



CVM™ – Demonstration over Aircraft Surface Finishes

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Commercial-in-Confidence

A series of experimental tests have been conducted to ascertain the sensitivity of the Comparative Vacuum Monitoring (CVM™) technique for detecting crack propagation in metallic specimens coated with a variety of different aircraft paint surface finish schemes.

Analysis of the experimental results indicates that detection of the crack front was achieved in all cases. Detection of the crack is unaffected by the presence of primer or a single layer of new or aged paint. Multiple layers of paint caused a linear increase in the delay of crack detection. However, aging the paint improved the accuracy of the measurement by approximately 0.2 mm and the maximum measured delay in crack tip measurement was less than 1 mm with three layers of new topcoat (105 µm total thickness).

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Amendments

<i>Issue Number</i>	<i>Amendment</i>	<i>Date</i>
Issue 1	Initial issue	March 2002
Issue 2	Introduction of CVM term into text	April 2002
Issue 3	Text changes for new Figures 4, 5, 6 and 7	May 2002

List of Effective Pages

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Executive Summary	<i>iii</i>	Issue 2
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Executive Summary

A series of experimental tests have been conducted to ascertain the sensitivity of the Comparative Vacuum Monitoring (CVM™) technique offered by Structural Monitoring Systems Ltd (SMS) when detecting crack propagation in painted aluminium specimens. The specimens had a variety of aircraft paint surface finish schemes in order to evaluate the capability of the CVM technique.

Analysis of the experimental results indicates that the crack front is detected though the various finish schemes. However, the sensitivity of the technique is influenced by multiple topcoat layers.

- The presence of primer coat (to a primer thickness of 60 μm) does not effect the detection of the crack.
- The presence of one coat of polyurethane (fresh or aged), such that the total paint thickness is less than 60 μm , similarly did not delay the detection of the crack tip detection.
- The presence of multiple polyurethane topcoats with a total thickness greater than 60 μm caused an increase in the delay of crack tip detection. The delay in detection is linearly related to the total paint thickness, however aging the paint improved the accuracy of the measurement by approximately 0.2 mm.

In all cases, the paint is acting as an unwanted sensor sealant. Increased stiffness of the paint through aging assists in early fracture of the paint (i.e. at the same time as the aluminium substrate) and thus improves the accuracy of crack detection.

The maximum average difference measured with a freshly painted polyurethane topcoat was 0.9 mm \pm 0.2 mm for a 105 μm total paint thickness; the equivalent of three topcoats.

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1 AIM

The aim of the program was to ascertain the sensitivity of Comparative Vacuum Monitoring (CVM™) to detect the location of a crack in a metallic specimen during cyclic fatigue testing. The testing particularly focused on the sensitivity and accuracy of the CVM technique when employed on various paint surface finish schemes.

2 BACKGROUND

SMS has successfully deployed laboratory configurations of its patented Comparative Vacuum Monitoring (CVM) technique of structural integrity monitoring into research and testing facilities in Australia, USA and Europe. The company is now undertaking a number of activities to develop and demonstrate CVM for application to operational aircraft structures. The rationale for this investigation is to conduct a series of preliminary studies to determine the functionality of intended aircraft configurations of the CVM technology whereby the sensors are mounted over surface finishes in structural targeted areas. The preference for the application of this technology on aircraft structures is to avoid, wherever possible, surface finish removal in order to retain the integrity of the corrosion protection system.

3 EXPERIMENTAL EQUIPMENT

The following equipment was used in this test program. The equipment includes SMS specimens and sensing equipment and a testing machine and support equipment supplied by RMIT to apply the fatigue test spectrums.

- 100 kN MTS testing machine.
- Lap-top computer.
- 4 Individual identified specimens, not painted.
- 48 Individual identified specimens painted on one side only, comprising:
 - 4 examples of each of 3 paint systems, with 3 thicknesses of each paint system (36 non aged paint specimens) and
 - 4 examples of one paint system, with 3 thicknesses, the paint having been aged (12 aged paint specimens).
- Traveling microscope.
- Sensors and vacuum lines to connect the equipment to the test article.
- SMS Kvac 4 (S/N: 0005).
- SMS SIM 8b (S/N: 0015).
- Associated SMS ancillary equipment.

4 TESTING PROCEDURE

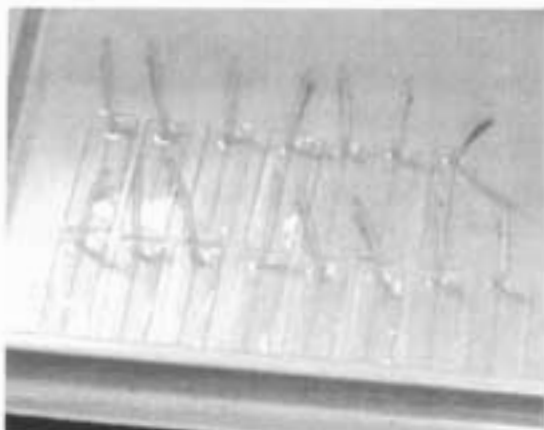
The following procedure was repeatedly employed to prepare and set-up the test specimens within the testing machine, conduct fatigue testing and measure as well as record the results.

Specimen Preparation and Set-up

1. Clean specimen surface by wiping it with isopropyl alcohol.
2. Use perspex guide to position the sensor.
3. Consolidate the sensor (Figure 1(a)) into position with the supplied roller.
4. Note specimen number and record this on both sides of the specimen.
5. Zero calibrate the SIM (Figure 1(b)).
6. Connect lap-top computer to SIM to record pressure history.
7. Place specimen within the MTS machine.
8. Set-up traveling microscope (Figure 2(a)).

Pre-Testing Phase

9. Apply a 9 kN load to the test specimen.
10. Record the distance from the inner edge of the gallery to the specimen edge, as well as the initial crack distance (Figure 2(b)).
11. Remove specimen from the machine.
12. Insert specimen back into the MTS but with other side facing the microscope.
13. Re-apply the 9 kN and record the distance of the initial crack length.
14. Compare Step 13 with Step 10 to ensure that the distances are comparable.
15. Connect the vacuum tube between the sensor and the SIM.
16. Connect the SIM to the Kvac using the supplied umbilical and turn the vacuum valve to "Supply".
17. Ensure that the SIM stabilizes to a reading less than 20 Pa, to ensure that a good seal is present.



(a)



(b)

Figure 1(a) Sensors as Supplied by SMS and (b) the SIM Fluid Flow Meter

Testing Phase

18. Initiate fatigue specimen testing using fatigue spectrum.
19. Once the alarm is tripped, stop test, record time, record number of cycles and crack propagation distance.
20. Halt sensor operation by clamping the gallery hose.

Notes

Fatigue spectrum:

- | | |
|--------------------|------------|
| - Target set point | = 4.725 kN |
| - Amplitude | = 4.725 kN |
| - Frequency | = 10 Hz |

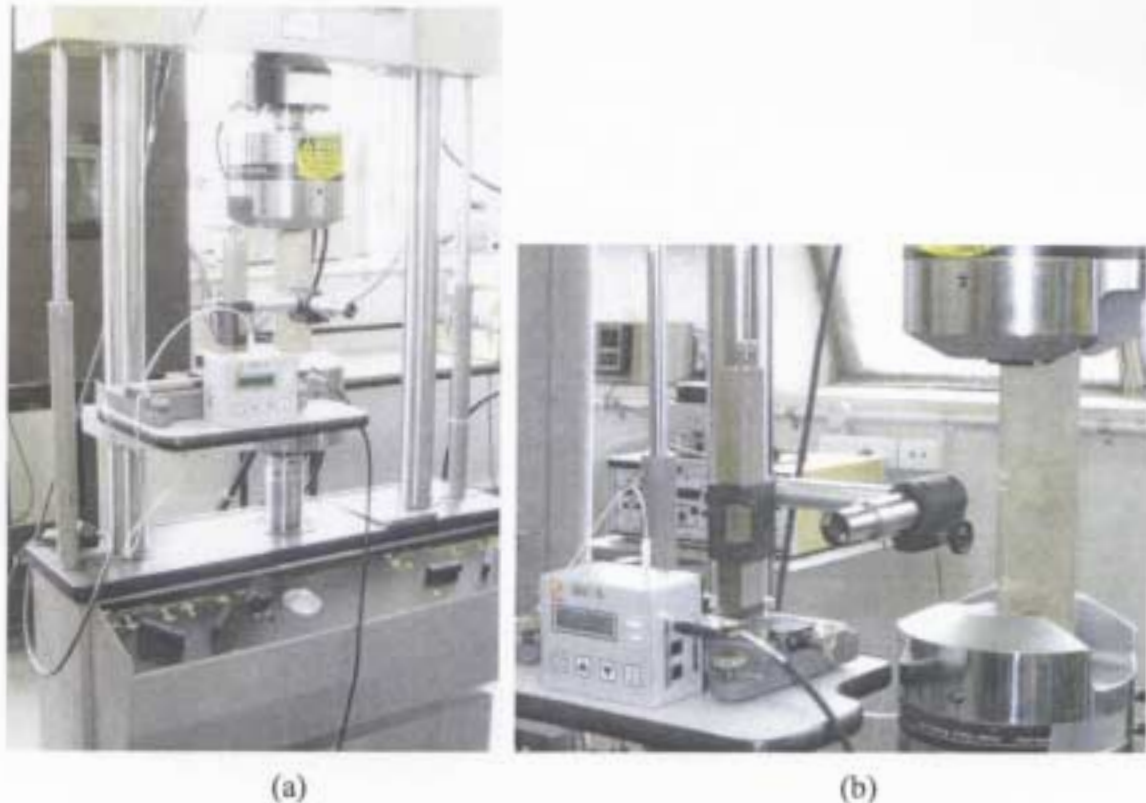


Figure 2(a) Experimental Set-up and (b) Close-up Showing the Position of the Traveling Mmicroscope, SIM and the Mounted Sensor

5 DISCUSSION OF THE RESULTS

Results of the experimental tests are shown in *Table 1 Experimental Test Results*. There are two main points associated with this table that needs clarification. Firstly, within each specimen batch supplied by SMS to RMIT there were five individual samples. Testing was always conducted with four of the five supplied samples with one kept as the control specimen. The main difference between each sample batch is the thickness of the applied paint scheme finish. *Table 2 Measuring Error as a Function of Systematic Error and Paint Thickness* provides a description of the sample batches.

To obtain the true systematic error present within the testing methodology, the test procedure was repeated using two un-painted specimens provided by SMS to RMIT as dummy samples. These results were used to obtain the systematic error as well as to act as control samples from which the painted specimens were compared. For these two specimens an error of $0.08 \text{ mm} \pm 0.02 \text{ mm}$ was measured.

However measurement error may be due to:

1. A difference in the position of the crack tip on either side of the coupon, ie due to uneven crack front tunneling.
2. A positioning error in the microscope.
3. An error in measuring the position of the gallery edge in relation to the edge of the coupon (directly related to the positioning error of the microscope).
4. "Actual" crack tip past "visible" crack tip measured by the microscope.
5. A delay in the CVM system reaching the alarm value.
6. A delay in the operator switching off the testing machine once the alarm is triggered (the automatic shut-off option was not used).

Errors 5 and 6 will result in a crack longer than the distance to the edge of the gallery being measured, as the crack will continue to grow past the gallery edge until the testing machine is turned off.

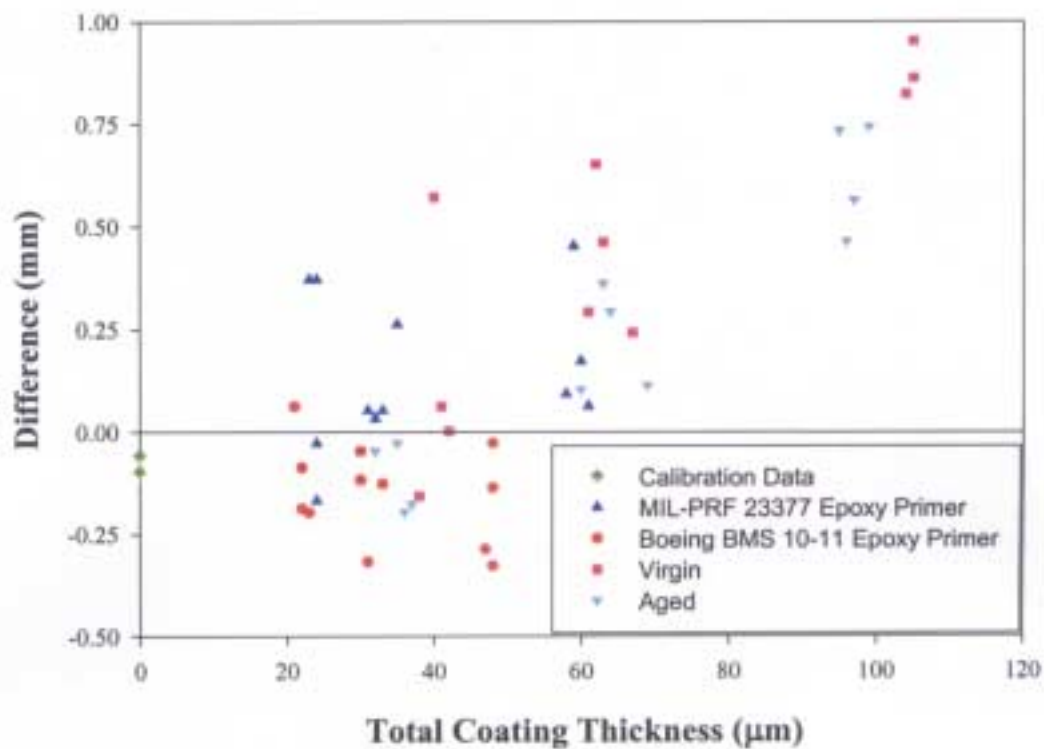


Figure 4 Graph Showing the Raw Data for the Difference between the Crack Tip Position Measured by the Microscope and the Gallery Edge Position

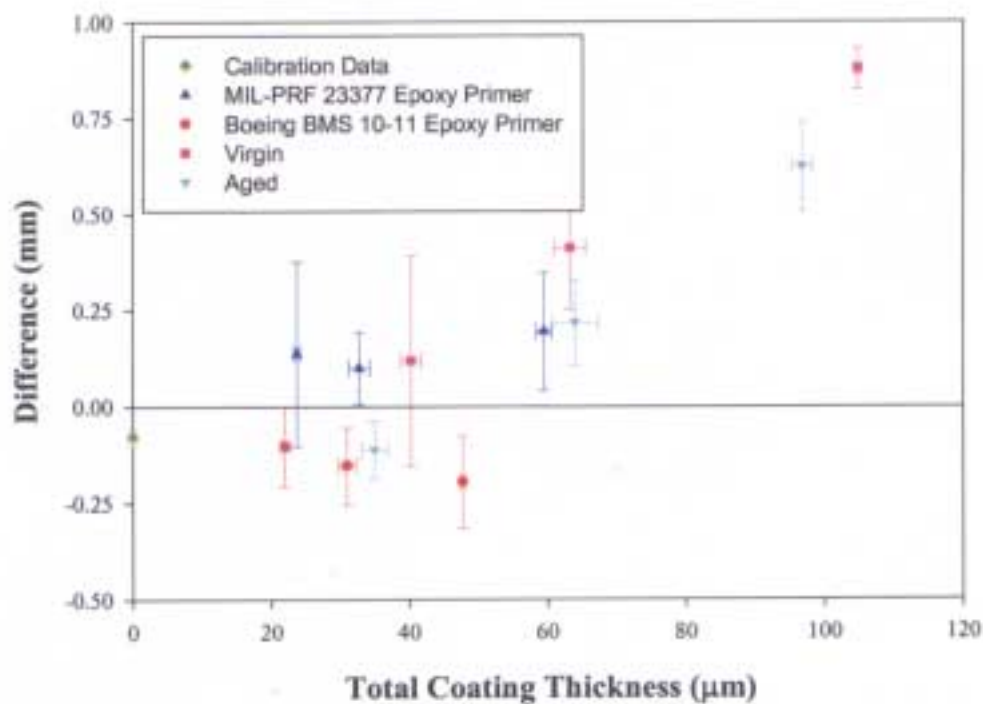


Figure 5 Graph Showing the Average Difference between the Crack Tip Position Measured by the Microscope and the Gallery Edge Position where Error Bars are the Standard Deviation for Each Measurement

Figures 4 and 5 illustrate the average difference between the crack tip position measured by the microscope and the gallery edge position. The difference value is the subtraction of the value measured by the microscope from the gallery position.

“Negative” values must be considered as measurement error as the CVM system cannot detect the crack until the tip reaches the gallery edge. As the two uncoated calibration coupons both gave a negative value for the difference, the negative values are not due to tunneling and/or the permeability of the paint system.

From the graphs, if the assumption is made that primer does not effect the detection position of the crack tip, the average difference (calculated using the calibration coupons and the coupons with the coated with primer) is $-0.011 \text{ mm} \pm 0.203 \text{ mm}$. Hence, the measurement error is $\pm 0.20 \text{ mm}$, with the small sample size a function of the nature of the test.

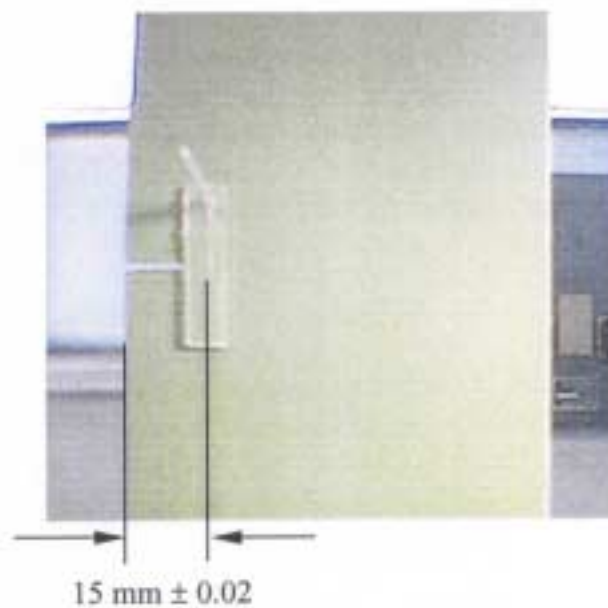


Figure 6 Profile View Showing the Position of the Gallery with Respect to Initial Crack Front

6 CONCLUSION

The CVM technique offered by Structural Monitoring Systems Ltd can be employed to detect fatigue crack propagation through painted aluminum materials.

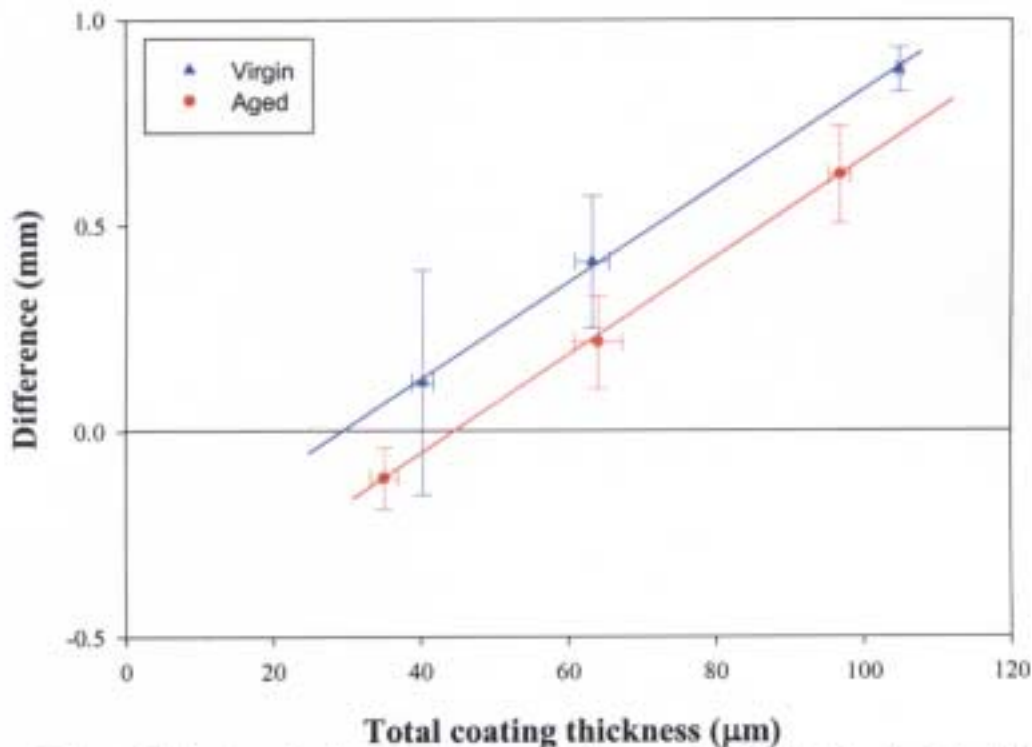


Figure 7 Graph Showing the Average Difference between the Crack Tip Position Measured by the Microscope and the Gallery Edge Position for the Coupons with a Polyurethane Top Coat where Error Bars are the Standard Deviation for Each Measurement

- The measurement error for this trial was determined to be ± 0.20 mm for all measurements.
- The presence of primer coat (to a primer thickness of $60 \mu\text{m}$) does not effect the detection of the crack.
- The presence of one coat of polyurethane (fresh or aged), such that the total paint thickness is less than $60 \mu\text{m}$, similarly did not delay the detection of the crack tip detection.
- The presence of polyurethane topcoats with a total thickness greater than $60 \mu\text{m}$ caused an increase in the delay of crack tip detection. The delay in detection is linearly related to the total paint thickness, however aging the paint delayed improved the accuracy of the measurement by approximately 0.2 mm.

All coupons with a polyurethane topcoat had a standard primer thickness of approximately $20 \mu\text{m}$. The maximum average difference measured with a freshly painted polyurethane topcoat was $0.9 \text{ mm} \pm 0.2 \text{ mm}$ for a $105 \mu\text{m}$ total paint thickness; the equivalent of three topcoats.

Table 1 Experimental Test Results

Reading	Coupon Number	Date	Start time	Material edge (mm)	Gallery edge (mm)	Edge to gallery (mm)	Microscope start (mm)	Microscope end (mm)	Microscope crack length (mm)	Cycles to Alarm	Cycles to Failure	Crack length difference (mm)
Column Label	A	B	C	(B-A)	D	E	F	(E-D)	G	H	I	(F-C)
1	1-1-2	10/22/01	16:00	104.65	120.23	15.58	107.67	123.08	15.41	25564	27795	-0.1700
2	1-1-3	10/22/01	9:20	107.00	122.29	15.29	105.69	120.95	15.26	22858	25358	-0.0300
3	1-1-4	10/22/01	10:24	103.14	118.18	15.04	106.95	122.36	15.41	29582	32756	0.3700
4	1-1-5	10/22/01	11:44	103.44	118.30	14.86	110.95	126.18	15.23	15850	17803	0.3700
5	1-2-2	10/22/01	13:35	101.33	116.42	15.09	105.30	120.65	15.35	19048	21588	0.2600
6	1-2-3	10/22/01	14:30	105.99	121.20	15.21	102.70	117.96	15.26	26333	30409	0.0500
7	1-2-4	10/22/01	14:00	102.28	120.45	18.17	97.90	116.12	18.22	24565	26356	0.0500
8	1-2-5	10/22/01	9:27	103.66	118.48	14.82	106.87	121.71	14.84	33079	35569	0.0300
9	1-3-2	10/22/01	15:06	100.97	116.03	15.06	102.20	117.35	15.15	39223	41929	0.0900
10	1-3-3	10/22/01	16:36	113.50	128.72	15.22	119.12	134.40	15.28	8104	8695	0.0600
11	1-3-4	10/22/01	11:07	118.35	133.19	14.84	119.30	134.59	15.29	11317	12207	0.4500
12	1-3-5	10/22/01	12:04	115.15	130.00	14.85	113.10	128.12	15.02	19271	20973	0.1700
13	2-1-2	10/22/01	15:08	113.34	128.43	15.09	118.31	133.31	15.00	8487	9569	-0.0900
14	2-1-3	10/22/01	15:47	119.77	134.60	14.83	118.59	133.48	14.89	9913	10540	0.0600
15	2-1-4	10/22/01	16:30	118.67	133.50	14.83	118.11	132.75	14.64	8823	9576	-0.1900
16	2-1-5	10/22/01	9:12	118.66	133.90	15.24	118.40	133.44	15.04	14090	15269	-0.2000
17	2-2-2	11/12/01	12:08	120.90	135.75	14.85	120.19	134.91	14.72	11829	12524	-0.1300
18	2-2-3	11/12/01	14:00	118.85	134.29	15.44	118.41	133.80	15.39	12591	13321	-0.0500
19	2-2-4	11/12/01	14:40	119.51	134.88	15.37	120.08	135.33	15.25	11254	12304	-0.1200
20	2-2-5	11/12/01	16:18	119.17	134.41	15.24	119.92	134.84	14.92	14051	15305	-0.3200
21	2-3-2	11/13/01	9:20	119.26	134.3	15.04	120.60	135.35	14.75	11077	12152	-0.2900
22	2-3-3	11/13/01	11:27	119.49	134.81	15.32	119.39	134.38	14.99	9327	10375	-0.3300
23	2-3-4	11/13/01	13:36	120.05	135.24	15.19	119.84	135.00	15.16	11145	11791	-0.0300
24	2-3-5	11/13/01	14:12	119.62	134.98	15.36	119.47	134.69	15.22	10811	11909	-0.1400

Notes:

(1) Columns A and B are referenced to the microscope based which is fixed throughout the experiments.

Table 1 Experimental Test Results (continued)

Reading	Coupon Number	Date	Start time	Material edge (mm)	Gallery edge (mm)	Edge to gallery (mm)	Microscope start (mm)	Microscope end (mm)	Microscope crack length (mm)	Cycles to Alarm	Cycles to Failure	Crack length difference (mm)
Column Label				A	B	C	D	E	F	G	H	I
				(mm)	(mm)	(B-A)	(mm)	(mm)	(D-E)	(mm)	(mm)	(F-C)
25	3-1-2	11/13/01	14:52	119.90	135.08	15.18	119.09	134.84	15.75	13211	14280	0.5700
26	3-1-3	11/14/01	9:49	119.88	134.78	15.10	120.05	135.15	15.1	10103	10813	0.0000
27	3-1-4	11/14/01	11:17	119.31	134.66	15.35	120.21	135.40	15.19	12465	13540	-0.1600
28	3-1-5	11/14/01	11:53	119.44	134.53	15.09	120.18	135.33	15.15	9884	10982	0.0600
29	3-2-2	11/14/01	13:37	119.83	134.54	14.71	120.55	135.50	14.95	9494	10551	0.2400
30	3-2-3	11/14/01	14:20	119.37	134.46	15.09	119.75	135.13	15.38	9051	10075	0.2900
31	3-2-4	11/14/01	14:50	119.42	134.93	15.51	120.08	136.05	15.97	9118	10039	0.4600
32	3-2-5	11/14/01	16:40	120.24	135.41	15.17	119.91	135.73	15.82	14965	15609	0.6500
33	3-3-2	11/15/01	15:40	120.05	135.28	15.23	119.15	135.20	16.05	14073	14281	0.8200
34	3-3-3	11/16/01	15:00	120.20	135.24	15.04	119.90	135.89	15.99	19247	20595	0.9500
35	3-3-4	11/16/01	15:55	119.46	134.63	15.17	119.43	135.46	16.03	12352	13603	0.8600
36	3-3-5	10/15/01	16:24	93.95	109.32	15.37	90.42	107.53	17.11	37263	N/A	1.7400
37	4-1-2	11/19/01	9:10	119.55	134.80	15.25	119.61	134.83	15.22	15691	17311	-0.0300
38	4-1-3	11/19/01	9:47	119.42	134.61	15.19	119.83	134.97	15.14	10996	12031	-0.0500
39	4-1-4	11/19/01	10:18	119.11	134.87	15.76	119.62	135.21	15.59	16305	17820	-0.2000
40	4-1-5	11/19/01	11:00	119.33	134.53	15.20	119.66	134.68	15.02	14498	15970	-0.1800
41	4-2-2	11/19/01	11:38	120.01	135.37	15.36	119.20	134.98	15.78	12549	13889	0.3600
42	4-2-3	11/19/01	12:13	119.45	134.57	15.12	119.46	134.68	15.22	10318	11371	0.1000
43	4-2-4	11/19/01	14:45	119.90	134.93	15.03	118.63	133.95	15.32	9920	10989	0.2900
44	4-2-5	11/19/01	16:25	119.18	134.38	15.20	119.27	134.58	15.31	9603	10611	0.1100
45	4-3-2	11/20/01	13:55	119.55	134.58	15.03	120.09	135.58	15.49	13662	14526	0.4600
46	4-3-3	11/20/01	14:30	119.76	134.85	15.09	120.46	136.08	15.62	11896	12423	0.5600
47	4-3-4	11/20/01	15:00	120.20	135.50	15.30	119.59	135.61	16.02	13207	13780	0.7300
48	4-3-5	11/20/01	15:35	120.50	135.54	15.04	119.48	135.26	15.78	8369	8931	0.7400

Notes:

(1) Columns A and B are referenced to the microscope based which is fixed throughout the experiments.

Table 2 Measuring Error as a Function of Systematic Error and Paint Thickness

Reading	Coupon Number	Pretreatment	First Paint Coat		Second Paint Coat		Total		Edge to gallery (mm)	Microscope crack length (mm)	Difference			Measurement Error (mm)
			Paint Detail	Thickness (µm)	Thick (µm)	Thin (µm)	Thick (µm)	Thin (µm)			Raw (mm)	Mean (mm)	Standard Deviation (mm)	
									A	B	C	D	E	F
A	Ctrl	None (Control specimen)	None (Control specimen)	0.0				0.0	15.20	15.10	-0.1	-0.08	0.02	±0.20
B	Ctrl	None (Control specimen)	None (Control specimen)	0.0				0.0	15.13	15.07	-0.06			
1	1-1-2	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	24.0				24.0	15.56	15.41	-0.17			
2	1-1-3	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	24.0				24.0	15.29	15.26	-0.03	0.13	0.24	±0.20
3	1-1-4	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	24.0				24.0	15.04	15.41	0.37			
4	1-1-5	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	23.0				23.0	14.86	15.23	0.37			
5	1-2-2	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	35.0				35.0	15.09	15.35	0.26			
6	1-2-3	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	31.0				31.0	15.21	15.26	0.05	0.10	0.09	±0.20
7	1-2-4	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	33.0				33.0	16.17	16.22	0.05			
8	1-2-5	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	32.0				32.0	14.82	14.85	0.03			
9	1-3-2	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	58.0				58.0	15.06	15.15	0.09			
10	1-3-3	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	61.0				61.0	15.22	15.28	0.06	0.18	0.15	±0.20
11	1-3-4	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	59.0				59.0	14.84	15.29	0.45			
12	1-3-5	Deoxidise & Chromate conversion	MIL-PRF 23377 Epoxy Primer	60.0				60.0	14.85	15.02	0.17			
13	2-1-2	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	22.0				22.0	15.09	15.00	-0.09			
14	2-1-3	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	21.0				21.0	14.83	14.89	0.06	-0.10	0.10	±0.20
15	2-1-4	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	22.0				22.0	14.83	14.64	-0.19			
16	2-1-5	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	23.0				23.0	15.24	15.04	-0.20			
17	2-2-2	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	33.0				33.0	14.85	14.72	-0.13			
18	2-2-3	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	30.0				30.0	15.44	15.39	-0.05	-0.15	0.10	±0.20
19	2-2-4	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	30.0				30.0	15.37	15.25	-0.12			
20	2-2-5	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	31.0				31.0	15.24	14.92	-0.32			
21	2-3-2	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	47.0				47.0	15.04	14.75	-0.29			
22	2-3-3	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	48.0				48.0	15.32	14.99	-0.33	-0.20	0.12	±0.20
23	2-3-4	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	46.0				46.0	15.19	15.16	-0.03			
24	2-3-5	Deoxidise & Chromate conversion	Boeing BMS 10-11 Epoxy Primer	48.0				48.0	15.36	15.22	-0.14			

Table 2 Measuring Error as a Function of Systematic Error and Paint Thickness (continued)

Reading	Coupon Number	Pre-treatment	First Paint Coat		Second Paint Coat		Total Thick (μm)	Edge to gallery (mm)	Microscope crack length (mm)	Raw (mm)	Difference		Measurement Error (mm)
			Paint Detail	Thick (μm)	Paint Detail	Thick (μm)					Mean (mm)	Standard Deviation (mm)	
								A	B	C	D	E	F
								(B-A)					
25	3-1-2	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	21.0	RAAF K62 Polyurethane	19.0	40.0000	15.18	15.75	0.57			
26	3-1-3	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	20.0	RAAF K62 Polyurethane	22.0	42.0000	15.10	15.10	0.00	0.12	0.27	± 0.20
27	3-1-4	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	19.0	38.0000	15.35	15.19	-0.16			
28	3-1-5	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	20.0	RAAF K62 Polyurethane	21.0	41.0000	15.08	15.15	0.06			
29	3-2-2	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	20.0	RAAF K62 Polyurethane	47.0	67.0000	14.71	14.95	0.24			
30	3-2-3	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	42.0	61.0000	15.09	15.38	0.29	0.41	0.18	± 0.20
31	3-2-4	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	44.0	63.0000	15.51	15.97	0.46			
32	3-2-5	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	17.0	RAAF K62 Polyurethane	45.0	62.0000	15.17	15.82	0.65			
33	3-3-2	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	16.0	RAAF K62 Polyurethane	88.0	104.0000	15.23	16.05	0.82			
34	3-3-3	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	17.0	RAAF K62 Polyurethane	88.0	105.0000	15.04	15.99	0.95	0.88	0.05	± 0.20
35	3-3-4	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	87.0	105.0000	15.17	16.03	0.86			
36	3-3-5	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	86.0	105.0000	15.37	17.11	1.74			
37	4-1-2	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	16.0	35.0000	15.25	15.22	-0.03			
38	4-1-3	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	13.0	32.0000	15.19	15.14	-0.05	-0.11	0.08	± 0.20
39	4-1-4	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	17.0	36.0000	15.79	15.59	-0.20			
40	4-1-5	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	20.0	RAAF K62 Polyurethane	17.0	37.0000	15.20	15.02	-0.18			
41	4-2-2	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	16.0	RAAF K62 Polyurethane	47.0	63.0000	15.39	15.75	0.36			
42	4-2-3	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	18.0	RAAF K62 Polyurethane	42.0	60.0000	15.12	15.22	0.10	0.21	0.11	± 0.20
43	4-2-4	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	45.0	64.0000	15.03	15.32	0.29			
44	4-2-5	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	18.0	RAAF K62 Polyurethane	51.0	69.0000	15.20	15.31	0.11			
45	4-3-2	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	18.0	RAAF K62 Polyurethane	78.0	96.0000	15.03	15.49	0.46			
46	4-3-3	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	16.0	RAAF K62 Polyurethane	79.0	97.0000	15.09	15.65	0.56	0.62	0.12	± 0.20
47	4-3-4	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	19.0	RAAF K62 Polyurethane	76.0	95.0000	15.30	16.03	0.73			
48	4-3-5	Decidise & Chromate conversion	RAAF K62 Mod. Epoxy Primer	20.0	RAAF K62 Polyurethane	79.0	99.0000	15.04	15.78	0.74			

Notes:

(1) Columns A and B are referenced to the microscope base which is fixed throughout the experiments.

(2) Two changes to the original test procedure were incorporated. The first was to place the jaws of the testing machine in-line with that of the crack edge to ensure results consistency. The second was the application of a 9 kN load for determining the position of the specimen edge as well as for measurement of the crack length.

