School of Science and Engineering

STUDY OF THE DEGRADATION OF MAGNESIUM OXIDE WALLBOARD

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Executive Summary

Magnesium oxide (MgO) wallboards have been linked to damages reported globally and within Australia. These damages include dampness, cracking, and accelerated corrosion of contacting metal fixtures. There is currently no standard way of assessing the quality of marketed products and for this reason, there are several MgO board products of varying performance available on the market. This investigation compared 5 different MgO products from different sources to determine their suitability for use as construction materials. The various tests and evaluations examined the potential failure mechanisms. In particular, the effects of relative humidity on the degradation of metal inserts in MgO boards was assessed by the study of exposures in high humidity environments, achieved by saturated salts in an enclosed environment.

The results suggest that MgO sample F performs most similarly to fibre cement board (the nearest competitor to MgO boards) compared to other MgO boards analysed. MgO sample F absorbed significantly less moisture during the high humidity moisture absorption analysis, which was attributed to the absence of magnesium oxychloride in the material composition. This resulted in the lowest corrosion rate among the analysed MgO boards.

MgO sample B, C, and D will likely lead to severe corrosion of contacting metal fixtures, while MgO sample A may lead to mild corrosion. This is attributed to the presence of magnesium oxychloride, which is known to absorb excessive moisture in high humidity environments, causing chloride to be excreted through leachate. MgO sample A had lower concentrations of chloride and was not observed leaching during analysis, leading only to mild corrosion of contacting metal. The use of these magnesium oxide products should be cautioned, as evidence suggests corrosion of contacting metal fixtures and excessive moisture absorption may occur, leading to product failure.

316 and 304 stainless steels resisted corrosion when used in conjunction with all MgO boards. When using MgO boards containing magnesium oxychloride, stainless steel fasteners are suggested due to their high corrosion resistance. MgO samples which do not contain chloride may allow fasteners with lower corrosion resistance, such as galvanised fasteners, depending on their use and environmental conditions.

Certificate of Authorship/Originality

I certify the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

22nd October 2017

Date

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Contents

1. Introduction 2

1.1 Project aims 2

1.2 Methodology 3

2. Background and Literature Review 5

2.1 Current Damages 5

2.2 Certification of Magnesium Oxide Wallboard 7

2.2.1 Composition of MgO Boards 7

2.2.2 Standard Installation of Magnesium Oxide Wallboards 8

2.3 Humidity Chambers and Controlling Humidity 10

2.4 Measurement of Humidity 12

2.5 Experimental Methods Used in Literature 12

3. Experimental Methods 15

3.1 Humidity and Temperature Datalogging Sensor 16

3.2 Water Temperature Datalogger 19

3.3 Design of Fan Controller 20

3.4 Water Absorption 21

3.5 Moisture Absorption in Controlled Humidity 23

3.6 Fastener Corrosion Analysis 25

3.7 Analysis of Board Composition and Porosity with SEM/EDS 28

3.8 Thermal Analysis 29

4. Results 32

4.1 Water Absorption Analysis 32

4.2 Moisture Absorption in Controlled Humidity 33

4.3 Analysis of Board Composition and Porosity with SEM/EDS 38

4.4 Thermal Analysis 43

4.5 Fastener Corrosion 47

5. Discussion 56

6. Conclusions and Future Work 59

7. References 61

Appendix 1

Appendix 1. Equilibrium Relative Humidity Values for Selected Saturated Aqueous Salt Solutions A1

Appendix 2. Water Absorption Data A2

Appendix 3. Capstone Assessment Form A3

Appendix 4. Gantt Chart A7

Appendix 5. Weekly Reflections A8

Appendix 6. Arduino Humidity and Temperature Sensor Code A15

Appendix 7. Arduino Water Temperature Datalogger Code A19

Appendix 8. Fan Control Arduino Code A23

List of figures:

Figure 2-1-Evidence of damages due to MgO boards: Leachate visible on MgO board due to excessive moisture absorption (left) and corrosion of contacting metal framework (right)......6
Figure 2-2- Interior timber installation 9
Figure 2-3 Recommended mechanical fasteners 10
Figure 3-1: QP6013 temperature/humidity datalogger......16
Figure 3-2- Humidity and temperature sensor circuit diagram......18
Figure 3-3-Validation of DHT22 sensors 19
Figure 3-4-Stainless steel housing waterproof DS18B20 temperature probe......20
Figure 3-5- Arduino fan controller circuit diagram 21
Figure 3-6- Water immersion temperature validation 22
Figure 3-7- Controlled humidity setup 25
Figure 3-8- Fasteners used in corrosion analysis......26
Figure 3-9-Solid model illustration of board fastened to a steel section 27
Figure 3-10- Cross section illustration of fastener installation......28
Figure 3-11- SEM cross-sectional analysis samples (shown with gold sputter) 29
Figure 3-12- SEM surface analysis samples (shown with gold sputter)......29
Figure 3-13-STA 449 F3 sample holder 30
Figure 4-1- Comparison of mass change due to 48-hour water immersion......33
Figure 4-2- Moisture absorption at 97% RH 35
Figure 4-3-Moisture absorption at 75% RH 36
Figure 4-4- Evidence of leachate on sample C 37
Figure 4-5- Effects of relative humidity on moisture absorption 37
Figure 4-6- Calcium-Oxide present on sample D surface analysis......39
Figure 4-7- EDS surface analysis of sample D, showing calcium oxide (point A) present on the surface......40
Figure 4-8- EDS analysis of sample B, showing the presence of perlite (point B) within the MgO structure (point A) 41
Figure 4-9- Cross section analysis of the different boards using SEM......42
Figure 4-10- Thermogram comparing mass loss during thermal analysis......44
Figure 4-11- Thermal analysis showing DSC for MgO sample B......45
Figure 4-12- Thermal analysis showing DSC for MgO sample F 45
Figure 4-13- Thermal analysis showing DSC for fibre cement sample E 46

Figure 4-14- MgO sample C after 24 hours at 500ºC 46
Figure 4-15-Screw sample after exposure to corrosion analysis (steel fixed MgO sample B)49
Figure 4-16- Zinc coated screw (top left and bottom left Vs 316 stainless steel screw (top right and bottom right) of MgO sample B (steel) 49
Figure 4-17- SEM/EDS analysis of corroded section of zinc coated screw in MgO sample B (steel) showing the presence of chloride 50
Figure 4-18-SEM/EDS analysis of 316 stainless steel fastener in MgO sample B 51
Figure 4-19- Comparison of gold passivated fastener corrosion from MgO sample B (steel) leaching (left) and MgO sample B with no leaching (right) 52
Figure 4-20-Corrosion of steel section due to leachate 52
Figure 4-21- Comparison of corrosion of zinc coated fasteners in MgO board F (steel) (left) and MgO board B (steel) (right) 53
Figure 4-22- Comparison of zinc coated screw (Screw D) in MgO sample B (steel) (left top and bottom) and in MgO sample F (steel) (right top and bottom) 54

List of tables:

Table 3-1 -Different MgO samples analysed 15
Table 3-2- Humidity absorptivity specimen labelling 24
Table 3-3- Fastener characteristics 26
Table 4-1- Comparison of cross-sectional sample compositions using EDS 38
Table 4-2- Comparison of surface sample compositions using EDS 39
Table 4-3- Typical composition of Perlite (Samar & Saxena 2016) 41
Table 4-4- Fastener corrosion analysis 48

Chapter 1

Introduction

1. Introduction

Magnesium Oxide (MgO) wallboards are an alternative construction material to fibre cement and gypsum sheeting, and is a relatively new product on the Australian market. The product is being widely used throughout other regions including Europe and Asia. Recent studies from Denmark, however, have indicated that the product leads to accelerated corrosion of contacting metal fixtures and dampness when exposed to high humidity environments. It has been reported that MgO boards have been used in more than 20,000 apartments in Denmark (Marquard 2015). However, due to damages caused by magnesium oxide wallboard, 69 public buildings and 12000 homes require replacement of these boards, with the estimated cost of removal in the order of tens of million Euro.

These failures raise questions about the appropriateness of the magnesium oxide wallboards for the Australian market. MgO board products are now available on the Australian market, and whilst these products have passed current certification procedures (which do not consider environmental moisture absorption), there has been no studies of their performance. This report investigates five different magnesium oxide panels available on the Australian market, and investigates the likelihood of the products leading to failures associated with excessive moisture absorption and corrosion. Based on this, the variability in quality between different magnesium oxide wallboard products can be assessed and recommendations regarding the use of MgO board products in Australia can provided.

This project is being conducted in consultation with CertMark International. CertMark International is responsible for the certification of building products within Australia. As a consequence of the failures reported in Denmark, CertMark International has approached the university to assist in determining whether the array of MgO products available are suitable for use in Australian conditions.

1.1 Project aims

This project will assess the variability in quality of different magnesium oxide wallboard products available on the Australian market, based on likelihood of the product leading to failure due to corrosion or excessive moisture absorption. Recommendations regarding the appropriateness of the MgO products for the Australian market will then be provided.

1.2 Methodology

The methodology of this project will follow a sequential process of researching, experimentation, and analysis. The steps of this process will include:

- Review of appropriate literature investigating current damages and current findings related to magnesium oxide wallboards
- Design of experimental methods to assess the quality of the MgO boards
- Design and construction of data acquisition systems and experimental environments
- Execution of experimental methods
- Analysis of experimental results
- Forming recommendations based on analysis of results

Chapter 2

Background and Literature Review

2. Background and Literature Review

Magnesium Oxide Board is a relatively new construction material used as an alternative to fibre cement sheeting or gypsum panels. MgO boards are used as an alternative due to their energy efficiency in production, cost effectiveness, acoustic damping, and fire resistant properties (Shanghai Metal Corperation n.d.). The board has multiple uses, including fascia's, soffits, tile backing, and underlays, however the most common use is as a wall or ceiling panel, in place of gypsum panels or as external cladding.

A survey conducted in 2016 showed that since 2010, approximately 275000 m^2 of MgO panels had been installed throughout Denmark in both renovations and new constructions (Byggeskadefonden 2016). Magnesium oxide boards became very popular throughout Denmark from 2010, and were widely recognised as a cheap and efficient alternative boarding material until recent failures became documented.

2.1 Current Damages

Due to the corrosive leachate which forms when some magnesium oxide boards are exposed to high humidity environments, many reports of damage attributed to the use of MgO boards have been observed. The reports of damage pose a global issue, as the boards have been certified and widely used in many countries. A notable example of MgO board use is all 101 stories of Taipei 101 skyscraper, used inside and outside all the walls, fireproofing beams, and as subfloor sheathing (Building and Construction Authority Singapore 2012).

Several reports of magnesium oxide board damages have been observed within Australia. Most notable of which concerns the damages reported in the nine-story unit complex in Chermside, Queensland. The reported damages included cracking and bulging of the walls, dampness issues (Figure 2-1), and accelerated corrosion of metal in contact with the boards (Body Corporate for HQ Apartments CTS 39869 v Queensland Building and Construction Commission 2015). It was found that accelerated corrosion was due to "chloride-ion induced corrosion of the galvanised steel stud frame sections" (Body Corporate for HQ Apartments CTS 39869 v Queensland Building and Construction Commission 2015). Similar damages have been reported at Silverstone Apartments, Tweed Heads, where cracking walls, dampness, and corrosion have also been reported (Turner 2015).

Severe corrosion and moisture damages have also been observed throughout Europe. MgO boards had been used throughout Denmark in 82 public buildings and almost 12000 homes, most of which require replacement, with an estimated repair bill of just under DKK 1 billion (Building Damage Fund 2016). Reports suggest that almost all magnesium oxide sheeting will be required to be replaced by the Building Damage Fund in Denmark to prevent further damages occurring over time (Byggeskadefonden 2016). Several reports of damages have also been reported in Sweden, a majority of which are caused by the same brand boards used throughout Denmark (Kornum 2015).

Figure 2-1-Evidence of damages due to MgO boards: Leachate visible on MgO board due to excessive moisture absorption (left) and corrosion of contacting metal framework (right)
Source: (Hansen et al. 2016)

Studies conducted on the Danish MgO board problem had implicated the tendency of the MgO sheets to absorb moisture from the environment, leading to leaching of saline water. A detailed study by Bunch Bygningsfysik (2015) found that after 7 days exposure at 90% relative humidity, leaching was observed. A report conducted by the Building Damage Fund Denmark concluded that the MgO panels used were not suitable for use as a wind breaker in Danish conditions as the relative humidity throughout winter often peaked above 90% RH and thus can lead to leaching to the saline solution which is attributed to the dampness and resulting corrosion of metal fixtures (Byggeskadefonden 2015). This saline solution resulted in the corrosion of non-stainless steel fixtures. Bunch Bygningsfysik (2015) further found that the MgO sheets can lose cohesion over time as the binder decomposes at relative humidity's above 95%. These results related to the use of MgO board branded as "Eco Board".

Hansen et al. (2016) concluded that relative humidity's above 84% would result in excessive moisture absorption, resulting in leaching. This leachate contained corrosive elements, such as Cl^- and Na^+, which then lead to corrosion of metallic fixtures around the boards.

2.2 Certification of Magnesium Oxide Wallboard

The Australian Building Codes Board (ABCB) manages the CodeMark scheme that outlines the requirements for product evaluation and certification, for which a product must conform to before it can be approved for use in Australia. CodeMark Certificates of Conformity are issued by accredited certification bodies, such as CertMark, who are responsible for the evaluation of the product (Australian Building Codes Board 2015).

The current Australian assessment criteria for magnesium oxide sheeting depends on many performance requirements which must be demonstrated by the manufacturer through accredited testing laboratories. The assessment criteria analyse performance indicators such as the mechanical properties of the sheeting (e.g. bending strength), combustibility, water absorption (48 hour immersion analysis), and content of chloride ion (CertMark International 2016). However, the current assessment criteria does not assess the tendency of MgO boards to absorb moisture from the environment before entering the market. This is similar to many other building codes, such as Swedcert, Sweden (Kornum 2015).

2.2.1 Composition of MgO Boards

Magnesium Oxide wallboards have a composition consisting of magnesium oxychloride cement (Sorel Cement), magnesium oxide, and inorganic fillers such as sand and perlite. The boards are structurally aided by 3 layers of fibreglass mesh, where one is strengthened high density, and one layer is nonwoven.

The typical material compositions of the boards range from:

- MgO = 48-52%
- $MgCI_2$ = 22-26%
- Wood fibre = 10-12 %
- Perlite = 10-12 %
- Other = 2-5%

Sorel cement (magnesium chloride cement) is used as the cement binder for magnesium oxide sheeting. Sorel cement is used over Portland cement for its many superior qualities, such as high fire resistance, low thermal conductivity, and its strong bond with inorganic and organic aggregates (Phair 2006). Magnesium oxychloride cement is the result of a magnesium chloride ($MgCI_2$) brine solution mixed with magnesium oxide (MgO) in a stoichiometric ratio of H_2O, $MgCI_2$, and MgO (Caine & Ellis 2008). The chemical reaction for the setting of Sorel Cement can take many forms, one of which forms 5-phase hydrated magnesium oxychloride product (Caine & Ellis 2008), shown in Equation 1.

$$5\ MgO + MgCI_2 + 13\ H_2O \rightarrow 5Mg\left(OH\right)_2 \bullet MgCl_2 \bullet 8H_2O \qquad (1)$$

However, the magnesium chloride phases are not stable after extended exposure to water. This instability of the binding phases leads to leaching of magnesium chloride or magnesium hydroxide (Phair 2006). Consequently, Sorel cement is limited in use throughout the construction industry despite many beneficial characteristics. Zhou et al. (2015) suggests the 5 phase is unstable in a magnesium solution molarity of 1.47mol/kg, and the 3 phase is unstable for magnesium molarities less than 2.25 mol/kg. The presence of magnesium chloride in the leachate leads to significant steel corrosion for contacting fixtures (Walling & Provis 2016). Corrosion is possible in relatively dry environments due to the hygroscopic nature of magnesium chloride, as the pores containing magnesium chloride will not dry in relative humidity above 32% RH (Nürnberger 2001).

2.2.2 Standard Installation of Magnesium Oxide Wallboards

The installation of MgO boards varies slightly between suppliers, however as the supplier information for each sample was not included within the scope of the project, a generic installation manual was considered. One such manual is provided by Magnesium Oxide Board Corporation (2014). For interior walls, magnesium oxide wallboards are installed in a similar fashion to gypsum wall boards, as shown in Figure 2-2. When installed as per the installation instructions, Magnesium Oxide Board Corporation (2016) state for their ResCom MgO products, that 10 mm external sheets will provide a 90 minute fire rating, a 12mm sheet provides a 120 minute fire rating, and a 14mm sheet provides a 180 minute fire rating.

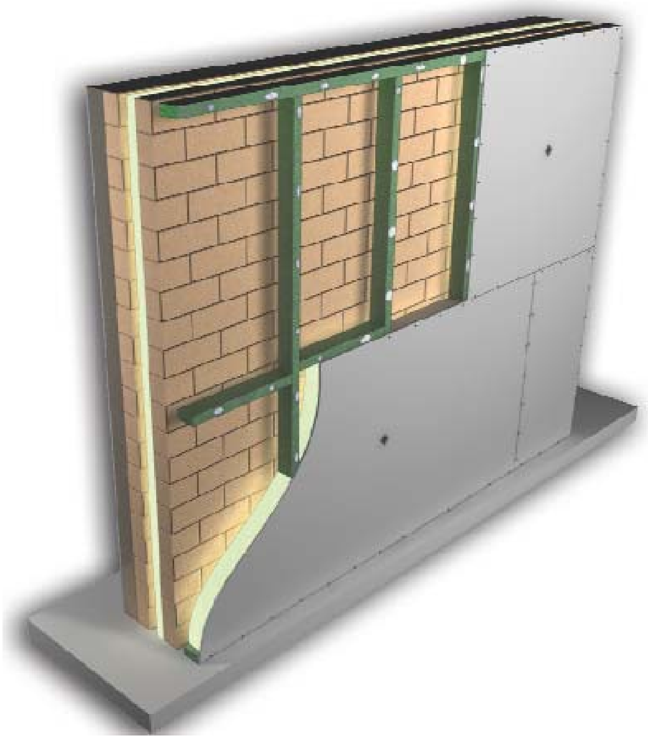


Figure 2-2- Interior timber installation
Source: (Magnesium Oxide Board Corporation 2016)

Material Safety Data Sheets provide information on the methods for cutting the boards that reduce exposure to dust. Although MgO boards are deemed non-toxic, exposure to dust should be kept to a minimum to reduce any health hazards (Magnesium Oxide Board Corporation 2012). The preferred method of cutting MgO boards is using a dust reducing circular saw, fitted with vacuum extraction and the appropriate blade. However other methods deemed appropriate are the use of carbide-tipped utility knives for scoring the board then snapping along the score, fibre cement sheers, or circular saws with appropriate dust reducing measures.

Magnesium Oxide boards can be fitted to timber or metal framing, and masonry products which conform with the Building Code of Australia. For application on masonry materials, masonry adhesives are suitable for fitting. Magnesium Oxide Board Corporation (2014) recommends the use of both fasteners and adhesives for general installations, where mechanical fastener only systems are recommended for fire rated installations, tiled wet areas, over existing linings, or over existing vapour barriers. For use with ResCom Board® class 3 to 5 non-corrosive screws are recommended, with a minimum grade 304 SPAX or 316 stainless steel non-corrosive fastener required for external fixtures or corrosive air environments. Class 3 to 5 non-corrosive 10g to 12g screws are recommended for interior ceilings and walls. Figure 2-3 shows the recommended types of mechanical fasteners. When fixing magnesium oxide wallboards to metal framing, minimisation of corrosion due to dissimilar metals or other corrosion mechanisms can be achieved by the application of a silicone film, mastic tape, sarking over the metal frame where the fastener will fix to (Magnesium Oxide Board Corporation 2014). DragonBoard MgO sheathing boards recommend coating their panel with acrylic-siloxane water proofing sealer and an oil based paint when the boards are exposed to rain and or weather directly.

Nails
(NON-CORROSIVE)
Hardwood 25 x 2.8mm
Softwood 30 x 2.8mm

Self-Counter Sinking Screws
NON-CORROSIVE
For timber framing

N°6 Type 'S' Needle Point
NON-CORROSIVE
For lightweight steel studs and furring channel up to 0.8mm thickness.

N°6 Type 'S' Drill Point
NON-CORROSIVE
For steel framing 0.8mm to 1.2mm thickness.

Figure 2-3 Recommended mechanical fasteners

Source: (Magnesium Oxide Board Corporation 2014)

2.3 Humidity Chambers and Controlling Humidity

In the absence of a controlled humidity chamber available for testing, alternative methods for humidity control were investigated. Wexler and Brombacher (1951) describe the most commonly used methods as saturated salt solutions, water-sulfuric-acid mixtures, and Glycerin solutions. However, as both sulfuric acid and glycerol solutions are two-phase systems (vapor-liquid), they are limited to applications when test subjects do not absorb water vapour, as this will alter the relative humidity (Rockland 1960). As saturated salts are a three-phase system (vapour-liquid-solid), they are independent of total moisture content variations.

To achieve the required relative humidity in a closed system, the correct salt solution must be selected. Appendix 1 provides a list of relative humidity values for selected saturated salt solutions, suggested by ASTM E104-02. This list is adapted from Greenspan (1976), who provides a much more exhaustive list. However, the salt solutions selected by ASTM E104-02 have more widely accepted values, and are more stable with varying temperatures. Winston (1960) cautions the use of particular salts near their transition temperature, as this may result in the loss of the water of hydration. No transition points were found for a number of salts, including NaCI, HCI, KBr, KI, $NaNo_3$, $NaNO_2$, CrO_3, or KF within the temperature range of 15°C to 50°C (Carr & Harris 1949).

When using saturated salts, several design considerations and precautious must be observed to obtain satisfactory results. The container holding the samples tested and solution must be air tight to reduce interference from the outside atmosphere (Winston 1960). It is further suggested that the chamber be constructed of corrosion resistant, non-hygroscopic materials such as glass (American Society for Testing and Materials 2012). This is supported by Wexler and Hasegawa (1954) who adds the use of hygroscopic materials will increase the required time for the environment to reach equilibrium, potentially requiring days or weeks. Having the solution contained in dish of the appropriate material would allow for the use of materials such as plastic and metal as the environmental chamber. To optimise the process of diffusion, the saturated salt solution should have a large surface area exposed to the chamber air. ASTM E104-02 recommends a maximum proportion of 25 cm^3 container volume per cm^2 surface area of the solution.

Several studies suggest the use of mechanical convection when using saturated solutions. Winston (1960) suggests that in environment volumes greater than one litre, a device to circulate the air within the chamber should be used, such as a fan. Rockland (1960) shows the importance of mechanical convection in saturated solutions, with the study demonstrating mechanical convection can reduce the time to reach equilibrium from 10 to 50 times. Operating the fan intermittently can also reduce the heat generation, which is important to reduce environmental abnormalities, and hence Rockland (1960) found operating the fan in cycles of 20 seconds on, 600 seconds off produced the most reliable results.

The purity of reagents must also be accurately maintained. ASTM E104-02 requires the use of reagents conforming to the specifications of the Committee on Analytical Reagents of the American Chemical Society. Either amorphous or hydrated reagents should be used for preparing saturated salt solutions, with hydrated reagents preferred for solvating characteristics. Water reagents must be produced via ion exchange, distillation, or reverse osmosis followed by distillation (American Society for Testing and Materials 2012).

Temperature regulation is vital to obtain accurate relative humidity's within the chamber. ASTM standard E104-02 outlines the needs for temperature regulation, as ±0.1 °C temperature changes can result in relative humidity differences of ±0.5 % (American Society for Testing and Materials 2012). Winston (1960) however states that this difference will vary depending on the salt solution selected, as some salts have larger temperature coefficients resulting in larger fluctuations with temperature changes. This fluctuation can therefore be minimised by selecting salts with small temperature coefficients.

2.4 Measurement of Humidity

The absolute humidity of an environment can be defined as the amount of water vapour per unit of gas, at a certain temperature and pressure, measured as g/m^3 or mg/litre. The temperature of the gas determines the maximum amount of water vapour that can be observed in a volume of gas, and as the temperature increases the maximum water vapour present also increases (Agarwal & Griffiths 2006). The relative humidity can be defined as the ratio of absolute humidity and the maximum water vapour the gas can carry at the specified temperature and pressure, and is expressed as a percentage.

Many transduction techniques for humidity measurements are practiced, including optical, gravimetric, capacitive, resistive, piezo-restive, and magnetoelastic. Approximately 75% of humidity sensors available are of the capacitive type (Lee & Lee 2005). The advantages of capacitive type sensors over other transducer sensors are the low power consumption of the senor, and the high output signals. These sensors measure the humidity by measuring moisture induced changes in the dielectric constant of a hygroscopic layer (Lee & Lee 2005). The major advantage of humidity transduces are the signals can be read digitally, which allows the humidity to be logged at intervals throughout the test, without the need to be present to read and record the measurements.

2.5 Experimental Methods Used in Literature

In a similar study conducted by Hansen et al. (2016), a climate control chamber was used to test the moisture absorption in MgO boards. The methodology analysed 4 different samples of MgO wallboard, which were subjected to humidities of 35%, 80% and 95%. Before being subjected to climate control, the specimens were dried for 4 days at 105 °C. The weight difference from the initial dried weight to the weight after testing was used to determine moisture absorption. The results found significant mass increase at relative humidity's of 80% and 95%. By gradually increasing the relative humidity until sweating occurred on the surface, the leaching threshold was determined to be 84% RH.

The leachate was analysed using ICP (Inductively Coupled Plasma Optical Emission Spectrometry) and IC (Ion Chromatograph) equipment. Samples were exposed to a relative humidity of 95-100% for 2.5 weeks before being analysed. Potassium, sodium, magnesium and chloride ions were all evident in the leachate excreted from the MgO boards (Hansen et al. 2016).

However, this study did not investigate the effects of the corrosive nature of magnesium oxide boards. To enable justified recommendations regarding the use of MgO boards, the corrosive nature of the leachate should be investigated to determine the impacts on metal fasteners and other contacting metal fixtures.

Chapter 4

Experimental Methods

3. Experimental Methods

The experiments conducted considered five different brands of magnesium oxide (MgO) cladding, and one fibre cement cladding sample (used as a control). Table 3-1 lists the sample description and the numbering convention used throughout the report. To evaluate the samples, five different experiments were used and these are:

- Water absorptivity analysis
- Moisture absorption in controlled humidity
- Fastener corrosion analysis
- Analysis of Board Composition and Porosity with SEM/EDS
- Thermal Analysis

Table 3-1 -Different MgO samples analysed

Specimen	Sample Numbering
A (MgO)	A1, A2….
B (MgO)	B1, B2….
C (MgO)	C1, C2….
D (MgO)	D1,D2….
E (Fibre cement control)	E1, E2….
F (MgO)	F1,F2….

A humidity chamber with controlled constant humidity is required to study the effect of humidity on MgO boards. The validity of these experiments depends on ability to maintain and control the environment in terms of relative humidity (RH) and temperature. Ideally, factory built humidity chambers should be used, however since these were not available, a make shift chamber was developed. On research, it was determined that to use saturated salt solutions which published equilibrium relative humidity values. For this chamber to work well for the planned experiment, constant monitoring of RH and temperature is important.

As the volume of the environmental chambers was larger than 1 litre, Winston (1960) suggests mechanical convection to reduce equilibrium time of the saturated solutions used to create relative humidity. This was achieved by utilising the Arduino platform as a fan controller, cycling the operation of the fan to reduce generated heat inside the environment.

3.1 Humidity and Temperature Datalogging Sensor

To monitor the environmental conditions of the experiments, humidity and temperature dataloggers were required. Many datalogging humidity hygrometers are available on the market, however as several humidified environments required monitoring, the cost of such units becomes impracticable within the available budget. One such unit is the QP6013 Temperature/Humidity Datalogger available from Jaycar Electronics for $119 (Figure 3-1). This unit has a relative humidity accuracy varying from ±3% to ±5% (at the extremes of relative humidity), and ±1°C in the temperature range of -10°C to 40°C. This appears common in this price range.

Figure 3-1: QP6013 temperature/humidity datalogger

Source: https://www.jaycar.com.au/temperature-humidity-datalogger/p/QP6013

Instead of the more expensive QP6013, a DHT22 digital relative humidity and temperature sensor was employed to reduce the costs of multiple sensors. The DHT22 is a low cost, capacitive type digital sensor, which outputs a calibrated digital signal that can be interfaced with the Arduino microprocessor. The sensor has an accuracy ranging from ±2% to ±5% for relative humidity, and ±0.5°C for temperature. Such specifications are to the comparable standard to off the shelf hygrometers such as the QP6013 unit. It has been demonstrated that the DHT22 can be successfully used for the monitoring of temperature and humidity. Gaddam et al. (2014) designed a sensor network using the DHT22 for environmental data monitoring and has been used for predicting draughts, Mesas-Carrascosa et al. (2015) used the sensor in hardware to monitor environmental parameters in agriculture, and Mašic (2015) designed a unmanned aerial vehicle data acquisition system using the DHT22, showing the sensors wide use throughout literature.

The unit was built with two DHT22 humidity and temperature sensors to allow two environments to be monitored simultaneously. As data is required to be recorded for analysis, the XC4536 Data Logging Shield (Jaycar Electronics 2017) was used to store data onto a SD card. To view the live temperature and humidity for monitoring, the 1602A-1 LCD module (Shenzhen Eone Electronics 2012) was interfaced with the Arduino. This set up has advantages over other humidity dataloggers, such as the QP6013, such as the ability to have the sensor separate from the display, which allowed the live environmental conditions to be monitored without opening the environmental chamber, which could affect the equilibrium state. Figure 3-2 describes the pinout for the unit, and the relevant code can be found in Appendix 6

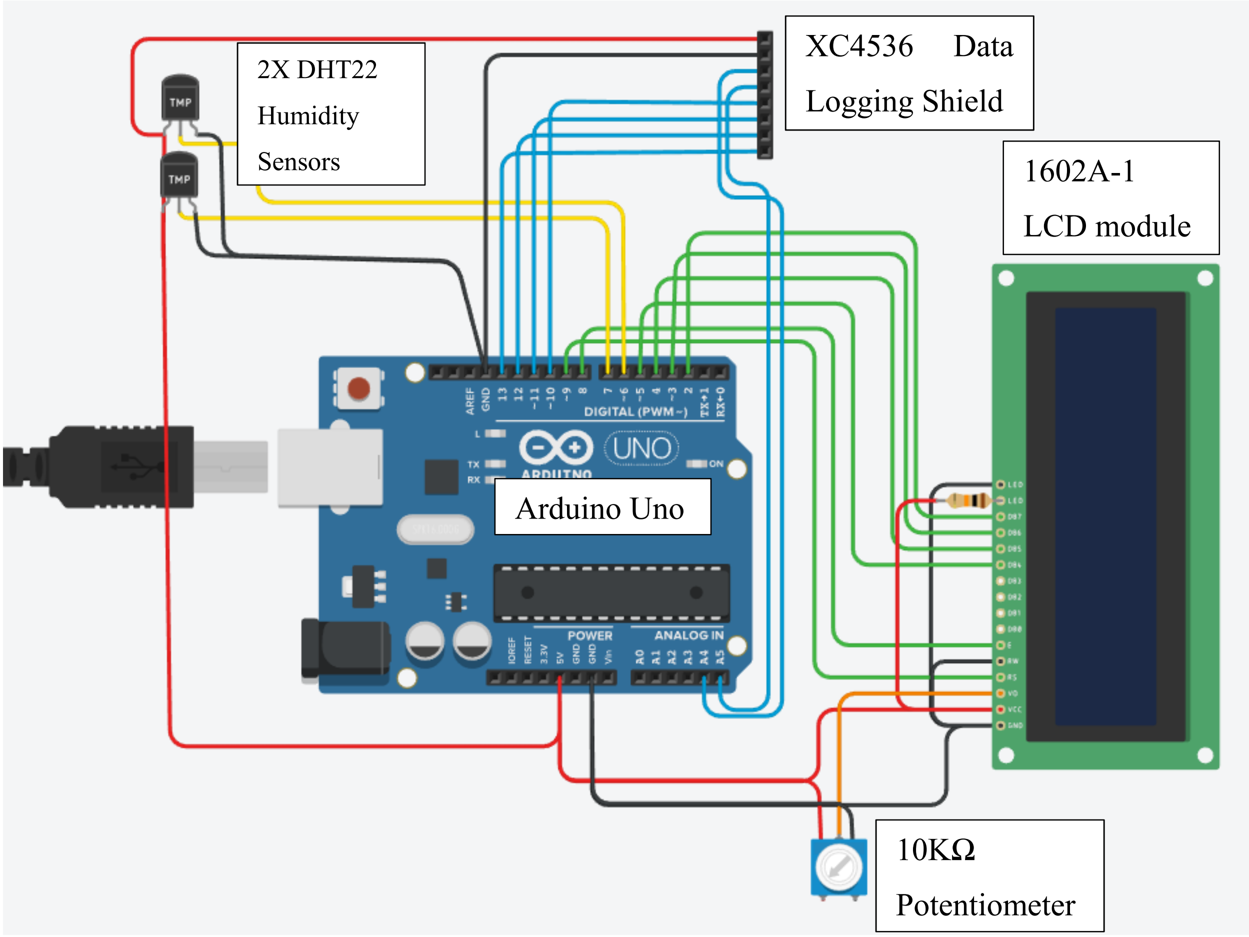


Figure 3-2- Humidity and temperature sensor circuit diagram

A comparison of the DHT22 sensors and the Duinotech QP6013 is shown in Figure 3-3. The sensors monitored ambient conditions over 36 hours in order to compare the performance of the DHT22 to the well-established Duinotech Qp6013. It is shown that RH values follow similar trends over the 36-hour period. However, there is a near constant difference of approximately of 3-5% RH. This was deemed an acceptable tolerance as the environmental chamber humidity was controlled with saturated salts with known relative humidity values.

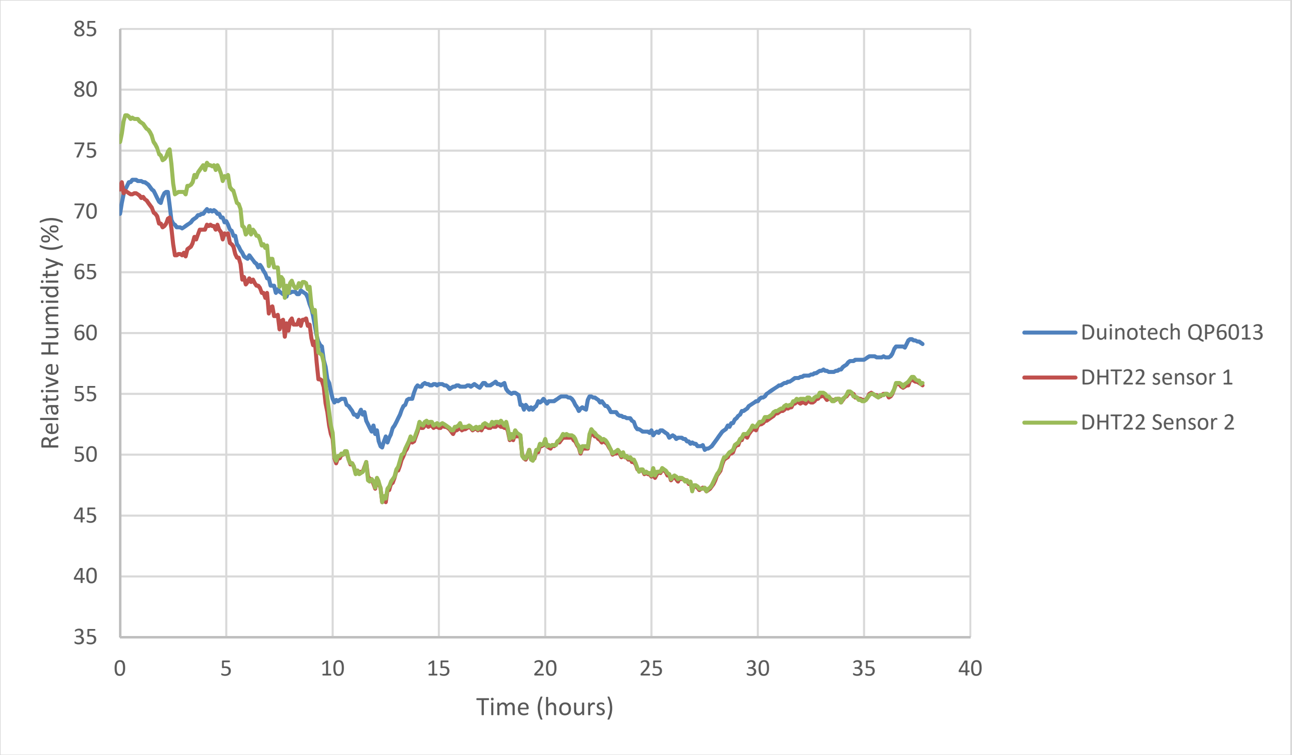


Figure 3-3-Validation of DHT22 sensors

3.2 Water Temperature Datalogger

For validation of the water absorptivity analysis, the water temperature was monitored. This task required a waterproof temperature sensor that was capable of recording the water temperature at intervals. As both the humidity datalogger (high humidity moisture absorption analysis) and the water temperature datalogger (water absorptivity analysis) were not required simultaneously, the humidity datalogger was repurposed to operate as a water temperature datalogger. The DHT22 humidity sensors were replaced with a Waterproof DS18B20 Temperature Probe (Figure 3-4) in the schematic shown in Figure 3-2, and the code rewritten to incorporate the sensor (Appendix 7).

Figure 3-4-Stainless steel housing waterproof DS18B20 temperature probe

Source:* *http://www.altronics.com.au/p/z6386-stainless-steel-housing-waterproof-ds18b20-temperature-probe/

3.3 Design of Fan Controller

As the efficiency of humidified environments using saturated solutions can be greatly increased by using mechanical convection, as shown by Wexler and Hasegawa (1954); Rockland (1960); Winston (1960), a fan controller was required to circulate air within the environments. As suggested by Rockland (1960), the fan was operated intermittently, cycling 20 seconds on, and 600 seconds off. Arduino was selected as the system microcontroller due to the availability, ease of use, and small cost. As Arduino digital output pins can only supply 30 mA, a TIP120 Darlington transistor was used to provide additional current from the main power source for operation of the fans. The circuit diagram is illustrated in Figure 3-5, and the code for the fan controller is found in Appendix 8.

The fan selected was a 30mm x 30mm x 6mm 5VDC fan. The fan size was selected as the environment size required only low airflow, and had limited available space. As the Arduino was powered from a 5VDC power source, using a 5V fan allowed a transistor to be simply implemented in the design. The fans were installed into the environmental chamber by using an epoxy adhesive to attach the fans to the environments inner enclosure.

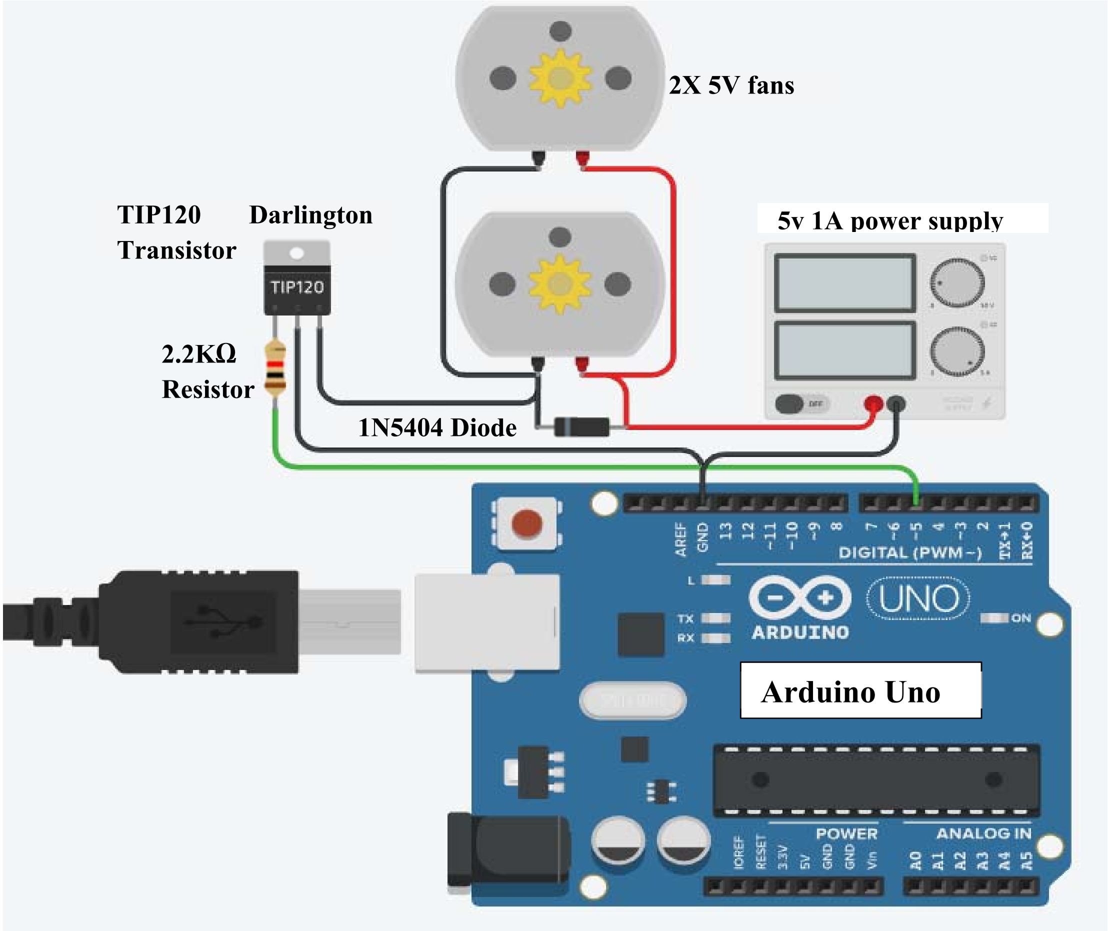


Figure 3-5- Arduino fan controller circuit diagram

3.4 Water Absorption

Water absorption is a routine test for non-asbestos fibre-cement boards, and magnesium oxide wallboards currently on the market. Before been certified for use, wall boards are evaluated for their water absorption according to test guidelines in accord with ASTM C1185-08. As a starting point for this investigation, the water absorption test was conducted in accordance with the ASTM standard C1185-08 in order to compare the water absorptivity of the different boards being studied.

Water absorption samples were cut to $70mm \times 70mm$ in size. Each specimen was dried using a drying chamber at 90±5°C until constant weight, to remove any pre-existing moisture, and allowed to cool to room temperature in a desiccator type cabinet. The initial mass of the specimens was recorded using a 3-point balance. The specimens were then fully submerged in clean tap water for 48 hours at ambient temperature (23±4°C). The water temperature was monitored using the datalogger described in Section 3.1. The verification of temperature throughout the experiment is shown in Figure 3-6, where the average temperature is 21.2°C, which is within the specified tolerances. A plastic rack was used to separate the specimens to ensure all specimens had an equal surface area exposed. For sample C, a metal weight was placed on top of the sample due to its buoyant nature. The temperature of the water was monitored using a datalogger to ensure the temperature remained within the specified bounds throughout the test. The specimens were removed from the water tank, and wiped with a damp cloth. The final saturated weight of the boards was recorded using the 3-point balance. The mass increase due to water absorption was calculated using Equation 2.

$$\text{Water Absorption, mass }\% = \left(\left[W_s - W_d\right] / W_d\right) * 100 \qquad (2)$$

Where:

- W_s= Saturated Mass (g)
- W_d= Dry Mass (g)

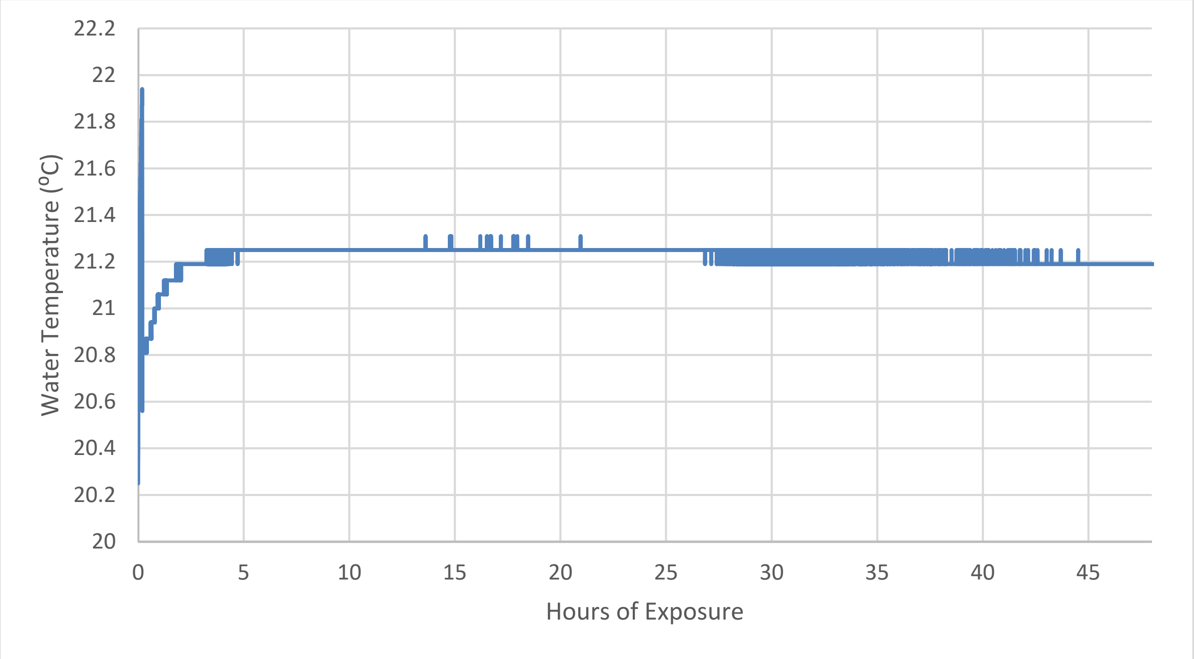


Figure 3-6- Water immersion temperature validation

3.5 Moisture Absorption in Controlled Humidity

The second test was to assess the moisture absorption of the magnesium oxide boards in high humidity conditions over a prolonged period. As the facilities to accurately and efficiently determine the threshold relative humidity for excessive moisture absorption were not available, the threshold determined by Hansen et al. (2016) is assumed accurate, and this test aimed only to compare the moisture absorption of the different MgO boards in high humidity environments.

For this test, new samples were prepared, with a size of 40mm x 40mm. For each sample, 6 specimens were prepared, with 3 specimens used for a targeted controlled humidity. Because of variation in the thicknesses of the various board, epoxy coating was applied to the edges of the samples to eliminate the effects of water absorption through edges and allow a normalised comparison of absorptivity of the working surface. Each specimen was then dried using a drying chamber at 90±5°C until constant weight to remove any pre-existing moisture, and allowed to cool to room temperature in a desiccator type cabinet. The initial mass of the specimens was recorded using a 3-point balance.

In the absence of climate control apparatus, saturated salt solutions were used to attain a controlled humidity environment. The targeted controlled humidities are based on the published equilibria values (Rockland 1960) of relative humidity for saturated salts at fixed temperatures. Since equilibrium RHs are temperature sensitive, an incubation chamber was utilized for temperature regulation. The Incubation chamber was set at 32°C. Previous study (Hansen et al. (2016) suggested that the threshold for excessive moisture absorption in MgO boards was 84% RH. Two salts were selected whom published saturated equilibrium RH were above and below this threshold of 84%RH in order to achieve two controlled RH atmosphere. The selected salts were potassium sulphate to achieve environments (97.0±0.4 % RH @ 30°C) and sodium chloride to achieve environment (75.1±0.2 % RH @ 30°C).

Table 3-2- Humidity absorptivity specimen labelling

Sample	*Specimen numbering 97% RH environment*	*Specimen numbering 75% RH environment*
A	A1, A2, A3	A4, A5, A6
B	B1, B2, B3	B4, B5, B6
C	C1, C2. C3	C4, C5, C6
D	D1, D2, D3	D4, D5, D6
E (control; fibre cement board)	E1, E2, E3	E4, E5, E6
F	F1, F2, F3	F4, F5, F6

In order to prepare a specific humidity chamber, the bottom of the saturated solution dish was filled to a depth of 1.5 cm with the selected salt. Distilled water was added in 2 mL increments until the solution was saturated, stirring after each addition of water. Excess undissolved fluid was kept to a minimum to minimise RH stability variations with temperature variations. This process was followed to create a potassium sulphate and a sodium chloride saturated solution. As an indication, one gram of sodium chloride dissolves in 2.8mL at 25°C (Haynes 2013), and 1g of potassium sulphate dissolves in 8.3 mL of water (*The Merck Index* 1976).

The environment chambers used had a volume of 3.5L and were fabricated from of polypropylene plastic. Polypropylene plastic was selected for its non-hygroscopic properties, which reduce the impact on the environmental equilibrium. Two chambers were required, one to contain each set of relative humidity values. The chamber was airtight to minimise effects of the atmosphere influencing the RH equilibrium. As the chamber volume was greater than 1L to accommodate the specimens tested, a small fan was used to circulate the air within the chamber (Section 3.3). The saturated solution was placed in the respective chambers and allowed 1 day for the chamber to equalise. The temperature and relative humidity of the chambers environment was monitored via temperature and humidity sensors attached to a datalogger (Section 3.1). The wires for the sensors and the fan power were inserted through the chamber walls and sealed using silicon to minimise losses around the wire hole. The controlled humidity setup is schematically illustrated in Figure 3-7.

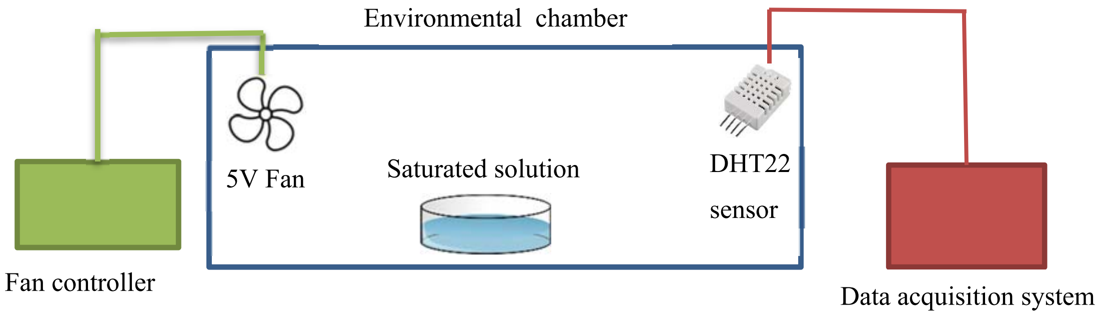


Figure 3-7- Controlled humidity setup

The specimens were subjected to the set RH values and the weight change of the specimens was followed for up to 41 days. To weigh the specimens, the board samples were removed from the chamber, wiped with a damp cloth to remove surface water or leachate from the board, and weighed using 4-point scales. The specimens were then returned into the chamber. Care was taken to minimise the chambers exposure time to the atmosphere to reduce the impact on equilibrium conditions. Any leachate evident on the samples was documented. Percentage weight gain were similarly evaluated as described in section 3.4.

3.6 Fastener Corrosion Analysis

The aim of this test is to evaluate the susceptibility to corrosion of standard fasteners and steel sections that are normally used for the installation of the boards. Due to size restrictions of the humidity chamber, 4 boards out of 6 were selected for analysis. The samples selected were based on water absorptivity results and the semi quantitative elemental analyses information from SEM/EDS analysis. Sample F was selected as it is thought it would cause the least corrosion, sample A and B were considered (based on water absorption tests) the most likely to aid corrosion. Sample E (fibre cement board) was selected as the control being the conventional wall board material the MgO board is competing with. Two $300mm \times 40mm$ strips from each board were cut. One strip of each board was used for testing corrosion of fasteners, and the second to assess corrosion of fasteners mounted to a 40mm x 40 mm x 300mm square steel section, where the fasteners pieced the magnesium oxide board and fastened into the steel section, as illustrated in Figure 3-10 and Figure 3-9.

As the steel section is coated in a protective paint, the coating was removed using sand blasting. The fasteners and steel sections to be tested were cleaned by rinsing with purified water and dried using forced hot air, with a temperature between 40° to 60°C. The characteristics of the fasteners tested are given in Table 3-3 and shown in Figure 3-8.

Table 3-3- Fastener characteristics

Designation	*Fastener Coating*	*Coating Description*	*Size*
A	Gold Passivated	Gold passivated coatings are a yellow zinc plating, with relatively poor corrosion resistance and not recommended for exterior use	6G x 25mm
B and C	Galvanised (class 3)	Hot dipped zinc coating with higher corrosion resistance then other zinc coatings	6G x 25mm
D	Zinc Plated	Electrolytic application of zinc coating, with relatively poor corrosion resistance and not recommended for exterior use	6G x 1 1/4”
E	304 Stainless Steel	Economic choice of stainless steel, with good corrosion resistance	6G x 1”
F	316 Stainless Steel	The addition of molybdenum drastically increases the corrosion resistance of 316 stainless steel, making it suitable for saline and chloride exposed environments	6G x 1”

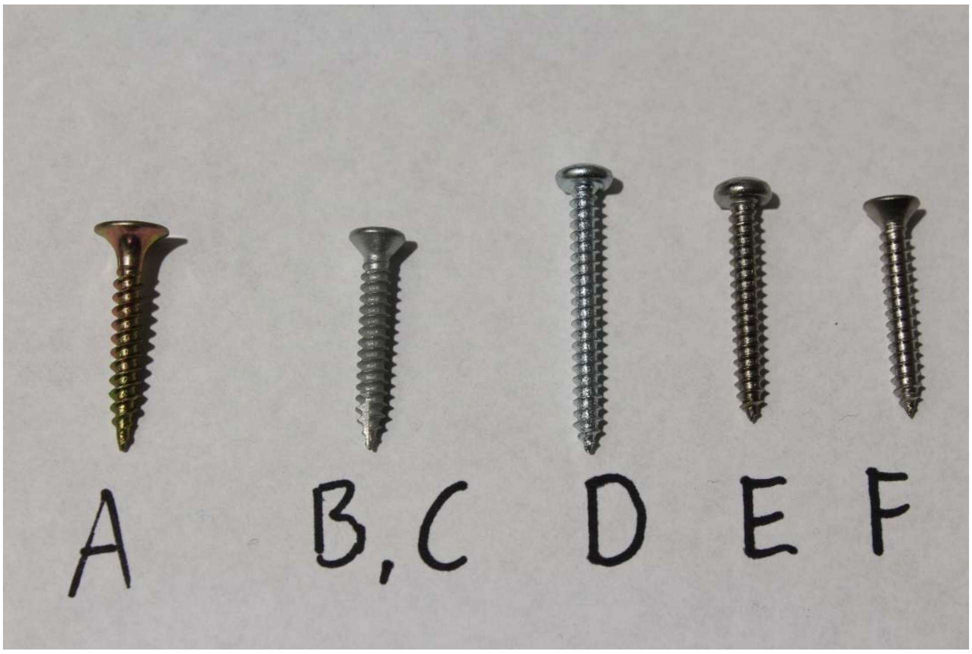


Figure 3-8- Fasteners used in corrosion analysis

The installation of the fasteners was conducted in accordance with practices for standard installation of wall boards. To reduce any potential for splitting of the board, the location of the fasteners was staggered. The test samples were placed such that sufficient space allowed for air flow across all components. The environmental chamber was maintained at 32±2°C, in accordance with ASTM A90/A90M specifications. Saturated solutions of potassium sulphate (97.0±0.4 RH @ 30°C) was used to create the humidified environment within the test chamber, to achieve a humidity above the published humidity threshold for excessive moisture absorption (Hansen et al. 2016). The chamber remained closed for the duration of the experiment, apart from interruptions less than 10 minutes for inspections and to replenish the saturated solution, with a maximum of one inspection per day. The test was conducted for 94 days.

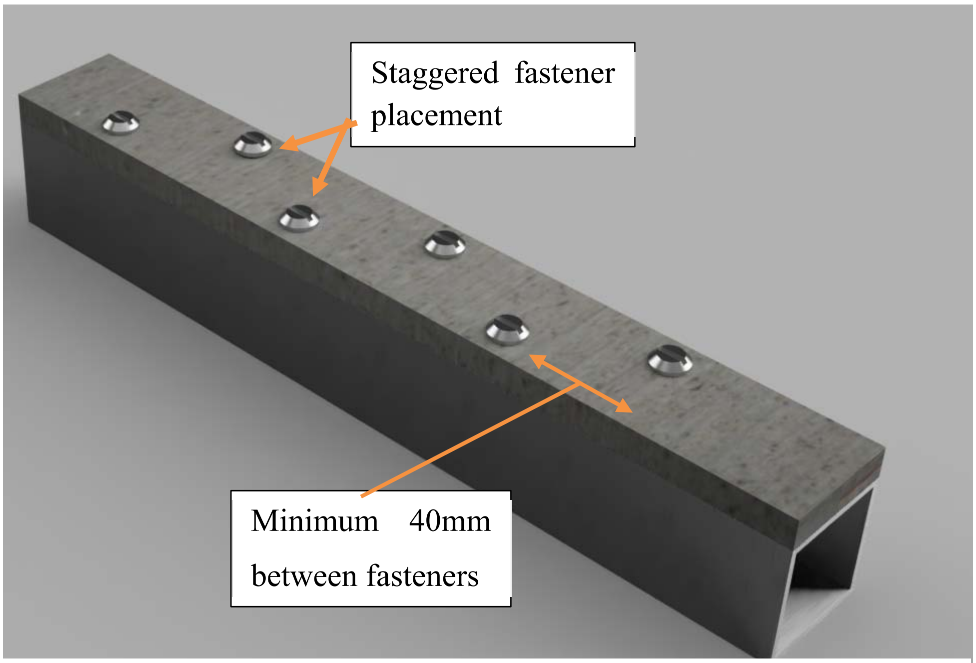


Figure 3-9-Solid model illustration of board fastened to a steel section

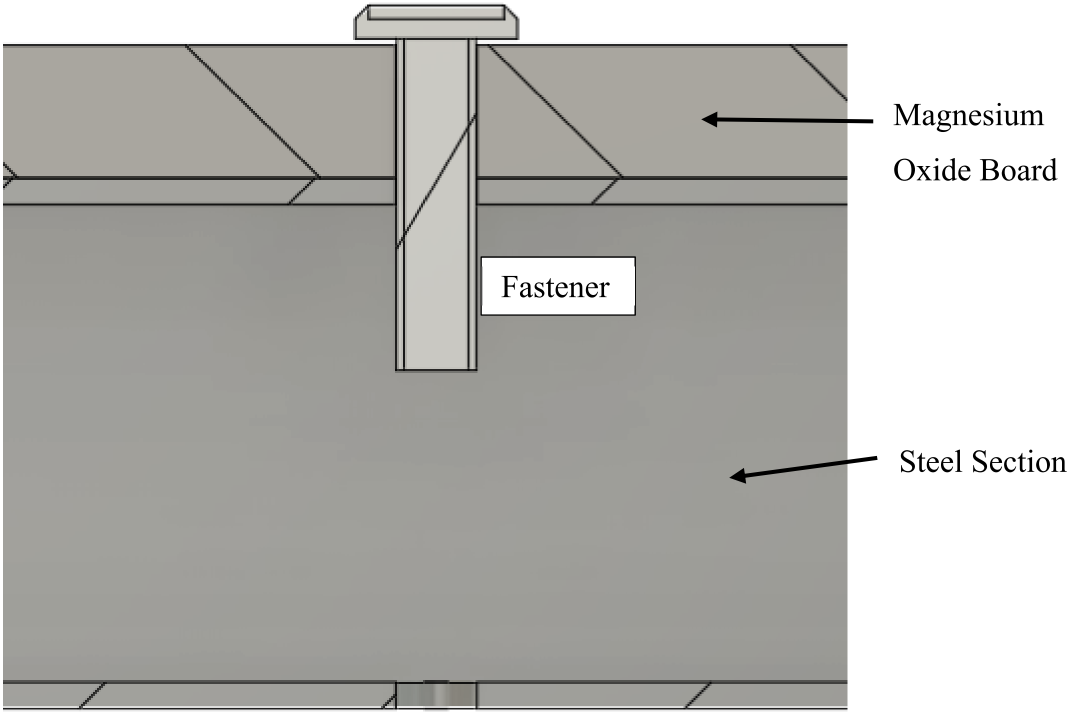


Figure 3-10- Cross section illustration of fastener installation

After testing had ceased, and a visual inspection of the samples had been conducted (documenting anything notable using a camera), the fasteners were removed from the magnesium oxide boards.

3.7 Analysis of Board Composition and Porosity with SEM/EDS

To analyse the porosity and chemical composition of the magnesium oxide boards, Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) techniques were employed. The SEM was operated at 30keV. The samples were cut to fit onto 12mm diameter sample holders, as shown in Figure 3-11 and Figure 3-12 Samples for analysis were mounted on an aluminium stub by a double-sided carbon tape. For electrical conductivity, these were gold coated using an argon ion sputter coater. Both the cross-sectional area and the surface of the boards was examined. All five MgO boards and the control fibre cement board (sample E) were examined with SEM/EDS for comparison.

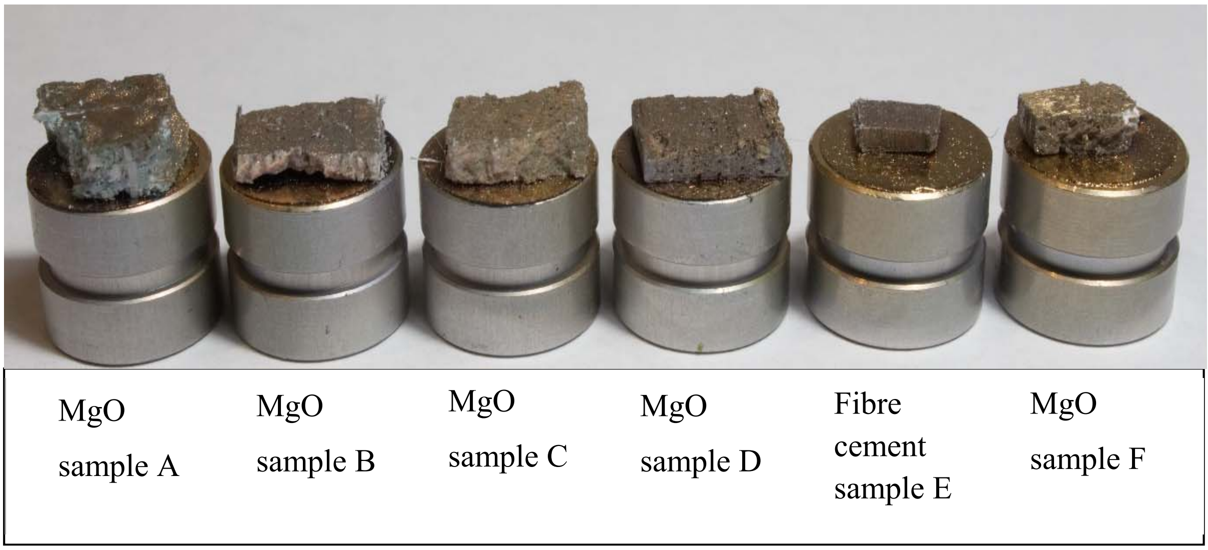


Figure 3-11- SEM cross-sectional analysis samples (shown with gold sputter)

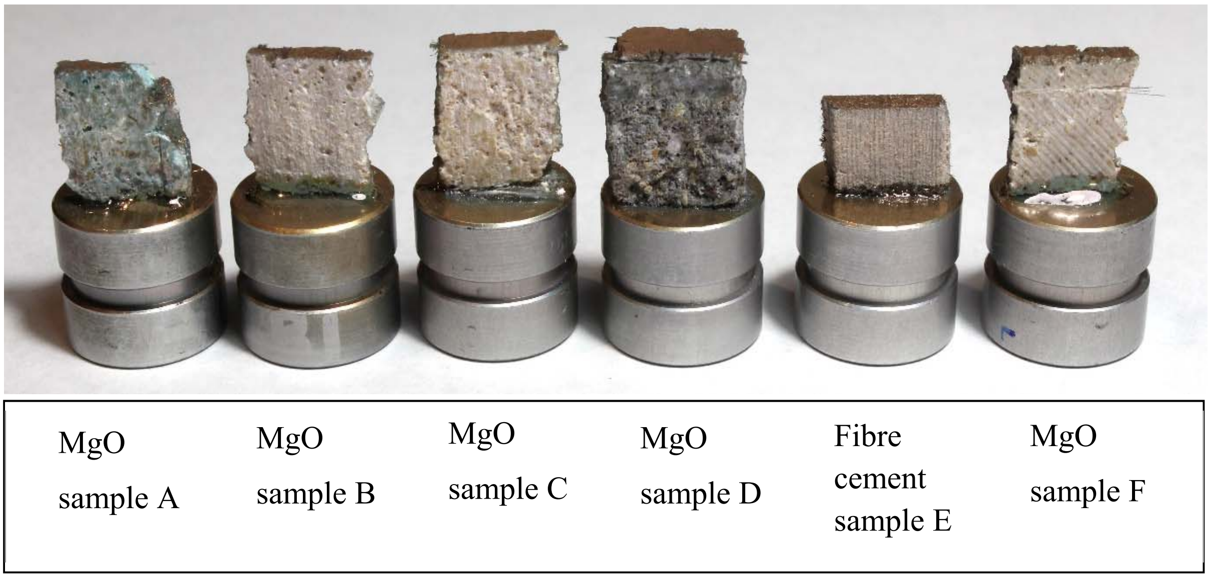


Figure 3-12- SEM surface analysis samples (shown with gold sputter)

3.8 Thermal Analysis

Thermal analysis of samples was conducted to follow moisture absorption characteristics, and determine whether decomposition of the MgO boards occurs during high temperatures. A representative sample of each board was crushed into a powder. About 20 to 50mg of crushed powder were loaded onto an alumina sample pan Figure 3-13. Thermal analysis was conducted using a simultaneous thermal analyser. The thermal scans were conducted using an empty alumina pan as a reference. The instrument was programmed to run the thermal scan from room temperature to 800^0C at the heating rate of $10^0C/min$. During thermal scan, data for differential energy calorimetry (DSC) and mass change (TG) were simultaneously taken. This enabled the following of thermal reactions and the TG gives indication decomposition reactions. The analysis software was used to process and evaluate the collected data.

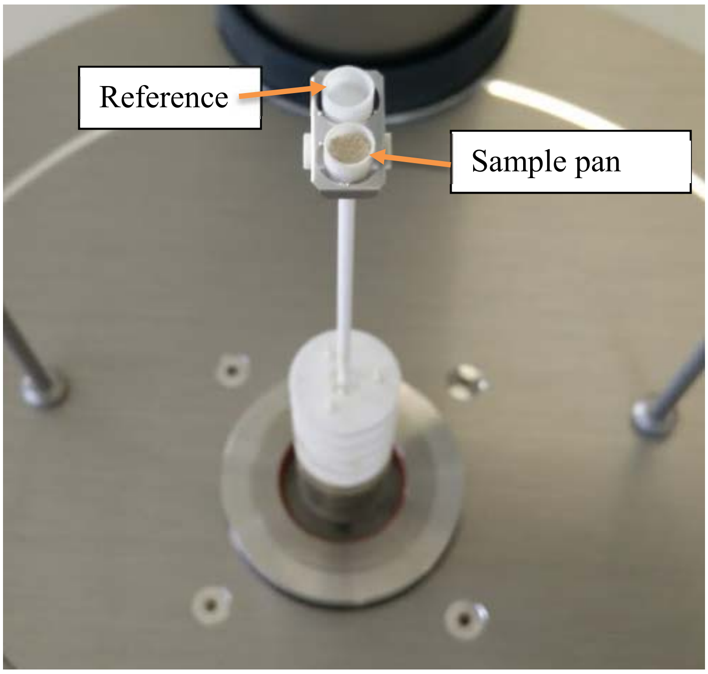


Figure 3-13-STA 449 F3 sample holder

Chapter 5

Results

4. Results

4.1 Water Absorption Analysis

The first test assessed the tendency of the specimens to absorb water. The results of the water immersion analysis for the different boards are given in Figure 4-1, which shows the mass increase due to water immersion and the mass loss due to initial drying of samples.

During the drying process, MgO boards lost significantly more residual water mass compared to the fibre cement board (sample E), as shown in Figure 4-1. On average, MgO boards lost 4% - 8% more water mass than the fibre cement board, which suggests the MgO boards originally contain a higher water content when exposed to standard conditions.

Sample B had the smallest mass decrease from the "as received" state compared to other MgO boards during the drying process, and gained the least through water submersion. This suggests sample B has a lower tendency than the other MgO boards to absorb water. Sample C absorbed significantly more water than other MgO boards, and is the only MgO sample to have a higher mass increase than the cement fibre board (sample E).

Fibre cement samples lost significantly less mass during the drying process, suggesting they absorb less moisture in ambient conditions (as supplied) then magnesium oxide samples. When submersed in water however, the control samples had a larger mass increase than most MgO samples. This is attributed to the large concentration of wood fibres often used in fibre cement boards.

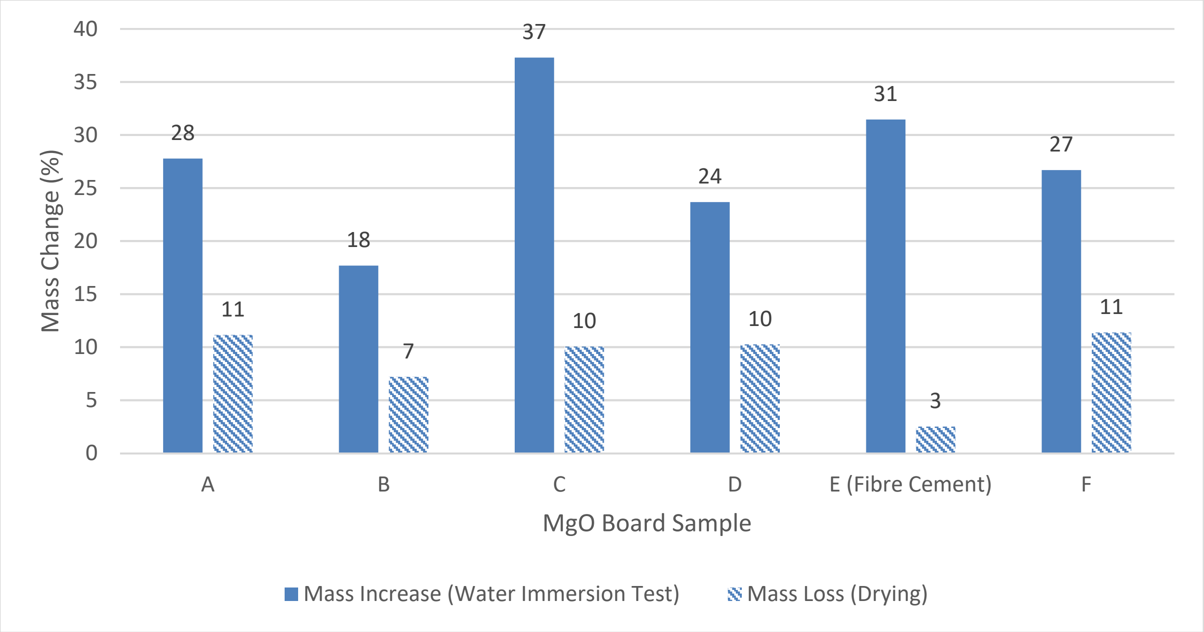


Figure 4-1- Comparison of mass change due to 48-hour water immersion

4.2 Moisture Absorption in Controlled Humidity

This test assessed the tendency of samples to absorb moisture from the surrounding environment in controlled high humidity conditions. To achieve the required relative humidity, saturated salt solutions were used within sealed containers, as per methods described by Rockland (1960). The mass increase due to exposure to high humidity environments was followed periodically throughout experimentation.

The results from the high humidity moisture absorption analysis further show the variability in quality found throughout the MgO board market. The results for moisture absorption for the different boards are presented in in Figure 4-2 and Figure 4-3 for 97% RH and 75% respectively. The boards generally follow the trend of increasing mass over time until saturation is achieved, where samples which achieved saturation excreted leachate, however the absorption rate of the different samples varied.

Sample C had the highest average mass increase in both humidity ranges, however it is evident that significantly more moisture was absorbed in the 97% RH environment compared to the 75% RH environment. Leaching was observed after 20 days of exposure to 97% RH, which was evident by the formation of droplets on the surface of the board (Figure 4-4). Comparing the MgO samples at the different relative humidities shows the influence of RH on the moisture absorption. Figure 4-5 shows that at 75% RH, sample C had a mass increase of 11%, however at 97% RH the mass increase over the same period more than doubled to 26%. This trend is observed in all MgO boards, and shows the tendency of MgO boards to absorb excessive moisture in relative humidities higher than 84%, as shown by Hansen (2016).

Sample D also experienced significant mass increase compared to other samples exposed to 97% RH. Leaching was observed on sample D after 41 days of exposure. Figure 4-2 shows that after 41 days of exposure, both sample C and D had an average mass increase of approximately 26%, however the rate of moisture absorption was initially significantly higher in MgO sample C. After 20 days exposure, sample C and sample D observed mass increases of 24% and 17 % respectively, showing the variation in the rate of absorption. This suggests that sample C achieves saturation, and therefore leaching, much faster than other MgO boards and therefore is more prone to failures relating to dampness and corrosion.

Sample B and A experienced moderate mass increase when exposed to 97% RH. The samples still followed the trend of increasing mass with increasing relative humidity, where both MgO products absorbed twice as much moisture at 97% RH than at 75% RH. Due to the decreased moisture absorption compared to other MgO boards, no leaching was observed from either sample. Based on this, these board are less likely to cause damages relating to dampness.

Sample F had the smallest mass increase compared to other MgO boards when exposed to the high humidity environments, and performed similarly to the cement fibre board (sample E). Very low variability between Sample F specimens compared to other MgO boards was also observed, which may be attributed to a more uniform board structure and composition. No leaching was observed during testing.

Based on the above findings, MgO Sample F has the best performance when exposed to high humidity environments, and in terms of moisture absorption, is similar in performance to regular fibre cement board.

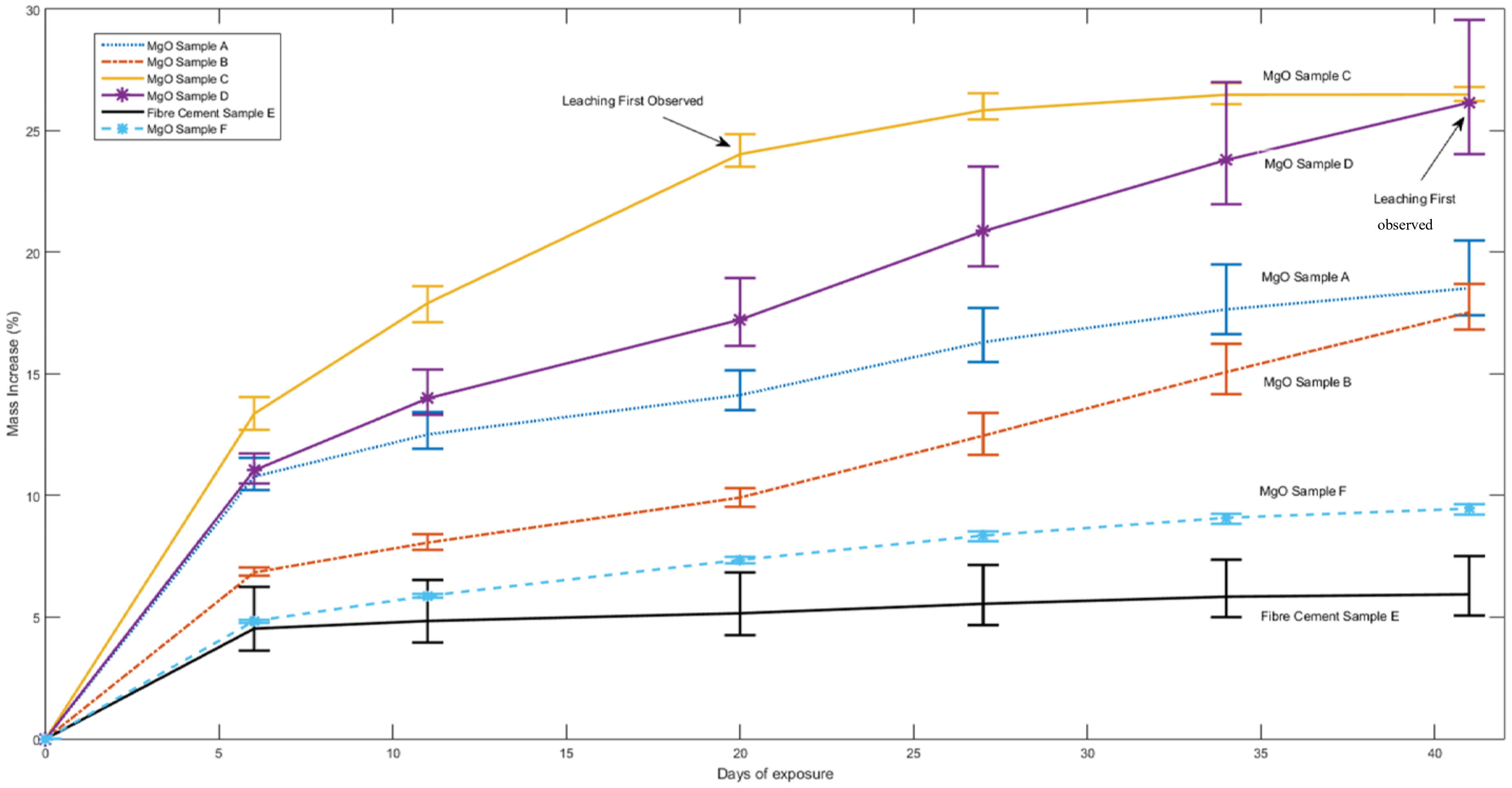


Figure 4-2- Moisture absorption at 97% RH

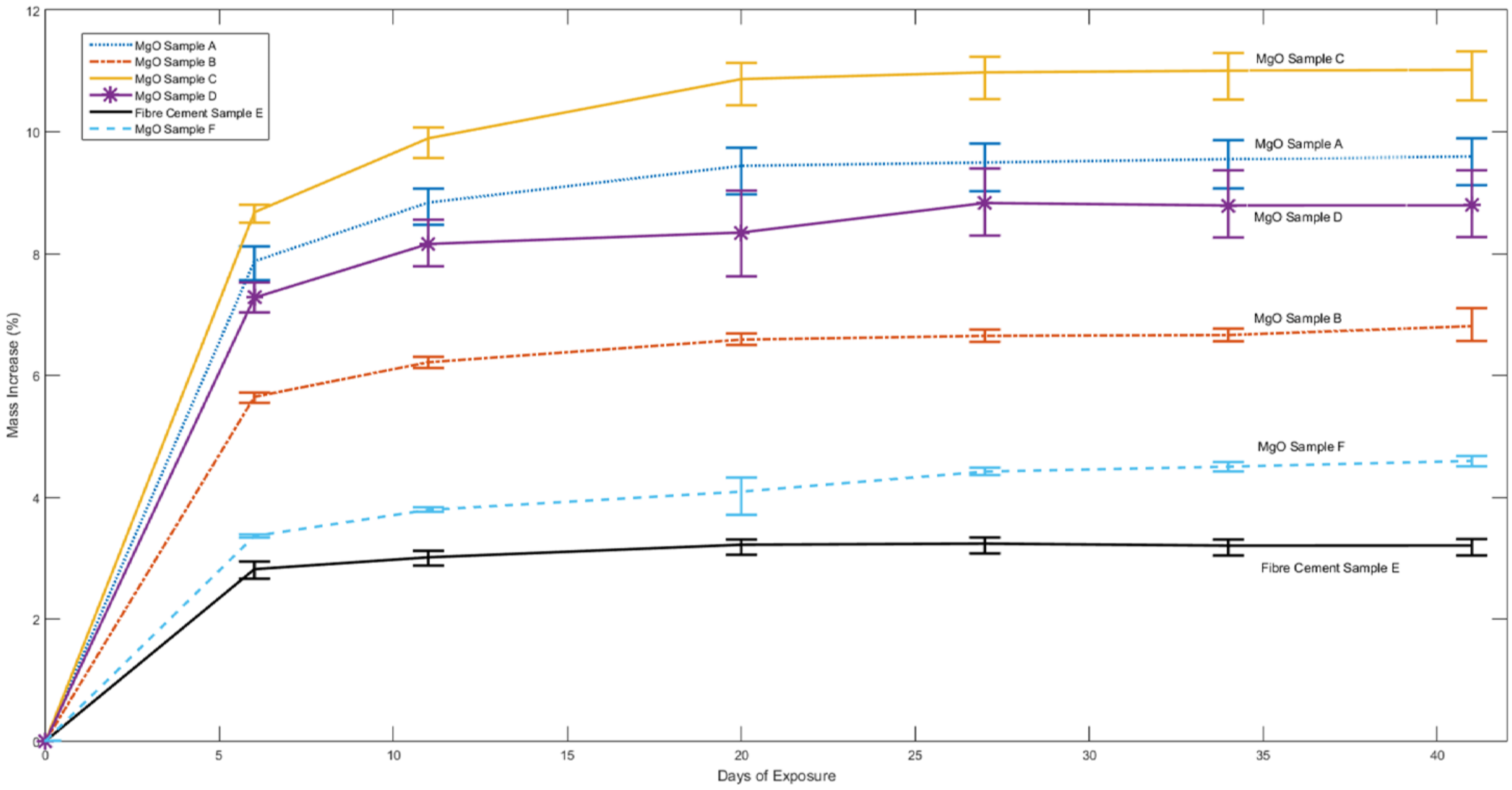


Figure 4-3-Moisture absorption at 75% RH

Figure 4-4- Evidence of leachate on sample C

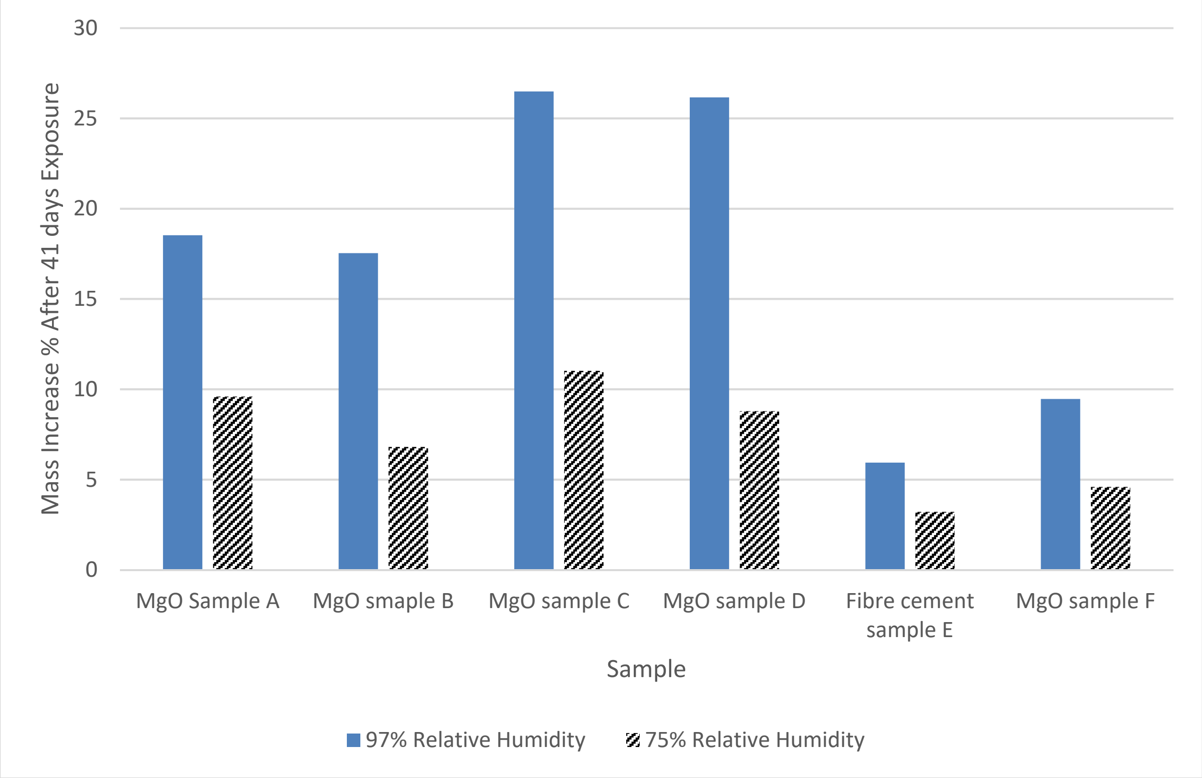


Figure 4-5- Effects of relative humidity on moisture absorption

4.3 Analysis of Board Composition and Porosity with SEM/EDS

Since the corrosive behaviour related with MgO boards has been associated with the presence of magnesium oxychloride, the intention of the energy dispersive x-ray spectroscopy (EDS) analysis was to probe the different samples for the presence of chloride ions and evaluate the concentrations present in the samples. The EDS probes were taken both for the surface of the sample, and the sample's cross-section. The elemental analysis of sample compositions is presented in Table 4-1 (cross sectional analysis) and Table 4-2 (surface analysis).

The cross-sectional analysis presented in Table 4-1 shows that all MgO samples other than MgO sample F contained chloride. Chloride was detected in samples B, C and D, which suggests these samples are more likely to lead to the corrosion of metals in contact with the MgO boards due to the corrosive nature of chloride. Chloride was not detected on the surface analysis of sample A, however was detected during the cross-sectional analysis. This suggests sample A may contain trace amounts of chloride, which may lead to accelerated corrosion of contacting metal fixtures, however the effects of corrosion may be less significant than MgO sample B, C, and D. Typical for a fibre cement board, no chloride was detected in the composition of sample E when analysed using EDS.

Calcium was detected during the surface analysis (Table 4-2) on many MgO samples. The SEM for sample D showing significant formations is shown in Figure 4-6, where the formations are scattered across the sample surface. It is shown that the formations are calcium rich in the EDS probe analysis (Figure 4-7), whereas the general surface of the sample contains no or trace amounts of calcium.

Table 4-1- Comparison of cross-sectional sample compositions using EDS

	Sample					
Composition mass %	A	B	C	D	E (Fibre Cement)	F
O	55.97	53.84	57.15	48.07	51.55	52.92
Mg	39.46	31.58	34.58	37.68	-	41.27
Al	-	-	-	-	2.44	
Si	-	-	-	-	26.97	1.81
Cl	4.57	11.32	8.27	14.25	-	-
Ca	-	3.25	-	-	19.05	3.99

Table 4-2- Comparison of surface sample compositions using EDS

	Sample					
Composition mass %	A	B	C	D	E (Fibre Cement)	F
O	55.66	41.63	55.96	45.26	52.56	44.54
MG	40.25	41.58	24.87	27.48	-	47.97
SI	-	-	-	-	29.47	-
CL	-	16.79	4.06	7.62	-	-
CA	4.09	-	15.11	19.64	17.97	7.5

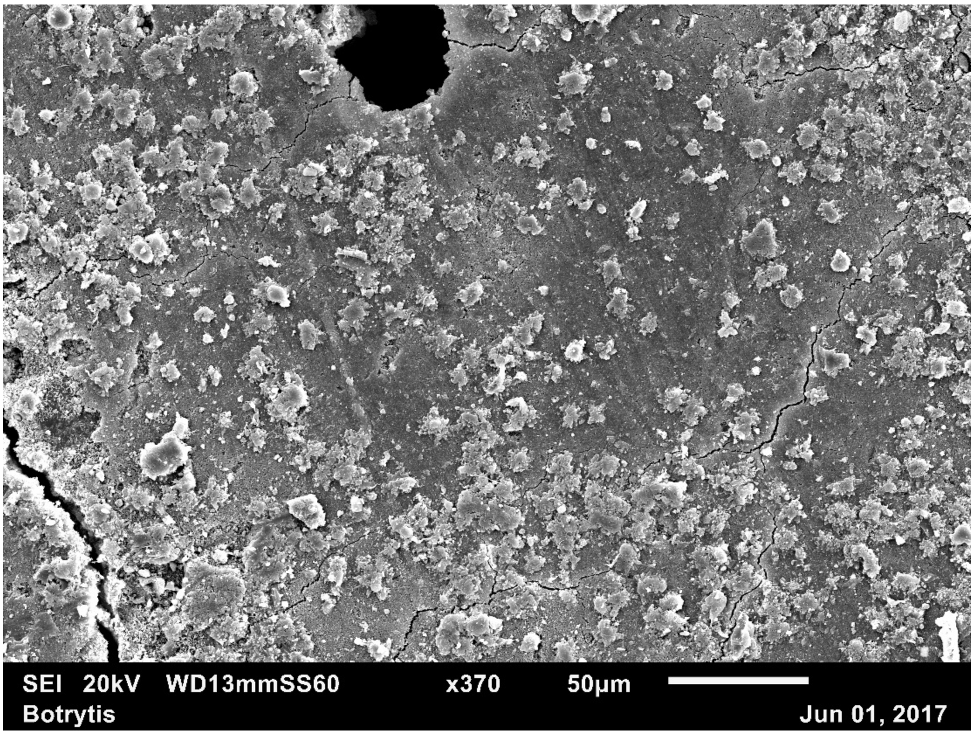


Figure 4-6- Calcium-Oxide present on sample D surface analysis

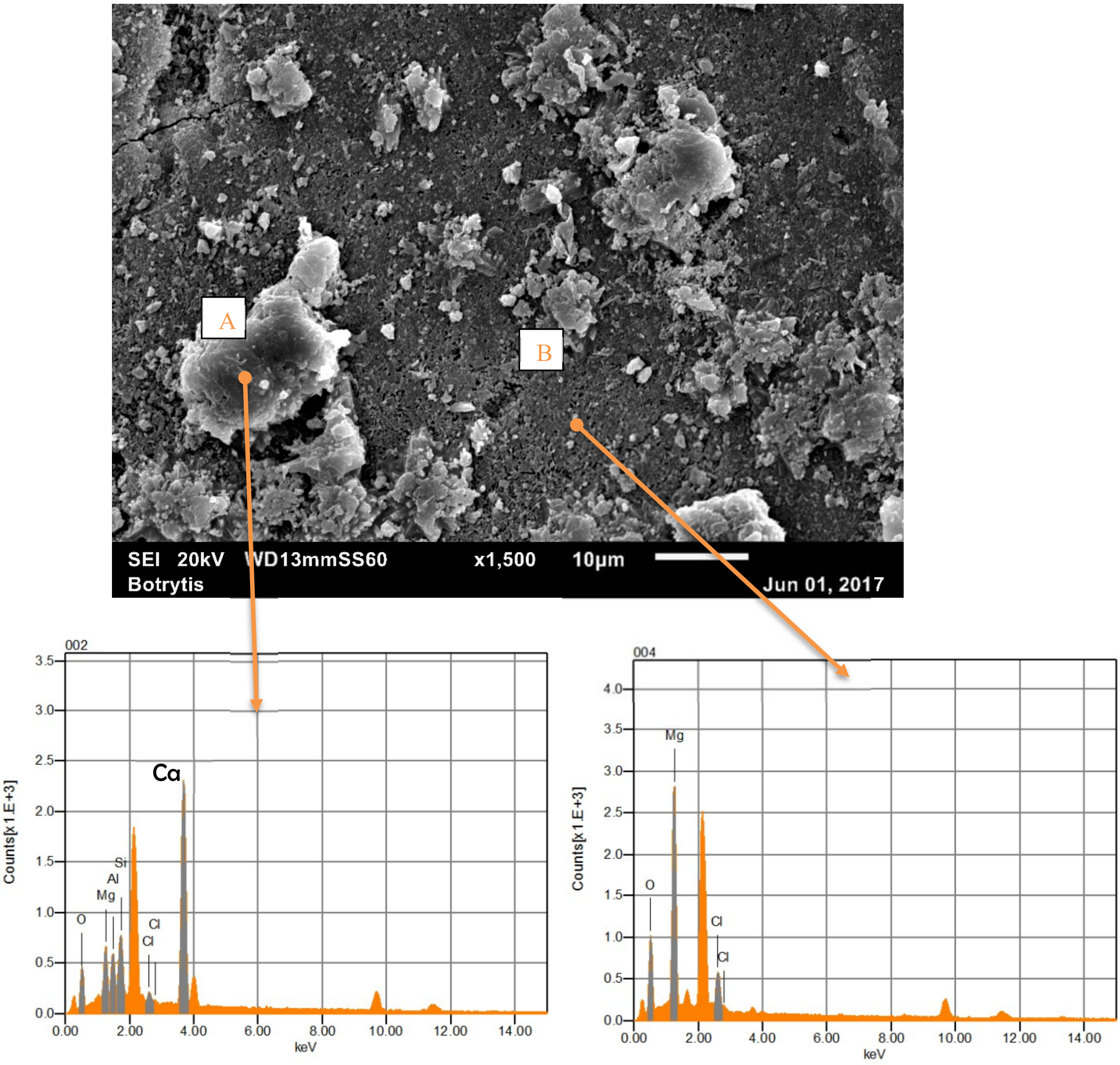


Figure 4-7- EDS surface analysis of sample D, showing calcium oxide (point A) present on the surface

Porous sections were observed in many MgO samples during cross-sectional analysis. Sample A, B, and C show a porous material surface, evidenced in Figure 4-9, which is likely to absorb and hold a higher water content. Sample F shows a smoother cross-sectional surface, similar to the fibre cement board (sample E). Sample D appears nonporous, with imperfections which may be attributed to contamination.

Many of the porous sections observed in MgO samples can be attributed to perlite used as a filler in the material composition, which is introduced to increase the fire resistance of the boards. This is supported by Table 4-3, which shows the composition of perlite, which when compared to the SEM/EDS analysis of the samples shown in Figure 4-8, demonstrates the presence of perlite.

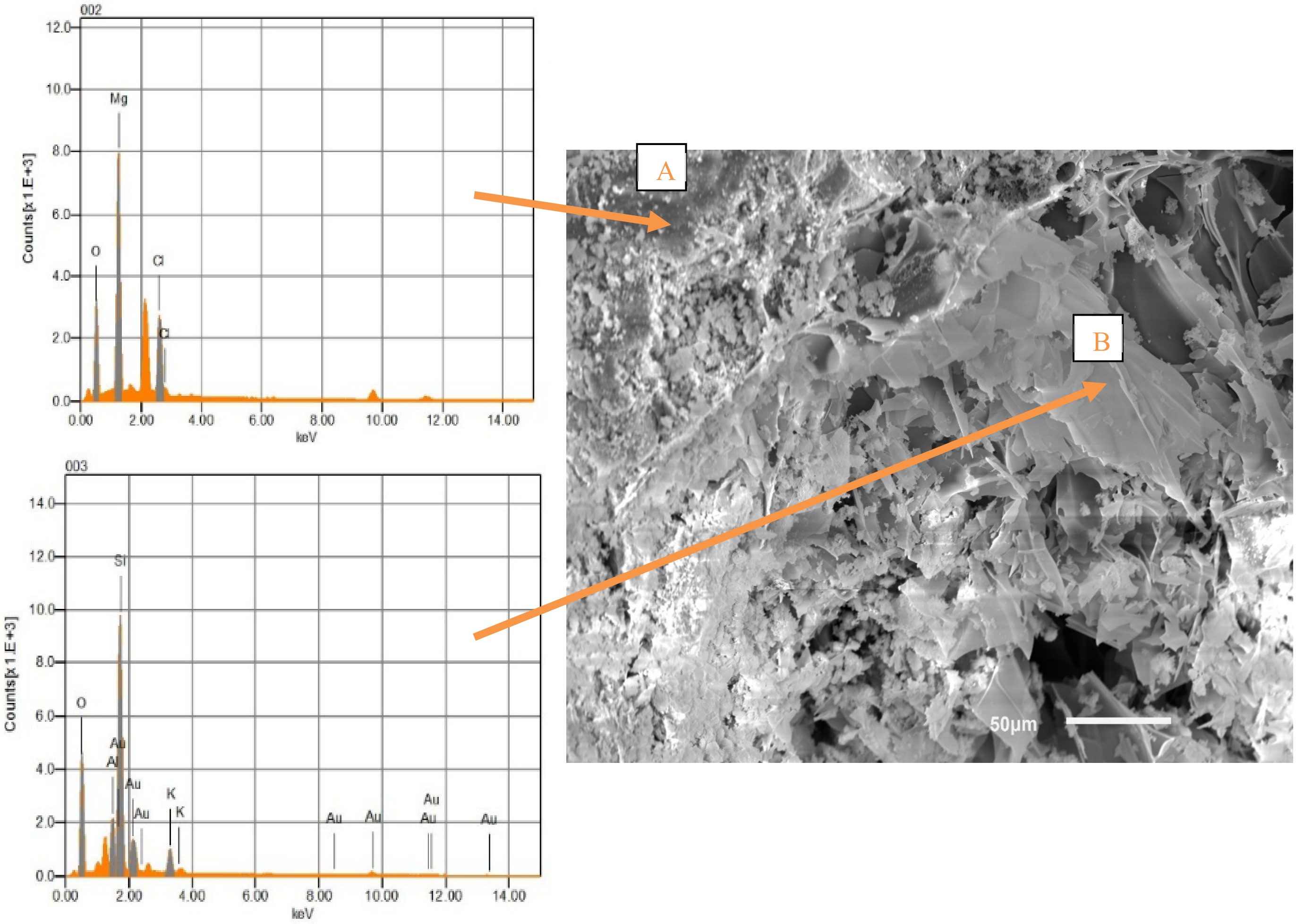


Figure 4-8- EDS analysis of sample B, showing the presence of perlite (point B) within the MgO structure (point A)

Table 4-3- Typical composition of Perlite (Samar & Saxena 2016)

Element	*Silicon (Si)*	*Aluminium (Al)*	*Potassium (K)*	*Sodium (Na)*	*Iron (Fe)*	*Calcium (Ca)*	*Magnesium (Mg)*	*Mica*	*Oxygen (O)*
Composition %	33.8	7.2	3.5	3.4	0.6	0.6	0.2	0.2	47.5

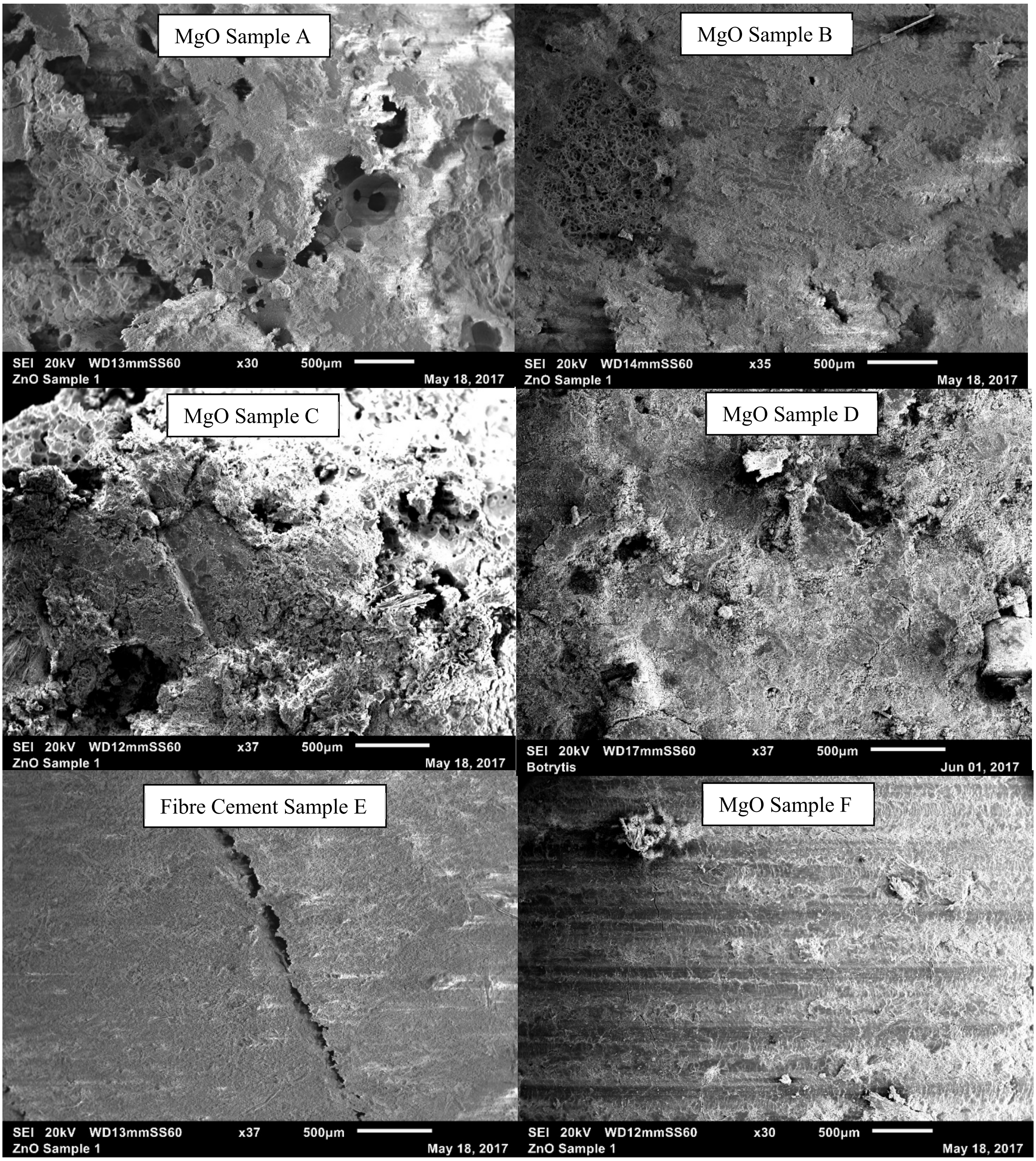


Figure 4-9- Cross section analysis of the different boards using SEM

4.4 Thermal Analysis

Figure 4-11 shows the typical thermogram observed for MgO boards during thermal analysis. The thermogram shows a relatively constant mass decrease until approximately 360ºC, which is attributed to evaporation of residual water from the sample. After 360ºC, the rate of mass loss increases significantly, which is shown by the differential mass loss (DTG). Peaks in DSC coinciding with accelerated weight loss suggest decomposition of the samples, which was attributed to structural water loss. This decomposition can be observed in all samples (Figure 4-10), however is much less significant in the fibre cement sample (sample E). The decomposition of structural water hydration has implications for the structural integrity of the boards at high temperatures or when exposed to fire.

In order to verify that DSC and TG thermal event is due to structural water release, a sample of MgO board was heated in an oven at 500ºC for 24 hours. Figure 4-14 shows the picture of sample C after such thermal treatment. The crumbling evidenced after the heat treatment is attributed to the loss of structural water, a key mechanism of the cementation process for rigidity of cement solids.

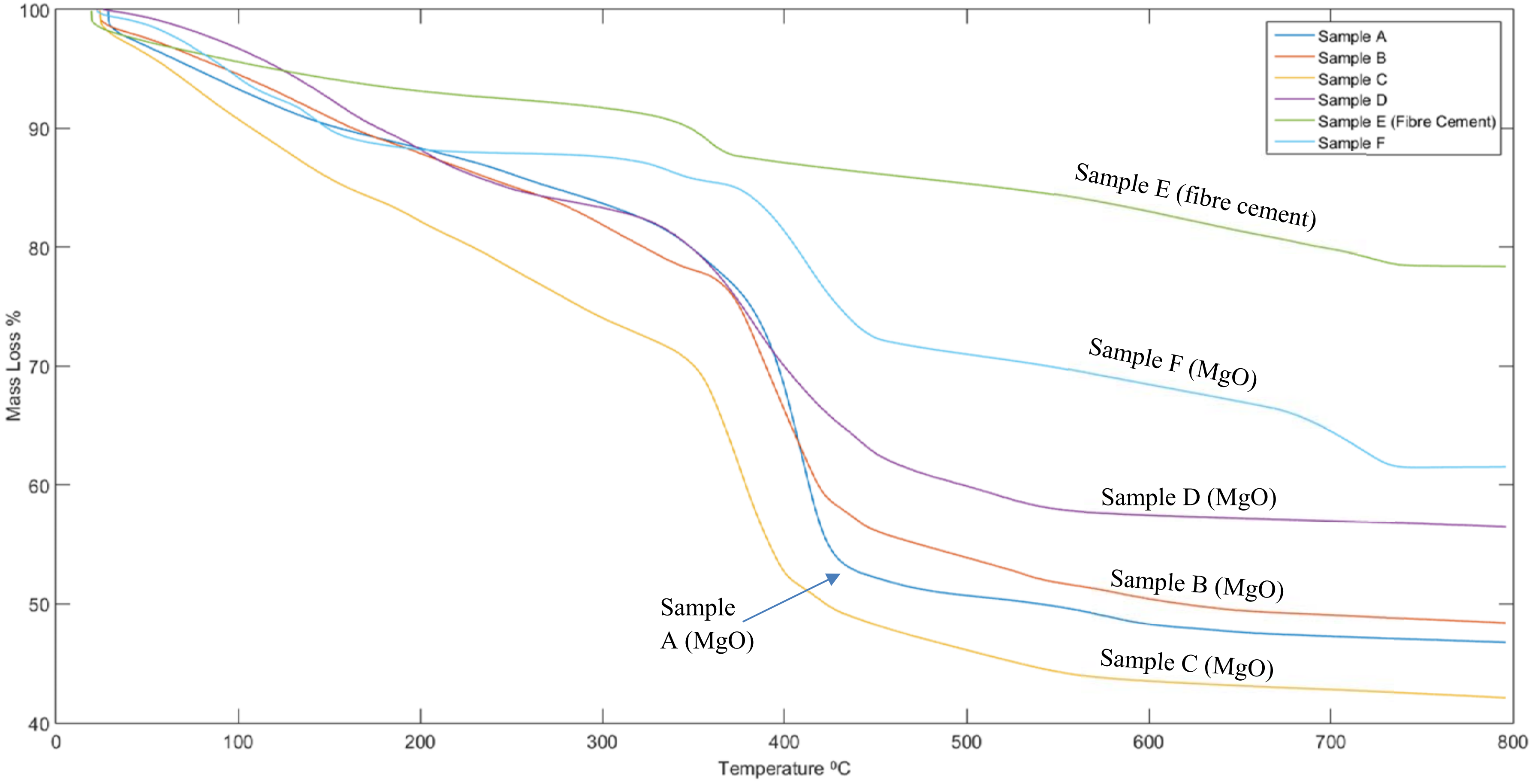


Figure 4-10- Thermogram comparing mass loss during thermal analysis

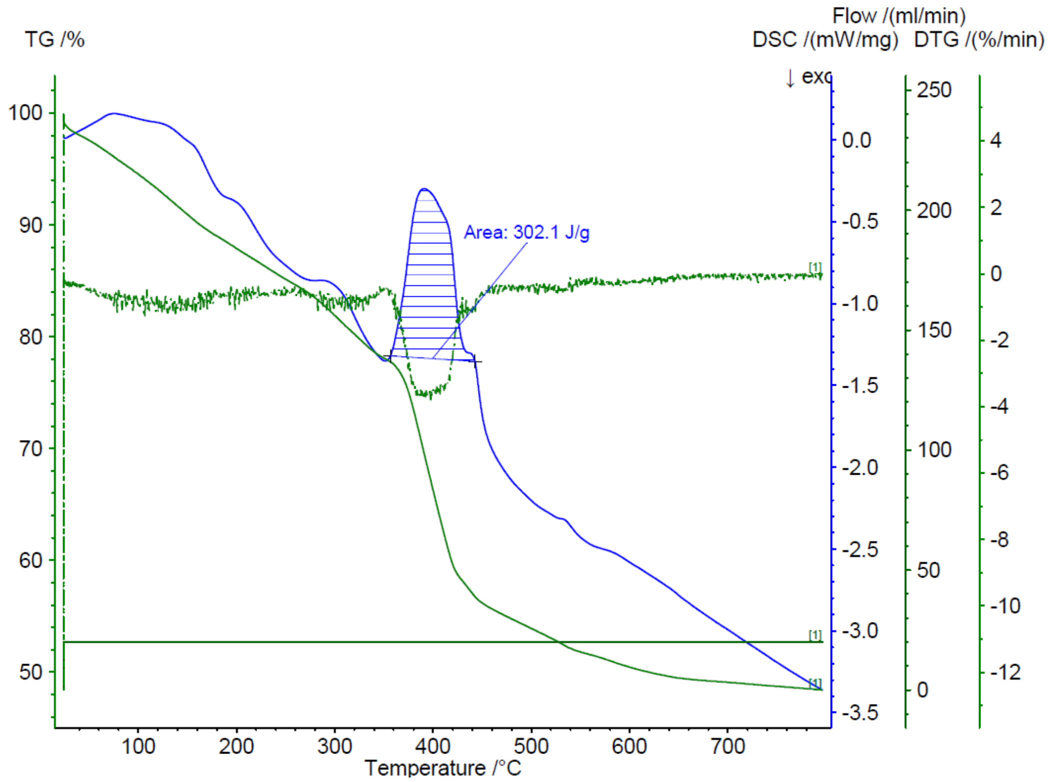


Figure 4-11- Thermal analysis showing DSC for MgO sample B

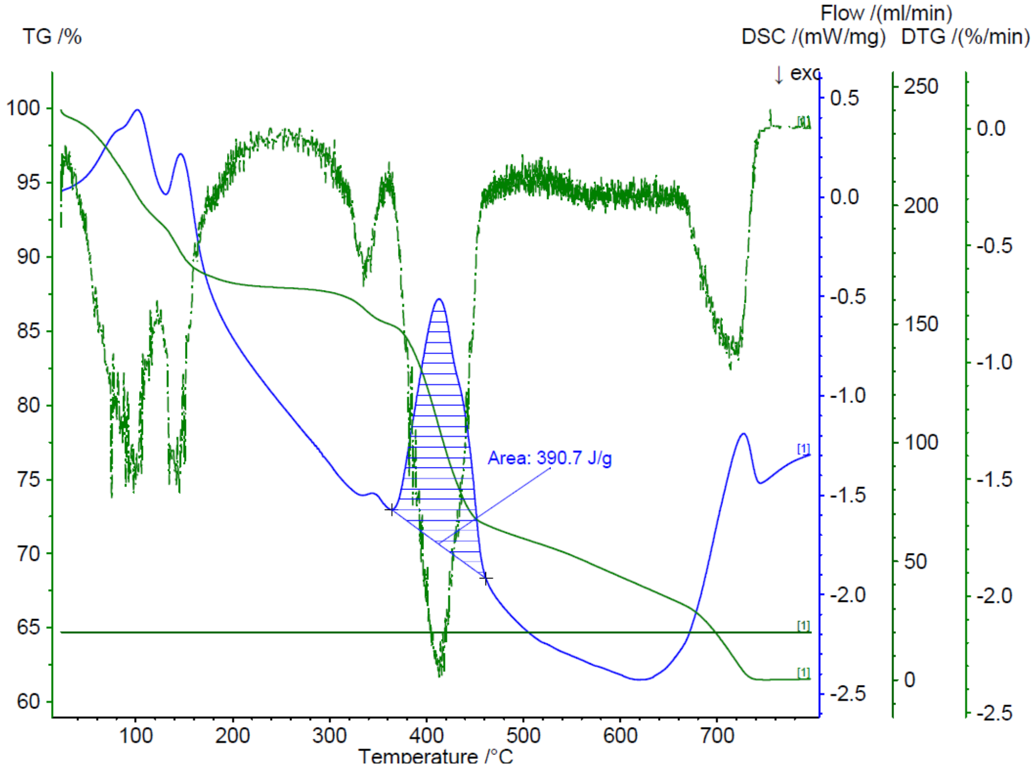


Figure 4-12- Thermal analysis showing DSC for MgO sample F

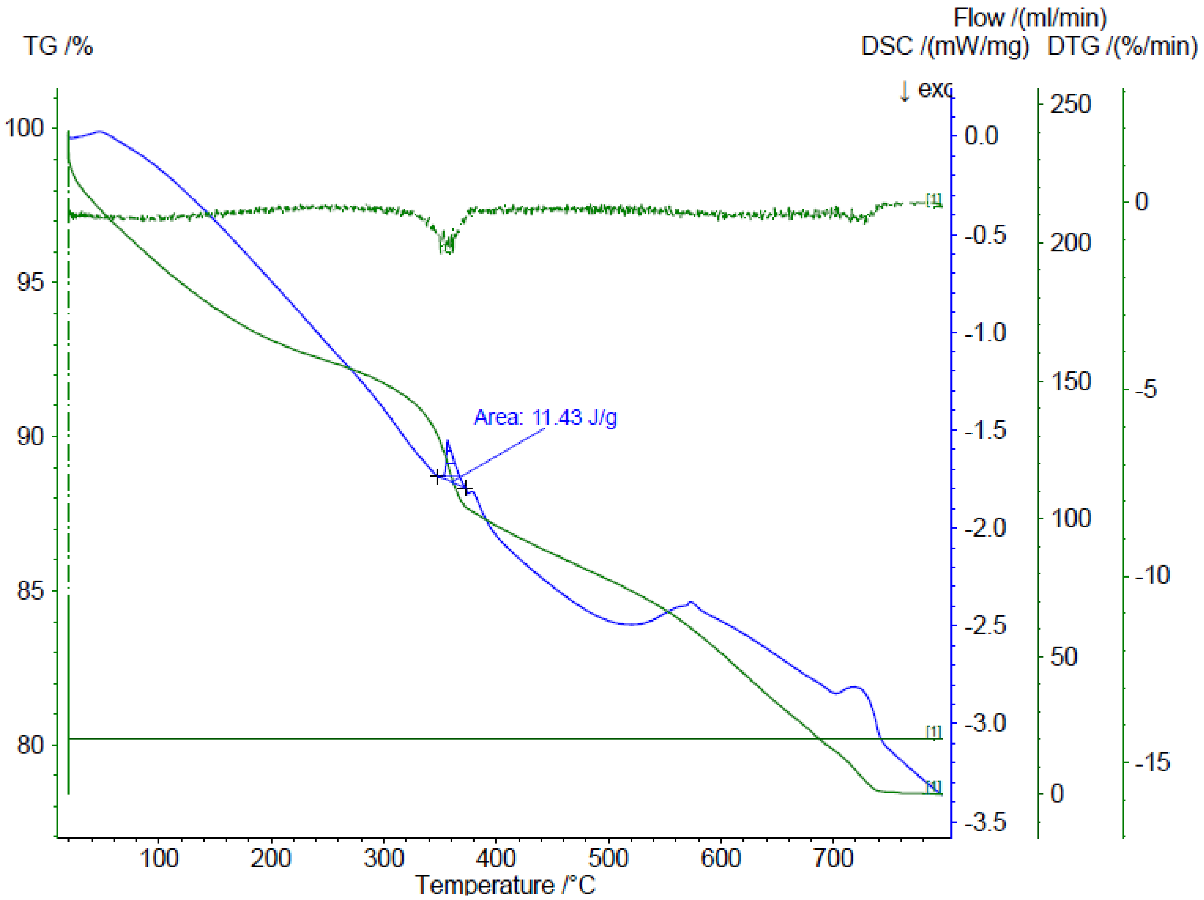


Figure 4-13- Thermal analysis showing DSC for fibre cement sample E

Figure 4-14- MgO sample C after 24 hours at 500ºC

4.5 Fastener Corrosion

The resulting level of corrosion for the different fastener types and for different boards are summarised in Table 4-4. Many conclusions regarding the use of fasteners in MgO boards and the corrosiveness of MgO boards can be established based on this.

From Table 4-4 it is evident that zinc coated fasteners (screw D) are not suitable for MgO board installations due to their low corrosion resistance. Zinc fasteners corroded severely in MgO sample B, and mildly in sample A. The results demonstrate the only fastener types suitable for the installation of MgO boards based on corrosion resistance are 316 stainless steel (Screw F) and 304 stainless steel (Screw E) as no corrosion was present when used in conjunction with any MgO board analysed. Figure 4-15 demonstrates the corrosion resistance of 316 and 304 stainless steel fasteners, as other fastener types corroded heavily when used in conjunction with sample B, whereas 316 and 304 fasteners displayed no signs of corrosion other than residue of corrosion of the steel section due to sample B leaching.

A comparison of 316 stainless steel fasteners and zinc coated fasteners in MgO sample B fastened to the steel section is shown in Figure 4-16. Severe corrosion was evident on the zinc coated fastener, particularly on the underside of the fastener head contacting the MgO board. Using SEM/EDS techniques, chloride was detected throughout the corroded areas, shown in Figure 4-17. The strong presence of chloride throughout the corrosion products indicates the corrosive attack was aided by the presence of chloride. 316 stainless steel fasteners however showed no signs of corrosion. Figure 4-18 shows the SEM/EDS analysis of 316 stainless steel, analysed on the underside of the fastener head contacting with the MgO board, which provides no evidence of corrosion or chloride. This demonstrates the corrosion resistance of 316 stainless steel against chloride induced corrosion.

Table 4-4- Fastener corrosion analysis

With Steel Section				Without Steel Section			
Board Sample	**Screw Sample**	**Screw Type**	**Corrosion**	**Board Sample**	**Screw Sample**	**Screw Type**	**Corrosion**
A	A	Gold Passivated	-	A	A	Gold Passivated	Mild
	B	Galvanized	-		B	Galvanized	-
	C	Galvanized	-		C	Galvanized	-
	D	Zinc Coated	-		D	Zinc Coated	Mild
	E	304 Stainless Steel	-		E	304 Stainless Steel	-
	F	316 Stainless Steel	-		F	316 Stainless Steel	-
B	A	Gold Passivated	Severe	B	A	Gold Passivated	Moderate
	B	Galvanized	Severe		B	Galvanized	Moderate
	C	Galvanized	Severe		C	Galvanized	Moderate
	D	Zinc Coated	Severe		D	Zinc Coated	Moderate
	E	304 Stainless Steel	-		E	304 Stainless Steel	-
	F	316 Stainless Steel	-		F	316 Stainless Steel	-
E	A	Gold Passivated	-	E	A	Gold Passivated	-
	B	Galvanized	-		B	Galvanized	-
	C	Galvanized	-		C	Galvanized	-
	D	Zinc Coated	-		D	Zinc Coated	-
	E	304 Stainless Steel	-		E	304 Stainless Steel	-
	F	316 Stainless Steel	-		F	316 Stainless Steel	-
F	A	Gold Passivated	-	F	A	Gold Passivated	-
	B	Galvanized	-		B	Galvanized	-
	C	Galvanized	-		C	Galvanized	-
	D	Zinc Coated	-		D	Zinc Coated	-
	E	304 Stainless Steel	N/A		E	304 Stainless Steel	-
	F	316 Stainless Steel	-		F	316 Stainless Steel	-

No corrosion	No corrosion	Severe corrosion	Severe corrosion	Severe corrosion	Severe corrosion

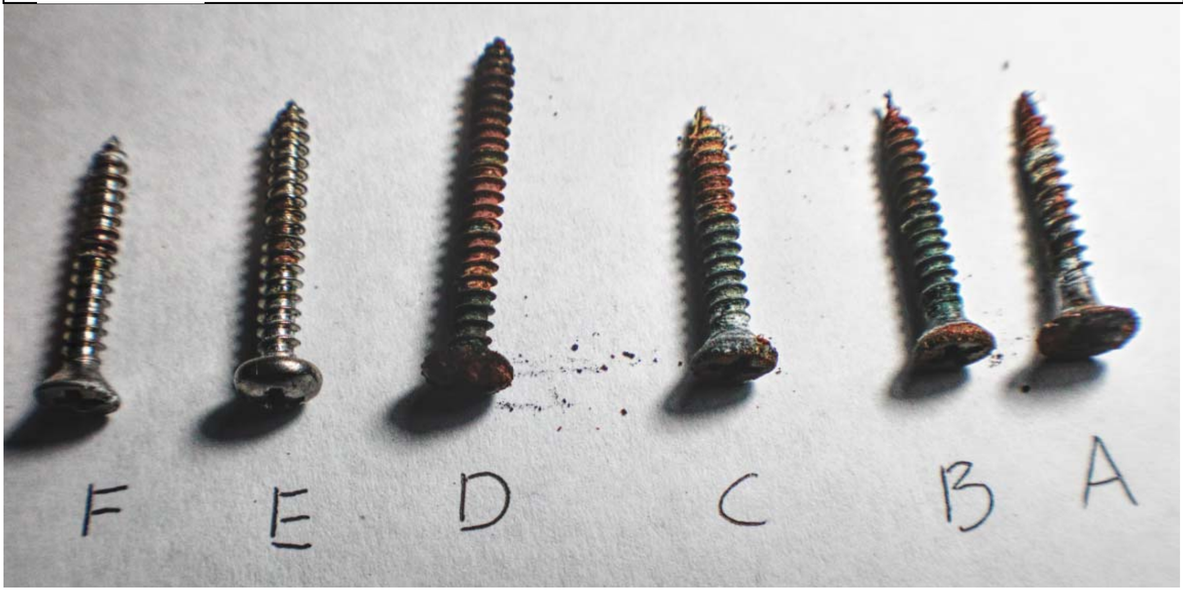


Figure 4-15-Screw sample after exposure to corrosion analysis (steel fixed MgO sample B)

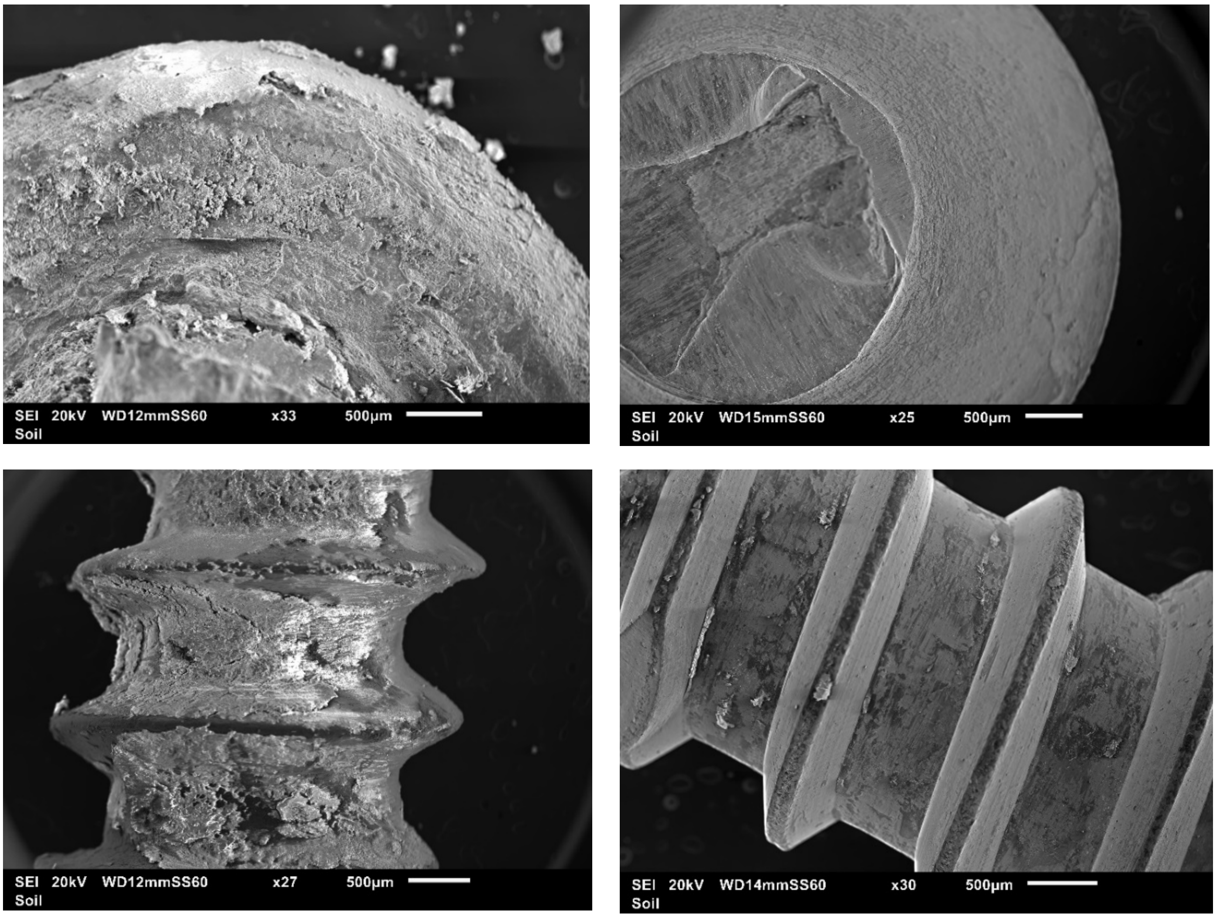


Figure 4-16- Zinc coated screw (top left and bottom left Vs 316 stainless steel screw (top right and bottom right) of MgO sample B (steel)

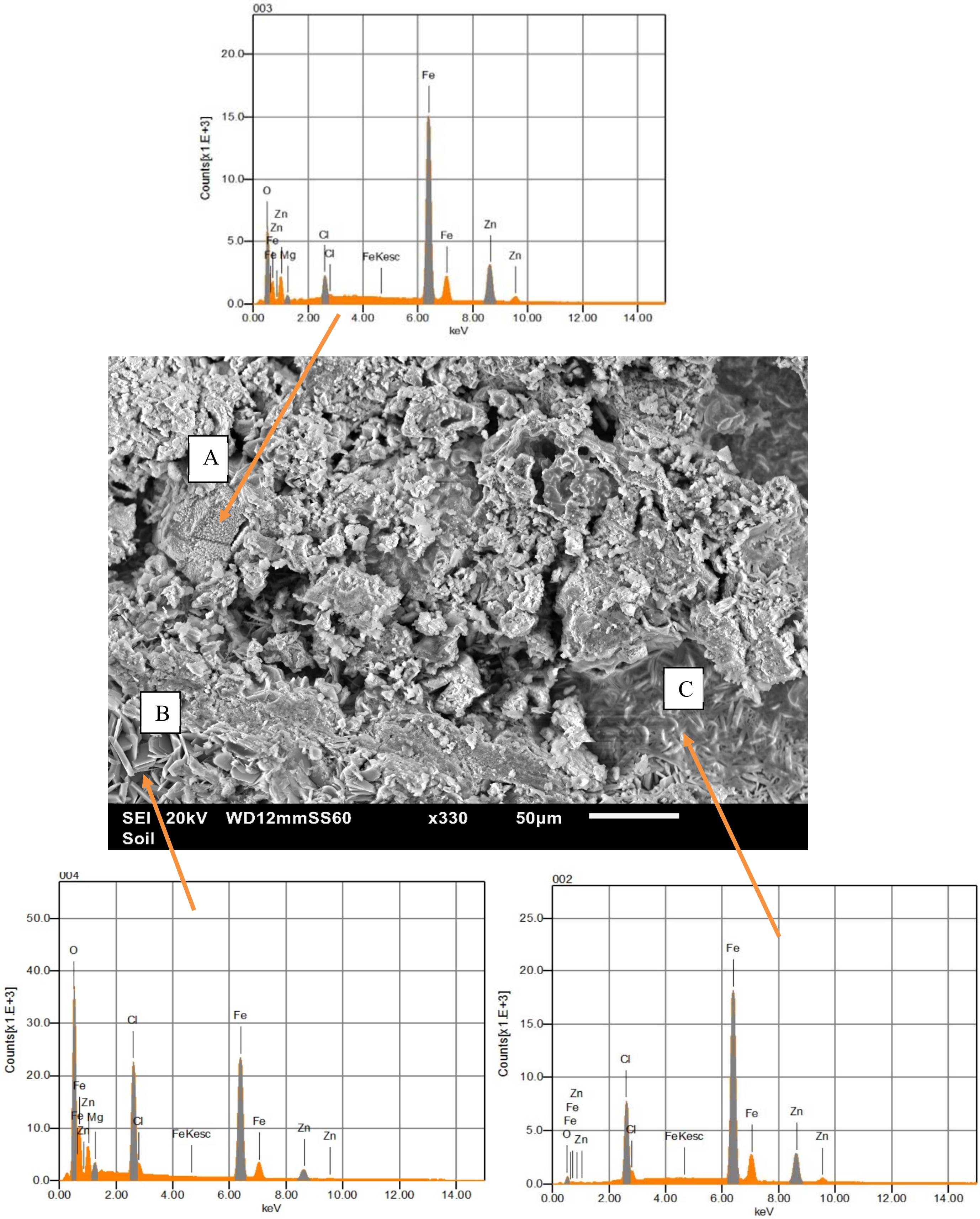
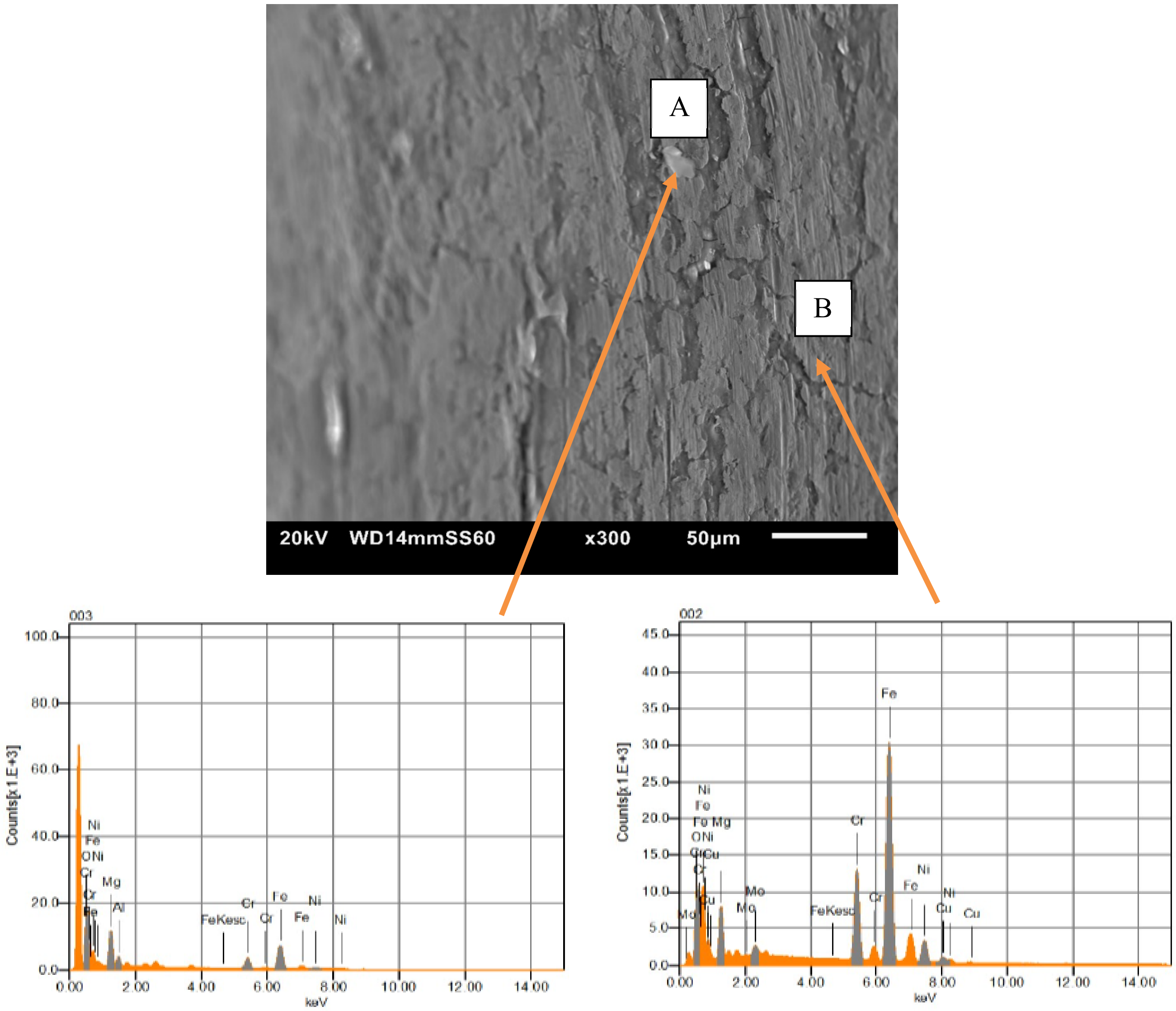


Figure 4-17- SEM/EDS analysis of corroded section of zinc coated screw in MgO sample B (steel) showing the presence of chloride



Chemical formula		mass%	Atom%	Sigma	Net	K ratio	Line
O	27.73	49.59	0.04	382917	0.5874665		K
Mg	16.48	19.39	0.05	335415	0.1683517		K
Al	3.95	4.18	0.03	91935	0.0452678		K
Cr	10.45	5.75	0.04	205134	0.3006803		K
Fe	36.21	18.55	0.06	489308	0.9614109		K
Ni	5.19	2.53	0.04	48108	0.1329306		K
Total	100.00	100.00					

Chemical formula		mass%	Atom%	Sigma	Net	K ratio	Line
O	5.74	16.60	0.01	187913	0.3061151		K
Mg	5.15	9.82	0.02	218348	0.1163684		K
Cr	15.43	13.74	0.03	805729	1.2540249		K
Fe	59.92	49.68	0.05	2102969	4.3874226		K
Ni	9.37	7.39	0.03	219722	0.6446658		K
Cu	2.61	1.90	0.03	51141	0.1743242		K
Mo	1.79	0.86	0.02	76763	0.0847996		L
Total	100.00	100.00					

Figure 4-18-SEM/EDS analysis of 316 stainless steel fastener in MgO sample B

The leaching excreted by sample B significantly accelerated the corrosion of fasteners. Leaching was evident on MgO sample B fastened to the steel section, but was not evident on the standalone MgO sample B. A comparison of the effects of leaching on the corrosion rate is shown in Figure 4-19, which shows leaching resulted in significantly accelerated corrosion. This is attributed to the presence of chloride.

The effects of leachate on steel section can be shown in Figure 4-20. MgO sample B excreted leachate during testing, which flowed down onto the contacting steel section. Due to the presence of chloride in the leachate, severe corrosion of the steel section occurred.

Figure 4-19- Comparison of gold passivated fastener corrosion from MgO sample B (steel) leaching (left) and MgO sample B with no leaching (right)

Figure 4-20-Corrosion of steel section due to leachate

Although stainless steel fasteners resisted corrosion when used in conjunction with all MgO boards analysed, the use of other fastener types may be suitable for less corrosive boards. A comparison of the zinc coated fastener in MgO sample B and MgO sample F is shown in Figure 4-21, where severe corrosion is evident on the fastener contacting MgO sample B, however no corrosion was evident on the fastener contacting MgO sample F. This is demonstrated in the SEM/EDS analysis shown in Figure 4-22, which shows no chloride was detected on the sample fastened to MgO sample F, and high concentrations of chloride were detected on the fastener in MgO sample C. The large concentrations of zinc evident on the surface of the MgO sample

F fastener suggest the zinc coating is largely intact, however the large concentrations of iron detected on the surface of the MgO sample B fastener suggest the zinc coating is largely removed, a consequence of corrosion.

Figure 4-21- Comparison of corrosion of zinc coated fasteners in MgO board F (steel) (left) and MgO board B (steel) (right)

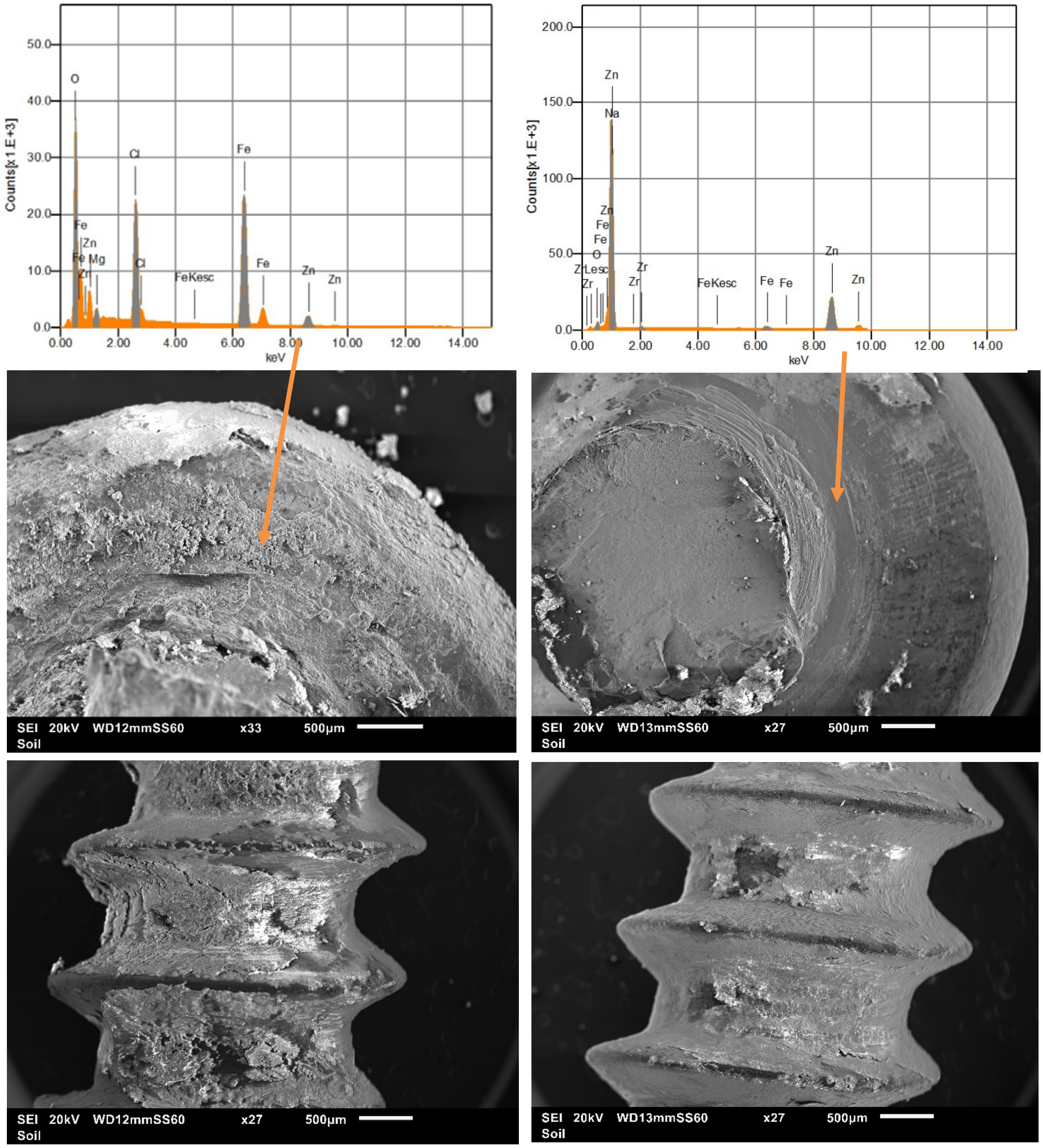


Figure 4-22- Comparison of zinc coated screw (Screw D) in MgO sample B (steel) (left top and bottom) and in MgO sample F (steel) (right top and bottom)

Chapter 6

Discussion

5. Discussion

The results obtained during experimentation show the significant variation of quality which can be seen throughout the MgO board market. Some boards analysed may not be suitable for all applications and their use should be considered.

Through the different studies conducted, it is evident MgO sample F performs most similarly to fibre cement board in terms of moisture absorption and corrosion acceleration. This is attributed to an apparent difference in composition compared to other MgO samples examined. Through SEM/EDS analyse techniques in Section 3.7, it was found the composition did not include chloride, and hence unlikely to contain magnesium oxychloride. This is affirmed in the moisture absorption analysis, as MgO sample F absorbed significantly less moisture than other MgO samples, and was comparable to the fibre cement sample (sample E), attributed to the absence of magnesium oxychloride in the composition. The absence of magnesium oxychloride resulted in significantly better corrosion resistance than other MgO boards, with all fasteners examined in sample F displaying no corrosion.

MgO sample A lead only to mild corrosion of the gold passivated and zinc coated fasteners during fastener corrosion analysis. This was attributed to lower concentrations of chloride found in the board, evidenced through SEM/EDS analysis in Section 4.3. The presence of chloride in the composition suggests corrosion of contacting metals such as steel sections may occur over extended time periods, or should the boards leach chloride when the board is wetted. During the duration of experimentation, no evidence of leaching was observed, however significant moisture absorption still occurred, which created a suitable environment for mild chloride induced corrosion.

MgO sample B, C, and D are all likely to lead to accelerated corrosion of contacting metal fixtures. The boards absorbed significantly more moisture during higher humidity moisture absorption analysis, and were observed leaching during either high humidity analysis or corrosion analysis, attributed to the presence of magnesium oxychloride. Drying of magnesium oxychloride cement does not occur in relative humidity's above 32% (Nürnberger 2001) allowing corrosion to be promoted in relatively low humidity environments. During the fastener corrosion analysis, severe corrosion was observed due to chloride present in the leachate excreted from MgO sample B. As MgO sample C and D both observed higher moisture absorption rates than MgO sample B, leading to leaching, they are likely to cause a similar degree of corrosion. Leaching will also lead to corrosion of any contacting metals, such as steel sections. The high corrosion and leaching susceptibility of MgO boards B, C, and D may render the boards unsuitable for use as a construction material, particularly in environments with a high relative humidity.

316 and 304 stainless steel fasteners were unaffected by corrosion when used in conjunction with all tested MgO board samples. When using MgO board samples containing magnesium oxychloride, stainless steel fasteners should be used to avoid corrosion. When using MgO boards that do not contain magnesium oxychloride, lower grade fasteners, such as galvanised, may be suitable.

The effects of magnesium oxychloride correlate with findings in literature. As found in Section 2.2.1, magnesium oxychloride is a hygroscopic material. The SEM/EDS analysis (Section 4.3) found all MgO boards other than MgO sample F contained chloride, which would be introduced as magnesium oxychloride into the composition. The high humidity analysis (Section 4.2) showed MgO sample F performed similarly to fibre cement sheeting, whilst other MgO boards absorbed significantly more moisture than the fibre cement board, which ultimately lead to the leaching and corrosion. Based on these results, damages due to dampness of the boards may be attributed to the presence of magnesium oxychloride and its hygroscopic nature. Damages due to corrosion may also be attributed to magnesium oxychloride, as chloride present in the leachate after excessive moisture absorption is an aggressive corrosion accelerate for many metals such as steel.

Chapter 7

Conclusions and Future Work

6. Conclusions and Future Work

Based on the findings of this report, there is significant variance in the quality of magnesium oxide boards available. Reports of damages such as dampness and accelerated corrosion can be attributed to the hygroscopic nature of magnesium oxychloride, which is used as the cement binder in many MgO boards. Through testing, the presence of magnesium oxychloride in MgO samples resulted in significant moisture absorption and consequently leaching from several boards. The presence of chloride in the leachate significantly accelerated the corrosion of contacting metal fixtures. These characteristics were observed in MgO samples A, B, C, and D. MgO sample F is thought not to contain the cement binder magnesium oxychloride, evidenced by SEM/EDS analysis, and this resulted in moisture absorption and corrosion performances similar to cement fibre board. This suggests that when considering which MgO boards may meet the acceptance criteria, consideration should be given to the use of binder, namely if the cement binder is magnesium oxychloride.

These results also suggest additional criteria required for acceptance of magnesium oxide wallboards for the Australian Market. The hygroscopic nature of the boards should be assessed, to determine the tendency of the board to absorb moisture from the environment. Further studies should be conducted to determine a suitable acceptance value for moisture absorption through the environment.

Additionally, an acceptance criterion regarding the composition of the MgO board should be considered. This study suggests that boards containing the cement binder magnesium oxychloride are more susceptible to moisture absorption, and consequently corrosion, than boards using alternative binders.

Many magnesium oxide board manufacturers state that their products must be used with coatings applied to eliminate moisture absorption. Both faces of the board would require coatings to prevent moisture absorption through the exterior face and the interior (facing the wall cavity) face. Using such coatings on both faces of the MgO boards, whilst using stainless steel fasteners, may alleviate damages resulting from high humidity moisture absorption and corrosion. Further research would be required to verify the ability of coatings to prevent damages associated with MgO boards.

END

7. References

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Appendix

Appendix 1. Equilibrium Relative Humidity Values for Selected Saturated Aqueous Salt Solutions

Source: (American Society for Testing and Materials 2012)

t (°C)	HFP4 Caesium fluoride	HFP7 Lithium bromide	HFP12 Lithium chloride	HFP23 Potassium acetate	HFP33 Magnesium chloride	HFP43 Potassium carbonate	HFP59 Sodium bromide	HFP70 Potassium iodide	HFP75 Sodium chloride	HFP85 Potassium chloride	HFP98 Potassium sulfate
5	—	7.4 ± 0.8	13 (11.2 - 14.0)	—	33.6 ± 0.3	43.1 ± 0.5	63.5 ± 0.8	73.3 ± 0.4	75.7 ± 0.3	87.7 ± 0.5	98.5 ± 1.0
10	—	7.1 ± 0.7	13 (11.3 - 14.3)	23.4 ± 0.6	33.5 ± 0.3	43.1 ± 0.4	62.2 ± 0.6	72.1 ± 0.4	75.7 ± 0.3	86.8 ± 0.4	98.2 ± 0.8
15	4.3 ± 1.4	6.9 ± 0.7	12 (11.3 - 13.8)	23.4 ± 0.4	33.3 ± 0.3	43.2 ± 0.4	60.7 ± 0.6	71.0 ± 0.3	75.6 ± 0.2	85.9 ± 0.4	97.9 ± 0.7
20	3.8 ± 1.1	6.6 ± 0.6	12 (11.1 - 12.6)	23.1 ± 0.3	33.1 ± 0.2	43.2 ± 0.4	59.1 ± 0.5	69.9 ± 0.3	75.5 ± 0.2	85.1 ± 0.3	97.6 ± 0.6
25	3.4 ± 1.1	6.4 ± 0.6	11.3 ± 0.3	22.5 ± 0.4	32.8 ± 0.2	43.2 ± 0.4	57.6 ± 0.4	68.9 ± 0.3	75.3 ± 0.2	84.2 ± 0.3	97.3 ± 0.5
30	3.0 ± 0.8	6.2 ± 0.5	11.3 ± 0.3	21.6 ± 0.6	32.4 ± 0.2	43.2 ± 0.5	56.0 ± 0.4	67.9 ± 0.3	75.1 ± 0.2	83.6 ± 0.3	97.0 ± 0.4
35	2.7 ± 0.7	6.0 ± 0.5	11.3 ± 0.3	—	32.1 ± 0.2	—	54.6 ± 0.4	67.0 ± 0.3	74.9 ± 0.2	83.0 ± 0.3	96.7 ± 0.4
40	2.4 ± 0.6	5.8 ± 0.4	11.2 ± 0.3	—	31.6 ± 0.2	—	53.2 ± 0.5	66.1 ± 0.3	74.7 ± 0.2	82.3 ± 0.3	96.4 ± 0.4
45	2.2 ± 0.5	5.7 ± 0.4	11.2 ± 0.3	—	31.1 ± 0.2	—	52.0 ± 0.5	65.3 ± 0.3	74.5 ± 0.2	81.7 ± 0.3	96.1 ± 0.4
50	2.1 ± 0.4	5.5 ± 0.4	11.1 ± 0.3	—	30.5 ± 0.2	—	50.9 ± 0.6	64.5 ± 0.3	74.5 ± 0.9	81.2 ± 0.4	95.8 ± 0.5
55	2.0 ± 0.4	5.4 ± 0.3	11.0 ± 0.3	—	29.9 ± 0.2	—	50.2 ± 0.7	63.8 ± 0.3	74.5 ± 0.9	80.7 ± 0.4	—
60	2.0 ± 0.4	5.3 ± 0.3	11.0 ± 0.3	—	29.3 ± 0.2	—	49.7 ± 0.8	63.1 ± 0.4	74.4 ± 0.9	80.3 ± 0.5	—
65	2.1 ± 0.5	5.3 ± 0.3	10.9 ± 0.3	—	28.5 ± 0.3	—	49.5 ± 1.0	62.5 ± 0.4	74.2 ± 0.9	79.9 ± 0.5	—
70	2.2 ± 0.6	5.2 ± 0.3	10.8 ± 0.4	—	27.8 ± 0.3	—	49.7 ± 1.1	61.9 ± 0.3	74.1 ± 0.9	79.5 ± 0.6	—
75	2.4 ± 0.7	5.2 ± 0.3	10.6 ± 0.4	—	26.9 ± 0.3	—	50.3 ± 1.3	61.4 ± 0.5	74.0 ± 0.9	79.2 ± 0.7	—
80	2.6 ± 0.8	5.2 ± 0.3	10.5 ± 0.5	—	26.1 ± 0.4	—	51.4 ± 1.5	61.0 ± 0.5	73.9 ± 0.9	78.9 ± 0.8	—

Appendix 2. Water Absorption Data

Mass increase due to water immersion

SAMPLE	A1	A2	A3	B1	B2	B3
DRY MASS (G)	44.1284	44.7592	43.9555	57.8280	56.0495	56.5576
SATURATED MASS (G)	56.4959	57.1790	56.0535	67.0840	66.8100	66.6528
MASS INCREASE (%)	28.03	27.75	27.52	16.01	19.20	17.85

SAMPLE	C1	C2	D1	E1	E2	F1
DRY MASS (G)	38.0998	39.4969	50.5934	38.4830	39.5680	48.7887
SATURATED MASS (G)	52.3165	54.2108	62.5674	50.7050	51.8942	61.8057
MASS INCREASE (%)	37.31	37.25	23.67	31.76	31.15	26.68

Mass decrease due to drying of samples

SAMPLE	A1	A2	A3	B1	B2	B3
DRY MASS (G)	44.1284	44.7592	43.9555	57.828	56.0495	56.5576
AS PROVIDED MASS (G)	49.733	50.354	49.441	62.265	60.404	61.001
MASS DECREASE (%)	-11.269	-11.111	-11.095	-7.126	-7.209	-7.284

SAMPLE	C1	C2	D1	E1	E2	F1
DRY MASS (G)	38.0998	39.4969	50.5934	38.4834	39.5680	48.7887
AS PROVIDED MASS (G)	42.126	44.152	56.376	39.474	40.584	55.050
MASS DECREASE (%)	-9.558	-10.543	-10.257	-2.509	-2.503	-11.374

Appendix 3. Capstone Assessment Form

ENG402 Engineering Project 2

Final Project Report & Oral Defence

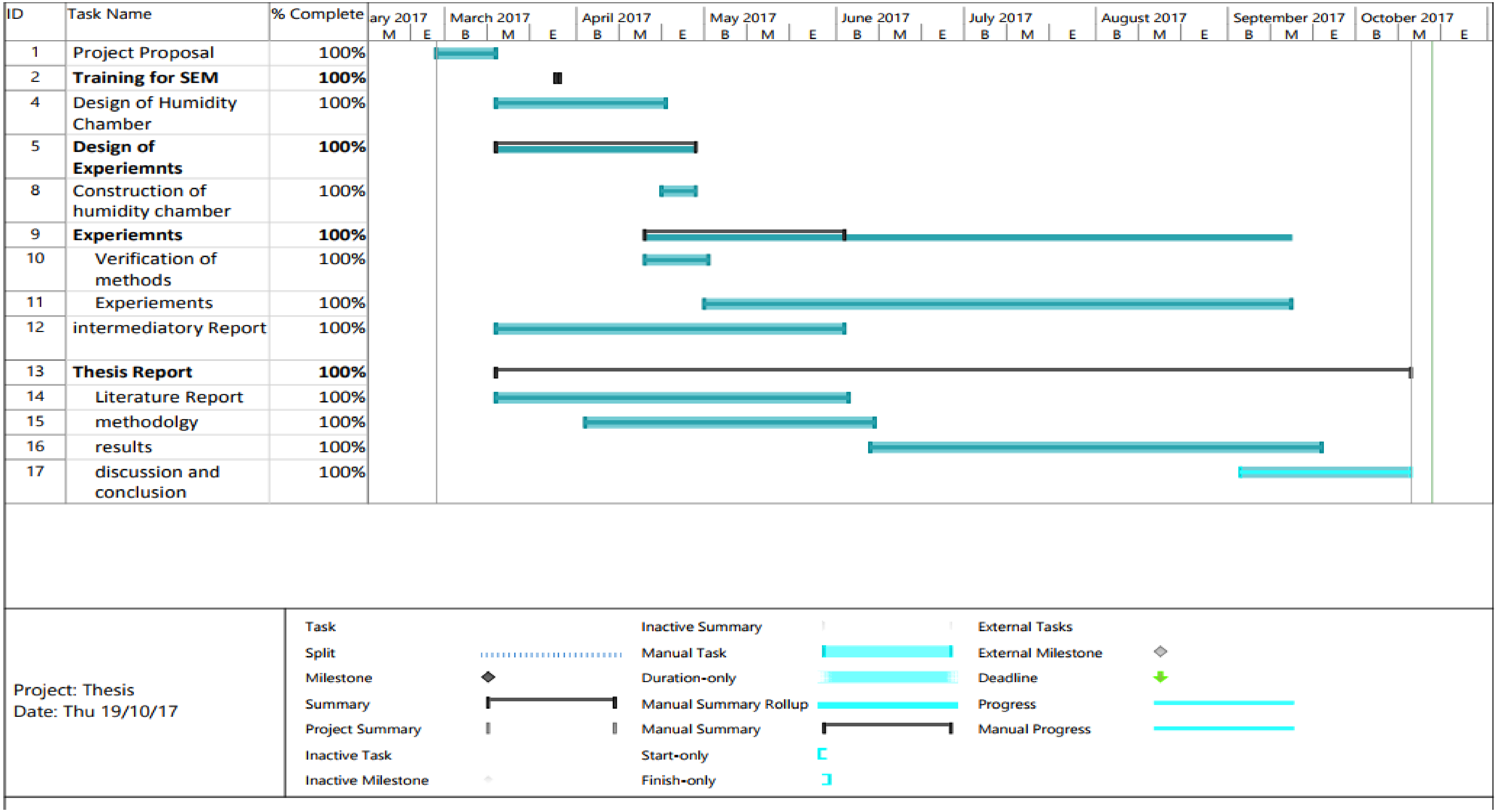
Student name:	Nick Jays
Student ID:	1080082
Project title:	Degradation of Magnesium-Oxide Wallboard
Academic supervisor:	Prof. David Young and Dr Ayodele Olofinjana
External supervisor:	CertMark International

	Demonstration of attainment (A brief summary of how, where and when you have applied the Competency)	**Self assessment (scale: 1–5)**	**Supervisor's or Assessor's assessment (scale: 1–5)**
PE1 KNOWLEDGE AND SKILL BASE			
PE1.1 Comprehensive, theory-based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline	This project was largely material based, and investigated the material composition, structure, mechanical properties and chemical properties of MgO boards. Using SEM testing methods, we were able to identify and compare the composition of the boards, identify chloride induced corrosion, and using fundamental knowledge of corrosion and materials, identify which boards may be prone to corrosion.	5	5
PE1.3 In-depth understanding of specialist bodies of knowledge within the engineering discipline	To analyse material composition, porosity, and corrosion products, utilisation of scanning electron-microscopy (SEM) was required (Section 4.3). This required training provided by the university to use the equipment. This project required in depth knowledge relating to corrosion and the moisture absorptivity to conduct and analyse testing.	5	5
PE1.5 Knowledge of contextual factors impacting the engineering discipline	This project is being used as evidence for compliance of MgO boards on the market, and which boards are most appropriate for the Australian market. For this reason, appropriate communication between the external supervisor and care to ensure accurate information conveyed will continue to be maintained.	5	5
PE1.6 Understanding of the scope, principles, norms, accountabilities and	A large portion of this project requires the Magnesium-Oxide board being assessed against the relevant standards, to determine whether the board is suitable for use in Australia. By	5	5

bounds of contemporary engineering practice in the specific discipline	doing so, I am demonstrating the ability to appreciate the basis and relevance of standards and codes.		
PE2 ENGINEERING APPLICATION ABILITY			
PE2.1 Application of established engineering methods to complex engineering problem solving	To achieve many of the experimental methods, controlled humidity environments were required. This was achieved through the use of saturated salt solutions, based on findings through literature in Section 2.3. SEM/EDS techniques were employed to access the corrosion products and composition of the samples to make justified conclusions.	5	5
PE2.2 Fluent application of engineering techniques, tools and resources	Careful selection of materials, chemicals, and equipment was required to maximise the efficiency of the humidity chambers. This was achieved through implementing findings from research conducted in Section 2.3	5	5
PE2.3 Application of systematic engineering synthesis and design processes	As this is an industry based project, I have and will continue to work closely with the industry partner to ensure their needs are met. Design processes have been applied throughout the project, such as the design of Arduino humidity and temperature sensors to reduce the costs associated.	5	5
PE3 PROFESSIONAL AND PERSONAL ATTRIBUTES			
PE3.1 Ethical conduct and professional accountability	Thorough risk analysis was performed as the project requires time in laboratories and the handling of chemicals. Inductions into laboratories, and workshops were conducted to ensure all safety briefing and required training were conducted.	5	5
PE3.2 Effective oral and written communication in professional and lay domains	This report serves as evidence for my effective written communication. Further evidence of my effective written communication can be seen in progress reports issues to my industry partner, and a summary of results report issues to my industry partner for use at an	5	5

	international conference.		
PE3.4 Professional use and management of information	As the issue addressed by this report was new, limited available information on the topic was widely available. Some of the required information was issued by my industry partner, where some information was sensitive, and as such this information was treated professionally and managed accordingly.	5	5
PE3.5 Orderly management of self, and professional conduct	I presented a professional image to parties involved by ensuring my physical presentation is appropriate, communication is professional and regular, and by arriving to all meetings on time.	5	5
	TOTAL	55	55

Appendix 4. Gantt Chart



ID	Task Name	% Complete
1	Project Proposal	100%
2	**Training for SEM**	**100%**
4	Design of Humidity Chamber	100%
5	**Design of Experiemnts**	**100%**
8	Construction of humidity chamber	100%
9	**Experiemnts**	**100%**
10	Verification of methods	100%
11	Experiements	100%
12	intermediatory Report	100%
13	**Thesis Report**	**100%**
14	Literature Report	100%
15	methodolgy	100%
16	results	100%
17	discussion and conclusion	100%

Project: Thesis
Date: Thu 19/10/17

Appendix 5. Weekly Reflections

Semester 1 Week 1

The project was officially accepted 1 week before the commencement of the semester, however due to other commitments, work on the project had not begun until now. This week was centred around preparing a proposal for submission. I had received some relevant papers to the project and a basic scope prior to week 1, which I used to begin the proposal. This allowed me to construct questions required to further define the project scope, which were discussed in the meeting with Dr Olofinjana.

Meeting with Dr Olofinjana 03/03/17

Key notes:

- Need to design and build approximately 3 humidity control chambers for testing purposes
    - Possible material for construction: Perspex
    - Need to purchase a Hygrometer is the university does not have access to one
    - Can use water in the humidity control unit to increase humidity, and desiccants (such as Silica gel) to remove humidity.
- Will follow the corrosion mechanism of the metallic fasteners
    - Insert nails (use galvanised and un- galvanised if a specific fastener is not prescribed) into the board until corrosion is evident through visual inspection.
    - Use difference in weight between the initial weight and weight after removing corrosion to determine the weight of corrosion removed
    - Inspect the corrosion elements under electro-microscopy
- To use the electro-microscopy machine, I will need to undergo training
- If more than 1 sample is provided by CertMark and differences in the samples are evident, then we will most likely be unable to determine the difference.

Semester 1 Week 2

Based on the meeting with Dr Olofinjana, I updated the scope and information in the proposal. In my meeting with CertMark, this was used to ensure both parties agreed on the project scope and what was to be achieved. This was integrated into the proposal and summited. This week the preliminary stages of the of the humidity chamber design and experiment design were conducted, beginning research on humidity dataloggers and the design considerations.

Meeting with CertMark 07/03/17

Key points:

- There are 4 different branded MgO boards they would like tested
- Any thickness board can be provided for our use, but since the standard size used in wall sheeting is 10-12 mm, this would be most appropriate.
- Any size board can be provided, although we thought a 100 x 200 mm may be appropriate
- I will report back to CertMark with regards to board requirements once the experiments have been designed and more accurate quantities can be requested
- I was provided with the relevant standards and acceptance criteria that govern the use of MgO boards in Australia, as well as a technical guide for MgO boards prepared by the Canadian Construction Materials Centre.
- CertMark will be having a video conference with the Canadian company on Friday
- CertMark has appointed a new engineer, Roni who will be the main contact with CertMark and provide assistance where required

Semester 1 Week 3

This week I created a prototype of an Arduino humidity data logger. As 3 different environments will require simulation, this would require the use of 3 dataloggers which will use a large portion of the available project funds. The use of Arduino significantly reduces the cost involved, and allows for a much more flexible system. I have continued to review literature, however need to progress further on the design of experiments to ensure timelines are kept.

Semester 1 Week 4

This week I continued to review literature and contribute towards my thesis. I have been in contact with university personnel regarding available facilities for temperature regulation to maintain the humidified environment. However thus far, the only suitable equipment is the asphalt testing apparatus, which is not available for the time required. I will continue to investigate possible equipment, or investigate methods to the reduce the temperature fluctuation when exposed to the atmosphere. Reviewing the literature as provided many resources for the appropriate design of the experiments.

Semester 1 Week 5

In preparation for my use of the SEM for corrosion analysis, I attended the training to allow access to the room. I also received verification access to the science laboratory's incubator for temperature regulation is available. For this, I will require to undergo a laboratory induction for access.

To access the accuracy of the Arduino humidity datalogger, I ran tests to compare the data to the data collected from a store-bought device, which perform comparatively, suggesting its use may be valid. However, this use of incubators presents the issue of battery life for powering the Arduino, and tests will be conducted to assess the viability in the coming week.

Semester 1 Week 6

This week I began writing the methodology for testing to be completed. The Arduino humidity sensor has been tested further, adding the additional sensor, however the additional sensor's accuracy (different brand to first sensor as a comparison) is not as accurate. Battery life remains an issue, particularly as an air circulation fan will be required due to the volume of the chamber. I will investigate the accuracy incurred when using the saturated salts in a relatively stable atmosphere, such as in a laboratory room. This will eliminate the battery issue. This week I also received my induction to the labs, and thus testing can begin once the methodology is complete.

Meeting with CertMark, with Prof. Young and Dr Olofinjana 4/4/17

- Received MgO board samples from CertMark
- Discussion of further testing

Semester 1 Week 7

During the mid-semester break and this week I began finalising the methodology. After the previous meeting, additional testing had been added to the scope, and thus additional testing samples were requested from CertMark. An incubator for the use of saturated solutions was found, meaning stable regulation of the saturated solutions, and power outlets for the sensors.

Semester 1 Week 8

Further finalisation into the testing methods was conducted throughout this week. My initial thoughts on experimentation time was severely inaccurate, as through investigation I found the standard for corrosion analysis of fasteners requires approximately 120 days. This also poses problems for the availability of the incubator, as the incubator is required in the teaching labs for semester 2 classes.

Semester 1 Week 9

Some alterations to the intended methodology, such as the scaling of corrosion tests to suit the size of humidified environment possible. Also, intend to seal the edges of samples in the humidified moisture absorption tests to represent all sized boards (eliminate edge effects). By this point, verification of testing methods (setting up humidity chambers) was expected to be completed, however this is now anticipated for week 10. This was due to awaiting arrival of Potassium Sulphate.

Semester 1 Week 10

One week behind schedule, I began a test of the saturated solutions for humidified solutions. This test was successful, and when checked a few days after, the humidity had reached stability at the anticipated relative humidity. The data collected from the datalogger will be investigated soon to check the stability of the solution. Have organised to begin testing next week, using SEM.

Semester 1 Week 11

Began testing of the samples, investigating differences between the provided samples using SEM, assistance by Dr Olofinjana. Samples were not prepared correctly by me, and although data obtained is still relevant, additional testing in Week 12 will be conducted. Further testing methods are awaiting samples provided by CertMark.

Semester 1 Week 12

Due to sickness, SEM testing on the samples was unable to be performed, and consequently will be completed in week 13. Further refined methodology for corrosion testing, and began collecting the necessary equipment to commence the tests. Will aim for the commencement of corrosion testing in week 13. Additional Samples were provided by CertMark, however not all samples were able to be provided for each test. Further investigation into the management of the samples for each test will need to be conducted.

Semester 1 Week 13

Due to ununiform dimensions of test samples. Sample size needed to be reduced using a bandsaw to accurately cut the samples. Doubts were raised of the saws ability to cut the samples, however proved effective and will be used for further samples cutting. Steel sections were provided for corrosion testing, however slight corrosion was evident on the internal of the sections, and thus sand blasting was used to remove the corrosion. SEM testing was preformed this week on the face surface of the samples.

Semester 2 Week 1

Thermal analysis was conducted over several days this week in the laboratory, as well as beginning the moisture absorption in controlled humidity and fastener corrosion testing.

Semester 2 Week 2

Some follow up thermal analysis was conducted this week. Moisture absorption and fastener corrosion experiments were observed. The results of the thermal analysis were investigated and the resulting conclusions were incorporated in the report.

Semester 2 Week 3

The moisture absorption analysis was removed from the environmental chamber to obtain the mass increase due to exposure to high relative humidities. Leaching was already evident on Sample C.

Semester 2 Week 4

The moisture absorption analysis was removed from the environmental chamber to obtain the mass increase due to exposure to high relative humidities. The fastener corrosion analysis was observed, with leaching from sample B evident, which will likely lead to corrosion at later stages of this test.

Semester 2 Week 5

The moisture absorption analysis was removed from the environmental chamber to obtain the mass increase due to exposure to high relative humidities.

Semester 2 Week 6

The main focus this week was to complete a draft of my poster and obtain feedback from my supervisors. The feedback I had received was positive, however the need to reduce the quantity of words on the poster was highlighted, and this will be considered for the final poster.

Semester 2 Week 7

The moisture absorption analysis was removed from the environmental chamber to obtain the mass increase due to exposure to high relative humidities. The fastener corrosion analysis was removed from the environmental chamber for analysis. Photos of the results were collected, then a meeting with Dr Olofinjana was set to review the results. SEM analysis was then conducted on the corroded samples.

Semester 2 Week 8

The moisture absorption analysis was removed from the environmental chamber to obtain the mass increase due to exposure to high relative humidities. The moisture absorption analysis was removed at this stage. Following the thermal analysis results, a secondary experiment was set up using a furnace to investigate the decomposition of the MgO boards at high temperatures. This week was also poster night, where my poster was displayed in The Cave as I presented to other students and industry present. All experimentation concluded this week.

Semester 2 Week 9

This week was largely spent on a report of completed results for CertMark which was to be presented at the World Federation of Technical Assessment in London next week. The conclusions formed during this report can then be incorporated into the thesis. This task would have been simpler if experiments had been completed earlier.

Semester 2 Week 10

This week was spent tidying and rewriting sections of the literature review and introduction, and tidying up the format of the report for draft submission.

Semester 2 Week 11

Whilst the draft of my thesis was being reviewed, I continued to work on sections which required further work, such as further elaboration on the discussion section.

Semester 2 Week 12

This week I received feedback for my thesis draft from my academic supervisor, and worked on incorporating this feedback into my report. I also provided a draft to a family member to review the grammar and spelling throughout the report.

Semester 2 Week 13

Final reading and editing of report ready for submission

Appendix 6. Arduino Humidity and Temperature Sensor Code

```
#include "DHT.h"
#include <stdio.h>
#include <Wire.h>
#include "RTClib.h"
#include <SPI.h>
#include <SD.h>
#include <LiquidCrystal.h>

RTC_DS1307 rtc;

#define DHTPIN 6     // what pin we're connected to
#define DHTPIN2 7

#define DHTTYPE DHT22   // DHT 22  (AM2302)

DHT dht(DHTPIN, DHTTYPE);
DHT dht2(DHTPIN2, DHTTYPE);

LiquidCrystal lcd(9, 8, 5, 4, 3, 2);

File f;
int i = 0;
char  daysOfTheWeek[7][12] = {"Sunday", "Monday", "Tuesday", "Wednesday",
"Thursday", "Friday", "Saturday"};

void setup() {
  Serial.begin(57600);
  Serial.println("DHT test");

  dht.begin();
  dht2.begin();

  SD.begin(10); //CS on pin 10;

  while (!Serial); // for Leonardo/Micro/Zero

  if (! rtc.begin()) {
    Serial.println("Couldn't find RTC");
    while (1);
  }
```

```
  if (! rtc.isrunning()) {
    Serial.println("RTC is NOT running!");
    // following line sets the RTC to the date & time this sketch was compiled
     //rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));
    // This line sets the RTC with an explicit date & time, for example to
set

  }
  f=SD.open("data.txt",FILE_WRITE); //open file for writing

   f.print("Humidity1: ");
   f.print("Temperature1: ");
   f.print("Humidity2: "); //output some data
   f.print("Temperature2: ");
   f.print("Day: ");
   f.print("Month: ");
   f.print("Year: ");
   f.print("Weekday: ");
   f.print("Hour: ");
   f.print("Minute: ");
   f.println("Second: ");

   f.close(); //then close the file

   lcd.begin(16, 2);
   lcd.print("hi");
}

void loop() {
  // Reading temperature or humidity takes about 250 milliseconds!
  // Sensor readings may also be up to 2 seconds 'old' (its a very slow
sensor)
  float h1 = dht.readHumidity();
  float h2 = dht2.readHumidity();
  float t1 = dht.readTemperature();
  float t2 = dht2.readTemperature();

  if (isnan(t1) || isnan(h1)) {
    Serial.println("Failed to read from DHT #1");
   } else {
```

```
      Serial.print("Humidity 1: ");
      Serial.print(h1);
      Serial.print(" %\t");
      Serial.print("Temperature 1: ");
      Serial.print(t1);
      Serial.println(" *C");
   }
    DateTime now = rtc.now();

    Serial.print(now.year(), DEC);
    Serial.print('/');
    Serial.print(now.month(), DEC);
    Serial.print('/');
    Serial.print(now.day(), DEC);
    Serial.print(" (");
    Serial.print(daysOfTheWeek[now.dayOfTheWeek()]);
    Serial.print(") ");
    Serial.print(now.hour(), DEC);
    Serial.print(':');
    Serial.print(now.minute(), DEC);
    Serial.print(':');
    Serial.print(now.second(), DEC);
    Serial.println();
   // delay(2000);
    if (isnan(t2) || isnan(h2)) {
      Serial.println("Failed to read from DHT #2");
     } else {
      Serial.print("Humidity 2: ");
      Serial.print(h2);
      Serial.print(" %\t");
      Serial.print("Temperature 2: ");
      Serial.print(t2);
      Serial.println(" *C");
  }

    f=SD.open("data.txt",FILE_WRITE); //open file for writing

    f.print(h1);
    f.print(" ");
    //delay(2000);
    f.print(t1);
```

```
  //delay(2000);
  f.print(" ");
  f.print(h2);
  //delay(2000);
  f.print(" ");
  f.print(t2);
  f.print(" ");
  f.print(now.day(), DEC);
  f.print(" ");
  f.print(now.month(), DEC);
  f.print(" ");
  f.print(now.year(), DEC);
  f.print(" ");
  f.print(daysOfTheWeek[now.dayOfTheWeek()]);
  f.print(" ");
  f.print(now.hour(), DEC);
  f.print(" ");
  f.print(now.minute(), DEC);
  f.print(" ");
  f.print(now.second(), DEC);
  f.print(" ");
  f.println();

  f.close(); //then close the file

  lcd.setCursor(0, 0);
  lcd.print("h1 ");
  lcd.print(h1);
  lcd.print(" h2 ");
  lcd.print(h2);
  lcd.setCursor(0, 1);
  lcd.print("t1 ");
  lcd.print(t1);
  lcd.print(" t2 ");
  lcd.print(t2);

}
```

Appendix 7. Arduino Water Temperature Datalogger Code

```
#include <stdio.h>

#include <Wire.h>

#include "RTClib.h"

#include <SPI.h>

#include <SD.h>

#include <LiquidCrystal.h>

#include <OneWire.h>

#include <DallasTemperature.h>


RTC_DS1307 rtc;


#define DHTPIN 6     // what pin we're connected to

#define DHTPIN2 7

#define DHTTYPE DHT22   // DHT 22  (AM2302)


#define ONE_WIRE_BUS 6

OneWire oneWire(ONE_WIRE_BUS);

// Pass our oneWire reference to Dallas Temperature.

DallasTemperature sensors(&oneWire);

/********************************************************************/


LiquidCrystal lcd(9, 8, 5, 4, 3, 2);


File f;

int i = 0;

char  daysOfTheWeek[7][12]  =  {"Sunday",  "Monday",  "Tuesday",  "Wednesday",

"Thursday", "Friday", "Saturday";


void setup() {
```

```
Serial.begin(57600);

Serial.println("Temperature");


Serial.println("Dallas Temperature IC Control Library Demo");

// Start up the library

sensors.begin();


SD.begin(10); //CS on pin 10;


while (!Serial); // for Leonardo/Micro/Zero


if (! rtc.begin()) {

  Serial.println("Couldn't find RTC");

  while (1);

}


if (! rtc.isrunning()) {

  Serial.println("RTC is NOT running!");

}

f=SD.open("datatemp.txt",FILE_WRITE); //open file for writing


 f.print("Temperature: ");

 f.print("Day: ");

 f.print("Month: ");

 f.print("Year: ");

 f.print("Weekday: ");

 f.print("Hour: ");

 f.print("Minute: ");

 f.println("Second: ");


 f.close(); //then close the file
```

```
   lcd.begin(16, 2);
   lcd.print("Temp datalog");
}

void loop() {

  sensors.requestTemperatures(); // Send the command to get temperature
readings
  float t1=sensors.getTempCByIndex(0);



      Serial.print(t1);
      Serial.println(" *C");

    DateTime now = rtc.now();

    Serial.print(now.year(), DEC);
    Serial.print('/');
    Serial.print(now.month(), DEC);
    Serial.print('/');
    Serial.print(now.day(), DEC);
    Serial.print(" (");
    Serial.print(daysOfTheWeek[now.dayOfTheWeek()]);
    Serial.print(") ");
    Serial.print(now.hour(), DEC);
    Serial.print(':');
    Serial.print(now.minute(), DEC);
    Serial.print(':');
    Serial.print(now.second(), DEC);
    Serial.println();
```

```
  f=SD.open("datatemp.txt",FILE_WRITE); //open file for writing

  f.print(t1);
  f.print(" ");
  f.print(now.day(), DEC);
  f.print(" ");
  f.print(now.month(), DEC);
  f.print(" ");
  f.print(now.year(), DEC);
  f.print(" ");
  f.print(daysOfTheWeek[now.dayOfTheWeek()]);
  f.print(" ");
  f.print(now.hour(), DEC);
  f.print(" ");
  f.print(now.minute(), DEC);
  f.print(" ");
  f.print(now.second(), DEC);
  f.print(" ");
  f.println();

  f.close(); //then close the file

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("temp ");
  lcd.setCursor(0, 1);
  lcd.print(t1);

}
```

Appendix 8. Fan Control Arduino Code

```
void setup() {
 pinMode(5, OUTPUT);
}

void loop() {
  digitalWrite(5, HIGH);   // turn the fan on (HIGH is the voltage level)
  delay(20000);              // wait
  digitalWrite(5, LOW);    // turn the fan off by making the voltage LOW
  delay(600000);              // wait
}
```