

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

<b>CLOCK SPRING CONTOUR ISO TS 24817 QUALIFICATION DATA</b>		
QUALIFICATION REQUIREMENT	RESULT	RESULT
Ply or layer thickness	2.1mm	0.0827 inch
Tensile modulus (circumferential)	11.0 GPa	1.60 x 10 <sup>6</sup> psi
Tensile modulus (axial)	10.8 GPa	1.57 x 10 <sup>6</sup> 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 <sup>-6</sup> °C <sup>-1</sup>	8.7 x 10 <sup>-6</sup> F <sup>-1</sup>
Thermal expansion coefficient (axial)	15.7 x 10 <sup>-6</sup> °C <sup>-1</sup>	8.7 x 10 <sup>-6</sup> F <sup>-1</sup>
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 <sup>6</sup> 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, $\gamma_{LCL}$	149 Jm <sup>-2</sup>	0.851in lbf/in <sup>2</sup>

## 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 <sup>2</sup> )	Load to Failure (kN)	Tensile Strength (N/mm <sup>2</sup> )	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
<b>Mean</b>	<b>25.02</b>	<b>3.59</b>	<b>89.75</b>	<b>13.17</b>	<b>146.75</b>	<b>10.96</b>	<b>-0.29</b>	<b>1.84</b>	<b>2-direction</b>
<b>SD</b>	<b>0.18</b>	<b>0.12</b>	<b>2.78</b>	<b>0.36</b>	<b>3.39</b>	<b>0.94</b>	<b>0.04</b>	<b>0.28</b>	

Sample ID QUAD	Width (mm)	Thickness (mm)	CSA (mm <sup>2</sup> )	Load to Failure (kN)	Tensile Strength (N/mm <sup>2</sup> )	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
<b>Mean</b>	<b>24.97</b>	<b>4.07</b>	<b>101.72</b>	<b>15.12</b>	<b>148.58</b>	<b>10.76</b>	<b>-0.30</b>	<b>1.91</b>	<b>1-direction</b>
<b>SD</b>	<b>0.04</b>	<b>0.09</b>	<b>2.41</b>	<b>0.66</b>	<b>5.06</b>	<b>1.71</b>	<b>0.01</b>	<b>0.11</b>	

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 <b>Plate 1</b>	Width (mm)	Overlap (mm)	CSA (mm <sup>2</sup> )	Load to Failure (kN)	Shear Strength (N/mm <sup>2</sup> )
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
<b>mean</b>	<b>25.42</b>	<b>12.38</b>	<b>315</b>	<b>3.10</b>	<b>9.95</b>
<b>SD</b>	<b>0.13</b>	<b>0.15</b>	<b>5</b>	<b>1.35</b>	<b>4.42</b>

### 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 <b>Plate 2</b>	Width (mm)	Overlap (mm)	CSA (mm <sup>2</sup> )	Load to Failure (kN)	Shear Strength (N/mm <sup>2</sup> )
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	
<b>mean</b>	<b>25.48</b>	<b>12.35</b>	<b>210</b>	<b>2.91</b>	<b>9.26</b>
<b>SD</b>	<b>0.19</b>	<b>0.29</b>	<b>163</b>	<b>0.17</b>	<b>0.74</b>

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

## Measurement of fracture toughness parameter, $\gamma_{LCL}$

### 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
<b>mean</b>	<b>50</b>	<b>25</b>	<b>66</b>
<b>sd</b>	<b>2</b>	<b>0</b>	<b>9</b>

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
<b>mean</b>	<b>55</b>	<b>20</b>	<b>73</b>
<b>sd</b>	<b>6</b>	<b>0</b>	<b>5</b>

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
<b>mean</b>	<b>52</b>	<b>15</b>	<b>108</b>
<b>sd</b>	<b>7</b>	<b>0</b>	<b>25</b>

LEAKAGE TEST RESULTS IN ACCORDANCE WITH ISO TS 24817 ANNEX D

## Calculation of $\gamma_{LCL}$

**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, $\nu$	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 <sup>2</sup> )	$P_r P_{pred}$	$\gamma$ (J/m <sup>2</sup> )
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			
		$\gamma$ (J/m <sup>2</sup> ) - mean	211.245			
		$\sigma^2$	2.31E+12			
		97.5% student t value	2.685			
		$\gamma_{LCL}$ (J/m <sup>2</sup> )	148.544			

Fracture toughness of repair, $\gamma_{mean}$ (J/m <sup>2</sup> )	211.2
Fracture toughness of repair, $\gamma_{LCL}$ (J/m <sup>2</sup> )	148.5

## CALCULATION OF $\gamma$ USING ANALYSIS IN ISO TS 24817