An Analysis of Magnesium Oxide Wall Panels Located in an Educational Building in Trinidad — A Case Study

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Abstract. An Educational Building in Trinidad commenced in 2010 and was handed over to the client in 2011. The internal walls of the building were constructed using composite panels with magnesium oxide boards as cladding. Discolouration of the walls was first observed during painting activities and persisted despite the start-up of the air conditioning system and several cleaning and repainting exercises. A request was made to undertake an analysis to determine the root cause of the discolouration and provide recommendations to prevent the occurrence.

Key words: Magnesium oxide, panels, discolouration, educational building.

Introduction

The client indicated that the building contractor sourced the magnesium oxide boards from three different suppliers and only one Material Safety Data Sheet (MSDS) (MAC Reinforcement Board, 2010) was obtained. The client also indicated that the internal walls were painted with locally supplied paints that include one coat of primer and two coats of an oil paint. The discolouration persisted in areas even though sealants were used. The client also removed about a 10” x 10” piece of the board from the eastern wall of the Reception Area and replaced it with gypsum material. This material surprisingly did not show any signs of discolouration.

Approach

The analysis undertaken was limited to samples identified and taken from the Reception Area, the South Western Staircase and ground floor Faculty Office. The investigation process involved the following:

Field Investigations

(i) *Visual Inspection*: Visual examinations of the affected areas were carried out to determine the extent and possible cause of the damage and photographs were taken.

(ii) *Extraction of Samples*: Four material samples (50 mm diameter) from two locations of the affected areas and non-affected areas were taken for analysis. Extraction was performed with the use of a bi-metal hole saw. A sample from the ground floor wall of the Faculty Office was also taken for comparison.

(iii) *Collection of Deposits / Secretions*: Deposits/secretions from affected area were collected with the use of cotton swabs.

(iv) *Temperature and Relative Humidity Measurements*: The localized Temperature and Relative Humidity at three locations were measured at various intervals using a temperature and Humidity Logger model Dickson ENV 17.

Lab Investigations

(i) *Moisture Content Measurements*: Moisture content of the magnesium oxide boards was determined using the Despatch – LBB2-18-1 oven dry method.

Elemental Analysis: The elemental analysis was carried out using a Bruker-Axs X-Ray Fluorescence (XRF) Spectrometer, Model SRS 3400.

(ii) *Compound Analysis*: The compound analysis was carried out using a Bruker-Axs X-Ray Diffractometer (XRD), Model D8 Advance.

(iii) *SEM and Microprobe Analysis*: Analysis of the deposit/secretion on the swab was carried out on a JEOL Scanning Electron Microscope (SEM), Model JSM 6490 LV, with an attached Energy Dispersive Spectrometer (EDS), Model Oxford 7574.

Results

Visual Inspection

Visual inspection of the inner walls of the Academic Building that included the Reception Area, the South Western Staircase, the ground floor Faculty Office and the Attic revealed the following:

Reception Area: The walls were painted with a red colour and showed darker tints of the colour in certain areas. These darker areas showed liquid stains and small droplet formation of liquid percolated on the surface (Fig. 1).

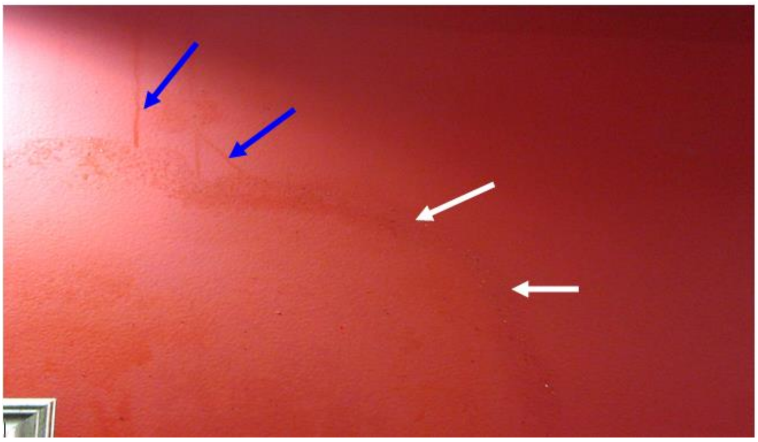


Fig. 1. The walls were painted red and displayed darker and lighter tints of colour at certain areas; the darker areas also showed liquid stains (white arrows) and small droplet formation of liquid percolated on the wall (blue arrows)

In the darker tinted region of the wall that was covered by picture frames, dead insects were seen stuck to the damp regions (Fig. 2).

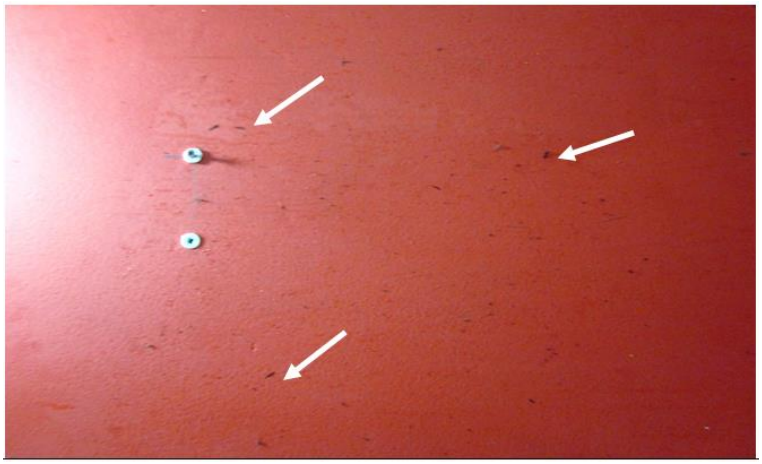


Fig. 2. In the darker tinted region of the wall that was covered by picture frames, dead insects were seen stuck to the damp regions (white arrows)

The darker tinted damp region was observed to be in close proximity to the supported steel frames where the wall panels were cladded (Fig. 3).

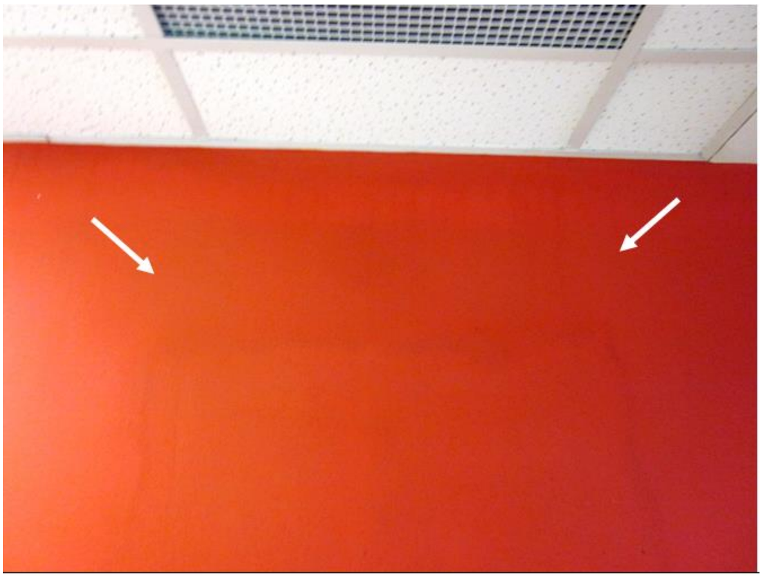


Fig. 3. The darker tinted damp region was observed to be in close proximity to the supported steel frames where the wall panels were cladded (white arrows)

South Western Staircase: The walls were painted with a cream colour and showed similar darker tints at certain areas; the darker areas also showed liquid stains (Fig. 4).

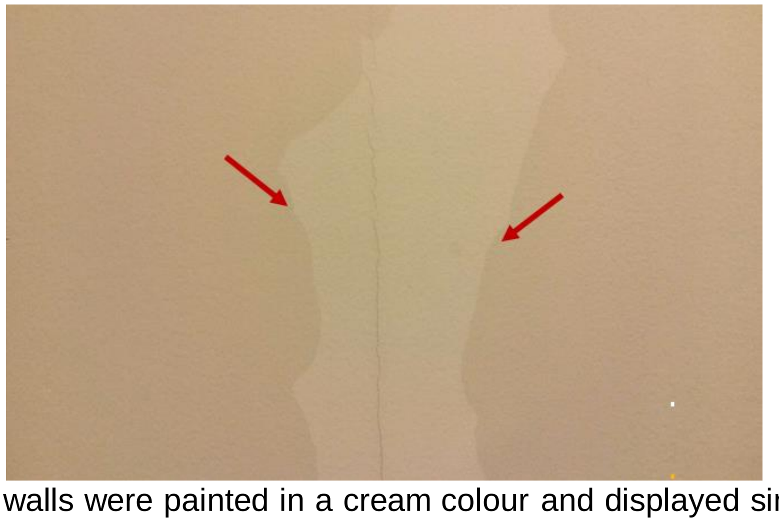


Fig. 4. The walls were painted in a cream colour and displayed similar darker and lighter tints at certain areas; the darker areas also showed liquid stains (red arrows)

A darker tinted damp region was observed to be in close proximity to the main steel column. Crack propagation along the length of the column wall at the corner to the adjacent wall is shown in (Fig. 5).

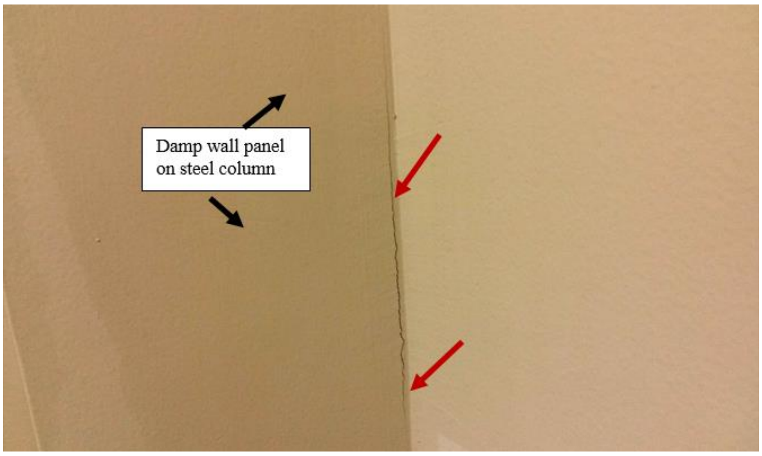


Fig. 5. A darker tinted damp region was observed to be in close proximity to the main steel column. Crack propagation occurred along the length of the column wall at the corner to the adjacent wall (red arrows)

Faculty Office: The walls were painted with a grey colour and showed a large section of the darker tint at certain areas. Severe blisters that occurred on the painted wall are shown in (Fig. 6).

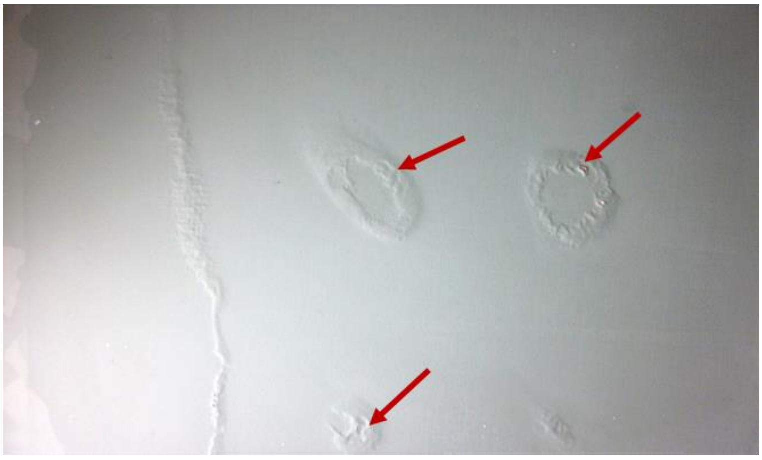


Fig. 6. The walls were painted in a grey colour and displayed a larger section of the darker tint at certain areas. Severe blisters occurred on the painted wall (red arrows)

The darker tinted damp regions were also observed to be in close proximity to the supported steel frames where the wall panels were cladded (Fig. 7).

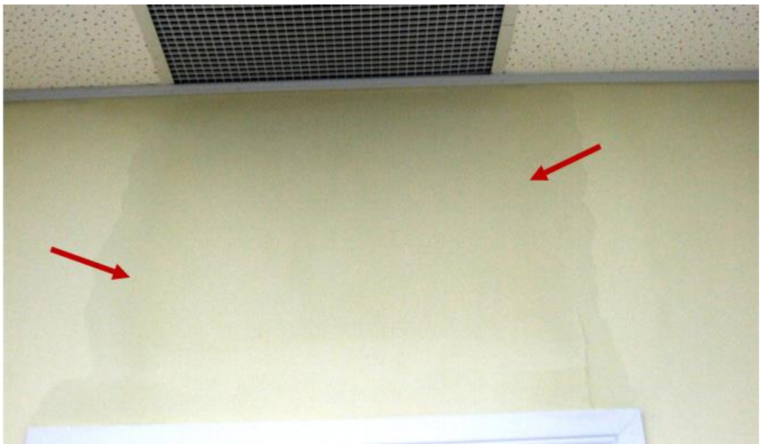


Fig. 7. The darker tinted damp regions were also observed to be in close proximity to the supported steel frames where the wall panels were cladded (red arrows)

The ceiling close to the affected wall was removed to observe the conditions above the ceiling. It was observed that the galvanized steel showed localized white spots, and the cladded inner panel also showed a darker tint in close proximity to the metal frame (Fig. 8).

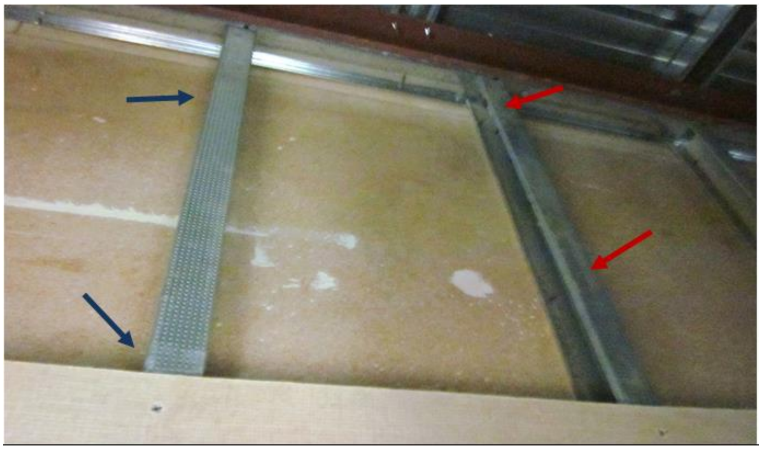


Fig. 8. The ceiling close to the affected wall was removed; it was observed that the galvanized steel showed localized white spots (red arrows) and the cladded inner panel also showed a darker tint in close proximity to the metal frame (blue arrows)

Attic in the Building: The wall panels extended in the Attic and were left exposed to the attic's environment. The electrical conduit that passed through the narrow opening of the wall panels are shown in (Fig. 9).

Fig. 9. The wall panels extended in the Attic (red arrows) and were left opened to the attic's environment. The electrical conduit passing through the hollow opening of the wall panel (white arrow) can be seen

Localized white rust (corrosion) was observed on galvanized steel channels. Also noted the insulation attached to the underside of the roof (Fig. 10).

Fig. 10. Localized white rust (corrosion) was observed on the galvanized steel bar channels (red arrows) and the insulation attached to the underside of the roof (blue arrows)

Extraction of Samples and Collection of Deposit/Secretion

Two core samples were taken from the Reception Area and two from the South Western Staircase. The samples represented the original coloured areas and the darker tinted region respectively. A core sample was also taken from the ground floor wall of the

Faculty Office. A typical picture identifies the positions where the core samples were taken (Fig. 11).

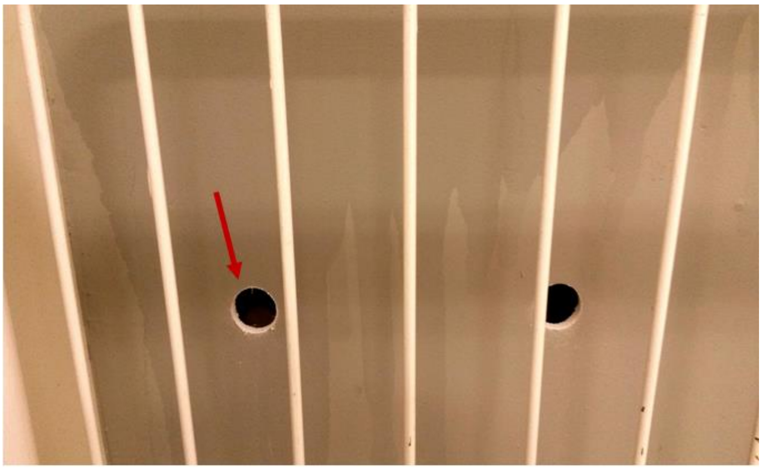


Fig. 11. A typical picture is shown of where the core samples were taken. Note the darker region within the liquid stains (red arrows)

The samples were assigned identification numbers and are presented in Table 1.

Table 1. Sample Identification

Identifications	Client's Identifications Core samples
MO-1	Reception Area (original)
MO-2	Reception Area (darker tint)
MO-3	Staircase Dark (original)
MO-4	Staircase (darker tint)

The darker tinted region containing the liquid deposit/secretion was collected by swabbing with cotton.

Temperature and Relative Humidity

The Temperature and Relative Humidity readings of the Reception Area, the South Western Staircase, the ground floor Faculty Office and the Attic were taken at different intervals; the morning period (approximately 10.30 am) and the evening period (approximately 7.30 pm). The Temperature and Relative Humidity reading of the Attic region were only recorded for the morning period. The readings are presented in Table 2.

Table 2. Temperature and Relative Humidity Readings

Identified Areas	Temperature (ºC)		Relative Humidity (%)	
	Morning	Evening	Morning	Evening
Reception	24.1	23.0	73.0	72.0
Staircase	23.7	22.7	75.1	72.5
Faculty Office	22.8	22.5	75.5	71.8
Attic	30.7	-	68.2	-

The Temperature and Relative Humidity within the building and in the Attic area showed varying results from the morning to evening periods. The Relative Humidity readings exceeded the standard guidelines given by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (Metal Building Manufactures Association, n/d).

Moisture Content Measurements

A forced convection oven that maintained a temperature of 110 ± 2ºC was used to determine the moisture content of the samples. The results are presented in Table 3.

Table 3. Moisture Content Measurements

Sample ID	Mass of original sample (g)	Mass of dry sample (g)	Difference in mass (g)	Total moisture content (%)
MO-1/ Reception (original)	24.173	18.453	5.720	31.0
MO-2/ Reception (Darker)	25.200	18.714	6.486	33.6
MO-3/ Staircase (original)	28.028	23.529	4.499	19.1
MO-4/ Staircase (Darker)	28.626	23.933	4.693	19.6
Faculty Office	23.006	17.828	5.178	29.0

The darker tinted samples showed a higher moisture content value than the original-coloured samples.

Elemental Analysis

A Standard-less Elemental analysis was used to determine percentage composition by weight of elements present in the magnesium oxide boards. The results are presented in Table 4.

The main elements identified in the magnesium oxide wall panel samples included oxygen, magnesium and chlorine; they showed varying concentrations of the main elements at the two locations.

Table 4. Elemental Analysis of Magnesium Oxide Boards

Elements	Percentage composition by weight %			
	MO-1/ Reception (original)	MO-2/ Reception (Darker)	MO-3/ Staircase (original)	MO-4/ Staircase (Darker)
Oxygen	40.04	41.76	27.77	28.78
Magnesium	23.45	23.72	31.63	31.98
Chlorine	21.82	18.31	22.61	21.24
Silicon	4.59	5.72	8.26	8.57
Carbon	6.63	6.59	4.82	4.62
Aluminum	0.77	1.13	1.54	1.63
Calcium	0.99	1.11	1.50	1.46
Potassium	0.62	0.64	0.86	0.90
Sodium	0.63	0.50	0.44	0.50
Iron	0.22	0.28	0.34	0.32
Sulphur	0.06	0.09	0.07	0.08

Titanium	0.08	0.04	0.05	0.08

Compound Analysis

X-Ray Diffraction analysis was used to identify the possible compounds in the magnesium oxide wall panel samples. The results are presented in Table 5. The X-Ray Diffractograms of a representative sample is shown in Appendix 1.

Table 5. Compound Analysis of MgO Wall Panels

Sample Id				Compound Name	Formula
MO-1/ Reception (original)	MO-2/ Reception (Darker)	MO-3/ Staircase (original)	MO-4/ Staircase (Darker)		
Yes	Yes	Yes	Yes	Magnesium Chloride	$MgCl_2$
Yes	Yes	Yes	Yes	Magnesium Chloride Hydroxide Hydrate	$Mg_3Cl(OH)_5 \cdot 4H_2O$
Yes	Yes	Yes	Yes	Pericase	MgO
Yes	Yes	Yes	Yes	Magnesite	$MgCO_3$
Yes	Yes	Yes	Yes	Offretite	$K_{1.1}Ca_{1.1}Mg_{0.7}Al_{5.2}Si_{12.8}O_{36} \cdot 15.2(H_2O)$
Yes	Yes	Yes	Yes	Minnesotaite	$(Fe^{2+},Mg)_3Si_4O_{10}(OH)_2$
Yes	Yes	Yes	Yes	Tachyhydrite	$CaMg_2Cl_6 \cdot 12H_2O$
Yes	Yes	No	No	Magnesium Chloride Hydrate	$MgCl_2 \cdot 6H_2O$
Yes	Yes	No	No	Iowaite	$Mg_6Fe^{3+}{}_2(OH)_{16}Cl_2 \cdot 4H_2O$
Yes	Yes	No	No	Northupite	$Na_3Mg(CO_3)_2Cl$
No	No	Yes	Yes	Bischofite	$MgCl_2 \cdot 6H_2O$
No	No	Yes	Yes	Shelkovite	$Mg_7(CO_3)_5(OH)_4 \cdot 24H_2O$
No	No	Yes	Yes	Chlorartinite	$Mg_2(CO_3)Cl(OH) \cdot 3(H_2O)$

All samples contained similar chloride compounds that included magnesium chloride and magnesium chloride hydroxide hydrate. They also contained similar oxide and carbonate compounds including pericase and magnesite. Also common to all samples included the compound tachyhydrite which is a hydrous chloride. Mineral compounds also found common to all samples included offretite and minnesotaite.

SEM and Microprobe Analysis

The SEM and Microprobe was used to analyse the deposit/secretion on the cotton swab and also to analyse and compare the elements of darker tint regions to the original-coloured samples of the painted MgO boards. The results of the analysis revealed the following.

An SEM micrograph of the cotton swab showed a matted deposit/secretion entangled within the fibres (Fig. 12).

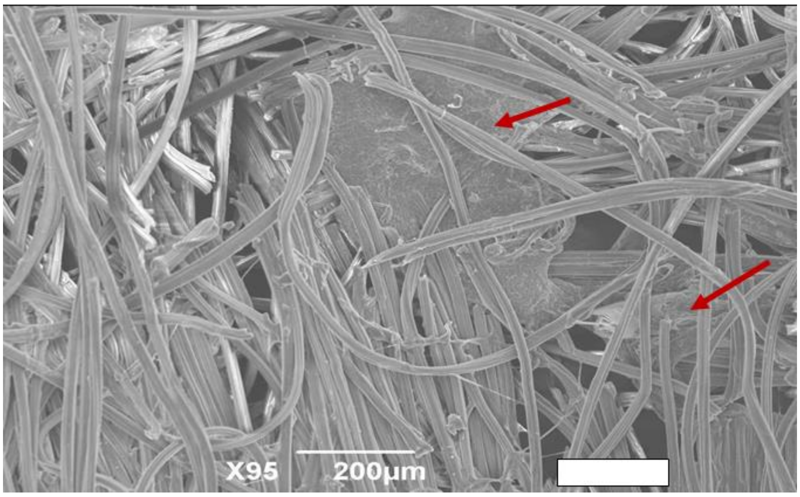
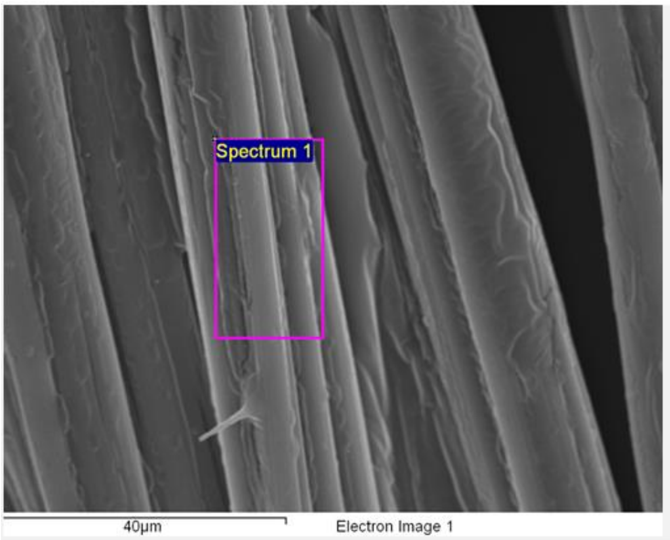


Fig. 12. SEM micrograph of the cotton swab showed a matted deposit/secretion entangled within the fibres (red arrows)

SEM microprobe analysis of the deposit/secretion on the cotton swabs revealed a high concentration of chlorine and a lesser concentration of magnesium on individual fibres (Fig. 13).

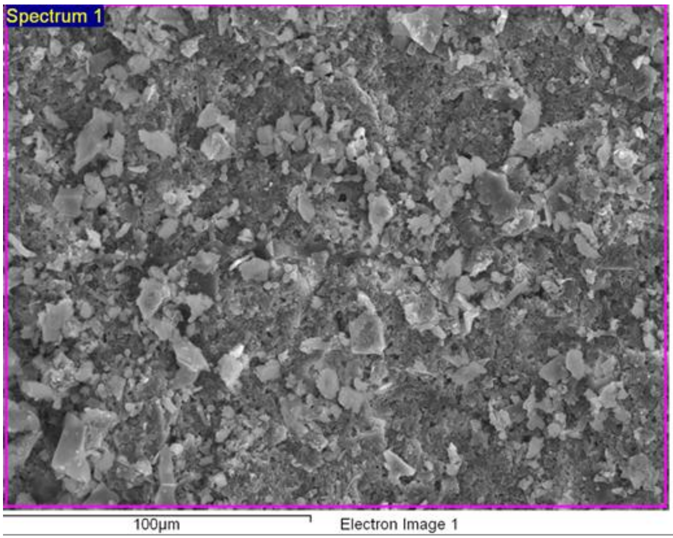


Elemental analysis of Spectrum 1

Element	Weight %
C	39.33
O	27.36
Mg	1.42
Cl	**30.62**
Ti	1.28
Totals	100.00

Fig. 13. SEM micrograph of deposit on cotton swab revealed a high concentration of chlorine and a lesser amount of magnesium

SEM Microprobe analysis on the surface area of the darker tinted regions of the painted board showed high percentage concentrations of the chlorine element at the surface (Fig.14).

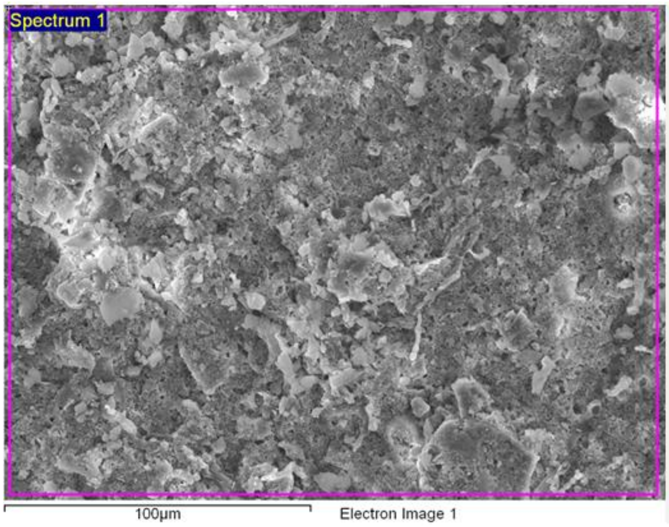


Elemental analysis of Spectrum 1

Element	Weight %
O	49.00
Na	0.59
Mg	6.43
Al	6.18
Si	17.31
Cl	**7.91**
K	0.52
Ca	0.49
Ti	10.76
Fe	0.81
Totals	100.00

Fig. 14. SEM micrograph of darker region of painted board showed the chlorine element had a high percentage concentration at the surface.

Analysis of the surface area of the original regions of the painted board showed a small percentage concentration of the chlorine element at the surface (Fig. 15).

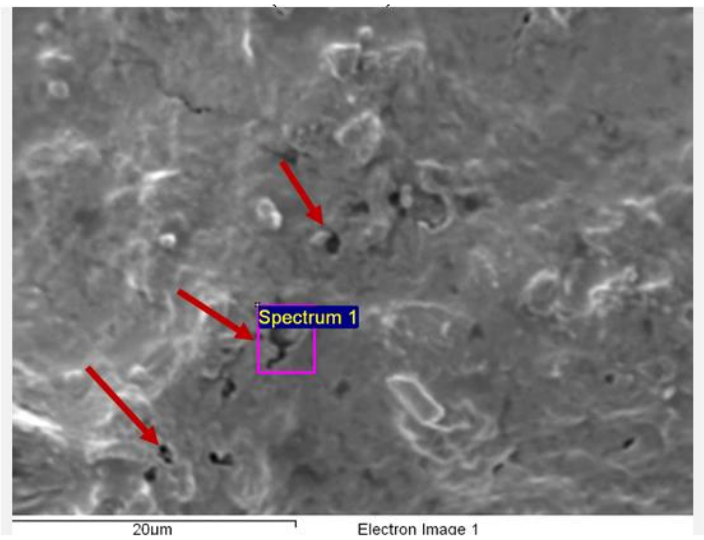


Elemental analysis of Spectrum 1

Element	Weight %
O	56.54
Na	0.42
Mg	3.36
Al	7.44
Si	18.13
Cl	**0.80**
K	0.63
Ca	0.52
Ti	11.10
Fe	1.08
Totals	100.00

Fig. 15. SEM micrograph of lighter region of painted board showed the chlorine element had a low percentage concentration at the surface

Analysis at a higher magnification of the painted surface in the darker tinted region showed minute pore openings, and at these openings a high percentage concentration of the chlorine element was observed (Fig. 16).



Elemental analysis of Spectrum 1

Element	Weight %
O	40.73
Mg	21.33
Cl	**29.26**
Ti	8.67
Totals	100.00

Fig 16. SEM Microprobe at a higher magnification of the painted surface in the darker region showed small pores, and high concentration of chlorine (red arrows)

Discussion

Visual examination of the inner walls of the upper and lower floors of the Educational Building showed that the painted walls were largely affected by a liquid form of contamination which showed liquid stain marks at certain regions of the walls. These regions also had a darker colour tint that looked damp and was cold to the touch (Figs. 1-7). Small droplet formation of liquid was also observed on the walls in the Reception Area (Fig. 1) and this region also had dead insects stuck to the damp areas (Fig. 2). Swabs of the deposit/secretion were collected from this damp region and analysed (Figs. 12, 13). The painted wall showed no signs of degradation.

The wall at the South Western Staircase encompassed the two floors (from the ceiling to the ground floor) and the wall of the main column showed a large area of the darker tint than the adjacent wall colour. The darker tint discolouration of the main column wall seemed to overflow in parts to the adjacent wall (Figs. 5, 11). A longitudinal crack was also observed that propagated the length of the wall at the intersection between the main column and the adjacent wall.

The walls in the ground floor Faculty Office were most affected by the liquid stains. The painted walls contained areas that had blistering and peeling of the paint; in some blistered areas the paint flaked off and white precipitates were observed on the surface (Fig. 6). A ceiling tile was removed to observe the conditions above the ceiling. It was observed that the galvanized steel frame showed localized white spots, and the cladded inner panel that was unpainted also showed a darker tint in close proximity to the metal frame (Fig. 8).

The Attic area showed where the MgO wall panels (approximately 10 mm thick) were cladded to galvanize metal frames to form hollow rectangular sections. The electrical pipe conduits passed through these hollow openings to provide the necessary electricity to the building, and the air-conditioning duct piping crossed the exposed wall panels. The wall panels remained exposed to the environment of the Attic (Fig. 9). In some areas galvanized steel channels exhibited white rust stains, and this is typically caused by a high degree of moisture or some stagnant liquid being in contact with the metal (Fig. 10).

Temperature and Relative Humidity measurements were taken at two periods of the day (morning and evening) and they included the Reception Area, the South Western Staircase, the ground floor Faculty Office and the Attic of the building. The evening period showed a general decrease in temperature and relative humidity. There were also significant variations in temperature and relative humidity readings in the Attic when compared to the inner building (Table 2).

SEM analysis of the deposit/secretion collected from the damp region in the Reception Area showed a matted structure that entangled the fibres of the swab material (Fig. 12). Microprobe analysis identified the deposit/secretion to contain a high concentration of chlorine. Comparing the elemental analysis of the darker tint region of the painted panel to the original-coloured region also showed a higher concentration of chlorine at the darker region (Figs. 14, 15). At higher magnification of the darker region of the sample, minute pores (openings) were observed on the surface and the microprobe analysis at a point identified a high concentration of chlorine (Fig. 16); this indicated the leaching of a liquid.

MgO board is manufactured from a combination of magnesium oxide and magnesium chloride and includes fibrous reinforcement and other magnesium-based compounds, but MgO is supposed to be the main compound (65%) as shown in the MSDS supplied by the client (Appendix 2). A general property of the board includes the ability to absorb water but remain unchanged (no swelling). The results of the Elemental and X-Ray Diffraction analysis identified the main compounds as the hydrated form of the magnesium chloride and the carbonated form of the magnesium oxide compounds (Appendix 1). Another compound identified in all samples was tachyhydrite, which is an unstable mineral, a hydrous chloride of calcium and magnesium; upon exposure to moist air, it rapidly deliquesces and dissolves.

The results of the moisture content of the samples showed that the darker tinted regions had higher moisture content than the original-coloured regions of the same wall (Table 3). One can deduce that the sample with the higher moisture content i.e., the darker tint samples affected the appearance of the walls. These areas were saturated and damp to the touch and showed a stain effect after the moisture had evaporated. The dampness (high moisture) also encouraged insect life.

In metal framed building systems visible condensation occurs when condensation appears on surfaces that are adjacent to the warm side of materials; and concealed condensation occurs when moisture has passed into interior regions and then condenses on a surface that is below the dew point temperature. Fiberglass insulation will hold moisture either as water or water vapour that has condensed within the insulation.

The nature of discolouration of the MgO wall panels occurred when the panels became saturated with condensed moisture due to the extreme environmental conditions that included temperature variations, high moisture content and high relative humidity readings throughout the building. The building is a metal framed building constructed using composite panels with magnesium oxide board as cladding on to the galvanize frame. The insulation material at the underside of the roof of the Attic trapped the moisture and as the temperature fluctuated within the system the moisture condensed on the metal frame where the MgO panels were cladded.

The MgO board absorbed the condensed moisture as observed on the outer painted wall panels; it showed up as darker tints and stained regions in close proximity to the framed panel-members and joints. The MgO board remained physically unaffected by the absorbed water but leaching of the soluble chlorides took place within the panel. $MgCl_2$

and its various hydrates together with tachyhydrite compound, upon exposure to moist air, became soluble in the liquid.

The dissolved chlorides then leached out the material and found its way through small openings of the painted substrate (this was confirmed by the results that showed the concentration of chlorine on the swab samples and the elemental analysis at the pore opening of the painted sample). As the chloride solution percolated and settled on the painted surface of the panel the high moisture content encouraged insect life as observed on the damped panels.

A combination of visual and concealed condensation influenced the damp conditions of the panels. Signs of concealed condensation included the damp spots, the stains, blisters and the peeling of the paint as seen in the Faculty Office. The building showed an absence of vapour retarders and a proper ventilation system. Moist air was allowed to circulate freely within the system and between the framed panels, and as there was no restriction, the panels remained opened to the environment as seen in the Attic, and the cycle continued.

Conclusion

Based on the analysis conducted and the results obtained the following conclusions were drawn. The nature of discolouration of the MgO wall panels occurred when the panels became saturated with condensed moisture. A combination of visual and concealed condensation within the building influenced the discoloured and damp conditions of the panels. The MgO board remained physically unaffected by the absorbed water but leaching of the soluble chlorides took place within the panels. $MgCl_2$ and its various hydrates together with tachyhydrite compound upon exposure to moist air became soluble in the liquid. The dissolved chlorides then leached out the material and found its way through small openings of the painted substrate. As the chloride solution percolated and settled on the painted surface the high moisture content encouraged insect life as observed on the saturated panels.

All metal buildings require adequate ventilation. A lack of proper ventilation can create an uncomfortable working condition through elevated heat levels, excessive humidity, and stale air. It can also contribute to condensation problems. To effectively control visible condensation, it is necessary to reduce the cold surface areas where condensation may occur. It is also important to minimize the air moisture content within a building by the use of properly designed ventilating systems. Vapour retarder can be used to inhibit the passage of warmer moist air into the inner regions of the roof or wall system. The proper selection and installation of the vapour retarder can help control condensation problems in the building. In rooms such as bathrooms that are moisture laden, air should be exhausted to the outside of the building, not into the roof space.

Acknowledgements

We are grateful to Professor Clément Alexander Imbert who moderated this paper and, in that line improved the manuscript significantly.

References

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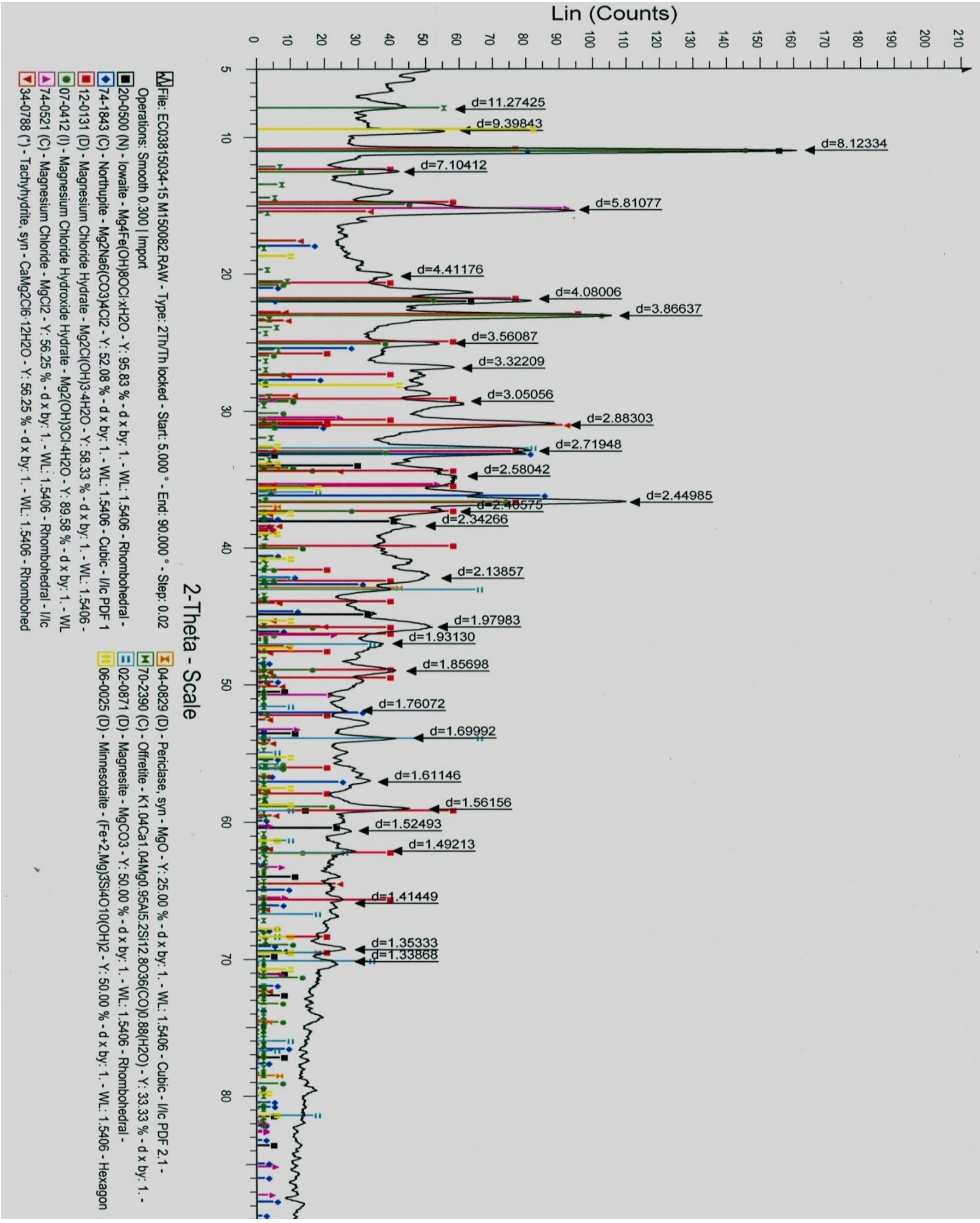
Metal Building Manufacturers Association. (n/d). *Condensation Fact Sheet* 1300 Summer Ave., Clevland, Ohio 44115-2851 USA.

Appendix 1

A representative X-Ray Diffraction pattern of a sample from one of the building's room



Appendix 2

Material Safety Data Sheet

BO DA BODA BMP

MATERIAL SAFETY DATA SHEET

Section I. Chemical Products and Company Identification

Product Name: MAC Reinforced Board

Other Names: Magnesium Oxide Board

Use: The above product is used as sheathing for Omega Building Systems Ltd structured insulated panels.

Manufacturer: **Kunshan Boda Building Material Co.,Ltd.**

Effective date: November 8, 2010

Note: As of the date of the preparation of this document, the information contained herein is believed to be accurate.

Substance Name	CAS #	UN #	EINECS #	Proportion (by weight)
Magnesium Oxide	1309-48-4	Not a hazardous material for shipping	215-171-9	65%
Magnesium Chloride	7791-18-6	Not a hazardous material for shipping		25%
Fiberglass Non-woven Mesh		Not a hazardous material for shipping		< 10%
Talc		Not a hazardous material for shipping		< 5%
Other non-hazardous ingredients (fillers)		Not a hazardous material for shipping		< 5%

Section 2. Hazards Identification

Emergency Overview: Not explosive, not a fire hazard
Primary Routes of entry and Potential Health Effects:
Acute effects - Dust may cause irritation of the nose, throat, and airways, resulting in coughing