Study Report

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Testing an evaluation method for structural insulated panels (SIPs)

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Preface

This pilot study forms one part of the BRANZ research project QR00206 Materials Performance Testing Methodologies. The aim of the project was to develop practical, accelerated and reliable laboratory tests to assess the durability of a range of building materials and products. The project involved several workstreams that each had a different focus. The focus of this study was the design of a proposed evaluation method for assessing the durability performance of structural insulated panels (SIPs).

Testing an evaluation method for structural insulated panels (SIPs)

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Reference

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Abstract

Structural insulated panels (SIPs) have become increasingly popular internationally, driven by the demand for fast, affordable and energy-efficient building solutions. SIPs construction is increasing in New Zealand, but there is currently no information available on how the system will perform in the long term under New Zealand conditions. SIPs must comply with the relevant sections of the New Zealand Building Code (NZBC), including clause B2 *Durability*, which sets a minimum durability requirement of 50 years for structural materials. This pilot study aimed to develop and test an evaluation method that could be used to assess the durability performance of SIPs. The methodology was based on existing, well accepted methods that use accelerated ageing to predict durability. The experimental work tested the change in tensile strength (before and after ageing) of six different SIP types, including both laboratory-made and commercially available products. The results show that performance differences could be identified between the different products following accelerated ageing under the proposed test methods. Further work is recommended to develop the test methods so that they can be used to assess quality.

Keywords

Structural insulated panels, SIPs, durability.

Contents

Figures

Tables

1. Introduction

SIPs are lightweight, prefabricated, sandwich panels typically comprising two high-density face layers bonded to a low-density cellular core (Bregulla & Enjily, 2005). In residential and light-commercial construction, SIPs can be used as both structural and non-structural components such as walls, roofs and floors. SIP face layers are commonly made from engineered wood panels, cement board or metal. Common core materials include expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane (PUR) and polyisocyanurate (PIR).

SIPs have some history of use in regions such as North America and Europe but their performance in the New Zealand climate is not well known, and the long-term performance is especially important given the requirements of the New Zealand Building Code (NZBC). New Zealand has an immediate need for large-scale, affordable housing solutions that can be constructed quickly, and SIPs could be part of the solution. To be used with confidence, it must be demonstrated that SIPs meet the 50-year durability requirement described in the NZBC. The NZBC states that proof of performance should consider service history, laboratory testing and performance of similar building elements. The work described in this report sought to address the need for a robust, reliable test method to predict the durability performance of SIPs.

2. Methodology

2.1 Evaluation method design

This project involved the design of an evaluation method to assess the long-term performance of SIPs. The design of the evaluation method was based on BRANZ's extensive experience of durability testing. Predicting long-term performance typically involves accelerated ageing, which replicates the natural ageing process in a reduced timeframe. Accelerated ageing offers a time-efficient and economical means of assessment. Freeze-thaw cycling is a well-accepted method that involves subjecting samples to fluctuating temperature extremes and measuring the subsequent changes in mechanical properties.

The existing BRANZ Evaluation Method 4 (EM4) uses freeze-thaw cycling for durability testing, and it is a referenced method in the NZBC. Other standards that use freeze-thaw cycling to predict performance are:

- AS/NZS 2908.2:2000 *Cellulose-cement products – Flat sheets* for fibre-cement products
- AS 2753-1985 *Adhesives – Mastic – For bonding gypsum plaster linings to wood and metal framing members* for wallboard adhesives
- AS/NZS 4364:2010 *Timber – bond performance of structural adhesives* for structural adhesives.

The above methods are well known in the field as being used to assess performance. Accurately correlating the accelerated and natural ageing times is a significant challenge in durability predication. It is generally accepted that exposing materials to a high temperature for a short time is equivalent to exposing them to lower temperatures for a longer time.

The evaluation method developed in this project is based on five accelerated ageing tests, taken from existing standards, that were identified as using high temperature and long duration accelerated ageing conditions. The accelerated ageing cycles are based on adaptations of the following existing tests:

- *European recommendations for sandwich panels. Part I: Design* (ECCS/CIB Joint Committee, 2000) – tests C1 and C2.
- *Test procedure for coating and jointing systems for flush finished fibre cement sheet cladding* (BRANZ, 2005) – test EM4.
- EN 14509:2013 *Self-supporting double skin metal faced insulating panels – Factory made products – Specifications* – tests DUR1 and DUR2.

The evaluation method is intended to apply to SIPs made from a variety of materials. However, the current study only tested SIPs with engineered wood panel faces and either (a) a self-adhering polyurethane (PUR) core or (b) an expanded polystyrene (EPS) core with polyvinyl acetate (PVA) adhesive. Samples were subjected to accelerated ageing conditions and then tensile tested. The change in tensile strength was used as the main parameter to assess durability. This work aimed to establish whether the proposed evaluation method could allow for performance differences to be identified between the different samples.

2.2 Materials

A total of six different wood-faced SIP systems were tested and are summarised in Table 1. The products used as samples were selected to be representative of the category of SIPs made with the same component materials.

Table 1. Composition of SIPs tested.

SIPs sample group	Material composition			Origin
	Facing	Core	Adhesive	
A	Reconstituted wood panel 1	EPS M-grade	PVA 1	Lab-made
B	Reconstituted wood panel 1	EPS S-grade	PVA 1	Lab-made
C	Reconstituted wood panel 2	PUR	No adhesive	Commercial
D	Reconstituted wood panel 3	PUR	No adhesive	Commercial
E	Reconstituted wood panel 4	PUR	No adhesive	Commercial
F	Reconstituted wood panel 1	EPS S-grade	PVA 2	Lab-made

EPS M-grade = expanded polystyrene with density 20 kg/m$_3$, EPS S-grade = expanded polystyrene with density 15 kg/m$_3$, PVA = polyvinyl acetate, PUR = polyurethane foam.

Samples had a nominal surface area of 100 mm$_2$. Commercial samples were sourced from one supplier and were cut to size from full-scale SIP panels with a nominal thickness of 115 mm. Lab-made samples were assembled individually, clamped for a minimum of 2 hours and then left to cure under normal lab conditions for a minimum of 24 hours. Control samples were conditioned under constant climatic conditions (21°C ± 2°C and 65% ± 5% relative humidity) and were not exposed to the ageing cycles. Weight and dimensional measurements were taken before and after accelerated ageing to provide information about how the samples behaved during testing and their mode of failure.

2.3 Accelerated ageing cycles

Table 2 describes the ageing cycles used in this study and their acceptance criteria. For each SIPs type, five replicates were tested under each ageing condition. The criteria state the acceptable levels of tensile strength degradation that samples can exhibit post-ageing. Accelerated ageing was carried out using environmental chambers with temperature and humidity control. The accelerated ageing tests are based on existing tests for metal-skinned SIPs (ECCS/CIB Report 257 and EN 14509:2013) and fibre-cement sheet cladding (BRANZ EM4), whereas the SIPs tested in this study use reconstituted wood panel facings. The methods were selected because they use high-temperature and long-duration accelerated ageing conditions that simulate realistic in-service maximums. It was assumed that, if SIPs performed well under these conditions, they were likely to perform well under more moderate conditions. According to EN 14509:2013, test DUR1 can be carried out at one of three temperature levels: 90°C, 75°C or 65°C. For this study, 75°C was chosen after considering the face material to be tested, i.e. reconstituted wood panel, compared to the metal face used in EN 14509:2013.

C1 and DUR1 tests involve high temperatures in dry conditions and are used where temperature is the main cause of ageing. C2 and DUR2 cycles involve the same conditions and are used where humidity is the main cause of ageing. Under EN 14509:2013, the core material EPS is tested under DUR1. For this experiment, the composite system of reconstituted wood panel/PVA/EPS was also tested under DUR2 to understand the ageing process.

Table 2. Accelerated ageing cycles and acceptance criteria used in the evaluation method for SIPs.

Source	Ageing cycle	Description	Acceptance criteria
ECCS/CIB Report 257 (2000) for thin metal skin SIPS	C1	5 days at +70°C (± 5°C), 90% (± 10%) RH 1 day at -20°C (± 5°C) 1 day at +90°C (± 5°C), RH < 15% Thus, 1 cycle = 7 days 1, 5, 10 cycles	$R_1 \geq 0.6*R_0$ $R_5 \geq 0.4*R_0$ $(R_1-R_5) \leq (R_0-R_1)$ If this is not fulfilled, then $(R_5-R_{10}) \leq (R_1-R_5)$ If not fulfilled but $R_{10} \geq 0.6*R0$, the result is considered acceptable Dimensional changes < 5%
	C2	+65°C (± 3°C), 100% RH 28 days	$R_{28} \geq 0.4*R_0$
BRANZ EM4 (2005)	EM4	6 hours at +30°C, 95% RH 6 hours at +60°C, 75% RH 6 hours at +10°C, 50% RH 6 hours at -10°C, low RH Thus, 1 cycle = 1 day 30, 60 cycles	$R_{30} \geq 0.6*R_0$ $R_{60} \geq 0.4*R_0$
EN 14509 (2013) for metal skin SIPS	DUR1	+75°C, RH < 15% 42, 84 days	$(R_{42}$ or $R_{84}) \geq 0.5*R_0$ $(R_{42}$ or $R_{84}) \geq 0.02$ MPa Dimensional changes <5%
	DUR2	+65°C (± 3°C), 100% RH 7, 28, 56 days	$(R_7-R_{28}) \leq 3*(R_0-R_7)$ and $R_{28} \geq 0.4*R_0$ If not fulfilled, then $(R_{28}-R_{56})$ shall be less than (R_7-R_{28}) and $R_{56} \geq 0.4*R_0$ Dimensional changes < 5%

Note: R is the mean tensile strength of the reference (R_0), for example, after 1 cycle of C1 (R_1), after 5 cycles of C1 (R_5), after 10 cycles of C1 (R_{10}).

2.4 Tensile testing

Tensile strength was chosen as the main measure of durability because of the importance of the face/core bond in the overall performance of the SIP. The acceptance criteria for the accelerated ageing tests are based on the level of degradation deemed acceptable after each ageing period. The degradation in tensile strength with accelerated ageing can provide some measure of the longer-term durability performance.

After accelerated ageing, samples were weighed immediately and then at intervals until the mass had stabilised under constant climate conditions (21°C ± 2°C and 65% ± 5% relative humidity). Constant mass was assumed when the change in mass over 24 hours was less than 1% of the total mass. The tensile testing was carried out in accordance with EN 14509:2013 A.1 Cross-panel Tensile Test using an Instron 5699 Universal testing machine with Instron Bluehill software control. A 10 kN load cell and crosshead speed of 2 mm/minute (1.7% strain rate) was used. Aluminium dollies were attached to the sample faces and were gripped by the jaws of the Instron machine. One of two methods was used to attach aluminium dollies to each sample:

- Two-part epoxy adhesive – samples A, B and F.
- 4x screws – samples C, D and E.

The first method involved a time-consuming step to remove epoxy adhesive from used dollies to reuse them. The second method greatly reduced the sample preparation time. A subset of samples was tested using both methods and demonstrated that the method of attachment did not affect the test results.

3. Results

3.1 Accelerated ageing cycles

Table 3 shows how each SIP type performed against the acceptance criteria of each ageing test (data and calculations are provided in Appendix A).

All commercial samples (C, D and E) retained acceptable tensile strength under all ageing conditions. Sample C showed a dimensional change greater than the acceptable limit of ± 5% (+ 7.8%) after DUR2 ageing. Sample A failed C1 based on tensile strength and DUR2 based on the dimensional criteria. Sample B failed DUR2 based on both tensile strength and dimensional change. Sample B was not exposed to C1 and C2. Samples C, D and E were not exposed to C2. Sample F was only exposed to DUR2.

Table 3. Performance of SIPs samples against the acceptance criteria.

	Evaluation method for SIPs – ageing conditions									
Series	**C1**		**C2**		**DUR1**		**DUR2**		**EM4**	
	Tensile strength	**Dimension change**	**Tensile strength**	**Dimension change**	**Tensile strength**	**Dimension change**	**Tensile strength**	**Dimension change**	**Tensile strength**	**Dimension change**
A	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Fail	Pass	Pass
B	-	-	-	-	Pass	Pass	Fail	Fail	Pass	Pass
C	Pass	Pass	-	-	Pass	Pass	Pass	Fail	Pass	Pass
D	Pass	Pass	-	-	Pass	Pass	Pass	Pass	Pass	Pass
E	Pass	Pass	-	-	Pass	Pass	Pass	Pass	Pass	Pass
F	-	-	-	-	-	-	Pass	-	-	-

Pass = sample passed against the acceptance criteria. Fail = sample failed against the acceptance criteria. - = data not available.

3.2 Tensile testing

Figures 2–6 show the average relative changes in tensile strength before and after ageing for each SIP type under the different ageing conditions. Error bars represent the standard deviation from the mean.

The tensile strength of sample A shows a downward trend that decreased to 48% of its original value after 10 weeks of ageing under C1 conditions. The tensile strength of sample C is at 90% of its original strength after 10 weeks. Similarly, samples D, E and F exhibit high relative tensile strength (85%, 111% and 93% respectively) after 10 weeks. Sample D shows an initial decrease to 79% after 1 week of ageing, which then increases and plateaus. The increases in tensile strength shown by samples D, E and F were unexpected and cannot be readily explained. Sample B was not exposed to C1 ageing conditions.

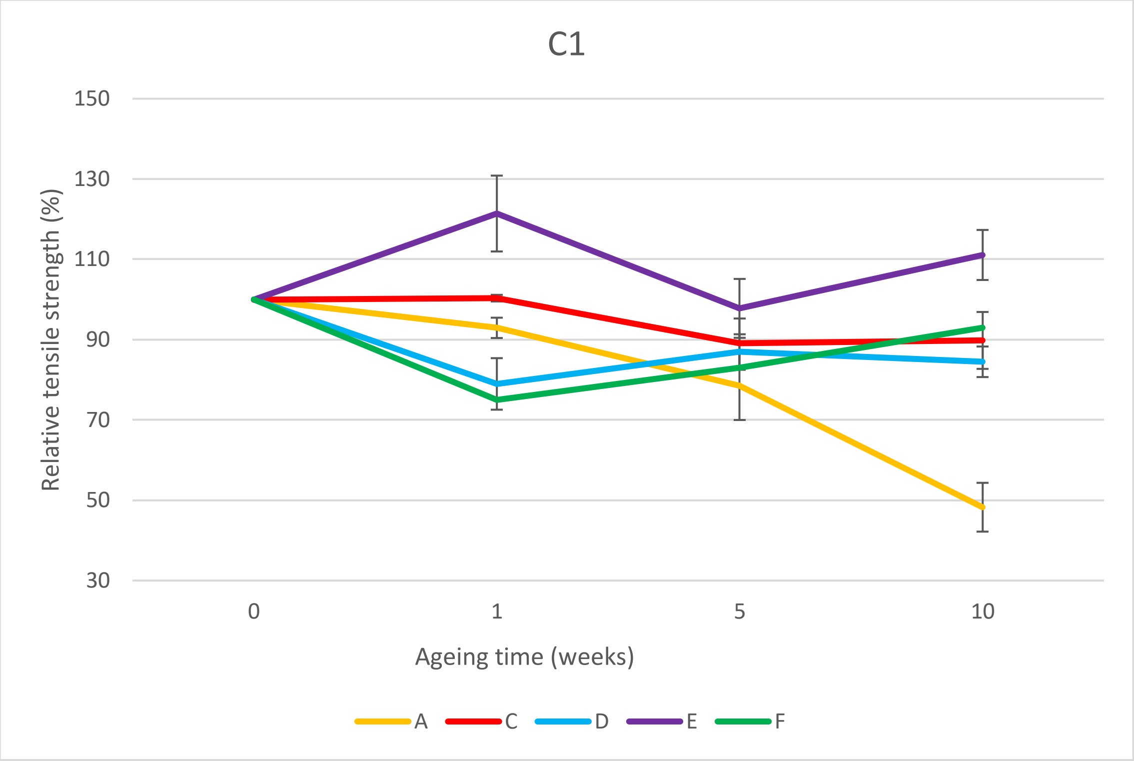

Figure 1. Tensile strength changes during ageing cycle C1.

Sample A was the only group exposed to C2 conditions and retained 92% of its tensile strength after 28 days.

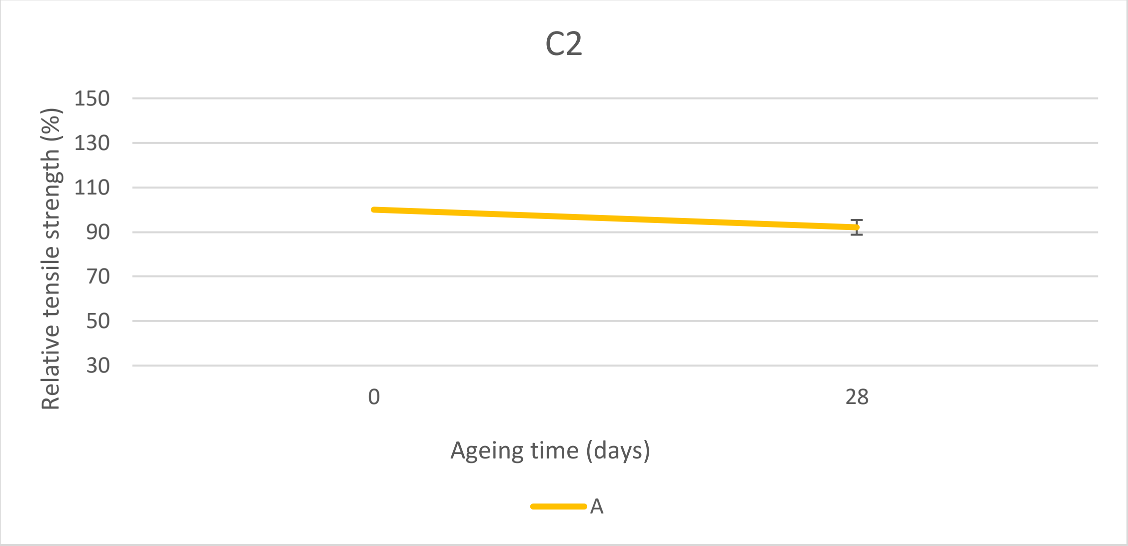

Figure 2. Tensile strength change with C2 ageing.

The relative change in tensile strength with DUR1 ageing is variable across the sample groups. Again, increases in tensile strength were unexpected. The three commercial samples (C, D and E) exhibit quite different tensile strength changes with ageing, including a large increase in tensile strength of sample C (+20%) between 42 and 84 days. Samples A and B demonstrate a slight downward trend, which reaches 95% and 87% of its original value after 84 days of ageing.

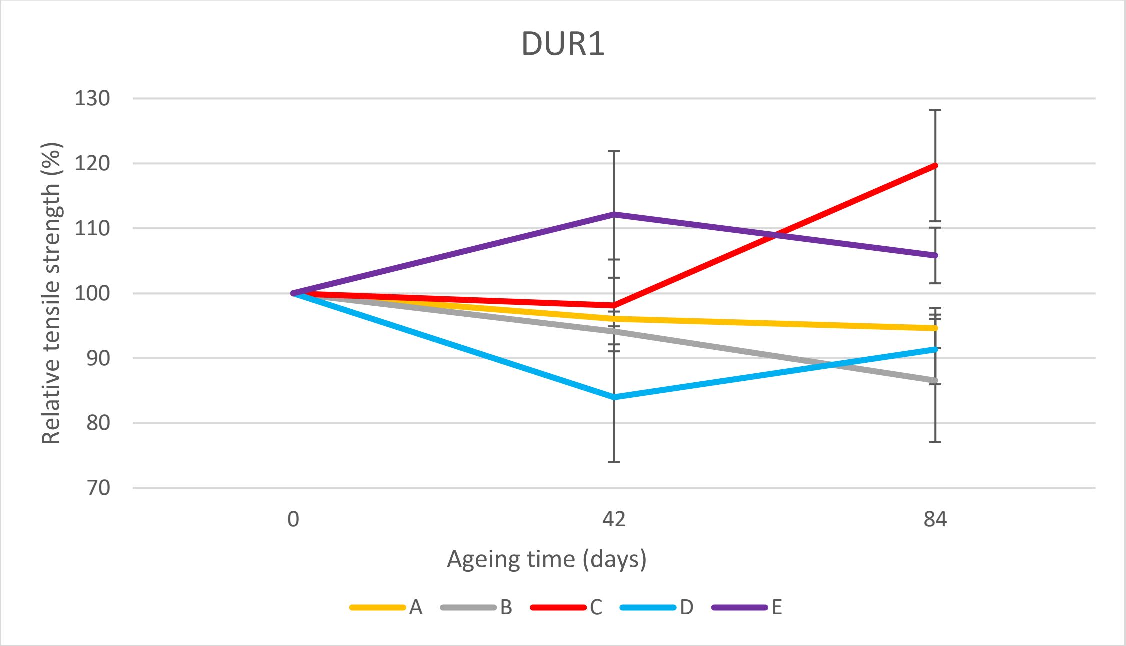

Figure 3. Tensile strength changes during ageing cycle DUR1.

All samples were exposed to the DUR2 ageing cycle. Most samples show a decrease in relative tensile strength after 7 days of ageing. The tensile strength of samples A, B and C decreases further after 28 days, reaching 70%, 76% and 65% respectively. Samples A and C then appear to stabilise around 70% after 56 days. Sample B shows a continuing downward trend to 55% of its original tensile strength after 56 days. Samples D and E show some fluctuation. Sample E increases slightly between 0 and 28 days and then decreases to 99% of its original strength.

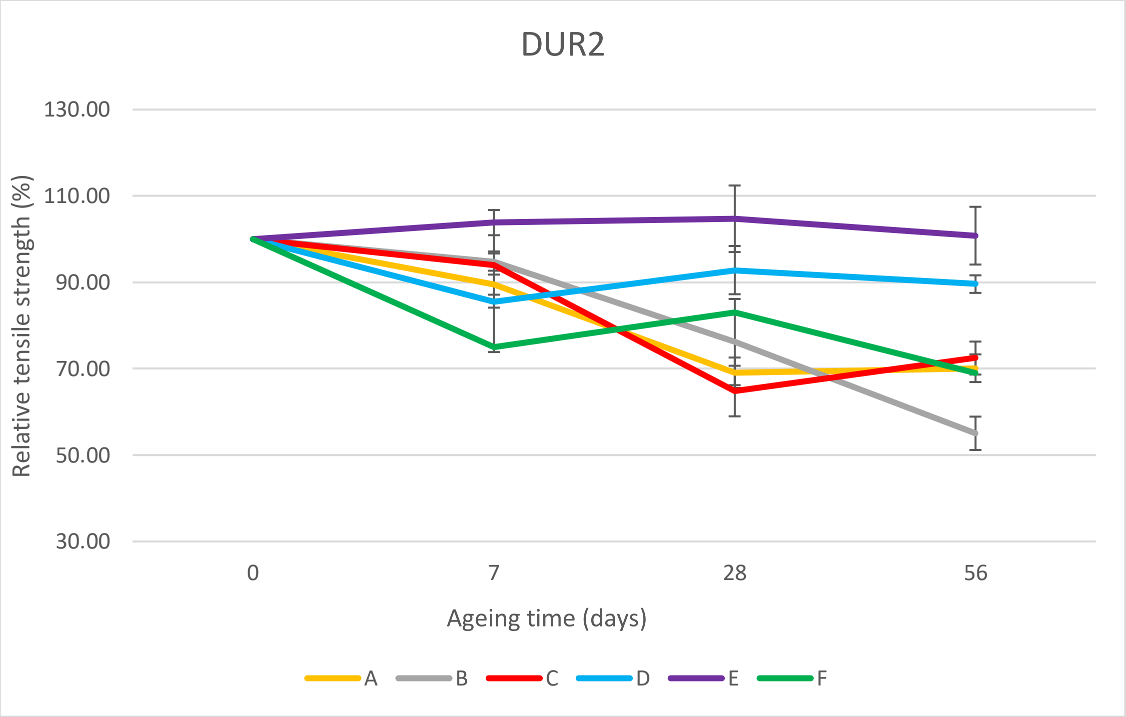

Figure 4. Tensile strength changes during ageing cycle DUR2.

Sample B was only exposed to EM4 for 30 days. Three sample groups show a decrease in tensile strength after 30 days and sample B reaches 76% of its original strength. Between 30 and 60 days, all samples show an increase in tensile strength. After 60 days, samples C and E increase to 112% and 106% of their original strength and samples A and D increase to 97% and 89% respectively.

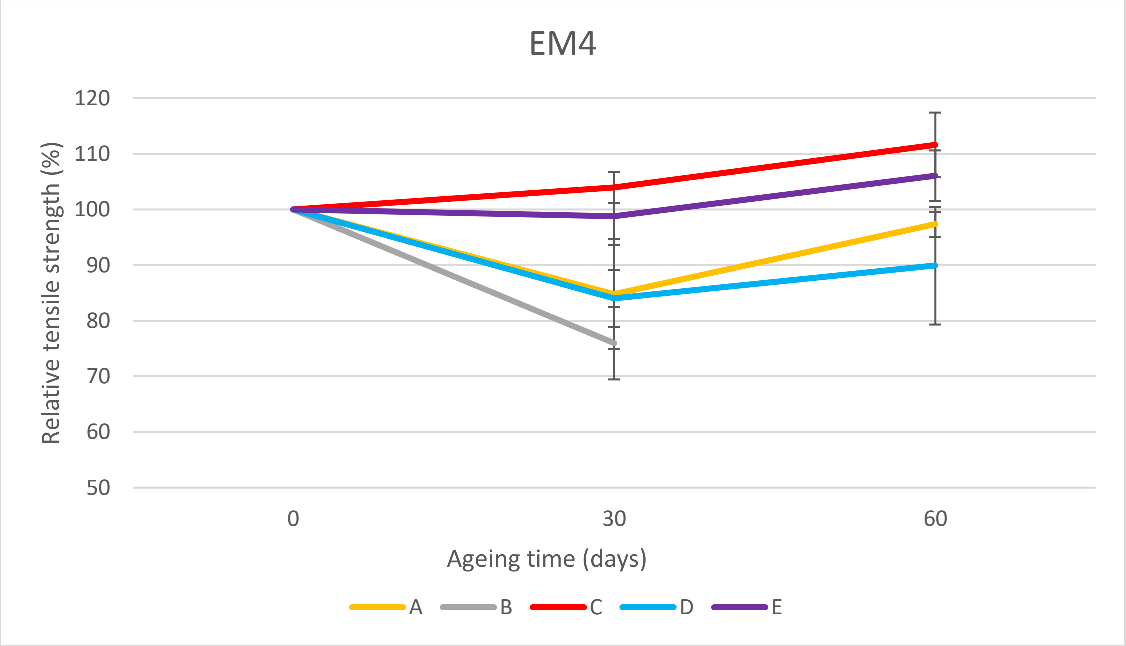

Figure 5. Tensile strength change during ageing cycle EM4

4. Discussion

The aim of this work was to develop an evaluation method for assessing the long-term performance of SIPs. The developed method was then used on a select group of SIPs samples. The aim of the testing was to assess whether the evaluation method could distinguish performance differences between different SIPs samples under different ageing conditions. The SIPs samples were composed of different materials and were therefore expected to perform differently after undergoing accelerated ageing. Not all samples were exposed to all ageing conditions, so comparison is only possible between samples that were exposed to the same conditions. The results show that different samples exhibited different tensile strength changes (before and after ageing) between the different sample types. The results support the initial hypothesis that the test methods would be able to show performance differences between different SIPs types.

Tensile strength was chosen as the main parameter to assess durability because of the importance of the face/core bond in the overall strength of the SIP. Changes in tensile strength were found to be quite variable, with both increases and decreases occurring with ageing. Samples were expected to degrade with ageing and so increases in tensile strength were surprising. Where this cannot be explained by variability in the results, it is possible that strength increased due to curing of the PUR foam or strengthening of the PVA with ageing or other unknown reasons. Further work could be done to see the effects of different mechanical tests (such as shear or flexural testing) on the variability of results.

There are three main limitations of this work.

- The component materials used in this study represent only a portion of the SIP types available commercially. The application of the evaluation method to SIPs made from other materials has not been studied.
- The testing was done on small-scale SIP samples. This study did not investigate the correlation between the behaviour of small-scale and full-scale SIP panels.
- Not all samples were exposed to all ageing conditions.

5. Conclusion and future work

This pilot study developed an evaluation method for assessing the durability of SIPs and investigated its ability to distinguish performance differences between different SIPs. The study found that different SIPs samples exhibited different changes in tensile strength after ageing in different conditions. The results show that the evaluation method has the potential to assess performance under different ageing conditions.

This work provides a basis for further development of the evaluation method. Further work is needed to assess whether the method can be used to assess the quality of different SIPs and therefore offer a potential route to compliance with the NZBC durability requirements. There are three main recommendations for future work:

- Establish a laboratory standard SIPs sample that has a known and reliable performance in the accelerated ageing tests and can be compared to new SIPs being tested.
- Ensure that all SIPs samples are tested under all five accelerated ageing tests
- Develop acceptance criteria for the evaluation method that outlines what is considered acceptable in terms of pass/fail for each ageing test and any weighting that should be applied to the ageing methods based on the anticipated realistic in-service conditions.

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Appendix A

The following tables show the results for each sample against the acceptance criteria for each accelerated ageing test.

In the 'Dimensional change' column, the figure in brackets denotes the greatest change observed in any direction of the sample.

Table 4. Sample A results.

Ageing test	Acceptance criteria		Test result		Overall	Dimensional change (<5%)
C1	R1/R0	≥ 0.6	0.9	Pass	Fail	Pass (-3.7%)
	R5/R0	≥ 0.4	0.8	Pass		
	(R1-R5)/(R0-R1)	≤ 1.0*	2.0	Fail		
	(R5-R10)/(R1-R5)	≤ 1.0*	2.1	Fail		
	R10/R0	≥ 0.60*	0.5	Fail		
C2	RT/R0	≥ 0.4	1.0	Pass	Pass	Pass (+4.5%)
DUR1	(lowest of R42, R84)/R0	≥ 0.5	1.0	Pass	Pass	Pass (-1.5%)
	(lowest of R42, R84)	≥ 20 kPa	267.1	Pass		
DUR2	(R7-R28)/(R0-R7)	≤ 3.0	2.0	Pass	Pass	Fail (+5.0%)
	R28/R0	≥ 0.4	0.7	Pass		
	(R28-R56)/(R7-R28)	≤ 1.0	-0.1	Pass		
	R56/R0	≥ 0.4	0.7	Pass		
EM4	R30/R0	≥ 0.6	0.8	Pass	Pass	Pass (+0.8%)
	R60/R0	≥ 0.4	0.6	Pass		

Table 5. Sample B results.

Ageing test	Acceptance criteria		Test result		Overall	Dimensional change (<5%)
DUR1	(lowest of R42, R84)/R0	≥ 0.5	0.9	Pass	Pass	Pass (-1.3%)
	(lowest of R42, R84)	≥ 20 kPa	265.6	Pass		
DUR2	(R7-R28)/(R0-R7)	≤ 3.0	3.5	Fail	Fail	Fail (+5.3%)
	R28/R0	≥ 0.4	0.8	Fail		
	(R28-R56)/(R7-R28)	≤ 1.0	1.1	Fail		
	R56/R0	≥ 0.4	0.6	Pass		
EM4	R30/R0	≥ 0.6	0.8	Pass	-	Pass (+1.0%)
	R60/R0	≥ 0.4	-	-		

Table 6. Sample C results.

Ageing test	Acceptance criteria		Test result		Overall	Dimensional change (<5%)
C1	R1/R0	≥ 0.6	1.0	Pass	Pass	Pass (+3.8%)
	R5/R0	≥ 0.4	0.9	Pass		
	(R1-R5)/(R0-R1)	≤ 1.0*	-33.7	Pass		
	(R5-R10)/(R1-R5)	≤ 1.0	-0.1	Pass		
	R10/R0	≥ 0.6	0.9	Pass		
DUR1	(lowest of R42, R84)/R0	≥ 0.5	1.0	Pass	Pass	Pass (-1.0%)
	(lowest of R42, R84)	≥ 20 kPa	148.8	Pass		
DUR2	(R7-R28)/(R0-R7)	≤ 3.0	4.8	Fail	Pass	Fail (+7.9%)
	R28/R0	≥ 0.4	0.6	Pass		
	(R28-R56)/(R7-R28)	≤ 1.0	-0.3	Pass		
	R56/R0	≥ 0.4	0.7	Pass		
EM4	R30/R0	≥ 0.6	1.1	Pass	Pass	Pass (+2.4%)
	R60/R0	≥ 0.4	1.2	Pass		

Table 7. Sample D results.

Ageing test	Acceptance criteria		Test result		Overall	Dimensional change (<5%)
C1	R1/R0	≥ 0.6	0.8	Pass	Pass	Pass (+2.1%)
	R5/R0	≥ 0.4	0.9	Pass		
	(R1-R5)/(R0-R1)	≤ 1.0*	-0.4	Pass		
	(R5-R10)/(R1-R5)	≤ 1.0	-0.3	Pass		
	R10/R0	≥ 0.6	0.8	Pass		
DUR1	(lowest of R42, R84)/R0	≥ 0.5	0.8	Pass	Pass	Pass (-1.4%)
	(lowest of R42, R84)	≥ 20 kPa	162.8	Pass		
DUR2	(R7-R28)/(R0-R7)	≤ 3.0	-0.5	Pass	Pass	Pass (+3.4%)
	R28/R0	≥ 0.4	0.9	Pass		
	(R28-R56)/(R7-R28)	≤ 1.0	-0.4	Pass		
	R56/R0	≥ 0.4	0.9	Pass		
EM4	R30/R0	≥ 0.6	0.9	Pass	Pass	Pass (-1.4%)
	R60/R0	≥ 0.4	0.9	Pass		

Table 8. Sample E results.

Ageing test	Acceptance criteria		Test result		Overall	Dimensional change (<5%)
C1	R1/R0	≥ 0.6	1.2	Pass	Pass	Pass (+2.3%)
	R5/R0	≥ 0.4	1.0	Pass		
	(R1-R5)/(R0-R1)	≤ 1.0	-1.1	Pass		
	(R5-R10)/(R1-R5)	≤ 1.0	-0.6	Pass		
	R10/R0	≥ 0.6	1.1	Pass		
DUR1	(lowest of R42, R84)/R0	≥ 0.5	1.1	Pass	Pass	Pass (-1.1%)
	(lowest of R42, R84)	≥ 20 kPa	197.4	Pass		
DUR2	(R7-R28)/(R0-R7)	≤ 3.0	-0.2	Pass	Pass	Pass (+4.8%)
	R28/R0	≥ 0.4	1.0	Pass		
	(R28-R56)/(R7-R28)	≤ 1.0	-4.4	Pass		
	R56/R0	≥ 0.4	1.0	Pass		
EM4	R30/R0	≥ 0.6	1.0	Pass	Pass	Pass (+0.8%)
	R60/R0	≥ 0.4	1.0	Pass		

Table 9. Sample F results.

Ageing test	Acceptance criteria		Test result		Overall	Dimensional change (<5%)
DUR2	(R7-R28)/(R0-R7)	≤ 3.0	-0.3	Pass	Pass	Data not available
	R28/R0	≥ 0.4	0.8	Pass		
	(R28-R56)/(R7-R28)	≤ 1.0	-1.7	Pass		
	R56/R0	≥ 0.4	0.7	Pass		

Appendix B

Table 10 shows the greatest dimensional change observed in each sample type after accelerated ageing.

Table 10. Dimensional changes after accelerated ageing cycles.

	Relative dimensional change (% of original)										
Sample	**C1-1**	**C1-5**	**C1-10**	**C2**	**EM4-30**	**EM4-60**	**DUR1-42**	**DUR1-84**	**DUR2-7**	**DUR2-28**	**DUR2-56**
A	-2	-2.6	-3.7	4.5	0.3	0.8	-1.3	-1.5	2.8	5	4.9
B	-	-	-	-	1	-	-1.2	-1.3	2.9	4.9	5.3
C	1.7	2.6	3.8	-	1.5	2.4	-1	-0.6	4.4	5.8	7.9
D	0	1.3	2.1	-	-1.4	-1.1	-1.4	-1.3	2.6	3.2	3.4
E	0.9	1.7	2.3	-	0.7	0.8	-1.1	-1	4.8	4.4	4.3

- = data not available