

# *Papermaking Science and Technology*

a book series  
covering the latest  
technology and  
future trends

*Book 12*

# Paper and Paperboard Converting

*Second Edition*

# Totally updated version

***Book editor***

Jurkka Kuusipalo, Professor, Tampere University of Technology,  
Paper Converting Technology

***Publisher***

Finnish Paper Engineers' Association/Paperi ja Puu Oy



**Paperi ja Puu Oy**

# Table of Contents

1	Introduction.....	9
2	Wetting and adhesion.....	13
3	Dispersion coating.....	58
4	Extrusion coating and products.....	106
5	Conventional and novel coating methods.....	167
6	Lamination.....	186
7	Fibre-based packaging materials.....	209
8	Converting of fibre-based packaging materials.....	243
9	Converted paper and paperboard as packaging materials.....	284
	Conversion factors.....	340
	Index.....	342

# CHAPTER 1

## Introduction

1	Introduction.....	10
---	-------------------	----

# CHAPTER 2

## Wetting and adhesion

<b>1</b>	<b>Introduction.....</b>	<b>14</b>
<b>2</b>	<b>Theories of adhesion .....</b>	<b>14</b>
2.1	Mechanical interlocking .....	14
2.2	Diffusion theory .....	15
2.3	Electrostatic theory .....	16
2.4	Thermodynamic adsorption theory and surface energy .....	17
2.5	Chemical adhesion.....	21
2.6	Consolidated theory .....	22
2.7	Weak boundary layer theory.....	22
2.8	Work of adhesion vs. failure energy.....	22
<b>3</b>	<b>Measuring wetting, adhesion and peel strength.....</b>	<b>24</b>
3.1	Wetting tension solutions .....	24
3.2	Contact angles and surface energy .....	25
3.3	General information for adhesion measurements .....	30
	3.3.1 Peel tests .....	31
	3.3.2 Other tests .....	31
<b>4</b>	<b>Industrial and practical applications.....</b>	<b>33</b>
4.1	Paper and paperboard as substrates .....	33
4.2	Adhesion in extrusion coating .....	35
4.3	Adhesion in other applications .....	40
4.4	Surface treatment.....	42
	4.4.1 Flame treatment.....	43
	4.4.2 Corona treatment.....	45
	4.4.3 Plasma treatment.....	47
	4.4.4 Other treatments.....	49
	References .....	50

# CHAPTER 3

## Dispersion coating

<b>1</b>	<b>Introduction.....</b>	<b>60</b>
<b>2</b>	<b>Polymer dispersions as barrier coatings.....</b>	<b>62</b>
<b>3</b>	<b>Application techniques.....</b>	<b>67</b>
3.1	Introduction .....	67
3.2	Blade coaters.....	68
3.3	Rod coaters .....	69
3.4	Air knife coaters.....	69
3.5	Gravure coaters .....	70
3.6	Dip coaters .....	70
3.7	Premetered size press .....	71
3.8	Jet application coaters.....	71
3.9	Spray coaters.....	71
3.10	Curtain coaters .....	72
3.11	Drying and cooling.....	72
<b>4</b>	<b>Polymerization and formulation.....</b>	<b>74</b>
4.1	Emulsion polymerization theory .....	76
4.2	Styrene-butadiene .....	77
4.3	Acrylates.....	78
4.4	Other synthetic polymers .....	79
4.5	Biopolymers.....	80
4.5.1	Polysaccharides .....	80
4.5.2	Proteins .....	80
4.5.3	Polyesters and other naturally occurring biodegradable polymers.....	81
4.6	Fillers and additives .....	81
4.7	Nanocomposites .....	82

<b>5</b>	<b>Film formation.....</b>	<b>83</b>
5.1	Basic mechanism.....	83
5.2	Intermolecular forces between colloidal particles .....	86
5.3	Film formation theories .....	87
5.4	Minimum film formation temperature.....	91
<b>6</b>	<b>Rheology .....</b>	<b>92</b>
6.1	Rheology of polymer dispersions.....	94
<b>7</b>	<b>Base sheet effect on dispersion coating .....</b>	<b>97</b>
<b>8</b>	<b>Properties of polymer dispersion films.....</b>	<b>98</b>
8.1	Barrier .....	98
	8.1.1 Water vapour transmission rate.....	99
	8.1.2 Cobb value.....	100
8.2	Gluing, heat sealing, and blocking .....	100
8.3	Grease resistance, odour and taste properties.....	101
<b>9</b>	<b>Polymer dispersion-coated products.....</b>	<b>102</b>
<b>10</b>	<b>Recycling.....</b>	<b>103</b>
	References .....	104

# CHAPTER 4

## Extrusion coating and products

<b>1</b>	<b>Introduction.....</b>	<b>108</b>
<b>2</b>	<b>Extrusion coating equipment .....</b>	<b>108</b>
2.1	Hopper, extruder and adapter .....	108
2.2	Extrusion coating die.....	111
2.3	Coextrusion.....	114
2.4	Laminator system .....	116
2.5	Auxiliary equipment .....	117
<b>3</b>	<b>Extrusion coating process.....</b>	<b>119</b>
3.1	Principles of extrusion.....	119
3.2	Principles of rheology in extrusion coating .....	124
3.3	Melt flow in a slit die.....	127
3.4	Melt fracture phenomenon in extrusion .....	129
<b>4</b>	<b>Critical processing and product properties.....</b>	<b>130</b>
4.1	Rheology related to extrusion coating.....	130
4.2	Odour and taste .....	135
4.3	Pinholes.....	136
	4.3.1 Curling.....	136
4.4	Coefficient of friction.....	137
<b>5</b>	<b>Extrusion coating plastics.....</b>	<b>138</b>
5.1	General .....	138
5.2	Polyolefins .....	139
	5.2.1 Polyethylene.....	139
	5.2.2 Polypropylene .....	143
5.3	Copolymers.....	145

5.4 Adhesives ..... 148

    5.4.1 Adhesives to substrate ..... 148

    5.4.2 Interply adhesion in coextrusion ..... 148

5.5 Barrier polymers ..... 149

5.6 Other polymers ..... 151

5.7 Biopolymers..... 152

5.8 Compounds ..... 157

5.9 Additives in coating resins ..... 157

    5.9.1 Primary antioxidants ..... 157

    5.9.2 Secondary antioxidants ..... 158

    5.9.3 UV stabilisers ..... 158

    5.9.4 Slip agents..... 158

**6 Substrates and main applications ..... 158**

6.1 Liquid packaging ..... 159

6.2 Other rigid packaging..... 160

6.3 Industrial applications ..... 162

6.4 Flexible packaging ..... 162

6.5 Photographic papers ..... 163

References ..... 164



# CHAPTER 5

## Conventional and novel coating methods

<b>1</b>	<b>Introduction.....</b>	<b>168</b>
<b>2</b>	<b>Metallising .....</b>	<b>168</b>
2.1	Processes .....	168
2.2	Web materials.....	170
2.3	Product applications .....	170
<b>3</b>	<b>Conventional coating methods.....</b>	<b>171</b>
3.1	Wax coating.....	171
3.2	Hot melt coating .....	171
3.3	Lacquer coating .....	172
3.4	Cold seal coating .....	173
<b>4</b>	<b>Novel coatings .....</b>	<b>173</b>
4.1	Inorganic coatings.....	173
4.2	Sol-gel coatings.....	176
4.3	Chitosan coatings .....	177
<b>5</b>	<b>Deposition .....</b>	<b>178</b>
5.1	Plasma Enhanced Chemical Vapour Deposition (PECVD).....	178
5.2	Evaporation.....	179
5.3	Sputtering.....	180
<b>6</b>	<b>Electron beam .....</b>	<b>181</b>
<b>7</b>	<b>Plasma polymerisation.....</b>	<b>182</b>
	References .....	184

# CHAPTER 6

## Lamination

<b>1</b>	<b>Introduction.....</b>	<b>188</b>
<b>2</b>	<b>Laminating methods.....</b>	<b>188</b>
2.1	Web materials.....	188
2.1.1	Fibre-based substrates .....	188
2.1.2	Aluminium foil.....	188
2.1.3	Plastic films .....	189
2.1.3.1	Polyethylene .....	189
2.1.3.2	Polypropylene .....	189
2.1.3.3	Polyester.....	190
2.1.3.4	Polyamides .....	190
2.1.3.5	Lactic acid polymers .....	190
2.1.4	Oriented plastic films .....	190
2.1.5	Metallised plastic films.....	191
2.1.6	Net materials .....	191
2.2	Laminating methods .....	191
2.2.1	Wax and hot melt laminating.....	191
2.2.2	Extrusion laminating.....	193
2.2.3	Wet laminating.....	193
2.2.3.1	Sodium silicate .....	194
2.2.3.2	Casein .....	194
2.2.3.3	Starch and dextrin.....	194
2.2.3.4	Synthetic latex .....	194
2.2.4	Dry laminating .....	194
2.2.4.1	Solvent-based adhesives .....	195
2.2.4.2	Water-based adhesives.....	196
2.2.5	Solventless laminating.....	197

2.3 Drying ..... 199

2.4 Radiation curing..... 199

2.5 Adhesion in laminating..... 200

2.6 Laminated product applications ..... 200

**3 Pressure-sensitive adhesive label laminates ..... 202**

3.1 General ..... 202

3.2 Production of pressure-sensitive adhesive laminate ..... 202

    3.2.1 Silicone coating..... 203

    3.2.2 Adhesive coating..... 203

    3.2.3 Lamination..... 204

3.3 Manufacturing of pressure-sensitive adhesive label web..... 204

    3.3.1 Laminate runnability requirements for the label printing machine..... 204

    3.3.2 Printing ..... 204

    3.3.3 Die cutting ..... 205

3.4 Labelling..... 206

3.5 Functional requirements for pressure-sensitive adhesive labels ..... 207

    References ..... 208

# CHAPTER 7

## Fibre-based packaging materials

<b>1</b>	<b>Introduction.....</b>	<b>210</b>
<b>2</b>	<b>Packaging paper.....</b>	<b>211</b>
2.1	Kraft paper.....	211
2.2	Bleached paper.....	212
2.3	Vegetable parchment paper.....	212
2.4	Greaseproof and glassine papers.....	213
2.5	Water-, grease- and oil-resistant papers.....	213
2.6	Waxed paper.....	214
2.7	Specialty treated papers.....	214
2.8	Wet strength papers.....	215
2.9	Tissue papers.....	215
2.10	Coated papers.....	216
<b>3</b>	<b>Paperboards.....</b>	<b>216</b>
3.1	Cartonboards.....	216
3.1.1	Folding boxboard (FBB).....	217
3.1.2	White-lined chipboard (WLC).....	218
3.1.3	Solid bleached sulphate board (SBS/SBB).....	218
3.1.4	Solid unbleached sulphate board (SUS/SUB).....	219
3.1.5	Liquid packaging board (LPB).....	219
3.2	Containerboards.....	219
3.2.1	Linerboard.....	219
3.2.2	Corrugating medium.....	220
<b>4</b>	<b>Corrugated board manufacturing.....</b>	<b>220</b>
4.1	Introduction.....	220
4.2	Corrugated board grades.....	220
4.3	Production of corrugated board.....	224
4.4	Gluing.....	233
4.5	Quality characteristics of a corrugated sheet.....	235
4.6	Faults in corrugated sheets.....	236
4.7	Die-cutting.....	237
4.8	Printing of corrugated board.....	239
4.9	Requirements for corrugated board set by packaging machines.....	240
	References.....	241

# CHAPTER 8

## Converting of fibre-based packaging materials

<b>1</b>	<b>Introduction.....</b>	<b>244</b>
<b>2</b>	<b>Package printing.....</b>	<b>244</b>
2.1	Printing methods.....	244
2.2	Adhesion in printing.....	246
<b>3</b>	<b>Paperboard converting technologies.....</b>	<b>249</b>
3.1	Varnishing.....	249
3.2	Cutting and creasing.....	250
3.2.1	Machines and tools.....	251
3.2.2	Cutting.....	252
3.2.3	Creasing.....	253
3.3	Embossing.....	257
3.4	Foil blocking.....	258
3.5	Skiving.....	259
<b>4</b>	<b>Sealing and gluing.....</b>	<b>260</b>
4.1	General theory of heat sealing.....	261
4.2	Factors affecting heat sealability and seal strength.....	261
4.2.1	Influence of polymer properties.....	262
4.2.2	Influence of product manufacturing process.....	263
4.2.3	Influence of heat sealing process parameters.....	264
4.2.4	Peelable seals.....	265
4.2.5	Hot tack.....	266
4.2.6	Reclosable seals.....	267
4.2.7	Testing of seal strength.....	267
4.3	Different sealing methods.....	267
4.3.1	Bar or thermal sealing.....	267
4.3.2	Ultrasonic sealing.....	268
4.3.3	Hot gas and flame sealing.....	268
4.4	Gluing.....	269
4.4.1	Gluing process.....	269
4.4.2	Adhesion in gluing.....	270
4.4.3	Gluing of carton structures.....	271
<b>5</b>	<b>Fibre-based packages and packaging machines.....</b>	<b>272</b>
5.1	Folding cartons.....	273
5.2	Liquid packaging.....	274
5.3	Flexible packaging.....	277
	References.....	280

# CHAPTER 9

## Converted paper and paperboard as packaging materials

<b>1</b>	<b>Introduction.....</b>	<b>286</b>
<b>2</b>	<b>Interactions between packaging material, packed foodstuff and environment.....</b>	<b>288</b>
2.1	Permeability of polymers.....	288
2.1.1	Background .....	288
2.1.2	Factors affecting permeability .....	290
2.1.3	Permeability of heterogeneous polymer structures .....	296
2.1.4	Water vapour barrier .....	298
2.1.5	Oxygen barrier .....	299
2.1.6	Grease barrier .....	300
2.1.7	Aroma barrier.....	301
2.2	Migration .....	302
<b>3</b>	<b>Packaging of food products .....</b>	<b>304</b>
3.1	Food shelf life stability .....	304
3.2	Food spoilage mechanisms .....	304
3.2.1	Microbiological mechanisms .....	304
3.2.2	Chemical/biochemical mechanisms .....	306
3.2.3	Physical mechanisms.....	307
3.3	Different food groups and their requirements for packaging materials.....	308
3.3.1	Ambient foods.....	308
3.3.2	Chilled foods .....	309
3.3.3	Frozen foods .....	312
3.4	Packaging techniques improving the safety and quality of foods .....	314
3.4.1	Modified atmosphere packaging .....	314
3.4.2	Active and intelligent packaging.....	316
3.5	Testing of food packaging materials.....	319
3.5.1	Barrier tests .....	319

## Converted paper and paperboard as packaging materials

3.5.2	Sealability and hot tack .....	322
3.5.3	Coefficient of friction .....	323
3.5.4	Odour and taint .....	324
<b>4</b>	<b>Packaging of non-food products .....</b>	<b>325</b>
4.1	Basic requirements for non-food packaging materials.....	325
4.2	Different product groups and their requirements for packaging materials.....	325
4.2.1	Pharmaceutical packaging .....	325
4.2.2	Electronics packaging .....	327
4.2.3	Industrial wrappings.....	328
4.3	Testing of non-food packaging materials.....	329
<b>5</b>	<b>Environmental effects of packaging .....</b>	<b>330</b>
	References .....	333