วารสารราชบัณฑิตยสถาน
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# Short- and Long-term Performance of Fibre-Reinforced Cement Profile Sheets Containing Asbestos and Non-asbestos Materials

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งานวิจัยนี้ได้ทำการศึกษาเพื่อเปรียบเทียบสมรรถนะของผลิตภัณฑ์กระเบื้องหลังคาแผ่นลอนที่เสริมและไม่เสริมเส้นใยหิน กระเบื้องที่ใช้ทดสอบแบ่งออกเป็น ๔ ยี่ห้อ โดยได้ลบเอายี่ห้อออกก่อนส่งมาทำการศึกษา การจำแนกกระเบื้องจำแนกตามสีกระเบื้องแบ่งเป็น สีฟ้า สีน้ำตาล สีแดง และสีเขียว กระเบื้องที่ส่งมาได้ทำการตรวจสอบสมบัติทางกายภาพและเคมีเพื่อแยกประเภท หลังจากนั้นทำการทดสอบสมบัติระยะสั้นของกระเบื้องโดยทำการศึกษากำลังแตกหักต่อความกว้างในหน่วยเมตร ส่วนสมบัติระยะยาวได้ทำการศึกษาความต้านทานการซึมผ่าน การทดสอบในน้ำอุ่น และการทดสอบวงรอบระหว่างความร้อนกับฝน ผลการทดสอบที่ได้พบว่ากระเบื้องสีฟ้าและน้ำตาลมีไฟเบอร์รูปร่างใกล้เคียงกัน ซึ่งแตกต่างจากไฟเบอร์ของกระเบื้องสีแดงและเขียว ค่ากำลังดัดของกระเบื้องสีฟ้าและน้ำตาลมีค่าสูงกว่าค่ากำลังดัดของกระเบื้องสีแดงและเขียว แต่พบว่ากระเบื้องสีฟ้าให้ความต้านทานการซึมผ่านที่ต่ำที่สุดเนื่องจากปัญหาเกี่ยวกับการเคลือบสีผิว การทดสอบในน้ำอุ่นพบว่ากระเบื้องสีเขียวไม่สามารถผ่านเกณฑ์มาตรฐานได้ ส่วนการทดสอบวงรอบระหว่างความร้อนกับฝนพบว่ากระเบื้องทุกประเภทสามารถผ่านตามเกณฑ์มาตรฐานได้

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## Introduction

In the past, asbestos has been widely used in many commercial industries since $19^{th}$ century[1]. Because the asbestos was claimed to resist the degradation underheat and cold climates as well as also exhibit good resistance to chemicals and acids. However, the use of asbestos was banned in many countries due to the case reports of the patients who had the asbestos-related illness[2]. Currently, the asbestos is still used in some commercial products, especially in building supplies such as cement tiles. Russia and

China were reported to still consume the large quantities of asbestos used in commercial products followed by Brazil, India, and Thailand(1). The concern of Thai government authorities relating to the health and safety recently addresses with controlling the use of asbestos in industrial products in order to minimize the quantity of asbestos to be used.

Several studies on the mechanical and durability properties for the asbestos and non-asbestos roof tiles were conducted(3, 4). However, the controversial findings of the results reported in two studies were still in questions(5, 6). Comments have also been addressed on the properties of tiles and the methodologies used in two studies(5).

The study was, therefore, aimed at investigating the short- and long-term performance of roof products in asbestos- and non-asbestos-reinforced cement profile sheets. The properties of tiles were also included in the study for classification of the tiles.

**Materials and Methods**

A total of 96 cement tiles which could be classified as four types; namely blue, brown, red and green tiles, were chosen for this investigation. All of the sources of these tiles were blinded. Therefore, the types of cement tiles containing asbestos or non-asbestos material were unknown during the study.

The cement content for each type of tile was determined by measurement of three major cement compounds; namely calcium, silica, and alumina. A total of five specimens for each type of tile were prepared by crushing one-sixth tiles with a rock crusher. The 10-g crushing powder was dispersed with 75-ml of deionised water and then acidified with 25-ml of nitric acid. The tested sample was heated and then filtered. The major cement compositions; namely calcium, silica, and alumina, of the prepared sample were tested using the frame atomic absorption.

The shape of fibre containing in each type of tile was determined by monitoring crushing powder as mentioned previously with the optical microscope using the magnification of 100x.

The dimension of each tile was undertaken. The thickness of each tile was measured at six points using vernier caliper and then averaged. The corrugation height, length and width dimensions of each tile were also measured using a metal ruler.

The bending test for the cement tiles was performed as specified within the ISO 9933 standard(7) using 1000kN universal testing machine. A total of eight specimens for each type of tile were prepared by immersing them in water for 24 hours. Each wet specimen was placed on supports at right angle with the corrugations and then loaded at midspan until the breaking point. The load and deflection at midspan of the specimen at a given point were automatically recorded. The results of bending tests were expressed as the breaking load per meter width.

The impermeability test for cement tiles was determined as specified within the ISO 9933 standard(7). A total of 8 specimens for each type of tile were sealed with the acrylic frame with the dimensions of 450-mm width, 500-mm length and 40-mm height above the tops of the corrugation. Thereafter, water was filled in the frame until the level of water was about 20 mm above the tops of the corrugations and stored for 24 hours. Traces of moisture on the underface of the sheet for each tile were visually observed.

The warm water test was also conducted as specified within the ISO 9933 standard(7). A total of 20 specimens for each type of tiles were transversally cut to a length of 30 cm. The specimens for each type of tiles were divided randomly into two lots of 10 specimens. The first lot of 10 specimens being classified as the control set was kept for bending test. Whereas the second lot of 10 specimens was immersed in water controlled at 60±0.5˚C. for 56 days. The bending test was then carried out for both lots under wet conditioning. Each specimen was placed on supports at half one pitch on each side of the central and then loaded along with the top of corrugation until the breaking point. Further details of the test are specified in the ISO 9383 standard(8). The breaking load of each specimen was automatically recorded. The lower estimation of the mean breaking load at 95% confidence level for the second lot immersed in warm water ($L_s$) and the upper estimation of the mean breaking load at 95% confidence level for the first control lot ($L_1$) were calculated. The ratio (L) of $L_s$ over $L_1$ at the 95% lower confidence limit was determined. Moreover, the surface of each specimen was observed using digital microscopy to detect cracks, leachate stains, and defects of coating.

The heat-rain test was conducted as specified within the ISO 9933 standard(7). A total of 8 specimens for each type of tile were placed in the plastic tank on the frame inclined at 25±5˚ and then subjected for 25 cycles of heat and rain consecutively. Each cycle contains wetting for 2 hours and 50 minutes, interval for 10 minutes, heating for 2 hours and 50 minutes, and then interval for 10 minutes. The wetting process used in the study was controlled by delivering water at the speed of 2.5 l/min/m$^2$ and the controlled temperature of 15±2˚C. The heating process was controlled at the temperature of 70±5˚C. using the ceramic heaters. After subjected to 25 cycles, each specimen was inspected visually for cracks, delamination, and other defects on the surface of the specimens. Further test was also carried out to determine the bending test of the tiles subjected to heat-rain cycle. The testing results were expressed as the breaking load per meter width.

The technique for analysis of variance (ANOVA) was conducted using the PASW statistics 18 program for finding the contribution of factors in the measurements of the tests. Significant level ($\alpha$) used in the studies was set at 0.05.

## Results and Discussion

### Major compounds of cement present in tiles

The quantities of calcium, silica, and alumina which are the major compounds of cement present in each type of tile are shown in Figure 1. It could be seen that the percentages of calcium and alumina for all four types of tile were insignificantly different. The green tile had the silica content slightly higher than the others. However, the significant levels of the statistical analysis for the percentages of calcium, silica, and alumina were 0.23, 0.08, and 0.89 respectively. It could, therefore, be concluded that the major compounds of cement present in each type of tile were not statistically different, with a two-sided p-value higher than 0.05.

### Shape of reinforcing fibre

Figure 2 shows the shape of fibre containing in blue and brown tiles. It was found that the shape of fibre was short and may be present in the form of webs. On the contrary, the shape of fibre containing in red and green tiles was found to be discrete elements randomly dispersed (see Figure 3). Then it may be implied that blue and brown tiles had similar type of fibre which were different from red and green tiles.

### Dimension of tiles

The individual thickness of the tiles being investigated was found to be approximately constant throughout the width of the profile. The results of mean thickness for all types of tiles are shown in Figure 4. It was found that the red tiles had the thickness of the sheets slightly more than the other types. This was also confirmed by the statistical analysis of variances for all of the thickness of the sheets. However, all types of tiles being investigated could be classified as category C of ISO 9933(7). This is due to the fact that the minimum thickness results for each individual tile were more than 4.5 mm. In addition, the nominal height of corrugations for all types of the tiles was found to be between 54 and 55 mm which could also be classified as category C of ISO 9933(7).

**Bending Strength**

The typical relationships between flexural load and deflection for all types of tiles are shown in Figure 5. It was found that the blue and brown tiles exhibited the flexural loads and deflections significantly more than the red and green tiles. Figure 6 shows the mean breaking loads per metre width for all types of tiles, comparing with the class specified within the ISO 9933(7). The results of mean breaking load per metre width for blue and brown tiles were significantly higher than those red and green tiles. This was also confirmed by the statistical analysis which the blue and brown tiles only exhibited similar results of breaking load per metre width. However, the mean breaking load per metre width of red and green tiles could still meet with the lowest class (Class 4) for the category C (see Figure 6).

**Impermeability**

Traces of moisture appearing on the underface of the sheet for all types of tiles are given in Table 1. The moisture could be observed on the underface of the sheet for blue, red and green tiles. However, many defects of coating could be investigated for the blue tiles having severely damped underface of the sheets (see Figure 7). Therefore, the failure of coating for the blue tiles could not constitute the failure of the product as specified in ISO 9933(7). However, no formation of water drops was observed on the underface of the sheet for brown, red and green tiles. It could be concluded that these tiles could meet with the standard requirement(7).

**Warm water**

Warm water test was used for investigating the possible degradation of the tiles studied. The results of mean bending moment at rupture for each type of tiles are given inTable 2. It was found that the warm water minimized the mean bending moment at rupture of blue, red, and green tiles. However, no degradation due to warm water was observed for brown tiles. When the results of ratio L expressed as 95% lower confidence limit were compared to the criterion given in the ISO 9933[7], three types of tiles; namely blue, brown, and red, could meet with the standard criterion. However, the green tiles failed to meet with the standard requirement due to their ratio L lower than 0.70.

In addition, the standard deviation of the mean bending moment at rupture for the blue tiles was found to be the highest (see Table 2). It could be due to the fact that the failure of coating in the blue tiles caused the amount of cement unequally leaching out of the tiles. Figure 8 shows the failure of coating; such as blistering, usually observed in the blue tiles. The higher leachate of cement could possibly exhibit the mean bending moment at rupture lower than the lower leachate of cement.

**Heat-rain**

After all types of tiles were subjected to 25 cycles of heat and rain, no sign of crack cracks, delamination, and other defects on the surface of the specimens could be observed. It could then be concluded that all types of the tiles meet with the criterion for heat-rain test given in ISO 9933[7]. Further test was carried out to compare the mean breaking load per metre width for control and heat-rain-cycle sets as shown in Figure 9. It was found that the 25 cycles of heat-rain test could slightly reduce the mean breaking load per metre width of blue and brown tiles by about 14%. Whereas the results of mean breaking load per metre width for red and green tiles in the control sets were not statistically different from those corresponding sets subjected to 25 cycles of heat and rain.

**Conclusions**

1. All types of tiles studied could be classified as category C of ISO 9933[7]. The quantities of major compounds in the cement used for all types of the tiles were similar. Blue and brown tiles had similar shape of reinforcing fibre which was different from the shape of the fibre present in red and green tiles.

2. The bending strength results of blue and brown tiles were significantly higher than those red and green tiles. However, the bending strength of red and green tiles still met with the lowest class criterion given in ISO 9933[7].

3. Long-term properties obtained from the impermeability, warm-water and heat-rain-cycle tests of all types of tiles were mostly found to meet with the standard criteria except that the green tiles could not meet with the standard criterion for warm-water test.

**Acknowledgements**

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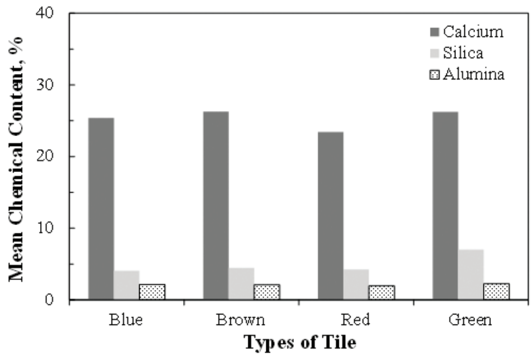


Figure 1 Major compounds of cement present in each type of tile

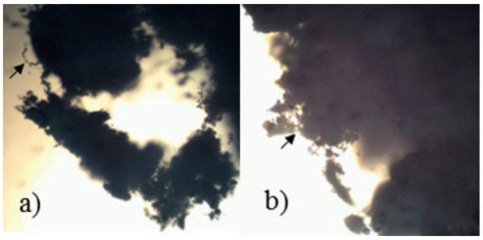


Figure 2 Short fibers present in a) blue tile and b) brown tile

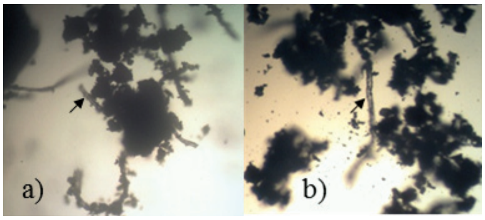


Figure 3 Long and discrete fibers present in a) red tile and b) green tile

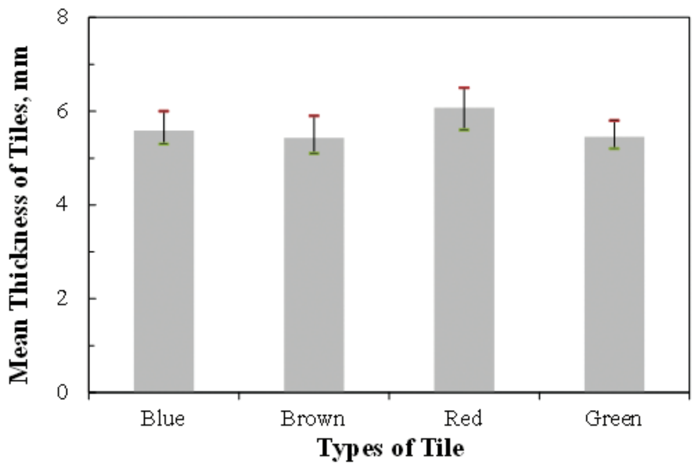


Figure 4 Mean thickness of tiles being investigated

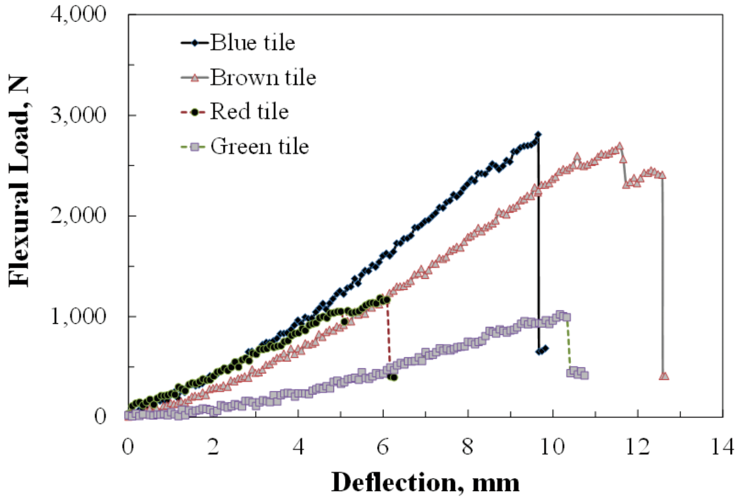


Figure 5 Relationship between flexural load and deflection for all types of tiles

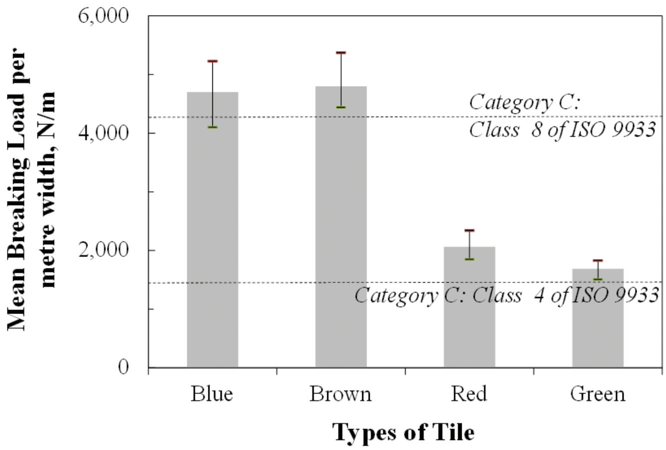


Figure 6 Mean breaking loads per metre width for all types of tiles

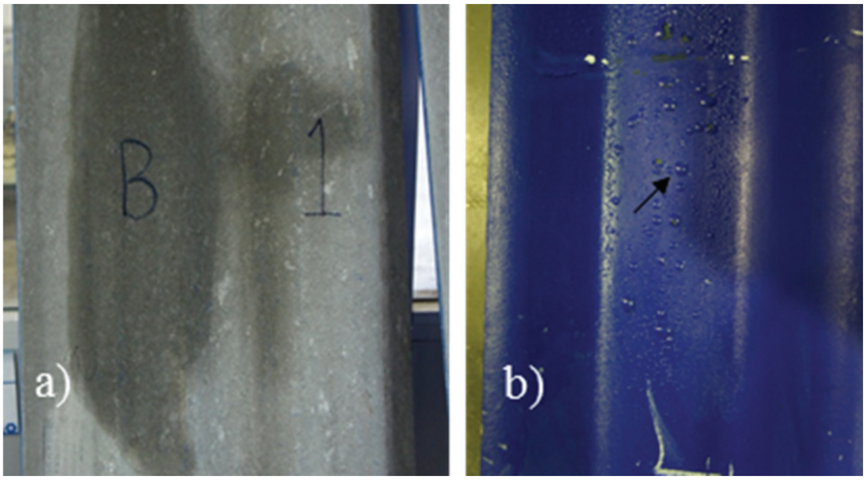


Figure 7 Impermeability results of blue tiles: a) severe dampness on the underface of the sheet and b) failure of coating

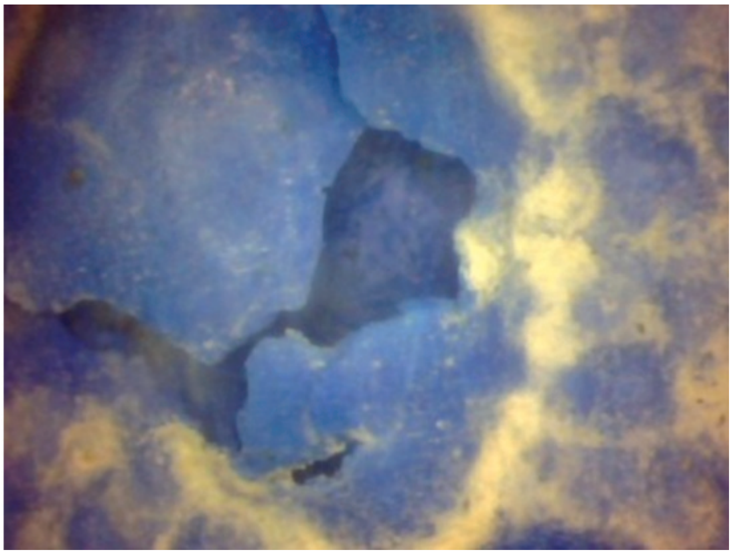

Figure 8 Blistering on the surface coating of blue tile

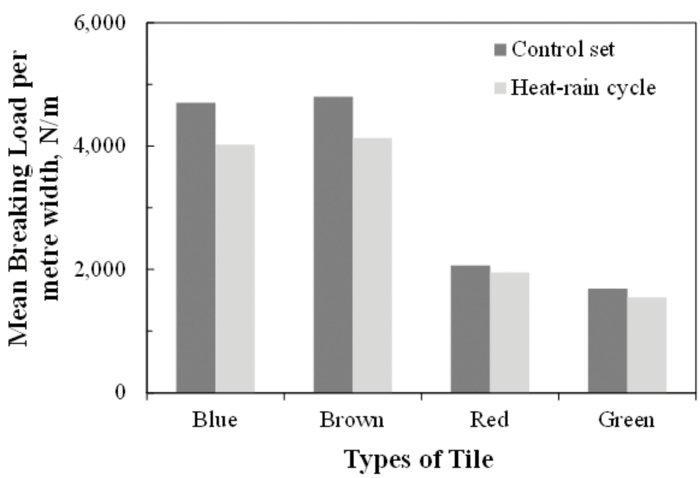


Figure 9 Comparison of mean breaking load per metre width for control and heat-rain-cycle sets

Table 1 Classification of moisture appearing on the underface of the sheet

| Appearance | Quantities, Types of Tiles | | | |
|---|---|---|---|---|
| | Blue | Brown | Red | Green |
| No moisture | 2 | 8 | 6 | 5 |
| Partially damp | 4 | 0 | 2 | 2 |
| Severely damp | 2 | 0 | 0 | 1 |

Table 2 Comparison of mean bending moment at rupture for control and warm-water sets

| Bending Moment at Rupture, N-m/m | Types of Tiles | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Blue | | Brown | | Red | | Green | |
| | Control Set | Warm water | Control Set | Warm water | Control Set | Warm water | Control Set | Warm water |
| Mean (M) | 85.7 | 74.4 | 70.4 | 81.1 | 43.1 | 35.9 | 31.3 | 24.3 |
| Std* (Sd) | 5.8 | 18.2 | 4.4 | 6.0 | 5.2 | 4.8 | 6.1 | 4.2 |
| L1 =M+0.58×Sd | 89.0 | - | 73.0 | - | 46.1 | - | 34.8 | - |
| Ls =M-0.58×Sd | - | 63.8 | - | 77.6 | - | 33.1 | - | 21.9 |
| L =Ls/L1 | 0.72 | | 1.06 | | 0.72 | | 0.63 | |

* Standard deviation

*Abstract* **Short- and Long-term Performance of Fibre-Reinforced Cement Profile Sheets Containing Asbestos and Non-asbestos Materials**

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The paper was aimed at comparing the performance of roof products in asbestos- and non-asbestos-reinforced cement profile sheets. Four brands of cement tiles were blinded and then sent for investigation. They were classified as blue, brown, red and green tiles. The physical and chemical tests were conducted to distinguish the properties of these tiles. The short-term properties of cement tiles were determined by breaking load per metre width. Whereas the impermeability, warm water, and heat-rain tests were conducted for the determination of long-term properties for all types of cement tiles. The results undertaken have shown that blue and brown tiles had similar types of fibres which were shorter than those fibres of red and green tiles. The bending results of blue and brown tiles were significantly higher than those red and green tiles. However, the blue tiles exhibited the worst impermeability results due to their imperfection of coating. Whereas the test conditioning the tiles in warm water was found that only green tiles could not meet with the requirement of ISO 9933 standard. The heat-rain test for all of the tiles being investigated was found to meet with the standard criterion.

**Keywords:** asbestos, cement tiles, strength, performance