.

[7]Kettell, op. cit., p. 10.

[8]Ibid., p. 11.

Today's manufacturers produce hinges to meet the needs and requirements of the many users, from the small jewelry cases to the larger hinges required on large doors of garages and industrial concerns. Some manufacturing concerns will make special hinges to the order of the buyer, if the required hinge is not made or kept in regular stock.

Wood Joints

There is a very good reason why the early cabinet makers were often called joiners or jointers. A large part of their skill was needed in the making of joints between the various components used in the building of a house or in furniture. Joints were the means employed for holding component pieces of wood together.

The three most widely used wood joints were the mortise and tenon, the common butt joint, and the various forms of the dovetail joint. Of these three joints, the mortise and tenon joint was perhaps the most widely used. Certainly it was widely and almost exclusively used in the construction of tables and ladder-back chairs. It is simple to produce and is exceptionally strong when it is properly made, even without the benefit of glue.[9] The dovetail joint is the strongest joint that can be used when the ends of two boards are to be brought together and held in position. If the dovetail has been accurately cut and fitted, it is the strongest of

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[9]Yates, op. cit., p. 38.

all joints. If it is not properly made, the joint will be weak, and there is no remedy for the weakness.

The records and some actual remains indicate that the Egyptian woodworker was making chairs before even the Celts came to the British Islands. Chair and bed legs with perfect tenons have been found dating from at least 4000 B. C. There is a coffin in the British Museum which is at least five thousand and possibly seven thousand years old. The back and front of this coffin are framed; that is, the rails are tenoned into the stiles. The thick boards forming the panels are pierced from side to side, and long slats or keys are driven through. The panels fit into rebates cut into the rails, and the whole box is fastened together with wooden pegs. This type of framing was not done by the English woodworkers until the reign of Henry IV. Many Egyptian mummy cases and the huge cases which contained them were made of wood; the large wooden slabs were squared and exquisitely finished. The corners of the cases were mitered, pegged, and had a key at the top and the bottom.[10]

Examples of the work of these early skilled joiners are a carrying chair, bed, arm-chair, and several boxes which were found in the Fourth Dynasty Tomb of Hetepheres. At this date the mortise and tenon joints were used. The furniture taken from the tomb of Tut-Ankh-Amen also shows the use of

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[10]Smith, _op_. _cit_., p. 1.

the mortise and tenon, the tongue and groove, and dovetail joints.[11]

Before the invention of nails and screws, round wooden pegs or dowels were used to hold the wood joints in place. As a matter of fact, a dowel joint that has been glued together is stronger than one that has been nailed together. This type of joint is used extensively in furniture construction. The dowel joint is a good substitute for the mortise and tenon joint, but it is not as strong as the mortise and tenon joint.[12]

A study of the woodwork of past centuries shows that elementary methods of construction were either evolved and handed down or rediscovered by skilled craftsmen through the ages. As a result, throughout the Middle Ages the cofferers were gaining in the acquisition of skill, and sometime between 1400 and 1450 A. D. they began to use a really great invention. The inventor, the date of origin, and the place of origin of the wood panel are not known. Most likely it was introduced into England by the Flanders or the French, and its use was probably accepted slowly. All types of wood construction were affected by the introduction of the panel. The frame was fastened together by the use of the mortise and tenon joint.[13]

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[11]Lucas, op. cit., p. 394.

[12]Tustison and Brown, op. cit., p. 162.

[13]Smith, op. cit., p. 14.

The introduction of the use of the mortise and tenon joint and of the panel resulted in one of the great revolutions in woodworking. Furniture could be made which was lighter, and the old stiff, standardized patterns were exchanged for an infinite variety of new shapes. So it was that "joined" furniture or "joinery" was born. The woodworker who was referred to as a "joiner" and who joined wood together by means of joints became quite separate from the "carpenter" who joined wood together by the use of nails or pegs.

About the time of the Wars of the Roses, 1455 to 1485, new ways of furniture construction were learned by the English joiners. They began to use the "mitre," first in the corners of the panels and much later in the framework. Finally, the true dovetail joint came to be used.[14]

Extra firmness could be secured in the mortise and tenon joint by the use of the draw-bore process. The pin-hole through the tenon was made slightly out of line with those in the mortise walls so that as the dowel pin was driven in, the tenon was drawn more tightly into position. Very little glue was used in these joints by the earlier craftsmen, but the later Victorian cabinet makers in the provinces used glue.

In the first drawers, the fronts and sides were nailed together. By the end of Elizabeth's reign in 1603 one large

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[14] _Ibid._, p. 16.

dovetail was used. By the time of Queen Anne's reign in the early Eighteenth Century the common dovetail was in full use in drawer construction, and from then on very beautiful varieties of the dovetail joint were introduced.[15]

Today a clever cabinet maker can make what is known as a secret or blind dovetail joint which appears from both outside and inside to be just a plain, mitered joint. This is scarcely more than a very clever flourish and was certainly not known in the Seventeenth or Eighteenth Centuries.[16]

A machine used in a rather new process is an evolution of the well-known Linderman machine used for a quarter of a century to eliminate waste in the lumber industry. The prime characteristic of this machine is that it "welds" wood together in such a manner that a wider piece made from two narrower pieces is at least as strong as and frequently stronger than would be a single piece of the same width. This is accomplished by use of a double-tapered dovetail joint with one or more dovetails for the pieces, supplemented by an automatic gluing process. This type of joint is stronger than solid wood.[17]

All of the standard methods of joinery were common knowledge by the close of the Seventeenth Century. The woodworker had practically the same "bag of tricks" as has the

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[15] _Ibid._, p. 20. [16] Kettell, _op. cit._, p. 6.

[17] "Dovetails," _Scientific American_, CLXXIII (September, 1945), 179.

cabinet maker today, with one point in exception--the woodworker had to perform these tricks by hand in earlier times, whereas today there are machines to perform them for him.

Corrugated Fasteners

Corrugated fasteners are sometimes called "wiggletails." These fasteners can be used in making window screens, screen doors, window frames, flower boxes, and for tightening loose joints or cracks in woodwork. The corrugated fastener with a plain edge is used for hardwoods, whereas the saw-edge fastener is for the softwoods. Fasteners with divergent corrugations tend to draw the joint together as the fastener is driven into place. Corrugated fasteners are seldom used in fine cabinet work, but they are used by repairmen when a better means of fastening wood together is not available.

In selecting corrugated fasteners for use, the length of the corrugated fastener should be about half the thickness of the board; otherwise the joint will be weakened. The ordinary nail hammer should be used to drive the corrugated fastener, and it must be driven with blows evenly distributed over the entire length of the fastener.

Timber Connectors

Timber connectors are essentially metal rings or plates which are embedded partly in each face of adjacent wooden members to transmit the load from one to the other. They are used in combination with nails and bolts of small diameter.

Connectors enlarge the bearing area of the joint stress, thereby making it possible to develop the full allowable load of the members connected.

According to tests conducted by the Wood Research Laboratory of Virginia Polytechnic Institute, toothed-ring fasteners and reinforced nailed joints carry large loads at small deformations compared with ordinary nailed or bolted joints. Nails and toothed-ring fasteners are relatively low-cost, light weight, and, since they are hammer-driven into the lumber, the need for drilling holes is eliminated. Thus it appears that the tested tooth-ring fasteners are an effective and efficient reinforcement for lumber joints. If combined with nails, they can effectively and economically replace small-diameter bolts.[18]

Probably no single factor is more responsible for revolutionizing design in timber construction than is the development of modern timber connectors. The results of tests on many types of connectors were first reported in this country in 1933 by Nelson S. Perkins, Peter Landsem, and G. W. Trayer. These tests formed the basis for assigning safe working loads to connectors when they were used with native woods. In 1934, the Timber Engineering Company of Washington, D. C., a subsidiary of the National Lumber Manufacturers' Association, acquired the patent rights on a number of these timber connectors

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[18] E. George Stern, "Toothed Rings Strengthen Nailed Joints," Engineering News Record, CXLVII (September 27, 1951), 39.

for the purpose of distributing them on a commercial basis. Since then, many additional tests and refinements in the manufacturing of timber connectors have been made, and more than sixty different types of connectors have been patented in the United States and Europe. Among the most commonly used connectors in this country are the slit ring, toothed-ring shear and claw plates, spike girds, and clamping plates.[19]

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[19]Hansen, _op. cit._, p. 102.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The earliest mention of the common nail is found in the Bible and is stated as follows: "And David prepared iron in abundance for the nails, for the doors of the gates, and for the couplings." Nails appear to have been among the earliest inventions involving the use of metals, preceded here and there by thorns taken from convenient trees, and by wooden pins. Excavations in the burial places of the Egyptians and the early Northmen have revealed evidence and examples of nails. By the time the Romans invaded Britain, nails were in common use, and there is a striking similarity between the nails forged by the Romans and the types which are manufactured at the present time. The most notable early development in the manufacture of nails was made by Christopher Polhem when he invented a power-driven slitting mill in Stiernsund, Sweden.

The making of nails in the Colonial United States was largely a household industry, and nails were so valuable that when a house burned, the ashes were carefully sifted in order to recover the nails. In 1716, an act was passed granting Ebenezer Fitch and Company the exclusive right to erect a slitting mill for the manufacturing of nails. It is claimed that the first cold-cut nail in the world was made in 1777 by Jeremiah Wilkinson, and the first man to invent a nail-making machine was Eziekiel Reed who received a patent in 1786.

Between 1790 and 1800, twenty-three patents were granted in the United States involving nail-making machinery. Square-cut nails came into general use early in the Nineteenth Century and were used rather extensively for several years after the invention of the wire nail in the 1830's in France. The first wire nail produced in the United States was made in 1851 by Morton and Bremmer of New York City.

Two important changes occurred in the nail-making industry between 1880 and 1890, namely, the substitution of steel for iron and the rapid introduction of wire nails for use previously monopolized by the cut nails. No radical changes in the manufacture of nails occurred between 1893 and 1914, although the manufacture of cut nails declined and the manufacture of wire nails more than correspondingly increased.

During the past several years many improvements have been made in the shape of the nail shank, but the basic manufacturing methods have remained the same. Nails are now manufactured which have twisted, or spirally, hellically, or annularly-grooved shanks, and tests have proven that their holding power is greater than that of nails with smooth shanks. The use of nails has also been increased through the use of special alloys of metals which permit them to be used successfully where steel nails were not practical or did not achieve maximum efficiency.

Animal glue is the oldest type of glue, and its use dates back to antiquity. Examples of glue have been found in the tombs of ancient Egypt. Animal glue has been mentioned in the literature since 200 A. D., but it was not until 1690 that the first commercial glue plant was erected in Holland. Ten years later a factory was established in England. The increased production of glue caused a greater use of glue instead of dowel pins in mortise and tenon joints, and forms of construction became infinitely more varied. In the Seventeenth and Eighteenth Centuries, glue was used in applying veneer.

The glue industry in the United States was founded by Peter Cooper in 1827, and since that time the manufacture of glue has been one of the nation's basic industries. Hide glue is the stronger and is of higher quality than either of the bone glues; it also commands a higher price. Hide glue is used to the exclusion of the other animal glues in the manufacture of furniture. While this type of glue is not classed as a water-resistant glue, it will give long and enduring service when exposed to ordinary atmospheric conditions, even high humidity.

Craftsmen of China and the ancient Mediterranean countries and the European artisans of the Middle Ages have left some evidence of the use of crude casein glue in gluing wood. The technical utilization of casein as an industrial product, however, did not occur until more recent times. The manufacture of casein glue as a separate industry seems to have started either in Switzerland or Germany in the early years of the Nineteenth Century.

While the existence of casein glue has been known in the United States since 1873, the first commercial production of casein glue is generally considered to have started about 1900. Casein glues did not become commercially important until about 1916, when the need for water-resistant glues for airplane construction in World War I led to their development. Casein glue is made in many strengths which are broadly classified as veneer, joint, and universal which may be made to order to meet specific individual requirements. Casein glue is in wide use in woodworking plants, and the amateur craftsman will find it superior to liquid and animal glues for home repairs and for many other purposes.

Liquid glues are commonly called fish glues, because practically all liquid glues are made from waste materials of several species of fish. While the ancient Greeks and Romans actually produced an adhesive from fish skins and used it for such exacting duty as setting precious stones in jewelry, they had no means of preserving it and made it only when needed. The use of fish glue disappeared along with some other lost arts and was not used again until 1873, when Isaac Stanwood began experiments which gave birth to the now-famous LePage's glue.

Fish glue is marketed almost exclusively in the liquid state, with a very small percentage of it being sold in sheet form. This glue is used extensively in the woodworking arts, particularly on alignment and inlay work. A large quantity of fish glue is sold for household use, because fish glue is especially adapted for minor repairs because of its ease of application and because it may be bought in small quantities.

The two principal types of vegetable glues are tapioca and soybean glues, with soybean glue being used more extensively at this time in the woodworking industry. Soybean glue has a tendency, however, to stain and is therefore not well suited for application on hard woods or on fancy thin veneer. All vegetable glues are cold glues; that is, they need not be applied at high temperatures nor need the article to be glued be heated. Vegetable glues do not have the adhesive strength of animal glues and consequently cannot be used in applications where a strong bond is important.

Wood glues extracted from the soybean were brought to the attention of the plywood manufacturers of the Pacific Northwest about 1923. It was not until 1926, however, that soybean glue became commercially important in the fir plywood industry. Soybean glue has now become one of the standard adhesives, not only in the Douglas Fir and Pine Industry, but also in the manufacture of industrial and box-grade plywood in other parts of the United States.

There are three important classes of synthetic resins that are recognized in the adhesive field, namely, vinyl and acrylic compounds, phenol-formaldehyde, and urea-formaldehyde. The adhesive qualities of certain synthetic resins were noted in the laboratory about 1920, but their cost seemed prohibitive. In the early 1930's, a phenol-formaldehyde resin film was introduced into the European Plywood Program, and the unusual durability of the plywood resulting from its use attracted attention on both sides of the Atlantic. In the latter part of 1935, phenol-formaldehyde became commercially available in the United States. Urea-formaldehyde glues were introduced in 1937. This type of glue cures at lower temperatures and is compatible with extenders which reduce the cost at a more rapid rate than it lessens the quality of the bond. The urea-formaldehyde bond, after polymerization, is insoluble, and because it lacks protein elements, it is fungus-resistant.

The principal use of thermoplastic resins has been in the manufacture of molded plywood. An adhesive with a reversible bond, like a thermoplastic, may have definite advantages in the preparation of models and mock-ups, because bonds can be released and reset at will, but as a production adhesive, its limitations are considered serious.

Next to nails, screws are the most common fasteners used in woodwork. Screws are more expensive than nails, and more time and effort are required to insert them, but screws hold better, and if it becomes necessary to do so, the assembled material may be taken apart by removing the screws without splitting or marring the pieces of material.

There is no evidence available which indicates that iron screws were used by the ancient people in the cradles of civilization, but what may have been the predecessor of the screw was known as early as the Bronze Age. These were copper and bronze pins found in the ruins of prehistoric Swiss lake dwellings. A screw of a later date was found in the ruins of Rome, but the use of screws for wood was negligible because the screws were hand made.

In the Middle Ages both lathes and dies were used in making screws, but for many years ordinary screws for use in wood construction continued to be made by hand. About 1569, Besson improved the lathe for turning wood screws, and in 1760, the Wyatt brothers perfected an improvement on the screw lathe and were granted a patent in England.

It is probable that the gimlet-pointed screw was made as far back as 1755, but the wood screw used in Colonial America was blunt on the end. The first American patent in connection with machinery for making screws was granted in 1790 to David Wilkinson, and the first enterprise for the manufacture of screws in America was undertaken in 1810.

It was in 1854 that a practical and serviceable machine, the result of American invention, gave the first impetus to the screw industry.

Without doubt, the greatest improvement in the form of the wood screw was made when a patent for a machine for making a wood screw with a gimlet-point was granted in 1846. About 1850, machines were developed with automatic feeders which held a quantity of screw blanks and fed them continuously into the machine. By 1854, the use of these machines had cut the price of screws in half.

A new type of screw head, called the "recessed head," or more commonly called the Phillips screw, has rather recently been made available and is the first major change in the design of screws in more than half a century. While the conventional type of screw driver may be used for inserting the Phillips screw, a special type is recommended.

Wood screws vary in the materials from which they are made, the shape of the head, in size, and in finish. Most of the screws are made of steel, and the common shapes of the heads are flat, round, and oval. When wood screws were first made, the metal was cut out between the threads, but this weakened the screw so that they are now made by raising the thread by a process of rolling and compression.

The hinge has long been an important item of household hardware. Hinges are made in many forms from a number of materials. The first hinges were probably made of leather, and later the cotter-pin hinge was invented. In the first years of the Seventeenth Century there were two types of hinges used for chests. One was the hardware dowel, but more common was the bent wire or staple hinge and later the "H" type of hinge which was a variation of the staple hinge. "H" hinges were not the typical interior hinges used in Colonial America, because in order for the hinge to operate efficiently the pin had to be round, quite smooth, and carefully fitted. At first this was beyond the powers of the settler's hand tools.

In 1775 came the English-patented invention of cast butt hinges. This new invention, imported at first, then later manufactured in America, completely supplanted all other types of hinges for interiors, once the Revolutionary War was over. On outside doors the use of the strap hinge was long continued, and for barn doors it has never been entirely replaced.

The three most widely used joints in woodwork were the mortise and tenon, the common butt joint, and the various forms of the dovetail joint. Of these three joints, the mortise and tenon joint is perhaps the most widely used, whereas the dovetail joint is the strongest of all three joints when it is properly made.

The skilled Egyptian woodworkers used many of the joints that are still used today. Examples of the mortise and tenon, tongue and groove, and dovetail joints have been found in the tombs of Egypt.

Sometime between 1400 and 1450, the use of the panel was introduced into woodwork. The inventor, date of origin, and the place of origin of the panel are not known, but it was probably introduced into England from Flanders or France. The introduction of the mortise and tenon joint and the panel gave stimulus to one of the great revolutions in woodworking. During the War of Roses the mitre joint was first used, and finally the true dovetail joint came to be used in woodwork.

At the close of the Seventeenth Century all the standard methods of joinery were common knowledge. The woodworker had practically the same "bag of tricks" as has the cabinet-maker of today, with one point in exception--the woodworker had to perform these tricks by hand, whereas today there are machines to do the work for him.

Corrugated fasteners are sometimes called "wiggletails." They are used chiefly in rough work and repair work, and for best results the length of the fastener should be about half of the thickness of the board in which they are to be used.

Timber connectors are essentially metal rings or plates which are embedded partly in each face of adjacent members to transmit the load from one to the other. Probably no single factor is more responsible for revolutionizing design in heavy timber construction than is the development of the modern timber connectors. Tests have shown that when the timber connector is combined with nails, it can effectively and economically replace small-diameter bolts which are used often.

Conclusions

From the information obtained and presented in this study the following conclusions have been reached.

With the invention of machinery for the manufacturing of nails, nails have become more plentiful, cheaper, and are used in a much wider range today than ever before in the history of man. Improvements have been made in the design of the shanks of nails, and tests have proven that these specially-designed nails have greater holding power than the conventional nail with a smooth shank. The use of alloy metals has made it possible to use nails where the use of steel nails was not satisfactory because of rust and corrosion.

With the invention of the gimlet-pointed screw and the automatic screw-making machinery, the number of screws made has increased immensely, and the price of screws has decreased 50 per cent. The above factors are responsible for the great increase in the number of screws used in woodwork today.

Even though glue has been used for centuries to fasten together pieces of wood, modern research has developed glues which are adapted to a wider range of uses. Through research, modern waterproof glues have been developed. The conventional glues have been improved to the extent that they are now designed to give far better results than in the beginning, and the water-resistance quality of glues has been especially increased.

Tests indicate that timber connectors, when used in connection with nails, form a joint stronger than one in which a small bolt is used. Bolts will probably be replaced in many instances, because no holes have to be drilled when timber connectors are used, and much time can be saved.

Although the basic principles of ancient craftsmen are still employed, the manufacturers of all wood fasteners are continually striving to develop more economical ways of manufacturing these fasteners so that better results will be obtained when they are used. Much time, effort, and money are spent annually in conducting research and tests on new techniques of production, improvements, and new products in connection with wood fasteners.

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