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Effect of Variation of Cutting Angle On Surface Quality in Shaping Aspen
A Study on Machinability

Thomas B. Miller

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Wood Technology, School of Forestry and Conservation, University of Michigan.

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Acknowledgments

My sincere thanks are expressed to Mr. L. A. Patronsky of the Laboratory of Wood Technology, School of Forestry and Conservation under whose direction this investigation was made. I am indebted to Professor Robert Craig, Jr. for kindly interest shown in this study and to Professor Dow. V. Baxter for suggestion pertaining to the preparation of the manuscript. Mr. Glen Bruneau aided in preparing the panels from which test samples were obtained. Thanks are also expressed to Mr. A. F. Miller and the engineering department of the Johns-Manville Corporation of Waukegan, Illinois for whole hearted cooperation in making parts for the fixture assembly so necessary to obtain reliable results. To my capable friend, Mr. L. J. Barnett of the American Can Company, North Chicago, Illinois grateful acknowledgment is made for his assistance in making the feed control mechanism and in preparing the shaper knives. Appreciation is also due to Mr. H. Andrew Andrejko for the photographs presented in this report.

T. B. M.

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Figure 1 -- Shaper and Complete Equipment

Introduction

Shaping is an important machining operation in certain types of furniture manufacture where the edges of wood are not veneered but are worked to some form or pattern. There are relatively few species which are outstanding in this quality and they, for the most part, are the better cabinet woods. Aspen,[1] which has received much attention in recent years (1, 3) is being used somewhat extensively as core stock in furniture manufacture. However, lack of information concerning its property in shaping still prevents wide acceptance.

Previously no satisfactory method has been developed for producing a smooth surface in shaping aspen (1). In this study the cutting action of a wood-working shaper, using high-speed steel knives upon this wood was investigated. The surface quality in regard to five different cutting angles and one set of operating conditions was examined in considering the cutting angle under which aspen machines best in shaping.

This report deals specifically with the effect of variation of cutting angle on surface quality in shaping aspen and on the description of new equipment invented during the

[1]Aspen is defined in this report to include large tooth aspen (*Populus grandidentata*) and the major species, trembling aspen (*Populus tremuloides*).

course of this study.

The newly designed equipment not only eliminated the danger associated with the operation of a wood-working shaper but it also greatly simplified and speeded the actual cutting operation.

In presenting the results of this investigation it is hoped that these findings will contribute to knowledge of aspen and facilitate its use.

General Procedure

The machinability of 24 native hardwoods was studied at the Forest Products Laboratory. The same general procedure used by E. M. Davies (2) in that work was followed in the shaping study described here.

Mechanical Equipment Used in Investigation

Shaper

The machine tests were made on a Porter No. 105 Single Spindle Production Shaper having a spindle speed of 12,000 rev. per min. This machine and the complete equipment used in this investigation is shown in Figure 1, page vi. High speed steel shaper knives having a Rockwell "C" hardness of 61 were used to do the actual cutting. To hold the knives, the shaper spindle is fitted with two knife collars. The collars are slotted at 60 degrees for two knives. One of the collars has locking screws which engage serrated edges of the knives. These screws make it possible to adjust the knives accurately and also prevent them from flying out of the collars. When using two knives it is seldom likely that both will cut equally due to vibration caused by the spindle operating at high speed. Since this condition cannot be entirely eliminated only one knife was used to do the actual cutting; the other of similar width was set back a little and only served as a filler to balance the spindle. In so far as actual shaping called for the use of five knives, one of which acts as a filler, they were balanced alike before making the first knife setup. In locating each knife in the collars a 2 3/4" cutting circle was maintained. The necessity of maintaining the same cutting circle throughout the study is emphasized in the section of this report dealing with knife preparation, page 21. Once the knife was located, the whole assembly was tightened with a nut which screws on the upper end of the spindle. Figure 2 shows the spindle assembly. It also illustrates the method of locating the knife in the collars.

Shaping Fixture

It became apparent that, in order to maintain uniform operating conditions throughout this study some devise was needed that would serve as a "hold-down" in which the test piece could be held securely and moved safely past the knife. It was also necessary to prevent the tendency of the knife to fling the test piece off the table. Since no satisfactory "hold-down" existed, a shaping fixture had to be designed and constructed.

Figure 2 -- Shaper Spindle Assembly showing knife collars and method of locating knives.

In designing this new equipment, the problem of holding the test sample did not present difficulties because the piece to be tested required cutting on the edge. Therefore, the problem resolved itself to one of clamping the piece to a movable carriage which could be drawn along a slide by power-feed. Such a fixture would facilitate moving the test sample past the knife safely and at a uniform rate of feed. The shaping fixture with the test sample in the starting position is shown in Figure 3.

As this fixture undoubtedly will be used by others in machinability studies a detailed description is warranted. Figure 4 shows the fixture assembly in detail.

The fixture assembly consists essentially of five parts, namely: a slide (Fig. 4-1), made of hot rolled steel to prevent warping after machining; three carriages (Fig. 4-4) which are mounted on the slide forming a work-carriage to which the test sample is clamped; a clamping device (Fig. 4-5), fitted to each carriage to hold the test piece in position; two base plates (Fig. 4-2), fitted to the slide to facilitate clamping the fixture to the shaper table; and a locating bracket (Fig. 4-3), centrally screwed to the slide. This bracket locates the fixture in a central position with respect to the spindle by means of two screw holes in the shaper table. Besides Figure 4, the parts are shown in detail in Plates 1 through 5.

A description of the work-carriage and the clamping device will give a better understanding of how the test

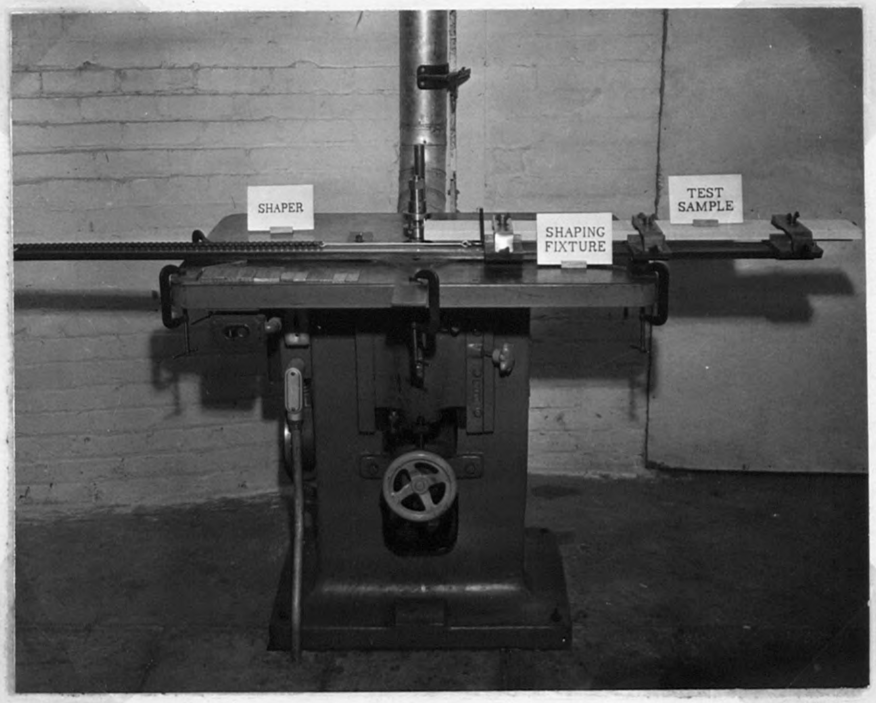
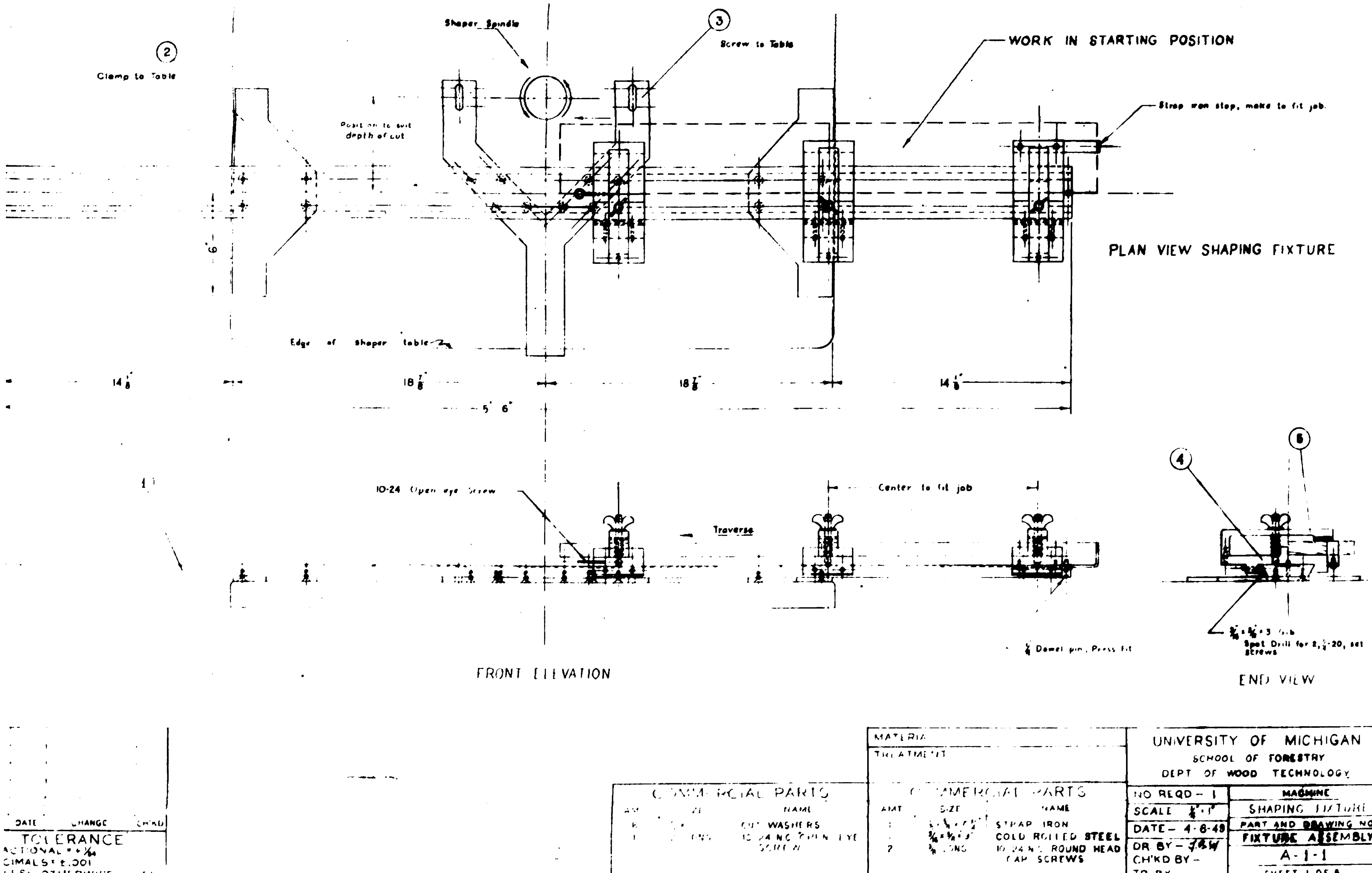


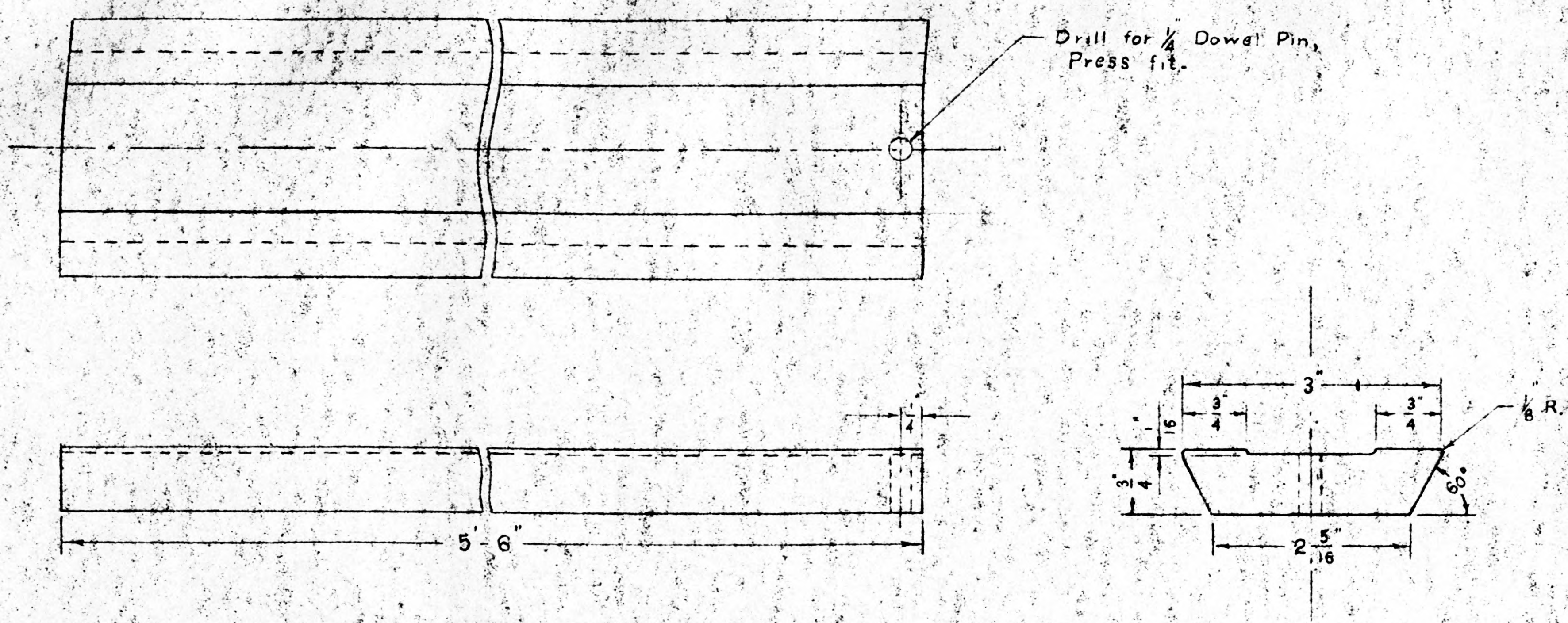
Figure 3 -- Shaping Fixture located
on shaper table.



Clamp to Table
Shaper Spindle
Screw to Table
WORK IN STARTING POSITION
Strap iron stop, make to fit job.
Position to suit depth of cut
PLAN VIEW SHAPING FIXTURE
Edge of shaper table
14 1/8"
18 7/8"
18 7/8"
14 1/8"
5' 6"
9"
10-24 Open eye screw
Traverse
Center to fit job
1/4 Dowel pin, Press fit
Spot Drill for 2, 1/4-20, set screws
FRONT ELEVATION
END VIEW
DATE
CHANGE
CH'KD
TOLERANCE
UNIVERSITY OF MICHIGAN
SCHOOL OF FORESTRY
DEPT OF WOOD TECHNOLOGY
MATERIAL
TREATMENT
COMMERCIAL PARTS
AMT
SIZE
NAME
CUT WASHERS
10-24 NC OPEN EYE SCREW
STRAP IRON
COLD ROLLED STEEL
10-24 NC ROUND HEAD CAP SCREWS
NO REQD - 1
SCALE
DATE - 4-6-49
DR BY -
CH'KD BY -
TR BY -
MACHINE
SHAPING FIXTURE
PART AND DRAWING NO.
FIXTURE ASSEMBLY
A-1-1
SHEET 1 OF 6

Figure - 4

Plate 1



NOTE: Drill and tap for 1/4-20 N.C. Flat Head Gap Screws in assembly with parts NO. 2 and 3.

SIGN	DATE	CHANGE	CH'KD

TOLERANCE
FRACTIONAL = ± 1/64
DECIMALS = ± .001
UNLESS OTHERWISE GIVEN

MATERIAL – HOT ROLLED STEEL
TREATMENT – FINISH ALL OVER

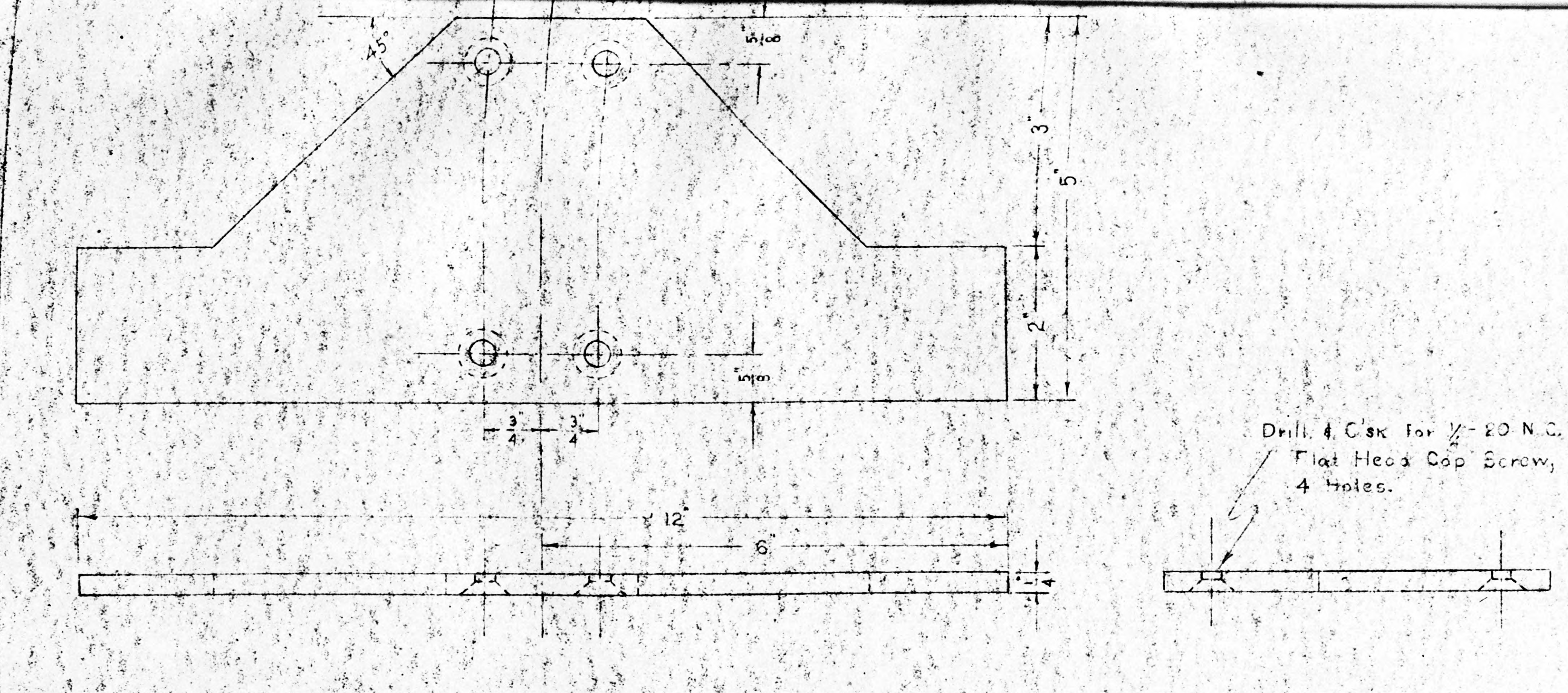
COMMERCIAL PARTS

AMT.	SIZE	NAME
1	1/4" x 3/4" LONG	DOWEL PIN

UNIVERSITY OF MICHIGAN
SCHOOL OF FORESTRY
DEPT. OF WOOD TECHNOLOGY

NO. REQD – 1
SCALE – 1/2" = 1"
DATE – 4-6-49
DR. BY – [illegible]
CH'KD BY –
TR. BY –

MACHINE
SHAPING FIXTURE
PART AND DRAWING NO.
SLIDE
A-1-2
SHEET 2 OF 6



SIGN	DATE	CHANGE	CH'KD

TOLERANCE
FRACTIONAL = ± 1/64
DECIMALS = ± .001
UNLESS OTHERWISE GIVEN

MATERIAL – HOT ROLLED PLATE
TREATMENT –

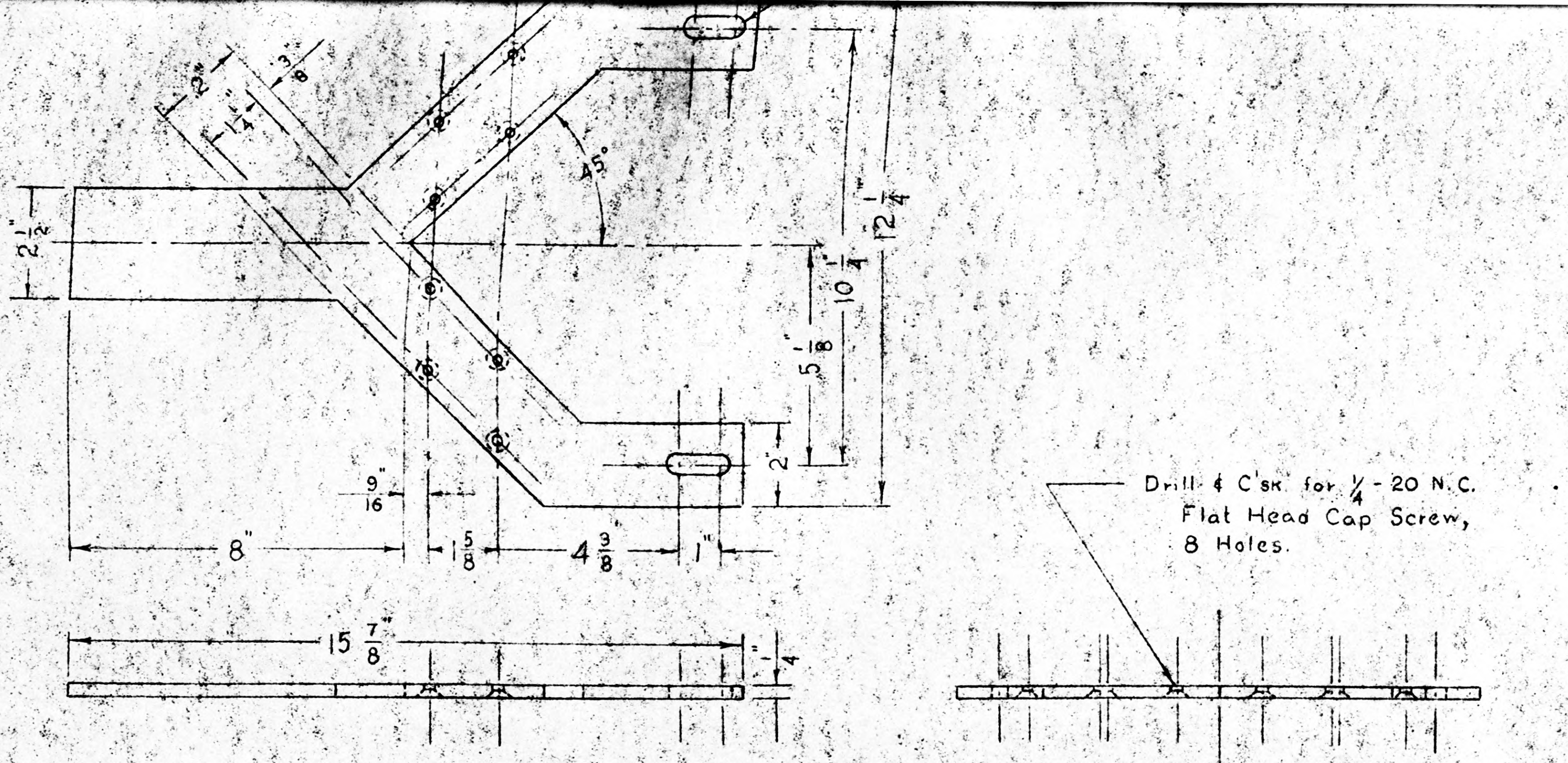
COMMERCIAL PARTS

AMT.	SIZE	NAME
6	1/2 LONG	1/4-20 N.C. FLAT HEAD CAP SCREWS

UNIVERSITY OF MICHIGAN
SCHOOL OF FORESTRY
DEPT. OF WOOD TECHNOLOGY

NO. REQD – 2
SCALE – 1/2" = 1"
DATE – 4-6-49
DR. BY – JBH.
CH'KD BY –
TR. BY –

MACHINE
SHAPING FIXTURE
PART AND DRAWING NO.
BASE PLATE
A-2-3
SHEET 3 OF 6



SIGN	DATE	CHANGE	CH'KD

TOLERANCE
FRACTIONAL = ± 1/64
DECIMALS = ± .001
UNLESS OTHERWISE GIVEN

MATERIAL – HOT ROLLED PLATE
TREATMENT –

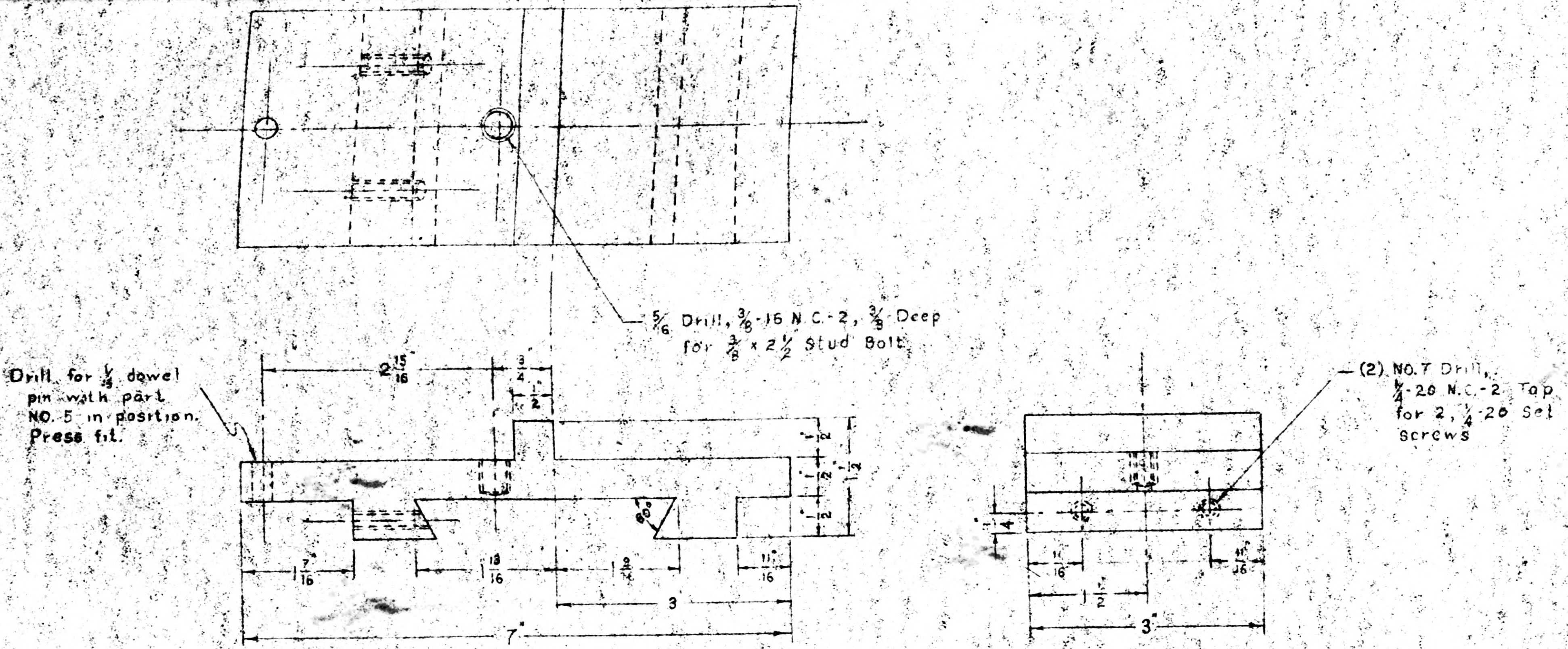
COMMERCIAL PARTS

AMT.	SIZE	NAME
8	1/2" LONG	1/4-20 N.C. FLAT HEAD CAP SCREWS

UNIVERSITY OF MICHIGAN
SCHOOL OF FORESTRY
DEPT. OF WOOD TECHNOLOGY

NO. REQD – 1
SCALE – 1/4" = 1"
DATE – 4-6-49
DR. BY – JRM
CH'KD BY –
TR BY –

MACHINE
SHAPING FIXTURE
PART AND DRAWING NO.
LOCATING BRACKET
A-3-4
SHEET 4 OF 6



SIGN	DATE	CHANGE	CH'RD

TOLERANCE
FRACTIONAL = ± 1/64
DECIMALS = ± .001
UNLESS OTHERWISE GIVEN

MATERIAL – CAST IRON
TREATMENT – FINISH ALL OVER

COMMERCIAL PARTS

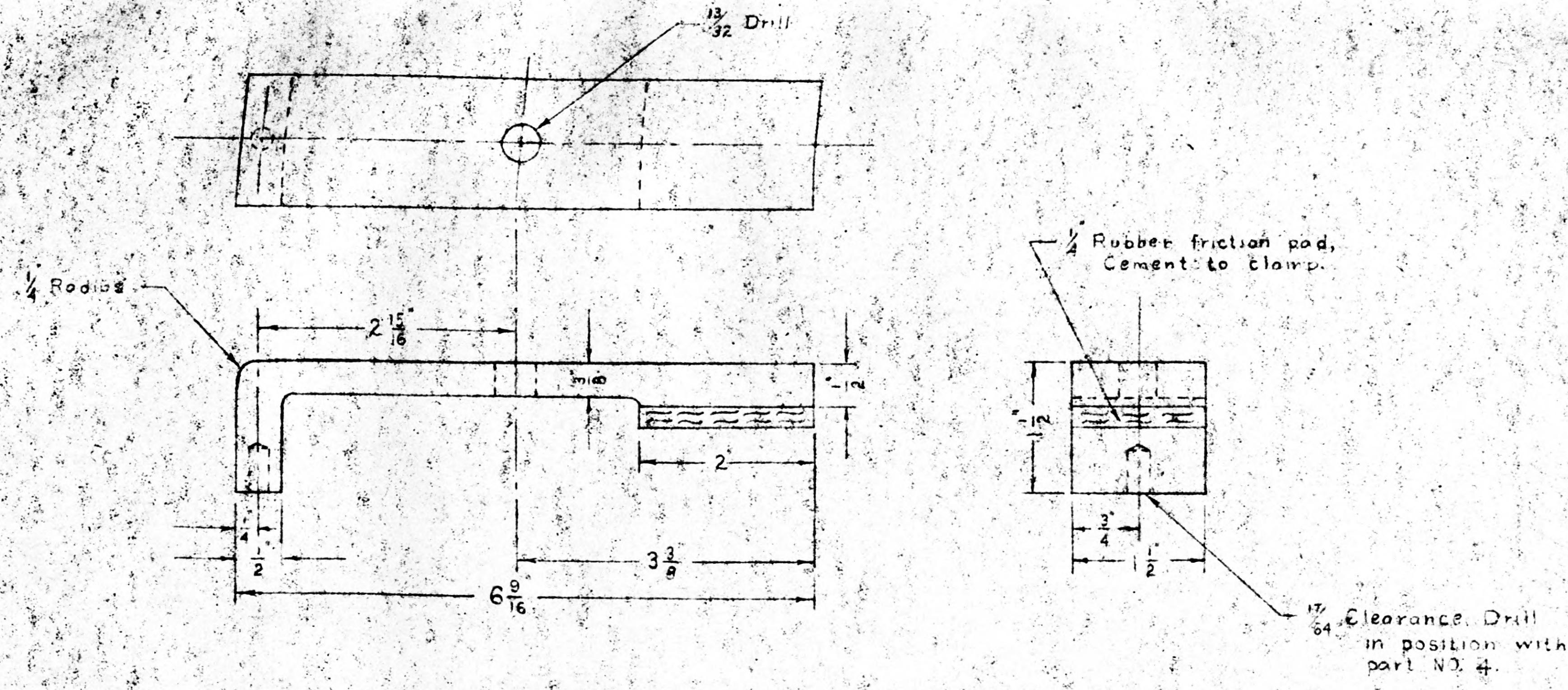
AMT.	SIZE	NAME
6	1 1/4 LONG	1/4-20 N.C. ALLEN-SET-SC'WS
3	2 1/2 LONG	3/8-16 N.C. STUD BOLTS
3	3/8-16 N.C.	WING NUTS
3	NO. 13, 3/8 x 1 1/2	COMPRESSION SPRINGS
3	1/4 x 1/2 LONG	DOWEL PINS

UNIVERSITY OF MICHIGAN
SCHOOL OF FORESTRY
DEPT. OF WOOD TECHNOLOGY

NO. REQD – 3
SCALE – 1/2" = 1"
DATE – 4-6-49
DR. BY – J.B.H.
CH'KD BY –
TR. BY –

MACHINE
SHAPING FIXTURE
PART AND DRAWING NO.
CARRIAGE
A-4-5
SHEET 5 OF 6

Plate 4



NOTE: Saw from 1½ Sq. Bar Stock

SIGN.	DATE	CHANGE	CH'KD

TOLERANCE
FRACTIONAL = ±1/64
DECIMALS = ±.001
UNLESS OTHERWISE GIVEN

MATERIAL – COLD ROLLED STEEL
TREATMENT – FINISH ALL OVER

COMMERCIAL PARTS

AMT.	SIZE	NAME
1	¼ x 2 x 4½	RUBBER GASKET MATERIAL

UNIVERSITY OF MICHIGAN
SCHOOL OF FORESTRY
DEPT. OF WOOD TECHNOLOGY

NO. REQD – 3	MACHINE
SCALE – ½ = 1"	SHAPING FIXTURE
DATE – 4-6-49	PART AND DRAWING NO.
DR. BY – C.R.W.	CLAMP
CH'KD BY –	A-5-6
TR. BY –	SHEET 6 OF 6

sample is positioned and held during the actual cutting operation. Since the work-carriage is comprised of three similar carriage units, only one will be described.

To fit the carriage to the slide a flat steel gib is placed between the back bevel of the carriage and the corresponding bevel on the slide. Two set screws are used to adjust the gib thereby permitting the carriage to move freely along the slide. The gib and set screws are shown better in the end view of the fixture assembly, Figures 4 and 5. Since a means was needed for locating the text piece before clamping, a stop was machined on the carriage. To facilitate making several cuts of equal depth on the same sample, shims of the proper thickness are placed between that stop and the back edge of the test sample. Holding pressure on the clamp is exerted by a wing nut screwed to a stud bolt. When pressure on the clamp is removed a spring fitted to the stud bolt holds the clamp up from the test piece. This device facilitates rapid positioning and removal of the samples by freeing both hands. To prevent the clamp from turning out of alignment during the cutting operation its leg is drilled to fit over a pin located in the tail stack of the carriage. A rubber friction pad is glued to the face of the clamp. This pad helps prevent the test sample from slipping during the actual cutting operation and also allows for slight variation in thickness of samples thereby permitting uniform clamping pressure on the test piece. An end-stop fitted to the end-carriage keeps the sample from slipping and so eliminates any uncertainty of the clamps holding power. Figure 5, shows the method of positioning and clamping the test sample. The work-carriage is drawn along the slide by a feed chain attached to the lead carriage. A description of the feed mechanism is given on page 16.

The shaping fixture is clamped to the machine table and so located that the first pass across the shaper will serve as a preliminary cut to true the edge of the test sample and thereby insure the required depth of cut in the subsequent run. Figure 3 shows the location of the shaping fixture with respect to the shaper spindle. It also shows the work carriage in the starting position with a test sample clamped in place.

In the "Feed Mechanism Section" of this report it is pointed out that spring tension on the roller chain tends to draw the work carriage out of its starting position. To avert the hazard which that creates while clamping a sample to the work-carriage, a stop pin is used in front of the lead carriage. A hole is drilled in the slide for this purpose. When a test run was to be made, the pin was removed from the hole.

Consideration was given to the possible damage that might be incurred to the equipment if the stop pin should not be removed from the slide, before the feed is engaged. In this event, a soft aluminum rod is used to attach the feed chain to the lead carriage. An open-eye is formed on both ends of the rod to facilitate the attachment. If the work-carriage should resist movement along the slide, the eyes will straighten and so prevent damage to the equipment.

The operation of the shaping fixture is given under "Test-

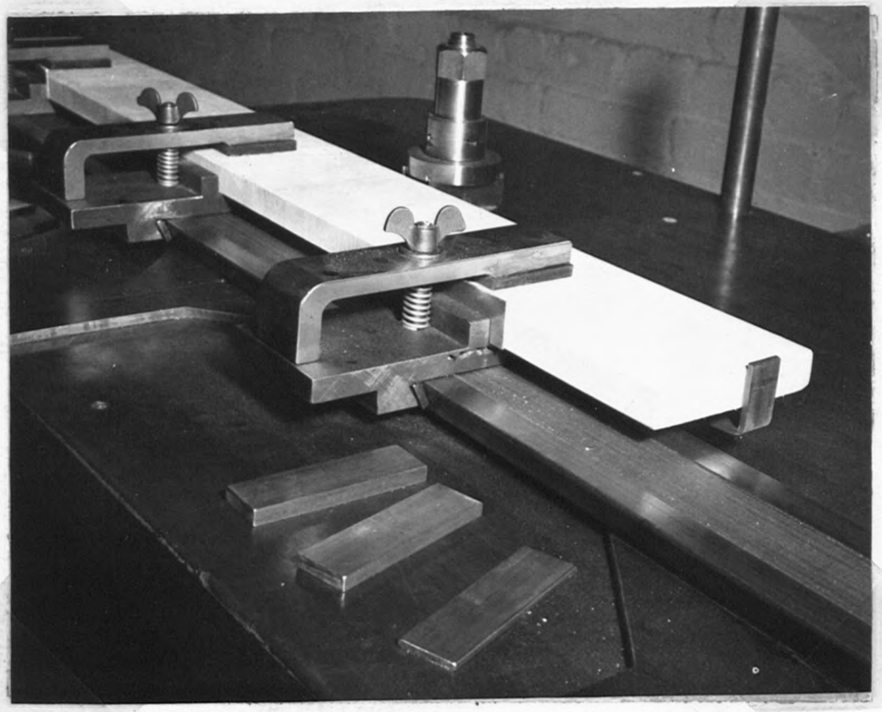


Figure 5 -- Work-Carriage showing method of positioning and clamping test sample.

ing Procedure", page 28; for 'Shaping Operation', page 31.

Feed Mechanism

Since surface quality cannot be used as a criterion of cutting action unless all operating conditions remain constant, it was necessary to employ a feed mechanism that would eliminate any variation in the rate of feed selected for this study. A standard speed-ranger was used for this purpose. Figure 6 shows the speed-ranger and the complete feed mechanism employed.

The speed-ranger is equipped with a geared-reduction mechanism which reduces the feed motor output to obtain the required rate of feed. The speed of motor was 1725 rev. per min. with a variable range of 180 to 2700 rev. per min. This made possible the selection of the correct motor output which when transmitted through the geared-reduction mechanism (speed reducer) gave the required rate of feed.

The work-carriage is drawn along the slide by a roller chain meshed into a drive sprocket. One end of the chain is attached to the lead carriage whereas the other end is linked over the sprocket which is mounted on the drive shaft of the speed reducer. The free end of the chain is attached to a spring which holds the chain taut while the work-carriage is in a starting position. This also prevents the chain from jamming at the sprocket.

It was previously mentioned that a provision was made to eliminate the hazard encountered by the use of the spring attachment. If a longer chain had been used a spring would

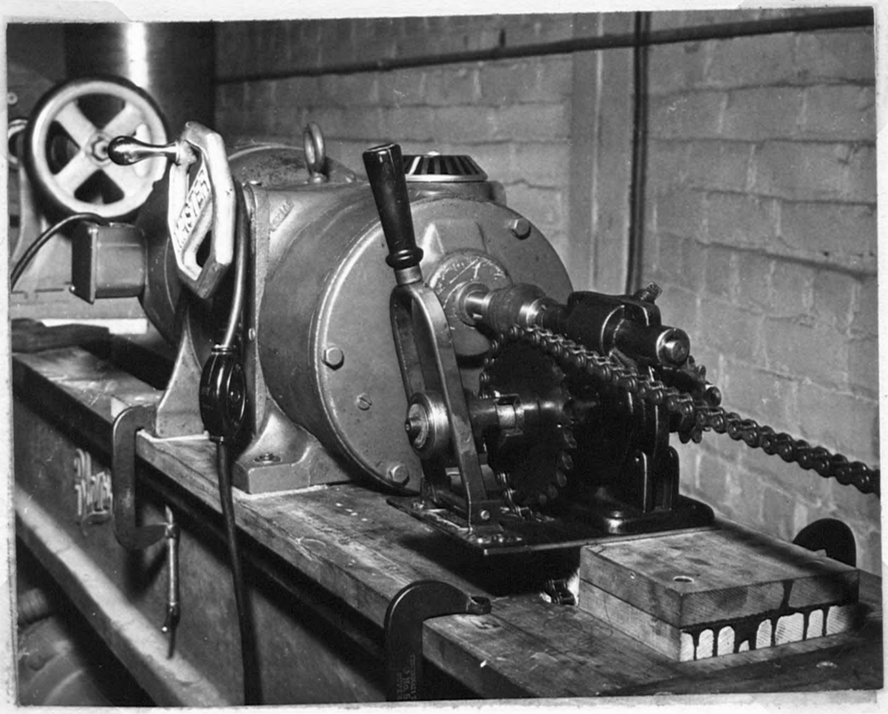


Figure 6 -- Complete Feed Mechanism

not be necessary because the weight of the free chain would keep it taut without pulling the work-carriage out of its starting position.

The speed-ranger operates by two driver cones and two driven cones with a metal ring transmitting power from the former to the latter. By changing the relative position of the ring and cones variable speed is obtained. The two driver cones are splined to and driven by the input or motor shaft, whereas, the set of driven cones are splined to the output or variable speed shaft. Power is transmitted from the variable speed shaft through a rubber coupling to the input shaft of the speed reducer. Here a 48:1 worm gear reduces the input speed and transmits power through a drive gear to a step shaft on which the drive sprocket is mounted. A drive jaw keyed to and still free to slide on the step-shaft engages a corresponding jaw fixed to the sprocket. Power is thereby transmitted to the drive sprocket. The sprocket in turn draws the roller chain which is attached to the work-carriage. Figure 8 illustrates the Feed Control Mechanism and also shows how power is transmitted through the speed reducer to the drive sprocket.

Feed Control Mechanism

Although the feed mechanism just described was adequate for this investigation, the tendency of the feed motor to coast when stopped gave rise to the problem of stopping the feed in time to prevent the lead carriage from being pulled off the slide. This problem was solved by inventing a jaw clutch, which is fitted to the drive shaft of the speed reducer, to control the driving motion of the sprocket. Figure 7 shows the jaw clutch and illustrates the relative position of the drive jaw in controlling the driving motion of the sprocket.

In order to fit the jaw clutch to the speed reducer it was necessary to design a new drive shaft and sprocket. The sprocket instead of being fixed to a straight shaft, as originally equipped, is now mounted on a step shaft and revolves on a bronze bearing. A movable sliding drive jaw is keyed to the step shaft and a stationary driven jaw is fixed to the sprocket. The jaws are made of hardened steel to withstand the sudden impact of driving when they are engaged. Figure 8 shows the jaw clutch and speed reducer cut away to illustrate the working parts and how they operate.

In describing the operation of the feed mechanism, the operating principle of the jaw clutch was mentioned. Without stopping the feed motor, the driving motion of the sprocket is controlled simply by changing the relative position of the sliding drive jaw. A hand lever facilitates this change.

Before any actual cutting was done considerable thought was given to designing and putting into operation the shaping fixture and feed control mechanism already described. It is likely that a shaping study might have been made without the use of this new equipment, but it is doubtful if as reliable

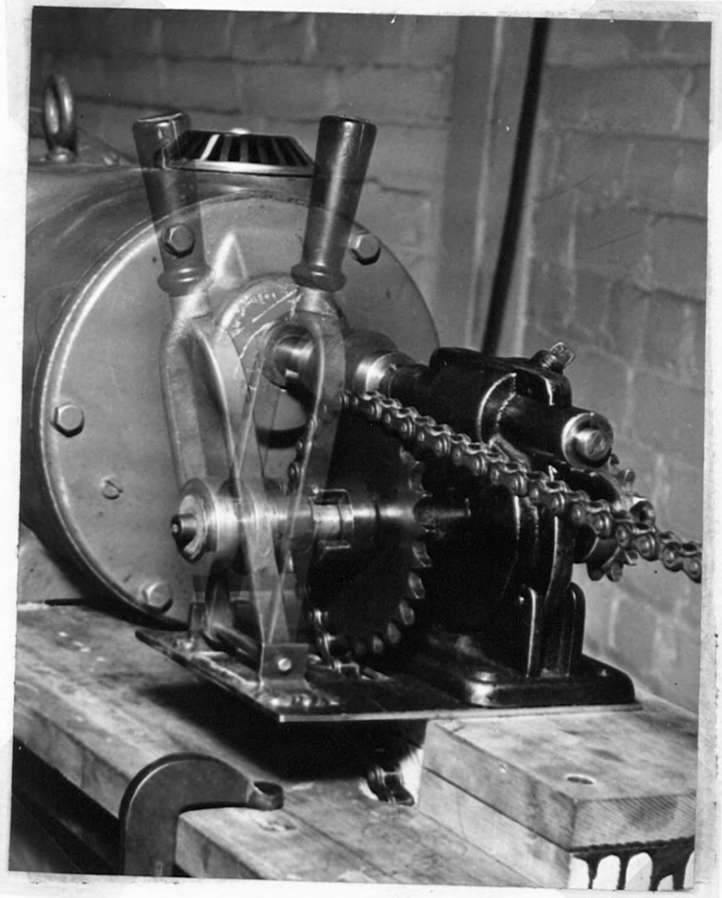


Figure 7 -- Jaw Clutch Feed Control Mechanism showing relative position of drive jaw in controlling driving motion of sprocket.

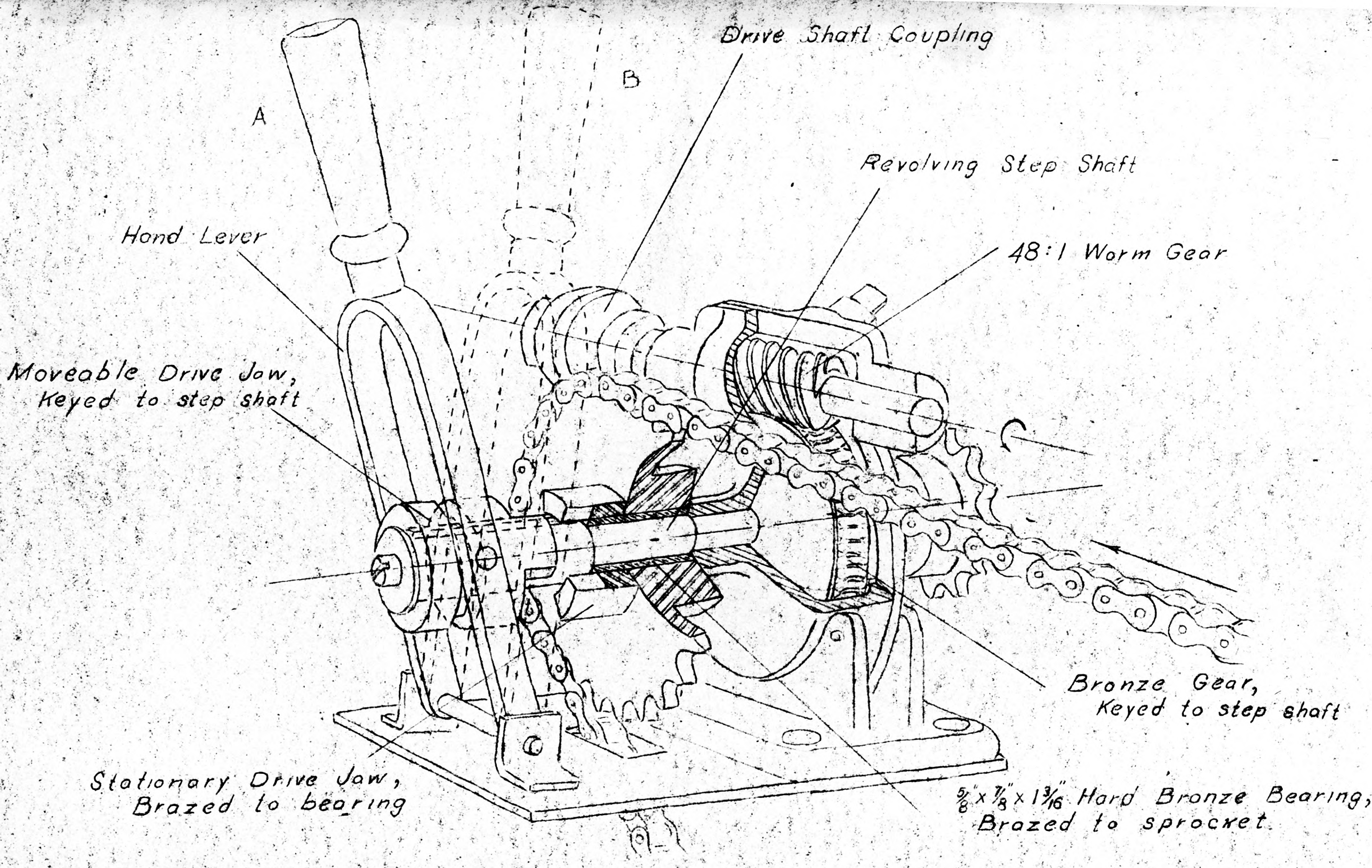


Figure 8 - Sketch of Jaw Clutch and Speed Reducer showing working parts: A, Movable drive jaw disengaged, sprocket idle; B, jaw engaged to drive sprocket.

results could have been obtained.

The shaping fixture and feed control mechanism have proven their merit in this investigation and will undoubtedly be useful in future machinability studies. However, it should be emphasized that if the new equipment is to function to the best advantage, future operators will need to be instructed as to its proper use.

Knife Preparation

Variation of cutting angle (knife angle) was accomplished by grind a back bevel on each knife, Figure 9.

Actual grinding was done on a No. 2 Cincinnati Tool and Cutter Grinder operating at 4000 rev. per min. A 4" Norton No. 38A46L5VBE cup wheel was used for grinding clearance bevels and a 5/8" X 6" Norton No. 38A36H8VE flat wheel for grinding back bevels.[1] The knives were ground dry and were held in a universal vise during the preparation. All angles were checked on a

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[1]Grinding bevels are for a 2 3/4" cutting circle and are a function of the grinding bevel (index angle) for a 0 degree cutting angle. The index angle was calculated by the formula $\sin \alpha = a/c$; where α is the interior angle between the knife and a center line through the axis of the spindle, at a point on the diameter of the knife collar; a is the perpendicular distance from the knife to the axis of the spindle; and c the radius of the knife collar. The calculation is as follows:

$$\sin \alpha = .562/1.250$$
$$= .4496$$
$$= 26^\circ\ 43' \text{ (index angle)}$$

Accordingly, by adding to or deducting from 26° 43', the value for the cutting angle under consideration, the grinding bevel required to obtain that cutting angle was determined.

A 55 degree clearance bevel was ground on all knives. For a 2 3/4" cutting circle, this gives a clearance angle of 8° 17' (the compliment of the clearance bevel less 26° 43'). Relatively little clearance angle was chosen so as to obtain a maximum lip angle so necessary to hold a keen cutting edge.

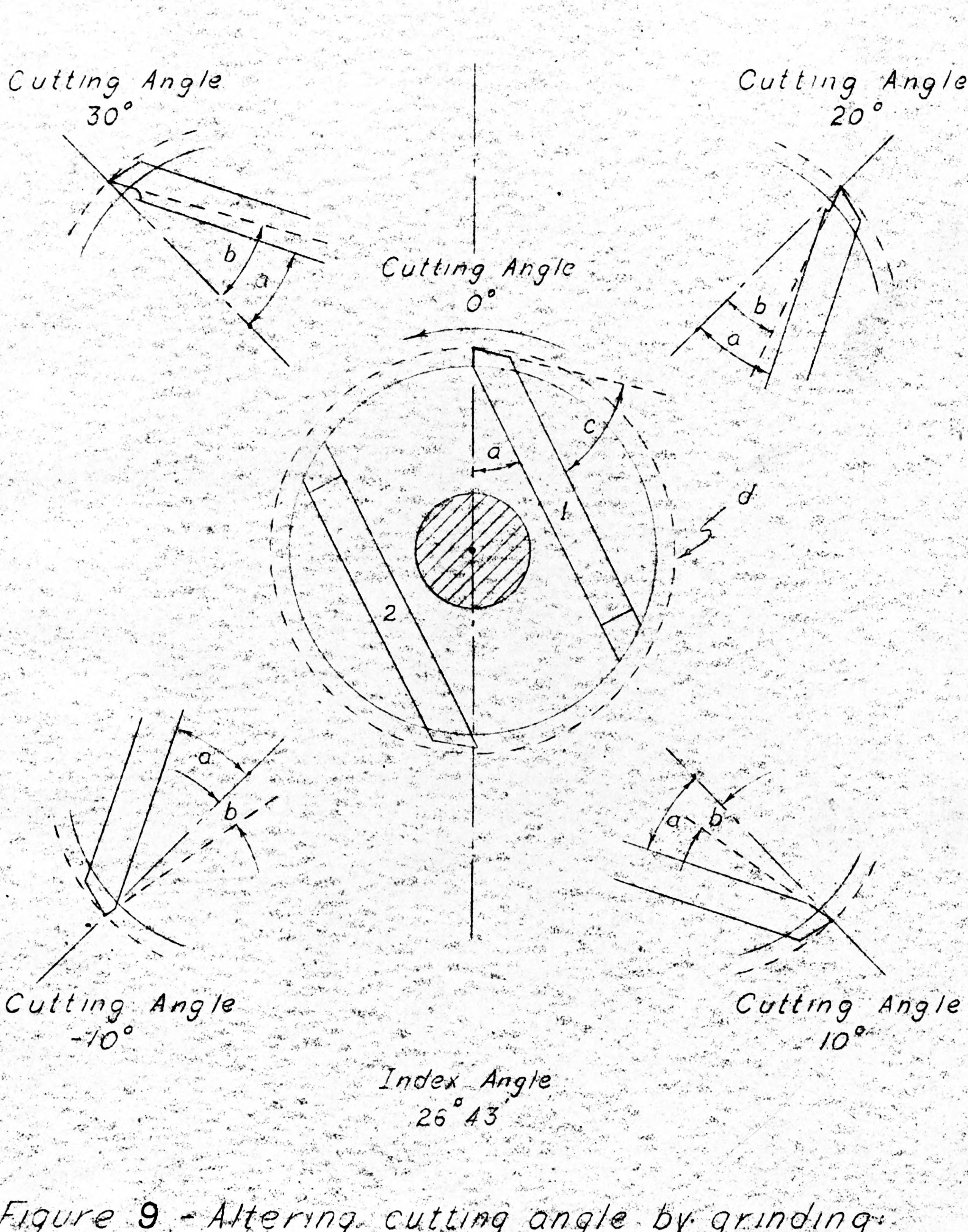

Figure 9 - Altering cutting angle by grinding: a, Index angle; b, cutting angle and grinding bevel; c, clearance bevel; d, cutting circle; 1, shaper knife, and 2, filler.

Jones and Lamson Optical Comparator to plus or minus 3 minutes of angle.

Wood-Test Material Used in Investigation

Source of Test Material

The aspen samples tested in this study were Minnesota aspen obtained from lumber stored at the Wood Laboratory of the University of Michigan.

Standard Test Sample

A standard 3/4" X 4" X 36" test sample was chosen for this investigation. A sample of this size was large enough to permit making specific gravity and moisture determinations on the same material, leaving ample material from which to obtain representative cuts. Clear material was selected in preparing 36 samples, 30 of which were used in the actual shaping operation.

Preparation of Test Samples

Since wood differs in the way it cuts at different angles to the grain, test samples which required cutting side grain (parallel to the grain), diagonal grain (diagonal to the grain), and end grain (at right angles to the grain) were prepared. Side grain samples were selected and cut to standard size without further preparation other than planing to the required thickness. To obtain samples for cutting diagonal and end grain, it was necessary to assemble edge glued panels. To fulfill this need narrow strips of lumber were cut and edge glued to form panels large enough to give standard test samples. Five panels were assembled, using vegetable starch glue which has a minimum dulling action on cutting tools. Two of the panels yielded standard test samples for cutting at right angles to the grain, the remaining three yielded samples for cutting diagonal to the grain. Figure 10 shows the type of panel assembled for this preparation and in Figure 11 can be seen the type of test samples obtained by cutting.

Before cutting the panels into standard size test pieces each was cut into three narrower panels which were planed to standard thickness.

Conditioning Test Samples.

Test samples were conditioned for shaping in a constant-temperature-humidity room held at 70° F. and 35% relative humidity. The samples were grouped and placed in the control room until they reached a 6 to 7% equilibrium moisture content at which time they were removed for shaping.[1] The actual

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[1]It was thought at first necessary to make shaping tests at 7 to 8 % moisture content because this particular range represents the condition at which wood is generally worked. However, time did not permit the samples to reach this condition in the control room. Therefore, they were removed and tested when at equilibrium moisture content of 6 to 7 percent. Although this particular moisture content is not the usual it corresponds to the moisture condition of samples at which previous machinability studies have been made (1, 2). In this respect the results reported here may be compared with the established woods in regard to machinability in shaping. Although future investigation may involve testing aspen with moisture content of 7 to 8%, it is doubtful if such study would reveal any more satisfactory results than are presented in this paper. The fact that aspen has soft texture, in itself, suggests that it will work best at low moisture content.

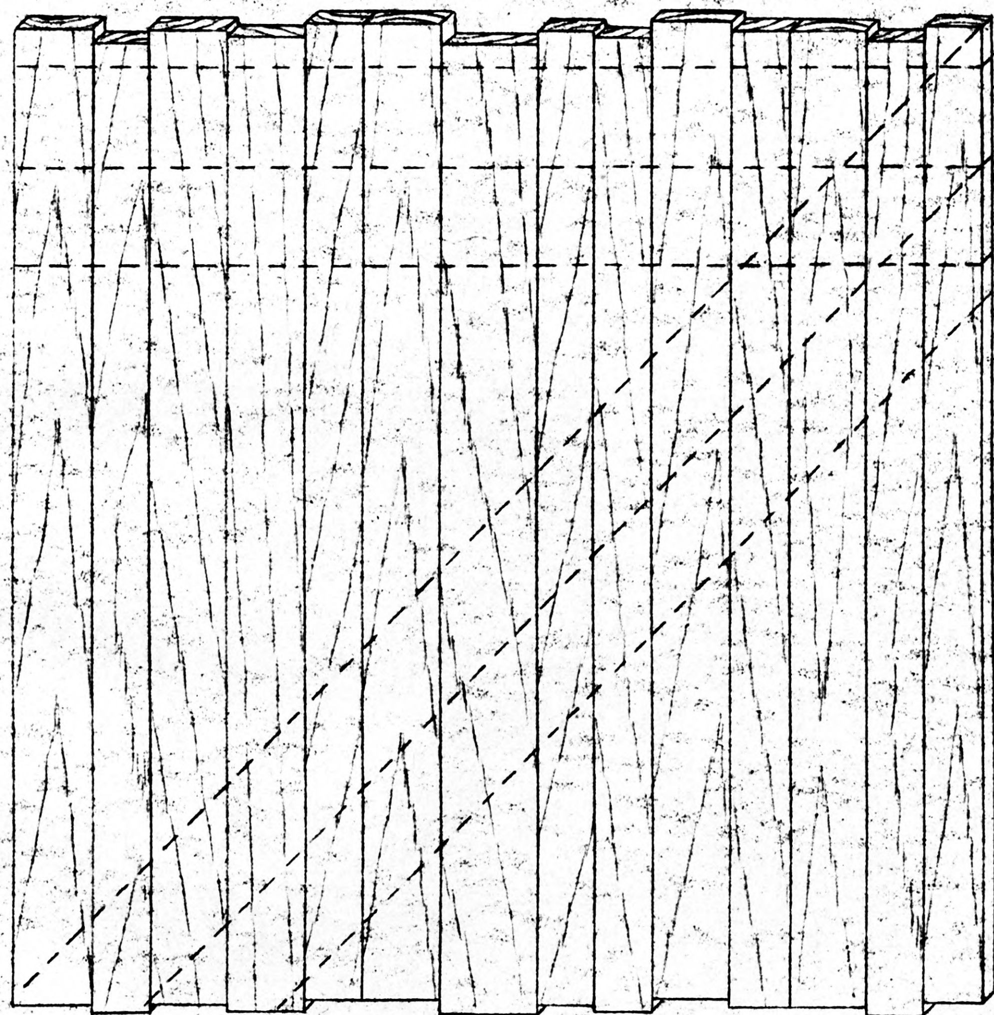

Figure 10 - Type of panel from which test samples type B and C shown in figure 11 were cut. Broken line indicates cutting line at right angles and diagonal to the grain.

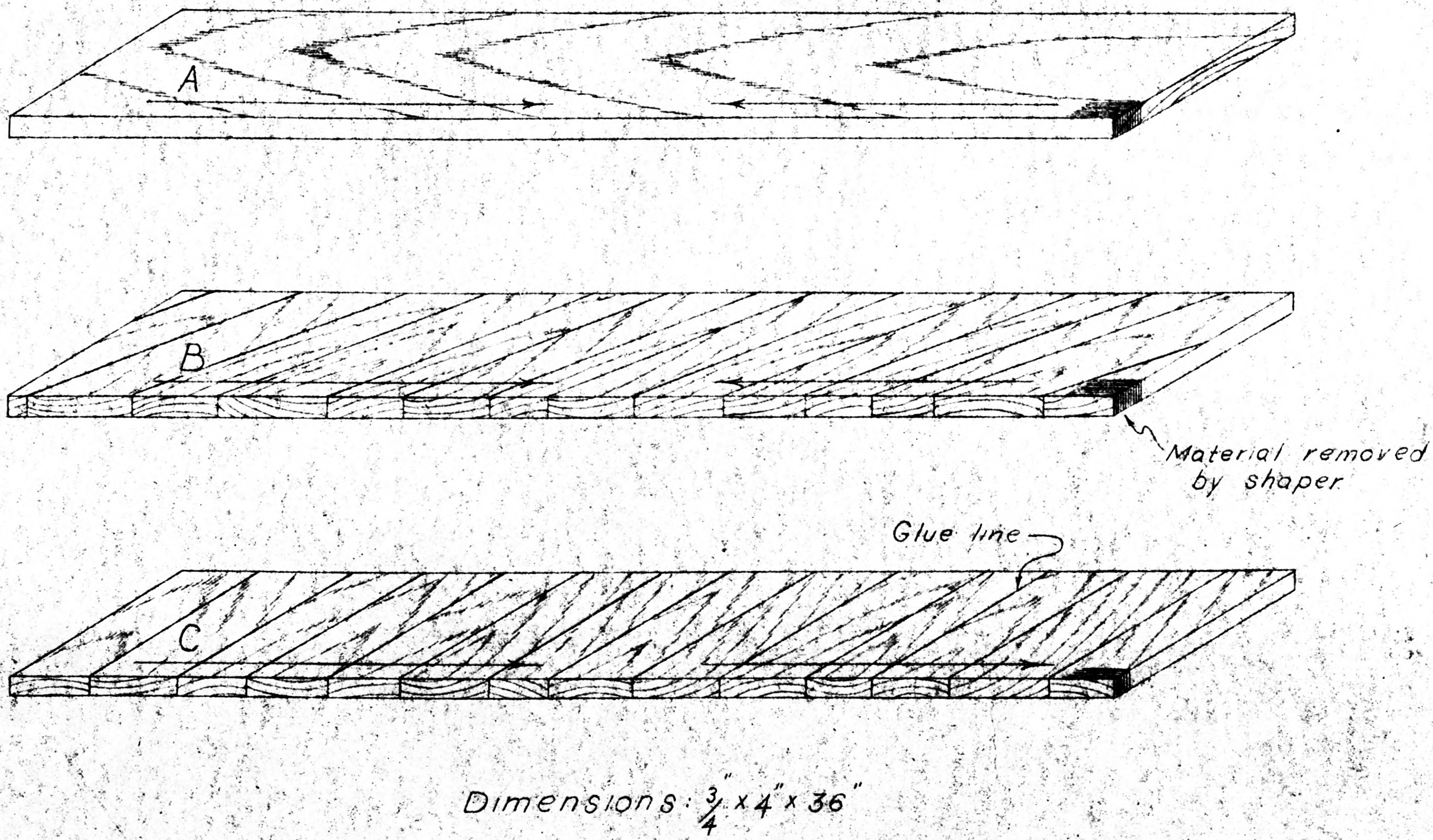

Figure 11 – Type of test samples for shaping: A, Sample for shaping side grain; B, diagonal grain; and C, end grain. Arrows indicate direction of the different cuts in samples A through C.

testing was done in a relatively short time. This made it possible to remove and work with all samples at one time without danger of the moisture content changing appreciably.

Moisture Content and Specific Gravity

The moisture content of the samples at the time of testing varied from 5.9 percent to 6.7 percent and averaged 6.3 percent. The specific gravity based on volume and weight at 6 to 7 percent moisture varied from 0.41 to 0.46 and averaged 0.44. Moisture content and specific gravity determinations were made according to standard procedure (5).

Operating Conditions for Tests

More than a study of the typical conditions for a shaper operation was not within the scope of this paper.

Throughout a series of tests made on aspen, the only variable investigated was the cutting angle; all other operating conditions were kept uniform. The effect of variation of cutting angle on surface quality was obtained from a series of 10 cuts at five different cutting angles: -10, 0, 10, 20, and 30 degrees, combined with a shaper speed of 12,000 rev. per min., a feed of 50 ft. per min.,[1] a depth of cut of 1/16 inch,[1] and

[1]In order to make the results of this study comparable to those obtained at the United States Forest Products Laboratory (1, 2), a depth of cut of 1/16 inch and a rate of feed of 50 ft. per min. were used as two operating conditions. The rate of feed was governed by the speed of the spindle and 20 knife cuts per inch. The calculation is as follows:

$$\text{Rate of Feed (ft. per min.)} = \frac{\text{Speed of spindle(rev/min.)}}{\text{No. knife cuts per inch X 12}}$$
$$= 12{,}000/20 \text{ X } 12$$
$$= 50 \text{ ft. per min.}$$

moisture content of 6 to 7 percent.

Testing Procedure

Measuring Surface Quality

Smoothness of surface is considered a criterion of workability by American woodworkers (2). In this study, surface quality was judged by the degree of smoothness. A Brinell microscope and a Jones and Lamson Optical Comparator were tried experimentally in an attempt to discover a mechanical means of measuring the smoothness of surface, but these instruments proved unsatisfactory. Since no device for the measurement of smoothness was available, a method of visual inspection, somewhat modified from that defined by the United States Forest Products Laboratory (2), was used in this investigation at the Michigan Laboratory.

Surface quality was measured by the occurrence of shaping defects and graded accordingly on the basis of the additional sanding considered necessary to make acceptable finish. More

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(con't.)

To obtain a rate of feed of 50 ft. per min. it was necessary to determine the chain velocity in ft. per min. and in turn the output speed at which to set the speek ranger. The chain velocity was calculated by the formula V = SNP/12 (4); where V is the chain velocity in ft. per min.; S the sprocket speed in rev. per min. at an output speed of 48 rev. per min.; N the number of teeth; and P the pitch (in inches) of the sprocket. The calculation is as follows:

$$\text{Chain Velocity (ft. per min.)} = 1 \times 24 \times .5/12 = 1 \text{ ft. per min.}$$

Since the chain velocity was 1 ft. per min. at an output speed of 48 rev. per min.; by simple proportion the speed-ranger output at which to obtain a rate of feed of 50 ft. per min. was determined. The calculation is as follows:

$$\frac{48}{1} = \frac{x}{50}$$;where x is the speed-ranger output (rev. per min.)

$$x = 2{,}400 \text{ rev. per min.}$$

than one kind of defect may be present and any given defect may vary in occurrence. Therefore, for all practical purposes the most outstanding defect on a shaping determines the grade. This modified method of grading shows both the frequency and degree with which a given defect occurs. Table I, shows the grading system used for measuring surface quality.

Order of Testing

Shaping tests were made on three groups of samples each comprising a series of ten samples. The groups were designated A, B, and C representing cutting side grain, diagonal grain, and end grain respectively. Group A and B in turn were subdivided into groups AA and BB. The order of testing followed this grouping. Group A and B required cuts with the grain, whereas group AA and BB required cuts against the grain. Group C required cuts across the grain only. Figure 11, page 26 shows the direction of the different cuts made on series samples A through C.

Eact test sample in a series required a single cut at five different knife angles. Thus surface quality as affected by variation of cutting angle was obtained from a series of ten cuts at each knife angle. The samples used in series A and B were also used in series AA and BB. Thereby, a total of ten actual test cuts were made on each sample in group A and B, whereas only five cuts were made on samples in group C. More than 200 shaping tests were made.

Table I -- Grading System Used For Measuring Surface Quality

Grade	Surface Quality	Sanding Necessary to remove outstanding defect	Shaping Defect
1	Excellent	Minimum to extremely light	Minimum fuzzy grain
2	Good	Very light	Slight fuzzy grain; raised grain; roughness; torn grain; or chipped grain
3	Fair	Light to moderately heavy	Pronounced fuzzy grain; raised grain; roughness; torn grain; or chipped grain
4	Poor	Moderate to exceedingly heavy	Exceedingly fuzzy grain; raised grain; rough grain; torn grain; or chipped grain
5	Reject	Extremely heavy	Extremely raised grain; rough grain; torn grain; or chipped grain

Knife Sequence

Testing followed in the order of series samples A through C beginning with a 30 degree cutting angle. After completing the entire series of tests required at the 30 degree cutting angle, the knife was changed and the testing procedure repeated, but with a 20 degree cutting angle. These tests were followed by others at a cutting angle of 10, 0, and -10 degrees.

Shaping Operation

In the entire series of shaping tests reported in this paper, cutting angle is the only variable investigated.

In the actual cutting operation, the fixture was positioned centrally with respect to the spindle. The first test sample was clamped in place with the work-carriage in the starting position. The feed rate was set before the first pass across the shaper and instantaneous starting and stopping of the feed was controlled by the jaw clutch. The shaper motor was started before and stopped after each pass across the shaper.

Following the first test run, the work-carriage was drawn back to the starting position on the slide; the sample removed and the cycle repeated.

After running a series of ten cuts, surface finish on each sample was examined and recorded, a representative shaping-effect was selected for photographing. (Plates 6 through 10).

This procedure was followed for more than 200 tests. Figure 12 shows the actual shaping operation. Figure 13 is a sample data sheet used for recording the entry observations.

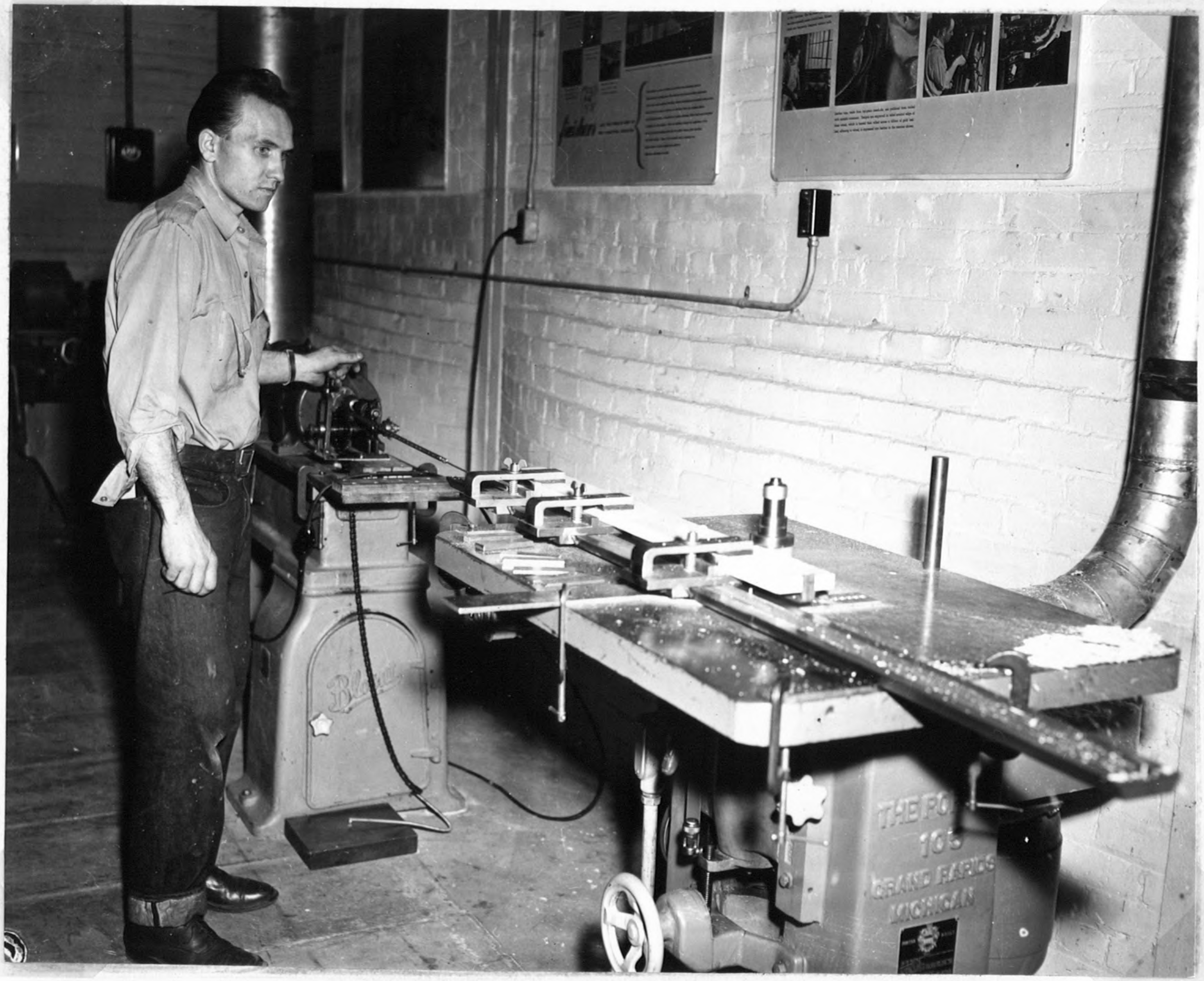


Figure 12 -- Actual Shaping Operation

Shaping Data

Test Series and Group____ Date________________

Species________________________ Cutting Tool__________________

Sp. Gr.__________ @ __________ m.c. R.P.M.________________________

Shaping Test__________________ Cutting Angle__________________

Direction of Cut______________ Clearance Angle________________

Width of Cut______________inch Lip Angle______________________

Depth of Cut______________inch

Length of Cut____________inches

Feed______________f.p.m.

Finish Obtained________________ Outstanding Defect________________

Grade__________________________ Sanding Necessary_________________

Surface Quality

Run No.	Shaping Defect	Sanding Necessary	Grade	Finish	General Observations
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Figure 13 -- Data sheet used to record entry observations at time of taking test cuts.

Results of Shaping Tests

Results of tests with five different cutting angles in shaping aspen are shown in Tables II and III, pages 37 and 38 and illustrated in Plates 6 through 10, page 39 through 43.

Parallel to the Grain (side grain)

In the shaping tests made in a direction parallel to the grain (cutting with or against the grain) the best results were obtained at a cutting angle of 10 degrees. Tests conducted in a direction parallel to and with the grain produced 90 percent of defect-free test samples at a cutting angle of 10 degrees. In runs made against the grain, aspen yielded 40 percent of defect-free test samples at the same cutting angle, Table II.

In tests made in a direction parallel to and cutting with or against the grain, aspen exhibited a relatively wide variation in smoothness of surface as affected by five different cutting angles, Table III (Plates 6 and 7).

In contrast to all other angles, a 10 degree cutting angle produced the smoothest surface in all shaping tests made in a direction parallel to the grain. In cuts made with or against the grain at a cutting angle of -10 or 0 degrees torn grain was the worst surface defect. Examples of chipped grain were encountered in tests conducted with the grain at a 20 degree cutting angle. Such a surface defect was also produced at a 30 degree cutting angle, to an even greater degree. However, it only resulted in tests made on samples that showed the presence of cross-grain. A minute fuzzyness, that increased in degree in cuts made against the grain, was the most characteristic surface defect produced by a 30 degree cutting angle.

Diagonal to the Grain (diagonal grain)

The best results of shaping tests made in a direction diagonal to and cutting with the grain (in aspen) were produced at a cutting angle of 10 degrees. Cutting against the grain, the better surface finish was obtained at a cutting angle of 20 degrees.

Shaping tests made in a direction diagonal to and with the grain at a cutting angle of 10 degrees resulted in 100 percent of good to excellent test samples. In contrast to the satisfactory results produced by cutting with the grain, aspen yielded 100 percent of poor to fair test samples at the best cutting angle (20 degrees) in tests made against the grain, Table II.

A limited number of shaping experiments were made by cutting diagonal to and against the grain because the test samples split before any single run in the entire series was completed. Extreme roughness that was somewhat lessened by cutting angles of 20 or 30 degrees was by far the most outstanding surface defect produced by the few tests conducted against the grain. In shaping tests made with the grain, raised grain that varied considerably in degree resulted at five different cutting angles. In both series of shaping tests (with or against the grain) in a diagonal direction to the grain, feather edges were produced. In this regard, a general improvement was noted in surfaces machined diagonally to and with the grain, Table III, (Plates 8 and 9).

In the shaping tests made diagonal to and against the grain at cutting angles of -10, 0, and 10 degrees the surfaces were so rough that they did not meet acceptable surfacing requirements. There was an improvement in surface smoothness produced by cutting angles of 20 or 30 degrees. However, the results were not considered satisfactory.

At Right Angles to the Grain (end grain)

The best cutting angle in shaping across the grain in aspen was obviously 10 to 20 degrees.

Shaping tests made at right angles to the grain at a cutting angle of 10 degrees resulted in 80% of poor to fair samples, whereas a 20 degree cutting angle produced 40% of samples that were fair to good and only 60% of poor to fair test pieces, Figure II.

In shaping across the grain at a -10 or 0 degree cutting angle, aspen yielded 100 percent of samples that did not meet acceptable surface requirements. A general improvement in the quality of the surface was produced by cutting angles of 10, 20, and 30 degrees. However, the test results were unsatisfactory in that poor surface finish was produced, Table III, (Plate 10).

Conclusion and Suggestions for Future Study

From the foregoing tests it is concluded, that under the conditions of the experiments, aspen machines best in shaping at a cutting angle of 10 to 20 degrees. However, no satisfactory means is revealed for producing a first-class finish on aspen

Table II -- Results of Shaping Tests: Effect of variation of cutting angle on quality of work in shaping aspen[1]

Shaping Test	Direction of Cut	Cutting Angle	Quality of Work				
			Defect Free Shapings	Good to Excellent Shapings	Fair to Good Shapings	Poor to Fair Shapings	Rejected Shapings
		Degrees	Percent	Percent	Percent	Percent	Percent
Parallel to the grain	With the grain	-10		20	80		
		0		30	70		
		10	90	10			
		20		30	50	20	
		30	60	20	10	10	
	Against the grain	-10			30	70	
		0			30	70	
		10	40	60			
		20		80	20		
		30		50	30		20
Diagonal to the grain (at 45 degrees)	With the Grain	-10			40	60	
		0			30	70	
		10		100			
		20			70	30	
		30			100		
	Against the grain[2]	-10					100
		0					100
		10					100
		20				100	
		30				100	
At right angles to the grain	Across grain	-10					100
		0					100
		10				80	20
		20			40	60	
		30				70	30

[1] Based on 1/16 inch depth of cut, 50 ft. per min., feed at 12,000 rev. per min., and 6-7 percent moisture content.

[2] Tests resulted in splitting.

Table III -- Results of Shaping Tests: Effect of variation of cutting angle on smoothness of surface in shaping aspen[1]

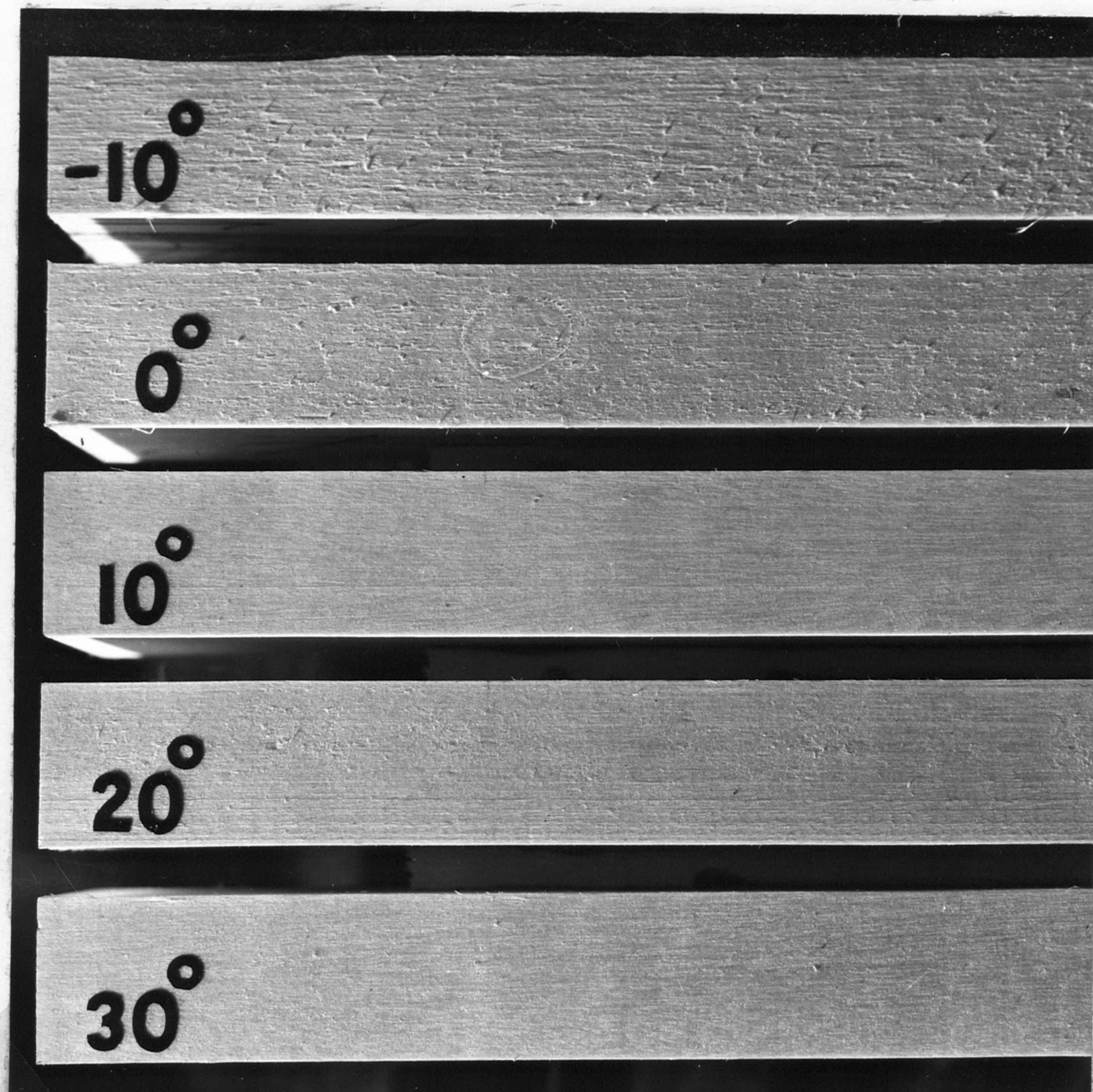
Shaping Test	Direction of Cut	Cutting Angle	Smoothness of Surface: Outstanding Defect	Surface Quality	Sanding Necessary
		Degrees			
Parallel to the grain	With the grain	-10	torn grain	fair	moderately heavy
		0	torn grain	fair	light
		10	no defect	excellent	minimum
		20	chipped grain	fair	light
		30	fuzzy grain	excellent	extremely light
	Against the grain	-10	torn grain	poor	exceedingly heavy
		0	torn grain	poor	moderately heavy
		10	no defect	excellent	minimum
		20	raised grain	good	very light
		30	fuzzy grain	good	very light
Diagonal to the grain (at 45 degrees)	With the grain	-10	roughness	poor	exceedingly heavy
		0	raised grain	poor	exceedingly heavy
		10	raised grain	good	very light
		20	raised grain	fair	light
		30	raised grain	poor	moderately heavy
	Against the grain[2]	-10	roughness	reject	extremely heavy
		0	roughness	reject	extremely heavy
		10	roughness	reject	extremely heavy
		20	roughness	poor	exceedingly heavy
		30	roughness	poor	exceedingly heavy
At Right Angles to the grain	Across the grain	-10	roughness	reject	extremely heavy
		0	roughness	reject	extremely heavy
		10	raised grain	poor	moderately heavy
		20	raised grain	poor	moderately heavy
		30	raised grain	poor	exceedingly heavy

[1]Based on 1/16 inch depth of cut, 50 ft. per min. feed at 12,000 rev. per min., and 6-7 percent moisture content.

[2]Tests resulted in splitting.

Effect of variation of cutting angle on
surface quality in shaping aspen

PLATE 6

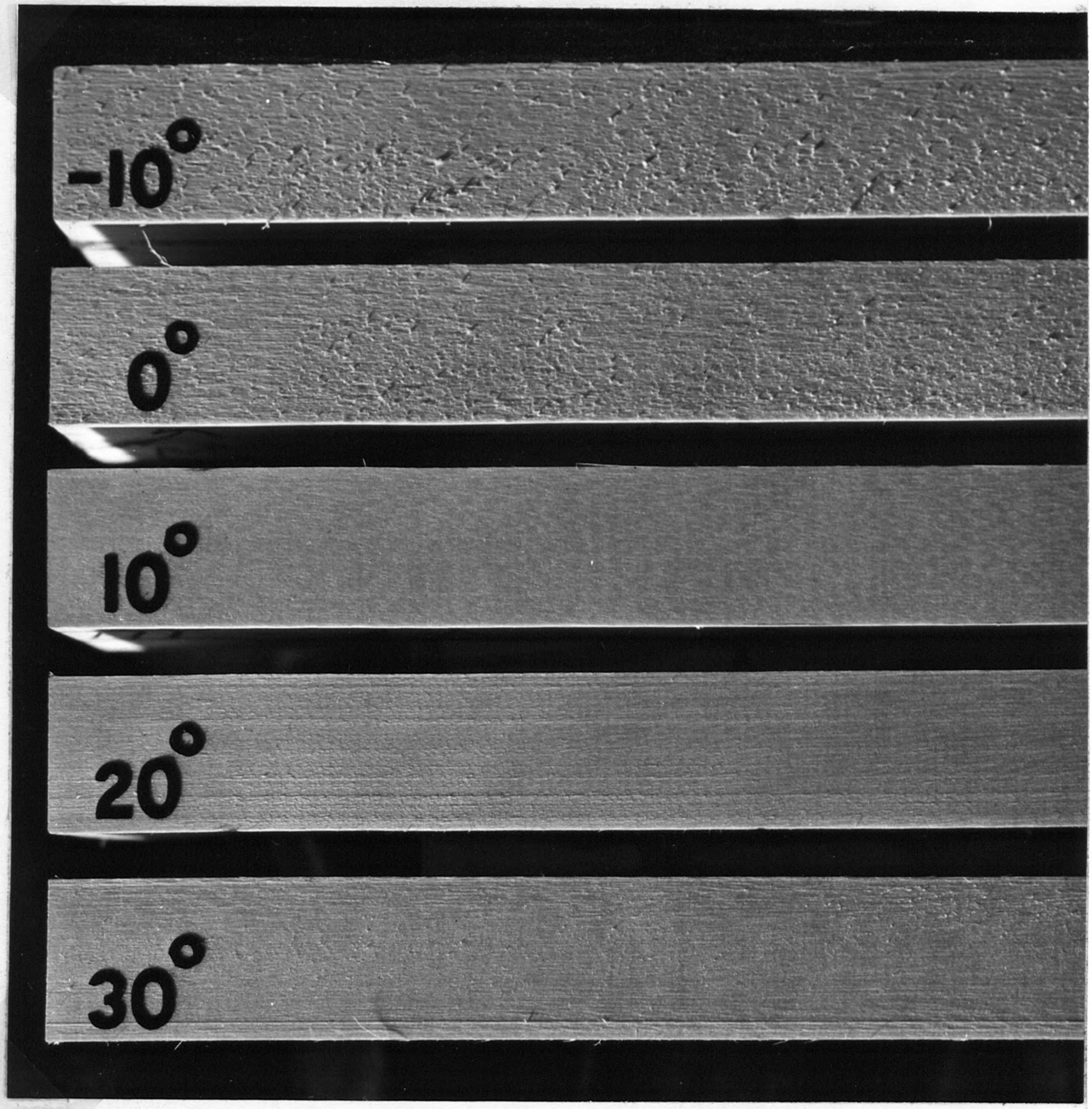


——— Side Grain ———→

Results of Shaping Test: Contrast in smoothness of cuts made With the Grain: -10°, torn grain; 0°, torn grain; 10°, no defect; 20°, chipped grain; 30°, fuzzy grain. Arrow indicates direction of cut.

Effect of variation of cutting angle on surface quality in shaping aspen

PLATE 7

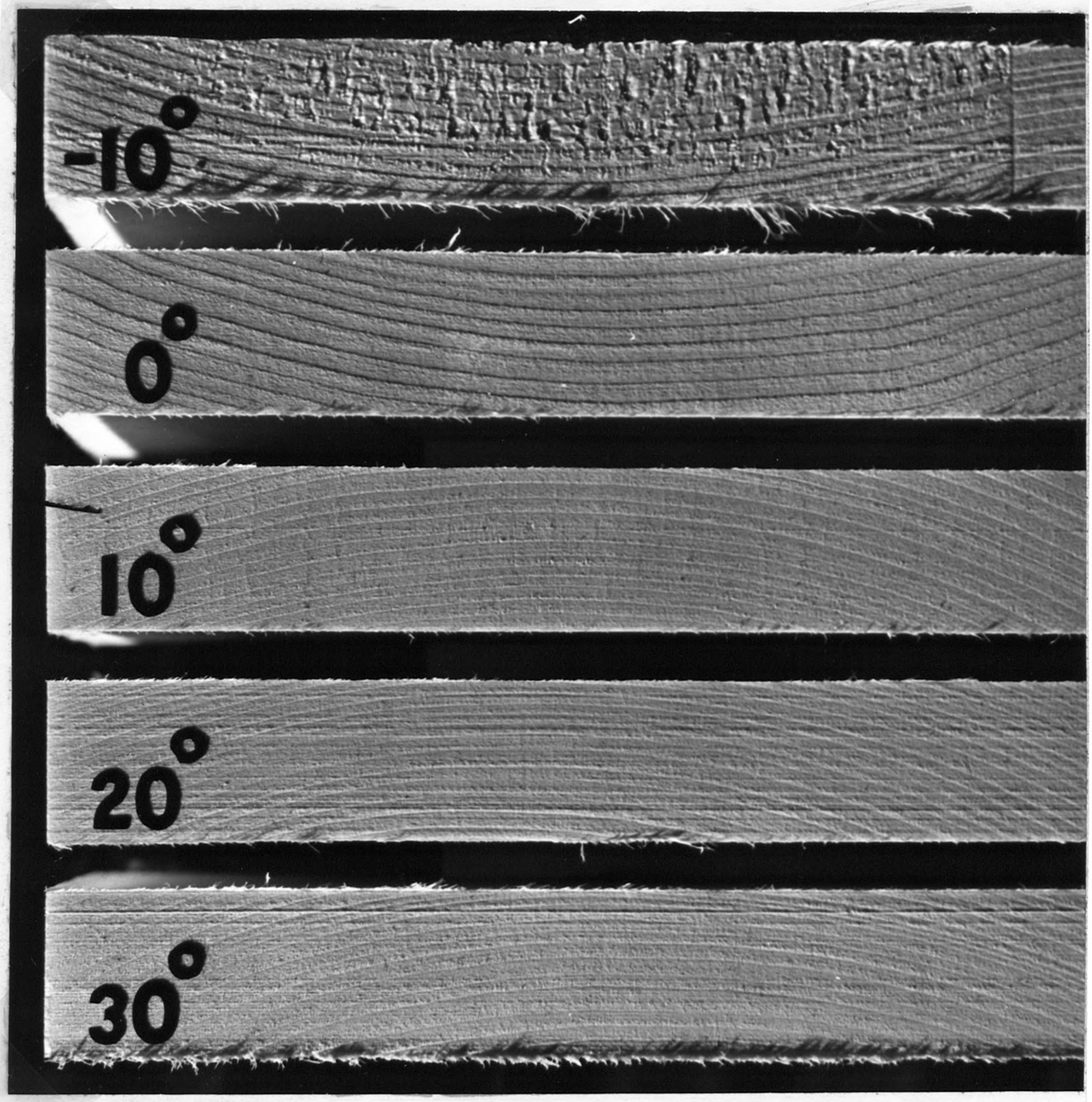


———— Side Grain ————>

Results of Shaping Test: Contrast in smoothness of cuts made <u>Against the Grain</u>: -10°, torn grain; 0°, torn grain, 10°, no defect; 20°, raised grain; 30°, fuzzy grain. Arrow indicates direction of cut.

Effect of variation of cutting angle on
surface quality in shaping aspen

PLATE 8

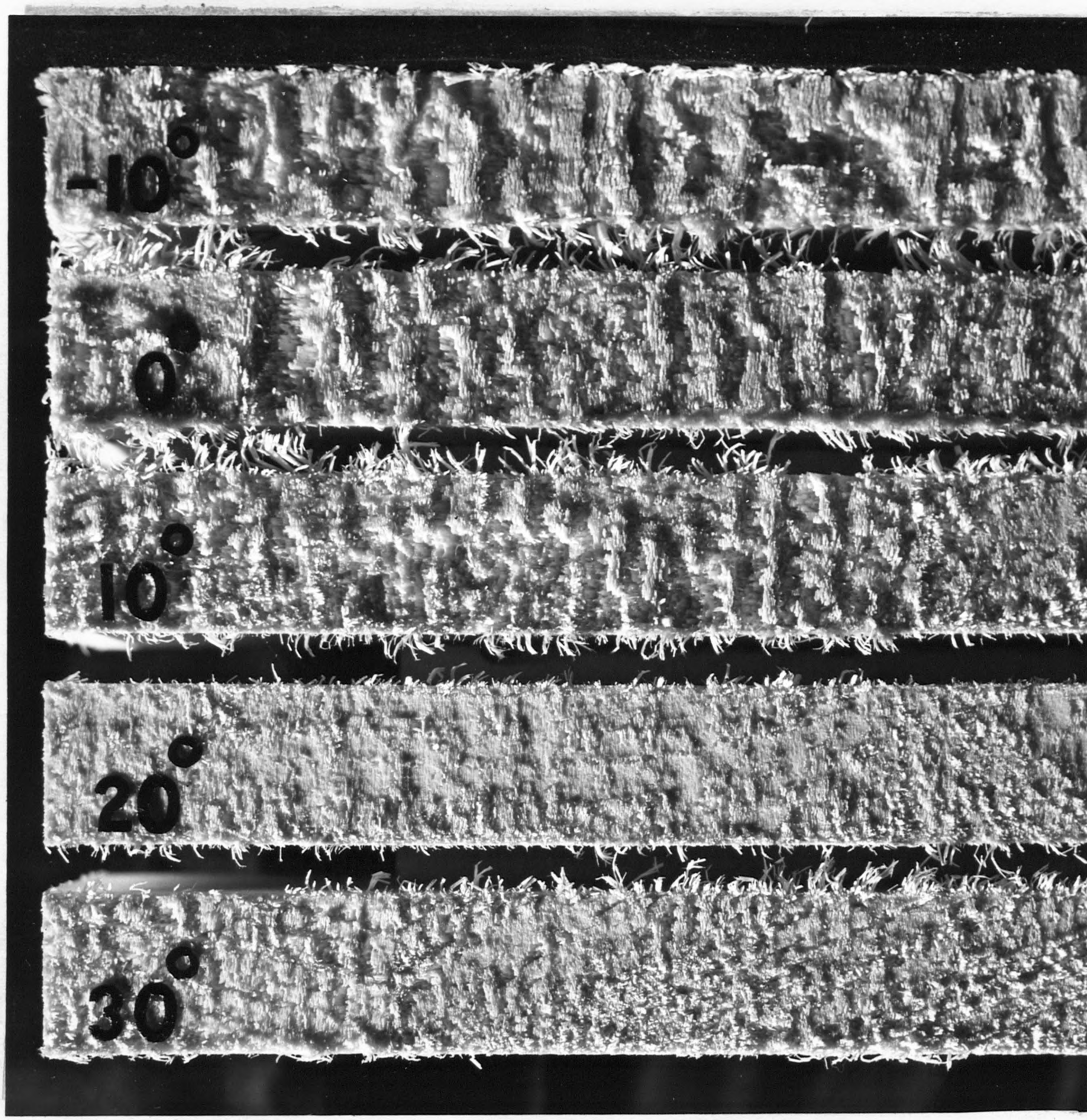


——— Diagonal Grain ———→

Results of Shaping Test: Contrast in smoothness of cuts made With the Grain: -10° roughness; 0°, raised grain; 10°, raised grain; 20°, raised grain; 30°, raised grain. Arrow indicates direction of cut.

Effect of variation of cutting angle on surface quality in shaping aspen

PLATE 9



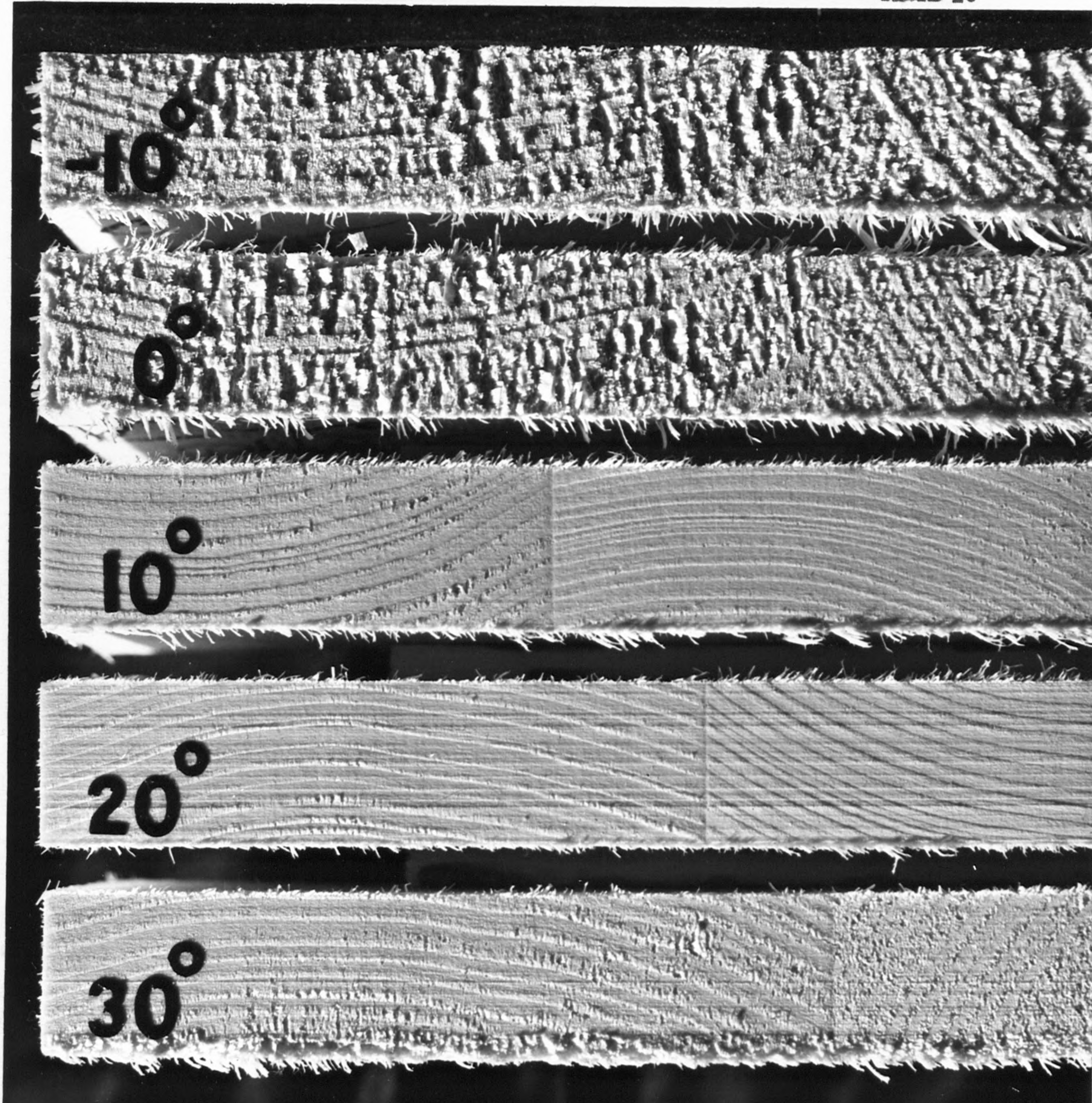
——— Diagonal Grain ———>

Results of Shaping Test: Contrast of smoothness of cuts made <u>Against the Grain</u>: -10° through 30°, roughness. Arrow indicates direction of cut.

H3

Effect of variation of cutting angle on surface quality in shaping aspen

PLATE 10



——— End Grain ———→

Results of Shaping Test: Contrast in smoothness of cuts made Across the Grain: -10°, roughness; 0°, roughness; 10°, raised grain; 20°, raised grain; 30°, raised grain. Arrow indicates direction of cut.

by shaping

In shaping tests made in a direction diagonal to and with or against the grain, aspen exhibited considerable difference in surface smoothness as affected by a variation of cutting angle. However, at a cutting angle of 10 degrees a highly satisfactory finish is obtained.

In tests conducted parallel to and with or against the grain or diagonal to and with the grain, a higher percentage of satisfactory work was produced by a 10 degree cutting angle than in tests made diagonal to and against the grain or across the grain at the same cutting angle.

A point of interest in this connection was noted. Extreme roughness was produced by cutting diagonal to and against the grain and splitting developed in such tests, but by cutting with the grain splitting was averted and at a cutting angle of 10 degrees, a satisfactory surface was obtained. It is desirable, therefore, to avoid as far as possible cutting diagonally to and against the grain in shaping aspen.

With aspen, raised grain may be bad in cuts made at right angles to the grain but at a 10 to 20 degree cutting angle it can be pretty well controlled.

The cutting angle which gives the best surface finish is not necessarily the optimum cutting angle when all factors which determine machinability are taken into consideration. How are we to know that the results of this investigation represent the best to be expected when shaping aspen? Without making further tests, the best we can say is that these results represent relative surface quality to be expected for aspen under the given set of operating conditions. For a more thorough understanding of the effect of cutting angle on surface quality in shaping aspen, it is necessary to take into consideration changes in moisture content as well as changes in speed, feed, and depth of cut.

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