EPOXY/GLASS SYSTEMS FOR SAILPLANE CONSTRUCTION

Steve Bowen
Evansville, Indiana, U.S.A.

INTRODUCTION

This short paper summarizes work directed toward evaluation of epoxy/glass composite systems, suitable for sailplane construction. The object of this project is to provide designers with reliable data, based on systems employing domestic materials and hand lay-up techniques with a room temperature cure.

The mechanical properties of simple composite structures of epoxy resin reinforced with glass fiber, depend upon the proper selection of both glass and resin, and also depend upon the chosen method of fabrication. Fabrication of large components, such as glider wings, generally requires hand lay-up techniques and room temperature cure. All data was obtained from samples prepared by hand lay-up and cured at room temperature (20-30°C).

DISCUSSION

A series of epoxy resin formulations have been evaluated with various types of glass reinforcement. Data has been tabulated which can be useful in sailplane design.

A summary of the resin work to date is presented. Additional work is continuing, although it is primarily concerned with unique diluents possessing multifunctionality. Future reports will be made in this area if useful data is derived from the study.

Glass evaluation has been restricted to approximately twenty-five types of roving and one type of woven fabric (style 181). Proper reinforcement selection is very important if high values are to be achieved. Modulus of elasticity in flexure, for example, can increase by > 80% by substituting one roving for another in a given resin system (the percent glass by weight remaining constant).

Hand lay-up fabrication techniques do not optimize conditions for close control of glass and resin content in the composite structure. Mechanical properties of the laminate are dependent upon the glass content; therefore, the percentage of glass in the system must be closely controlled to insure that property values do not deviate unnecessarily. Proper procedure, however, can consistently produce laminates with glass contents of 80% ± 0.25%.(1) Data are presented for several glass roving systems and several systems with style 181 glass fabric.

RESIN

The selection of the proper matrix is, perhaps, the most difficult aspect of developing a composite system. The matrix (or resin) consists of the epoxy resin and its hardener (coreactant), and may also include diluents and other modifiers. Significant parameters for evaluating the matrix include pot life, viscosity at room temperature (R.T.), elongation, heat distortion temperature, cost, availablity, health hazard, etc.

The epoxy resins used in this evaluation were the diglycidyl ether of biphenol A (DEGBA) type liquid resins which are available under a variety of trade names and are commonly referred to as "epoxies." Typical of this type of epoxy is:

---

(1) A good general reference for laying up rovings is Technical Report No. TC/TOS/RT/70/1, titled "Recommended Techniques for Handling Type 30 Rovings," Owens-Corning Fiberglas Co.

Shell	Epon	815 820 826 828
CIBA	Araldite	502 6004 6005 6006
Dow	DER	330 331 334
Union Carbide	ERL ERL	2772 2774

Much of the evaluation for unidirectional composites was based on resin systems using Shell's Epon 826 epoxy resin.

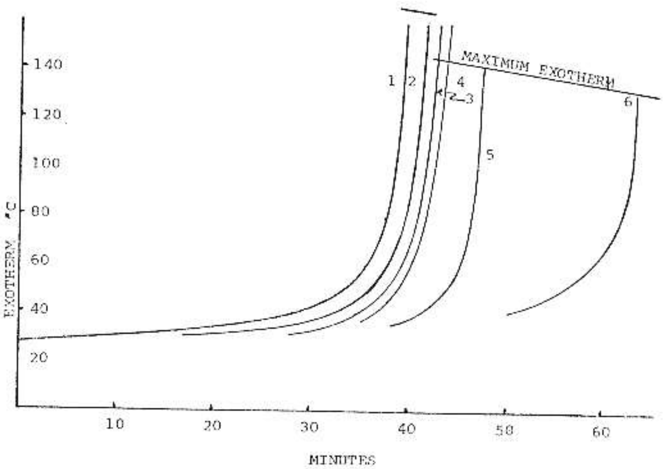
The hardener used in most studies was Triethylenetetramine (TETA). This hardener provides very good mechanical properties in the cured laminate. The primary objection to the use of TETA as a hardener for hand lay-up is that the system cures or hardens too quickly. This fact in itself is not objectionable, perhaps even desirable; however, the time available to "work" with the laminate before noticeable hardening of the system occurs is so limited that the resin often begins to harden before the lay-up is completed. A formulation has been developed that substantially lengthens the "pot life" of a TETA cured resin system, effectively overcoming this objectionable quality.

Several diluents have been evaluated as modifiers for the Epon 826 epoxy resin. These diluents lower the viscosity of the resin and, in some instances, lengthen the pot life of TETA cured systems. Very low viscosity resins are desirable because higher percentages of glass reinforcement can be impregnated with them.

The selective use of silane additives to the resin can also modify the properties of the cured laminate, as well as effect the pot life of the resin. Concentrations of 1% silane are shown to be effective. Many silanes accelerate the rate of cure of epoxy systems; however, at least one alicyclic epoxyalkylsilane ester will inhibit the rate of cure and simultaneously enhance other system properties.

Figure 1 shows the effect of silane concentration on the pot life of an 826/BGE/TETA system. Note that A-1100 accelerates the rate of reaction, while A-186 inhibits it (various silanes differ in chemical composition and also differ in their effect, if any, upon an epoxy system).

FIGURE 1



1. 1.0 gamma-aminopropytriethyoxysilane*
2. 0.5 gamma-aminopropyltriethoxysilane
3. CONTROL no silane
4. 0.5 beta-(3,4-epoxycyclohexyl) ethlytrimethoxysilane**
5. 1.0 A-186
6. 2.0 A-186

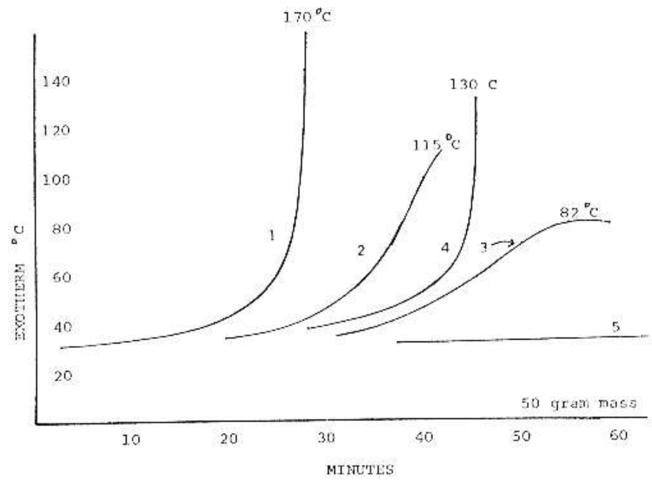
* Union Carbide, A-1100 silane
** Union Carbide, A-186 silane

Figure 2 gives the pot life of several selected systems.

Figure 3 illustrates the pot life as a function of TETA concentration. Although long pot life is desirable, mechanical properties and heat distortion temperature decrease with decreasing concentration of TETA. To insure optimum properties, it is suggested that the TETA concentration be strictly held to 12-13 phr (parts per hundred resin - or diluted resin).

Figure 4 gives selected property values for laminates with A-186 added to the resin. It is interesting to note that the mechanical property values of laminates

FIGURE 2



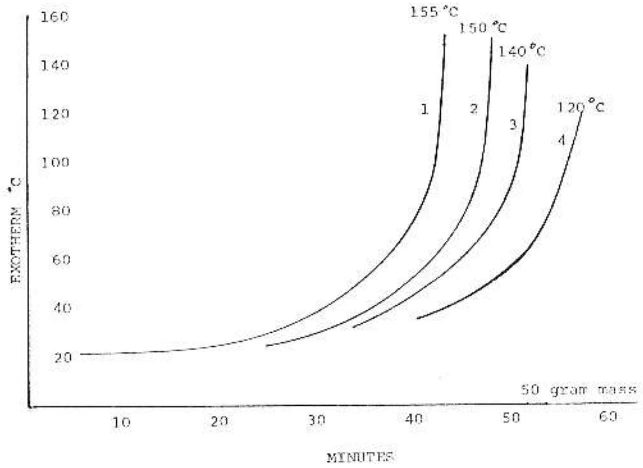
1. Epon 826 (100) TETA (12.5)
2. Ciba LY554
3. Epon 826 (100) Genamide 2000 (34)*
4. Epon 826 (90) BGE (9.0) A-186 (1) TETA (12.5)
5. Epikote 162 (100)** Laromin 260 (38)***

* General Mills Chemicals

** Shell Chemical (sold only in Europe)

*** BASF Corporation

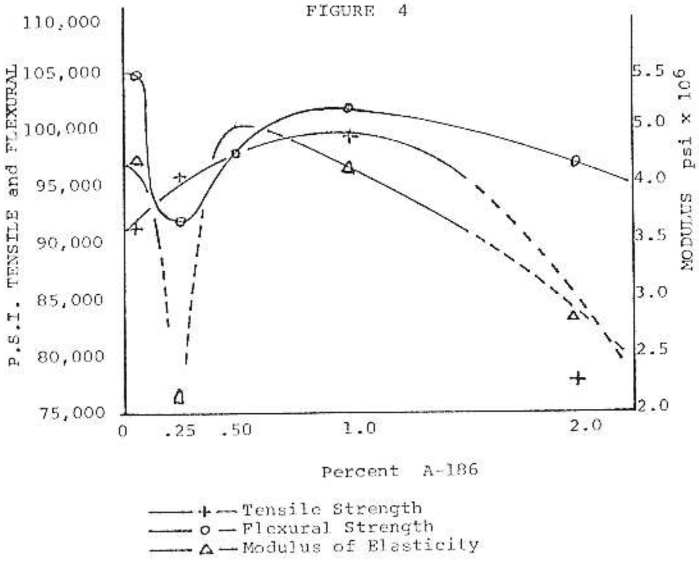
FIGURE 3



1. Epon 826 (90) BGE (9.0) A-186 (0.5) TETA (13 phr)
2. Epon 826 (90) BGE (9.0) A-186 (0.5) TETA (12 phr)
3. Epon 826 (90) BGE (9.0) A-186 (0.5) TETA (11 phr)
4. Epon 826 (90) BGE (9.0) A-186 (0.5) TETA (10 phr)

Epon 826	Shell Chemical Company
BGE	Butyl glycidyl ether
A-186	Silane, Union Carbide Corporation
TETA	Triethylenetetramine

FIGURE 4



CURE CONDITIONS	room temperature for 7 days atmospheric pressure
REINFORCEMENT	830 X8 225 Roving (Owens Corning Fiberglas) 65-70% glass content, by weight
LAY-UP PROCEDURE	-wet out mold with resin -apply layer of roving -work resin into glass -apply additional resin as necessary -repeat, until desired thickness is attained -work out any air bubbles and excess resin
RESIN	Epon 826 (90), BGE (9.0), TETA (12.5)

with 1.0% A-186 added exceed the values of the same system without silane. It appears that the initial silane addition acts as an impurity in the system and actually reduces the property values. Increasing the silane concentration above 0.25% progressively improves the mechanical property values until they seem to reach a maximum near 1.0% silane. At 1.0% A-186 addition most properties are improved and also a longer pot life is achieved.

The effect of butyl glycidyl ether on pot life is shown in Fig. 5a. Figures 5b, 5c, 5d give property values for several resin formulations. These samples were simply prepared by saturating rovings with resin and squeezing out as much excess resin as possible. Glass content was held to 65% ± 5, with OCF 830 X8 225 roving.

FIGURE 5-A

POT LIFE
(MINUTES)

TRIETHYLENETETRAMINE \ BUTYL GLYCIDYL ETHER	10	9	8	7	6	5	4	3	2	1	0
14											
13	56	54	52	50	49	47					
12	60	58	56	54	53	52	48	45	42	39	36
11	88	78	67	62	58	56	53	50			
10	110	90	77	69	64	60	57	54	51	48	46
DGEBA RESIN (EPON 826)	90	91	92	93	94	95	96	97	98	99	100

1.0% beta-(3,4-Epoxycyclohexyl) ethlytrimethoxysilane (A-186)

Pot life based on 50 gram samples

FIGURE 5-B

MODULUS OF ELASTICITY
(p.s.i. X 10^6)

TRIETHYLENETETRAMINE \ BUTYL GLYCIDYL ETHER	10	9	8	7	6	5	4	3	2	1	0
14											
13	3.2						3.3				
12	3.7	3.8	3.4	3.9	3.2	3.4	2.8	3.6	2.6		
11	3.7						3.1				
10	2.3						3.6				
DGEBA RESIN (EPON 826)	90	91	92	93	94	95	96	97	98	99	100

1.0% beta-(3,4-epoxycyclohexyl) ethlytrimethoxysilane (A-186) added to all formulations

CURE CONDITIONS	room temperature for 7 days atmospheric pressure
REINFORCEMENT	830 X8 225 glass roving (OCF) 65-70% glass content, by weight
LAY-UP PROCEDURE	-wet out mold surface with resin -apply layer of roving -work resin into glass -apply additional resin as necessary -repeat, to attain desired thickness -work out excess resin and air bubbles

Lay-up samples measured 1/8" x 1/2" x 40"

FIGURE 5-C

TENSILE STRENGTH
(p.s.i. X 10^5)

TRIETHYLENETETRAMINE \ BUTYL GLYCIDYL ETHER	10	9	8	7	6	5	4	3	2	1	0
14											
13	.91						.81				
12	.95	1.0	.89	.90	.89	.67	.98	.70	.86		
11	.96						.92				
10	.85						.77				
DGEBA RESIN (EPON 826)	90	91	92	93	94	95	96	97	98	99	100

1.0% beta-(3,4-epoxycyclohexyl) ethyltrimethoxysilane (A-186) added to all formulations

CURE CONDITIONS	room temperature for 7 days atmospheric pressure
REINFORCEMENT	830 X8 225 glass roving (OCF) 65-70% glass content, by weight
LAY-UP PROCEDURE	-wet out mold surface with resin -apply layer of roving -work resin into glass -apply additional resin as necessary -repeat, to attain desired thickness -work out excess resin and air bubbles Lay-up samples measured 1/8" x 1/2" x 40"

FIGURE 5-D

FLEXURAL STRENGTH

(p.s.i. x 10^5)

TRIETHYLENETERAMINE	10	9	8	7	6	5	4	3	2	1	0
14											
13	.92						1.0				
12	1.1	1.1	.98	1.1	.99	.98	.98	1.0	.81		
11	.96						.92				
10	.68						.77				
	90	91	92	93	94	95	96	97	98	99	100

DGEBA RESIN (EPON 826)

1.0% beta-(3,4-epoxycyclohexyl) ethyltrimethoxysilane (A-186) added to all formulations

CURE CONDITIONS	room temperature for 7 days atmospheric pressure
REINFORCEMENT	830 X8 225 glass roving (OCF) 65-70% glass content, by weight
LAY-UP PROCEDURE	-wet out mold surface with resin -apply layer of roving -work resin into glass -apply additional resin as necessary -repeat, to attain desired thickness -work out excess resin and air bubbles Lay-up samples measured 1/8" x 1/2" x 40"

REINFORCEMENT

The selection of glass for a given resin system requires the hand lay-up of potentially good glasses and the subsequent testing of samples for mechanical values. Specimens in this study were tested for tensile strength, flexural strength, and modulus of elasticity. The majority of the evaluation was directed toward producing a superior unidirectional material, suitable for wing spar construction. The results of tests on unidirectional laminates is presented in Fig. 6.

A more limited amount of data has been generated using woven fabric reinforcement. This data is presented in Fig. 7.

Results of tests on graphite reinforced laminates is also progressing. Results to date are most encouraging. A separate report on this study will be made available in early 1971.

FABRICATION

Woven Glass Fabric--Epoxy

The reinforcement of epoxy resin with woven glass fabric by hand lay-up techniques is quite simple. The resin is blended with the hardener and/or other additives and the mixture is applied to the core of the mold surface. A layer of glass fabric is applied and squeezed or brushed to work the resin up through the fabric. Additional resin is often added to the top surface to get complete "wet out" of the fabric. Additional plies of fabrics are added in the same manner until the desired thickness is achieved. Great care should be taken to remove all entrapped air bubbles.

FIGURE 6

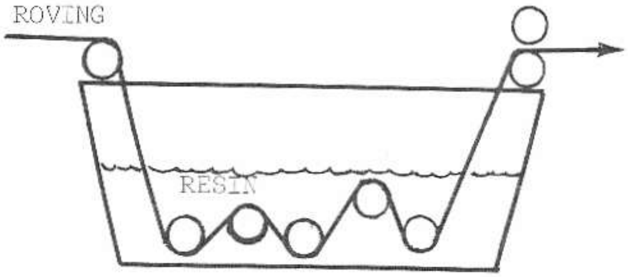
SAMPLE NO.	158	156	153	157	154
RESIN	Laromin 260 (38) Epikote 162 (100)	Epon 826 (90) BGE (9) A-186 (1) TETA (12.5)	Epon 826 (90) BGE (9) A-186 (1) TETA (12.5)	Epon 826 (90) BGE (9) A-186 (1) TETA (12.5)	Epon 826 (90) BGE (9) A-186 (1) TETA (12.5)
GLASS	OCF 836	OCF 836	OCF 830	OCF 830	OCF 830
% GLASS	70	70	73	80	91
MECHANICAL PROPERTIES					
TENSILE STRENGTH, psi	93,000	103,229	99,000	110,722	98,200
FLEXURAL STRENGTH, psi	89,933	124,000	106,333	115,000	112,900
MODULUS OF ELASTICITY, psi x 10^6	3.48	4.76	3.9	4.75	5.3

FIGURE 7

LAMINATE NO.	GLASS %	TENSILE	FLEX. STR.	FLEX. MOD.	IMP. STR. FT-LB/IN.	HDT @264 PSI	THICKNESS	POT LIFE
L101	42.3	36,264	46.5×10^3	2.55×10^6 (ave. 3)	12.1 (ave.)	>470°F	0.091	30-40 min.
L102	40.0	35,309	48.0×10^3	2.46×10^6	12.4 (ave.)	>490°F	0.087	30-40 min.
L103	42.2	34,650	34.0×10^3	1.6×10^6	16.3	>510°F	0.092	3-4 hr
L104	52.3	32,609	43.0×10^3	2.05×10^6	11.2	>490°F	0.097	30-40 min.
L105	59.3	35,139	54.0×10^3	2.15×10^6	10.1	>400°F		30 min.
L106	61.8	35,600	38.0×10^3	1.9×10^6	11.1	>400°F		3 hr

Unidirectional Roving

The highest mechanical strengths for plastic materials can be achieved in unidirectional laminates of glass roving and epoxy resin. Laminates of up to 90% glass by weight can be achieved with refined fabrication procedures. Important considerations in the lay-up of rovings include proper wet out of the fibers, proper alignment of the fibers and precise control of the amount of resin added to the roving. These requirements can best be satisfied by the use of an impregnation bath similar to the one illustrated below.



It is important to achieve complete "wet out" of the glass and remove any excess resin. Care should be taken to keep glass free of contamination prior to use. Also avoid small radius bends (< 1/4 in.) in the roving during any handling procedure.