

**Clock Spring Contour
Qualification Data as Required by ISO TS 24817**

**Test Report
For work undertaken by
Oxford Brookes University**

**Report No. JTRC/CS/01-2007
January 2007**

**Work undertaken for: Clock Spring Company, L.P.
14107 Interdrive West
Houston
Texas
77032 USA**

To Order No.: SM82306-PH1

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Summary of Test Data

Material: Clock Spring Contour
Resin: CS600A/B
Fabric: Four layer, stitched glass fibre fabric

CLOCK SPRING CONTOUR ISO TS 24817 QUALIFICATION DATA		
QUALIFICATION REQUIREMENT	RESULT	RESULT
Ply or layer thickness	2.1mm	0.0827 inch
Tensile modulus (circumferential)	11.0 GPa	1.60 x 10 ⁶ psi
Tensile modulus (axial)	10.8 GPa	1.57 x 10 ⁶ psi
Tensile Strain to failure (circumferential)	1.8 %	1.8%
Tensile Strain to failure (axial)	1.9 %	1.9%
Tensile Strength (circumferential)	147 MPa	21.3 ksi
Tensile Strength (axial)	149 MPa	21.6 ksi
Thermal expansion coefficient (circumferential)	15.7 x 10 ⁻⁶ °C ⁻¹	8.7 x 10 ⁻⁶ F ⁻¹
Thermal expansion coefficient (axial)	15.7 x 10 ⁻⁶ °C ⁻¹	8.7 x 10 ⁻⁶ F ⁻¹
Poisson's ratio (circumferential)	0.29	0.29
Poisson's ratio (axial)	0.30	0.30
Shear Modulus (resin)	1.1 GPa	0.159 x 10 ⁶ psi
Barcol/Shore Hardness	82.5 shore D	82.5 shore D
Glass Transition	99°C	210°F
Lap Shear Strength to Steel	10.0 MPa	1450 psi
Aged Lap Shear Strength (1000 hours in 93 °C water)	9.3 MPa	1349 psi
Fracture Toughness, γ_{LCL}	149 Jm ⁻²	0.851in lbf/in ²

Measurement of tensile properties

Cure Conditions

Date: 14/11/2006
De-ionised Water: n/a
Temperature: 23 °C
Humidity: 60 %
Period: 0 hours
Test Date: 14/12/2006

Test Set-up

Test Machine: Nene Universal Tester
Load Cell: 100kN
Extensometer: LVDT (0.01 Resolution)
Gauge Length: 50mm
Test Speed: 2mm/min.
End Tabs: GFRP Quad (3 ply - Tapered)

Specimen Length: 300mm
Specimen Width: 25mm
Specimen Thickness: 2-ply
Strain Gauge: EA-06-060RZ-120
Gauge Length: 3mm
Gauge Factor: 2.06
Gauge Resistance: 120ohms
Data Logger: Spider8

Sample ID QUAD	Width (mm)	Thickness (mm)	CSA (mm ²)	Load to Failure (kN)	Tensile Strength (N/mm ²)	Tensile Modulus (kN/mm2)	Poisson's Ratio	Strain to failure (%)	Mode of Failure
Q1-A	25.38	3.46	87.81	13.20	150.32	9.58	-0.25		Transverse within free length
Q1-B	24.89	3.66	91.10	13.25	145.45	11.20	-0.30		Transverse within free length
Q1-C	24.90	3.72	92.63	13.79	148.88	12.11	-0.33		End tab failure
Q1-D	24.98	3.63	90.68	12.92	142.48	11.21		2.161	End tab failure
Q1-E	24.99	3.65	91.21	13.09	143.51	10.09		1.693	End tab failure
Q1-F	24.95	3.41	85.08	12.75	149.86	11.55		1.672	End tab failure
Mean	25.02	3.59	89.75	13.17	146.75	10.96	-0.29	1.84	2-direction
SD	0.18	0.12	2.78	0.36	3.39	0.94	0.04	0.28	

Sample ID QUAD	Width (mm)	Thickness (mm)	CSA (mm ²)	Load to Failure (kN)	Tensile Strength (N/mm ²)	Tensile Modulus (kN/mm2)	Poisson's Ratio	Strain to failure (%)	Mode of Failure
Q2-A	24.99	4.24	105.96	15.72	148.36	10.59	-0.30		End tab failure
Q2-B	24.96	4.06	101.34	15.39	151.87	8.66	-0.28		End tab failure
Q2-C	24.91	4.0	99.14	14.86	149.89	11.27	-0.31		End tab failure
Q2-D	25.02	4.1	101.33	15.63	154.25	13.76		2.009	End tab failure
Q2-E	24.97	4.1	102.63	15.15	147.62	10.45		1.934	End tab failure
Q2-F	24.98	4.00	99.92	13.94	139.51	9.81		1.789	End tab failure
Mean	24.97	4.07	101.72	15.12	148.58	10.76	-0.30	1.91	1-direction
SD	0.04	0.09	2.41	0.66	5.06	1.71	0.01	0.11	

Sample ID	Stress (N/mm2)	Longitudinal micro-strain	Transverse micro-strain	Poisson's Ratio	Mean Poisson's Ratio	Tensile Modulus (N/mm2)		
Q1B	20.04	1726	-520	-0.3013		11609		
	40.07	3715	-1110	-0.2988		10786	11197	11.20
Q1C	20.13	1657	-541	-0.3265		12148		
	40.06	3319	-1093	-0.3293		-0.33	12070	12109
Q1A	20.01	2095	-506	-0.2415		9553		
	40.03	4170	-1060	-0.2542		-0.25	9599	9576
Q2A	20.03	1889	-577	-0.3055		10603		
	35.02	3312	-998	-0.3013		-0.30	10574	10589
Q2B	20.17	2375	-667	-0.2808		8491		
	40.14	4547	-1314	-0.2890		-0.28	8827	8659
Q2C	20.01	1750	-538	-0.3074		11436		
	40.03	3603	-1126	-0.3125		-0.31	11109	11273

Samples Q1 Tested in Circumferential Direction
Samples Q2 Tested in Axial Direction

TENSILE TEST RESULTS IN GENERAL ACCORDANCE WITH ASTM D3039

Measurement of lap shear strengths (short term and after 1000 hour exposure in water)

Plate 1 - DRY

Date made: 07/11/2006
 Conditions: DRY
 Cure (both plates): 46 hrs 24°C
 Test temps: 24°C / 43%rh
 Period: 24 hours
 Test date: 09/11/2006

Sample ID Plate 1	Width (mm)	Overlap (mm)	CSA (mm ²)	Load to Failure (kN)	Shear Strength (N/mm ²)
L1-B	25.41	12.3	313	3.19	10.20
L2-C	25.36	12.4	314	Broke before test	
L4-D	25.45	12.5	318	Broke before test	
L3-E	25.66	12.6	323	1.17	3.63
L5-F	25.34	12.2	309	4.08	13.20
L6-G	25.29	12.3	311	3.97	12.78
mean	25.42	12.38	315	3.10	9.95
SD	0.13	0.15	5	1.35	4.42

Plate 2 -WET

Date made: 07/11/2006
 De-ionised water: 5.2µS
 Temperature: 93°C
 Humidity: Immersed in water
 Period: 1000 hours
 Test date: 20/12/2006

Sample ID Plate 2	Width (mm)	Overlap (mm)	CSA (mm ²)	Load to Failure (kN)	Shear Strength (N/mm ²)
L1-B	25.37	12.2	309.01	2.88	9.31
L2-C	25.44	12.0	306.30	3.15	10.29
L4-D	25.76	12.7	326.38	2.88	8.81
L3-E			0.00	Broke before test	
L5-F	25.36	12.5	316.75	2.74	8.65
L6-G			0.00	Broke before test	
mean	25.48	12.35	210	2.91	9.26
SD	0.19	0.29	163	0.17	0.74

LAP SHEAR TEST RESULTS IN GENERAL ACCORDANCE WITH BS EN 1465 - 1995

Measurement of fracture toughness parameter, γ_{LCL}

Leak tests

Laminate thickness: 6.7mm (5-ply)
 Pressure fitting: 1/4" bsp
 Cure: 7 days at ambient (23°C±2, 50% RH ±5)
 Surface preparation: Grit blast with P60 Alumina
 Surface roughness: Medium (50µm)
 Test temperature: 22.4°C / 44% rh
 Test rate: ~200 bar per minute (closed-loop control)
 Test date: 31/10/2006

Sample ID	Surface Roughness (µm)	Hole Diameter (mm)	Failure Pressure (bar)
LT 1	50	25	72
LT 2	48	25	56
LT 3	52	25	71
mean	50	25	66
sd	2	0	9

Sample ID	Surface Roughness (µm)	Hole Diameter (mm)	Failure Pressure (bar)
LT 4	60	20	78
LT 5	48	20	68
LT 6	56	20	73
mean	55	20	73
sd	6	0	5

Sample ID	Surface Roughness (µm)	Hole Diameter (mm)	Failure Pressure (bar)
LT 7	46	15	80
LT 8	59	15	117
LT 9	50	15	127
mean	52	15	108
sd	7	0	25

LEAKAGE TEST RESULTS IN ACCORDANCE WITH ISO TS 24817 ANNEX D

Calculation of γ_{LCL}

Test data

Test No.	Defect diameter (mm)	Pressure (bar)	Repair thickness (mm)
LT1	25	72	6.7
LT2	25	56	6.7
LT3	25	71	6.7
LT4	20	78	6.7
LT5	20	68	6.7
LT6	20	73	6.7
LT7	15	80	6.7
LT8	15	117	6.7
LT9	15	127	6.7

Material constants

Combined Tensile modulus, E_{sc} (GPa)	10.9
Poissons ratio, ν	0.29
Shear modulus, G (GPa)	1.1

Repair data

Average thickness (mm)	6.70
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Design data

Service factor	1
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Defect diameter (mm)	Repair thickness (mm)	A_i for hole	Pressure (bar)	Pressure (N/m ²)	$P_r P_{pred}$	γ (J/m ²)
25	6.70	4.35E+05	72	7.20E+06	8.80E+05	274.13
25	6.70	4.35E+05	56	5.60E+06	-7.20E+05	165.83
25	6.70	4.35E+05	71	7.10E+06	7.80E+05	266.57
20	6.70	5.47E+05	78	7.80E+06	-1.48E+05	203.44
20	6.70	5.47E+05	68	6.80E+06	-1.15E+06	154.62
20	6.70	5.47E+05	73	7.30E+06	-6.48E+05	178.20
15	6.70	7.22E+05	80	8.00E+06	-2.50E+06	122.68
15	6.70	7.22E+05	117	1.17E+07	1.20E+06	262.41
15	6.70	7.22E+05	127	1.27E+07	2.20E+06	309.18
		Number of data point	9	Mean		
		Sum A_i	5.11E+06	5.68E+05		
		Sum P_i	7.42E+07	8.24E+06		
		Sum A_i^2	3.02949E+12			
		Sum $A_i P_i$	4.40314E+13			
		γ (J/m ²) - mean	211.245			
		σ^2	2.31E+12			
		97.5% student t value	2.685			
		γ_{LCL} (J/m ²)	148.544			

Fracture toughness of repair, γ_{mean} (J/m ²)	211.2
Fracture toughness of repair, γ_{LCL} (J/m ²)	148.5

CALCULATION OF γ USING ANALYSIS IN ISO TS 24817

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Summary of Test Data

Material: Clock Spring Contour
Resin: CS600A/B
Fabric: Two layer, 0/90 glass fibre fabric

CLOCK SPRING CONTOUR ISO TS 24817 QUALIFICATION DATA		
QUALIFICATION REQUIREMENT	RESULT	RESULT
Ply or layer thickness	2.1mm	0.0827 inch
Tensile modulus (axial)	9.1 GPa	1.32 x 10 ⁶ psi
Tensile modulus (circumferential)	14.4 GPa	2.09 x 10 ⁶ psi
Tensile Strain to failure (axial)	2.7 %	2.7 %
Tensile Strain to failure (circumferential)	1.8 %	1.8 %
Tensile Strength (axial)	138 MPa	20.1 ksi
Tensile Strength (circumferential)	153 MPa	22.3 ksi
Thermal expansion coefficient (axial)	25.6 x 10 ⁻⁶ °C ⁻¹	13.9 x 10 ⁻⁶ F ⁻¹
Thermal expansion coefficient (circumferential)	20.0 x 10 ⁻⁶ °C ⁻¹	11.0 x 10 ⁻⁶ F ⁻¹
Poisson's ratio (axial)	0.07	0.07
Poisson's ratio (circumferential)	0.11	0.11
Shear Modulus (resin)	1.1 GPa	0.159 x 10 ⁶ psi
Barcol/Shore Hardness	82.5 shore D	82.5 shore D
Glass Transition	99°C	210°F
Lap Shear Strength to Steel	10.0 MPa	1450 psi
Aged Lap Shear Strength (1000 hours in 93 °C water)	9.3 MPa	1349 psi
Fracture Toughness, γ_{LCL}	149 Jm ⁻²	0.851in lbf/in ²

Note: material directional properties referrer to pipe axes

Measurement of tensile properties

Tested on 17/11/2006

Cure Conditions

Date: 14/11/2006
 De-ionised Water: n/a
 Temperature: 23 °C
 Humidity: 60 %
 Period: 0 hours
 Test Date: 14/12/2006

Test Set-up

Test Machine: Nene Universal Tester
 Load Cell: 100kN
 Extensometer: LVDT (0.01 Resolution)
 Gauge Length: 50mm
 Test Speed: 2mm/min.
 End Tabs: GFRP Quad (3 ply - Tapered)
 Specimen Length: 300mm
 Specimen Width: 25mm
 Specimen Thickness: 2-ply
 Strain Gauge: EA-06-060RZ-120
 Gauge Length: 3mm
 Gauge Factor: 2.06
 Gauge Resistance: 120ohms
 Data Logger: Spider8

Sample ID	Width (mm)	Thickness (mm)	CSA (mm ²)	Load to Failure (kN)	Tensile Strength (N/mm ²)	Tensile Modulus Ext (kN/mm ²)	Normalised (kN/mm ²)	Tensile Modulus Gauge (kN/mm ²)	Normalised (kN/mm ²)	Poisson's Ratio	Normalised Value	Strain to failure (%)	Mode of Failure
NCF 0/90						8.97	14.05	12.84	20.12	-0.20	-0.13	3.315	
PL1-A	24.83	4.64	115.21	13.02	113.01								End tab failure
PL1-B	24.85	4.31	107.10	15.81	147.61								End tab failure
PL1-C	25.01	4.47	111.79	15.37	137.48	9.56	14.99					2.274	End tab failure
PL1-D	24.81	4.24	105.19	14.83	140.98			13.02	20.40	-0.18	-0.11		Transverse within free length
PL1-E	24.81	4.24	105.19	15.32	145.64			10.40	16.30	-0.13	-0.08		Transverse within free length
PL1-F	24.95	4.40	109.78	15.79	143.83	8.7	13.63					2.526	End tab failure
Mean	24.88	4.38	109.05	15.02	138.09	9.08	14.22	12.08	18.94	-0.17	-0.11	2.71	2-direction
SD	0.08	0.16	3.99	1.05	12.79	0.44	0.69	1.46	2.29	0.03	0.02	0.54	

Sample ID	Width (mm)	Thickness (mm)	CSA (mm ²)	Load to Failure (kN)	Tensile Strength (N/mm ²)	Tensile Modulus Ext (kN/mm ²)	Normalised (kN/mm ²)	Tensile Modulus Gauge (kN/mm ²)	Normalised (kN/mm ²)	Poisson's Ratio	Normalised Value	Strain to failure (%)	Mode of Failure
NCF 0/90													
PL2-A	24.87	4.21	104.70	18.51	176.79			13.09	20.52	-0.19	-0.079		Longitudinal splitting of fibres
PL2-B	25.08	4.13	103.58	20.40	196.95	15.68	24.57					2.044	Longitudinal splitting of fibres
PL2-C	25.06	4.04	101.24	19.01	187.77			12.21	19.14	-0.17	-0.070		Longitudinal splitting of fibres
PL2-D	25.00	4.31	107.75		0.00			13.79	21.61	-0.17	-0.053		Longitudinal splitting of fibres
PL2-E	24.98	4.16	103.92	18.77	180.63	14.18	22.22					1.902	Longitudinal splitting of fibres
PL2-F	25.08	4.09	102.58	17.74	172.94	13.47	21.11					1.534	Longitudinal splitting of fibres
Mean	25.01	4.16	103.96	18.89	152.51	14.44	22.64	13.03	20.42	-0.18	-0.07	1.83	1-direction
SD	0.08	0.10	2.21	0.97	75.20	1.13	1.77	0.79	1.24	0.01	0.01	0.26	

Sample ID	Stress (N/mm ²)	Longitudinal micro-strain	Transverse micro-strain	Poisson's Ratio	Normalised Value	Mean Poisson's Ratio	Normalised Value	Tensile Modulus (N/mm ²)
PL1B	20.01	1571	-313	-0.1992				12736
	40.02	3093	-616	-0.1992	-0.20	-0.13		12938
PL1D	20.37	1548	-273	-0.1764				13159
	40.18	3119	-555	-0.1779	-0.18	-0.11		12881
PL1E	20.93	2047	-273	-0.1334				10225
	40.18	3801	-512	-0.1347	-0.13	-0.08		10571
PL2A	20.08	1543	-296	-0.1918				13014
	40.18	3050	-570	-0.1869	-0.19	-0.079		13172
PL2C	20.19	1698	-287	-0.1690				11888
	35.08	2798	-471	-0.1683	-0.17	-0.070		12538
PL2D	20.07	1426	-238	-0.1669				14074
	40.14	2972	-498	-0.1676	-0.17	-0.053		13506
								13790
								13790

Samples PL1 Tested in Axial Direction
 Samples PL2 Tested in Circumferential Direction

TENSILE TEST RESULTS IN GENERAL ACCORDANCE WITH ASTM D3039