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Supplement to REPAIR OF AIRCRAFT SANDWICH CONSTRUCTIONS

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Supplement to
REPAIR OF AIRCRAFT SANDWICH CONSTRUCTIONS^{1, 2}

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Summary

This work was undertaken in an attempt to improve the appearance and tensile strengths of repairs to sandwich-type constructions having glass-cloth reinforced facings similar to those presented in Forest Products Laboratory Report No. 1584. Methods employing room-temperature-setting resins and contact pressure resulted in repairs considered to have satisfactory tensile strength and containing no entrapped air pockets.

The repair methods involving vacuum blankets on sandwich panels with glass-cloth facings, although showing improvement on previous results, were still relatively low in strength and often contained air or gas pockets between the plies of the repair facings. On an experimental scale, this difficulty was overcome by placing the entire panel to be repaired in a rubber bag and applying vacuum pressure, but this method might be impracticable on large structures.

Repair strengths were improved by increasing the number of plies in the repair-patch facings above that of the six-ply panel facings or by increasing the width of the scarfed area. Repair efficiencies of more than 90 percent were obtained with repairs having seven-ply facings on a 2-1/2-inch scarf, or six-ply facings on a 3-inch scarf.

A core replacement without facings was acceptable when one facing of the sandwich panel was repaired at a time. A core replacement with facings was desirable if only contact pressure was being used in a one-step process in which both facings were applied and cured at the same time.

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²This report presents information supplemental to Forest Products Laboratory Report No. 1584 of the same title.

³Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

A method of repairing curved, solid, glass-cloth laminates was devised for use with room-temperature-setting resins. The repairs appeared to be satisfactory, but no strength or rain-erosion tests were conducted.

Introduction

The purpose of this study was to devise improved methods of making repairs in sandwich-type constructions having glass-cloth-reinforced plastic facings, and to evaluate, by inspection and tensile tests, the quality of the repairs developed. The work was performed mainly on flat sandwich panels with various core materials, and some supplementary work was done on curved specimens of solid glass-cloth-reinforced laminates. One type of construction used for radomes consists of glass-cloth-reinforced facings on glass-cloth honeycomb core, and a considerable portion of the work was done on this combination. The methods of repair discussed in this report are based on the assumption that both sides of the sandwich panel are accessible.

Sandwich Constructions

The three combinations of aircraft sandwich construction used for evaluating repair techniques were: glass-cloth facings on balsa core, glass-cloth facings on paper honeycomb core, and glass-cloth facings on glass-cloth honeycomb core. The panels had cores 1/4 inch thick and six-ply facings of 112-114 cloth, cross-laminated and impregnated with resin A, a high-temperature-setting, high-viscosity, contact-pressure laminating resin of the polyester type.⁴ The glass-cloth facings were impregnated with resin approximating 45 percent of the total weight of resin and glass cloth. The panels were made by wet laminating the facings, assembling the panels on a flat aluminum mold, and bag molding them under vacuum pressure at a temperature of 225° F. for one hour.

Repair Techniques

The several methods that were devised to make repairs in glass-cloth-faced sandwich panels can be classified as (1) high-temperature or (2) room-temperature methods. In either case, the assumption was made that both sides of the panels were accessible.

Preliminary Preparation of Sandwich Panels

The size of the repair area, which was oval in shape, was 2-1/2 by 8-1/2 inches and was the same for all panels (fig. 1). Preliminary preparation of the repair area consisted of cutting holes at the end of the oval

⁴-Appendix, note 1.

repair by means of a centerless hole saw in a hand brace, of sawing out the damaged area with a reciprocating-saw attachment for an electric drill, and of scarfing the area around the hole with a flexible-disk sander. The fiber sanding disks used were coated with abrasive grit No. 80.

High-temperature Methods

High-temperature procedures, summarized in table 1, required heat normally used to cure the resins in accordance with the manufacturer's instructions. In this series resin A was used and cured at a temperature of 225° F. for about 1 hour.

Method 1.--Repairs by method 1 were made on sandwich panels with glass-cloth facings on balsa and on paper honeycomb cores. After preliminary preparation of the repair panels, core replacements or plugs were cut to the correct size and shape and fitted carefully into place. These core plugs consisted of sandwich panels with two-ply glass-cloth facings on balsa and on paper honeycomb cores. The facings were sanded with coarse sandpaper or emery cloth to provide a clean roughened surface. Patches for the facings were made with six plies, the same number as used in the original facings. Glass cloth was impregnated with 55 to 60 percent of resin A and stretched out smoothly on a sheet of colored cellophane. A second sheet of cellophane was placed on top of the glass cloth to facilitate handling. The outlines of the various plies of the patch were scribed on the cellophane and cut out with a scissors. The first ply was large enough to cover the core plug and to lap the scarfed facing about 1/2 inch around the entire repair area. Each successive ply was progressively larger, with the final ply covering the 2-inch scarf,

With the core plug in place, resin A was brushed on the core plug and on the scarfed area of the panel. After removing the cellophane from one side of the smallest ply of the patch it was centered on the repair area. The cellophane was then removed from the other side of the first ply and the wrinkles and air bubbles were worked out. The resin that adhered to the cellophane reduced the resin content of the impregnated glass cloth approximately 10 percent. The second and successive plies were laid in the same manner until the patch was completed. The entire repair area was covered with cellophane, which was trimmed about 1 to 2 inches beyond the repair and over which an electrically heated, cloth-surfaced, vacuum blanket was taped. The same procedure was followed to repair the other facing. A vacuum was drawn on the two blankets, and the temperature of each was raised gradually to 225° F. and maintained there constantly for 1 hour.

Method 2.--Method 2 was also carried out on sandwich panels of glass-cloth facings on balsa and on paper honeycomb cores. It differed from method 1 in that seven-ply repair facings were used instead of six-ply facings. All other details were the same.

Method 3.--Method 3 followed the same general procedure as method 1, but the number of plies in the facing repair was increased from six plies to eight plies and the scarf was increased from 2 inches to 2-1/2 inches wide.

Method 4.--The sandwich construction used for method 4 consisted of glass-cloth facings on balsa core. The details of this method were similar to those of method 1, but the method incorporated a 2-1/2-inch scarf with a seven-ply repair patch. The entire panel was placed in a rubber bag, as in normal bag-molding procedures, and the repair was cured under vacuum pressure in an air-circulating oven at a temperature of 225° F. for 1 hour.

Room-temperature Methods

Repairs made with vacuum blankets at high temperatures were not reliable because expanded air or gas often was trapped between the plies of the repair patch. In an attempt to eliminate this, room-temperature-setting resins were tried under positive pressure or under contact pressure only. There are several promoters or accelerators available that can be used in conjunction with various catalysts to produce cure of a polyester resin at room temperature or with the application of very little heat. In order to obtain a longer pot life of these resins the amount of accelerator recommended by the manufacturer was reduced. Because of the uncertainty of the degree of cure with the reduced amount of accelerator, the repairs were given a final cure in an oven or under a bank of heat lamps. The details of repair methods employing room-temperature cure are described in the following paragraphs and are summarized in table 1,

Method 5.--The damaged areas of two sandwich panels with six-ply glass-cloth facings on 1/4-inch balsa or paper honeycomb cores were prepared in method 5 as referred to under Preliminary Preparation of Panels. Oval core plugs 2-1/2 by 8-1/2 inches consisting of two-ply glass-cloth facings on a balsa or a paper honeycomb core were fitted into place in their respective panels and the facings were roughened with coarse sandpaper or emery cloth. The repair patches for the facings were composed of seven plies impregnated with the low-viscosity, contact-pressure polyester resin B² mixed with 1.6 percent benzoyl peroxide catalyst and 3.0 percent promoter. The oval-shaped glass-cloth plies were prepared in the same manner as discussed under method 1, except that the room-temperature-setting resin B was used in place of resin A. Resin was applied to the core plug and the scarfed area of the repair panel. The first ply covered the core plug and 1/2 inch of the scarfed area on all sides. Each successive ply was progressively larger, and the final ply covered a 2-1/2-inch scarf. After the final ply was laid down and the wrinkles were removed, a piece of cellophane was placed over the whole patch and some of the air in the repair patch was worked out with a hardwood squeegee. Both facings were repaired in this manner, and the sandwich panel was placed in a rubber bag and cured under positive air pressure (14 pounds per square inch) overnight at a temperature of 100° F. To insure a complete cure, the repair panel was given an additional cure of 1 hour at 225° F. in a circulating oven.

Method 6.--The sandwich construction for method 6 consisted of six-ply glass-cloth facings on 1/4-inch glass-cloth honeycomb core. As in method 5,

²Appendix, note 2.

a seven-ply repair patch impregnated with resin B mixed with a room-temperature promoter was used on a 2-1/2-inch scarf. After the repair patch was laid up and covered with cellophane, it was cured at room temperature without pressure for a minimum of 16 hours. This initial cure was followed by a final cure for 2 hours under a bank of heat lamps producing a temperature of about 175° F. on the exposed surface of the panel.

Method 7.--With use of glass-cloth facings on glass-cloth honeycomb sandwich construction, the same procedure was followed in method 7 as was described under method 5, except that a core plug without facings was employed and the initial cure of the repair patch was made at room temperature without pressure. The core plug without facings was employed in an attempt to minimize the variation in thickness of the facings.

Method 8.--Method 8 differed from method 5 in several respects. The procedure involved a two-step instead of a one-step repair on a sandwich panel of glass-cloth facings on glass-cloth honeycomb core. The two-step repair consisted of fabricating and curing one facing (with the core plug in place) before starting the second facing. The core plug was composed of only the core material. The resin used for this repair was a low-viscosity, contact-pressure laminating resin C,⁶ formulated for curing at room temperature with 22 parts of styrene, 1.2 parts of 1-hydroxycyclohexyl hydroperoxide-1, and 3 parts of an accelerator. The initial cure was at room temperature with contact pressure overnight, and was followed by a final cure at a temperature of 225° F. for 1 hour in an oven.

Method 9.--In method 9 the damaged area of a sandwich panel of glass-cloth facings on glass-cloth honeycomb core was sanded to produce a 3-inch scarf. A core plug consisting of a sandwich panel with single-ply facings was fitted in place. The repair patches for the facings were prepared and fabricated as discussed under method 5, except that resin C, mixed with 22 parts styrene, 1.2 parts 1-hydroxycyclohexyl hydroperoxide-1, and 1.5 parts of a room-temperature-setting accelerator, was used. The number of plies in the repair was also reduced to six. The resin had an initial set within 16 hours at room temperature and was given a final cure in an oven at a temperature of 225° F. for 1 hour.

Minor Repairs to Solid Laminates

Erosion of the plastic parts in frontal areas of high-speed aircraft by rain has caused serious trouble with glass-cloth-reinforced laminates. The erosion of these parts varies from shallow pits of very small diameter to large eroded areas that penetrate several plies of the laminate. Methods of repair for these parts, which would be equally applicable to similar defects of glass-cloth-laminate facings of sandwich parts, were explored. These eroded areas of typical-sample test pieces were sanded with a small

⁶Appendix, note 3.

emery disk or a small emery stone to provide a clean surface having beveled edges. The resin used for repair was resin B compounded with 3 percent of a room-temperature-setting promoter.

For the small holes, some of the room-temperature-setting resin was mixed with 15 to 20 percent of chopped glass fibers and the mixture was worked in the holes carefully to eliminate as many small air bubbles as possible, and it was then covered with cellophane to prevent contact of the resin with the atmosphere. After an overnight cure at room temperature, the cellophane was removed and the surface was sanded smooth. Usually an excess of the mixture of resin and glass fibers was used to allow for shrinkage and sanding.

The larger beveled repair areas were also repaired with the room-temperature-setting resin. Patches of 112-114 glass cloth were cut to the shape of the repair area. The number of plies required depended upon the depth of the repair. As in the repairs to sandwich facings, the first ply was the smallest and the size of each successive ply increased in accordance with the slope of the beveled surface. The repair area was coated with the room-temperature-setting resin, and the first ply of dry cloth was laid in place and brushed with additional resin. The successive plies were treated in the same manner. In irregular places where the glass cloth did not fill in properly, resin mixed with chopped glass fibers was added. After the repair was built up to the proper level, it was covered with cellophane and the air was worked out with a hardwood squeegee. Curing and finishing were done as described for the small pits.

Test Method

Three longitudinal-tension specimens were taken across the repair area, and three control tension specimens were cut from outside the repair area, as shown in figure 1. The tension specimens were 1-1/2 by 16 inches with the center portion tapered to 1 inch wide to reduce concentration of stresses near the grips. In order to prevent crushing of the ends held by the grips of the testing machine, the core was sawed out and a hard-maple block was inserted between the facings.

No tests were made to determine the efficiency of the repairs made on the solid glass-cloth laminates.

Results and Discussion

The results of the longitudinal-tension tests for the various repair methods discussed are summarized in table 2. Methods 1 to 3, inclusive, involving the heated vacuum blankets for obtaining curing temperatures and pressure, produced results that were erratic, partially because of the varying amounts of air that were being drawn from the core through the facings during the cure. An attempt was made to cut the test specimens from the

unblistered portions of the repairs. The methods of repair involving the placement of the entire panel in a rubber bag (method 4) produced a better appearance because there were fewer air or gas pockets in the facings. Pressure was not always necessary in making a satisfactory repair as is shown by methods 6 to 9, which utilized room-temperature-setting resins. A number of repairs were made under contact pressure only, but if heat was applied before the resin was initially set, the contact pressure was insufficient to prevent gas pockets from forming between the plies of cloth. After the initial set, heat only was applied without any visible harmful effect.

The amount of promoter or accelerator and the working temperature had considerable effect on the working life of the resin. In one case the amount of accelerator recommended by the manufacturer reduced the pot life of the resin at room temperature to such an extent that it was impractical for repair use. With a little experience it would be possible, however, to determine the amount of accelerator required for a certain temperature range.

From previous tests, reported in Forest Products Laboratory Report No. 1584, "Repair of Aircraft Sandwich Constructions," the maximum repair efficiency that was obtained from sandwich panels with glass-cloth facings was 89.6 percent. The average efficiency was about 61 percent. These repairs were composed of six plies (in panel facings of six plies) on a 2-inch scarf, with the first ply being the same size as the repair plug. Method 1, which also consisted of a six-ply repair on a 2-inch scarf, but with the first ply being 1/2 inch larger than the core plug on all sides, gave an average repair efficiency of approximately 76 percent. In method 2 the number of plies in the repair was increased to seven and the repair efficiency was increased to about 85 percent. It was observed that the major portion of failures in these two methods was in shear along the scarf. To overcome this difficulty the scarfed area was increased to 2-1/2 inches. Method 3 utilized the 2-1/2-inch scarf and an eight-ply repair. This combination resulted in an average repair efficiency of about 100 percent, and also produced a majority of tension failures in the facing material. In other repairs (methods 4 to 8, inclusive), a seven-ply repair was used on a 2-1/2-inch scarf, and repair efficiencies of 91.8 percent and higher were obtained. The repair efficiency of method 9, in which the number of plies in the repair was reduced to six and the scarfed area was increased to a 3-inch width, was 95.8 percent. This last method is more desirable for radome construction, since it is desirable that the facings and core thicknesses remain unchanged.

Core plugs of two constructions were used in the repairs. One type consisted of the core material that was used originally in the sandwich panel, and the other was similar but with facings of one or two plies of glass cloth. A core plug without facings was satisfactory for the two-step process where one facing was fabricated and cured at a time (method 8). It might also be applicable when positive pressure is used, as in method 5. When, however, a one-step process with room-temperature-setting resins was used on a core plug without facings (method 7), the air included in the core when the second facing was started, made it difficult to keep the opposite facing from separating from the core. This difficulty was eliminated when a core plug with facings was used.

10. No strength tests were conducted on the repairs made on the solid and glass-cloth laminates. Visually, the repairs appeared satisfactory. One difficulty experienced in this type of repair was the elimination of small air bubbles from the mixture of resin and chopped glass fibers. The fibers made the mixture so viscous that the air bubbles would not rise to the surface on standing; and, therefore, the mixture had to be applied gradually so that the air could be worked out.

Appendix

Note 1. Resin A - A high-temperature-setting, high-viscosity, contact-pressure laminating resin of the polyester (diallyl phthalate-alkyd) type.

Note 2. Resin B - A high-temperature-setting, low-viscosity, contact-pressure laminating resin of the polyester (styrene-alkyd) type.

Note 3. Resin C - A high-temperature-setting, low-viscosity, contact-pressure laminating resin of the polyester (styrene-alkyd) type.

Table 1.--Summary of details of repair methods

Method No.	Temperature during curing	Length of scarf	Number of plies in repair	Number of steps in repair	Pressure application	Construction of core replacement or plug	Resin ¹ used for repair
	° F.	Inches					
1	225	2	6	1	Vacuum	Sandwich panel with Resin A blankets: 2-ply facings	
2	225	2	7	1	do.	do.	Do.
3	225	2-1/2	8	1	do.	do.	Do.
4	225	2-1/2	7	1	Vacuum bag	do.	Do.
5	100	2-1/2	7	1	14 p.s.i. in bag	do.	Resin B plus room-temperature promoter
6	Room temperature	2-1/2	7	1	Contact	do.	Do.
7	do.	2-1/2	7	1	do.	Core without facing	Do.
8	do.	2-1/2	7	2	do.	do.	Resin C plus room-temperature accelerator (E)
9	do.	3	6	1	do.	Sandwich panel with 1-ply facings	Do.

¹See Appendix for description of resins.

Table 2.--Tensile strength of repairs in sandwich panels having glass-cloth facings¹

Core	Repair : method	Controls ² : Average : longitudinal : tensile : strength	Repair : Average : longitudinal : tensile : strength	Repair : Number : and : type of : failure	Repair : efficiency
		Pounds	Pounds		Percent
Balsa	1	1,435	1,063	(1-tension : (2-shear	74.1
Paper honeycomb	1	1,296	1,016	(1-tension : (2-shear	78.4
Balsa	2	1,469	1,232	3-shear	84.0
Paper honeycomb	2	1,295	1,121	(1-tension : (2-shear	86.8
Balsa	3	1,233	1,270	3-tension	103.0
Paper honeycomb	3	1,238	1,200	(2-tension : (1-shear	96.9
Balsa	4	1,263	1,250	(2-tension : (1-shear	99.0
Balsa	5	1,367	1,313	(2-tension : (1-shear	96.1
Paper honeycomb	5	1,240	1,173	3-tension	94.6
Glass-cloth honeycomb	6	1,210	1,110	(2-tension : (1-shear	91.8
Glass-cloth honeycomb	7	1,220	1,250	3-tension	102.4
Glass-cloth honeycomb	8	1,206	1,141	(2-tension : (1-shear	94.6
Glass-cloth honeycomb	9	1,238	1,185	3-tension	95.8

¹Facings consisted of six plies of 112-114 glass cloth, cross-laminated.
Cores were 1/4 inch thick.

²All control specimens failed in tension.

Figure 1.--Cutting diagram for test panels with glass-cloth facings, showing location and shape of repair area and tension specimens.

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