

List of Figures

Figures	Pages
2.1 Absorption in a porous material	10
2.2 Flow diagram showing the origin of acoustic materials	11
2.3 Inclined Conveyor System	14
2.4 The Moulding System	15
2.5 The Reticulation System	15
2.6 The Impregnation System	16
2.7 The Densification System	16
2.8 Overview of existing methods used to recycle polymeric waste	17
2.9 Chemistry of glycolysis of a polymer resulting in the formation of ether polyol	19
2.10 Chemistry of hydrolysis of a polymer resulting in the formation of diamines like diphenyl methane diamine (MDA)	20
2.11 Sound wave reflection and transmission through a porous layer	29
2.12 Stresses acting on the solid phase	32
2.13 Stresses acting on the fluid phase	32
2.14 Boundary conditions for open surface	34

2.15	Schematic diagram of a standard extruder (Crawford, (1992))	36
3.1	Schematic view of the cold extrusion process	41
3.2	The prototype extruder	43
3.3	The barrel with the injection ports	43
3.4	The inside of the hopper	44
3.5	Picture of a square pitch mixing screw	44
3.6	Schematic of the square pitch mixing screw used in the prototype extruder	44
3.7	Raw waste and the end products	46
3.8	Injection ports in extruder barrel	49
3.9	Picture of the extruder setup	50
3.10	Image of the material inside the stainless steel hopper	51
3.11	Image of the feed section	51
3.12	Picture of the extruder with die	52
3.13	Initial design of laboratory extruder	53
3.14	Picture of the prototype die	54
3.15	The dimensions of the main screw inside the barrel	56
3.16	Cut in the screw to allow insertion of pin	57
3.17	End of screw flight	57
3.18	Wiping flight at end of die	58
3.19	Schematic of the flange connected at the end of the barrel	58
3.20	Picture of the flange attached to barrel	59
3.21	Schematic casing for the die	59

3.22	Casing for the die (back view)	60
3.23	Casing for the die (front view)	61
3.24	Schematic of extruder die in casing	61
3.25	Extruder die in casing (back view)	62
3.26	Extruder die in casing (front view)	62
3.27	Conical screw to be placed in die casing	63
3.28	Modified schematic of die casing with a nozzle at the end	64
3.29	Mechanism for the addition of water to pre-wet the waste	64
3.30	Schematic of extruder with die attached	65
3.31	Cross-section through a porous material made using recycled PVC carpet	67
3.32	4,4 dipheylmethane diisocyanate isomer	70
3.33	Atomic charges of 4,4' dipheylmethane diisocyanate isomer	71
3.34	2,4' dipheylmethane diisocyanate isomer	71
3.35	Atomic charges of 2,4' dipheylmethane diisocyanate isomer	72
3.36	MDI molecule with polyol geometry optimised for the reaction	72
3.37	The atomic charges of MDI molecule with polyol	73
3.38	The initial reaction occurring between water and MDI	74
3.39	The intermediate molecular structure formed during the reaction of water with MDI	75
3.40	The end product with CO ₂ gas expelled	76
3.41	Rate of reaction of MDI binder with water	79
3.42	Influence of rate of reaction on the porosity of tyre	81

shred residue	
3.43	Rate of reaction of water with MDI 82
3.44	Influence of rate of reaction on porosity for increasing binder levels 83
3.45	Photo of porous material YL01 85
3.46	Samples with different pore size distributions 86
3.47	Graph of pore size distribution for water to MDI ratio 1:5 87
3.48	Probability density function graph for water to MDI ratio 1:5 87
3.49	Graph of pore size distribution for binder to water ratio 1:20 88
3.50	Probability density function graph for binder to water ratio 1:20 88
3.51	GC-MS spectrum for fume of extruded sample 90
3.52	GC-MS spectrum of the control 91
3.53	The mass fragments 92
4.1	Examples of acoustic porous media 96
4.2	Microscopic photograph of the Coustone structure 105
4.3	The pore size distribution 107
4.4	The two microphone impedance tube 110
4.5	Schematic of the two microphone impedance tube 110
4.6	A plane harmonic wave 112
4.7	A wave decaying exponentially with distance 113
4.8	Picture of the impact transmission rig 118

4.9	Schematic diagram of the impact transmission rig	119
4.10	Experiment setup for the measurement of porosity	122
4.11	Schematic diagram of the air volume comparison system	123
4.12	Setup of air flow resistivity apparatus	126
4.13	Schematic of flow resistivity apparatus	127
4.14	Pressure drop versus volume flow rate	128
4.15	Showing setup of dynamic stiffness (BS29052) apparatus	130
4.16	First resonance frequency	131
4.17	Diagrams on the definition of tortuosity	132
4.18	Photograph of the tortuosity rig	133
4.19	Schematic representation of the tortuosity rig	133
4.20	Determination of the tortuosity using the n^2 -method	136
4.21	Determination of tortuosity from the asymptotic behaviour of the real part of the characteristic impedance	137
4.22	Thermal conductivity apparatus setup	139
4.23	Schematic diagram of the thermal conductivity apparatus	139
4.24	Rate of reaction apparatus setup	141
4.25	Photographs of four types of materials produced using the cold extrusion process	143
4.26	Scanning electron micrographs of materials with a broad pore size distribution	143
4.27	Individual results of the measurements of the real and imaginary part of the normalised surface impedance for Material A for all partners	149

4.28	Individual results of the measurements of the real and imaginary part of the normalised surface impedance for material B for all partners	151
4.29	Individual results of the measurements of the real and imaginary part of the normalised surface impedance for Material C for all partners	153
4.30	Inter-laboratory measurements sample A	155
4.31	Inter-laboratory measurements sample B	156
4.32	Inter-laboratory measurements sample C	157
5.1	Tyre shred residue and car dashboard crumb used in the experiments	161
5.2	Defected PVC backed carpet tile	162
5.3	Calibration graph of MDI binder	163
5.4	Calibration graph for car dashboard	164
5.5	Calibration graph for water pump	165
5.6	Calibration graph for hopper	166
5.7	Calibration graph for tyre shred residue	167
5.8	Influence of binder (XP2261) levels on porosity and flow resistivity	173
5.9	Sudden change in porosity at 30% binder level	173
5.10	Influence of binder (FX1109) levels on porosity and flow resistivity	174
5.11	Influence of fibre to grain ratio on porosity and flow resistivity	175

5.12	Influence of grain size on porosity and flow resistivity	176
5.13	Influence of fibre length on porosity and flow resistivity	177
5.14	Influence of fibre length on sound absorption	178
5.15	Influence of grain size on sound absorption	179
5.16	Influence of binder (FX1109) on sound absorption	180
5.17	Influence of fibre to grain ratio on sound absorption	182
5.18	Comparison of impact sound insulation performance of extruded materials with a top commercial material	185
5.19	Impact performance of different waste streams versus dynamic stiffness	186
5.20	Picture of low density material made using tyre shred residue waste (YL01)	187
5.21	Picture of low density material made from carpet waste (ES10)	188
5.22	Absorption of tyre shred residue with 10% binder level	189
5.23	Pore size distribution for 10% binder	190
5.24	Probability density function for 10% binder	190
5.25	Absorption of tyre shred residue with 20% binder level	191
5.26	Pore size distribution for 20% binder	192
5.27	Probability density function for 20% binder	192
5.28	Absorption of tyre shred residue with 30% binder level	193
5.29	Pore size distribution for 30% binder	194
5.30	Probability density function for 30% binder	194
5.31	Absorption of tyre shred residue with 40% binder level	195

5.32	Pore size distribution for 40% binder	196
5.33	Probability density function for 40% binder	196
5.34	Absorption of tyre shred residue with 50% binder level	197
5.35	Pore size distribution for 50% binder	198
5.36	Probability density function for 50% binder	198
6.1	Pade approximation for 10% binder level	203
6.2	Pade approximation for 20% binder level	204
6.3	Pade approximation for 30% binder level	205
6.4	Pade approximation for 40% binder level	206
6.5	Pade approximation for 50% binder level	207
6.6	Johnson-Champoux-Allard model for 10% binder level	208
6.7	Johnson-Champoux-Allard model for 20% binder level	209
6.8	Johnson-Champoux-Allard model for 30% binder level	210
6.9	Johnson-Champoux-Allard model for 40% binder level	211
6.10	Johnson-Champoux-Allard model for 50% binder level	212
7.1	Picture of sample Rayon_02	220
7.2	Picture of sample YL_01	221
7.3	Picture of sample DB_02	222
7.4	Picture of sample TS_01	223
7.5	Picture of sample IM_07	224
7.6	Material made using tyre shred residue TS-05	226
7.7	Comparison of recycled materials performance with commercial products	227
7.8	Rubber extruder at RAPRA	230

7.9	Picture of extrudate leaving the die	231
7.10	Die used at the end of the rubber extruder	231
7.11	Screw used in the rubber extruder	232
7.12	Screw channel and pitch	232
7.13	Schematic of standard screw used in hot extrusion	232
8.1	Porosity gradient observed in a developed product (PG-1)	240
8.2	Influence of a porosity gradient on absorption coefficient	241
8.3	Material extruded through a circular die	242
8.4	Shows multilayer product	242