Chapter 8

Conclusions and Recommendations

8.1 Conclusions

This work presents a new clean continuous process to reuse polymeric waste materials that are otherwise dumped in landfills at an increasing cost both to the economy and the environment. The cold extrusion process is a low energy consuming process that reprocesses the post manufacturing waste into new acoustic products that can be used to meet the growing public expectations for a quieter environment.

Applications for the developed products are widespread and include acoustic underlay, insulation and panels in buildings, noise barriers for motorways and railway tracks, acoustic insulation in industrial appliances and transport vehicles.

The basis of the cold extrusion process is about tailoring a porous structure using plastic, rubber particulate and fibrous waste so that the final material posses particular acoustic properties. The operation is carried out in a cold (no heat is required) extruder which conveys and mixes the particulates and fibres with a reacting aqueous binder.

The extruder thus operates also as a reactor; the end result is a structure of bound particulates and fibres through which the CO_2 gas that has evolved during the reaction adds extra porosity. By controlling the size of the particulates, the ratio of binder to water and the level of compaction in the extruder, the structure is tailored to produce the desired acoustic properties. The process allows the design and production of 2-3 fold

cheaper noise control products with desired physical properties and minimum environmental impact exploited in a single structure.

As the extrusion is carried out cold and has the advantage of being a continuous process, this new production process requires 4-5 times less energy in comparison with that used for conventional commercial products.

Materials have been characterised using two models Johnson-Champoux-Allard model and the Pade approximation model. The Pade approximation model proved to provide the best agreement in predicting the absorption performance of the developed products.

Round robin testing was carried out between several laboratories around the world, for a particular set of material samples to determine the accuracy of experimental data on the performance of the impedance tube method. It was suggested by the partners taking part in the experiments to revise the ISO 10534-2 to enable quantification of the intrinsic experimental errors.

The formulations that produced high performance products included the use of binder FX457 with Rosecat 109 catalyst and n-pentane. Materials made using these formulations proved to be competitive against the existing commercial products such as glasswool.

8.2 Recommendations for further work

There is still a considerable amount of work that needs to be carried out in terms of product development; further work needs to be directed towards a more extensive investigation into developing new binder formulations specific for the cold extrusion process i.e. influence of polyol molecular weights on the density and acoustic properties

of products, the use of foaming agents to create ultra low density materials. A two component binder system consisting of polyol (softener) and the isocyanate (hardener) needs to be investigated. Trials need to be carried out with different ratios of polyol to isocyanate to achieve optimum products, typical formulation is shown in Table 8.1 for sample LD_02 with a density of 78 kg/m^3 and a thermal conductivity value of 0.048 (W/(m.k)).

Table 8.1: Shows the formulation for a low density product with good thermal conductivity value

Sample	Formulation	Content by weight (g)	Content (%)
LD_02	Tyre shred residue	100	40
	Isocyanate	60	24
	Polyol	40	16
	Water	50	20
	Total	**250**	**100**

Furthermore, work needs to be carried out in trying to develop porosity gradients within the acoustic products (Figure 8.1).

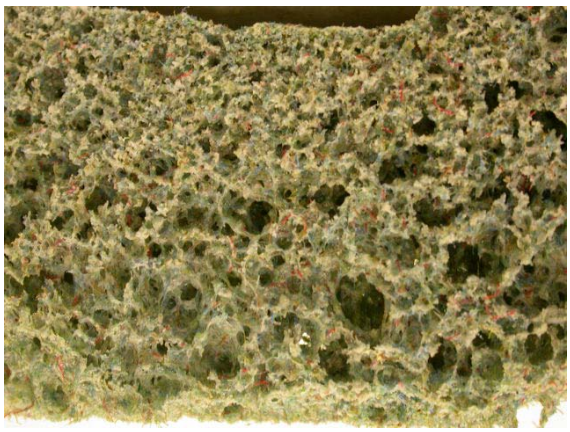

Figure 8.1: Porosity gradient observed in a developed product (PG-1)

A porosity gradient was created by applying heat to the sample i.e. if the sample is placed on a heated plate the large pores will be created at the bottom and smaller at the surface or the alternative is to use excess water were excess water sinks to the bottom of the container thus creating larger pores at the bottom of the sample, binder used in the formulation was XP256. The explanation of the larger pores at the bottom is due to the heat or water at the bottom of the container speeding up the rate of reaction, as more CO_2 gas is trapped at the bottom a porosity gradient is created throughout the sample. Due to this porosity gradient the absorption coefficient differs considerably from top to bottom (Figure 8.2).

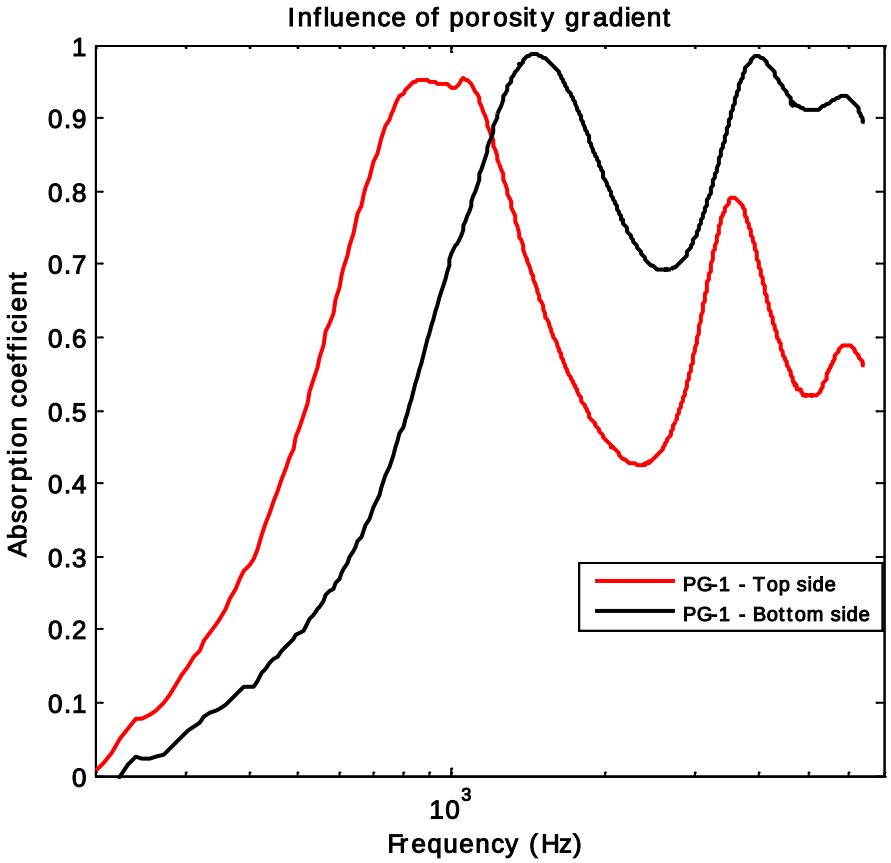

Figure 8.2: Influence of a porosity gradient on absorption coefficient

Further work needs to be carried out on the extruder optimisation, i.e. using FLUENT-POLYFLOW software to simulate the mixing action and flow occurring in the barrel and the compaction occurring in the die, several dies need to be made to stop the extrudate from flopping.

More experimental work needs to be done in extruding different shapes e.g. insulation for piping (Figure 8.3). Other waste streams need to be exploited like post consumer waste used to make acoustic products and multilayer products need to be investigated as shown in Figure 8.4.

Figure 8.3: Material extruded through a circular die

Figure 8.4: Shows multilayer product (base made from tyre shred residue waste, top chipboard)

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APPENDICES

APPENDIX A

List of Authors Publications

1. **A. Khan,** K. V. Horoshenkov, H. Benkreira and R. Patel, "Controlled extrusion of porous media for acoustic applications", Proceedings of the 1st symposium on the acoustics of poroelastic media (SAPEM), Lyon, France, 2005 Conference CD Proceedings.
2. **A. Khan,** R. Patel, , H. Benkreira K. V. Horoshenkov, "Extrusion of recycled polymeric granulates and fibrous particles for acoustic applications" Proceedings of the institute of acoustics, University of Southampton, Volume 28, Part 1, 2006.
3. **A. Khan,** K. V. Horoshenkov, H. Benkreira and R. Patel, L. Jaouen, F.X. Becot, "Acoustics of recycled materials", Proceedings of the institute of acoustics (Cambridge), Volume 29, Part 2, May 2007.
4. **A. Khan,** K. V. Horoshenkov, H. Benkreira and R. Patel, "Vibro-acoustic properties of porous media from recycled granulates", 19th International congress on acoustics (ICA), Madrid, September 2007, Conference CD proceedings.
5. G. Pispola, K. V. Horoshenkov, **A. Khan,** "Modelling the acoustic properties of extruded materials with complex pore size distribution", Euronoise 2006 Conference CD Proceedings, Tampere, Finland.
6. G. Pispola, K. V. Horoshenkov, **A. Khan,** "Comparison of two modelling approaches for highly heterogeneous porous media", J. Acoust. Soc. Am. 121 (2), February 2007.
7. K. V. Horoshenkov, **A. Khan,** F.X. Becot, L. Jaouen, F. Sgard, F. Pompoli, N. Prodi, P. Bonfiglio, G. Pispola, F. Asdrubali, J. Hubelt, N. Atalla, C. K. Amedin, W. Lauriks, L. Boeckx, "Reproducibility experiments on measuring acoustical properties of rigid frame porous media (round robin tests), J. Acoust. Soc. Am. 122 (1), July 2007.

8. **A. Khan,** K. V. Horoshenkov, H. Benkreira, L. Jaouen, F. Becot, "Interdisciplinary study of the cold extrusion process for making recycled based acoustic materials", IOA Spring conference 2008, University of Reading, Conference CD proceedings.
9. H. Benkreira, **A. Khan,** R. Patel, K. V. Horoshenkov, M. J. Swift, "Acoustic materials from waste plastics and rubber", 2nd International conference on engineering for waste valorisation, University of Patras, Greece, June 2008.
10. **A. Khan,** K. V. Horoshenkov, H. Benkreira and R. Patel, L. Jaouen, F.X. Becot, "A novel cold extrusion process for making vibro-acoustic products from recycled raw materials", Internoise 2008, Shanghai, China, Conference CD proceedings.

APPENDIX B - Matlab Script Files

Script file to calculate average absorption coefficient.

```
function[]=graph(F,alpha)


average_alpha=mean(alpha,2);
alpha_std=std(alpha')';


hold on;
h=fill([F ; flipud(F)],[average_alpha-alpha_std ;
flipud(average_alpha+alpha_std)],[0.85 0.85 0.85]);
set(h,'edgecolor',[0.65 0.65 0.65]);
plot(F,average_alpha,'k','linewidth',2)
axis([200 7000 0 1]);
xlabel('Frequency (Hz)')
ylabel('Absorption coefficient')
```

Pade Approximation Matlab Script file

```
function [param, opt] = pade_optimum4(R, om, q, stdev, d, freq,
Zs_exp)

% function [param, opt] = pade_optimum4(R, om, q, stdev, d, freq,
Zs_exp)
% Used to determine the coefficients in the Pade approximation from
% fitting to experimental data.
% Uses the Nelder-Mead simplex (direct search) method.

x(1) = R;x(2) = om;x(3)=q;x(4)=stdev;
option(1) = -1;option(2) = .1;option(14)=3000;
options = optimset('MaxFunEvals', 5000);
A = [1 1 -1 -1]; B = [1e7 1 -1 0]; lb = [1e-2 1e-2 1 1e-2]'; ub = [1e7
1 10 2]';
[param,opt] = fminsearchbnd('dpade4', x, lb, ub, options, d, freq,
Zs_exp);
%[param,opt] = fminsearch('dpade4', x, options, d, freq, Zs_exp);

%[param,opt] = fmincon('dpade4', x, [], [], [], [], lb, ub, [],
options, d,
%freq, Zs_exp);
%A = -[1 1 1 1 1];b = 0;
%lb = [1e4 .1 1 .1 .001]; ub = [1e8 1 2 2 .05];
%[param,opt] = fmins('dpade4', x, [], [], [],[],lb,ub, [], [], freq,
Zs_exp);

%(fun,x0,A,b,Aeq,beq,lb,ub,nonlcon,options,P1,P2,...)
```

Run mat lab script file PadeOptModel.mat (above) and then follow the commands below:

```
>> alpha1=alpha(:,2);
>> [param, opt] = pade_optimum4(1e4, .8, 1.3, .4, .0312, F, alpha1);
>> param

param =

  3.7462e+003  7.3222e-001  1.2416e+000  1.0057e+000

>> format short e
>> param

param =

  3.7462e+003  7.3222e-001  1.2416e+000  1.0057e+000

>> [impd, wnmb, Zs, rfl] = acu2pdc(F, param(1), param(2), param(3), param(4),
0.033);
>> plot(F,1-rfl,F,alpha1)
```

Johnson-Chapoux-Allard Script file

```
% Johnson-Champoux-Allard Model

%%%%% 5 acoustic parameters
% viscous effects: friction effect of air flow through frame
% thermal effects : heat transfer of between air and frame
phi = 0.918; % porosity
alpha_infty = 1.80; % high freq. limit of the tortuosity
sigma = 35456; % static air flow resistivity
lambda = 12e-06; % viscous characteristic length (usually related to
pore interconnection dimension)
lambda_prime = 75e-06; % thermal characteristic length (usually
related to pore dimension)
%%%%% Thickness
L   = 0.03;        % m

%%%%% Temperature and pressure conditions
T   = 26.60;              % degres C : temperature atmoshpérique
P_0 = 99660;      % N.m^-2 : pression atmosphérique



T = 273.16 + T;         % K
R = 287.031;            % J.Kg-1.K-1 :Gas constant (8.314 J.mol-1.K-1)
Cp = 4168.8*(0.249679-7.55179e-5*T+1.69194e-7*T^2-6.46128e-11*T^3);
```

```
gamma = Cp / (Cp-R);
c_0 = sqrt(gamma*R*T);
rho_0 = P_0/(R*T);
eta = 7.72488e-8*T-5.95238e-11*T^2+2.71368e-14*T^3;

Pr = 0.71;              % Prandtl number
kappa = 2.624e-02 * ( (T/300)^(3/2) * (300+245.4*exp(-
27.6/300))/(T+245.4*exp(-27.6/T)) );

%Frequancy
frequency = [10:10:6000];
omega = 2*pi*frequence;

% Determination of rho-equation and K-equation
% cf. Allard, 1993, pp 92-93
Gj = sqrt( 1 + 4*j*alpha_infty^2*eta*rho_0*omega / ...
             (sigma^2*lambda^2*phi^2)          );

rho_eq = (1/phi) * alpha_infty * rho_0 * ( 1 + sigma*phi*Gj ./ ...
                         (j*omega*rho_0*alpha_infty) );

K_eq = (1/phi) * gamma*P_0 ./ ...
         ( gamma - (gamma-1) ./ ...
               ( 1 +  8*eta./(j*lambda_prime^2*Pr*omega*rho_0) .* ...
                      sqrt( 1+j*rho_0*omega*Pr*lambda_prime^2/(16*eta)
) ) );

Z = sqrt(rho_eq.*K_eq);
k = i*omega.*sqrt(rho_eq./K_eq);

Z_onwall = Z.*coth(k*L);
alpha_j  = 1 - ( abs( (Z_onwall-rho_0*c_0)./(Z_onwall+rho_0*c_0) )
).^2;

% Comparison of measurement and simulation

data = load ('book1.txt');
figure(1)
set(gca,'fontsize',16)
plot(data(:,1),data(:,3),'b-','LineWidth',3)
hold on
plot(frequence,alpha_j,'r-','LineWidth',2)
xlabel('Frequency (Hz)')
ylabel('\alpha')
axis([150 4000 0 1])
```

APPENDIX C – Technical objectives for the recycled products

Technical objectives for recycled vibro-acoustic products

Markets: Automotive, Building and Equipment enclosures

ABSORBERS		Applications: General (Noise absorption), Cavity walls, Ceilings.						
		Absorption coefficient						
		500Hz	1000Hz	2000Hz	BS1793-3	Density (kg/m3)	Youngs modulus E(Pa)	Thickness (mm)
Optimum	Chipfoam,	>0.25	>0.7	>0.9	4	80 - 140	3.0 x 10^5	30
General	PU foams, Felts, Polyester fib.	>0.15	>0.4	>0.7	2	30 - 80	4.5 x 10^5	25
YL_01	PVC backed capet waste	0.26	0.85	0.71	4	80	N/A	30
Rayon_02	Tyre shred residue (FX1109_20%)	0.31	0.87	0.88	4	370	9.6 x 10^5	30
TS_05	Tyre shred residue (FX457_30%)	0.37	0.91	0.83	4	220	7.3 x 10^5	30

BARRIERS		Applications: General NVH (Noise, Vibration and Harshness), Doors, Flooring, Noise barriers						
		Transmission loss (dB)						
		500Hz	1000Hz	1600Hz	Average	Density (kg/m3)	Youngs modulus E(Pa)	Thickness (mm)
Optimum	mineral loaded pvc barrier, lead	>20	>25	>30	>25	2000	5.0 x 10^9	2-3mm
General	mineral loaded pvc barrier, lead	>25	>30	>35	>30	2000	16 x 10^9	2-3mm
DB_01	Dashboard crumb	27.5	32.9	37	32.5	732	N/A	6.5
TC_01	Tyre crumb	23.4	24.3	26.5	24.7	954	N/A	6.5
TSR_01	Tyre shred residue	21.1	23.8	25	23.3	850	N/A	7

ISOLATION LAYERS		Applications:General NVH(Noise, Vibration and Harshness), Isolation of mechanical components			
		Dynamic Stiffness (Pa/m)	Density (kg/m3)	Youngs modulus E(Pa)	Thickness (mm)
Optimum	Foamed Rubbers, PE, PP	Resoance Freq <100Hz	<200	3.0 x 10^5	20mm
General	Felts, Impregnated foam	Resoance Freq <100Hz	<400	4.5 x 10^5	20mm
IM_03	Rayon_1199	47.91	348	3.2 x 10^5	15mm
IM_04	Carpet_1109	62.73	234	6.2 x 10^5	15mm
IM_05	Carpet_1190	83.89	373	7.3 x 10^5	15mm

APPENDIX D - Material Formulations

Absorbers

Sample	Formulation	Content by weight (g)	Content (%)
YL_01	PVC Carpet grains	150	30
	Nylon66 Fibres	100	20
	Binder (Chemique XP)	100	20
	Water	100	20
	Pentane	50	10
	Total	**500**	**100**

Sample	Formulation	Content by weight (g)	Content (%)
Rayon_02	Tyre shred residue	300	60
	Binder FX1109	100	20
	Water	100	20
	Total	**500**	**100**

Sample	Formulation	Content by weight (g)	Content (%)
TS_05	Tyre shred residue	250	50
	Binder FX457	150	30
	Water	75	15
	Rosecat109	12.5	3
	Pentane	12.5	3
	Total	**500**	**100**

Sample	Formulation	Content by weight (g)	Content (%)
ES10	PVC Carpet grains	150	30
	Nylon66 Fibres	100	20
	Binder (Chemique XP2261)	100	20
	Water	100	20
	n-Pentane	50	10
	Total	**500**	**100**

Barriers

Sample	Formulation	Content by weight (g)	Content (%)
DB_01	Dashboard crumb	750	50
	Binder FX1109	450	30
	Water	300	20
	Total	**1500**	**100**

Sample	Formulation	Content by weight (g)	Content (%)
TC_01	Tyre crumb	750	50
	Binder FX1109	450	30
	Water	300	20
	Total	**1500**	**100**

Sample	Formulation	Content by weight (g)	Content (%)
TSR_01	Tyre shred residue	750	50
	Binder FX1109	450	30
	Water	300	20
	Total	**1500**	**100**

Isolation layers

Sample	Formulation	Content by weight (g)	Content (%)
IM_03	Tyre shred residue	250	50
	Binder FX1199	100	20
	Water	100	20
	Rosecat109	25	5
	Pentane	25	5
	Total	**500**	**100**

Sample	Formulation	Content by weight (g)	Content (%)
IM_04	PVC carpet	250	50
	Binder FX1109	150	30
	Water	100	20
	Total	**500**	**100**

Sample	Formulation	Content by weight (g)	Content (%)
IM_05	PVC carpet(Grains+Fibres)	250	50
	Binder FX1190	150	30
	Water	100	20
	Total	**500**	**100**

APPENDIX E - Cost Analysis of the High Performing Materials

Description	**Sustainable acoustic material calculation - YL_01**		
	BEST ABSORBER FOR LOW DENSITY		
Formulation:	Total labour cost [£/hr]	mass (g)	£10.000
	Scrap	250	50%
	Water	100	20%
	Binder level	100	20%
	Pentane level	50	10%
	Catalyst	0	0%
	Total	500	

Block-Volume in Production :			Production			
width	min	[mm]	1000.00			
	max	[mm]	1000.00			
	Average	[mm]	1000.00			
length	min	[mm]	10000.00			
	max	[mm]	10000.00			
	Average	[mm]	10000.00			
thickness	min	[mm]	200.00			
	max	[mm]	200.00			
	Average	[mm]	200.00	V [m³]	2.00	

Weight Block without scrap (zero waste) :					
Density:	[kg/m³]	80.00		[Kg]	160.0

Weight Block incl. scrap (trim, etc) :					
Trim	[%]	10%			
Volatility	[%]	20%			
Scrap	[%]	10%	Total	[Kg]	224.0

Cost formulation	GBP					Quantity			Content%
Scrap 1	0.000	100%	[£/Kg]	0.000	kg/block	112.00	[£/block]	0.00	0.0%
Water	0.000	100%	[£/Kg]	0.000	kg/block	44.80	[£/block]	0.00	0.0%
Binder	3.000	100%	[£/Kg]	3.000	kg/block	44.80	[£/block]	134.40	56.1%
Pentane	3.000	100%	[£/Kg]	3.000	kg/block	22.40	[£/block]	67.20	28.1%
Catalyst	1.800	100%	[£/Kg]	1.800	kg/block	0.00	[£/block]	0.00	0.0%
Sum raw material					kg/block	224.00	[£/block]	£201.60	84.2%

Cost Grinding	GBP							
Output [kg/hr]	300							
Manpower [man/hr]	1.00			0.37	min/block	22.40		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.033						cost/block	£7.47	3.1%

Cost sieving	GBP							
Output [kg/hr]	300							
Manpower [man/hr]	0.00		hrs/block	0.00	min/block	0.00		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.000						cost/block	£0.00	0.0%

Cost mixing	GBP							
Output [kg/hr]	400							
Manpower [man/hr]	1.00		hrs/block	0.56	min/block	33.60		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.025						cost/block	£5.60	2.3%

Cost Molding	GBP							
Output [kg/hr]	400							
Manpower [man/hr]	0.20		hrs/block	0.11	min/block	6.72		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.005						cost/block	£1.12	0.5%

Other labour cost (organisation, etc.)								
Output [kg/hr]	400							
Manpower [man/hr]	0.50		hrs/block	0.28	min/block	16.80		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.013						cost/block	£2.80	1.2%

Cost packaging material	GBP							
Carton/Pallet [£]	£3.500					Material	[£/Unit]	3.500	1.5%
blocks per carton/pallet	1								
wrapping and label cost [£]	£1.000					Material	[£/Unit]	1.00	0.4%
labels/carton	1								
						Total	[£/Unit]	£4.50	1.9%

Cost packaging labour	GBP							
Output [kg/hr]	280							
Manpower [man/hr]	0.50		hrs/block	0.36	min/block	21.60		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.018						cost/block	£4.00	1.7%

Cost Energy and Depreciation	GBP							
Energy overheads [£/kg]	£0.030					Energy	[£/block]	6.72	2.8%
Machine depreciation [£/kg]	£0.025					Machine Depreciation	[£/block]	5.60	2.3%
							cost/block	£12.32	5.1%
									100%

		min/block	101.12	Labour	£20.99
				Material	£206.10
		Energy and Machine Depreciation			£12.32
				Sum	239.41
SDC/block					**£239.41**
SDC/m3					**£119.70**

Description	**Sustainable acoustic material calculation - Rayon_02**								
	BEST ALL-ROUNDER								
Formulation:	**Total labour cost [£/hr]**		**mass (g)**	**£10.000**					
	Scrap		300	**60%**					
	Water		100	**20%**					
	Binder level		100	**20%**					
	Pentane level		0	**0%**					
	Catalyst		0	**0%**					
	Total		500						

Block-Volume in Production :			**Production**						
width	**min**	**[mm]**	**1000.00**						
	max	**[mm]**	**1000.00**						
	Average	**[mm]**	1000.00						
length	**min**	**[mm]**	**10000.00**						
	max	**[mm]**	**10000.00**						
	Average	**[mm]**	10000.00						
thickness	**min**	**[mm]**	**200.00**						
	max	**[mm]**	**200.00**						
	Average	**[mm]**	200.00				**V [m³]**	2.00	

Weight Block without scrap (zero waste) :									
Density:		**[kg/m³]**	**370.00**				**[Kg]**	740.0	

Weight Block incl. scrap (trim, etc) :									
Trim		**[%]**	**10%**						
Volatility		**[%]**	**20%**						
Scrap		**[%]**	**10%**			**Total**	**[Kg]**	1036.0	

Cost formulation	**GBP**					**Quantity**				**Content%**
Scrap 1	**0.000**	**100%**	**[£/Kg]**	**0.000**	**kg/block**	**621.60**	**[£/block]**	**0.00**		**0.0%**
Water	**0.000**	**100%**	**[£/Kg]**	**0.000**	**kg/block**	**207.20**	**[£/block]**	**0.00**		**0.0%**
Binder	**1.800**	**100%**	**[£/Kg]**	**1.800**	**kg/block**	**207.20**	**[£/block]**	**372.96**		**70.2%**
Pentane	**3.000**	**100%**	**[£/Kg]**	**3.000**	**kg/block**	**0.00**	**[£/block]**	**0.00**		**0.0%**
Catalyst	**1.800**	**100%**	**[£/Kg]**	**1.800**	**kg/block**	**0.00**	**[£/block]**	**0.00**		**0.0%**
Sum raw material					**kg/block**	**1036.00**	**[£/block]**	**£372.96**		**70.2%**

Cost Grinding	**GBP**								
Output [kg/hr]	**300**								
Manpower [man/hr]	**0.00**			**0.00**	**min/block**	**0.00**			**%AT**
Labour cost [£/hr]	**10.00**								
Labour cost/kg	**0.000**						**cost/block**	**£0.00**	**0.0%**

Cost sieving	**GBP**								
Output [kg/hr]	**300**								
Manpower [man/hr]	**1.00**		**hrs/block**	**2.07**	**min/block**	**124.32**			**%AT**
Labour cost [£/hr]	**10.00**								
Labour cost/kg	**0.033**						**cost/block**	**£34.53**	**6.5%**

Cost mixing	**GBP**								
Output [kg/hr]	**400**								
Manpower [man/hr]	**1.00**		**hrs/block**	**2.59**	**min/block**	**155.40**			**%AT**
Labour cost [£/hr]	**10.00**								
Labour cost/kg	**0.025**						**cost/block**	**£25.90**	**4.9%**

Cost Molding	**GBP**								
Output [kg/hr]	**400**								
Manpower [man/hr]	**0.20**		**hrs/block**	**0.52**	**min/block**	**31.08**			**%AT**
Labour cost [£/hr]	**10.00**								
Labour cost/kg	**0.005**						**cost/block**	**£5.18**	**1.0%**

Other labour cost (organisation, etc.)									
Output [kg/hr]	**400**								
Manpower [man/hr]	**0.50**		**hrs/block**	**1.30**	**min/block**	**77.70**			**%AT**
Labour cost [£/hr]	**10.00**								
Labour cost/kg	**0.013**						**cost/block**	**£12.95**	**2.4%**

Cost packaging material	**GBP**								
Carton/Pallet [£]	**£3.500**					**Material**	**[£/Unit]**	**3.500**	**0.7%**
blocks per carton/pallet	**1**								
wrapping and label cost [£]	**£1.000**					**Material**	**[£/Unit]**	**1.00**	**0.2%**
labels/carton	**1**								
						Total	**[£/Unit]**	**£4.50**	**0.8%**

Cost packaging labour	**GBP**								
Output [kg/hr]	**280**								
Manpower [man/hr]	**0.50**		**hrs/block**	**1.85**	**min/block**	**111.00**			**%AT**
Labour cost [£/hr]	**10.00**								
Labour cost/kg	**0.018**						**cost/block**	**£18.50**	**3.5%**

Cost Energy and Depreciation	**GBP**								
Energy overheads [£/kg]	**£0.030**					**Energy**	**[£/block]**	**31.08**	**5.8%**
Machine depreciation [£/kg]	**£0.025**					**Machine Depreciation**	**[£/block]**	**25.90**	**4.9%**
							cost/block	**£56.98**	**10.7%**
									100%

					min/block	**499.50**	**Labour**	**£97.06**	
							Material	**£377.46**	
							Energy and Machine Depreciation	**£56.98**	
							Sum	**531.50**	
SDC/block								**£531.50**	
SDC/m3								**£265.75**	

Description	**Sustainable acoustic material calculation - TS_05**								
	ALL-ROUND GOOD PERFORMANCE								
Formulation:	**Total labour cost [£/hr]**			**mass (g)**	**£10.000**				
	Scrap			250	**50%**				
	Water			75	**15%**				
	Binder level			150	**30%**				
	Pentane level			12.5	**3%**				
	Catalyst			12.5	**3%**				
	Total			500					
Block-Volume in Production :				**Production**					
width	**min**		**[mm]**	**1000.00**					
	max		**[mm]**	**1000.00**					
	Average		**[mm]**	1000.00					
length	**min**		**[mm]**	**10000.00**					
	max		**[mm]**	**10000.00**					
	Average		**[mm]**	10000.00					
thickness	**min**		**[mm]**	**200.00**					
	max		**[mm]**	**200.00**					
	Average		**[mm]**	200.00				**V [m³]**	**2.00**
Weight Block without scrap (zero waste) :									
Density:			**[kg/m³]**	**220.00**				**[Kg]**	**440.0**
Weight Block incl. scrap (trim, etc) :									
Trim			**[%]**	**10%**					
Volatility			**[%]**	**15%**					
Scrap			**[%]**	**10%**			**Total**	**[Kg]**	**594.0**
Cost formulation	**GBP**					**Quantity**			**Content%**
Scrap 1	**0.000**	**100%**	**[£/Kg]**	**0.000**	**kg/block**	**297.00**	**[£/block]**	**0.00**	**0.0%**
Water	**0.000**	**100%**	**[£/Kg]**	**0.000**	**kg/block**	**89.10**	**[£/block]**	**0.00**	**0.0%**
Binder	**1.800**	**100%**	**[£/Kg]**	**1.800**	**kg/block**	**178.20**	**[£/block]**	**320.76**	**66.2%**
Pentane	**3.000**	**100%**	**[£/Kg]**	**3.000**	**kg/block**	**14.85**	**[£/block]**	**44.55**	**9.2%**
Catalyst	**1.800**	**100%**	**[£/Kg]**	**1.800**	**kg/block**	**14.85**	**[£/block]**	**26.73**	**5.5%**
Sum raw material					**kg/block**	**579.15**	**[£/block]**	**£392.04**	**80.9%**
Cost Grinding	**GBP**								
Output [kg/hr]	**300**								
Manpower [man/hr]	**0.00**			**0.00**	**min/block**	**0.00**			**%AT**
Labour cost [£/hr]	10.00								
Labour cost/kg	0.000						**cost/block**	**£0.00**	**0.0%**
Cost sieving	**GBP**								
Output [kg/hr]	**300**								
Manpower [man/hr]	**1.00**		**hrs/block**	**0.99**	**min/block**	**59.40**			**%AT**
Labour cost [£/hr]	10.00								
Labour cost/kg	0.033						**cost/block**	**£19.80**	**4.1%**
Cost mixing	**GBP**								
Output [kg/hr]	**400**								
Manpower [man/hr]	**1.00**		**hrs/block**	**1.45**	**min/block**	**86.87**			**%AT**
Labour cost [£/hr]	10.00								
Labour cost/kg	0.025						**cost/block**	**£14.85**	**3.1%**
Cost Molding	**GBP**								
Output [kg/hr]	**400**								
Manpower [man/hr]	**0.20**		**hrs/block**	**0.29**	**min/block**	**17.37**			**%AT**
Labour cost [£/hr]	10.00								
Labour cost/kg	0.005						**cost/block**	**£2.97**	**0.6%**
Other labour cost (organisation, etc.)									
Output [kg/hr]	**400**								
Manpower [man/hr]	**0.50**		**hrs/block**	**0.72**	**min/block**	**43.44**			**%AT**
Labour cost [£/hr]	10.00								
Labour cost/kg	0.013						**cost/block**	**£7.43**	**1.5%**
Cost packaging material	**GBP**								
Carton/Pallet [£]	**£3.500**					**Material**	**[£/Unit]**	**3.500**	**0.7%**
blocks per carton/pallet	**1**								
wrapping and label cost [£]	**£1.000**					**Material**	**[£/Unit]**	**1.00**	**0.2%**
labels/carton	1								
						Total	**[£/Unit]**	**£4.50**	**0.9%**
Cost packaging labour	**GBP**								
Output [kg/hr]	**280**								
Manpower [man/hr]	**0.50**		**hrs/block**	**1.01**	**min/block**	**60.46**			**%AT**
Labour cost [£/hr]	10.00								
Labour cost/kg	0.018						**cost/block**	**£10.61**	**2.2%**
Cost Energy and Depreciation	**GBP**								
Energy overheads [£/kg]	**£0.030**					**Energy**	**[£/block]**	**17.82**	**3.7%**
Machine depreciation [£/kg]	**£0.025**					**Machine Depreciation**	**[£/block]**	**14.85**	**3.1%**
							cost/block	**£32.67**	**6.7%**
									100%
					min/block	**267.54**	**Labour**	**£55.65**	
							Material	**£396.54**	
						Energy and Machine Depreciation		**£32.67**	
							Sum	**484.86**	
SDC/block								**£484.86**	
SDC/m3								**£242.43**	

Description	Sustainable Acoustic Foam SDC Calculation - IM_04									
	ISOLATION LAYER									
Formulation:	Total labour cost [£/hr]		mass (g)	£10.000						
	Scrap		250	50%						
	Water		100	20%						
	Binder level		150	30%						
	Pentane level		0	0%						
	Catalyst		0	0%						
	Total		500							

Block-Volume in Production :			Production				
width	min	[mm]	1000.00				
	max	[mm]	1000.00				
	Average	[mm]	1000.00				
length	min	[mm]	10000.00				
	max	[mm]	10000.00				
	Average	[mm]	10000.00				
thickness	min	[mm]	200.00				
	max	[mm]	200.00				
	Average	[mm]	200.00		V [m³]	2.00	

Weight Block without scrap (zero waste) :					
Density:	[kg/m³]	234.00		[Kg]	468.0

Weight Block incl. scrap (trim, etc) :					
Trim	[%]	10%			
Volatility	[%]	20%			
Scrap	[%]	10%	Total	[Kg]	655.2

Cost formulation	GBP					Quantity			Content%
Scrap 1	0.000	100%	[£/Kg]	0.000	kg/block	327.60	[£/block]	0.00	0.0%
Water	0.000	100%	[£/Kg]	0.000	kg/block	131.04	[£/block]	0.00	0.0%
Binder	1.800	100%	[£/Kg]	1.800	kg/block	196.56	[£/block]	353.81	77.6%
Pentane	3.000	100%	[£/Kg]	3.000	kg/block	0.00	[£/block]	0.00	0.0%
Catalyst	1.800	100%	[£/Kg]	1.800	kg/block	0.00	[£/block]	0.00	0.0%
Sum raw material					kg/block	655.20	[£/block]	£353.81	77.6%

Cost Grinding	GBP						
Output [kg/hr]	300						
Manpower [man/hr]	1.00		1.09	min/block	65.52		%AT
Labour cost [£/hr]	10.00						
Labour cost/kg	0.033				cost/block	£21.84	4.8%

Cost sieving	GBP						
Output [kg/hr]	300						
Manpower [man/hr]	0.00	hrs/block	0.00	min/block	0.00		%AT
Labour cost [£/hr]	10.00						
Labour cost/kg	0.000				cost/block	£0.00	0.0%

Cost mixing	GBP						
Output [kg/hr]	400						
Manpower [man/hr]	1.00	hrs/block	1.64	min/block	98.28		%AT
Labour cost [£/hr]	10.00						
Labour cost/kg	0.025				cost/block	£16.38	3.6%

Cost Molding	GBP						
Output [kg/hr]	400						
Manpower [man/hr]	0.20	hrs/block	0.33	min/block	19.66		%AT
Labour cost [£/hr]	10.00						
Labour cost/kg	0.005				cost/block	£3.28	0.7%

Other labour cost (organisation, etc.)							
Output [kg/hr]	400						
Manpower [man/hr]	0.50	hrs/block	0.82	min/block	49.14		%AT
Labour cost [£/hr]	10.00						
Labour cost/kg	0.013				cost/block	£8.19	1.8%

Cost packaging material	GBP						
Carton/Pallet [£]	£3.500				Material	[£/Unit]	3.500	0.8%
blocks per carton/pallet	1							
wrapping and label cost [£]	£1.000				Material	[£/Unit]	1.00	0.2%
labels/carton	1							
					Total	[£/Unit]	£4.50	1.0%

Cost packaging labour	GBP						
Output [kg/hr]	280						
Manpower [man/hr]	0.50	hrs/block	1.17	min/block	70.20		%AT
Labour cost [£/hr]	10.00						
Labour cost/kg	0.018				cost/block	£11.70	2.6%

Cost Energy and Depreciation	GBP						
Energy overheads [£/kg]	£0.030				Energy	[£/block]	19.66	4.3%
Machine depreciation [£/kg]	£0.025				Machine Depreciation	[£/block]	16.38	3.6%
						cost/block	£36.04	7.9%
								100%

		min/block	302.80	Labour	£61.39
				Material	£358.31
			Energy and Machine Depreciation		£36.04
				Sum	455.73
SDC/block					£455.73
SDC/m3					£227.87

Description Sustainable acoustic material calculation - Rayon fibres only_01

Formulation:	Total labour cost [£/hr]	mass (g)	£10.000
	Rayon fibres	75	15%
	Water	250	50%
	Binder 457	150	30%
	Pentane level	0	0%
	Catalyst	25	5%
	Total	500	

Block-Volume in Production :			Production		
width	min	[mm]	1000.00		
	max	[mm]	1000.00		
	Average	[mm]	1000.00		
length	min	[mm]	10000.00		
	max	[mm]	10000.00		
	Average	[mm]	10000.00		
thickness	min	[mm]	200.00		
	max	[mm]	200.00		
	Average	[mm]	200.00	V [m³]	2.00

Weight Block without scrap (zero waste) :				
Density:	[kg/m³]	122.00	[Kg]	244.0

Weight Block incl. scrap (trim, etc) :					
Trim	[%]	10%			
Volatility	[%]	50%			
Scrap	[%]	10%	Total	[Kg]	414.8

Cost formulation	GBP					Quantity			Content%
Scrap 1	0.000	100%	[£/Kg]	0.000	kg/block	62.22	[£/block]	0.00	0.0%
Water	0.000	100%	[£/Kg]	0.000	kg/block	207.40	[£/block]	0.00	0.0%
Binder	1.800	100%	[£/Kg]	1.800	kg/block	124.44	[£/block]	223.99	68.4%
Pentane	3.000	100%	[£/Kg]	3.000	kg/block	0.00	[£/block]	0.00	0.0%
Catalyst	1.800	100%	[£/Kg]	1.800	kg/block	20.74	[£/block]	37.33	11.4%
Sum raw material					kg/block	394.06	[£/block]	£261.32	79.8%

Cost Grinding	GBP							
Output [kg/hr]	300							
Manpower [man/hr]	0.00			0.00	min/block	0.00		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.000					cost/block	£0.00	0.0%

Cost sieving	GBP							
Output [kg/hr]	300							
Manpower [man/hr]	1.00		hrs/block	0.21	min/block	12.44		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.033					cost/block	£13.83	4.2%

Cost mixing	GBP							
Output [kg/hr]	400							
Manpower [man/hr]	1.00		hrs/block	0.99	min/block	59.11		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.025					cost/block	£10.37	3.2%

Cost Molding	GBP							
Output [kg/hr]	400							
Manpower [man/hr]	0.20		hrs/block	0.20	min/block	11.82		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.005					cost/block	£2.07	0.6%

Other labour cost (organisation, etc.)								
Output [kg/hr]	400							
Manpower [man/hr]	0.50		hrs/block	0.49	min/block	29.55		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.013					cost/block	£5.19	1.6%

Cost packaging material	GBP							
Carton/Pallet [£]	£3.500					Material	[£/Unit]	3.500	1.1%
blocks per carton/pallet	1								
wrapping and label cost [£]	£1.000					Material	[£/Unit]	1.00	0.3%
labels/carton	1								
						Total	[£/Unit]	£4.50	1.4%

Cost packaging labour	GBP							
Output [kg/hr]	280							
Manpower [man/hr]	0.50		hrs/block	0.70	min/block	42.22		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.018					cost/block	£7.41	2.3%

Cost Energy and Depreciation	GBP							
Energy overheads [£/kg]	£0.030					Energy	[£/block]	12.44	3.8%
Machine depreciation [£/kg]	£0.025					Machine Depreciation	[£/block]	10.37	3.2%
							cost/block	£22.81	7.0%
									100%

		min/block	155.15	Labour	£38.86
				Material	£265.82
				Energy and Machine Depreciation	£22.81
				Sum	327.50
SDC/block					£327.50
SDC/m3					£163.75

Description	Sustainable acoustic material calculation - Rayon fibres_02								
Formulation:	Total labour cost [£/hr]		mass (g)	£10.000					
	Rayon fibres		75	15%					
	Water		150	30%					
	Binder level		250	50%					
	Pentane level		0	0%					
	Catalyst		25	5%					
	Total		500						

Block-Volume in Production :			Production				
width	min	[mm]	1000.00				
	max	[mm]	1000.00				
	Average	[mm]	1000.00				
length	min	[mm]	10000.00				
	max	[mm]	10000.00				
	Average	[mm]	10000.00				
thickness	min	[mm]	200.00				
	max	[mm]	200.00				
	Average	[mm]	200.00		V [m³]	2.00	

Weight Block without scrap (zero waste) :					
Density:	[kg/m³]	83.00		[Kg]	166.0

Weight Block incl. scrap (trim, etc) :					
Trim	[%]	10%			
Volatility	[%]	30%			
Scrap	[%]	10%	Total	[Kg]	249.0

Cost formulation	GBP					Quantity			Content%
Scrap 1	0.000	100%	[£/Kg]	0.000	kg/block	37.35	[£/block]	0.00	0.0%
Water	0.000	100%	[£/Kg]	0.000	kg/block	74.70	[£/block]	0.00	0.0%
Binder	1.800	100%	[£/Kg]	1.800	kg/block	124.50	[£/block]	224.10	77.8%
Pentane	3.000	100%	[£/Kg]	3.000	kg/block	0.00	[£/block]	0.00	0.0%
Catalyst	1.800	100%	[£/Kg]	1.800	kg/block	12.45	[£/block]	22.41	7.8%
Sum raw material					kg/block	236.55	[£/block]	£246.51	85.6%

Cost Grinding	GBP							
Output [kg/hr]	300							
Manpower [man/hr]	0.00			0.00	min/block	0.00		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.000					cost/block	£0.00	0.0%

Cost sieving	GBP							
Output [kg/hr]	300							
Manpower [man/hr]	1.00		hrs/block	0.12	min/block	7.47		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.033					cost/block	£8.30	2.9%

Cost mixing	GBP							
Output [kg/hr]	400							
Manpower [man/hr]	1.00		hrs/block	0.59	min/block	35.48		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.025					cost/block	£6.23	2.2%

Cost Molding	GBP							
Output [kg/hr]	400							
Manpower [man/hr]	0.20		hrs/block	0.12	min/block	7.10		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.005					cost/block	£1.25	0.4%

Other labour cost (organisation, etc.)								
Output [kg/hr]	400							
Manpower [man/hr]	0.50		hrs/block	0.30	min/block	17.74		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.013					cost/block	£3.11	1.1%

Cost packaging material	GBP							
Carton/Pallet [£]	£3.500					Material	[£/Unit]	3.500	1.2%
blocks per carton/pallet	1								
wrapping and label cost [£]	£1.000					Material	[£/Unit]	1.00	0.3%
labels/carton	1								
						Total	[£/Unit]	£4.50	1.6%

Cost packaging labour	GBP							
Output [kg/hr]	280							
Manpower [man/hr]	0.50		hrs/block	0.42	min/block	25.34		%AT
Labour cost [£/hr]	10.00							
Labour cost/kg	0.018					cost/block	£4.45	1.5%

Cost Energy and Depreciation	GBP							
Energy overheads [£/kg]	£0.030					Energy	[£/block]	7.47	2.6%
Machine depreciation [£/kg]	£0.025					Machine Depreciation	[£/block]	6.23	2.2%
							cost/block	£13.70	4.8%
									100%

	min/block	93.13	Labour	£23.33
			Material	£251.01
			Energy and Machine Depreciation	£13.70
			Sum	288.03

SDC/block	£288.03
SDC/m3	£144.02

Description **Sustainable acoustic material calculation - Dashboard crumb_03**

Formulation:	Total labour cost [£/hr]	mass (g)	£10.000
	Dashboard crumb (<2mm)	240	60%
	Water	60	15%
	Binder level	80	20%
	Pentane level	0	0%
	Catalyst	20	5%
	Total	400	

Block-Volume in Production :			Production			
width	min	[mm]	1000.00			
	max	[mm]	1000.00			
	Average	[mm]	1000.00			
length	min	[mm]	10000.00			
	max	[mm]	10000.00			
	Average	[mm]	10000.00			
thickness	min	[mm]	200.00			
	max	[mm]	200.00			
	Average	[mm]	200.00	V [m³]	2.00	

Weight Block without scrap (zero waste) :					
Density:	[kg/m³]	170.00		[Kg]	340.0

Weight Block incl. scrap (trim, etc) :					
Trim	[%]	10%			
Volatility	[%]	15%			
Scrap	[%]	10%	Total	[Kg]	459.0

Cost formulation	GBP					Quantity			Content%
Scrap 1	0.000	100%	[£/Kg]	0.000	kg/block	275.40	[£/block]	0.00	0.0%
Water	0.000	100%	[£/Kg]	0.000	kg/block	68.85	[£/block]	0.00	0.0%
Binder	1.800	100%	[£/Kg]	1.800	kg/block	91.80	[£/block]	165.24	59.2%
Pentane	3.000	100%	[£/Kg]	3.000	kg/block	0.00	[£/block]	0.00	0.0%
Catalyst	1.800	100%	[£/Kg]	1.800	kg/block	22.95	[£/block]	41.31	14.8%
Sum raw material					kg/block	436.05	[£/block]	£206.55	74.0%

Cost Grinding	GBP					
Output [kg/hr]	300					
Manpower [man/hr]	0.00		0.00	min/block	0.00	%AT
Labour cost [£/hr]	10.00					
Labour cost/kg	0.000				cost/block	£0.00 0.0%

Cost sieving	GBP					
Output [kg/hr]	300					
Manpower [man/hr]	1.00	hrs/block	0.92	min/block	55.08	%AT
Labour cost [£/hr]	10.00					
Labour cost/kg	0.033				cost/block	£15.30 5.5%

Cost mixing	GBP					
Output [kg/hr]	400					
Manpower [man/hr]	1.00	hrs/block	1.09	min/block	65.41	%AT
Labour cost [£/hr]	10.00					
Labour cost/kg	0.025				cost/block	£11.48 4.1%

Cost Molding	GBP					
Output [kg/hr]	400					
Manpower [man/hr]	0.20	hrs/block	0.22	min/block	13.08	%AT
Labour cost [£/hr]	10.00					
Labour cost/kg	0.005				cost/block	£2.30 0.8%

Other labour cost (organisation, etc.)						
Output [kg/hr]	400					
Manpower [man/hr]	0.50	hrs/block	0.55	min/block	32.70	%AT
Labour cost [£/hr]	10.00					
Labour cost/kg	0.013				cost/block	£5.74 2.1%

Cost packaging material	GBP					
Carton/Pallet [£]	£3.500			Material	[£/Unit]	3.500 1.3%
blocks per carton/pallet	1					
wrapping and label cost [£]	£1.000			Material	[£/Unit]	1.00 0.4%
labels/carton	1					
				Total	[£/Unit]	£4.50 1.6%

Cost packaging labour	GBP					
Output [kg/hr]	280					
Manpower [man/hr]	0.50	hrs/block	0.78	min/block	46.72	%AT
Labour cost [£/hr]	10.00					
Labour cost/kg	0.018				cost/block	£8.20 2.9%

Cost Energy and Depreciation	GBP					
Energy overheads [£/kg]	£0.030			Energy	[£/block]	13.77 4.9%
Machine depreciation [£/kg]	£0.025			Machine Depreciation	[£/block]	11.48 4.1%
					cost/block	£25.25 9.0%
						100%

	min/block	212.99	Labour	£43.00
			Material	£211.05
			Energy and Machine Depreciation	£25.25
			Sum	279.30
SDC/block				**£279.30**
SDC/m3				**£139.65**

APPENDIX F – Design of Experiments – Material Composition Sheet

Total Flow Rate	40	(kg/h)

	% Flow Rate in Barrel						Mass Flow Rate in Barrel (kg/hr)						Pressure Vessel (psi)
% Binder	10	10	10	10	10	10	4	4	4	4	4	4	8
% Water	20	25	30	35	40	45	8	10	12	14	16	18	
% Material	70	65	60	55	50	45	28	26	24	22	20	18	
Sample Name							5.9	8.0	10.0	12.1	14.1	16.2	Water pump speed (Hz)
Binder Temp													PVC carpet - rpm
Exp. Date													Rayon - rpm
Material							5.9	5.5	5.1	4.7	4.3	3.9	Dashboard - rpm

	% Flow Rate in Barrel						Mass Flow Rate in Barrel (kg/hr)						
% Binder	20	20	20	20	20	20	8	8	8	8	8	8	12
% Water	20	25	30	35	40	45	8	10	12	14	16	18	
% Material	60	55	50	45	40	35	24	22	20	18	16	14	
Sample Name							5.9	8.0	10.0	12.1	14.1	16.2	Water pump speed (Hz)
Binder Temp													PVC carpet - rpm
Exp. Date													Rayon - rpm
Material							5.1	4.7	4.3	3.9	3.5	3.1	Dashboard - rpm

	% Flow Rate in Barrel						Mass Flow Rate in Barrel (kg/hr)						
% Binder	30	30	30	30	30	30	12	12	12	12	12	12	16
% Water	20	25	30	35	40	45	8	10	12	14	16	18	
% Material	50	45	40	35	30	25	20	18	16	14	12	10	
Sample Name							5.9	8.0	10.0	12.1	14.1	16.2	Water pump speed (Hz)
Binder Temp													PVC carpet - rpm
Exp. Date													Rayon - rpm
Material							4.3	3.9	3.5	3.1	2.7	2.3	Dashboard - rpm

	% Flow Rate in Barrel						Mass Flow Rate in Barrel (kg/hr)						
% Binder	40	40	40	40	40	40	16	16	16	16	16	16	20
% Water	20	25	30	35	40	45	8	10	12	14	16	18	
% Material	40	35	30	25	20	15	16	14	12	10	8	6	
Sample Name							5.9	8.0	10.0	12.1	14.1	16.2	Water pump speed (Hz)
Binder Temp													PVC carpet - rpm
Exp. Date													Rayon - rpm
Material							3.5	3.1	2.7	2.3	1.9	1.5	Dashboard - rpm

	% Flow Rate in Barrel						Mass Flow Rate in Barrel (kg/hr)						
% Binder	50	50	50	50	50	50	20	20	20	20	20	20	24
% Water	20	25	30	35	40	45	8	10	12	14	16	18	
% Material	30	25	20	15	10	5	12	10	8	6	4	2	
Sample Name							5.9	8.0	10.0	12.1	14.1	16.2	Water pump speed (Hz)
Binder Temp													PVC carpet - rpm
Exp. Date													Rayon - rpm
Material							2.7	2.3	1.9	1.5	1.1	0.7	Dashboard - rpm

APPENDIX G – Probability Density Function Data

Pore Diameter	Pore count	Area of one pore of this diameter	Equivalent area of pores	log2(pore size, mm)	PDF
0.02	0	0.00	0.00	-6.64	0.00
0.03	0	0.00	0.00	-6.06	0.00
0.04	2	0.00	0.00	-5.64	0.00
0.05	101	0.00	0.20	-5.32	0.07
0.06	109	0.00	0.31	-5.06	0.07
0.07	105	0.00	0.40	-4.84	0.07
0.08	106	0.01	0.53	-4.64	0.07
0.09	115	0.01	0.73	-4.47	0.08
0.11	99	0.01	0.94	-4.18	0.07
0.12	85	0.01	0.96	-4.06	0.06
0.13	69	0.01	0.92	-3.94	0.05
0.14	47	0.02	0.72	-3.84	0.03
0.15	73	0.02	1.29	-3.74	0.05
0.16	47	0.02	0.94	-3.64	0.03
0.17	43	0.02	0.98	-3.56	0.03
0.18	35	0.03	0.89	-3.47	0.02
0.19	23	0.03	0.65	-3.40	0.02
0.2	32	0.03	1.00	-3.32	0.02
0.21	27	0.03	0.93	-3.25	0.02
0.25	15	0.05	0.74	-3.00	0.01
0.26	15	0.05	0.80	-2.94	0.01
0.27	16	0.06	0.92	-2.89	0.01
0.28	15	0.06	0.92	-2.84	0.01
0.3	7	0.07	0.49	-2.74	0.00
0.4	15	0.13	1.88	-2.32	0.01
0.5	20	0.20	3.93	-2.00	0.01
0.6	23	0.28	6.50	-1.74	0.02
0.7	17	0.38	6.54	-1.51	0.01
0.8	17	0.50	8.54	-1.32	0.01
0.9	13	0.64	8.27	-1.15	0.01
1	18	0.79	14.13	-1.00	0.01
1.1	5	0.95	4.75	-0.86	0.00
1.2	3	1.13	3.39	-0.74	0.00
1.5	11	1.77	19.43	-0.42	0.01
2	12	3.14	37.68	0.00	0.01
3	5	7.07	35.33	0.58	0.00
4	7	12.56	87.92	1.00	0.00
5	6	19.63	117.75	1.32	0.00
6	4	28.26	113.04	1.58	0.00
7	5	38.47	192.33	1.81	0.00
8	2	50.24	100.48	2.00	0.00
9	1	63.59	63.59	2.17	0.00
10	0	78.50	0.00	2.32	0.00