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Adhesive Material Characterisation

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Enforce EP Structural Adhesive (Standard & Winter Grade)

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For: weber sbd

To Purchase Order No.: F45036

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Introduction

The Joining Technology Research Centre, Oxford Brookes University were requested by weber sbd to undertake testing of Enforce Epoxy Plus Standard Grade (ST) and Winter Grade (WG) Structural Adhesives. The adhesive was supplied to JTRC for sample preparation and testing in the laboratory. The work to be conducted by JTRC included the determination of:

- Tensile Modulus and Strength
- Flexural Modulus
- UD CFRP Single Lap Shear Strength using Enforce Carbon Fibre Plates
- Steel Double Lap Shear Strength
- Glass transition temperature, T_g, using Dynamic Mechanical Thermal Analysis (DMTA) at 20°C and 30 °C cure
- Heat Distortion Temperature (HDT)

The results of the testing are presented in this report together with photographs of a selection of specimens before and after testing.

Materials

Adhesive Supplier:	weber sbd
Product ID:	Enforce EP Structural Adhesive Standard & Winter Grades
CFRP Supplier:	weber sbd / S&P Reinforcement
Product ID:	Enforce Carbon Fibre Plate

Specimen Preparation

Bulk Adhesive Specimens

The adhesive was mixed in accordance with the manufacturer's recommendations (mixing 1 complete tub of hardener and resin at a time). Bulk adhesive moulds were then filled with the mixed adhesive to make tensile dumb bell specimens (see Figure 1), flexure prisms, DMTA specimens and HDT prisms. All specimens and prisms were left to cure for a minimum of 7 days.

UD CFRP Single Lap Shear Specimens

Pultruded CFRP coupons of approximate dimensions 20mm x 11mm x 1.5mm, were supplied by weber sbd, which had been pre-ground on one surface in preparation for bonding. Immediately prior to bonding the pre-ground surfaces were degreased with a solvent (MEK). Single lap joints (see Figure 2), exhibiting an overlap length of 10mm, were made using the CFRP pultrusions. The bondline thickness was controlled to a uniform depth of 0.25mm using Ballotini (1% by weight). Aluminium end tabs were bonded onto the ends of the single lap shear specimens to prevent through-thickness crushing at the grips (See Figure 4). All specimens were left to cure for a minimum of 7 days.

Steel Double Lap Shear Specimens

Steel double lap shear specimens were prepared in accordance with BS 30/94. 6mm mild-steel was used. The double lap joints exhibited a nominal bond area of 2000mm^2 (80mm x 25mm) and the bondline thickness was controlled to a uniform depth of 0.25mm using Ballotini (1% by weight). All specimens were left to cure for a minimum of 7 days.

Experimental Programme

All tensile (Dumb bell) bulk adhesive specimens were tested in accordance with BS 2782. A universal tensile testing machine, fitted with a 5 kN load cell, applied a tensile loading at a cross-head deflection of 1mm/min. A linear voltage displacement transducer (LVDT) extensometer, having a gauge length of 50mm (resolution = 0.01mm), was attached to each of the specimens during testing.

The flexural bulk prism specimens were tested in accordance with BA 30/94, using a Nene universal tensile tester fitted with a 5kN load cell. The prisms were subjected to a 1mm/min deflection applied at the two central points of a 4-point flexure test rig configuration. The span length was 180mm and moment arm was 60mm. The central deflection was recorded using a digital Minutoyo Absolute LVDT (resolution = 0.01mm).

Single lap shear specimens were tested in accordance with BS 5350. A universal tensile testing machine, fitted with a 25 kN load cell, applied a tensile loading at a cross-head deflection of 1mm/min. The double lap shear specimens were tested, in accordance with BA 30/94, at 1mm/min using a universal tensile testing machine, fitted with a 100 kN load cell.

A Polymer labs DMTA machine was used to determine the T_g values. Specimens were tested, in accordance with NPL Measurement Good Practice Guide (ISO WD 6721-11), at a frequency of 1Hz and strain rate of x4. A dual cantilever configuration was used, having a span length of 8mm. The temperature was increased at a rate of 3°C/min. The glass transition temperature was taken to be the temperature at which the Tan δ curve peaked.

The HDT prism specimens were tested under a constant surface stress of 1.8MPa, applied centrally over a span of 64mm, in accordance with EN ISO 75-1&2: 1996. The temperature was increased at a rate of 2°C/min.

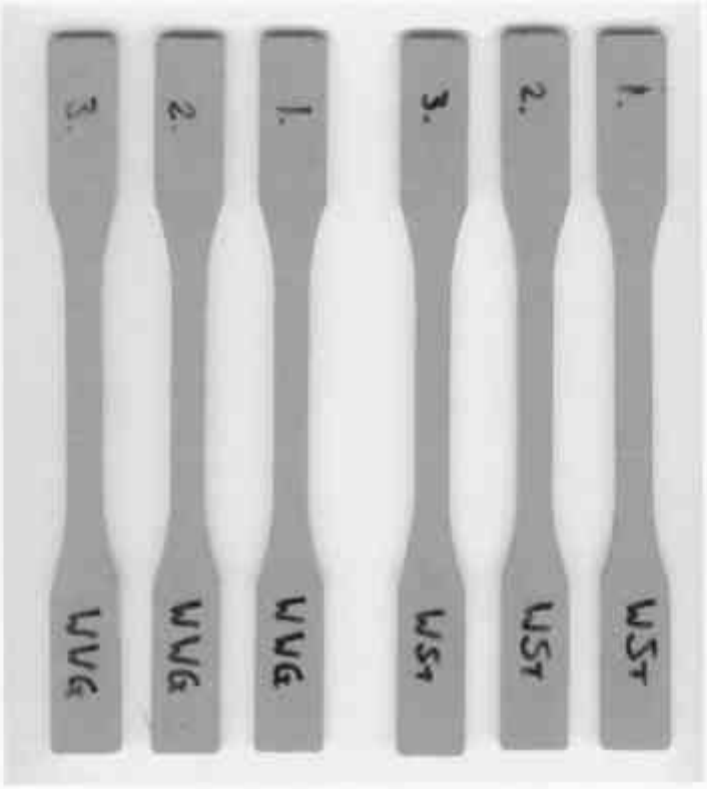

Figure 1. Dumb bell specimens prior to test

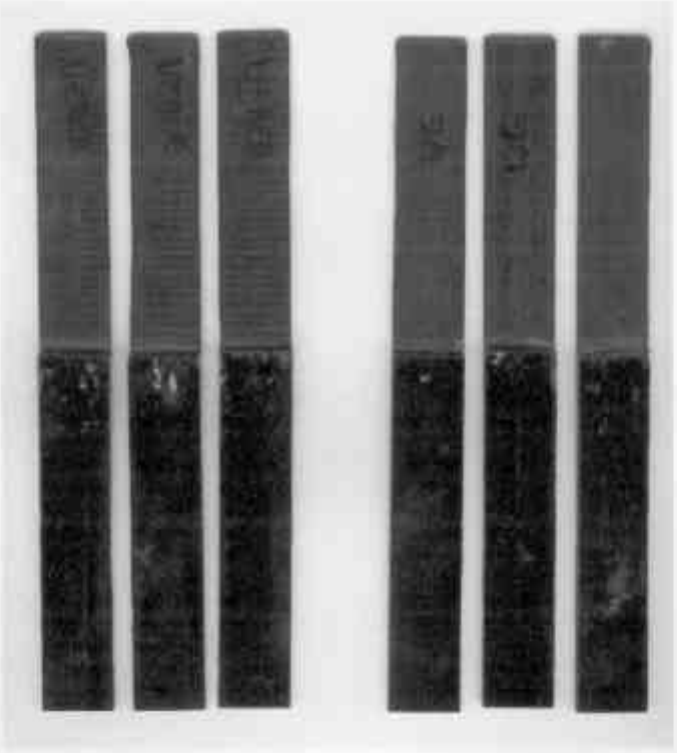

Figure 2. Single lap shear specimens prior to test

Results

Below is a summary table of the results, averaged to 1 decimal place (See Table 1). A complete set of results is provided in the Appendix. Photographs of the failed dumb bell and lap shear specimens are shown in Figures 3 and 4 respectively, and failed double lap shear specimens in Figures 5 and 6 respectively.

TABLE 1. SUMMARY TABLE OF RESULTS (averaged to 1 decimal place)

Test	*Units*	*Standard Grade*	*Winter Grade*
Tensile Strength	**(MPa)**	**27.0**	**25.4**
Tensile Modulus	**(GPa)**	**7.7**	**7.0**
Flexural Modulus	**(GPa)**	**7.6**	**7.1**
Single Lap Shear Strength (CFRP)	**(MPa)**	**18.9**	**17.9**
Double Lap Shear Strength (Steel)	**(MPa)**	**21.2**	**19.5**
DMTA T_g (20°C cure)	**(°C)**	**58.1**	**58.4**
DMTA T_g (30°C cure)	**(°C)**	**63.3**	**63.3**
HDT	**(°C)**	**51.7**	**51.8**

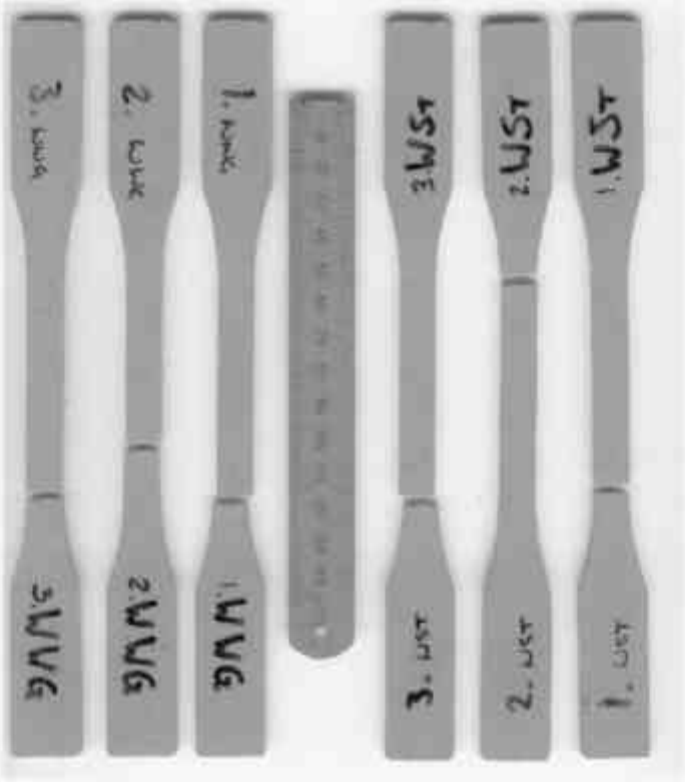

Figure 3. Dumb bell specimens after test

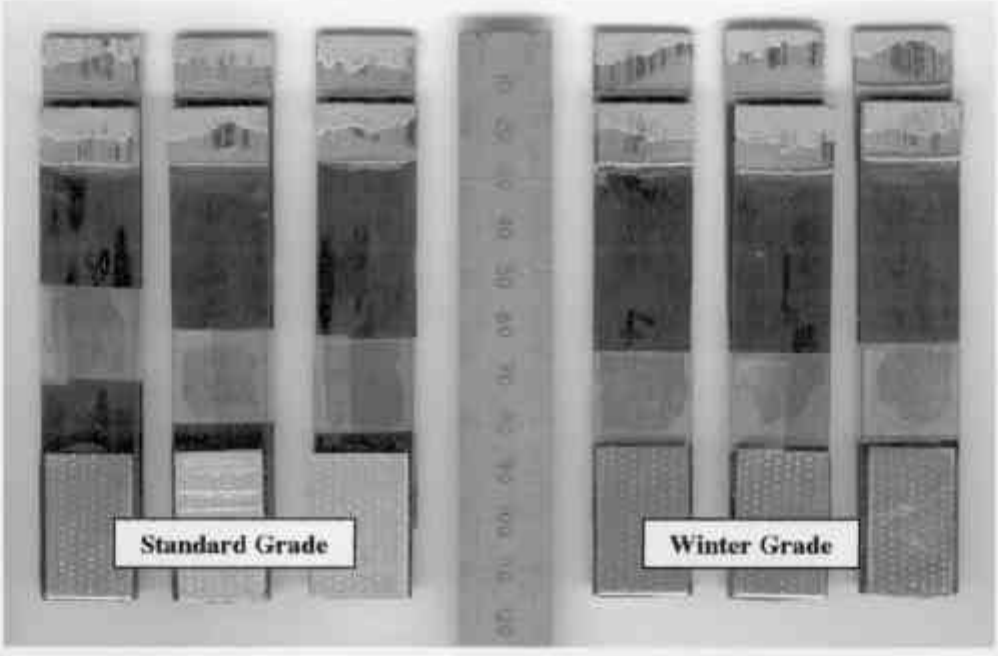

Figure 4. Single lap shear specimens after test

Figure 5. Double lap shear specimens after test (Standard Grade)

Figure 6. Double lap shear specimens after test (Winter Grade)

APPENDIX

TENSILE DUMB BELL RESULTS

Test Date:	08/03/2002
Test Speed:	1mm/min.
Gauge Length:	50mm
Load Cell:	5kN
Cured Temperature	20°C

Specimen Identification	Cure Period (days)	Tensile Modulus (GPa)	Tensile Strength (MPa)	Locus of Failure
ST 1	7	7.86	26.3	Failed O.G.L
ST 2	7	7.45	26.9	Failed O.G.L
ST 3	7	7.69	27.9	Failed O.G.L
	Mean	**7.67**	**27.0**	
WG 1	7	5.77	24.6	Failed O.G.L
WG 2	7	7.65	25.0	Failed O.G.L
WG 3	7	7.56	26.7	Failed O.G.L
	Mean	**6.99**	**25.4**	

Note: Failed O.G.L.= Specimen Failed **O**utside **G**auge **L**ength.

FLEXURAL PRISM RESULTS

Test Date:	05/06/2002
Test Speed:	1mm/min.
Load Cell:	5kN
Span Length:	180mm
Cured Temperature	20°C

Specimen Identification	Cure Period (days)	Specimen Thickness (mm)	Specimen Width (mm)	Tensile Modulus (GPa)	Tensile Load to Failure (N)	Locus of Failure
ST 1	12	11.95	24.84	7.553	650	W.C.L.P
ST 2	12	12.14	24.99	7.348	678	W.C.L.P
ST 3	12	11.91	25.14	7.887	652	W.C.L.P
			Mean	**7.596**	**660**	
WG 1	12	12.02	25.37	6.870	585	W.C.L.P
WG 2	12	11.93	25.45	7.623	608	W.C.L.P
WG 3	12	11.98	25.34	6.781	580	W.C.L.P
			Mean	**7.091**	**591**	

Note: Failed W.C.L.P; Specimen Failed **W**ithin **C**entral **L**oad **P**oints.

SINGLE LAP SHEAR RESULTS (UD CFRP)

Test Date: 08/03/2002
Test Speed: 1mm/min.
Adherend Thickness: 1.5mm (nominal)
Load Cell: 5kN
Cure Temperature 20°C

Specimen Identification (JTRC)	Cure Period (days)	Bond Area (mm^2)	Tensile Shear Strength (MPa)	Locus of Failure
ST 1	7	246.1	18.2	95% Thin Layer Cohesive in the Adhesive & 5% Fibre pull-out
ST 2	7	237.6	19.0	
ST 3	7	237.7	19.4	
		Mean	**18.9**	
WG 1	7	252.5	17.5	90% Thin Layer Cohesive in the Adhesive & 10% Fibre pull-out
WG 2	7	268.9	17.3	
WG 3	7	232.6	18.9	
		Mean	**17.9**	

Note: Locus of failure was determined by visual inspection only.

DOUBLE LAP SHEAR RESULTS (STEEL)

Test Date: 0/0/2002
Test Speed: 1mm/min.
Adherend Thickness: 6mm (nominal)
Load Cell: 100kN
Cure Temperature 20°C

Specimen Identification (JTRC)	Cure Period (days)	Bond Area (mm^2)	Tensile Shear Strength (MPa)	Locus of Failure
ST 1	12	1986	20.8	100% Thin Layer Cohesive Failure in the Adhesive
ST 2	12	2019	17.9	
ST 3	12	2035	19.6	
		Mean	**19.5**	
WG 1	12	2086	20.8	100% Thin Layer Cohesive Failure in the Adhesive
WG 2	12	2030	21.9	
WG 3	12	2007	20.9	
		Mean	**21.2**	

Note: Locus of failure was determined by visual inspection only.

DYNAMIC MECHANICAL THERMAL ANALYSIS RESULTS (DMTA)

Test Date:	08/03/02
Frequency:	1 Hz
Strain:	x4
Test Configuration:	dual cantilever
Nominal specimen size:	32mm x 8mm x 3mm

Specimen Identification	Cure Temperature (°C)	Cure Period (days)		T_g Value (°C)
ST 1	20	7		57.96
ST 2	20	7		58.25
ST 3	20	7		58.05
			Mean	**58.09**
WG 1	20	7		58.21
WG 2	20	7		58.49
WG 3	20	7		58.58
			Mean	**58.43**
ST 4	30	12		63.01
ST 5	30	12		63.54
ST 6	30	12		63.54
			Mean	**63.30**
WG 4	30	12		63.29
WG 5	30	12		63.36
WG 6	30	12		63.38
			Mean	**63.34**

HEAT DISTORTION TEMPERATURE RESULTS (HDT)

Test Date:	05/06/2002
Applied Stress:	1.8MPa.
Maximum Deflection:	0.35mm
Temperature ramp rate:	2°C/min.
Cure Temperature	20°C

Specimen Identification (JTRC)	Cure Period (days)	Specimen Thickness (mm)	Specimen Width (mm)	Initial Temperature (°C)	HDT Temperature (°C)	Remarks
ST 1	12	3.90	10.11	20.6	52.0	within 2°C
ST 2	12	3.98	10.01	20.6	51.0	
ST 3	12	3.90	10.20	21.0	52.0	
				Mean	**51.67**	
WG 1	12	4.01	10.10	22.6	52.4	within 2°C
WG 2	12	4.03	10.09	21.7	51.6	
WG 3	12	3.96	9.97	21.2	51.5	
				Mean	**51.83**	