RESEARCH AND DEVELOPMENT REPORT

ON THE

APPLICATION OF ULTRASONICS TO THE
NON-DESTRUCTIVE TESTING OF
FIBER GLASS REINFORCED PLASTICS

Lab. Project 6188, Progress Report 4
Project No. SR007-03-04
Identification No. 18-1010-1

25 July 1961

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Materials Development Branch
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MATERIAL LABORATORY
New York Naval Shipyard
Brooklyn 1, New York

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ADMINISTRATIVE INFORMATION

Ref: (a) BUSHIPS ltr R007 03 04 Ser 643C3-1159 of 20 Jul 1960
(b) COMNAVSHIPYDNYK MATLAB Project 6188, Progress Report 3 of 5 Oct 1960
(c) Inspection Manual for Fibrous Glass Reinforced Plastic Laminates NAVSHIPS 250-346-2 Jan 1960

1. In accordance with reference (a) the Material Laboratory is conducting a research and development program to obtain non-destructive test methods for field inspection of glass reinforced plastic end products including filament wound high strength laminates.

OBJECT

2. The purpose of this project is to investigate or develop methods applicable to the non-destructive inspection of glass fiber reinforced plastic end-items leading to the evaluation of the quality of these products. The object of this progress report is to describe investigations of the feasibility of measuring laminate glass content by an ultrasonic method, and to describe the results of preliminary investigations directed toward developing techniques for correlating ultrasonic attenuation measurements with physical properties of laminates.

BACKGROUND

3. Progress Reports 1 and 2 described the results of Material Laboratory investigations of the Battelle Memorial Institutes Dielectric Tester and the Laboratory's conclusions regarding its ability to meet the non-destructive testing objectives of this program.

4. Progress Report 3 covered the exploration and development of ultrasonic techniques for thickness gaging and flaw detection. The Branson Co. Ultrasonic Flaw Detector was employed in this work as representative of instruments commercially available for this application. In Progress Report 3 it was shown that this instrument could measure laminate thicknesses in range of 1/8 to 1/2 inch with 2% accuracy. Laminate thicknesses up to 12 inches could also be gaged and explored for defects. The types of faults detected with this instrument may be classified as follows:

a. Delaminations and voids

b. Porosity and resin starvation

c. Lack of bond in adhered materials

d. Resin-inch areas (resin pockets)

5. Comparative measurements at transducer frequencies of 0.4, 1.0 and 2.25 megacycles indicated that transmission and resolution of ultrasonic signals were best at the 1.0 mc. frequency for most reinforced glass laminate materials.

METHOD

RESIN-GLASS RATIO MEASUREMENTS

6. The concept of measuring resin-glass ratio by ultrasonic techniques is predicated on the wide difference in acoustic velocity between resin and glass. The velocity of compressional waves is about 5,600 meters/sec in glass and 2,600 meters/sec in polyester resin. Thus, it might be expected that velocity measurements in laminates would bear a relationship to the relative proportion of glass and resin. Several devices were developed to measure ultrasonic wave velocity in laminates with sufficient accuracy to disclose small differences which could be evaluated in terms of glass content. Since the measurement was intended to be comparative between known and unknown samples, absolute determinations of velocity were unnecessary. If the time-base setting of the instrument remained unchanged during the measurement of a group of laminates, the relative velocities obtained should be in direct proportion to the actual velocities and could be used for determining relative glass content.

7. Relative ultrasonic velocity was obtained by pulse-echo transmission from one side of the laminate. The time required for the pulse to travel from the transducer, through the laminate thickness, and return was measured in arbitrary units. Since this traverse time is proportional to the distance between the leading edge of the "outgoing" pulse and the leading edge of the "back reflection", this distance would be proportional to traverse time. The measurement of relative traverse time was facilitated by the use of a bore-sight mounted on a worm-driven carriage. Vertical hairs installed at the front and rear of the bore-sight essentially eliminated parallax when sighting the oscilloscope trace. A calibrated scale and revolution counter geared to the carriage enabled accurate measurement of carriage travel. By successively sighting the leading edges of the two ultrasonic signals displayed on the oscilloscope screen the distance between them could be measured by measuring the bore-sight carriage travel. This measurement divided into the traversed dimension of the material yields the relative velocity. Measurements of relative velocities in the three principle directions were made on groups of laminates of similar fabrication, having various resin-glass ratios determined by destructive test.

PHYSICAL PROPERTIES MEASUREMENT

8. The possibility of estimating physical properties of laminates by ultrasonic attenuation measurements is being explored. Truell[1] and Mason[2] have found associations between acoustical losses in metals and properties such as yield strength, impact strength, and hardness. In the case of laminates the amplitude of the received ultrasonic pulse transmission or reflection is indicative of the attenuation experienced. Comparisons of similar laminates may be made on this basis and conclusions drawn regarding certain properties and the quality of the material.

9. Attenuation of sound in laminates is produced by energy losses arising from many acoustic phenomena such as dispersion, diffusion and visco-elastic damping. In laminates of similar geometry, fabrication, and history it is expected that most sources of attenuation will remain the same at a given frequency for all samples. On the other hand, structural defects which may vary from sample to sample, could also contribute to dispersion and diffusion of the wave and thus increase attenuation. Porosity and insufficient resin to glass bonding are defects which may behave this way.

10. Acoustic attenuation is a difficult quantity to measure accurately. The overall result of a measurement includes losses due to beam spread, field effects, couplant mismatch and transducers loading. In comparing similar laminates the assumption is made that these loss mechanisms remain constant and only structural differences in the laminates contribute to changes in attenuation. By employing a reference sample a convenient comparitive level of attenuation may be established. Large differences in attenuation are indicated as sizable changes in the reflected signal obtained from the far face of specimens (back reflection). Thus, "loss of back reflection tests" may be conducted on the basis of relative rather than absolute attenuation measurements.

11. After ultrasonically surveying and mapping several laminates for variations in attenuation, samples were cut representing areas of greatest difference in back reflection. These were subjected to destructive tests to obtain their physical strength properties and the results compared to the relative attenuation measurements previously obtained. If a relationship between attenuation and physical properties exists, it would be expected that samples having high relative attenuation would exhibit the poorest physical properties. The properties explored were flexural strength and modulus, and flatwise compressive modulus since these have the greatest likelihood of exhibiting relationships to the attenuation of a compressional wave traveling through a laminate.

RESULTS

12. The results of resin-glass ratio measurements made on sample laminates of various glass contents, but otherwise of similar fabrication, are shown in Table 1. The percent glass content obtained by destructive measurements are given on the basis of both volume and weight determinations. Relative sound velocities along the three principle directions of the laminates are also indicated in arbitrary units. In Table 2 the data of Table 1 are evaluated by comparisons between laminates of relatively large differences in glass content, showing these differences as percentages of the glass content of the laminates containing the least glass. A similar computation of percent differences was made with regard to the relative sound velocity data of Table 1 to determine the relationship between sound velocity and glass content for these laminates.

13. The results of correlating relative acoustic attenuation measurements made at 1 megacycle with variuous physical properties are given in Tables 3, 4 and 5. These tables are arranged in descending value of the mechanical property to facilitate the study of trends. Because of the size of the test specimen and the limited range of the testing machine, the compressive specimens were not tested to failure. It is planned to conduct such measurements at a future date using smaller specimens.

ANALYSIS AND CONCLUSIONS

14. The comparison of resin-glass ratio measurements with relative acoustic velocity, presented in Tables 1 and 2, demonstrated the following:

a. Acoustic velocity tends to be greater in laminates of higher glass content.

b. Fair correlation between relative acoustic velocity and glass content was observed for measurements in the lengthwise and crosswise directions. Correlation in the thickness direction was extremely poor. Since the thickness direction of testing would be the only practical one for field inspection work, these results are not encouraging.

c. The percent differences in acoustic velocities in lengthwise and crosswise directions are about half the percent difference in glass contents, indicating relatively poor acoustic velocity sensitivity to differences in laminate glass contents.

15. The investigation of the relationships existing between acoustic attenuation and mechanical properties are summarized as follows:

a. Variations in compressive modulus were roughly paralleled by similar variations in relative acoustic attenuation.

b. None of the other mechanical properties measured, namely, flexural strength and modulus exhibited identifiable relationship's with acoustic attenuation. However, a tendency for lower values of back reflection (high acoustic attenuation) to be associated with low values of flexural strength was noted.

DISCUSSION

16. The measurement of glass content of laminate end-products by the ultrasonic methods employed in this report does not appear to be feasible as a field inpection technique. Under favorable conditions this technique can only discriminate between relatively large differences in glass content and appears to be reliable only when the wave path is in a direction parallel to the glass fibers. Other undesirable features of this method include a need for accurate knowledge

of the distance travelled by the ultrasonic wave (traverse distance) and difficulty in interpreting the reflected signals. The desired reflected signal is usually obscured by signals reflected from the sides of the test piece, mode transformed signals, and dispersed signals created by interfaces and traverse paths differing in acoustic velocities.

17. Since laminates constitute non-homogeneous media, wide differences exist in the acoustic velocities of the materials through which the wave front travels. Filament-like paths, differing in wave velocities, tend to break up the wave front so that a series of reflected pulses of various amplitudes are received. Fortunately, the path through glass requires the shortest travel time and produces the earliest significant reflected signal. Measurements made from this signal were used for the acoustic velocity determinations of this report.

18. Acoustic velocity measurements through the thickness of the material involve wave motion along filamentary paths of continuous resin with the layers of glass cloth acting to distort and disperse the wave front. Because of the relative short traverse path, "near-field" effects are pronounced and serve to further confuse the response. The continuous resin paths in the thickness direction of the material can be exploited to provide fairly accurate thickness gaging since the acoustic velocity in this case is essentially that of the resin, and thus independent of glass content. By the same token, glass content connot be measured in the thickness direction with any worthwhile accuracy.

19. Correlation between compressive modulus and acoustic attenuation may be predicted from theoretical considerations of the nature of longitudinal wave propagation in a material. The transmission of this type of wave in a material is accomplished through elastic compression of the medium and is thus related to compressive modulus. Much remains to be done in determining how closely back reflection amplitude can be related to compressive modulus for various types of laminates, and in determining to what extent compressive modulus is indicative of strength and quality of laminates.

FUTURE WORK

20. Work plans for the immediate future include the following:

a. Continuation of investigations to correlate ultrasonic velocity and attenuation measurements with physical properties and quality of laminates. This work is planned to be extended to high strength filament wound laminates for thickness gaging, flaw detection, and to determine their quality and serviceability through acoustic velocity and attenuation measurements.

b. Initiate investigations to establish criteria for classification, acceptance, repair or rejection of defects disclosed by nondestructive tests. It is planned to conduct this work in collaboration with Naval inspectors and manufacturers.

c. Revision of the "Inspection Manual for Fibrous Glass Reinforced Plastic Laminates, NAVSHIPS 250-342-2". This will include general descriptions and applications of non-destructive test equipment investigated at the Laboratory including ultrasonic flaw detection, methods of thickness gaging, and neutron absorption techniques for measuring glass content.

d. Continued surveillance and analysis of literature on non-destructive tests and procedures for applicability to this program.

GEO. J. DASHEFSKY
Technical Director

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TABLE 1

COMPARISON OF RESIN-GLASS RATIO WITH 1MC RELATIVE ACOUSTIC VELOCITY

Laminated Samples Fabricated from 182-114 Cloth and Selectron 5003 Resin
Specific Gravity of Resin Taken as 1.22
Specific Gravity of Glass Taken as 2.57

Panel No.	No. of Plys of Glass	Laminate Thickness (Inches)	Spec. Gravity	Percent Glass		Relative Velocity (Avg. Arbitrary Units) Direction Measured		
				By Wgt.	By Vol.	Length-Wise	Cross-Wise	Thick-ness
1	16	0.235	1.80	63.1	43.0	1.34	1.34	1.33
2	16	0.192	1.94	72.6	53.4	1.44	1.48	1.39
3	22	0.336	1.77	62.4	40.7	1.32	1.36	1.48
4	22	0.257	1.94	73.6	53.3	1.44	1.46	1.59
5	25	0.296	1.92	73.5	51.9	1.44	1.49	1.65

TABLE 2

COMPARISON OF PERCENT DIFFERENCE IN GLASS CONTENT WITH PERCENT DIFFERENCE IN RELATIVE VELOCITY AMONG LAMINATES

Between Panels	Difference in Glass Content		Difference in Ultrasonic Relative Velocity Direction Measured		
	By Wgt.	By Vol.	Length-Wise	Cross-Wise	Thick-ness
	Percent Difference*				
1 and 2	15.1	24.2	7.5	10.4	4.5
3 and 4	17.9	31.0	9.1	7.4	7.4
1 and 5	16.5	20.7	7.5	11.2	24.1
3 and 5	17.8	27.5	9.1	9.6	11.5

*% Diff = $\frac{\text{Larger} - \text{Smaller}}{\text{Smaller}} \times 100$ (Values Taken from Table 1)

TABLE 3

COMPARISON OF FLATWISE COMPRESSIVE MODULUS WITH 1MC RELATIVE ACOUSTIC ATTENUATION
MATERIAL: #1044 Glass Cloth and Laminac 4128 Resin (66% glass by weight)

(Arranged in descending order of compressive modulus)

Spec. No.	Thick (Inch)	Compressive Modulus - Flatwise (PSI x 10^{-6})	Relative Height of Back Reflection
3	0.239	0.95	8.1
2	0.233	0.85	10+
1	0.234	0.64	6.8
4	0.246	0.55	6.0
5	0.251	0.41	5.0

TABLE 4

COMPARISON OF FLEXURAL STRENGTH WITH 1MC RELATIVE ACOUSTIC ATTENUATION
MATERIAL: #1044 Glass Cloth and Laminac 4128 Resin (66% glass by wgt.)
(Arranged in descending order of flexural strength)

Spec. No.	Thick (Inch)	Flexural Strength (PSI)	Relative Height of Back Reflection
2	0.237	44,400	6.5
1	0.239	42,300	2.7
4	0.243	41,800	6.0
5	0.243	41,500	5.0
6	0.245	41,400	2.5
7	0.247	41,100	5.0
3	0.240	40,600	3.0

TABLE 5

COMPARISON OF FLEXURAL MODULUS WITH 1MC RELATIVE ACOUSTIC ATTENUATION
(Arranged in descending order of flexural modulus)

Spec. No.	Thick (Inch)	Flex Mod. $\times 10^{-6}$	Relative Height of Back Reflection
7	0.243	3.11	6.0
2	0.247	3.08	5.0
5	0.239	3.08	2.7
4	0.240	3.05	3.0
8	0.243	2.95	6.5
3	0.245	2.94	2.5
6	0.237	2.93	6.5
1	0.251	2.89	6.0

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