

Jamal Y. Sheikh-Ahmad

Machining of Polymer Composites

1	Introduction to Polymer Composites	1
1.1	Definitions and Classification	2
1.2	Advantages and Limitations	3
1.3	Applications	5
1.4	Constituent Materials	7
1.4.1	Polymer Matrices	8
1.4.2	Reinforcement	12
1.4.3	Core Material	16
1.5	Material Forms and Manufacturing	16
1.5.1	Continuous Reinforcement Forms	17
1.5.2	Molding Compounds	18
1.5.3	Prepreg Layup and Autoclave Processing	20
1.5.4	Filament Winding	21
1.5.5	Pultrusion	23
1.5.6	Compression Molding	23
1.5.7	Liquid Molding	24
1.6	Properties of Composites	26
1.6.1	Density	26
1.6.2	Elastic Properties	28
1.6.3	Thermal Properties	29
1.6.4	Multiply Laminates	30
1.7	Summary	31
	Review Questions and Problems	33
	References	34
2	Conventional Machining Operations	37
2.1	Requirements for Machining FRPs	38
2.2	Turning	39
2.3	Single Point Cutting Tools	41
2.4	Milling and Trimming	42
2.5	Drilling	48

2.6	Abrasive Cutting	51
2.7	Surface Finish	55
2.8	Summary	59
	Review Questions and Problems	60
	References	62
3	Mechanics of Chip Formation	63
3.1	Fundamental Considerations	64
3.1.1	Orthogonal Machining	65
3.2	Machining of Polymers	71
3.3	Machining of Unidirectional FRPS	73
3.3.1	Chip Formation Modes	73
3.3.2	Cutting Forces	81
3.4	Machining of Multidirectional Laminates	89
3.4.1	Chip Formation	90
3.4.2	Cutting Forces	90
3.5	Modeling of the Chip Formation Process	91
3.5.1	Shear Plane Models	91
3.5.2	Mechanics Model of Zhang et al. [20]	97
3.5.3	Mechanistic Modeling	100
3.6	Summary	104
	Review Questions and Problems	106
	References	109
4	Tool Materials and Tool Wear	111
4.1	Tool Materials for Machining FRPs	111
4.1.1	Cemented Tungsten Carbides	114
4.1.2	Coated Carbides	115
4.1.3	Ceramics	116
4.1.4	Polycrystalline Diamond	117
4.1.5	Polycrystalline Cubic Boron Nitride	118
4.1.6	Diamond Coated Carbides	118
4.1.7	Future Outlook	119
4.2	Tool Wear	121
4.2.1	Types of Tool Wear	122
4.2.2	Measurement of Wear	123
4.2.3	Tool Wear Mechanisms	124
4.2.4	Tool Life	133
4.3	Summary	137
	Review Questions and Problems	138
	References	140

5	Conventional Machining of FRPs	143
5.1	Machinability of FRPs	143
5.2	Turning of FRPs	145
5.2.1	Fiber Orientation in Turning	145
5.2.2	Tool Wear in Turning of FRPs	146
5.2.3	Cutting Forces and Specific Cutting Energy	151
5.2.4	Cutting Temperatures	154
5.2.5	Machining Quality	157
5.3	Milling and Trimming of FRPs	160
5.3.1	Fiber Orientation in Milling Unidirectional FRPs	161
5.3.2	Tool Wear	162
5.3.3	Cutting Forces and Specific Cutting Energy	167
5.3.4	Machining Quality	177
5.3.5	Recommended Practices	183
5.4	Drilling of FRPs	187
5.4.1	Fiber Orientation in Drilling	188
5.4.2	Drilling Thrust Force and Torque	189
5.4.3	Cutting Temperatures	196
5.4.4	Machining Quality	197
5.4.5	Mechanics of Delamination	202
5.4.6	Recommended Practices	208
5.5	Abrasive Machining and Grinding	210
5.5.1	Abrasive Machining	211
5.5.2	Grinding	216
5.6	Summary	226
5.6.1	Turning	227
5.6.2	Milling and Trimming	227
5.6.3	Drilling	228
5.6.4	Abrasive Machining and Grinding	228
	Review Questions and Problems	229
	References	232
6	Nontraditional Machining of FRPs	237
6.1	Abrasive Waterjet Machining	237
6.1.1	Technology Overview	238
6.1.2	Material Removal Mechanisms	242
6.1.3	AWJ Machining Characteristics of FRPS	246
6.1.4	Modeling of AWJ Cutting	256
6.2	Laser Machining	260
6.2.1	Technology Overview	261
6.2.2	Mechanisms of Material Removal	264
6.2.3	Laser Machining Characteristics of FRPS	265
6.2.4	Modeling and Analysis	273
6.3	Electrical Discharge Machining	276
6.3.1	Technology Overview	277

6.3.2	Material Removal Mechanisms	279
6.3.3	EDM Characteristics of FRPS	280
6.4	Summary	285
6.4.1	AWJ Machining	285
6.4.2	Laser Machining	286
6.4.3	EDM	287
	Review Questions and Problems	287
	References	289
7	Health and Safety Aspects in Machining FRPs	293
7.1	Hazard Sources and Routes of Exposure	294
7.1.1	Matrix Material	296
7.1.2	Reinforcement Fibers	297
7.2	Dust Generation in Dry Machining	298
7.3	Aerosol Emissions in Laser Machining	300
7.4	Workplace Controls	302
7.4.1	Administrative Controls	302
7.4.2	Engineering Controls	303
7.4.3	Personal Protective Equipment	304
7.4.4	Machine Tool Health	304
7.5	Summary	304
	References	306
	Index	309