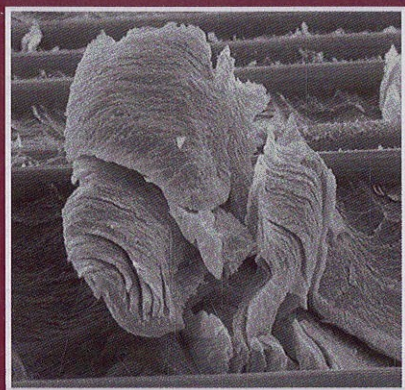


WOODHEAD PUBLISHING IN MATERIALS



# Failure analysis and fractography of polymer composites

Emile S. Greenhalgh



**WP**

## *Author contact details*

1	Introduction to failure analysis and fractography of polymer composites	1
1.1	Background	1
1.2	Introduction to polymer composites	1
1.3	Failure of composites	9
1.4	Aims and objectives of the book	15
1.5	References	18
2	Methodology and tools for failure analysis of polymer composites	23
2.1	Introduction	23
2.2	Health and safety issues associated with composite fractography	25
2.3	Procedure for analysis	28
2.4	Initial visual examination	36
2.5	Non-destructive evaluation	40
2.6	Photography of failure surfaces	45
2.7	Dissection	50
2.8	Confirmation of materials and construction	55
2.9	Overview of microscopy	57
2.10	Stereo microscopy	66
2.11	Compound microscopy (metallographic examination)	70
2.12	Scanning electron microscopy	76
2.13	Other characterisation methods	85
2.14	Crack paths and sequencing	87
2.15	Reporting	101
2.16	References	105

<b>3</b>	<b>Fibre-dominated failures in polymer composites</b>	<b>107</b>
3.1	Introduction	107
3.2	Unidirectional tension	108
3.3	Unidirectional compression	117
3.4	Unidirectional flexural failures	126
3.5	Intralaminar fracture	128
3.6	In-plane (translaminar) shear failures	137
3.7	Failure in cross-ply laminates	143
3.8	Tension failure in multidirectional laminates	146
3.9	Compression failure in multidirectional laminates	149
3.10	Flexural failure in multidirectional laminates	158
3.11	References	159
<b>4</b>	<b>Delamination-dominated failures in polymer composites</b>	<b>164</b>
4.1	Introduction	164
4.2	Bulk polymer features and the influence of matrix type	165
4.3	Mode I (peel) features	178
4.4	Mode II (shear) features	186
4.5	Mixed-mode I/II features	200
4.6	Delamination at multidirectional ply interfaces	210
4.7	Mode III and mixed-mode II/III	223
4.8	References	227
<b>5</b>	<b>Fatigue failures of polymer composites</b>	<b>238</b>
	<i>Co-written with Matthew Hiley, QinetiQ, UK</i>	
5.1	Introduction	238
5.2	General factors associated with fatigue failures	239
5.3	Bulk resin fracture morphologies under cyclic loading	241
5.4	Interlaminar failures	243
5.5	Intralaminar failures	266
5.6	Translaminar failures	268
5.7	References	274
<b>6</b>	<b>The influence of fibre architecture in the failure of polymer composites</b>	<b>279</b>
6.1	Introduction	279
6.2	Short-fibre composites	280
6.3	Filament wound composites	289
6.4	2D woven composites	296
6.5	Stitched composites	316
6.6	Non-crimp fabric composites	322

6.7	Z-pinned composites	336
6.8	3D composites	345
6.9	References	350
<b>7</b>	<b>Defects and damage and their role in the failure of polymer composites</b>	<b>356</b>
7.1	Introduction	356
7.2	Fibre defects	357
7.3	Matrix defects	366
7.4	Fibre-matrix defects	374
7.5	Manufacturing defects (laminate scale defects)	377
7.6	In-service degradation	399
7.7	Impact and durability damage	415
7.8	References	433
<b>8</b>	<b>Case studies: failures due to overload and design deficiencies</b>	<b>441</b>
8.1	Introduction	441
8.2	Overload failures	443
8.3	Design deficiencies	462
8.4	References	502
<b>9</b>	<b>Case studies: failures due to material and manufacturing defects</b>	<b>504</b>
9.1	Introduction	504
9.2	Failures caused by poor bonding	505
9.3	Failures due to embedded defects	529
9.4	References	542
<b>10</b>	<b>Case studies: failures of polymer composites due to <i>in-service factors</i></b>	<b>543</b>
10.1	Introduction	543
10.2	Impact-induced failures	544
10.3	Failure due to environmental factors	567
10.4	References	571
	<i>Index</i>	<i>573</i>