PRELIMINARY TEST RESULTS FOR A TYPE-TRIAL REPAIR ON AIR CANADA AIRBUS AIRCRAFT FLEET

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ABSTRACT

Passenger aircraft manufacturers are incorporating more composites components in their aircraft. Routine repair of these components for the airline plays a significant role in time and costs as part of these aircraft's maintenance. Air Canada is undertaking a series of type-trials to study the benefits of using electron-beam processing of composite components for routine on- and off-aircraft repair. The first component to be type-trialed will be the fairing from an Airbus A320 aircraft. The proposed type-trial will place an EB-cured component on an operational aircraft for 18 to 24 months. In this paper the preliminary test results before actual placing the component on the aircraft are presented comparing the present thermal-cured repair process with the proposed EB-curing process. These results indicate that the EB-cured repair should perform as well or better than the present thermal-cure process.

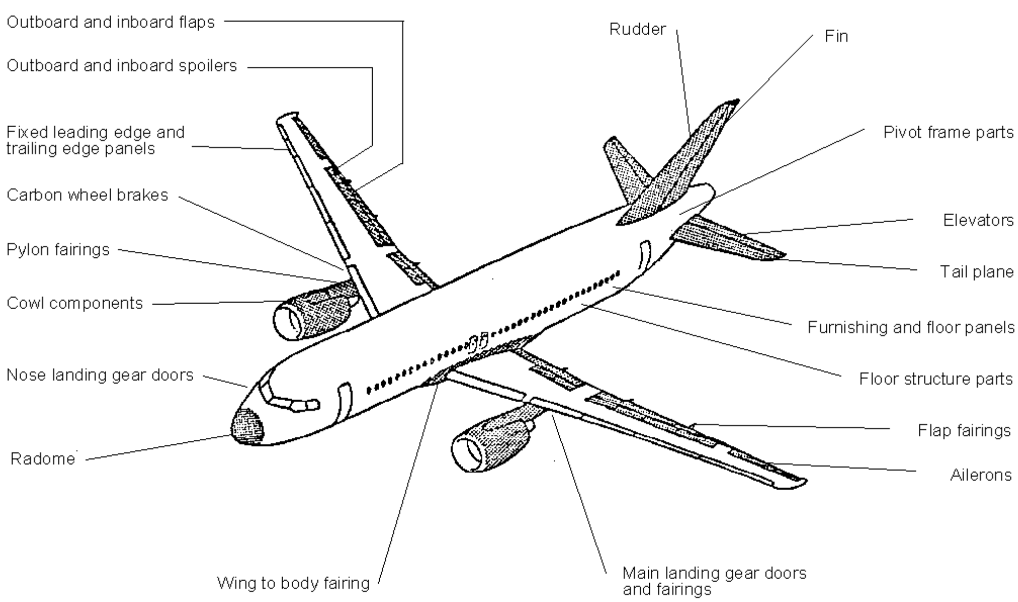
KEY WORDS: Electron Beam Repair, Air Canada, Airbus passenger aircraft

1. INTRODUCTION

Because aircraft manufacturers are incorporating more composite components as part of their aircraft, repair of these components using timely and cost-saving techniques is very important. The traditional thermal-curing repair method is very costly because of the time the aircraft is out of service due to hand lay-up and curing processes. Any method which would reduce the service time of the repair would be beneficial. EB processing for repair of composites parts as a routine system is considered economically viable. The EB process for repair offers a number of advantages, such as the rapid cure cycle (minutes compared to hours), curing at ambient temperature, and the possibility of curing repaired parts on the aircraft without loss of properties (1).

The Air Canada Winnipeg Maintenance Base is responsible for routine maintenance and repair of its Airbus A319 and A320 fleet as well as contract maintenance for other airlines. The Air Canada Airbus fleet is made up of A319, A320, and A340 aircraft. Composites made from fiberglass, graphite and aramid fibers make up approximately 20 - 25% of the aircraft's structural weight. Figure 1 shows the composite components on the Airbus A320 aircraft. Damage to these composite structures comes in many forms due to a number of different causes such as lightning strikes, bird strikes, foreign object damage and environmental causes.

Figure 1. Composite Components on A320 Aircraft



Air Canada plans to perform a number of repair type-trials on various composite components. These type-trials will evaluate the feasibility and economics of EB processing for repair. For the first type-trial, a fairing of a A320 aircraft will be repair tested. This particular component, constructed of fiberglass and a thermal-cured epoxy resin, is located at the lower rear of the aircraft fuselage, just aft of the wing. This particular component was chosen because its function and location expose the structure to severe environmental and aircraft handling situations. It is also a secondary structural component. The component receives the most damage and abuse from many sources. Damage is primarily caused from baggage loading equipment and objects being thrown up by the aircraft's wheels. The damage usually consists of a puncture in the range of 4 to 15 cm in diameter, resulting in the replacement of the outer and inner skin as well as the honeycomb core. The component also sees considerable amounts of various fluids, such as oils, hydraulic fluid, and water.

Before an EB-cured repaired component can be placed on operational aircraft, a number of preliminary tests have been undertaken to determine the feasibility of the process. This report compares the test results for the present thermal-cure repair process with the proposed EB-cured process.

2. RESULTS AND DISCUSSION

There have been several studies looking at electron and x-ray curing for composite repair (1, 2). A extensive study for the Canadian Defence Research Establishment Pacific showed that electron beam processing repair of composites was possible (1). This study looked at military aircraft repair under battlefield conditions using a mobile robot-controlled 10 MeV electron accelerator as well as some EB-curable adhesives properties. Another study done by Saunders et al. looked at EB-curing equipment and costs for remote repair of composites (2). Several studies looked at EB-curable adhesives (3). These studies showed that there were a great many EB-curable adhesives available, some with lap shear strengths above 21 MPa at room temperature. However, these were acrylated resins, which did not have acceptable solvent or elevated temperature properties.

Table 1. Comparison of Rheological and Mechanical Properties of EB cured Resins on S-2 Fiberglass

Property	Resin System					
	1L0		3K		8H	
Thermal Properties						
Service Temperature, °C	242		187		313	
Tg (Loss Modulus), °C	379		383		348	
Tg (Tan δ), °C	400		398		400	
Mechanical Properties	***25°C***	***71°C***	***25°C***	***71°C***	***25°C***	***71°C***
Tensile Strength, MPa	500	446	510		450	
Tensile Modulus, GPa	28	27	36		35	
Flexural Strength, MPa	510	435	570		420	
Flexural Modulus, GPa	26	25	30		26	
Compressive Strength, MPa	370	317	400		270	
Compressive Modulus, GPa	36	34	35		35	
Shear Strength, MPa	40	37	50		39	
Elevated Temperature						
Shear Strength, MPa (93°C)			38		39	
Shear Strength, MPa (149°C)			28		28	
Shear Strength, MPa (204°C)			12		20	
Shear Strength, MPa (260°C)			5		15	
Shear Strength, MPa (318°C)			4		13	

A recent development program to use electron beam processing for the manufacture of the T-38 windscreen studied several recently developed EB-curable epoxy resins, 1L0, 3K, and 8H on fibreglass for various mechanical and rheological properties (4). The study showed that these resins used with S-2 type fiberglass gave short beam shear strengths of about 40 MPa with 1L0 chosen for the actual manufacture of the windscreen. These resins also had excellent high temperature properties with service temperatures greater than 175°C. Table 1 summarizes the properties for these 3 resin systems on S-2 fiberglass. Other studies by AECL and Lockheed Martin Energy Research (LMER) studied low and high temperature impact and other mechanical properties properties for similar resin systems (5, 6). However, these studies looked at IM7 graphite unidirectional composites. All this data suggested that a candidate from these resin systems would be acceptable for the repair type-trial. The EB-curable resin 1L0 was considered the best possible candidate for this initial type-trial.

Figure 2. Unsized Graphite Fibre with Tactix 123/OPPI (3 phr) Resin

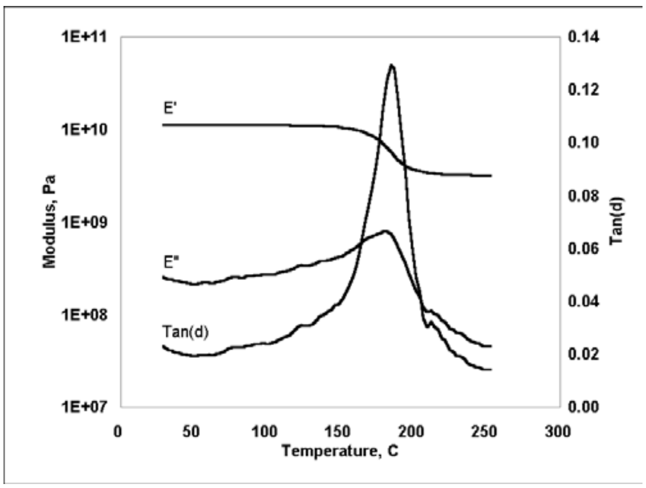
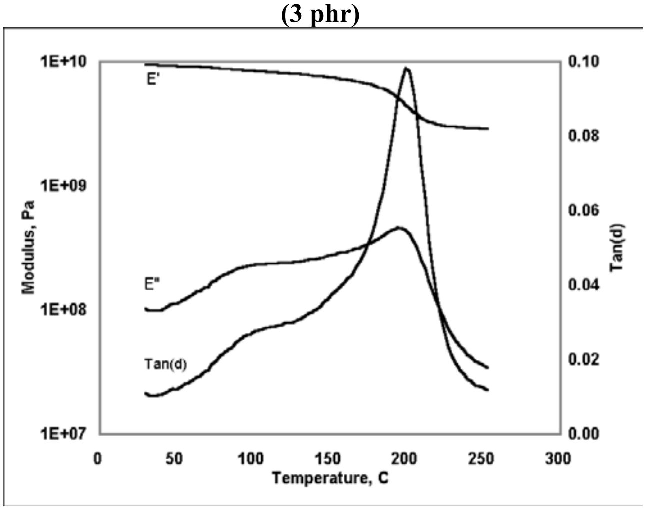


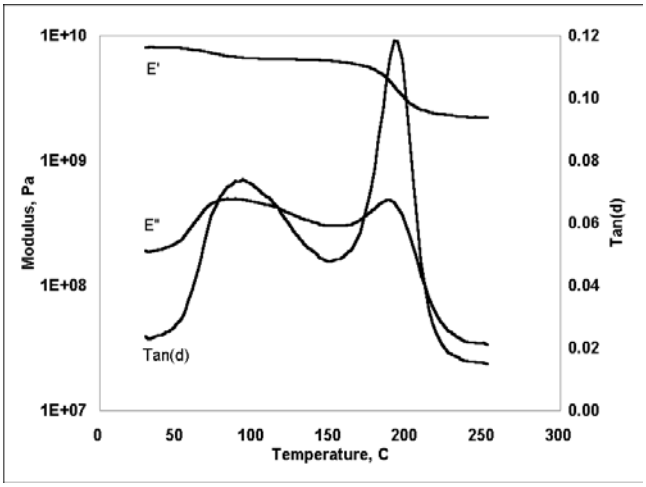
Figure 3. Style 181 Fiberglass with Tactix 123/OPPI (3 phr)



2.1 Material/Performance Evaluation The fairing used on the Airbus A319 and A320 aircraft is manufactured using fiberglass and a 120°C thermal-cured epoxy resin. Where possible the same materials were used for the electron beam curing process. For the routine repair of this component, Air Canada repair technicians use Style 181 fiberglass with Ciba Geigy Epocast 50-A epoxy resin with 946 hardener. The Epocast 50-A epoxy was modified with a cationic initiator (3 phr) to make it radiation-curable. Using the standard curing dose of 150 kGy this mixture did not cure and remained a liquid. This modified resin system was rejected for the test.

Fiberglass and graphite fabrics, release cloths, and bagging films were either prepregged or placed in contact with a solution of Tactix 123 epoxy (Dow Chemical) and OPPI (General Electric) (3 phr). The prepregs and resin/film combinations were then irradiated to a dose of 150 kGy. Dynamic mechanical analysis (DMA) specimens were prepared from the cured samples and tested using a Rheometrics RSA II Solids Analyzer. An EB-cured composite without radiation inhibition taking place should give only one tan (δ) peak at approximately 185°C. Figure 2 shows the typical DMA curves for a composite, which does not exhibit any radiation inhibition. In this case the composite was unsized AS4 graphite with Tactix 123/OPPI (3 phr). Radiation inhibition causes the EB-

Figure 4. AS4 Plain Weave Graphite Fiber with Tactix 123/OPPI (3 phr)



curable resin to be partially cured. This inhibition take place because of the sizing on the fiberglass or graphite fabric or the release cloth is basic in chemical nature, partially neutralizing the cationic polymerization of the epoxy. The bagging film, a nylon based material can release inhibiting substances into the EB curable cationic resin when in direct contact for extended times or high debulking temperatures. When radiation inhibition does occur, then the tan(δ) and loss modulus curves will show a secondary peak occurring at approximately 85^{o}C for the Tactix 123/OPPI (3 phr) system.

Figures 3 and 4 show the DMA curves for two materials used by Air Canada for their present composite repair. Figure 3 shows the DMA curve for fiberglass style 181 epoxy composite. In this case there is a slight inhibition. However, the degree of inhibition is low enough to have no significant impact on the mechanical or rheological properties of the composite part. Figure 4 shows the DMA curves for the graphite plain woven cloth composite. In this case there is a very large secondary peak in the tan(δ) curve at approximately 85^{o}C indicating significant radiation inhibition taking place. This particular cloth would cause significant reduction in the composite's mechanical properties at high temperatures.

Table 2 shows the various materials used by Air Canada for repair. The ratio of the secondary peak, P", to the primary peak, P', gives an indication of the amount of inhibition taking place. The table also shows the ratio of the secondary peak to the primary peak. A rule of thumb was established rejecting those materials with ratios greater than 0.30 from being used in the manufacture of composite parts or being used in direct contact with the EB-curing part.

Fiberglass style 181 was used for the process. The EB-curable fiberglass prepreg used for the study was prepared at AECL labs using resin films manufactured by YLA, Inc. (Benica, CA). The film with its release paper was placed on the fiberglass and then pressed to a pressure of 30 kPa at a temperature of 70^{o}C for approximately 1 minute infusing the resin into the fabric. The thermal-cured panels were wet laid-up using Epocast 50-A epoxy and 949 hardener. Hexcel supplied the thermal-cured fiberglass prepreg.

One panel was prepared with thermal-cured composite on one side and EB-cured composite on the other side. This panel had both sides prepared using Air Canada's normal paint surface preparation method. Both sides were then painted using normal paints and then weather-tested by Lockheed Martin Skunk Works.

2.2 Mechanical Properties Evaluation A series of fiberglass panels, 30 cm x 30 cm, were fabricated using typical lay-up procedures. The panels were either thermal-cured, EB-cured, or combinations of both methods. The thermal-cured panels were manufactured at the Air Canada Winnipeg Maintenance Base. The thermal-cured wet lay-up panels were cured at a temperature of

90°C and the thermal-cured prepreg panels at 120°C. The EB-cured and combination panels were cured at AECL's Whiteshell Laboratories. The EB-curable prepreg was first made by placing 1L0 EB-curable resin film on style 181 fiberglass and heated to 60°C under a pressure of 100 kPa. One EB-cured panel was first prepregged with 3K EB curable resin that is also being considered at a candidate resin. The EB curable adhesive was 11L.

Table 2. Material Radiation Inhibition Acceptability Test Results

Material	P"/P' Ratio	Status
Base Material Standard	0.20	
Fiberglass Style 120	0.45	Unacceptable
Fiberglass Style 181	0.29	Acceptable
Fiberglass Style PW7500	0.33	Unacceptable
Fiberglass Tooling Cloth	0.51	Unacceptable
Graphite, Plain Weave	0.63	Unacceptable
Release Cloth	0.34	Unacceptable

Note: P' - tan(δ) curve primary peak height
P" - tan(δ) curve secondary peak height

For the simulated repair panels, the surfaces were first evenly sanded using 150 Grit sandpaper. The surface was then cleaned with acetone using a lint-free cloth. In the case of the EB-curable repair, the prepreg was then laid on the surface. When the EB-curable adhesive, 11L, was used, it was applied to the surface with a paint brush and then scrapped with a polyethylene scrapper to produce an even, thin film before placing the EB-curable prepreg on. Care was taken to ensure that the EB-curable resin did not come in contact with the bagging film during the manufacturing process for the test panels. Teflon-coated fiberglass release cloth, which previous tests showed did not cause any radiation inhibition was placed on the surface of the EB-curable panels. A breather cloth was then placed on the stack and vacuum bagged. The stack was then placed under a vacuum of approximately 100 kPa for approximately 30 minutes. All EB-curable panels were irradiated to a dose of 150 kGy. Table 3 gives the details for the various panel combinations used in the preliminary tests. Lockheed Martin Skunk Works tested the lap shear strengths in accordance with ASTM D3165.

For the type-trial fairing repair, the aim was to produce a repair that gave lap shear strengths equal to or better than panel AC-EB-2 which represents the properties of the original component. The present wet lay-up repair method Air Canada uses for this component is represent by AC-EB-1.

Table 3. Test Panel Combination Descriptions for Preliminary Type-Trial Tests

Batch Number	Test Panel ID	Description	# Plies	Orientation
AC-EB-1	Wet Lay-up Baseline Thermal-cured	181 Fibreglass Epocast 50-A resin/946 Hardener	8	0 deg
AC-EB-2	Prepreg Baseline Thermal-cured	181 Fibreglass prepreg	8	0 deg
AC-EB-3	Baseline EB-cured 1L0 EB resin	181 Glass with EB 1L0 Resin Panel cured at dose of 150 kGy	8	0 deg
AC-EB-4	EB-cured Substrate and EB Wet Lay-up Repair 1L0 EB resin	4 plies of style 181 EB precured fiberglass 4 plies of style 181 glass and EB resin system Bonded as a wet lay-up repair	4 + 4	0 deg
AC-EB-5	EB Substrate and EB Wet Lay-up with EB Adhesive repair 1L0 EB Resin 11L EB adhesive	4 plies of style 181 EB precured fiberglass 4 plies of style 181 glass EB resin system Bonded as a wet lay-up with an EB paste adhesive 11L between EB precured and wet lay-up panels	4 + 4	0 deg
AC-EB-6	Baseline EB-cured 3K E-beam resin	181 Glass with EB 3K Resin Panel cured at dose of 150 kGy	8	0 deg

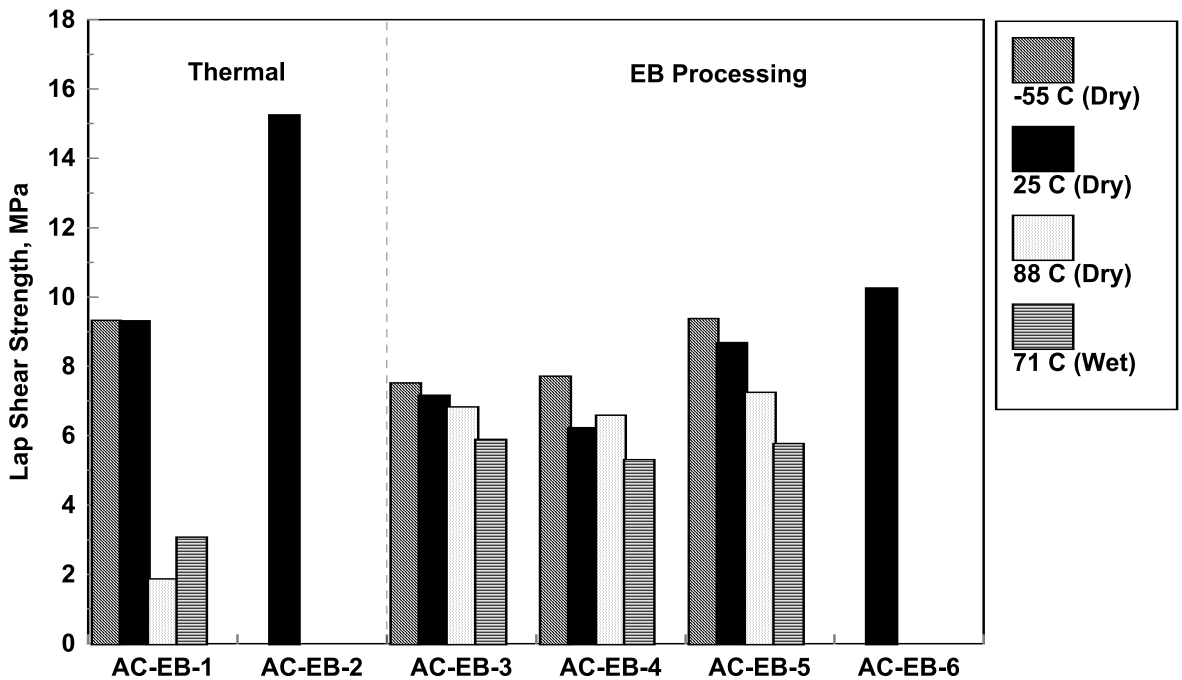
Table 4. Comparison of Lap Shear Strengths for Combinations of Thermal and EB-Cured Fiberglass Panels

Batch		Lap Shear Strength (MPa)			
		Dry Condition			Wet Condition
Number	Test Panel ID	-55°C	25°C	88°C	71°C
AC-EB-1	TC Wet Lay-up Baseline	9.33 +/- 0.48	9.32 +/- 0.26	1.87 +/- 0.11	3.07 +/- 0.18
AC-EB-2	TC Prepreg Baseline		15.25 +/- 0.41		
AC-EB-3	EBC Baseline 1L0 EB resin	7.52 +/- 0.52	7.16 +/- 0.37	6.83 +/- 0.73	5.90 +/- 0.15
AC-EB-4	EBC Substrate and EBC Wet Lay-up Repair	7.72 +/- 1.00	6.23 +/- 0.58	6.59 +/- 0.11	5.31 +/- 0.06
AC-EB-5	EBC Substrate and EBC Wet Lay-up Repair with EBC Adhesive	9.38 +/- 0.92	8.68 +/- 0.63	7.25 +/- 0.19	5.78 +/- 0.62
AC-EB-6	EBC Baseline 3K E-beam resin		10.26 +/- 0.37		

Note: TC: Thermally-cured; EBC: EB-cured 1L0 resin unless otherwise specified; EBC Adhesive was 11L

Most notable about the present repair method is the significant loss of shear strength at elevated dry and wet temperatures. On the other hand the EB-cured panels show little loss in the low and high dry temperature shear properties as well as hot wet properties. Figure 5 graphically shows the comparison between the two types of processing. This figure shows there are marked differences in properties between the thermal and EB-processed panels. AC-EB panels 1 and 2 represent the present thermal-cured systems. AC-EB panels 3, 4, 5, and 6 were EB-cured. The retention of properties at higher temperatures for the EB-cured resin panels is because of the high service temperature, 242°C, of the 1L0 resin. The better hot wet properties is because EB-cured resin systems tend to have higher crosslink densities compared to thermal systems. The higher crosslink densities prevents water and other liquids from intruding into the resin system which would result in loss of properties. This property will be beneficial for the fairing panel repair because the fairing experiences water, hydraulic fluid and oils which is suspected of deteriorating wet lay-up repairs over an extended period of time. Panel AC-EB-6 represents the shear strength properties for the 3K resin system which has been modified with a toughener. Its room temperature lap shear strength is similar to the present thermal-cured system. Its high dry and wet temperature properties should also be improved compared to 1L0 because this resin system maintains a high service temperature, 187°C.

Figure 5. Comparison of Shear Strengths for Thermal and EB-Cured Fiberglass Panels



3. CONCLUSIONS

The preliminary test results show that EB-processing for the repair of the fairing panel is possible. The lap shear strengths for the chosen resin system are maintained at low and room temperatures. One advantage of the EB process will be to produce a repair with higher lap shear strengths at elevated dry and wet temperatures. Overall, this should provide a better, more durable repair of the component. Based on these results a EB-processed fairing repair will be placed on an aircraft and flight-tested for approximately 18 months. The results of the flight-testing will be reported after the flight-testing has been completed.

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