E-Beam Spot Weld-bonding

How realistic is this technology
Can it be done on automotive body structures?

Primary Reference:

Electron Beam Curing Demonstration with Automobile Structures
C. C. Eberle1, C. J. Janke1, and C. S. Wang2
Oak Ridge National Laboratory1 and General Motors Corporation2

Note:

My name is not on the technical paper, but! I was involved through-out this research project.

This was a carry over effort utilizing the "Proof-of-concept" soft tooling from the mainstream CF/E Corvette Hood program.

E-Beam Cured Carbon Fiber Epoxy Hood Project

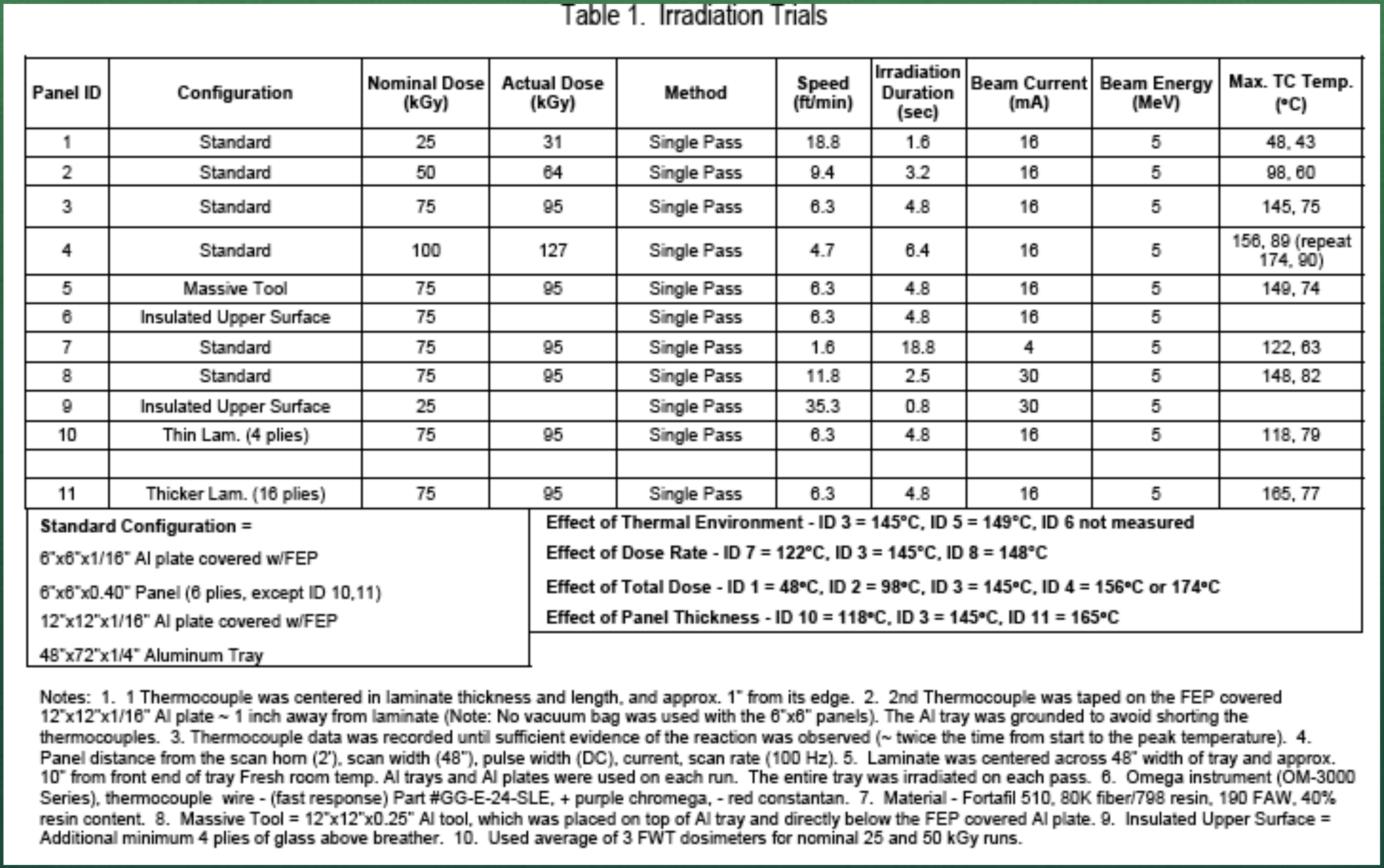

Table 1. Irradiation Trials

Panel ID	Configuration	Nominal Dose (kGy)	Actual Dose (kGy)	Method	Speed (ft/min)	Irradiation Duration (sec)	Beam Current (mA)	Beam Energy (MeV)	Max. TC Temp. (°C)
1	Standard	25	31	Single Pass	18.8	1.6	16	5	48, 43
2	Standard	50	64	Single Pass	9.4	3.2	16	5	98, 60
3	Standard	75	95	Single Pass	6.3	4.8	16	5	145, 75
4	Standard	100	127	Single Pass	4.7	6.4	16	5	156, 89 (repeat 174, 90)
5	Massive Tool	75	95	Single Pass	6.3	4.8	16	5	149, 74
6	Insulated Upper Surface	75		Single Pass	6.3	4.8	16	5	
7	Standard	75	95	Single Pass	1.6	18.8	4	5	122, 63
8	Standard	75	95	Single Pass	11.8	2.5	30	5	148, 82
9	Insulated Upper Surface	25		Single Pass	35.3	0.8	30	5	
10	Thin Lam. (4 plies)	75	95	Single Pass	6.3	4.8	16	5	118, 79
11	Thicker Lam. (16 plies)	75	95	Single Pass	6.3	4.8	16	5	165, 77

Standard Configuration =

6"x6"x1/16" Al plate covered w/FEP

6"x6"x0.40" Panel (6 plies, except ID 10,11)

12"x12"x1/16" Al plate covered w/FEP

48"x72"x1/4" Aluminum Tray

Effect of Thermal Environment - ID 3 = 145°C, ID 5 = 149°C, ID 6 not measured

Effect of Dose Rate - ID 7 = 122°C, ID 3 = 145°C, ID 8 = 148°C

Effect of Total Dose - ID 1 = 48°C, ID 2 = 98°C, ID 3 = 145°C, ID 4 = 156°C or 174°C

Effect of Panel Thickness - ID 10 = 118°C, ID 3 = 145°C, ID 11 = 165°C

Notes: 1. 1 Thermocouple was centered in laminate thickness and length, and approx. 1" from its edge. 2. 2nd Thermocouple was taped on the FEP covered 12"x12"x1/16" Al plate ~ 1 inch away from laminate (Note: No vacuum bag was used with the 6"x6" panels). The Al tray was grounded to avoid shorting the thermocouples. 3. Thermocouple data was recorded until sufficient evidence of the reaction was observed (~ twice the time from start to the peak temperature). 4. Panel distance from the scan horn (2'), scan width (48"), pulse width (DC), current, scan rate (100 Hz). 5. Laminate was centered across 48" width of tray and approx. 10" from front end of tray Fresh room temp. Al trays and Al plates were used on each run. The entire tray was irradiated on each pass. 6. Omega instrument (OM-3000 Series), thermocouple wire - (fast response) Part #GG-E-24-SLE, + purple chromega, - red constantan. 7. Material - Fortafil 510, 80K fiber/798 resin, 190 FAW, 40% resin content. 8. Massive Tool = 12"x12"x0.25" Al tool, which was placed on top of Al tray and directly below the FEP covered Al plate. 9. Insulated Upper Surface = Additional minimum 4 plies of glass above breather. 10. Used average of 3 FWT dosimeters for nominal 25 and 50 kGy runs.

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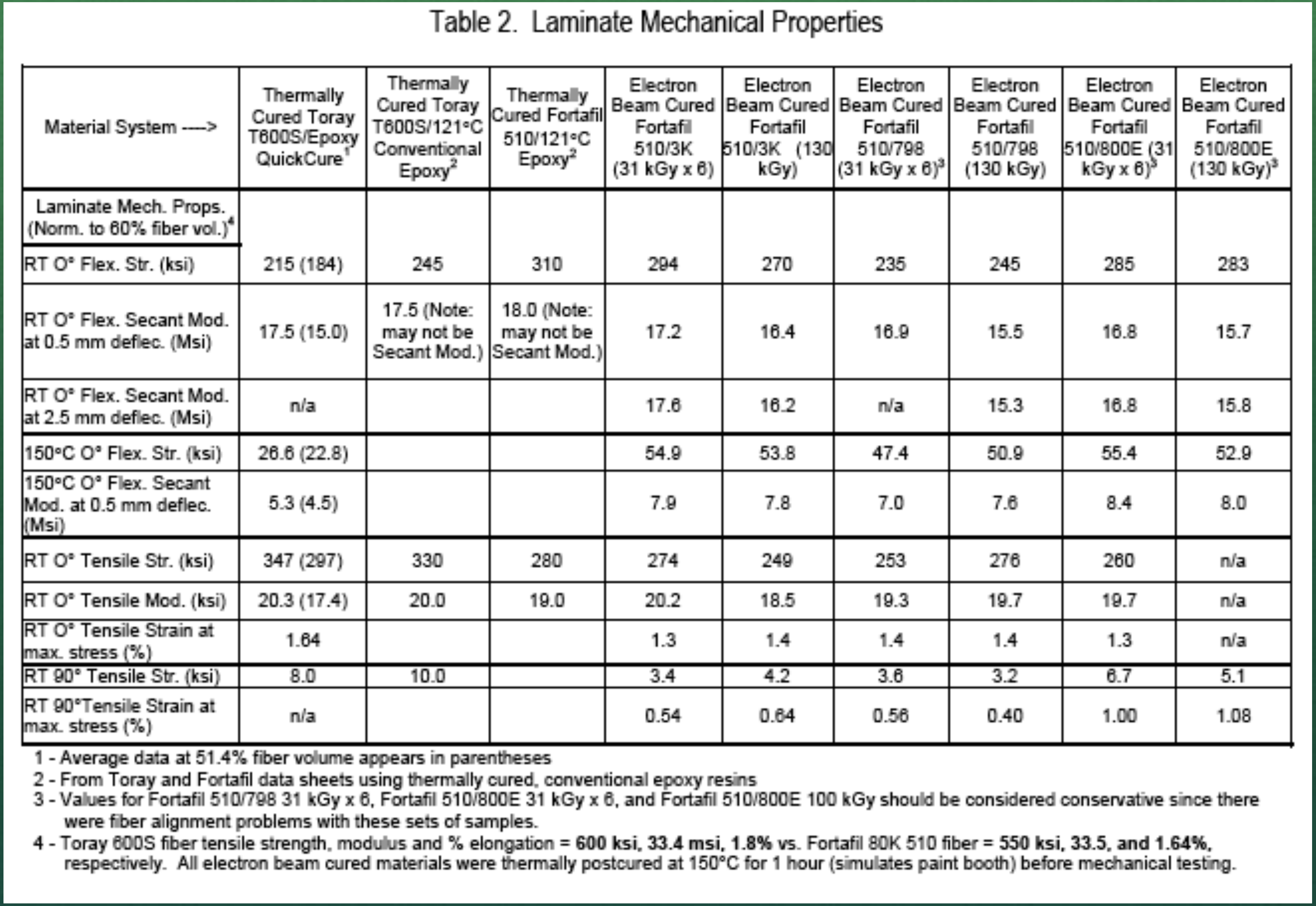

Table 2. Laminate Mechanical Properties

Material System ---->	Thermally Cured Toray T600S/Epoxy QuickCure[1]	Thermally Cured Toray T600S/121°C Conventional Epoxy[2]	Thermally Cured Fortafil 510/121°C Epoxy[2]	Electron Beam Cured Fortafil 510/3K (31 kGy x 6)	Electron Beam Cured Fortafil 510/3K (130 kGy)	Electron Beam Cured Fortafil 510/798 (31 kGy x 6)[3]	Electron Beam Cured Fortafil 510/798 (130 kGy)	Electron Beam Cured Fortafil 510/800E (31 kGy x 6)[3]	Electron Beam Cured Fortafil 510/800E (130 kGy)[3]
Laminate Mech. Props. (Norm. to 60% fiber vol.)[4]									
RT 0° Flex. Str. (ksi)	215 (184)	245	310	294	270	235	245	285	283
RT 0° Flex. Secant Mod. at 0.5 mm deflec. (Msi)	17.5 (15.0)	17.5 (Note: may not be Secant Mod.)	18.0 (Note: may not be Secant Mod.)	17.2	16.4	16.9	15.5	16.8	15.7
RT 0° Flex. Secant Mod. at 2.5 mm deflec. (Msi)	n/a			17.6	16.2	n/a	15.3	16.8	15.8
150°C 0° Flex. Str. (ksi)	26.6 (22.8)			54.9	53.8	47.4	50.9	55.4	52.9
150°C 0° Flex. Secant Mod. at 0.5 mm deflec. (Msi)	5.3 (4.5)			7.9	7.8	7.0	7.6	8.4	8.0
RT 0° Tensile Str. (ksi)	347 (297)	330	280	274	249	253	276	260	n/a
RT 0° Tensile Mod. (ksi)	20.3 (17.4)	20.0	19.0	20.2	18.5	19.3	19.7	19.7	n/a
RT 0° Tensile Strain at max. stress (%)	1.64			1.3	1.4	1.4	1.4	1.3	n/a
RT 90° Tensile Str. (ksi)	8.0	10.0		3.4	4.2	3.6	3.2	6.7	5.1
RT 90°Tensile Strain at max. stress (%)	n/a			0.54	0.64	0.56	0.40	1.00	1.08

1 - Average data at 51.4% fiber volume appears in parentheses

2 - From Toray and Fortafil data sheets using thermally cured, conventional epoxy resins

3 - Values for Fortafil 510/798 31 kGy x 6, Fortafil 510/800E 31 kGy x 6, and Fortafil 510/800E 100 kGy should be considered conservative since there were fiber alignment problems with these sets of samples.

4 - Toray 600S fiber tensile strength, modulus and % elongation = **600 ksi, 33.4 msi, 1.8%** vs. Fortafil 80K 510 fiber = **550 ksi, 33.5, and 1.64%**, respectively. All electron beam cured materials were thermally postcured at 150°C for 1 hour (simulates paint booth) before mechanical testing.

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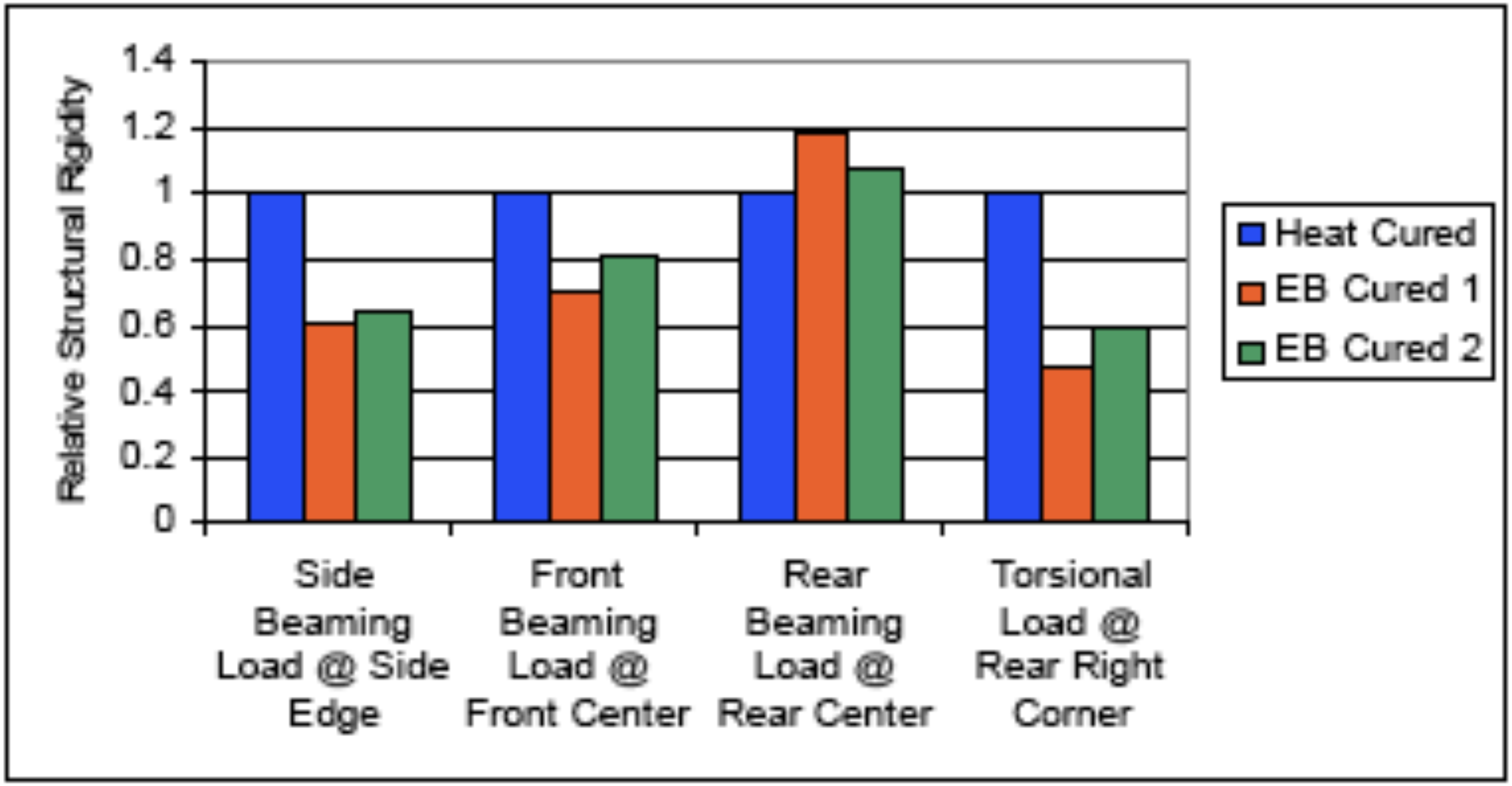

Figure 7. Relative structural rigidity of carbon fiber hoods

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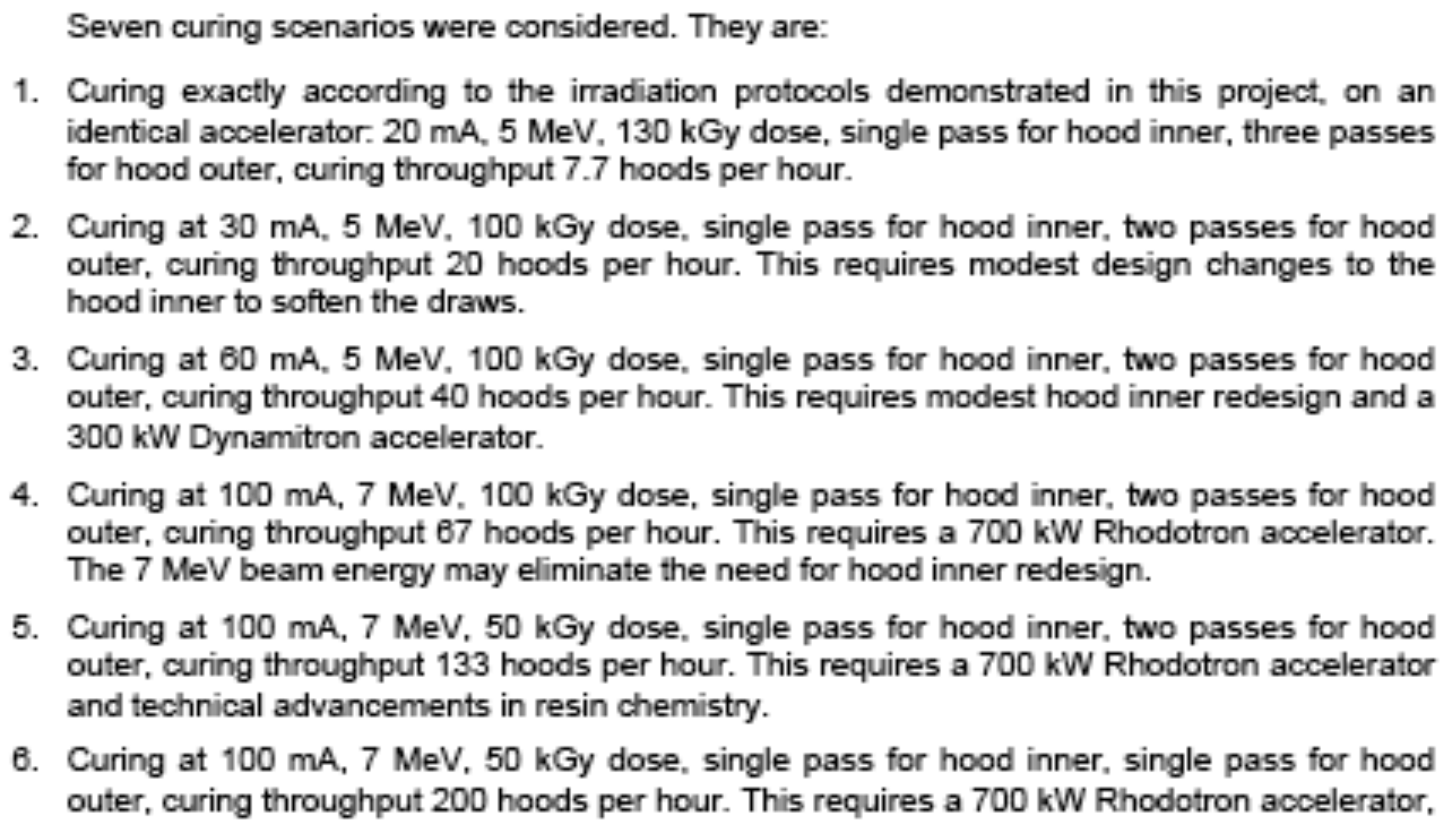

Seven curing scenarios were considered. They are:

1. Curing exactly according to the irradiation protocols demonstrated in this project, on an identical accelerator: 20 mA, 5 MeV, 130 kGy dose, single pass for hood inner, three passes for hood outer, curing throughput 7.7 hoods per hour.
2. Curing at 30 mA, 5 MeV, 100 kGy dose, single pass for hood inner, two passes for hood outer, curing throughput 20 hoods per hour. This requires modest design changes to the hood inner to soften the draws.
3. Curing at 60 mA, 5 MeV, 100 kGy dose, single pass for hood inner, two passes for hood outer, curing throughput 40 hoods per hour. This requires modest hood inner redesign and a 300 kW Dynamitron accelerator.
4. Curing at 100 mA, 7 MeV, 100 kGy dose, single pass for hood inner, two passes for hood outer, curing throughput 67 hoods per hour. This requires a 700 kW Rhodotron accelerator. The 7 MeV beam energy may eliminate the need for hood inner redesign.
5. Curing at 100 mA, 7 MeV, 50 kGy dose, single pass for hood inner, two passes for hood outer, curing throughput 133 hoods per hour. This requires a 700 kW Rhodotron accelerator and technical advancements in resin chemistry.
6. Curing at 100 mA, 7 MeV, 50 kGy dose, single pass for hood inner, single pass for hood outer, curing throughput 200 hoods per hour. This requires a 700 kW Rhodotron accelerator,

Summary

This experimental study demonstrated the feasibility of curing composite automotive structures at high production volumes using electron beam processing technology.

The study suggested that the electron beam curing process may be economically attractive, especially at high production volumes.

Judging from the thermo-mechanical properties of the electron beam cured laboratory laminates, it should be possible to increase electron beam cured hood rigidity to satisfy structural requirements.

To fully exploit the potential of electron beam curing, advancements in robust, high production volume upstream manufacturing are needed.

Discussion

- Back then… I wasn't sure we'd be E-beam curing complete hood structures any time soon.

- But?
  - What about ultra-high speed welding/ bonding?
  - We E-Beam cured over a 48" width at 3.2 feet per minute
    - That correlates to 3686 in^2 per minute

  - **I propose that we utilize the E-beam curing technology to spot weld-bond a typical weld-bond structural adhesive**

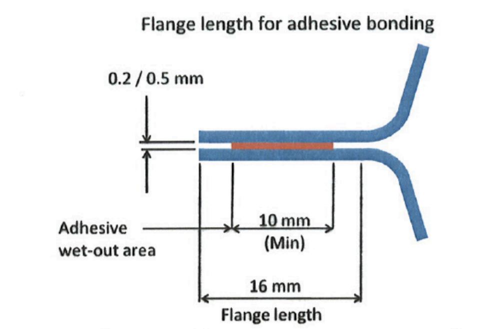

Figure 13.47: *Joint and flange required for adhesive bonding*

Multipurpose Dynamitron® E-beam Facility

With a multipurpose Dynamitron E-beam facility, irradiation of both reel-to-reel (wire and cable and heat-shrink) and parts of bulks on trays is possible.

① Dynamitron®
② Scanning Horn
③ Capstan Underbeam
④ Pay off and Take up Reels
⑤ Small Wire Capstan
⑥ Tray Conveyor System

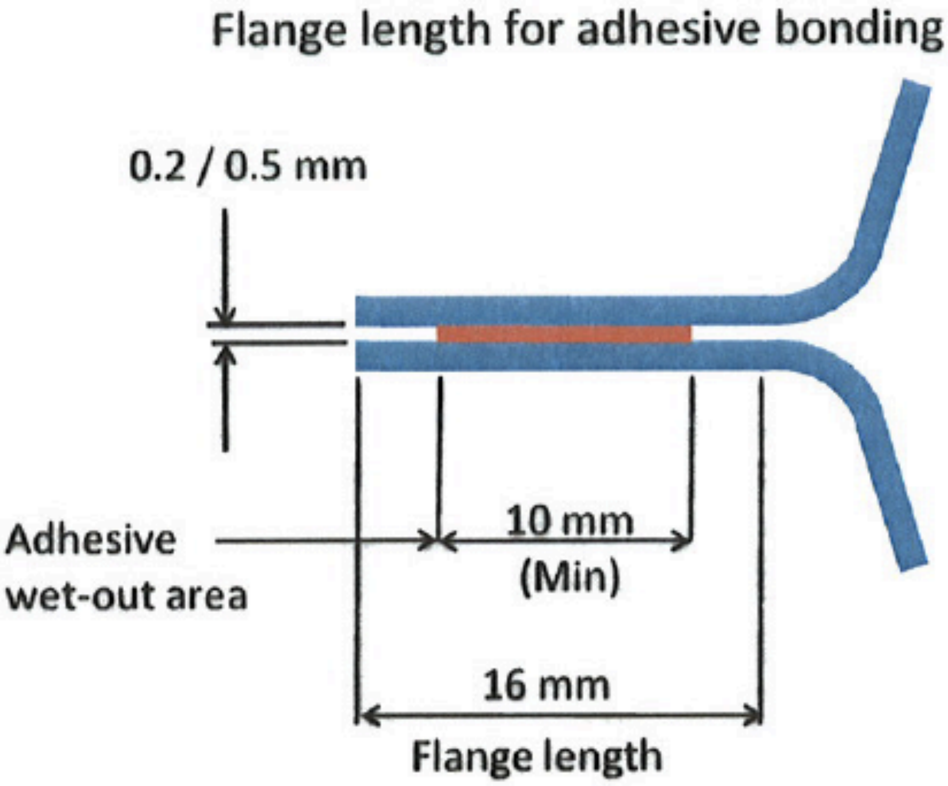

Figure 13.47: *Joint and flange required for adhesive bonding*

If we can cure CF/E @ >3500 in^2 per minute

Then we can cure one (1) in^2 of epoxy structural adhesive in **< 0.02 seconds**

Conclusion

- E-beam spot weld-bonding
    - At rates of < 0.02 seconds per weld
    - Is competitive with existing steel spot Weld-bonding
- The E-Beam Spot Weld-Bonding technology is relatively "Near-Term"

- The E-Beam Spot Weld-Bonding technology enables high volume, automated assembly (Joining) of composite intensive automated body structure.
    - Existing assembly lines of robotic spot welders can be "changed over" to E-beam spot welding