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Hygrothermal and Freeze-Thaw Assessment of 5 Brickwork Replica Panels

on behalf of

Compton Buildings Ltd

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Summary of Findings:

Testing of the 5 brickwork replica panel systems has been undertaken to evaluate the likely performance and suitability of the different systems for use in a British climatic situation. Testing of exposure to the hygrothermal (wetting and high temperature heating), part of MOAT 22 and exposure to 100 cycles of freeze-thaw cycling, to TS EN 772-22, test method for clay masonry units and the basis for the proposed mortar durability test, followed by specific physical performance tests to show any alteration of the physical properties has been undertaken. The results are summarised in the following table:

	Panel A	Panel B	Panel C	Panel D	Plywood
Hygrothermal Performance	No damage	No damage	No damage	No damage	No damage
Freeze-Thaw Performance	No damage	No damage	No damage	No damage	Crumbling of upper render (pigmented layer)
Pull Off - Control	2917N 1.49N/mm^2	2613N 1.33N/mm^2	891N 0.45N/mm^2	1864N 0.95N/mm^2	361N 0.18N/mm^2
Pull Off - After HP	1382N 0.75N/mm^2	1834N 0.93N/mm^2	578N 0.30N/mm^2	1852N 0.95N/mm^2	627N 0.32N/mm^2
Pull Off - After F/T	2111N 1.07N/mm^2	2048N 1.04N/mm^2	1510N 0.77N/mm^2	2621N 1.34N/mm^2	52N 0.03N/mm^2
Abrasion - Control	114 Revs	361 Revs	143 Revs	118 Revs	42 Revs
Abrasion - After HP	172 Revs	650 Revs	325 Revs	>715 Revs	>773 revs
Abrasion - After F/T	117 Revs	403 Revs	240 Revs	303 Revs	270 Revs
Hard Body Impact - Control	8	13	23	12	12
Hard Body Impact - After HP	8	10	23	10	20
Hard Body Impact After F/T	8	12	22	12	17

The conclusion that can be drawn from this testing is that, whilst all show some positive attributed, the preferred option the Panel B System, shows good resilience to both hygrothermal and freeze-thaw cycling, resulting in good strength characteristics, resistance to abrasion and hard body impacts. It is therefore likely that this system will perform the best in the British climatic conditions.

Background

Compton Buildings Ltd have for a number of years produced and sold a concrete panel system for the construction of prefabricated buildings (garages) which has an external finish replicating the appearance of stretcher bonded brickwork. As the market leader in this type of product, Compton Buildings Ltd are keen to develop a new look, principally a more true to life panel system that gives a close appearance to brickwork, but on a wet cast reinforced concrete backing panel, or in one case, as simple plywood backing.

As part of product development trials Compton Buildings Ltd supplied 5 panel systems for evaluation. These were identified as Panels A, B, C, D and Plywood.

Panel A	This is the current panel system which is simply a wet case reinforced concrete backing to which is applied a stained (coloured) sand finish to give a brickwork look-alike appearance.
Panel B	This is a 2 layer render system (each approximately 3mm in thickness) applied to a wet cast reinforced concrete backing. The base coat is not pigmented, whilst the top cost is pigmented. The outer surface is not sanded, but has brick like texture.
Panel C	This is a single thick (~10mm) render coat with a spray on colour onto the wet cast reinforced concrete backing.
Panel D	This is a single thin (~3mm) pigmented render coat onto the wet cast reinforced concrete backing.
Plywood	This panels construction is the same as that for panel B except that the render base coat has been applied to a 12mm untreated plywood backing.

Note: Panels A-D have all been cured for 28 days prior to commencing the testing. The Plywood panel was only cured for 10 days prior to the starting of the Hygrothermal and Freeze-Thaw testing.

The following “exposure” testing has been undertaken on the 5 panels in order to establish any detrimental effects on the panel systems.

<u>Exposure Tests</u>

Hygrothermal Testing:

Representative samples of each of the 5 samples were cut prior to testing to enable testing of the Heat-Rain portion of the Hydrothermal Performance testing as per MOAT 22 1988 (Clause 3.3.2). All 5 panels have been exposed to 140 cycles of 3hrs at 70°C followed by 3 hours being sprayed with water at between 13°C and 20°C. This test is designed to simulate rapid cooling and therefore differential thermal contraction/expansion of the panels replicating both diurnal and summertime solar heating and thunderstorm rainfall induced cooling.

Freeze-Thaw Testing:

Under the MOAT 22 Hygrothermal Performance test there is also a second exposure of the panels to 20 cycles of Freeze-Thaw cycling. This portion of the test has not been carried out as a more onerous test TS EN 772-22 2007 has been undertaken. TS EN 772-22 is the method for the testing of clay masonry units and cycles saturated panels between +20°C and -15°C over a 2 ½ hour period for 100 cycles.

In order to assess the effects on the 5 panels by the "exposure" testing regimes, a number of physical properties have been tested both before and after exposure:

Physical Properties

Pull Off Tests:

A simple pull off test has been performed on the panels both before and after the Hygrothermal and Freeze-Thaw exposure testing. The technique uses a measure of the force required to pull of a circular disc cemented (by epoxy resin based adhesive) to the surface of the panel. In each case the surface render is isolated from its surrounding render by drilling a circular channel around the test portion. This allows a true force to be measured based on a force over a specific surface area of contact.

Abrasion Tests:

Using a modified test based on the wide wheel abrasion test as per EN 1338 concrete paver abrasion test, it has been possible to assess the resistance to abrasion of the surface of the panels both before and after the "exposure" tests. The modification used to this standard test is that rather than just abrading the surface for 75 revolutions, abrasion continued until the backing was exposed, therefore the thickness of each panel type has a major effect upon the number of revolutions required to abrade to the reference point.

Hard-body Impact Test:

This test is undertaken by dropping a steel ball (1000g and Ø62.5mm) from a height of 1.02m. This gives an impact force of 10 joules. Any damage and the Ø of the indent (if any) is measured as indicative of the impact resistance.

Results

Hygrothermal Performance:

Following the 140 cycles, there was no detrimental effect observable on the surface of the sample Panels. The only notable was that there was significant discolouration and water marking/staining of the Plywood backing panel. This however appears to have had little or no significant impact on the performance of the panel, based on visual inspection.

After 7 days drying it was noted that the Plywood Panel had in places become detached from the render application, through the breakdown of the bond between the wood and the base coat of the render. This was further confirmed in the testing of the pull offs, discussed later in this report.

Freeze-Thaw Performance:

Inspection of the 5 panels following the 100 cycles identified that only the Plywood Panel showed any significant signs of deterioration following the exposure. The damage incurred is best described as a "crumbling" of the upper pigmented layer of the render. This had become soft and spongy to touch, and if gently rubbed would disintegrate.

Pull Off Performance

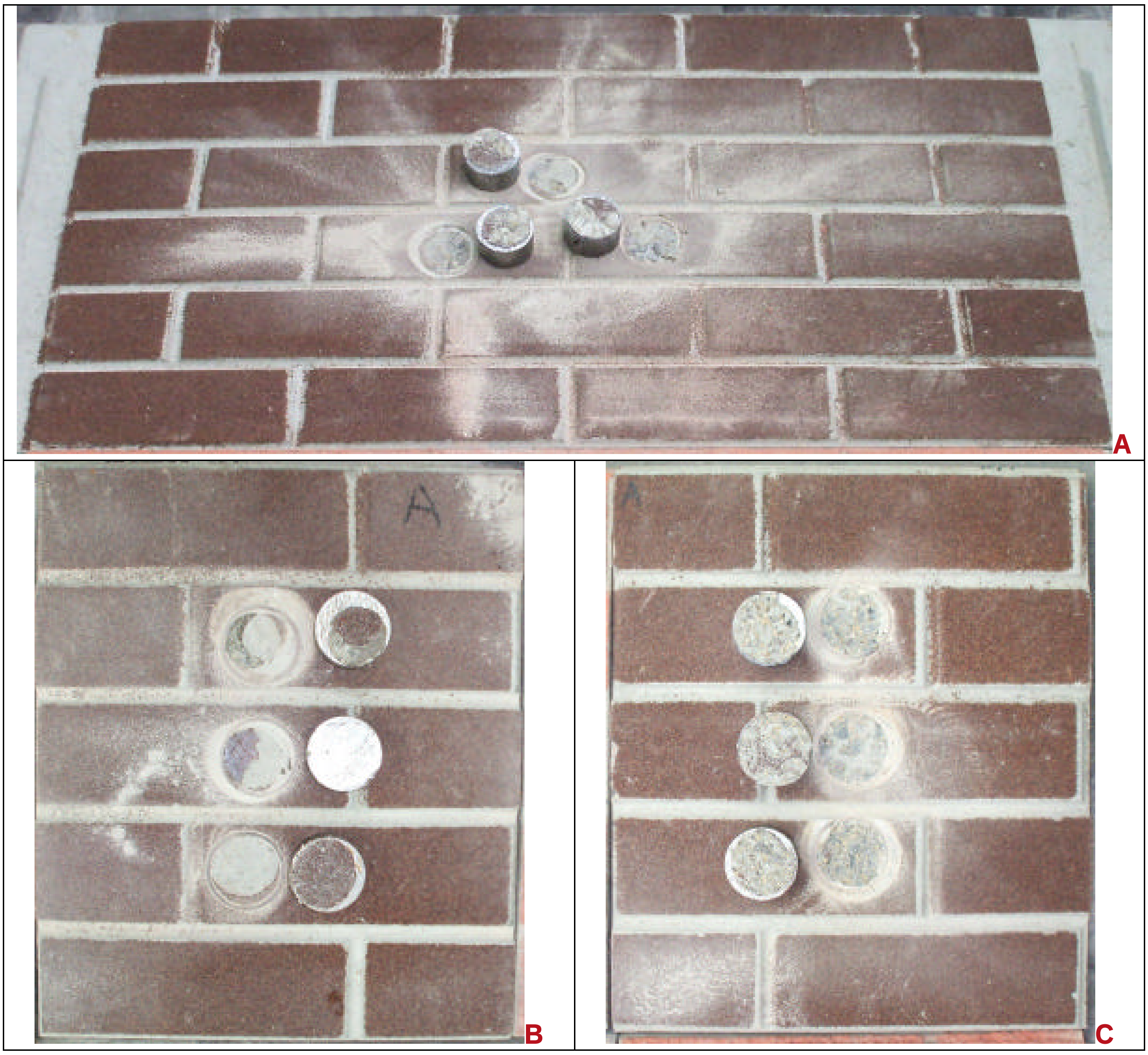
The following pages contain the sets of results for the pull offs and associated photographs showing the nature of the pull off failure mode.

Panel A

Panel A Control	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	3031	1.54	25% base 75% surface
2	3061	1.56	60% base 40% surface
3	2658	1.35	80% base 20% surface
Mean	**2917**	**1.49**	**55% base 45% surface**

Panel A HP	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	1819	0.93	50% base 50% surface
2	1126	0.57	60% base 40% surface
3	1202	0.61	10% base 90% surface
Mean	**1382**	**0.75**	**40% base 60% surface**

Panel A F/T	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	1549	0.79	100% failure in base
2	2284	1.16	100% failure in base
3	2499	1.27	100% failure in base
Mean	**2111**	**1.07**	**100% failure in base**



Pull Off Figures A – Control, B – After Hygrothermal Exposure, C – After Freeze/Thaw Exposure

Panel B

Panel B Control	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	2247	1.14	100% in pigmented layer
2	2693	1.37	100% in pigmented layer
3	2899	1.48	100% in pigmented layer
Mean	**2613**	**1.33**	**100% in pigmented layer**

Panel B HP	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	1608	0.82	100% failure in pigmented layer
2	1646	0.84	100% failure in pigmented layer
3	2247	1.14	100% failure in pigmented layer
Mean	**1834**	**0.93**	**100% failure in pigmented layer**

Panel B F/T	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	2231	1.14	100% failure in pigmented layer
2	1353	0.69	80% failure in pigmented layer
3	2560	1.30	100% failure in pigmented layer
Mean	**2048**	**1.04**	**+80% failure in pigmented layer**

Pull Off Figures A – Control, B – After Hygrothermal Exposure, C – After Freeze/Thaw Exposure

Panel C

Panel C Control	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	673	0.34	100% in render
2	1108	0.56	100% in render
3	892	0.45	100% in render
Mean	**891**	**0.45**	**100% in render**

Panel C HP	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	310	0.16	100% in render
2	846	0.43	100% in render
3	X	X	No adhesion
Mean	**578**	**0.30**	**100% in render**

Panel C F/T	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	1901	0.97	100% in render
2	1514	0.77	100% in render
3	1116	0.57	100% in render
Mean	**1510**	**0.77**	**100% in render**

Pull Off Figures A – Control, B – After Hygrothermal Exposure, C – After Freeze/Thaw Exposure

Panel D

Panel D Control	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	1923	0.98	100% in pigmented layer
2	2389	1.22	100% in pigmented layer
3	1279	0.65	100% in pigmented layer
Mean	**1864**	**0.95**	**100% in pigmented layer**

Panel D HP	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	2037	1.04	100% failure in pigmented layer
2	2368	1.21	100% failure in pigmented layer
3	1150	0.59	50% failure in pigmented layer
Mean	**1852**	**0.95**	**+50% failure in pigmented layer**

Panel D F/T	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	2064	1.05	100% failure in pigmented layer
2	2646	1.35	100% failure in pigmented layer
3	3152	1.61	100% failure in pigmented layer
Mean	**2621**	**1.34**	**100% failure in pigmented layer**

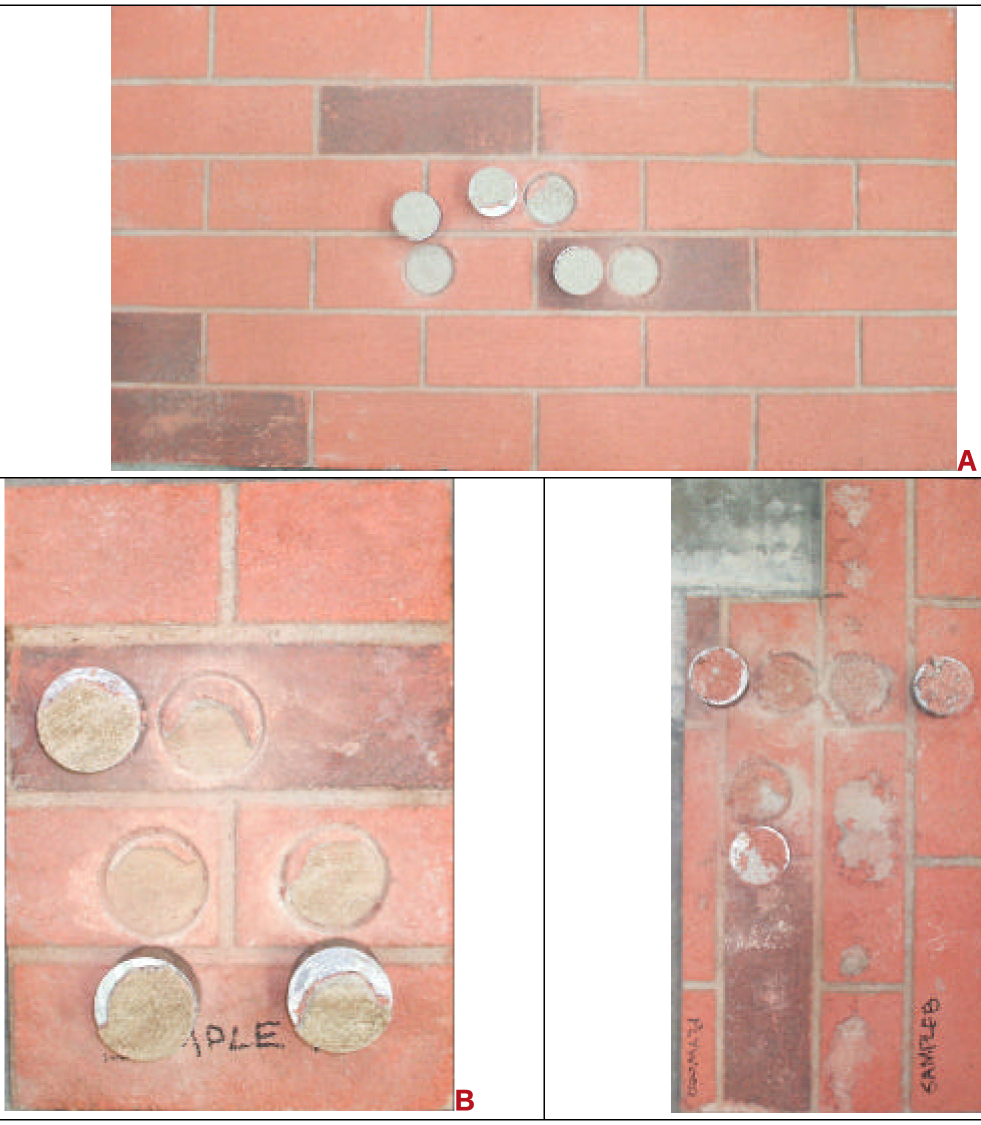
Pull Off Figures A – Control, B – After Hygrothermal Exposure, C – After Freeze/Thaw Exposure

Plywood

Plywood Control	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	400	0.20	90% failure in base coat
2	404	0.21	90% failure in base coat
3	280	0.14	90% failure in base coat
Mean	**361**	**0.18**	**90% failure in base coat**

Plywood HP	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	750	0.38	90% loss of adhesion to base
2	617	0.31	100% loss of adhesion to base
3	513	0.26	100% loss of adhesion to base
Mean	**627**	**0.32**	**+90% loss of adhesion to base**

Plywood F/T	F_u (N)	f_u (N/mm^2)	Fracture Pattern
1	X	X	No adhesion frost damage to top layer
2	52	0.03	Poor very weak bond to top layer
3	X	X	No adhesion frost damage to top layer
Mean	**52**	**0.03**	**Poor very weak bond to top layer**



Pull Off Figures A – Control, B – After Hygrothermal Exposure, C – After Freeze/Thaw Exposure

Abrasion Performance

Using the wide wheel abrasion technique and adapting the way in which the “resistance” to abrasion is measured allows the relative changes between the control samples and those subjected to the exposure testing regimes.

	Control		Hygrothermal Performance		Freeze-Thaw Performance	
	rev	**Mean** rev	rev	**Mean** rev	rev	**Mean** rev
Panel A	150	**114**		**172**		**117**
	150		150		150	
	75		185		110	
	135		180		90	
	75					
	100					
Panel B	240	**361**		**650**		**403**
	320		750		420	
	375		750		415	
	630		450		375	
	225					
	375					
Panel C	185	**143**		**325**		**240**
	150		450		281	
	75		300		225	
	115		225		215	
	160					
	175					
Panel D	70	**118**		**717**		**303**
	75		650		300	
	135		750		325	
	150		750		285	
	125					
	150					
Plywood	55	**42**		**733**		**270**
	40		700		300	
	44		750		300	
	37		750		210	
	37					
	41					

Hard Body Impact Performance

	Control		Hygrothermal Performance		Freeze-Thaw Performance	
	Ømm	Mean	Ømm	Mean	Ømm	Mean
Panel A	9	8	8	8	9	8
	7		8		7	
	8		8		7	
	8		7		8	
	8		8		8	
Panel B	12	13	9	10	10	12
	12		8		12	
	13		11		12	
	14		11		12	
	14		10		16	
Panel C	23	23	22	23	23	22
	25		24		22	
	22		22		22	
	22		25		20	
	22		20		23	
Panel D	12	12	12	10	13	12
	12		7		10	
	12		10		11	
	10		10		13	
	12		10		14	
Plywood	12	12	18	20	20	17
	12		20		18	
	11		18		18	
	12		18		11	
	13		28		18	

Conclusions

Based on the results of the testing, it is clear that the different exposure conditions have had different effects on the panels to different degrees. The only panel to show any significant damage following exposure was the Plywood Panel following Freeze-Thaw exposure. The upper layer of the 2 coat render system, in this case the pigmented layer, was adversely affected by the freeze-thaw action. The surface layer became soft, spongy and very friable. On the basis that this panel had only received 10 days curing prior to testing rather than the +28 days for Panels A-D. On this basis only partial hydration of the cement phases will have been completed prior to the first frost cycle, thus limiting the initial strength of the top layer of the render.

Panel A, for testing purposes here, is regarded as a Control panel. This panel is based on the method of current manufacture and is simple the bonding of stained sand to the surface of the concrete base. The values for the pull offs deteriorated (reduced) following exposure to both weathering conditions. The hygrothermal exposure appears form the pull offs to have had the most significant effect of the weathering exposures. The pull off value dropped to just under 50% of the starting value, for the freeze-thaw exposure panel the value dropped to just over 70% of the starting value. The mode of failure is different in both also, the hygrothermal panel failed by pulling the sand coating off the concrete, where as the freeze-thaw panel failed within the surface layer of the base concrete. This tends to indicate that the wetting and heating cycled has some how broken the bonding capacity to a degree of the adhesive between the sand and the concrete.

The abrasion tests show that the hygrothermal panel has increased in resistance to abrasion, whilst the freeze-thaw panel has remained similar to the control. The values are difficult to correlate with the previous observations from the pull offs. These results would tend to conflict with those of the pull offs where the decrease in pull off load was attributed to the heating and wetting cycles of the hygrothermal exposure breaking down some of the bond between the sand and the concrete. The increased resistance to abrasion for this panel would tend to indicate the opposite. I have no explanation for this result.

Panel A shows no modification to the size of the indent following the hard body impact testing. All tested panels show an Ø8mm indent. This is as would be expected as it is only the actual sand grains that are taking the majority of the impact force, therefore the values would tend to be expected to be the same if there was no damage or modification to the concrete based properties, of which none has been identified.

Panel B, the configuration that is likely to be the basis of the new product range, is a sprayed 2 coat render onto the concrete base. The two coats are of a very similar formulation, with the exception that the top coat contains the pigment for surface colouring.

Pull off values for the hygrothermal panel were again reduced compared to the control panel. The value had reduced to about 70% of the original pull off force. The value for the freeze-thaw panel was also reduced to about 80% of the control value. In both cases the failure mode was similar to that of the control panel, with the failure being within the pigmented layer.

Panel B abrasion results showed a significant increase in the number of revolutions required for the coatings to be abraded through. The hygrothermal panel abrasion resistance increased significantly, by 80%, whilst the freeze-thaw panel increased by 12%. It is possible that the repeated heating and drying of the panel in the hygrothermal test has resulted in a continued hydration and set of the cement phases, thus increasing the strength.

The hard body impact tests show a slight reduction in the size of the indent, again indicating that the exposure tests have increased the surface strength of the renders slightly.

Panel C, which is composed of a single render layer with a spray coat of the pigment onto the surface, shows a reduction in pull off load following hygrothermal cycling but an increased pull off load for the panel exposed to freeze-thaw cycling. The mode of failure is within the render layer in all cases, including the control panel.

Panel C shows a significant increase in the number of revolutions to abrade down to the base concrete. The hygrothermal panel increased the number of revolutions by 127%, whilst the freeze-thaw panel increased by 68%. Both again tend to indicate that the exposure has increased the strength of the render, and therefore increased the resistance to abrasion.

The hard body impact test on the type C Panels indicated that the abrasion resistance values are not reflected in the impact values. The impact indents remain consistent across the panels, and are consistently the highest values of all the panels, possibly reflecting the thickness of the single layer of render.

Panel D, the single pigmented spray coat of render onto the concrete base, has shown very good over all performance. The pull off values for both the hygrothermal panel and the freeze-thaw panel are the same (hygrothermal) or greater (F-T) than the control. This again indicates that the exposure has resulted in a continuation of the strength development over time of the render.

The abrasion resistance test also shows that the exposed panels have increased in resistance, the hygrothermal panel again the most significant by 506% and the freeze-thaw panel by 157%.

The hard body impact test reflects there abrasion results, the hygrothermal panel having a reduction on the size of the indent, indicating a stronger more resilient layer.

The Plywood panel were by far the system that showed significant signs of deterioration with exposure to the freeze-thaw cycling. It is therefore not surprising that the results of the pull off tests show that the required force to pull the discs off has been dramatically reduced. The hygrothermal panels however have increased in pull of resistance. Again the issue of the time of testing in relation to the curing period may be a significant factor in these results. The freeze-thaw exposure will have dramatically weakened the render, whilst the hygrothermal exposure may well have resulted in the continuation of curing.

Both hygrothernal and freeze-thaw panels, where not adversely affected by the freeze-thaw action that panels actually increased in resistance to abrasion, both being more resistant than the control. A very significant increase was recorded for the hygrothermal panel, increasing from 42 revolutions to over 770. Again attributed to the continued curing of the render with exposure to both water and heat.

Both panels showed significant reduction in the resistance to hard body impact. The size of the indents were significantly increased, therefore indicating that despite being more resistant to abrasion, the resistance to a hard body impact has been diminished.

Over all the properties of the panels show some degree of correlation between the tests, however there are a number of “outliers” where the relationship is not obvious. The most notable mismatch of results is that of the resistance to pull off and that of abrasion/hard body impact.

Panel B appears to be a very “sound” system, and has proven that under this testing regime it is a render system that appears to be resilient to the different environmental exposure conditions tested. On this basis it is likely that such a panel system would be suitable for the purpose intended.