ELECTRON BEAM PROCESSING FOR AIRCRAFT STRUCTURES

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Abstract

A low cost electron beam curable epoxy resin system was developed. The strength of QC130-34-154A using this resin system with toughening agent was almost same as QC130-31-154A developed in FY2004 and the cost reduction was 60%. QC130-34-154A was fully cured by irradiating 30 kGy. A trial fabrication of the "H" cross-sectional beam was carried out with the continuous pre-forming device. Electron beam of 30 kGy per each pass and the total dose of 120 kGy were irradiated to the pre-form. The quasi-isotropic SBS strength was 43MPa which was equal to the thermally cured. The electron beam dose distribution of the floor beam was measured and uniform distribution was confirmed with a scattering plate.

1 Introduction

Autoclave process, which requires high energy consumption, is usually used for CFRP fabrication of aircraft structures. Advanced Pultrusion (ADP) is an automated continuous fabrication system using an oven to fabricate stringers and floor beams. It reduces fabrication cost but requires long time to cure thermosetting material. If electron beam curing (EBC) material is used in ADP, cure time will be reduced[1] and high-speed fabrication will be achieved (Fig. 1). High strength EBC prepreg QC130-31-154A was developed in FY2004[2] for this high-speed fabrication system, but the prepreg cost was higher compared to the conventional thermal cure prepreg. In this study, low cost EBC prepreg development, electron beam irradiation, CFRP mechanical tests and pre-forming of the "H" beams were performed.

2 Material Development

2.1 Materials

QC130-34-154A prepreg was developed to reduce cost as same as the conventional prepreg, and almost 60% reduction compared to QC130-31-154A prepreg developed in FY2004. And also the toughness improvement was designed by adding toughening agent. Carbon fiber BESFIGHT IM600-24K (Toho Tenax Co., Ltd) was used and the resin system consists of bisphenol-A epoxy, flow control agent, toughening agent, and cationic photo initiator. Fiber areal weight was 150 g/m^2 and resin content was 35 wt%. A resin system for the bending test of the resin plate was the same composition as QC130-34-154A except flow control agent.

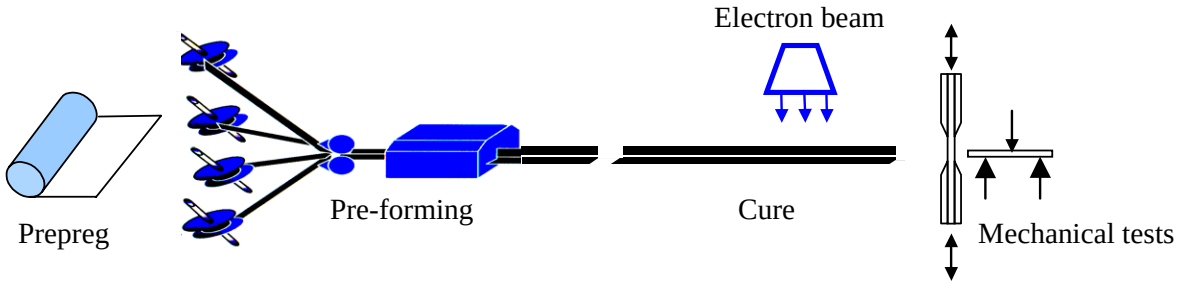

Fig. 1. EBC Continuous fabrication

2.2 Procedures

The bending test of the resin plate was conducted by JIS K 7171, and the specimens were thermally cured by 180 deg C, 2-hour.

For the degree of cure measurement, prepregs were hand lay-upped to 40-ply (approx. 6 mm thickness) using vacuum bag and cured by 10-150 kGy electron beam of 10 MeV irradiation device at Nuclear Fuel Industries, LTD. Differential scanning calorimetry (DSC) test was conducted by JIS K 7122; 10 deg C /min heat up rate, 50 ml/min flow rate nitrogen atmosphere.

FRP mechanical tests were performed on electron beam cured laminates using QC130-34-154A prepreg. Prepregs were hand lay-upped and heat debulked in an autoclave using vacuum bag; 0.5 MPa pressure, 90 deg C temperature hold for 10 minutes, and cured by 120 kGy electron beam. Fiber volume contents (Vf) of the cured specimens were approximately 55%. Testing condition was room temperature and specimens were prepared by dry condition. Tensile, compression, in-plane shear, open-hole compression (OHC) and short beam shear (SBS) test were conducted by ASTM-3039, SACMA SRM 1M, ASTM-3518, ASTM-6484 and ASTM-2344. Test data was normalized to 60% Vf except SBS test.

Glass transition temperature (Tg) was measured by thermo mechanical analysis (TMA) JIS K 7197, 3 mm square specimen size, 1gf force, 3 deg C/min heat up rate, 50 ml/min flow rate nitrogen atmosphere.

2.3 Results and Discussion

The toughening agent influence was confirmed by the bending test of the resin plate and the result is shown in Table 1. Elongation becomes twice by adding the toughening agent.

Fig. 2 shows the relationships between the total dose of electron beam and the degree of cure for QC130-31-154A and QC130-34-154A. High degree of cure was attained by 30 kGy for QC130-34-154A, while QC130-31-154A required 120 kGy.

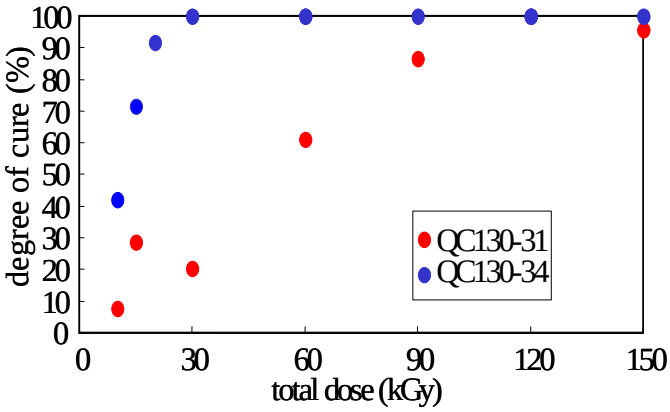

Fig. 2. Comparison of degree of cure between QC130-31-154A and QC130-34-154A

The mechanical test results of the electron beam cured laminates of QC130-34-154A are shown in Table 2 with the conventional thermally cured epoxy QC133-149A and electron beam cured QC130-31-154A. The strength of the low cost QC130-34-154A is almost same as QC130-31-154A.

Tg of QC130-31-154A was 175 deg C by thermal cure and QC130-34-154A was decreased to 150 deg C by thermal cure, but still high Tg for aircraft structure.

Table 1. Resin plate bending test results

Material	Strength (MPa)	Modulus (GPa)	Elongation (%)
Untoughened	137	3.7	5.7
Toughened	131	3.4	9.9

Table 2. Mechanical properties of electron beam cured and thermally cured CFRP

Material	Strength (MPa)					
	Tensile	Compression	In-plane shear	OHC	SBS (uni-directional)	SBS (quasi isotropic)
QC133-149A	2940	1600	147	324	98	77
QC130-31-154A	2860	1320	72	292	77	-
QC130-34-154A	2790	1650	77	282	71	42

3 Continuous Fabrication

The “H” cross-sectional beam was fabricated with a continuous pre-forming device using QC130-34-154A prepreg. The ply orientation of the H beam was quasi-isotropic $[45/90/-45/0]_{2S}$. The prepreg was cut into each oriented fiber direction tapes, laid up to 4 rolls and set up to the pre-forming stand. The prepreg rolls were intermittently pulled and gradually pre-formed into the “H” shape. In the molds, the pre-form was pressed for a specified time, released from the molds and pulled to a specified feed pitch. One cycle of pre-forming consists of pressing period and moving period as illustrated in Fig. 3. The pre-form was carried to the 10 MeV irradiation device at Nuclear Fuel Industries, LTD and electron beam of 30 kGy per each pass and the total dose of 120 kGy were irradiated to the pre-form on the 45 degree sloped table. The pre-forming condition, thickness and SBS strength of the cured pre-form are shown in Table 3. SBS strength of 43MPa which is equal to the hand lay-upped and thermally cured was obtained.

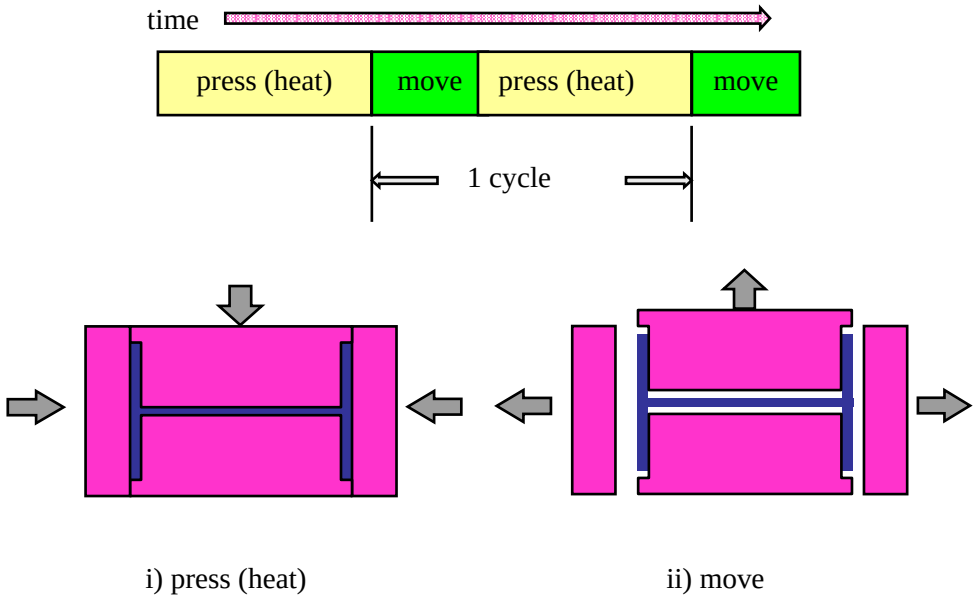

Fig. 3. Mechanism of continuous pre-forming

Table 3. Pre-forming conditions and results of the mechanical tests

Number	Pre-forming conditions				Results	
	Temperature (deg C)	Speed (m/h)	Feed pitch (mm)	Cycle time (sec)	Thickness (mm)	SBS (MPa)
No.1	145	10	25	9	1.72	27
No.2	150	10	25	9	1.74	32
No.3	155	10	25	9	1.94	37
No.4	160	10	25	9	2.04	43

4 Irradiation Studies

It is important to minimize the dose distribution for the uniform cure of the pre-form. However, the dose distribution differs when the shape of pre-form changes. To trace the electrons when irradiated to the "H" beam, the electron beam was visualized. Fig. 4 is the result of the calculation by EGS4 (ELECTRON GAMMA SHOWER 4) Monte-Carlo calculation code. The electron beam was diffused by the edge of the "H" beam (ellipse part in the figure).

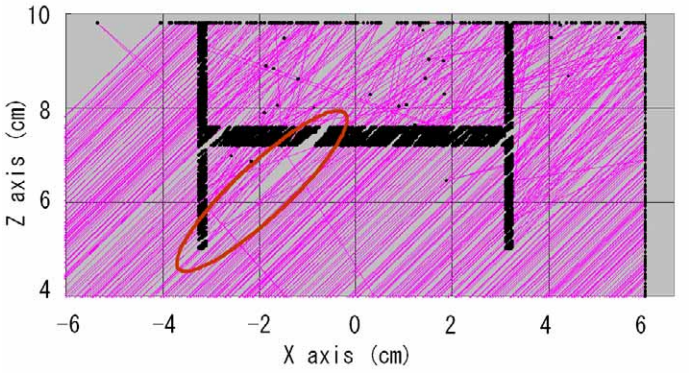

Fig. 4. Calculation result of electron beam trace by Monte-Carlo code

Dose distribution of the floor beam shape illustrated in the Fig. 5 was measured by dosimeters on the surface of the floor beam.10 MeV electron beam was irradiated so that the surface absorbed dose reached to 30 kGy by 45 degree.

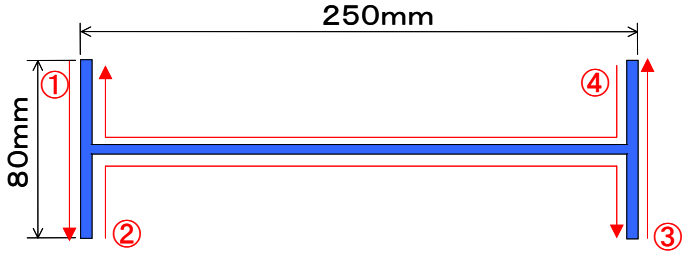

Fig. 5. Cross section of the floor beam

Fig. 6 shows the measured dose distribution. Without a stainless-steel scattering plate, the lower dose areas are observed, similar phenomena to the calculated electron beam trace (Fig. 4). With the scattering plate which diffuses the electron beam before the edge of the "H" beam becomes flat.

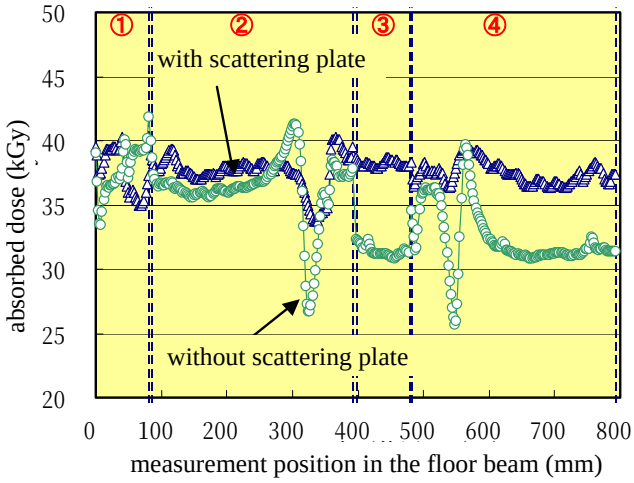

Fig. 6. Effect of scattering plate on absorbed dose

5 Conclusions

A low cost electron beam curable epoxy resin system was developed. The strength of QC130-34-154A was almost same as QC130-31-154A and high degree of cure was attained by 30 kGy for QC130-34-154A.

A trial fabrication of the "H" cross-sectional beam was carried out with the continuous pre-forming device. Electron beam of 120 kGy were irradiated to the pre-form and the quasi-isotropic SBS strength was 43MPa which was equal to the thermally cured.

The electron beam dose distribution of the floor beam was measured and uniform distribution was confirmed with the use of a scattering plate.

Acknowledgments

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References

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