Robustness testing of external wall insulation systems
Robustness Testing of External Wall Insulation Systems

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Acknowledgements

We would like to thank Natural Building Technologies and other suppliers for kindly providing us with external wall insulation samples to test; the work could not have been conducted without these and their support is very much appreciated.

The project would not have been possible without funding as part of the University of Sheffield’s SURE scheme, which funded the laboratory tests and our undergraduate student’s time.
Executive Summary

This report presents the results from laboratory-based robustness testing of external wall insulation systems. Two tests were conducted: impact tests and compression tests. These were carried out on three different insulation systems: woodfibre board, expanded polystyrene boards and phenolic foam boards.

In both impact and compression tests the woodfibre samples showed good bounce back (high elasticity) and low relative deformation. The jointing system utilised meant that on impact across two or more boards the woodfibre performed as a system, spreading impact across a larger area, reducing the permanent damage. High stresses (>1000KPa) were required to achieve a 50% deformation of the samples, making it unlikely that high levels of permanent deformation would occur to installed systems.

The phenolic foam samples required the highest stresses to reach a 10% deformation. However, under the higher stresses (>300KPa) that cause a 50% deformation, permanent deformation occurs to the cellular structure of the foam, which will be detrimental to its thermal performance. It is a possibility that this level of force could occur to installed products, through vandalism or hard body impacts.

The EPS samples suffered the greatest initial deformation across the impact tests, although demonstrate good bounce back and low relative deformation. An area of concern for this system is the level of cracking that occurs to the render upon impact. There is significant compression of the insulation on impact, which cracks the render system. This could perhaps be reduced if a render system with more flexibility was used, so it could bounce back after compression with less permanent damage. Due to the low level of stress required (>170KPa), it is likely that some compression and cracking to this in-situ system would occur if it is subjected to even modest impacts.

To improve the robustness of the systems, it is recommended that developments are made to two areas:

**The base rail detail of all systems** – cracking and metal deformation occurred here in the impact tests of all three insulation systems. This would result in water ingress through the render to the insulation, compromising the performance of the system.

**The jointing between four boards for the phenolic foam and expanded polystyrene systems** – significant cracking was seen in the impact tests for four board join samples. As above, this would allow water ingress into the systems.
1 Introduction

The aim of this work was to investigate the robustness of external wall insulation systems. As these systems encase the outside of a house it is important that they can resist impacts from projectiles, skateboards, vandalism and stand up to everyday life (e.g. ladders and bikes may be leant against them) without significant damage. A series of laboratory tests have been conducted to investigate the robustness of external wall insulation systems.

External wall insulation is applied to buildings, usually those with a solid wall, to improve their thermal performance, thus lowering heating requirements and bills, and reducing the environmental impacts associated with heating. These systems are built up of several layers (Figure 1) fixed onto the existing wall mechanically and/or with adhesives. Damage will most likely occur to the outer, rendered layer in the form of cracking. However, significant damage could allow water penetration into the system, and this in turn may affect the thermal conductivity of the insulation. Significant compression to the system could also affect the thermal conductivity. It is therefore important to understand the likelihood of cracking and compression to the systems.

![Figure 1: External Wall Insulation System - Layer Build up](image)

Three different insulation systems were investigated, a woodfibre board system, a phenolic foam system and an expanded polystyrene (EPS) system. The specification of these and system breakdowns can be seen in Table 1.
The systems were subjected to two tests: hard body impact tests and compression tests. The procedure and results of these are outlined in sections 2 and 3.

### 2 Hard Body Impact Tests

All the hard body impact tests were conducted on built up system, rendered, insulation panels. For each insulation type, four different samples were tested: a single panel, a joint between two boards, a joint between four boards (three in the case of woodfibre due to the system utilised) a base-rail detail, and an edge detail for the EPS and phenolic foam systems. More details of these can be seen in Figure 2. Details of where the systems were impacted are also shown in Figure 2, with up to three impacts per sample, each on a different area of the sample.

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1 Supplied by Natural Building Technologies, http://www.natural-building.co.uk/
Figure 2: External wall insulation sample types tested. The 'X' marks indicate where the samples were impacted (grey X marks are tests conducted on phenolic and EPS samples only).

The jointing technique between panels varied across the three systems, as shown in Figure 3. The woodfibre boards lock closely together with little air gap between them, whereas a small air gap can be seen between the phenolic foam and EPS boards.

Figure 3: Jointing between two insulation panels, (a) woodfibre board, (b) phenolic foam board, (c) EPS insulation board
Each of the boards was subjected to a 10J impact. A 1 kg steel ball was dropped from a height of 1.02m to the centre point of impact. A release point was marked on the red frame shown in Figure 4 to ensure the drop height remained consistent. This test set up was based on ISO 7892:1988 and ETAG 004 (2008). Each of the samples was attached to a metal frame (Figure 4); the point of impact was always against the centre steel section piece to mimic the stiffness of a wall. This was kept consistent throughout the tests. Videos of the impacts were taken using a high-speed camera operated at a frame rate of 900 frames per second. Photographs of the impacted surfaces were also taken and crack thicknesses recorded (Figure 5, Figure 6, Figure 7, Table 2, Table 3, Table 4).

![Figure 4: Photograph of the test set up for the impact tests, a mark on the red frame was used as a release point for the pendulum, to ensure consistency. The high speed camera which was used to capture the impacts can be seen in the bottom right corner.](image)

The results for the woodfibre impact tests can be seen in Table 2. Cracking was typically in a circular shape, as can be seen in Figure 5. In Table 2, the Dia. X is the widest diameter the crack extended in the horizontal direction and Dia. Y refers to it in the vertical direction, the greatest crack thickness is also given.
Comparing the crack sizes for the different woodfibre samples, it can be seen that the greatest crack thickness occurs for the three-board join, although the average diameter of this impact was no larger than that from other tests. The base rail sees the widest crack in a horizontal direction; the impact results in cracks along the base rail on average 167mm in length. From the high-speed camera footage of the three-board join it can be seen that the whole woodfibre board flexes on impact. This is seen to be particularly the case where two or three boards join together. This dissipates the force, reducing the localised compression. The material also visibly bounces back from the maximum compression point. The jointing system of the woodfibre boards appears to facilitate this unified behaviour so that it acts more as a system than an individual board.
Figure 5: Typical impact behaviour of the woodfibre boards, (a) a single board; (b) two-board join; (c) three-board join; (d) base rail impact

The impact results for phenolic foam can be seen in Table 3 and the typical cracking behaviour in Figure 6. The crack thickness and diameter increased the more boards that are joined, suggesting that the junction point between four boards is one of the weakest parts of the system. However, the likelihood of impacts occurring to this specific junction is small. The corner detail when impacted on a straight face performs well, although this might change if impacts were incurred directly to the edge; further testing would be required to ascertain this. The base rail damage, as with the woodfibre system, extends beyond the impact diameter, with a crack forming along the metal base rail fixture (Figure 6). This result implies that repeated impacts to this area would likely cause extensive damage and might result in the base rail detail becoming detached from the system. More testing would be required to conclusively ascertain the extent of damage that multiple impacts would cause. The high-speed camera footage of the four board join showed that there is a small amount of flex from the whole board upon impact, but the compression is significant and localised to the point of impact. There is some bounce back but a visible impression remains in the surface of the sample.
<table>
<thead>
<tr>
<th></th>
<th>Phenolic Single</th>
<th>Phenolic two-board</th>
<th>Phenolic Base Rail</th>
<th>Phenolic Corner</th>
<th>Phenolic four-board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>T</td>
<td>B</td>
<td>A</td>
<td>R</td>
</tr>
<tr>
<td>Dia. X (mm)</td>
<td>40</td>
<td>41</td>
<td>40</td>
<td>40.3</td>
<td>35</td>
</tr>
<tr>
<td>Dia. Y (mm)</td>
<td>33</td>
<td>45</td>
<td>38</td>
<td>38.7</td>
<td>35</td>
</tr>
<tr>
<td>Max. crack thickness (mm)</td>
<td>0.06</td>
<td>0.12</td>
<td>0.08</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Base rail damage length (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Crack sizes for phenolic foam impact tests (Note that A refers to the average size crack, the following notations indicate the position of impact on the board, R right, M middle, L left, C centre, T top and B bottom)

Figure 6: Impact test result for phenolic foam samples, (a) single board, (b) two-board join, (c) four-board join, (d) base rail impact
The impact results for EPS can be seen in Table 4 and Figure 7. The results show a similar pattern to those of the phenolic foam, the crack thickness increases the more boards that join together, although the crack thickness for EPS are larger than those for phenolic foam. The impacts to the corner face cause minimal damage, with no visible cracking on two impacts and a fine crack on the third. The base rail impacts show a similar pattern to the other samples, with cracking along the rail and some deflection of the metal. From the high speed camera image of the four board join it can be seen that there is significant compression to the sample on impact. There is substantial bounce back seen, but the initial compression is such that large cracks are formed in the render, with pieces breaking off.

<table>
<thead>
<tr>
<th></th>
<th>EPS Centre</th>
<th>EPS two-board</th>
<th>EPS Base Rail</th>
<th>EPS Corner</th>
<th>EPS four-board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C  T  B  A</td>
<td>R  M  L  A</td>
<td>R  M  L  A</td>
<td>L  M  R</td>
<td></td>
</tr>
<tr>
<td>Dia. X (mm)</td>
<td>45  61  31  45.7</td>
<td>58  46  49  51</td>
<td>71  45  59  58.3</td>
<td>0  0  110  64</td>
<td></td>
</tr>
<tr>
<td>Dia. Y (mm)</td>
<td>52  65  38  51.7</td>
<td>45  40  48  44.3</td>
<td>28  22  25  25</td>
<td>0  0  45  55</td>
<td></td>
</tr>
<tr>
<td>Max. crack thickness (mm)</td>
<td>0.5 0.4 0.06 0.32</td>
<td>0.2 0.14 3 1.1</td>
<td>0.3 0.3 0.2 0.27</td>
<td>0  0  0.06 1.6</td>
<td></td>
</tr>
<tr>
<td>Base rail damage</td>
<td></td>
<td></td>
<td>160 117 107 128</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Crack sizes for EPS impact tests (Note that A refers to the average size crack, the following notations indicate the position of impact on the board, R right, M middle, L left, C centre, T top and B bottom)
The woodfibre board systems tested had a greater thickness of insulation, 100mm, compared to the 50mm phenolic and EPS systems so the tests are not directly comparable. However, the material behaviour on impact would likely be similar with different thicknesses of insulation. Across the systems the base rail seems to be a weak point, with cracking occurring along it upon impact. If this were subjected to multiple impacts the damage could become more extensive. Multiple impacts are possible as this detail is close to the ground, so could be kicked or have footballs kicked against it. Exploring means of strengthening this detail in all systems is recommended.

Generally for the phenolic and EPS systems the base rail detail occurs 100mm off the ground, leaving a cold bridge from the end of the insulation to the ground, as seen in Figure 8. Detailing to avoid this cold bridge should be investigated in conjunction with improving the impact resistance.
3 Compression Tests

Small samples of 60mm thick woodfibre board insulation (80x90mm laterally) and 50mm thick EPS and phenolic foam (70x70mm laterally) were placed under compressive loads. Both the built up insulation systems and isolated insulation samples, without render, were tested. Before each test the exact size of the sample was measured; this size was measured again immediately after compression, 1 hour after the compression test and 24 hours later. The amount each sample recovered its thickness after the compression was calculated, as was the relative deformation after 24 hours (Table 5 and Table 7). The relative deformation is a ratio between the change in thickness and the initial thickness ([initial thickness-final thickness]/initial thickness).

The insulation samples were subjected to a compression test, taken to 10% deformation at a rate of 3 mm/min. 10% deformation means that the samples are compressed by 10% of their original size, e.g. a 50mm sample is compressed by 5mm. For each insulation type two samples were tested and the results of these averaged; these can be seen in Table 5. For the woodfibre insulation one of the samples increased in thickness from 59mm to 60mm, the other reduced from 61mm to 60mm. The increase in thickness could be due to the fibres within the samples being displaced from their original position and finding a new equilibrium position once the compression was removed. The average of these suggests negligible permanent deformation of woodfibre board under these test conditions. For the EPS samples, one had no permanent
deformation and the other sample a permanent deformation of 2%. Of the three samples, woodfibre insulation has the lowest relative deformation and phenolic foam the greatest, approximately 2.5%, when the samples are subjected to a 10% compression test.

<table>
<thead>
<tr>
<th></th>
<th>Woodfibre</th>
<th>Phenolic Foam</th>
<th>EPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bounce Back (mm)</td>
<td>6.00</td>
<td>3.85</td>
<td>4.35</td>
</tr>
<tr>
<td>Bounce Back, % of max. deformation</td>
<td>101%</td>
<td>76%</td>
<td>90%</td>
</tr>
<tr>
<td>Relative Deformation %</td>
<td>-0.05%</td>
<td>2.5%</td>
<td>1%</td>
</tr>
</tbody>
</table>

Table 5: Relative deformation 24 hours after for 10% compression test of un-rendered samples

During the 10% compression tests, the stress on the material was recorded, as shown in Table 6. This was compared to manufacturer’s data and predicted compressive resistance of the material at 10% compression. For the woodfibre board, test 1 shows a very similar strength to those stated in product data (NBT, 2013). In the second test this is reduced by almost 13%. As the samples were mechanically cut into appropriate test sizes it is possible that this process damaged the adhesion between fibres, resulting in a lower compressive strength than expected. Both phenolic foam samples exceeded the minimum compressive resistance as specified by ASTM Standard C1126-12a. As the EPS would be utilised in a wall application with minimal load, it is assumed it is classified as a Type I material for the ASTM Standard C578-12b. A compressive resistance of 69kPa is suggested for Type I EPS at either 10% deformation or at yield, whichever of these first occurs (ASTM Standard C578-12b). It can be seen (Table 6) that neither test results meet this criteria, one by more than 30%. The standard is based on a 25.4mm thick sample but suggests that lower values will result for thicker materials (ASTM Standard C578-12b, 2012). This might, at least in part, explain the lower test results for the 50mm thick samples used here.
Insulation and the built up systems were also tested under 50% compressive deformation, and as before, two samples of each type were tested and the results averaged (*Table 7*). All samples at 50% deformation were permanently compacted. The rendered woodfibre samples had the lowest relative deformation and the phenolic rendered system the largest.

**Table 6: Stress at 10% compressive deformation for un-rendered samples**

<table>
<thead>
<tr>
<th>Insulation</th>
<th>Min. compressive resistance for 10% compression or yield point (kPa)</th>
<th>Test 1 Result (kPa)</th>
<th>Test 2 Result (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodfibre</td>
<td>70²</td>
<td>69.8</td>
<td>61.0</td>
</tr>
<tr>
<td>Phenolic Foam</td>
<td>124³</td>
<td>162.5</td>
<td>138.3</td>
</tr>
<tr>
<td>EPS</td>
<td>69⁴</td>
<td>61.3</td>
<td>46.4</td>
</tr>
</tbody>
</table>

**Table 7: Relative Deformation, after 24 hours, of insulation materials and rendered systems, for 50% deformation**

<table>
<thead>
<tr>
<th></th>
<th>Woodfibre</th>
<th>Woodfibre Rendered System</th>
<th>Phenolic Foam</th>
<th>Phenolic Rendered System</th>
<th>EPS</th>
<th>EPS Rendered System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bounce Back (mm)</td>
<td>20.5</td>
<td>23.5</td>
<td>9.5</td>
<td>9.5</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Bounce Back % of max. deformation</td>
<td>69%</td>
<td>67%</td>
<td>37%</td>
<td>36.5%</td>
<td>65%</td>
<td>62%</td>
</tr>
<tr>
<td>Relative Deformation % ((initial-final)/initial)x100</td>
<td>16.5%</td>
<td>14.0%</td>
<td>31%</td>
<td>32.5%</td>
<td>17.0%</td>
<td>19.0%</td>
</tr>
</tbody>
</table>


³ ASTM Standard Specification for Faced or Unfaced Rigid Cellular Phenolic Thermal Insulation

⁴ ASTM Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation
Both compression tests show the same pattern for the material properties. Woodfibre has the least relative deformation, then EPS and then phenolic foam. Woodfibre insulation is a fibrous material, and has an elastic response to the compression. The EPS behaves elastically until it reaches its yield point at 40kPa stress, above which it will undergo permanent deformation. This is reflected in the relative permanent deformation of the EPS samples, which increased significantly from the 10% deformation to the 50% deformation. The phenolic foam also behaves elastically until it reaches its yield point at approximately 120kPa after which permanent deformation occurs to the insulation. Visible permanent compressive deformation can be seen in the sample (Figure 9). Examining this at a cellular level, Figure 10, it can be seen that voids are formed in the closed cell structure. This level of deformation would likely increase the thermal conductivity of the phenolic foam.

![Figure 9: Compressed phenolic foam samples showing deformation in the middle of the insulation sample, (a) non-rendered sample, (b) rendered sample with full system build up](image)

![Figure 10: Phenolic foam samples under optical microscope (a) in virgin state and (b) after 50% compression](image)
It is important to consider at what stress the different insulation samples reach 10% and 50% compression, as this will reflect the likelihood of this occurring to systems once installed on homes. Table 6 shows the stresses that attained a 10% deformation for each of the samples. EPS requires the least stress, 53.9KPa on average, to reach a 10% deformation and phenolic foam the most stress, averaging at 150.4KPa.

The stresses required for a 50% deformation are shown in Table 8, from this it can be seen that the built up systems require a much higher stress for a 50% deformation, which is part of the purpose of the fibre reinforcement and render. EPS has the lowest 50% compressive strength, 136.5KPa, but in contrast to the 10% compressive strength, unrendered woodfibre has the highest 50% compressive strength, 788KPa, whereas phenolic foam requires a stress of 285KPa for 50% compression. This is due the inherent material properties, once phenolic foam's cellular structure starts to break, its strength is weakened and visible compression occurs, as seen in Figure 9, these are characteristics of brittle behaviour. Whereas, for the woodfibre board, compression pushes the fibres together so they are more tightly packed, making it harder to compress and as such the stress required for a 50% deformation is nearly three times that of phenolic foam and almost six times that of EPS. It should be noted that the woodfibre samples are 60mm thick compared to 50mm thick EPS and phenolic foam samples. This in principle should not alter the pattern of results as the load is continuous through the material structure.

<table>
<thead>
<tr>
<th></th>
<th>Woodfibre</th>
<th>Woodfibre</th>
<th>Phenolic</th>
<th>Phenolic</th>
<th>EPS</th>
<th>EPS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rendered</td>
<td>Foam</td>
<td>Foam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Test 1 Stress</strong></td>
<td>804</td>
<td>1011</td>
<td>265</td>
<td>318</td>
<td>134</td>
<td>180</td>
</tr>
<tr>
<td><strong>Test 2 Stress</strong></td>
<td>772</td>
<td>1055</td>
<td>305</td>
<td>286</td>
<td>139</td>
<td>176</td>
</tr>
<tr>
<td><strong>Average Stress</strong></td>
<td>788</td>
<td>1033</td>
<td>285</td>
<td>302</td>
<td>136.5</td>
<td>178</td>
</tr>
</tbody>
</table>

*Table 8: Forces and stresses required to reach 50% deformation of sample*

It is important to explore what level of forces could be inflicted on the insulation systems in everyday life in order to understand what level of deformation is likely. In a study of Olympic boxers (across weight classes) the force from a straight/extended punch ranged from 1990-
Kicks would likely generate a larger force than this as more mass can be recruited. Impacts of this type in a vandalism context would likely fall into the lower range, but this would be sufficient to cause a 50% deformation in both the EPS and phenolic foam rendered systems, as from the tests conducted a 50% deformation was reached from 875N for the EPS system and 1484N for the phenolic foam system. The area over which the impact occurs is also significant, as the stress increases if the same force is applied over a smaller area. Projectiles with a smaller diameter could potentially cause a higher stress and therefore more damage to the systems than larger projectiles if the impact occurs with the same level of force.

From the tests it can be seen that the level of damage to the system also depends on the material properties of the insulation material. The distinction between the elastic behaviour of the woodfibre board and the more brittle behaviour of the EPS and phenolic foams leads to further conclusions. Permanent damage will occur to these materials when applied stress from impacts exceeds the materials' yield points. Based on our measurements, EPS and phenolic foam insulation materials have lower yield points, 40KPa and 120KPa respectively, compared to 200KPa for woodfibre boards; the former are therefore more susceptible to this type of damage. The more elastic behaviour of woodfibre board will also most likely lead to a spreading of any applied load over a wider area. This will have the effect of reducing the load experienced by the material and, therefore, reduce the likely damage.

4 Key Findings and Recommendations

From the impact tests it appeared that the woodfibre samples bounced back after impact, leaving little indentation in the sample, but some cracking to the render. This was further demonstrated in the compression tests where the woodfibre samples had the lowest relative deformation of the three samples tested. The render system did not seem to detrimentally affect the bounce back and enabled the sample to sustain a higher level of stress before reaching 50% deformation. The woodfibre boards required the highest loads to reach a 50% deformation.

The phenolic foam appeared to have a small amount of bounce back in the impact tests. This was confirmed in the compression tests. The render system improved the compressive resistance of the foam and did not alter the bounce back. The phenolic foam samples have the highest compressive resistance for a 10% deformation, but under higher loads, visible compression and deformation occurs in the middle of the sample and the closed cell structure is damaged, with voids opening up within it.
The EPS samples consistently have the lowest compressive resistance in the compression tests, although the rendered system did enable higher forces to be resisted. This corresponds with the impact tests where there is visibly more compression to the EPS compared to the other two samples. The visible bounce back is good, and from the compression tests it can be seen that EPS samples had a higher bounce back and lower relative deformation than the phenolic foam samples. This is likely due to air gaps being squashed during compression and the material then expanding again once the loading is released. However, due to the level of the initial compression, large cracks did form in the impact samples; these would likely allow water ingress to the insulation.

In the impact tests, both the phenolic foam and EPS samples had higher crack thicknesses as more boards were joined together. For the woodfibre board samples the three board joint had a greater crack thickness than the single and two board join, but there was no difference between the latter two samples. The jointing technique for the woodfibre boards allows them to act more cohesively, whereas, as can be seen in Figure 3, air gaps are present between phenolic and EPS joins, so the boards will act independently. Strengthening the four board joint in particular is recommended for the phenolic foam and EPS systems. Utilising additional reinforcing mesh over these joints might improve their impact resistance, but this would require further testing to ascertain.

For all three systems the base rail seems a weak point, improving the impact resistance of this is recommended. This is a vulnerable and accessible area of the system so may be prone to vandalism and impacts from projectiles. If repeated impacts cause the base rail to detach this would then allow significant ingress of water, affecting the thermal performance of the systems.
5 References


6 Appendix

6.1 Supporting information for compression tests

6.1.1 WoodFibre Board Samples

6.1.1.1 Example 10% Deformation Test – non rendered sample

6.1.1.2 Example 50% Deformation Test – non rendered sample
The stress-strain graph is described as a J-shaped curve. As the loading and unloading follow the same curve, the loading should be completely reversible, hence Woodfibre has an elastic response, which correlates with its low relative deformation. The Woodfibre insulation stress-strain graph demonstrates that the material follows Hooke’s Law at the beginning i.e. the stress is proportional to the strain. As this is constant, the modulus of elasticity, Young’s Modulus, can be calculated as 0.9MPa using the Elastic Region Response graph; from this it can be seen that the yield point is at 200kPa.
6.1.2 EPS Samples

6.1.2.1 Example from 10% Deformation Tests – non rendered sample

![Graph showing Elastic Region Response](image)

- y = 884.85x - 27.256

![Graph showing EPS Board](image)

- Standard force [N] vs. Deformation [%]
6.1.2.2 Example from 50% Deformation Tests – Non rendered samples

6.1.2.3 Example from 50% deformation tests of rendered EPS Samples
6.1.2.4 Stress Strain Response of EPS samples under 50% deformation

As the strain increases, the strain yield point determines the stress needed to induce plastic deformation in the EPS insulation. The internal cells move to a new equilibrium position. After the yield point, at approximately 40KPa, permanent deformation of the EPS insulation will occur.

6.1.3 Phenolic Foam Samples

6.1.3.1 Example from 10% Deformation Tests – non render samples
6.1.3.2 Example from 50% Deformation tests – non rendered samples

6.1.3.3 Example from 50% deformation tests - Rendered Phenolic Foam Samples
As the strain increases, the strain yield point determines the stress needed to induce plastic deformation in the phenolic insulation. The internal cells move to a new equilibrium position. The sharp dips in the graph demonstrate cracking within the phenolic foam, breaking the closed cell structure. After the yield point permanent deformation of the phenolic insulation will occur.