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DEVELOPMENT OF NON-DESTRUCTIVE TESTS FOR
LAMINATED GUNSTOCK BLANKS

Progress Report No. 3
October 1 to November 30, 1953

Development of Non-destructive Tests for Laminated
Gunstock Blanks. Progress Report No. 3 for the
Period October 1 to November 30, 1953.

Introduction

This is the third of a series of progress reports on work undertaken
at the Yale School of Forestry to develop a practical method of testing
laminated gunstock blanks. The study is sponsored by the Springfield
Ordnance District of the Department of the Army under Contract No. SAR/DA-
19-059-ORD-1329.

This study involves a determination of the integrity of the glue bond
in laminated gunstock blanks. It anticipates the application of appropriate
non-destructive test methods followed by recognized destructive testing of
the blanks. These blanks are to be fabricated under production conditions
in a commercial laminating plant. Work began on June 1, 1953, with a re-
view of the literature pertaining to this subject. The first progress re-
port of this series included a description of exploratory testing with x-ray
absorption and high-frequency sound transmission techniques, in addition to
the literature review mentioned above. The second progress report presented
sound transmission data collected on several laminated blanks assembled in
a manner to simulate gunstock types B and C, Class 1.[1] These are the two
types to be tested under the contract. In addition, x-ray photographs of
the same blanks were included in the second progress report.

This report includes a statistical analysis of the ultrasonic energy

[1] Final Report, Laminated Gunstock Blanks. Gamble Bros., Inc. Louisville,
Kentucky. Research No. G. G. 3728, Order No. L. A. 7220-50, March 14,
1952.

transmission data presented in Progress Report No. 2 and, in addition, a continuation of the literature review begun in the initial report. This literature review will be continued throughout all succeeding reports when suitable material is uncovered. This is done to provide a complete bibliography at the termination of the project.

Review of Literature

Testing by Audio Frequency Methods

Galginaites[2] and associates have presented further work with the testing of wood laminates by a vibration method. In this work beams were assembled from Douglas fir laminates with the plane of the glue lines parallel to their length. Another type of laminate was prepared by gluing short oak boards on top of each other until an assembly of 25 or 30 laminations was obtained. These were then sawed into beams with a two-inch cross-section. Some of these laminates were of sound construction, while others contained defective glue lines. In addition solid beams were used in the initial part of the study. The oak specimens, with the glue lines normal to their long axes, were vibrated longitudinally. Beams with the glue lines parallel to their length were vibrated both transversely and longitudinally and the solid specimens were vibrated longitudinally. Both resonant frequency and logarithmic decrement were determined for all specimens. Resonant frequency was observed as that frequency at which maximum amplitude of vibration occurred, as was indicated on the screen of a cathode ray oscilloscope. Logarithmic decrement was determined by photographing the decay of vibration

[2] Galginaites, S. V., E. R. Bell, A. M. Fine, and G. Auer. The Non-Destructive Testing of Wood Laminates. Tech. Report No. 1. Office of Naval Research, University of Louisville, Institute of Industrial Research. January, 1953.

on the screen of an oscilloscope and computing the logarithmic decrement
from the equation:

$$\delta = \frac{1}{n} \ln \frac{A_1}{A_n}$$

where A_1 and A_n are the amplitudes of two vibrations
n cycles apart.

Tests on solid specimens showed that logarithmic decrements of longitudinal vibration could be reproduced to within 10 percent. The results of vibration testing of these solid specimens showed an empirical relationship to exist between maximum crushing strength and the quotient

$$\frac{D}{fd}$$ where

D = density

f = resonant frequency

d = logarithmic decrement

Specimens assembled with the glue lines normal to their length were vibrated longitudinally and then tested to destruction in torsion. The results showed no correlation between vibrational characteristics (logarithmic decrement and resonant frequency) and either the quality of the glue bonds or the strength of the specimens.

Laminates assembled with the plane of the laminations parallel to the length of the beam consisted of three laminations and had the final dimensions 2 x 2 x 29 in. These beams were vibrated both longitudinally and transversely. Transverse vibrations were carried out with the glue lines both normal and parallel to the direction of vibration. This set of specimens consisted of eight matched pairs. One sample of each pair was well bonded, while the other was assembled with "delaminated" areas. Longitudinal vibration of these matched pairs of beams showed the log decrements of the defective beams to be consistently higher than the log decrements of the

well-bonded beams. In no case was the log decrement of a defective laminate as low as that of its mate or any of the well bonded specimens.

For transverse vibration the beams were freely supported at two points. The resonant frequency of the defective specimens showed an average decrease of 20 percent as compared to their matched specimens when vibrated transversely with the plane of the glue lines normal to the direction of vibration. As noted in a previous report, modulus of elasticity may be computed directly from the resonant frequency of a specimen.[3] The log decrement of the defective laminates showed an average increase of 130 percent over that of the well-bonded laminates when freely supported and vibrated transversely with the plane of the glue lines normal to direction of vibration.

Transverse vibrations of the same specimens with the plane of the glue lines parallel to the direction of vibration showed no relationship between the quality of the laminates and resonant frequency, dynamic modulus of elasticity, or log decrement. No destructive testing of these laminates had been carried out to verify the results of the vibrational testing.

Experimental Testing

Testing by Ultrasonics

Statistical analysis---Eight blanks with a width of 5 1/4 in., a thickness of 2 1/4 in., and a length varying from 10 to 17 in. had been assembled to simulate the butt of gunstock A, B and C, Class 1. Four blanks of each type were assembled. The blanks are assembled in a manner to deliberately produce glue line defects which took the form of void and waxed areas

[3] Progress Report No. 1. Development . Non-destructive Tests for Laminated Gunstock Blanks. June 1 to ly 31, 1953.

and areas containing small sheets of cellophane. These blanks were tested by continuous transmission of ultrasonic energy while under water and later x-rayed./4 Raw data collected during the transmission of ultrasonic energy have been analyzed statistically to determine the variation of transmission of ultrasonic energy existing in individual blanks as well as to establish whether areas in which abnormally low shear results occurred, coincided with areas of abnormally low transmission. This analysis is presented in the following paragraphs.

An analysis of transmission data obtained from the blanks was carried out in the following manner. A standard deviation of transmission readings taken about the mean reading of the entire blank was computed. Standard deviations of the transmission readings of each level taken about the mean of each particular level were also computed. From the sum of the squares of the deviations about the mean of each level it was possible to compute a standard deviation for the data of the entire blank based on pooled variance. This was done according to the formula:

$$SD_1 = \frac{\sum \left[\sum (x)^2 \right]}{N - 7}$$

where SD_1 = standard deviation based on pooled variance.

x = deviation of an individual reading from the mean.

$\sum \left[\sum (x)^2 \right]$ = summation of the sum of the deviations squared about the mean of each particular level.

N = total number of transmission readings taken through well-bonded areas.

7 = number of levels.

/4 Details of fabrication and testing of these blanks were presented in Development of Non-Destructive Tests for Laminated Gunstock Blanks. Progress Report No. 2. August 1 to September 30, 1953.

The t-value, used as a measure of significant difference between groups of data assumed to be of the same population, was computed from the formula:

$$t = \frac{M_1 - M_2}{SD_1 \ (1/n_1 + 1/n_2)}$$

where M_1 and $M_2 =$ mean values of the two groups of data to be compared.

              SD_1 $=$ standard deviation based on pooled variance.

              n_1 and $n_2 =$ number of cases in the two groups of data to be compared.

For this analysis the groups of data to be compared correspond to the individual levels of transmission data of each blank. The following levels were compared in each blank.

1 to 2	7 to 4
1 to 3	2 to 4
1 to 4	3 to 4
7 to 6	6 to 4
7 to 5	5 to 4

Standard deviations of shear and wood failure values were computed. To correspond with these, standard deviations of ultrasonic energy transmission were also computed for each row of shear test results.[5] This value was based on a mean transmission value of each row. With standard deviations by rows it was possible to make comparisons of individual shear results and transmission values which occurred outside the normal range of variation.[6]

[5] Computations of the various standard deviations presented were based only on values of transmission through well-bonded areas.

[6] For purposes of this analysis shear or transmission values occurring outside the limits of 2.58 x SD were considered to be outside the normal range of variation.

Table 1 shows data computed on Blank No. 1, which consisted of three 3/4 x 5 1/4 x 17-in. laminations assembled with an unmodified adhesive. A comparison of the various levels shows a highly significant difference to exist between the values of levels 7 and 6, 7 and 5, and 7 and 4, at the 1 percent level./1 No other t-values computed from the data of this blank proved to be significant. In row 1 of this blank one transmission value occurred outside the normal range of variation. This was an extremely low value, but did not coincide with a low shear strength or wood failure. No transmission values occurred outside the normal range of variation in either row 2 or row 3; however, there were three values of shear strength and wood failure which did occur outside their normal range of variation. These shear tests contained intentional defects which took the form of waxed areas.

Blank No. 2 (Table 2) consisted of three 3/4 x 5 1/4 x 17-in. laminations containing edge joints. This blank was assembled with an unmodified adhesive and included glue line defects as described previously.

Values of t computed to compare the various levels of ultrasonic energy transmission showed a highly significant difference to exist between the means of levels 1 and 2, 1 and 3, 1 and 4, 7 and 6, 7 and 4, 5 and 4, 3 and 4, and 4 and 6.

An analysis of transmission results of the three rows showed six values to occur outside the normal range of variation (five values below and one value above the range). In no case did these abnormal transmission values correspond to shear strength or wood failure values occurring outside their

/1 A t-value of 2.58 or larger indicates a highly significant difference to exist between two groups of data. A t-value of 1.95 to 2.58 indicates a significant difference.

Table 1. Statistical Results of Laminated
Black Walnut Blank No. 1.

Laminated blank consisting of three laminations
3/4-in. thick and 5 3/8-in, wide without edge joints
Cascophen IT-67 (Unmodified)

Transmission Data

Mean = .76
SD   = .293 (standard deviation based on a mean of the readings of
the entire blank)

Transmission Data by Levels[1]

Level	N	SD	Mean
1	35	.116	.70
2	34	.402	.60
3	25	.342	.60
4	23	.318	.64
5	26	.306	.71
6	34	.197	.93
7	35	.171	.36

Comparison of Transmission
at Different Levels (t-values)

Levels	t-values
1 and 2	1.52
1 and 3	1.39
1 and 4	1.92
7 and 6	8.60
7 and 5	7.80
7 and 4	6.57
2 and 4	0.54
3 and 4	0.51
6 and 4	1.22
5 and 4	0.89

Transmission and Shear Data by Rows

Transmission				Shear Strength (p.s.i.)				Wood Failure (%)			
Row	N	SD	Mean	Row	N	SD	Mean	Row	N	SD	Mean
1	69	.186	.75	1	16	507	2252	1	16	11.1	95.1
2	74	.403	.85	2	16	667	1984	2	16	27.3	86.3
3	69	.318	.65	3	16	512	1624	3	16	23.3	78.7

[1] Transmission values (means and standard deviations expressed in inches)
in this and the following tables are a measure of amplitude of the
ultrasonic energy transmitted.

Table 2. Statistical Results of Laminated
Black Walnut Blank No. 2.

Laminated blank consisting of three laminations
3/4-in. thick and 5 3/8-in. wide with edge joints
Cascophen LT-67 (Unmodified)

Transmission Data

Mean = .58
SD   = .224 (standard deviation based on a mean of the readings of the
              entire blank)

Transmission Data by Levels

Level	N	SD	Mean
1	30	.202	.29
2	32	.192	.56
3	33	.167	.62
4	30	.204	.82
5	33	.122	.59
6	34	.172	.70
7	26	.227	.50

Comparison of Transmission at Different Levels (t-values)

Levels	t-values
1 and 2	5.78
1 and 3	7.13
1 and 4	11.81
7 and 6	4.18
7 and 5	1.87
7 and 4	6.51
2 and 4	1.71
3 and 4	4.32
6 and 4	2.61
5 and 4	4.97

Transmission and Shear Data by Rows

	Transmission				Shear Strength, (p.s.i.)				Wood Failure, (%)		
Row	N	SD	Mean	Row	N	SD	Mean	Row	N	SD	Mean
1	62	.234	.42	1	16	673	1802	1	16	30.8	74.1
2	96	.187	.68	2	16	462	1842	2	16	22.8	82.5
3	60	.243	.60	3	16	357	1807	3	16	24.1	77.8

normal range of variation. Four values of wood failure occurred below the
normal range of variation. Three of the four also had abnormally low
shear strengths and occurred in intentionally produced defective areas.
None of these four shear values coincided with abnormally low ultrasonic
energy transmission.

An analysis of the data obtained on Blank No. 3 is presented in
Table 3. Values of t computed to compare the various levels showed a
highly significant difference to exist between levels 1 and 2, 1 and 3, and
1 and 4. A significant difference was indicated between the means of levels
7 and 6, 7 and 5, and 3 and 4. The ultrasonic transmission results of each
row showed only a small cluster of three values in row 2 to occur outside
the normal limits of variation. This group of low transmission values was
associated with a shear strength and wood failure below the normal limit
of variation. This shear area was a void, intentionally left in the glue
line. An abnormally low shear value in row 2 proved to be a waxed area,
but did not result in an ultrasonic transmission value below the normal
limit of variation.

Data of Blank No. 4 are presented in Table 4. A highly significant
difference existed between the means of levels 1 and 4, 7 and 6, 7 and 4,
3 and 4, and 6 and 4, as was observed from t values. A significant dif-
ference existed between levels 7 and 5.

Transmission data by rows showed only two values to occur outside the
normal limits of variation. These did not coincide with abnormally low
shear results. Two abnormally low shear results did occur in this blank,
but in neither case did these coincide with low transmission values as was
indicated above. Both low-strength shear blocks proved to include portions

Table 3. Statistical Results of Laminated
Black Walnut Blank No. 3.

Laminated blank consisting of three laminations
3/4-in. thick and 5 3/4-in. wide without edge joints
Cascophen LT-67 (Modified)

Transmission Data

Mean = .56
SD = .1964 (standard deviation based on a mean of the readings of the
entire blank)

Transmission Data by Levels

Level	N	SD	Mean
1	37	.126	.40
2	39	.181	.54
3	24	.174	.67
4	23	.257	.54
5	27	.247	.62
6	37	.174	.61
7	36	.152	.52

Comparison of Transmission
at Different Levels (t-values)

Levels	t-values
1 and 2	3.30
1 and 3	5.57
1 and 4	2.84
7 and 6	2.06
7 and 5	2.13
7 and 4	0.41
2 and 4	0.00
3 and 4	2.41
6 and 4	1.42
5 and 4	1.52

Transmission and Shear Data by Rows

	Transmission			Shear Strength (p.s.i.)				Wood Failure (%)			
Row	N	SD	Mean	Row	N	SD	Mean	Row	N	SD	Mean
1	76	.169	.47	1	16	275	2058	1	16	12.2	95.0
2	74	.223	.61	2	16	697	1902	2	16	28.9	80.9
3	73	.159	.51	3	16	528	2021	3	16	5.1	97.5

Table 4. Statistical Results of Laminated
Black Walnut Blank No. 4.

Laminated blank consisting of three laminations
3/4-in. thick and 5 1/4-in. wide with edge joints.
Cascophen LT-67 (Modified)

Transmission Data

Mean = .36
SD   = .2381 (standard deviation based on a mean of the readings of
the entire blank)

Transmission Data by Levels

Level	N	SD	Mean
1	32	.121	.43
2	30	.115	.50
3	39	.187	.44
4	37	.148	.29
5	39	.142	.23
6	36	.145	.47
7	36	.186	.16

Comparison of Transmission
at Different Levels (t-values)

Levels	t-values
1 and 2	1.80
1 and 3	0.28
1 and 4	3.79
7 and 6	8.71
7 and 5	2.00
7 and 4	3.65
2 and 4	1.21
3 and 4	3.93
6 and 4	5.06
5 and 4	1.57

Transmission and Shear Data by Rows

	Transmission				Shear Strength (p.s.i.)				Wood Failure (%)		
Row	N	SD	Mean	Row	N	SD	Mean	Row	N	SD	Mean
1	62	.127	.46	1	16	525	1948	1	16	32.0	74.1
2	115	.178	.32	2	16	486	1739	2	16	22.9	82.5
3	72	.222	.31	3	16	620	1462	3	16	23.3	77.8

of intentionally produced defects. One was a waxed area and the other contained a small sheet of cellophane.

From the data obtained it appears that generally a highly significant difference existed between the means of the outermost levels of transmission values and the inner levels. Due to the large amount of scattering of the ultrasonic energy it is thought that this may be a result of reflection of the energy by the edges of the laminates. Generally no significant difference existed between the means of the levels next to the edge *levels* and the inner levels of transmission and as a rule no significant difference existed between the three inner levels of ultrasonic energy transmission. Generally there appeared to be no relationship between transmission values outside the normal range of variation and shear results outside their normal range of variation since in only one case did abnormally low values of both shear and ultrasonic energy transmission coincide. This particular area proved to be a void in the glue line, while all other non-detectable defective areas were waxed. This obviously points toward a possible use of the method at least as a detector of actual void areas in glue lines. An attempt to plot shear strength and wood failure against transmission values resulted in no correlation.

An analysis of the data obtained from Blank Nos. 5 and 6 (Table 5), both of which consisted of seven 3/4 x 2 1/4 x 12-in. laminations, showed the same general trend of a highly significant difference between the mean values of the outer levels and those of the inner levels. However, these values were more erratic than those of the construction similar to gunstock type B. This may be a result of reflection of ultrasonic energy from the principal glue lines. Since no shear tests were made of the edge joints in these two blanks, no comparison with shear results will be made. This difference

Table 5. Statistical Results of Laminated
Black Walnut Blank Nos. 5 and 6.

Laminated blanks consisting of seven laminations
3/4-in. thick and 2 1/4-in. wide with edge joints.

<u>Blank No. 5</u>
Cascophen LT-67 (Unmodified)

<u>Blank No. 6</u>
Cascophen LT-67 (Modified)

Transmission Data

Mean = .72
SD = .387 (standard deviation
based on a mean of
the readings of the
entire blank)

Mean = .47
SD = .277 (standard deviation
based on a mean of
the readings of the
entire blank)

Transmission Data by Levels

Level	N	SD	Mean
1	29	.18	.33
2	30	.26	1.12
3	18	.19	.86
4	27	.27	1.19
5	29	.21	.59
6	22	.26	.52
7	23	.21	.45

Transmission Data by Levels

Level	N	SD	Mean
1	28	.26	.29
2	18	.08	.73
3	19	.20	.43
4	24	.17	.84
5	27	.21	.30
6	23	.16	.23
7	20	.14	.44

Comparison of Transmission at Different Levels (t-values)

Levels	t-values	Levels	t-values
1 and 2	11.99	1 and 2	7.80
1 and 3	7.83	1 and 3	2.53
1 and 4	14.29	1 and 4	10.59
7 and 6	1.04	7 and 6	3.66
7 and 5	2.23	7 and 5	2.53
7 and 4	11.51	7 and 4	7.05
2 and 4	1.04	2 and 4	1.79
3 and 4	1.81	3 and 4	7.15
6 and 4	10.31	6 and 4	11.19
5 and 4	1.91	5 and 4	10.30

of means obviously limits the applicability of such a test method. However, with a different transducer design and frequency it may be possible to minimize this factor of variation.

Plans for Future Work

Plans for the immediate future call for the evaluation of a vibrational method of detecting glue line defects in laminated blanks. This will involve the determination of resonant frequency, dynamic modulus of elasticity, and log decrement of both sound and defective blanks. These blanks will have the approximate dimensions of the gunstocks to be inspected. Additional transducers of larger dimensions and higher resonant frequency have been obtained. It is planned to make a comparison of the original and the new pair of transducers by transmission of ultrasonic energy through the same blanks to determine which pair is the more efficient in locating defective areas in laminates.

An order has been placed for 250 gunstock blanks (125 of type B and 125 of type C, Class 1). These blanks will be tested by whatever non-destructive methods are deemed feasible. Later, one hundred of each type will be tested in shear and delamination to determine the correlation between non-destructive and destructive test results. The remaining 25 of each type will be forwarded to Springfield Armory for machining and service trials.

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