The Corrosion of Steel Wall Ties within Cavity Brick and Brick Veneer Wall Air Cavities

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ABSTRACT

In brick veneer and cavity brick walls the steel wall ties are essential structural components linking the external leaf of masonry to the internal framework. Steel wall ties are susceptible to corrosion over time which can ultimately result in the complete deterioration of the material. Such corrosion significantly impacts the structural integrity of brick veneer and cavity brick walls, increasing the risk of failure under lateral forces from earthquake or wind. Detecting corrosion in embedded wall ties in masonry walls is difficult and often only becomes apparent after the wall has failed or been demolished. This limitation calls for a deeper understanding of the corrosion of steel wall ties within the air cavity of masonry walls. The current research provides data on the environmental conditions within the air cavity of a brick veneer and cavity brick wall structure, revealing the impact temperature and humidity have on the corrosion of galvanised and stainless-steel wall ties, and steel wall ties with no corrosion protection. After one year of exposure to the natural environment, the qualitative and quantitative data presented uncovers corrosion processes affecting wall ties in two types of masonry wall air cavities. The research reported herein signifies the influence that the cavity brick and brick veneer air cavity micro-climate have on wall tie corrosion over time.

KEYWORDS

Masonry, wall ties, cavity, corrosion.

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INTRODUCTION

Masonry veneer and cavity walls are extensively used in Australia for residential, industrial and commercial infrastructure. The steel wall ties utilised in these types of brick structures are vital to the stability and safety of the structure, connecting the external leaf of masonry to the internal framework (as shown in Fig. 1 (A)). Through corrosion processes within the air cavity of brick veneer and cavity brick walls, the steel wall ties experience deterioration over time, ultimately leading to the complete loss of section of the wall tie. The ongoing experimental investigation presents data on wall tie corrosion losses and monitored microclimate conditions over a one-year period. Two small masonry house modules, representing a brick veneer and cavity brick house, were constructed in August 2023 at a severe marine corrosion site in Belmont, NSW, Australia (see Fig. 1 (B)). Installed within the small brick modules are commercially available wall ties, including stainless steel, galvanised, and uncoated steel wall ties. After one year of exposure to the natural environment, wall ties were extracted from the brick house modules and analysed for corrosion losses including mass loss and pit depth formation. Temperature and humidity data over the one-year period was also collected within the air cavity, the internal and the external environments of both structures, providing clear results of the microclimate conditions experienced within the brick house modules. The results presented in this paper are directly comparable to the results presented in previous work by Jardim do Nascimento [1] where the atmospheric corrosion of wall ties embedded in brick couplets within three different mortar mixes was studied.

Many factors may influence the corrosion rate of wall ties. For example, where portions of the tie are in contact with moisture retained in mortar droppings or saturated insulation the tie may experience more severe corrosion losses [2]. Carbonation causes the reduction in pH of mortar from 12-13 to neutral at 8-9 or below which can initiate corrosion in steel embedded in mortar or concrete [2]; and has been observed in recent studies relating to the corrosion of wall ties in varied mortar types [1, 3]. Additionally, it has been shown that galvanised wall ties exposed to artificial corrosion using electrolysis had localised corrosion occurring within a 30 mm region between the mortar embedded and atmospheric exposed section of the wall tie, known as the mortar interface region [4]. Localised corrosion leading to the deterioration of the wall tie in this region only becomes apparent after the failure of brick walls, particularly the collapse of façades. This is clear where deteriorated wall ties were found following the Newcastle earthquake in 1989 after the collapse of external masonry walls [5, 6]; and where the mortar interface region of the wall tie was found to have corroded significantly for samples retrieved from various Canadian cities [2, 7]. Current Australian standards state that the wall tie is expected to last for the lifetime of the structure which is typically 50 years for masonry structures [8, 9]. To prevent failure of existing and future masonry structures, greater knowledge of the corrosion rate of wall ties is required.

Hagel et. al. presented data relating to the corrosion rate of zinc coated steel wall ties and metal lath in brick veneer walls [2, 10]. Hagel et. al. modelled the corrosion rate of zinc coated steel wall ties that were isolated within the mortar joint in the external leaf of masonry using the ISOCORRAG model. The experimental data referenced by Hagel et. al. [2] was based on a corrosion rate (CR) that was determined by comparing the initial zinc coating (g/m^2) to the number of years until the wall tie was extracted (with complete loss of the zinc coating observed). The ISOCORRAG model was used by the authors to provide a predicted CR of the same samples that were experimentally recorded. The ISOCORRAG mathematical model uses this formula:

$$(1)\ CR = a_1 + B_1(SO_2) + B_2(TOW) + B_3(Cl)$$

In Eq. (1), the sulphur dioxide (SO_2) deposition rate and chloride (Cl) deposition rate are in units g/(m^2.year) and the time of wetness (TOW) is taken as a percentage per year. Using the ISOCORRAG mathematical model, with parameters referenced by Hagel ($a_1 = 0$, $B_1 = 0.38$, $B_2 = 0.15$, and $B_3 = 0.31$), the CR to deplete the zinc coating on the wall ties was calculated. For example, at the coastal site of St John's in Canada, the experimental corrosion rate of extracted wall ties was 34.0 g/(m^2.year) while the ISOCORRAG CR was predicted to be 48.3 g/(m^2.year). Notably, the TOW data was factored to best represent the microenvironment of the mortar in Hagel et. al.'s work [2]. In the present paper, a direct comparison to the findings from Hagel et. al. is presented using data obtained from the exposure site in Belmont, NSW, Australia.

Details of the microclimate within the air cavity of typical Australian houses was presented by Cole et. al., in 1994 [11]. Over a year, Cole reported the variations in microclimate, including temperature and relative humidity, in the wall cavities of houses in Darwin, Brisbane and Melbourne, categorised as tropical, subtropical, and temperate climates, respectively [11]. Another study on the drying potential of brick veneer walls, by Vanpachtenbeke et. al. [12], consisted of the construction of four brick veneer test walls with cladding and a 40 mm air cavity in an outdoor test building in Belgium. The main focus of the study was on the two south-west-oriented walls which were exposed to the highest wind and solar loads. The findings of the study show a variation between the outside environment and the air cavity on a sunny and windless day, where the air cavity temperature is greater than the outside temperature. It was also found that with little rainfall and consistent sun over a long period, the air cavity will decrease in humidity, as it's drying out [12]. Alterman et. al. and Page et. al. [13, 14] studied the thermal performance of four housing test modules for 10 years at The University of Newcastle, Australia, in collaboration with Think Brick Australia. These systems have a range of thermal resistance (R) values and varying degrees of thermal mass properties. The detailed thermal performance of each system was observed over seasonal conditions, providing useful data on temperature variation between the internal and external environments of the brick walls [13, 14]. As corrosion is dependent upon several factors, including but not limited to material composition and size, temperature, time of wetness, pH of mortar (influenced by carbonation and chloride ingress processes) and galvanic interactions [15], further work is required in this field to provide meaningful data about the factors influencing the corrosion of steel wall ties. The current study provides a connection between the air cavity microclimate and the degradation of the materials within brick veneer and cavity brick walls.

METHODOLOGY

The ongoing field experimental program is based on findings from the existing literature and recent research observations detailed above. The location for the field experimental program is at the Belmont, NSW, Australia, corrosion site. The test site is less than 250 m from breaking surf. The atmospheric chloride content was measured in a previous study and is approximately 300 mg/(m^2.day) and sulphur deposition is 6 μg/m^2/day [16]. This severe marine atmospheric site is recognised in AS 2728:2007 and its use allows direct comparison to the results from the previous work [1]. This aspect is considered in this study where two one-story enclosed brick house modules have been constructed. Orientation impacts the drying potential of brick walls and consequently adds to moisture variation between the walls of a structure. The three main walls of the full-scale house modules are orientated as south, east and north facing, where the west wall is a doorway into the structure. The east wall experiences the most sea salt spray from breaking surf. The north and south walls experience more or less solar radiation in Australia, respectively, opposite to the findings in Belgium [12]. Fig. 1 (A) shows the cross sections of the two full-scale wall systems used for this experimental program. The brick veneer and cavity brick modules were constructed to ensure the overall wall systems are well-ventilated and representative of current construction practices in Australia [8, 17]. The fully constructed house modules, with the doorway on the west wall, are shown in Fig. 1 (B).

Commercially available wall ties were used in this study to allow estimation of the effectiveness of the various protective coatings currently used and recommended in Australia. In the north, east and south walls of the two brick house modules, sets of four wall tie samples were spaced at regular intervals. The majority of the wall ties were of the 'sheet' variety, having a corrugated section installed into the mortar of the brick walls. For the cavity brick house module, the dimensions of the wall ties were greater than that of the brick veneer wall ties. Each set of wall ties included galvanised Z600, galvanised Z950, stainless steel (SS316) and uncoated mild steel (MS) wall ties. The MS wall ties are no longer commercially available, however, they were likely used in many existing structures that were built before the standardisation of galvanised and stainless steel wall ties in Australia in 1977 [18]. The MS wall tie samples were initially created by chemically stripping the Z600 and Z950 wall ties of their galvanised coating. An accurate average of the zinc coating of these wall tie batches was calculated. The variability in this coating mass was determined with a maximum standard deviation of 60 g/m^2.

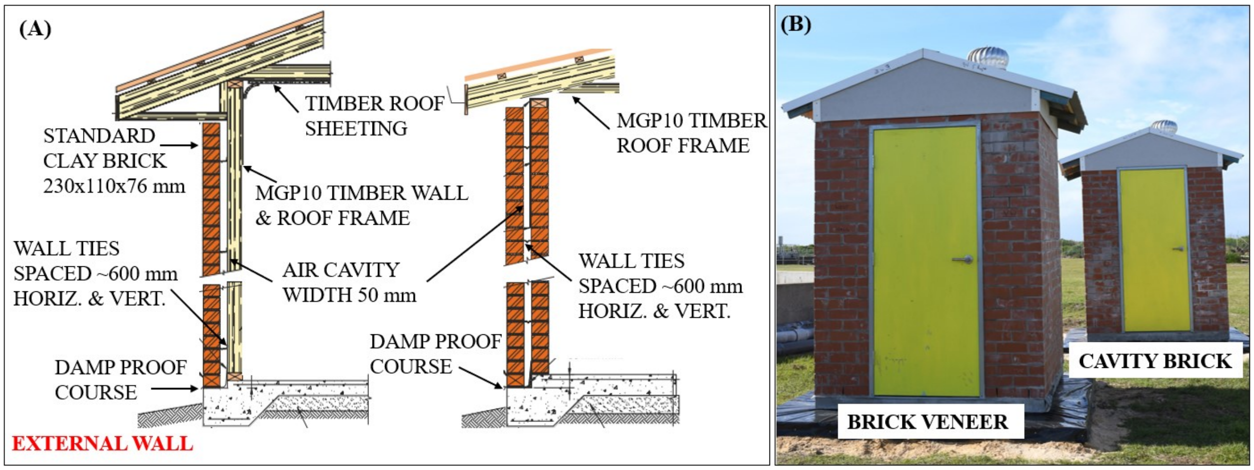

Figure 1. (A) Brick veneer (left) & cavity brick (right) wall cross sections; (B) Belmont house modules.

Over the one-year exposure period, the wall tie samples were regularly visually inspected, and monitoring data was progressively collected. Structurally redundant wall ties were initially constructed into the brick house modules and were extracted for laboratory corrosion mass loss and pitting depth quantification after the one-year exposure. One set of wall ties were extracted from the north, east and south walls of both house modules. As Jardim do Nascimento reported extremely minimal losses for stainless steel after one year of exposure to the atmosphere [1], no stainless steel samples were extracted from the brick house modules. For the brick veneer house module, the wall ties were unscrewed from the timber frame and extracted from the mortar joint, allowing the collection of one Z600, one Z950 and one MS wall tie from all three walls. In the cavity brick walls, whole bricks were removed from the walls to collect two Z600, two Z950 and two MS wall tie samples from each of the three walls. A pH reading was taken within the mortar each time the wall tie was extracted. Each wall tie was cleaned in the lab using a mortar remover spray to remove mortar from the embedded region. Next, the ties underwent chemical cleaning to remove corrosion products from the surface. After cleaning, each wall tie's mass was measured to determine mass loss in grams, excluding zinc layer loss for galvanized ties. The coating mass from the MS wall sample creation was used to estimate corrosion losses for the Z600 and Z950 wall ties after cleaning. To assess pit depths, the wall ties extracted from the brick modules were flattened, and the depths of up to 10 pits were measured and averaged for each wall tie sample.

In a brick veneer or cavity brick wall, the air gap between the external leaf of masonry and the internal structural system creates a microclimate that is postulated to affect the rate at which a wall tie corrodes [2]. The temperature and relative humidity were monitored from within the inside, the wall cavity, and the outside of both the brick veneer house and cavity brick house modules with USB data loggers. The data was logged at one-hour intervals for one year and a monthly average of this data is presented in this paper. The evaluation of how the monitored conditions may vary through the wall cavity types, how this is opposed to or in line with the readings from internal and external wall environments and the impact this has on the corrosion losses is also presented. Inferred from the tracked environmental conditions is the time of wetness (TOW), an important consideration for metal corrosion initiation [19]. The TOW is assumed to include the time during which the relative humidity of the ambient environment is greater than 80% for temperatures above 0°C [20].

RESULTS

Mass Loss and Pit Depth Data

The results include the temperature and relative humidity data logged within zones relating to the internal, air cavity and external environments of the brick house modules. Correspondingly, the data relating to the extracted wall ties are reported, comparing mass loss and average pit depth measurements between the different wall orientations, wall tie types and brick wall types. Fig. 2 summarises the wall tie corrosion losses reported after one year exposure in the brick veneer and cavity brick house modules. An important observation found when extracting the wall ties was that the pH was approximately 13-14, indicating that carbonation of the mortar had not yet occurred.

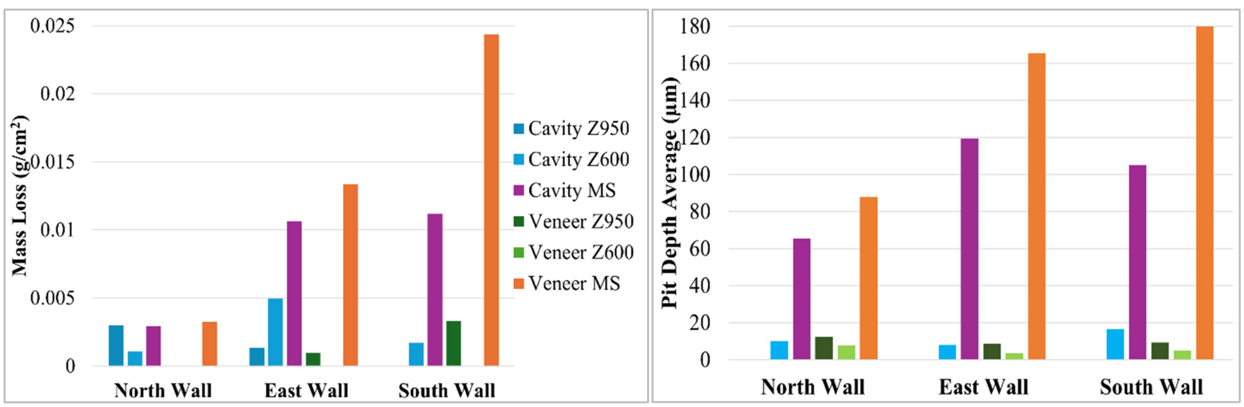

Figure 2. Comparison of mass loss (left) and pit depth average (right) measured for various wall tie types after one year exposure in cavity brick and brick veneer house modules.

From Fig. 2, there are minimal corrosion losses reported for the galvanised wall tie types and noticeable corrosion losses reported for MS wall tie samples. Jardim do Nascimento reported that after one year exposure, the Z600 and Z950 wall ties in M3 mortar experienced a mass loss of 0.027 g/cm^2 and 0.021 g/cm^2, respectively. In terms of maximum pit depths, Jardim do Nascimento recorded Z600 and Z950 as 88.1 μm and 123.7 μm, respectively [1]. A comparison of the results presented in Fig. 2 with Jardim do Nascimento's one-year findings highlights the effect the microclimate has on the corrosion rate of the wall ties. The galvanised wall tie samples in this study have little to no corrosion losses reported, a significant decrease in value compared with the samples in the past work. However, the corrosion losses for the mild steel (MS) samples reported in Fig. 2 are similar to or greater than that of Jardim do Nascimento's one-year findings for galvanised Z600 and Z950 wall ties. After one year exposure in the air cavity of the cavity brick and brick veneer walls, the MS samples have greater mass loss and pit depth measurements recorded for the east and south walls compared to the north facing wall. In the brick veneer walls, the MS samples present greater overall corrosion loss compared to the cavity brick walls, with noticeably higher mass loss in the southern facing wall. It is expected that any trends for the galvanised samples will become clearer after 2-year exposure recovery is later completed for this project.

Temperature and Relative Humidity Monitoring

Fig. 3 and 4 provide the accumulated monitoring data of temperature for the brick veneer and cavity brick modules, respectively, highlighting the clear variation between data obtained in the internal, air cavity and external environments. It should be noted that the modules are ventilated, but not climate controlled (heating or air-conditioning) as would be the case for most buildings in service. Fig. 5 and 6 then outline the tracked relative humidity for brick veneer and cavity brick modules, respectively. Fig. 3 to 6 were designed to show the variance in the average monthly data recorded over the one-year monitoring period. The 'north wall', 'east wall' and 'south wall' shown in Fig. 3 to 6 represent the conditions within the air cavity of the corresponding orientation noted. Presented in these figures is also the 'internal', which represents the inside of each module, the 'external' representing the outside conditions, and 'rainfall' showing the average rainfall found using the Bureau of Meteorology monthly observations from Newcastle Nobbys, Australia. Where monthly data was unobtainable due to monitoring equipment faults, the graph is left blank. Data from the Bureau of Meteorology was utilised to fill gaps for any missing monthly data in the external environment. This included January, May, June and September of 2024.

From Fig. 3 and 4, the north facing wall in both modules exhibits slightly higher temperature on average for many months in the one-year period compared with the south wall. Fig. 5 and 6 show the south wall with the highest average relative humidity per month compared to that of the east and north walls, in some cases showing a significant increase. From Fig. 3 to 6, the variance between the internal and external environment is noted in both modules, which is expected in masonry structures [14] Notably, higher humidity averages were recorded in the air cavities of the cavity brick module compared to the brick veneer module in the one-year period.

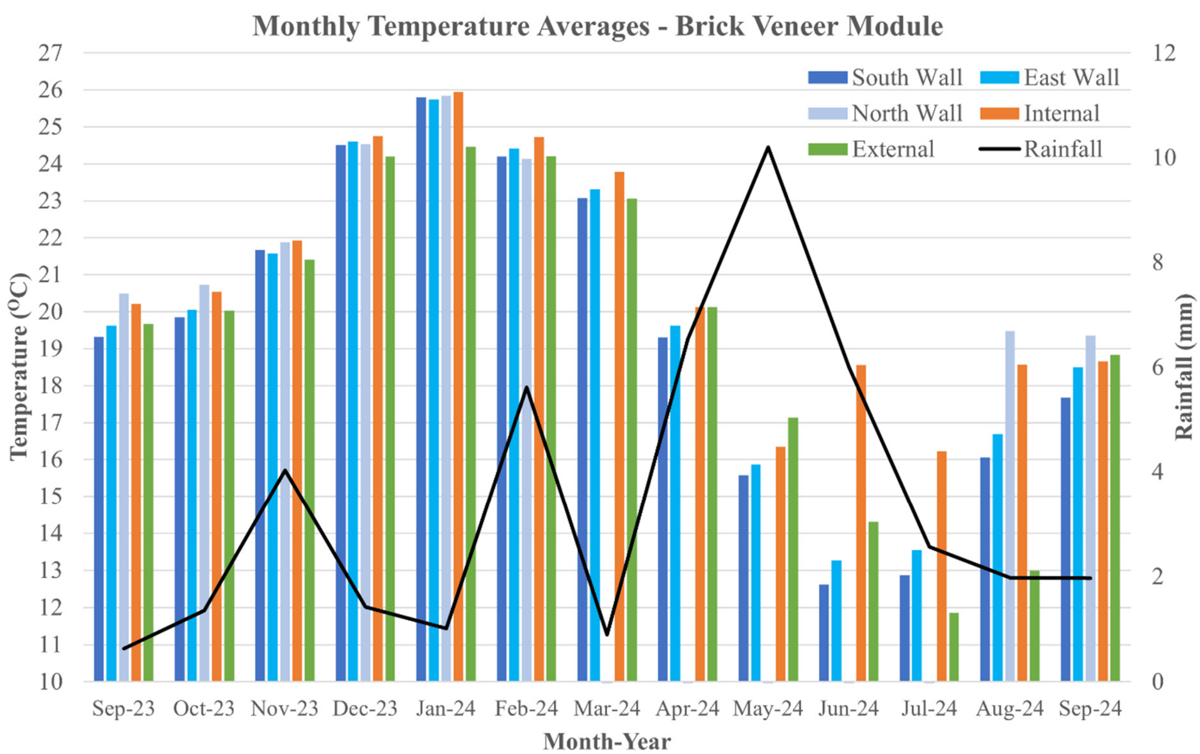

Figure 3. Brick veneer monthly average temperature for different monitoring zones.

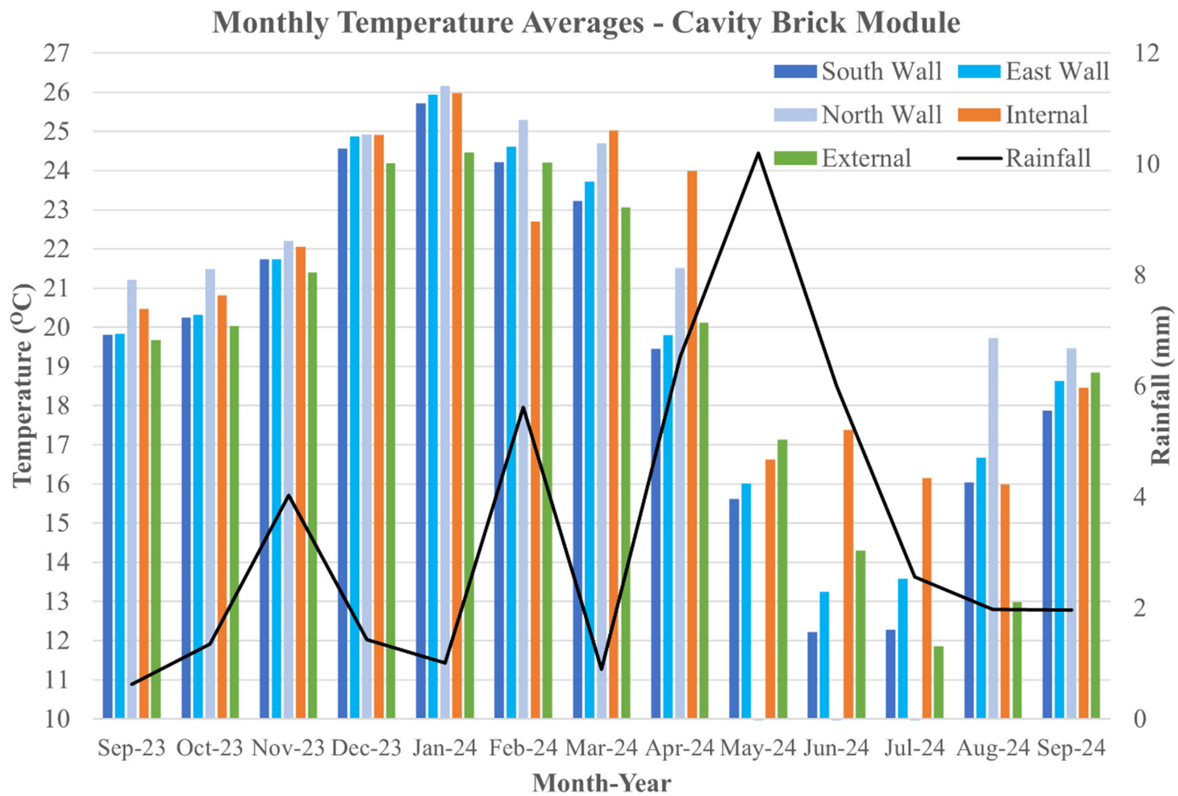

Figure 4. Cavity brick monthly average temperature for different monitoring zones.

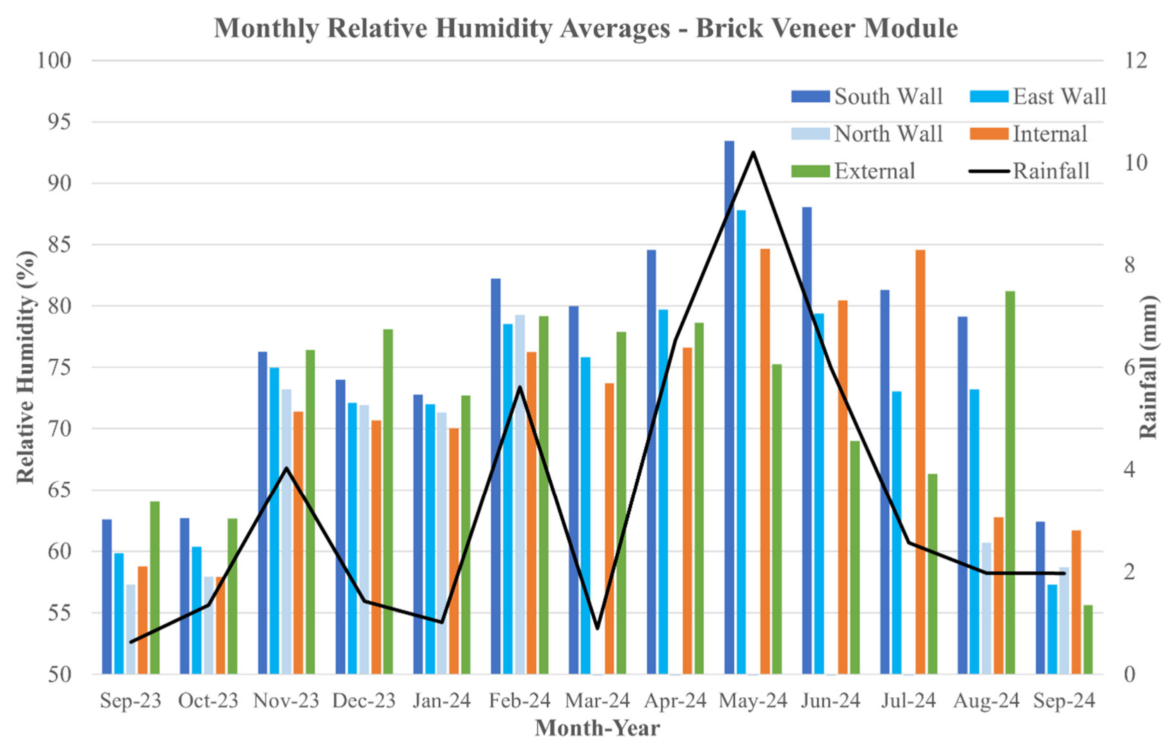

Figure 5. Brick veneer monthly average relative humidity for different monitoring zones.

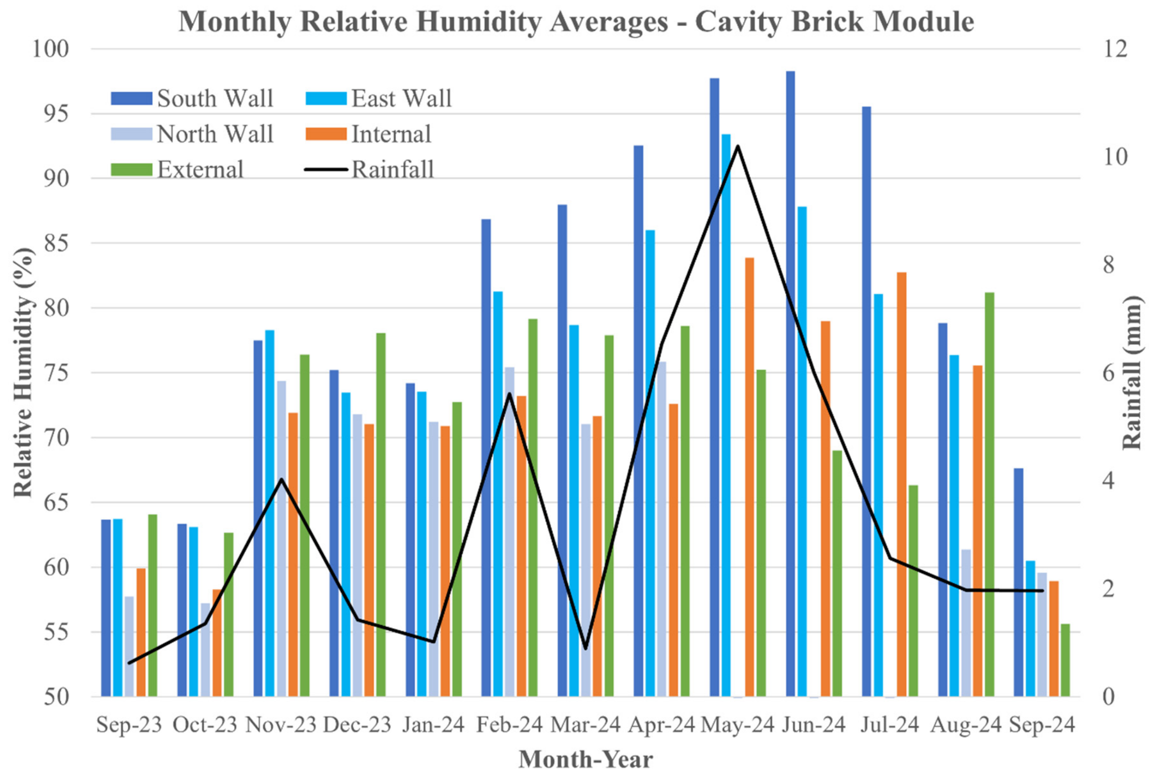

Figure 6. Cavity brick monthly average relative humidity for different monitoring zones.

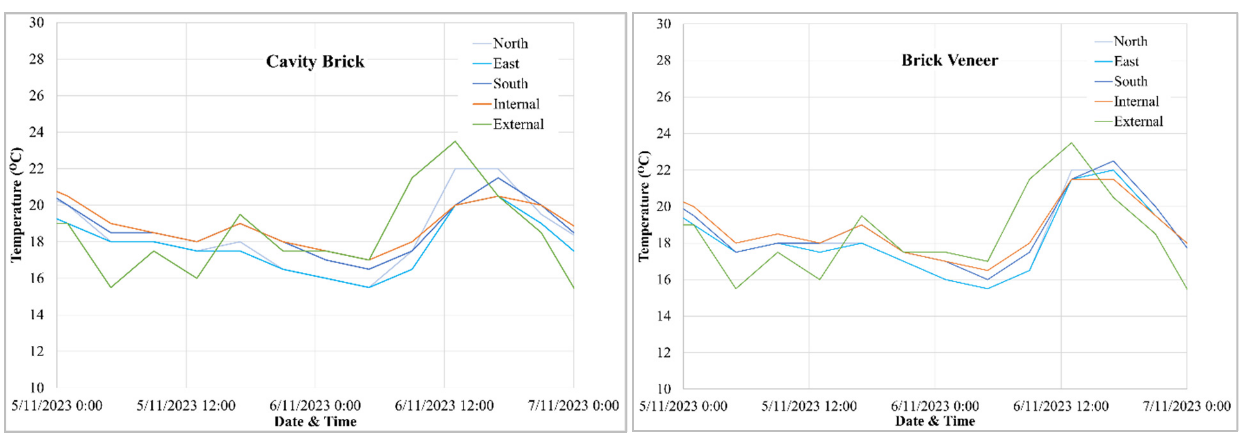

Figure 7. Temperature readings for a 3-day rainy period for cavity brick (left) and brick veneer (right).

Fig. 7 and 8 provide an example of the temperature and relative humidity readings during 3 days of heavy rainfall at the exposure site. In Fig. 7, there is some variability in temperature noted from the external wall to the internal environment, however, the cavity exhibits similar conditions to that of the internal environment. In Fig. 8, both graphs show similar relative humidity conditions between the three air cavity orientations (north, east and south), however, between the air cavity and the external environment there is a significant variation. The internal environment more closely follows the external relative humidity in Fig. 8. There is also some lag time noted, up to 6 hours, for the internal environment and air cavities to exhibit a decrease or increase in line with the external conditions recorded.

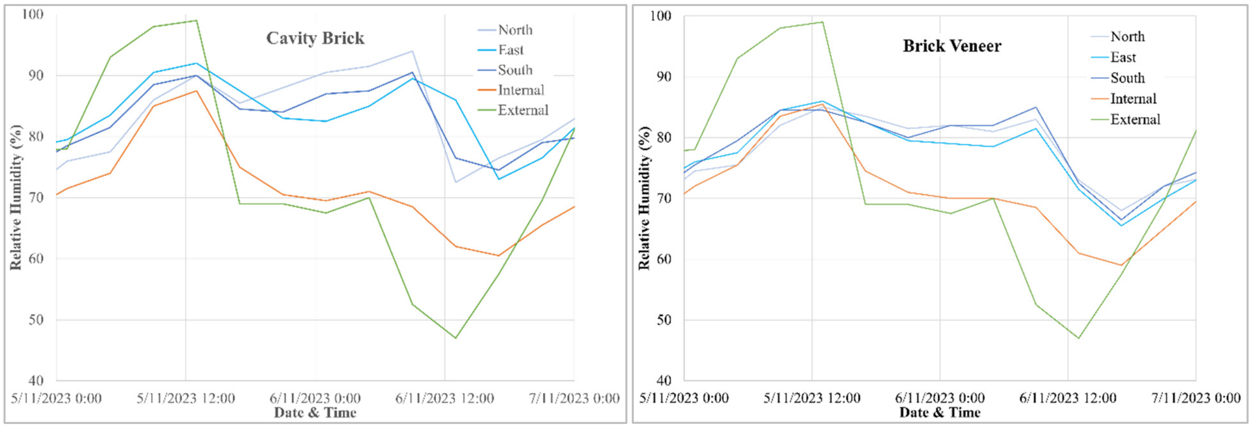

Figure 8. Relative humidity readings for a 3-day rainy period for cavity brick (left) and brick veneer (right).

Using data tracked in the southern wall cavity of the cavity brick house module, the TOW was calculated to give a total of 5413 hours/year. This TOW was used for the predicted corrosion rate presented in Table 1. Samples 1 and 2 are examples of the CR calculated using measured inputs from the Belmont, NSW site. Both samples also have the experimental corrosion rate that was recorded from the extracted wall tie samples. Comparing to the previous work by Hagel et. al. shows variability between the locations and the impact this has on the predicted corrosion rate. Notably, the ISOCORRAG model overestimates the corrosion rate of the zinc coating of the brick wall ties.

Table 1. Comparison of predicted corrosion rate (ISOCORRAG Model) and experimentally recorded corrosion rate for samples 1 and 2 in the current study and sample from previous work [2].

Location	Sample	Zinc Coating (g/m^2)	TOW (% per yr)	Cl deposition rate ($g/(m^2.yr)$)	SO_2 deposition rate ($g/(m^2.yr)$)	Predicted corrosion rate ($g/(m^2.yr)$)	Recorded corrosion rate ($g/(m^2.yr)$)
Belmont, NSW	1	275	62	109.5	2.19	44.1	7.0
	2	275	62	109.5	2.19	44.1	27.0
St John's, NL	Previous Work	255	85	109.5	4.02	48.3	34.0

DISCUSSION

The present study provides data to help identify relevant influences on the corrosion of wall ties in cavity brick and brick veneer walls. The extracted wall ties in this study show more corrosion losses in the south and east walls compared with the north wall of both brick modules (see Fig. 2), which was expected based on the low drying potential of the south wall and increased salt spray experienced on the east wall. The greater corrosion losses recorded predominantly occur in the MS samples extracted after one year exposure in the house modules, showing similar losses to the galvanised wall ties that were previously exposed directly to the atmosphere by Jardim do Nascimento [1]. As the galvanised wall ties presented in this study did not exhibit such corrosion losses after one year exposure within the brick veneer and cavity brick modules at the same exposure site, the air cavity of these walls is postulated to provide some level of protection against corrosion. The galvanised wall ties exhibited mass losses of up to 50 g/m^2. The variability of the coating mass was equal to or greater than the corrosion mass loss presented in Fig. 2 and Table 1 and is likely attributed to this variability only. The pit depths measured on the steel surface of the galvanised wall ties also showed minimal losses, indicating the performance of the galvanised coating as effective after one year exposure of wall ties in the brick house modules.

Using the ISOCORRAG model to predict the corrosion rate of the zinc coating and compare it to existing findings from Hagel et. al. [2] highlights the impact the various parameters of the site have on the corrosion rate. However, the pH of the mortar indicated that it had not yet reached carbonation in the brick house modules. Therefore, at this stage in the study, the ISOCORRAG model is not comparable to the experimental results presented. The ongoing monitoring of the cavity microclimate conditions within the brick veneer and cavity brick house modules will be useful for informed applications of corrosion models such as the ISOCORRAG model.

The variability of the climate conditions between the internal, air cavity and external environments after one year of monitoring is a key finding of this study. Compared to the north wall, the south wall experiences lower temperatures due to limited UV throughout the year and higher relative humidity likely due to slower drying, as seen in previous work [12]. Over a 3-day period, there is no clear variation between the cavity orientations, however, the air cavity micro-climate is noticeably different to the internal and external environments. In the cavity brick module, the relative humidity readings are higher than those of the brick veneer module which would expectedly exhibit greater corrosion of the steel wall ties [19, 20]. However, the wall tie corrosion losses reported for the brick veneer module indicate greater overall loss than the wall ties extracted from the cavity brick module. Majorly, the temperature and RH conditions of both brick veneer and cavity brick house modules are similar over the one-year period (see Fig. 3 to 6). Therefore, it is likely that other factors are affecting the variance between the brick veneer and cavity brick wall tie corrosion loss. Previous work by Jeffrey and Melchers showed that coupon size had a significant impact on the corrosion loss recorded at the Belmont severe marine corrosion site. Larger coupons exhibited less corrosion loss than that of the smaller size coupons [21]. The wall ties in the cavity brick module are similar in shape, however, are larger overall in terms of their width and thickness. It is postulated that this caused the brick veneer wall ties to have greater overall corrosion losses than that of the cavity brick wall ties.

CONCLUSION

This study presents the findings on wall tie corrosion losses and monitored environmental conditions following one year of exposure of brick veneer and cavity brick modules at a severe marine corrosion site. The results are summarised as follows:

- Variability exists between the air cavity micro-environment and the internal and external environments of brick veneer and cavity brick house modules.
- Negligible corrosion losses were observed for galvanised (Z600 and Z950) wall ties after one year exposure.
- Notable corrosion mass loss and pit depths were measured for mild steel (MS) wall ties after one year exposure.
- Greater corrosion losses were observed in mild steel (MS) wall ties extracted from south and east facing walls compared to north facing walls of both house modules, likely being the result of additional sea salt spray (east) and less drying potential (south).
- Corrosion losses for mild steel (MS) wall ties extracted from the brick veneer house module were greater overall than that of the cavity brick house module, likely due to wall tie sample size variation.

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