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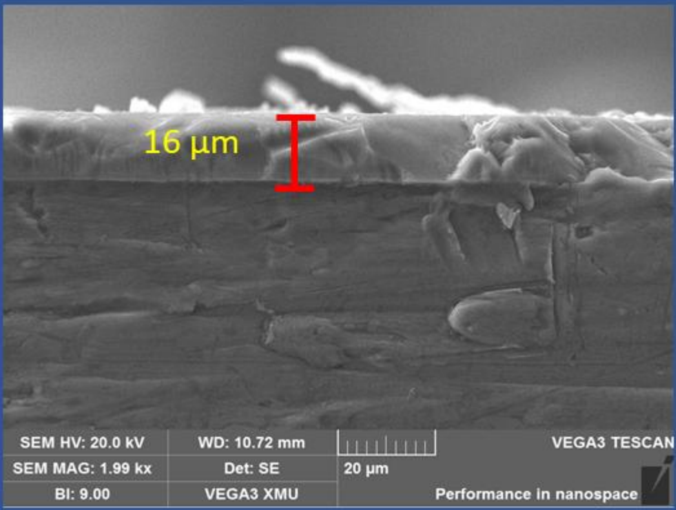
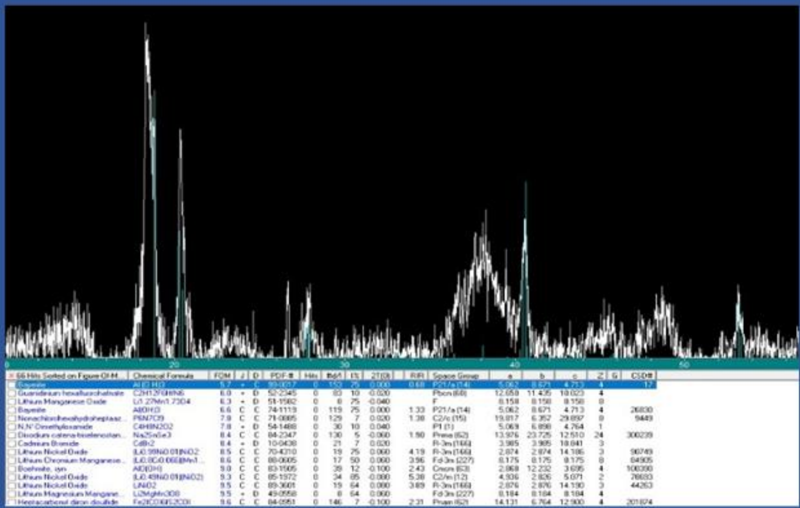
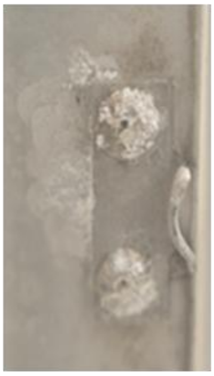
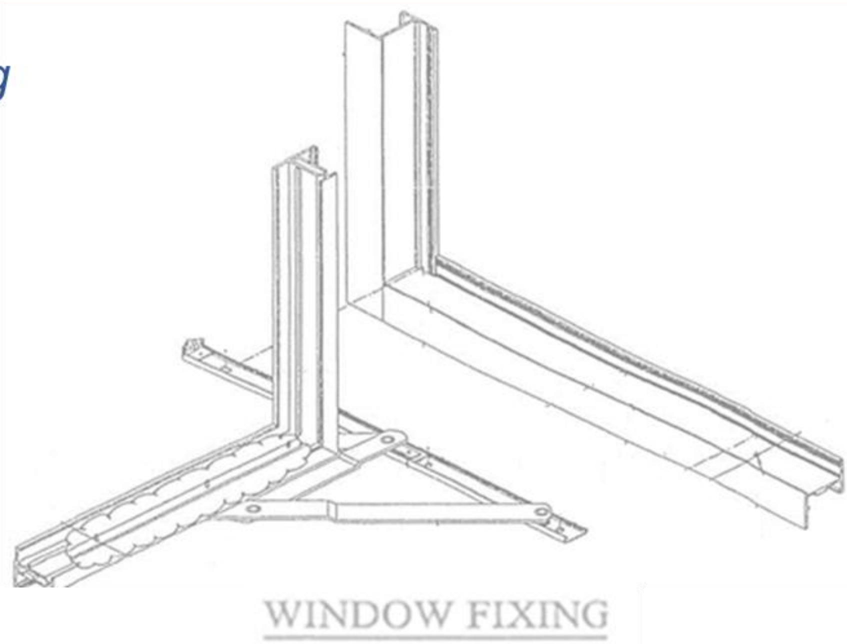




Technical Report on Corrosion of Aluminum Windows

M F Hui, K F Yuen & K F Chung





Greater Bay Area Modern Construction Technology

Hong Kong Experience on Aluminum Structures

2025

Technical Report on
Corrosion of Aluminium Windows

M F Hui, K F Yuen, K F Chung

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Foreword

Infrastructure in Hong Kong and various neighbouring cities in the Greater Bay Area are constantly subject to **severe corrosion due to high temperatures, humidity, and salt concentrations** imposed by the South China Sea. This significantly reduces the service life of constructional elements and structural members in building and structures, in particular, steel and metallic members in those offshore structures and also those along coastal areas.

Established in 2015, the Chinese National Engineering Research Centre for Steel Construction (Hong Kong Branch) (CNERC) is dedicated to promote modern construction technology in Hong Kong, and also in the Greater Bay Area. Durability of constructional elements and structural members has always been a research focus under its major work theme ***Sustainable Infrastructure Development***, and CNERC has conducted various research and development projects on corrosion mechanisms and protection technology on carbon steel, galvanized carbon steel, aluminium, stainless steel as well as stainless clad bi-metallic steel.

In collaboration with the Buildings Department, CNERC carried out a research project entitled "Corrosion of Aluminium Windows" in April 2023 with a view to gaining better understanding on the overall conditions, safety and integrity of windows in buildings in Hong Kong. With completion of Phase 1 of the project, this Technical Report provides information on literature review, surveys with seasoned practitioners, visual examination and chemical analyses on window components of selected samples. Riding on these findings, Phase 2 of the project is currently in progress with a view to establishing corrosion rates of exposed window components and an in-depth understanding of how these window components are corroded, when compared to research findings worldwide.

I would like to acknowledge those practitioners who shared their valuable experience and time in conducting the lengthy surveys during Phase 1 of the project. My heartfelt gratitude also goes to the Registered Minor Works Contractors Signatory Association Limited for its support and assistance in collecting window samples from various premises for examination and testing.

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1 Introduction

Since the introduction of aluminium window frames a few decades ago, it has gained popularity and aluminium frames are being used in the vast majority of windows in Hong Kong. While aluminium has good durability properties, signs of corrosion are found during window inspections, therefore, it is vital to gain understanding of the effects of corrosion on aluminium windows in Hong Kong. To this end, a research has been conducted by Chinese National Engineering Research Centre for Steel Construction (Hong Kong Branch) (CNERC) in collaboration with the Buildings Department (BD) to ascertain the general corrosion rates and corresponding effects on safety/integrity of aluminium window components in Hong Kong.

With close collaboration between BD and CNERC, the scope of the research was developed to cover fundamental aspects associated with safety and maintenance of aluminium windows to review the corrosion mechanism and integrity of window in Hong Kong. The main tasks of CNERC include a literature review, testing and data analysis, while BD provides reference information on common situations in buildings, typical window configurations and components, and practical types of aluminium alloys etc.

1.1 Scope of work

This research is divided into two phases. Phase 1 has been completed and Phase 2 is in progress.

Phase 1 includes the following tasks:

(a) Conduct comprehensive literature review on the corrosion mechanism and corrosion rate of various types of aluminium alloys exposed to different environments.

(b) Carry out chemical analysis of window components as well as any greyish powder and brown rust of windows from existing buildings

(c) Conduct questionnaire survey on the dilapidation of aluminium windows.

Phase 2 comprises the following:

(a) Conduct field exposure tests to estimate the corrosion rate of aluminium window components when exposed to local environments in Hong Kong.

(b) Conduct accelerated corrosion tests on aluminium window components with varying levels of corrosion.

(c) Mechanical tests when significant corrosion in the window components is found.

1.2 Literature Review

Literature review has been conducted on the mechanism and types of corrosion of aluminium alloys as well as local environmental factors and effects of cleansing agents. A concise summary of the literature review is given in Appendix A. The findings of the literature review may be summarised as follows:

(a) Aluminium alloys are generally not susceptible to severe corrosion as a protective oxide layer is formed on the surface shielding against further corrosion. This is entirely applicable to Hong Kong.

(b) For aluminium windows of reasonable material quality that are installed, used and maintained properly, corrosion of window components under common environmental exposures in Hong Kong are unlikely to cause integrity failure during the normal design service life of building structures, i.e. 50 years, provided that these components have been properly maintained to avoid severe pitting corrosion.

(c) Severe pitting corrosion in the order of 260 μm had been observed in environmental exposure of 20 years. However, it is unlikely to occur in the general environmental exposure in Hong Kong.

2. Questionnaire Survey on Dilapidation of Aluminium Windows

As part of the study on corrosion of aluminium windows, a survey is conducted by way of interview with experienced practitioners to obtain valuable insights from them on aluminium window developments, factors affecting the dilapidation and fallen window incidents etc. A total of 13 practitioners who have first-hand experience in the field of window inspection, maintenance and repair were interviewed. They comprise window specialists/installers, building professionals, contractors and building management professionals with experience ranging from 20 to 50 years. The interviews were done based on the question as set out in Appendix B.

One interviewee provided detailed information on the development of aluminium windows in Hong Kong. The information serves as a reference on the materials and configurations of window components used at different periods in the territory. Broadly speaking, since the emergence of aluminium windows in the market, the development in terms of materials may be divided into 3 eras, namely 1970s to 1980s, 1980s to 1990s and 2000s to present. The details are given in Appendix C. Such development is echoed by another interviewee who mentioned that window frames were relatively thin of about 1.2mm previously. Then, the materials and frames became more robust since the 1990s.

With regard to defects found in aged windows, most interviewees expressed that it is very common to have signs of corrosion in rivets/screws. Corrosion of windows may be the result of the use of strong acids in washing external walls, leaving traces of acids on the window components. Other common defects include loosen rivets and screws as well as windows that could not be opened smoothly. Some window frames which were inferior in quality might be distorted significantly, causing water leakage. The majority of interviewees considered the main cause of window defects is lack of maintenance. A couple of interviewees said that in their experience, it is not uncommon to find missing rivets i.e. rivet not put in during installation. Inferior material is also a common cause of defects. However, it is generally considered that window materials have been improving in the past 20 to 30 years.

Although corrosion of rivets and screws is very common and it may be more severe for windows facing the seafronts, it is not likely to be the only main cause of window failure. Many interviewees considered that the most common problems causing fallen window cases were windows that could not be opened smoothly. In general, these are windows that are often kept closed and hinges were rather stiff. Windows fall when they are forced open. Besides, loosen or missing rivets/screws, whether resulting from poor workmanship or dilapidation, is also a common cause of window failure.

Interviewees consider that the general conditions of windows have improved since the implementation of the Mandatory Window Inspection Scheme[1] (MWIS) in 2012. Owners' awareness of window maintenance and safety increased but they would only conduct inspection and repair required under the MWIS notices in general. While it is generally agreed that there is sufficient manpower in the market, interviewees believe that although the work of relatively new Qualified Person (QP) can meet the requirements of the MWIS, they require further training on workmanship. One of the interviewees said that the workmanships of the less-experienced QP are not good in general, resulting in less desirable quality of repair works, thus he suggests practical training for them.

With regard to the use of safety chain, most interviewees consider that it provides added safety. However, many think that it may not be acceptable to the owners. A couple of them pointed out that it may give a false sense of security and the actual capacity of the chain as well as other corresponding window components need to be checked.

An interviewee said that the rivet holes may be damaged during replacement of rivets and this could be a potential safety issue. He believes that a couple of spare hole locations on the window frame and the hinges could allow rivets to be put in new locations nearby if necessary. This would enhance safety of the finished works. Some interviewees consider that it is necessary to have more audit check and tighten control on QP to have deterrents effects. While a couple of interviewees suggest reviewing if the inspection interval need to be reduced to below 5 years. Another interviewee suggests BD to provide a guideline on how to install the window frames onto parent structures, and to specify the minimum requirements of the window frames.

[1] The Mandatory Building Inspection Scheme (MBIS) and the MWIS were introduced in 2012 to arrest the long-standing problem of building neglect and to ensure building safety in the long run. It is mandatory for owners to appoint registered building professionals to inspect their buildings and the windows therein with a view to identifying problems at an early stage and carry out timely remedial works to prevent their buildings from falling into disrepair thus causing danger to the occupiers and the public. Under the MWIS, owners of buildings aged 10 years or above (except domestic buildings not exceeding 3 storeys) and served with statutory notices are required to appoint a Qualified Person (QP) to carry out the prescribed inspection and supervise the prescribed repair works found necessary of all windows of the buildings

3. Physical and Chemical Examination of Window Components

As corrosion mechanism and extent of corrosion over time may vary significantly depending on the materials and exposure environment, therefore, chemical test on window samples are vital in establishing an understanding on the corrosion behaviour of windows in Hong Kong.

3.1 Sampling

Window samples were obtained randomly with the assistance of Registered Minor Works Contractors Signatory Association Limited (RMWCSA). Windows replaced by RMWCSA members in various premises territory-wide are used for testing. A total of eight windows from four premises were collected. Details of window samples are given in Appendix D. The corresponding test samples of the window components are shown in Appendix E. Tests were carried out on the chemical compositions of window frames, hinges, rivets/screws as well as the corresponding corrosion products. Moreover, the configurations and thickness of the window frames were also examined.

3.2 Frame and Coating Thickness

Cross section of window frame and glazing frame were examined, and thickness of the frames were measured by calliper. By making reference to Appendix C, the thickness and configuration of the frames would enable us to estimate the era at which the window frames were manufactured. The configuration and measured thickness are shown in Appendix F. It is noted that for sample HY01, window frames and glazing frame thickness are larger than 2mm, indicating that the frame was likely to be manufactured after year 2000. For all remaining samples, the window frame thickness ranges from about 1.2 mm to 1.7 mm, the glazing frame thickness ranges from about 1.1mm to 1.4mm. Therefore, they are likely to be manufactured between the 1980s and 1990s.

Moreover, protective coating was applied on windows HT01, HY01 and HY03. The coating thickness was measured by scanning electron microscopy (SEM), the measured data are given in Appendix G.

3.3 Chemical Composition of Window Components

To identify the chemical compositions of the window components, Energy-dispersive X-ray spectroscopy (EDX) was conducted on the window frames, hinges, rivets/screws samples. The EDX results are given in Appendix H and compared with the chemical composition of commercially available alloy as stipulated in BS EN 573-3:201 and BS EN 10088-1:2005 Stainless steels - Part 1 given in Appendix I.

For window frames, the composition by weight of HT05 comprises of aluminium and iron, the alloy falls within the range for AA1100. For all other window samples, the composition by weight of aluminium, magnesium and silicon resembles that of AA 6063.

For rivets, samples were found to contain aluminium as the major element, but their proportion of magnesium varies significantly, suggesting different types of aluminium alloys. Rivets for sample HT01 is made of AA 5056, whereas rivets for HY01, HY02, and HY04 are made of AA 6063. Rivets for sample HT06, the presence of aluminium and iron only, suggesting AA 1100. Whereas, screws for HY01 should be 304 stainless-steel.

For hinges, iron is the major element, along with chromium and nickel. These compositions suggested 304 stainless-steel.

A summary of the materials for the window samples is given in Appendix J.

3.4 Chemical Composition of Corrosion Products

For greyish powders or brown powders found on these samples, X-ray diffraction (XRD) was performed. The XRD results are given in Appendix K.

For sample HT01, the analysis of the greyish powder identified both aluminium hydroxide and sodium chloride. The presence of aluminium hydroxide suggested the corrosion of window frame/rivet. However, the origin of the salt remains uncertain, as the building was located 1 km away from the sea, making it unlikely that the salt originated from the seaside. Brown rust is present for HT01, the chemical analysis identified the presence of iron oxide hydroxide (FeOOH). Given that the hinge remains in good condition, it was believed that the rust was produced by corrosion of other component such as screws.

For HY02, aluminium hydroxide found on the rivet, indicating that powder was produced by corrosion of the rivet.

4 Audit and Window Incident Reports

To enhance understand of degree of corrosion on integrity of existing windows, five incident reports and five MWIS audit reports were obtained from BD for review. A summary of the findings in the review of these reports and the observations of the aged window samples collected as stated in Section 5.1 are given in Appendix M.

For the incident reports, the corresponding building age is 53 to 61 years; for audit reports, the buildings are aged 30 to 58 years; and aged window samples obtained with the assistance of RMWCSA are from buildings ranging from 32 to 49 years. Whilst the buildings with window incidents are within the older age range, there does not appear to be notable difference in degree of deterioration of window with building age. The defects found in the incident reports and the audit reports include moderately corroded rivets, missing rivets, broken rivets, loosen hinges etc. It is noted that corrosion is by far the most common defect found, which ties in with the views of interviewees in Section 4 that corrosion is very common. Once greyish white powder[2] at rivets or brownish rust at screws develops, it transpires a sign of corrosion[3].

It should be noted that both the upper and the lower hinges of a side hung type aluminium windows are critical structural components in securing the window sash to their parent aluminium frames. All the rivets and the screws of the hinges are the essential elements to ensure the window sashes securely held in position when subject to loads like dead loads, operation loads and wind loads. These rivets and screws are small and thin components and hence, their load capacities may be significantly reduced when subject to a certain degree of corrosion.

If any rivet or screw failed, loosen or gone missing, the applied loads will be resisted among those remaining rivets and screws. In extreme cases, this will cause failure of these window components.

[2] This phenomenon was also noted in the incident report.
[3] The relationship between corrosion and strength will be conducted in Phase 2.

5. Phase 1 Summary Findings

The main findings in Phase 1 are summarised below:

(a) Literature review shows that aluminium alloys are generally not susceptible to severe corrosion as a protective oxide layer is formed on the surface shielding against further corrosion. This is entirely applicable to Hong Kong. For aluminium windows of reasonable material quality that are installed, used and maintained properly, corrosion of window components under common environmental exposures in Hong Kong are unlikely to cause integrity failure of the window components during the normal design service life of building structures, i.e. 50 years, provided that these components have been properly maintained to avoid severe pitting corrosion.

(b) Through interview of experience practitioners, there is a general consensus that corrosion of rivets and screws in aged windows are very common, and it may be more severe for windows facing the seafronts. Corrosion of windows may be the result of the use of strong acid in washing the external wall, leaving traces of acid on the window components. The most common problems causing fallen window cases were windows that could not be opened smoothly. Windows fall when they are forced open. Besides, corroded, loosen or missing rivets/screws, whether resulting from poor workmanship or dilapidation, is also a common cause of window failure. They consider the main cause of window defects is lack of maintenance.

(c) Chemical compositions of window samples from buildings aged 32 to 49 indicates that for most of the windows, except one, the frames are manufactured between the 1980s and 1990s, that means some 30 years ago. The window frames and rivets are mainly made of AA6063. The conditions of the windows vary and salt deposits are found in HT01.

As stipulated in the Code of Practice for The MBIS and The MWIS (The Code), defective or corroded screws, rivets shall be replaced. It is considered that as a preventive measure for ensuring public safety through prescribed inspections and repairs of windows, it is necessary to act more prudent and rigorous, and hence, for any corroded rivets or screws, regardless of the degree or corrosion, they shall be replaced by new ones. When replacing a hinge with a stainless steel hinge, or replacing the rivets or screws of an existing stainless-steel hinge, stainless steel rivets or screws shall be used to replace the defective or corroded screws and rivets.

6. Phase 2 of the project

Phase 1 establishes the fundamental information of this research, however, establishing the rate of corrosion would provide an in-depth understanding of how window components fair compared to research findings worldwide. Therefore, field exposure tests, accelerated tests as well as further assessment of degree/extent of corrosion would be conducted in Phase 2.

6.1 Field Exposure Test

Phase 2 focuses on establishing the rate of corrosion of window components, a 24-month field exposure test would be carried out. Test samples would be put at three different locations, namely Yau Ma Tei, Yuen Long and Sai Ying Pun.

To ensure that windows commonly used by the general public are tested, window components including frames, hinges, rivets /screws were purchased from three different popular shops for the tests. Test coupons made of carbon steel, stainless steel, AA 1100, AA5056 and AA6063 would also be placed alongside with the window components for exposure test. The test programme is given in Appendix L. Corrosion sensors for i) carbon steel, and ii) aluminium will be placed to collect real-time data on temperature, humidity and corrosion current every hour. Corrosion products will be removed, and mass loss measurements will be conducted after exposure for 6, 12 and 24 months to estimate the corrosion rates.

The chemical composition of these test components as well as the window frame and glazing frame thickness are given in Appendix N.

The proposed location of the field exposure test on 9/F of BD Headquarter and the rack for holding the test samples are given in Appendix O.

6.2 Accelerated Corrosion Tests

Accelerated corrosion tests will also be conducted to similar samples used in the field exposure tests, i.e. stainless-steel rivets, screws and hinges, and aluminium frames, as well as aluminium rivets.

The test programme is given in Appendix P. Corrosion products will be removed, and mass loss measurements will be completed after 30 days of accelerated corrosion tests to estimate the corrosion rates, and compare with the results from those of the field exposure tests.

6.3 Assessment of Degree/Extent of Corrosion affecting Window Safety

Thorough understanding of the mechanism and degree/extent corrosion of window components in Hong Kong would enhance assessment of the effects of corrosion on the integrity of the rivets/screws/hinge and window safety. To this end, more corrosion samples would be collected with the assistance of RMWCSA for chemical compositions tests with a view to establishing a broader sample collection to ensure that all types of corrosion mechanisms would be covered. As stated in Section 5.4, the chemical composition of corrosion products of aged windows is associated with aluminium rivets, however, window samples currently widely available in the market comprise 304 stainless steel hinge and screws. If possible, aluminium rivets would be obtained to conduct accelerated corrosion test.

Appendix A

Literature Review on Mechanism and Type of Corrosion

Literature review has been conducted on the mechanism and types of corrosion of aluminium alloys in Hong Kong, as well as local environmental factors and effects of cleansing agents. A concise summary of the literature review is given below.

Types of aluminium alloys

Wrought aluminium alloys are categorised into eight series. For structural applications, European standards recommend the use of 6XXX series. For rivets, British standards cover 1XXX, 2XXX, 5XXX and 6XXX series.

Forms of corrosion

1. There are four different forms of corrosion -
   a. ***uniform corrosion*** involves a consistent and even loss of material across a surface. In general, an oxide layer is formed on the surface of aluminium which acts as a barrier, *effectively shielding off further corrosion*.
   b. ***pitting corrosion*** is a localised form of corrosion resulting in *pits or cavities*. It may occur in the presence of aggressive atmospheric chemicals, particularly *chloride* and *sulphate*.
   c. ***galvanic corrosion*** occurs when two dissimilar metals come into direct contact. When aluminium alloy is in contact with stainless steel (rivets/screws), *the rate of corrosion is generally insignificant*.
   d. ***crevice corrosion*** is a localised corrosion that occurs in locations such as narrow gaps. However, cervices are generally found to be filled with aluminium corrosion products which *tend to prohibit further corrosion*.

Environmental Factors

2. Corrosion of aluminium alloys is affected by local environmental conditions that they are exposed to. In general, atmospheric environments may be classified into i) rural, ii) urban, iii) industrial, and iv) marine conditions. Atmospheric corrosive chemicals such as sulphur dioxide (from industrial emissions) and chloride (in marine environment) can increase the rate of corrosion of aluminium. In heavily polluted environment, presence of acid rain with low pH may accelerate corrosion of aluminium. While heavy rainfalls may clean corrosive chemicals from aluminium surfaces, effects of atmospheric temperature and relative humidity are found to have an insignificant effect on corrosion.

Rate of Atmospheric Corrosion

3. Research studies on atmospheric corrosion have been conducted for different aluminium alloys in various countries over the past few decades. A summary of these corrosion rates for carbon steel, galvanised steel and aluminium in various countries are given in Table A1.

4. As there were only limited studies on corrosion rates of aluminium alloys in Hong Kong, CNERC has recently completed a comparative study on corrosion rates of aluminium alloys and other metals based on published data on a number of countries, including Hong Kong. Key data of the study are also provided in Table A1.

5. As shown in Table A1, depending on the atmospheric categories. the corrosion rates of *carbon steel* in these five countries are found to range from about *20 to 85 μm/year* while those of *galvanized steel* are found to range from *merely 1.0 to 3.0 μm/year*. More importantly, the corresponding corrosion rates of **aluminium alloys** are found to range from **0.1 to 4.7 μm/year**.

6. As the atmospheric corrosive chemicals, namely SO_2 and Cl- , are relatively low in Hong Kong compared to other regions, it is reasonable to estimate that the corrosion rate of aluminium alloys range merely from 1 to 5 μm/year in Hong Kong, depending on the atmospheric categories. **For typical buildings in rural and urban conditions, the corrosion rate is expected to be smaller than 2 μm/year.**

7. A comparison on the maximum pit depth of aluminium alloys subject to a 20-year exposure in various countries is presented in Table A2. **For samples of 6XXX series, the maximum pit depth is found to be 260 μm, and this value is considered to be applicable to Hong Kong.**

Effects of Cleansing Agents

8. The impact of different cleansing agents on aluminium window corrosion in Hong Kong was also reviewed. **Chemicals such as alcohol, glycol ethers and diluted ammonia solution found in cleansing agents often cause insignificant corrosion in aluminium.** However, concentrated caustic soda can react with aluminium and lead to severe corrosion. Therefore, if caustic soda is used, it should be diluted and rinsed thoroughly after use.

Conclusions

C1: Research at CNERC reveals that **aluminium alloys are generally not susceptible to severe corrosion** as *a protective oxide layer is formed on the surface shielding against further corrosion*. This is entirely applicable to Hong Kong.

C2: Corrosion of aluminium window components under common environmental exposures in Hong Kong are unlikely to cause integrity failure of the window components during the normal design service life of building structures, i.e. 50 years, provided that these components have been properly maintained to avoid severe pitting corrosion.

C3: Integrity failure may take place over a period of 20 years if severe pitting corrosion at **260 μm** is resulted.

Table A1 - Corrosion Rate of Carbon Steel, Galvanised Steel and Aluminum under Various Environmental Conditions

(Yang et al., 2017; Mendoza & Corvo, 2000; Wang et al., 2019; Sica et al, 2007; Environmental Protection Department, 2021)

Exposure site	Atmospheric categories	SO_2 (mg/m^{2}day)	Cl- (mg/m^{2}day)	Corrosion rate (µm/y) *assuming uniform corrosion*		
				Carbon steel	Galvanised steel	Aluminum alloys
Brazil	Rural	2	10	35.6	1.0	0.1
	Marine	4	30	22.6	1.9	1.3
	Rural	4	20	30.3	2.4	0.3
	Marine	7	70	21.8	1.9	4.7
Cuba	Rural	10.8	3.8	28.5	1.3	0.1
	Urban / industrial	34.5	7.5	43.9	1.5	0.2
	Marine	*30.1*	*489.6*	*454.3*	*11.1*	*1.2*
China	Marine	4.2	77	33.0	2.0	4.4
	Industrial	33	0.64	83.0	3.0	3.7
Thailand	Urban (tropical)	20	10	57.9	1.35	0.3
Hong Kong	**Rural**	**3.2**	**2.1**	**25.0**	**2.26**	$\leq 1^e$
	Urban	**3.2**	**2.1**	**30.0**	**3.35**	$\leq 2^e$
	Industrial	**-**	**-**	**28.4**	**2.29**	$\leq 2^e$
	Marine	**-**	**-**	**44.2**	**3.17**	$\leq 5^e$

Notes:

1) All data for Hong Kong are measured and assessed by CNERC between 2010 to 2022 except stated otherwise.
2) e denotes estimated data based on a systematic comparison on corrosion rates of carbon steel, galvanized steel and aluminum alloys.

Table A2 - Maximum pit depth of various aluminium alloys exposed for 20 years in various locations

(Vargel, 2020b, Sun et al, 2017)

Alloy	Location	Atmospheric categories	Maximum pitting depth (µm)
AA 1035	Beijing, China	Urban	10
	Jiangjin, China	Industrial	250
	Qionghai, China	Rural	50
	Wanning, China	Marine	250
AA 1050	Salin, France	Marine	295
AA 1100	La Jolla, USA	Marine	350
	USA	Industrial	275
AA 2024	China	Marine	800
AA 3003	Salin, France	Marine	250
	Germany	Industrial	140
AA 5005	Salin, France	Marine	220
AA 6061	Salin, France	Marine	190
AA 6082	Salin, France	Marine	260
6XXX	Hong Kong	Marine	260

Appendix B

Survey on Dilapidation of Aluminium Windows

Respondent credentials: Date of interview:

Name		Phone no.	
Company		email	
Job title		Year of experience	
Sector	- window installers / specialist - contractor - housing management - consultant - others ( )		

Respondents are invited to provide response in relation to their own working experience on the following questions.

Durability/defects

A. Common defects in aluminium windows :
   1. rivet/joint corrosion
   2. window frame
   3. loosen parts
   4. water leakage
   5. others (______________________)

B. Causes of dilapidation :
   1. normal wear and tear
   2. inferior material quality
   3. workmanship during installation
   4. lack of maintenance and repair
   5. use of aggressive cleansing agents
   6. factor affecting dilapidation rate: near sea/facing sea (____________________________)
   7. others (______________________________)

C. Possible main contributing factors of fallen window incidents :
   1. Dilapidation (________________________________)
   2. Lack of maintenance
   3. workmanship
   4. Improper use
   5. others (____________________________________)

D. Life of windows
   1. No. of years before replacement (____________________________________)
   2. No. of years before general maintenance (____________________________________)
   3. Difference due to location/usage (____________________________________)

General

A. Types of windows commonly used in Hong Kong over the past few decades:
   1. aluminium
   2. iron
   3. Wood
   4. other

B. Difference before and after implementations of MWIS in 2012 :
   1. General conditions
   2. Owners' awareness of window safety
   3. Owners' readiness in maintenance/repair
   4. others
   5. Any change in the window industry? Mode of business/skills training/human resources?

C. Change since implementation of minor works in 2010 :
   1. Change in work practice of window contractors (____________________________________)
   2. Workmanship (____________________________________)
   3. Change in materials (_________________________)
   4. Difficulty in comply with requirements (____________________________________)
   5. Price (_________________________)

6. Others (________________________)

D. Views on use of safety chain.

Recommendations

Aspect	**Suggestions**
Use of materials	
Installation workmanship	
Maintenance	
Guidelines	
Promotion/education	
Regulations	
Means to improve window safety	

Table C1 - Window Components in Different Eras

	1970s-1980s	1980s to 1990s	2000 to present
Frame*	• Aluminium alloy (單工子 – single I section) • Thickness of aluminium alloy window frame ranging from 1.2 mm to 1.6 mm (Thickness of aluminum alloy frame for the glazing is thinner – 1.1mm) • No material specification • Protective coating about 8-10µm	• Aluminium alloy (雙工子 – double I section) • Thickness of aluminium alloy window frame ranging from 1.2 mm to 1.6 mm (Thickness of aluminum alloy frame for the glazing is thinner – 1.2mm) • Material specifications available • Protective coating about 10 – 20µm	• Aluminium alloy (雙工子 – double I section) • Thickness of aluminium alloy window frame from 2 mm and some up to 3mm (Thickness of aluminum alloy frame for the glazing is thinner – 1.4 – 1.6 mm) • Aluminium plates added to frame • Material specifications available • Protective coating about 20µm
Hinge	• Hinge is shallow • Stainless steel	• Stainless steel	• Stainless steel
Rivet	• Aluminium alloy, aluminium • Overseas more expensive • Local cheaper and oxidise easily		• Stainless steel (seldom use rivets now, generally use screws – as it is hard to get rivets tight)
Screws	• Stainless steel	• Stainless steel	• Stainless steel

***** Detailed configuration of aluminium frames during different eras are given presented in Figure C1 to Figure C3

Figure C1 – Window frame configuration from 1970s to 1980s

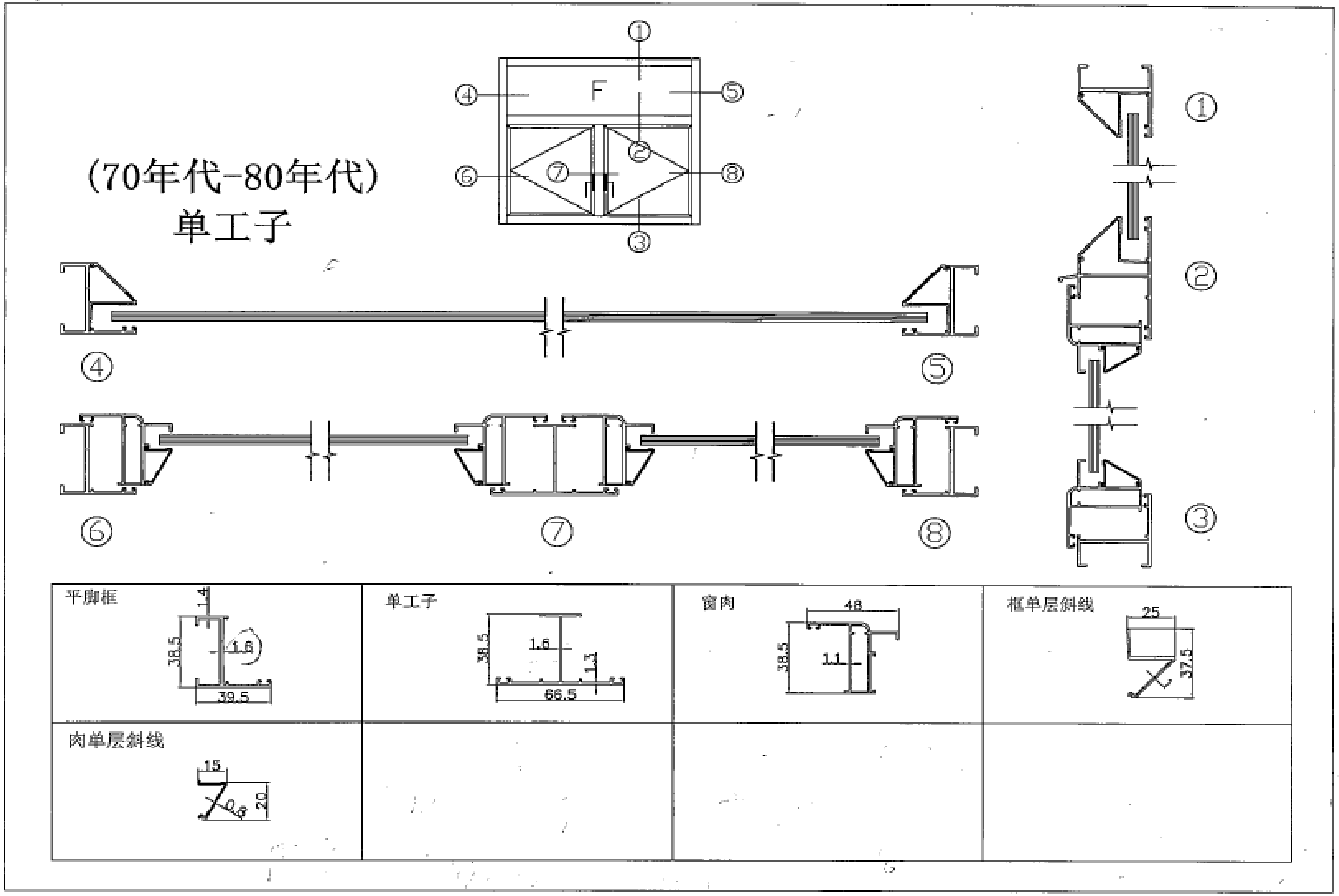


Figure C2 – Window frame configuration from 1980s to 1990s

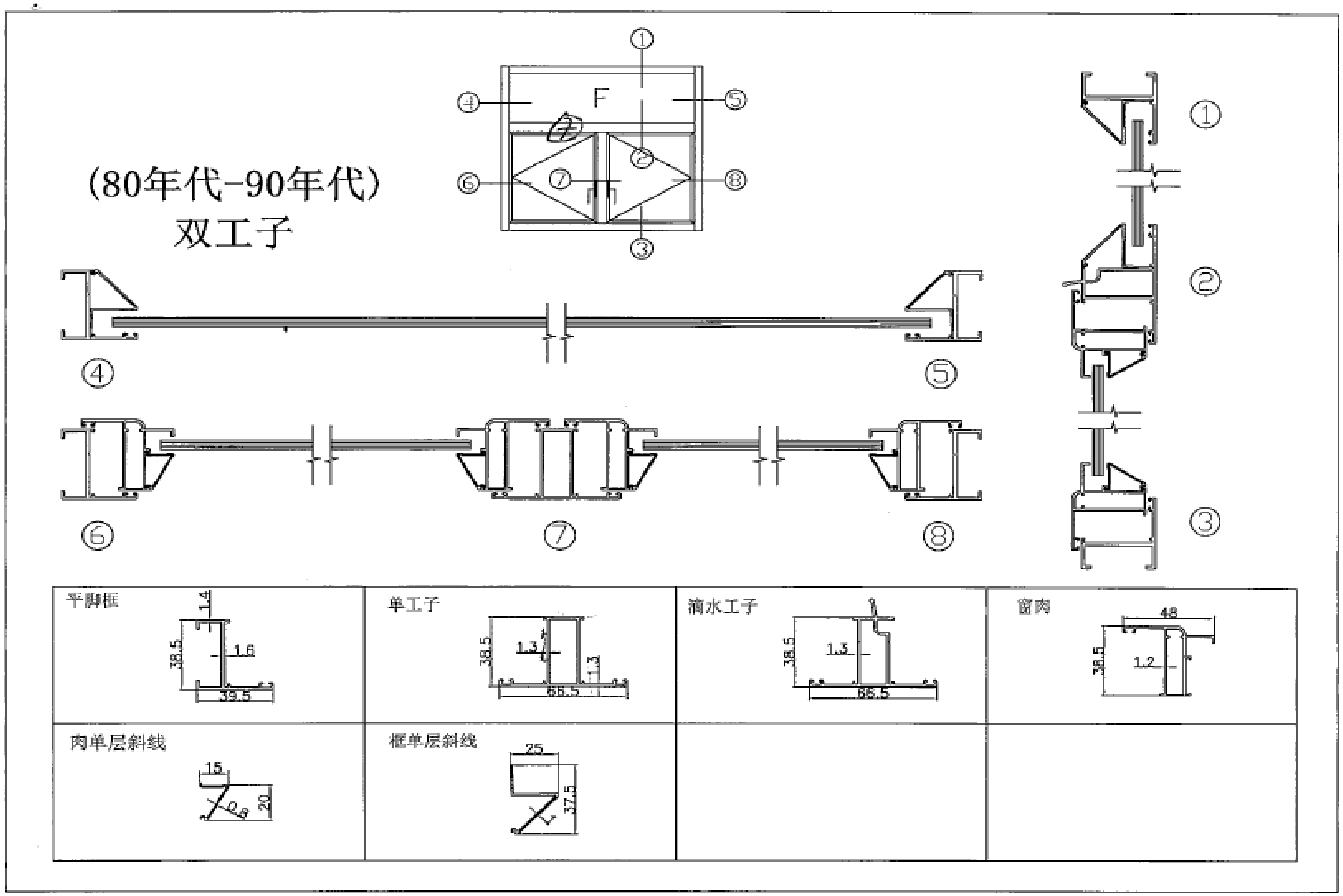
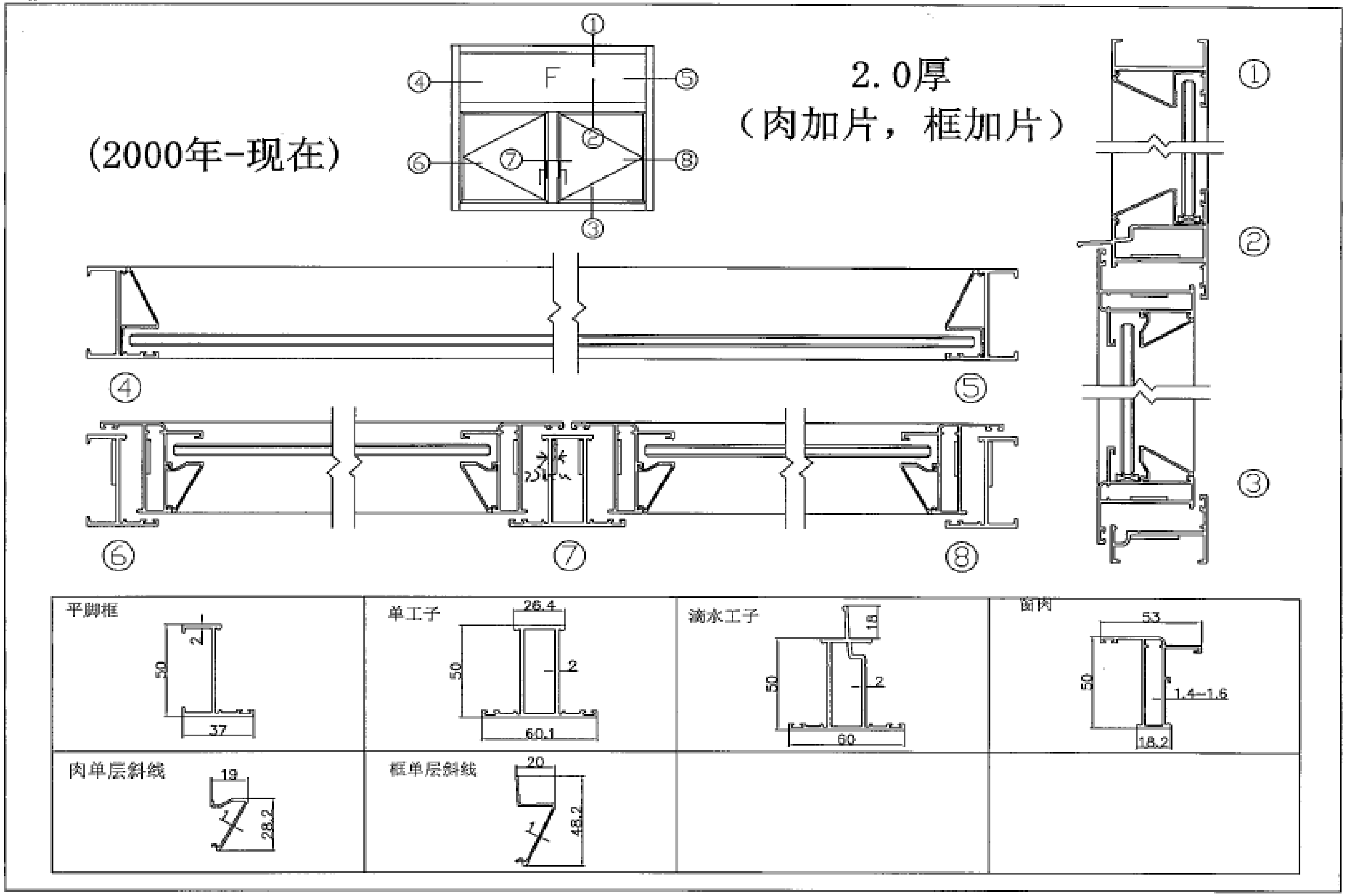


Figure C3 – Window frame configuration from 2000 to present



Appendix D

Details of Buildings from which Aged Window Samples were Collected

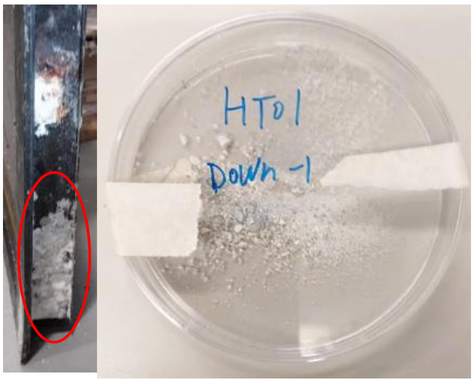
Windows	Building Age (year)	Site	Direction	Building type
HT01	32 (OP 1991)	Western District	向西南方 (opposite direction to seafront – abt. 1 km away)	Residential
HY01	36 (OP 1987)	Fortress Hill	向东 (perpendicular to seafront direction – abt. 0.4 km away)	Residential
HY02	33 (OP 1990)	Aberdeen	facing South (at seafront, facing sea)	Industrial
HY03	33 (OP 1990)	Aberdeen	facing South(at seafront, facing sea)	Industrial
HT04	49 (OP 1974)	Yau Ma Tei	facing Southeast (opposite direction to seafront – abt. 1 km away)	Residential
HT05	49 (OP 1974)	Yau Ma Tei	facing Southeast (opposite direction to seafront – abt. 1 km away)	Residential
HT06	49 (OP 1974)	Yau Ma Tei	facing Southeast(opposite direction to seafront – abt. 1 km away)	Residential
HT07	49 (OP 1974)	Yau Ma Tei	facing Southeast(opposite direction to seafront – abt. 1 km away)	Residential

Window HT01

(a) Frames

(b) Hinges

(c) Rivets and screws



(d) Greyish powder

(e) Brown rusts

Window HY01

(a) Frame (b) Hinge (c) Rivets and screws

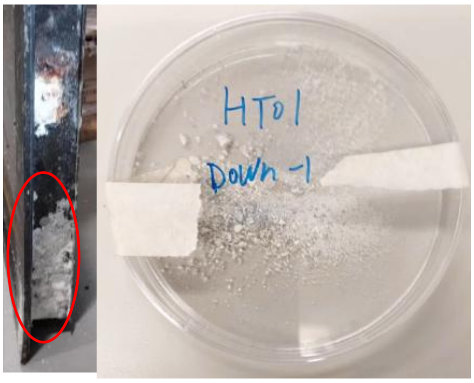
(d) Overview

Window HY02

(a) Frame

(b) Hinge

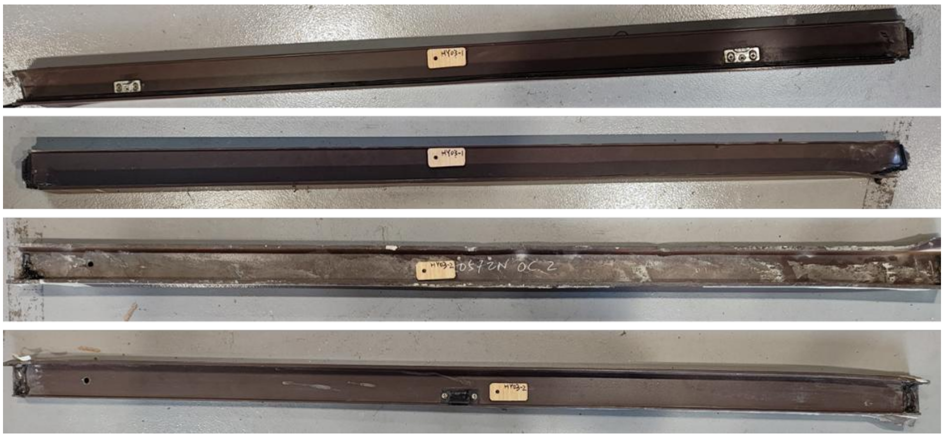
(c) Rivets and screws



(d) Greyish powder

(e) Overview

Window HY03



(a) Frame

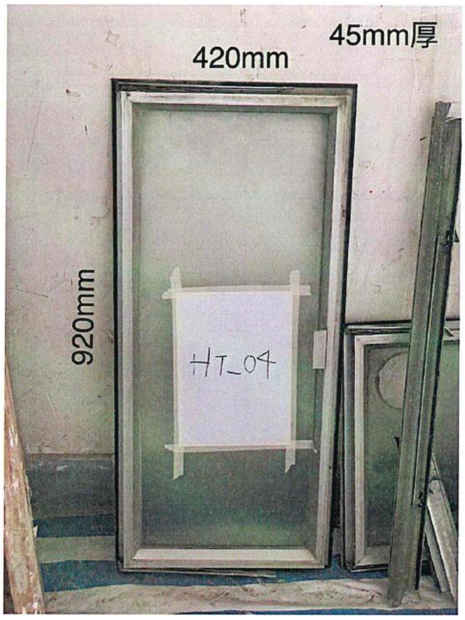
(b) Overview

Window HY04

(a) Frame

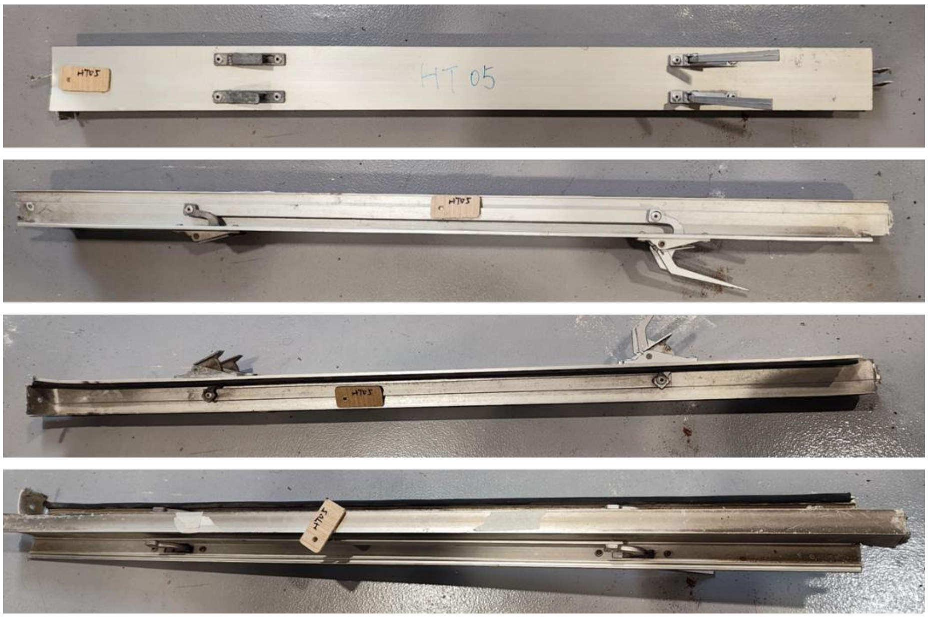
(b) Hinge

(c) Rivets and screws

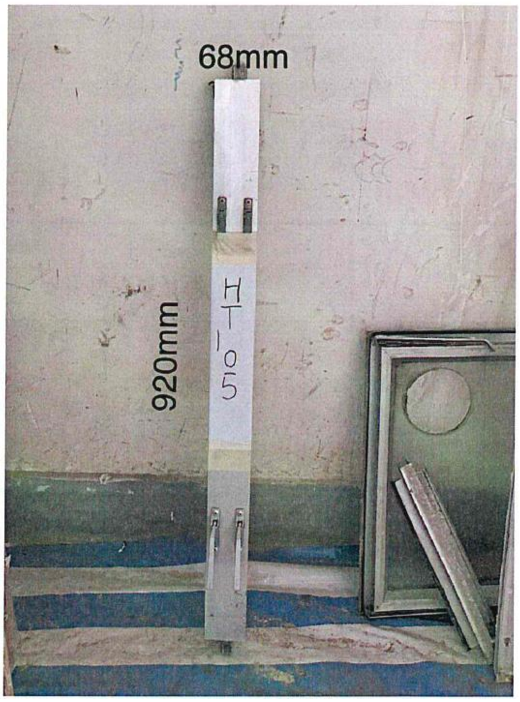


(d) Overview

Window HT05



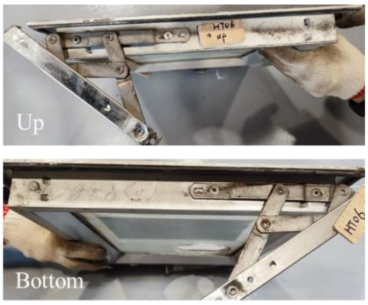
(a) Frame



(b) Overview

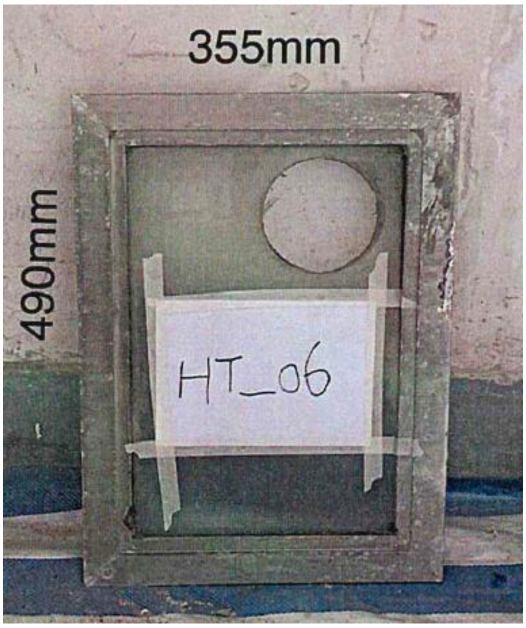
Window HT06

(a) Frame



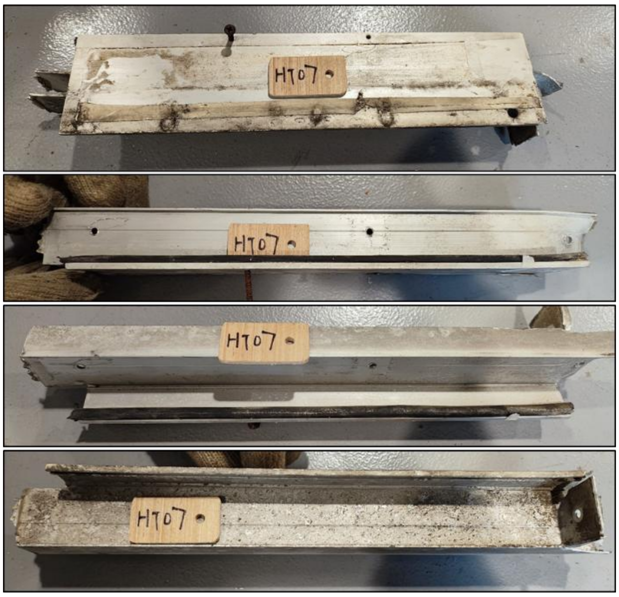
(b) Hinges

(c) Rivets and screws

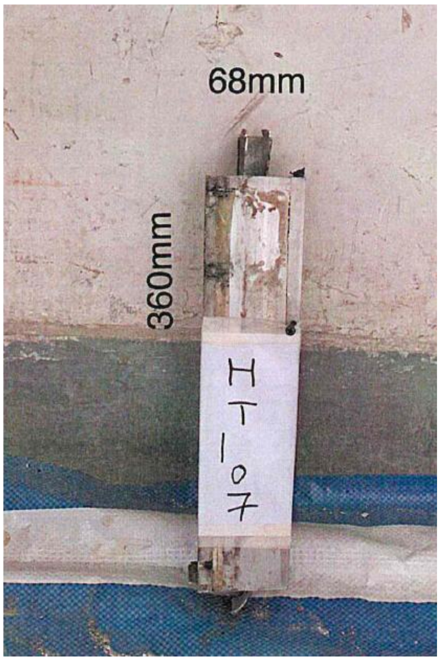


(d) Overview

Window HT07



(a) Frame



(b) Overview

Appendix E

Test Samples of Window Components Prepared from Windows in Appendix D

Windows	**Window frame**	**Glazing frame**	**Hinge**	**Rivets & screws**	**Greyish powder**	**Brown powder**
HT01	√ (coating)	√	√	√	√	√
HY01	√ (coating)	√	√	√		
HY02	√	√	√	√	√	
HY03		√ (coating)				
HT04	√		√	√		
HT05		√				
HT06	√		√	√		
HT07		√				

Note: (1) hinge and rivets were not available in some of the window samples

(2) greyish powder was found on adhered to the surface of some windows frame but they could not be removed and sampled for testing.

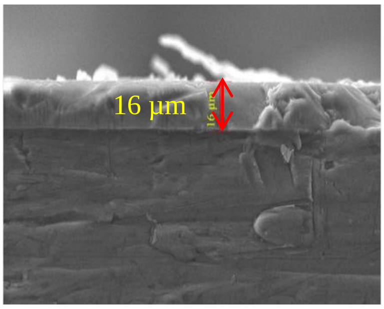
Configuration and Thickness of Window Frames

Windows	Configuration of window frame	Thickness of window frame (mm)	Thickness of glazing frame (mm)	Estimated year of fabrication
HT01	Double I section	1.46	1.12	1980s ~ 1990s
HY01	Double I section	2.78	2.24	> 2000s
HY02	Double I section	1.67	1.37	1980s ~ 1990s
HY03	Double I section	N/A	1.71	1980s ~ 1990s
HT04	N/A[1]	1.20	N/A[1]	1980s ~ 1990s
HT05	Double I section	N/A	1.23	1980s ~ 1990s
HT06	N/A[1]	1.18	N/A[1]	1980s ~ 1990s
HT07	Double I section	N/A	1.28	1980s ~ 1990s

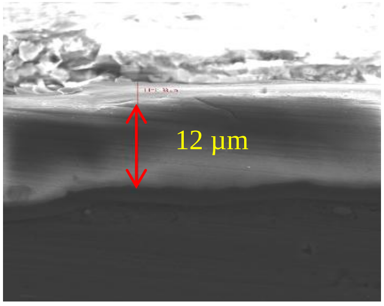
Notes: [1] denotes unknown configuration due to missing glazing frame

Coating Thickness

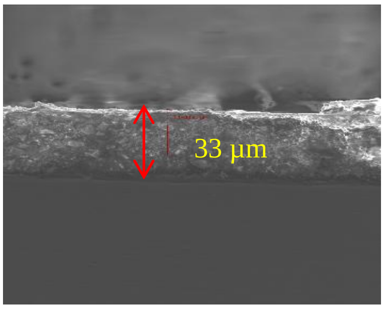
Figures below shows SEM images of cross section of window frame with coating thickness shown as marked.



a) Window HT01



b) Window HY01



c) Window HY03

Chemical Composition of Window Components

Sample		Chemical composition (wt%)											
		Al	Mg	Zn	Cr	Si	Fe	Mo	Ni	W	Mn	Cu	O
Frame	HT01	**98.93**	0.35	0.03	0.07	0.44	0.18						
	HY01	**97.24**	0.37			0.39							1.99
	HY02	**97.09**	0.40										2.50
	HY03	**96.68**	0.42			0.44	0.27						2.18
	HT04	**97.55**	0.46			0.43	0.25						1.30
	HT05	**97.35**					0.23						2.42
	HT06	**97.02**	0.51			0.37							2.10
	HT07	**96.67**	0.35			0.44	0.45						2.09
Rivet	HT01	**98.31**	4.39				0.27						1.42
	HY01	**95.34**	1.99		0.12		0.15						
	HY02	**97.38**	0.26				0.33				0.26		
	HT04	**96.25**	0.31				0.57						2.91
	HT06	**98.04**					0.53						1.12
Hinge	HT01				**18.96**	0.54	**70.94**	0.17	**8.75**	0.42			
	HY01				**18.12**	0.47	**71.43**	0.29	**9.21**	0.40			
	HY02				**17.95**	0.41	**70.45**	0.17	**9.23**	0.36	1.34		
Screw	HY01				**18.36**	0.37	**67.99**		**9.41**			3.41	

Appendix I

Commercially Available Alloy

(Reference 1: BS EN 573-3:2019 Aluminium and aluminium alloys — Chemical composition and form of wrought products.)

(Reference 2: BS EN 10088-1:2005 Stainless steels - Part 1: List of stainless steels)

Samples	**Chemical composition (wt%)**							
	Al	**Mg**	**Cr**	**Si**	**Fe**	**Ni**	**Mn**	**O**
AA 1100	**Balance**				0-1.0			
AA 5056	**Balance**	4.5 – 5.6			0.4			
AA 6061	**Balance**	0.8 - 1.2		0.4 – 0.8	0.4		0.15	
AA 6063	**Balance**	0.45 - 0.9		0.2 - 0.6	0.35			
SS 304			**17.5 - 19.5**	1.0	**Balance**	**8 - 10.5**	2.0	

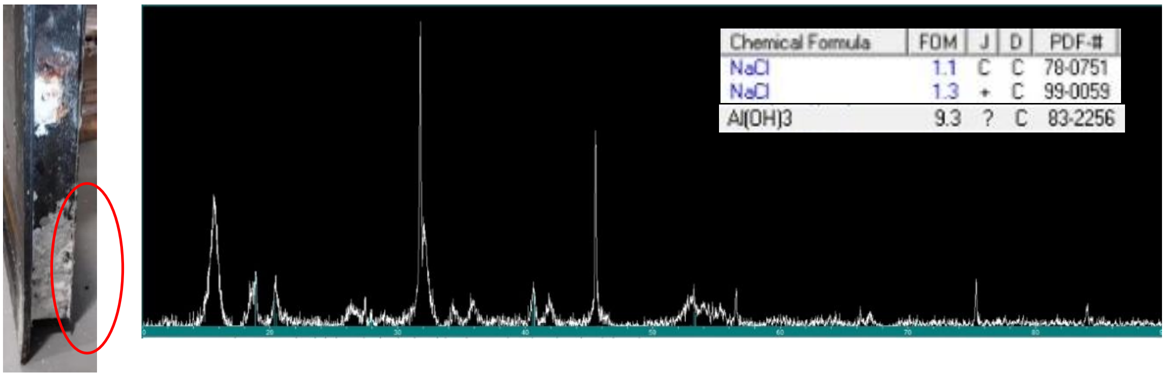
Appendix J

Window Samples Materials

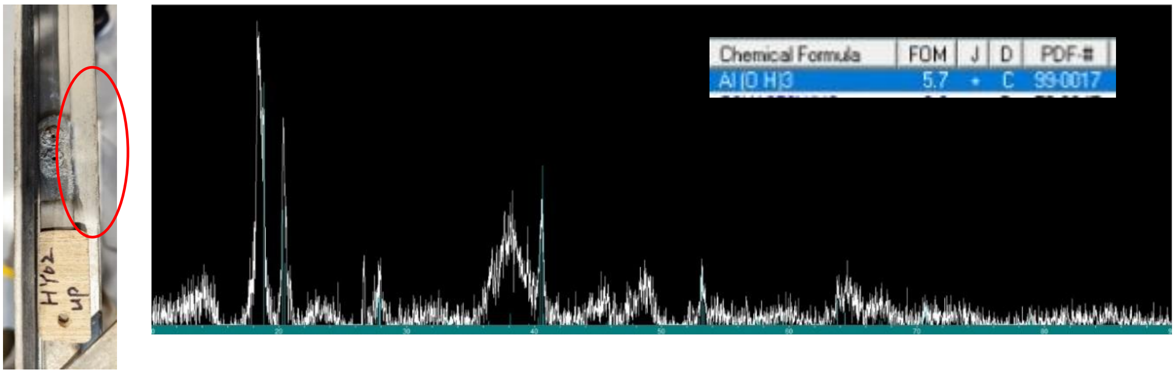
Windows	Year of manufacture of window frame	Parent material				Coating thickness (µm)	Corrosion product	
		Frame	Rivet	Hinge	Screws	Frame	Greyish powder	Brown rust
HT01	1980s ~ 1990s	AA 6063	AA 5056	SS 304		16	NaCl & $Al(OH)_3$	B-FeOOH
HY01	> 2000s	AA 6063	Not identified	SS 304	SS 304	12		
HY02	1980s ~ 1990s	AA 6063	AA 6063	SS 304			$Al(OH)_3$	
HY03	1980s ~ 1990s	AA 6063				33		
HT04	1980s ~ 1990s	AA 6063	AA 6063					
HT05	1980s ~ 1990s	AA 6063						
HT06	1980s ~ 1990s	AA 6063	AA 1100					
HT07	1980s ~ 1990s	AA 6063						

Appendix K

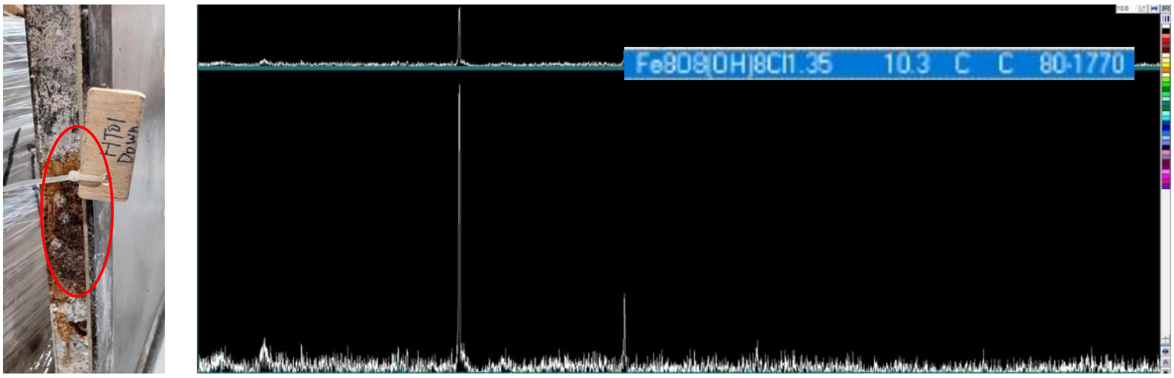
X-ray Diffraction Results



a) Window HT01 – window frame – greyish powder



b) Window HY02 – hinge – greyish powder



c) Window HT01 – window frame – brown rust

Test Programme for Field Exposure Tests

Test type	Location	Test duration (months)	Window samples			Plates						Total samples
			Frame*	Hinge*	Screw/rivet*	Carbon steel	Zinc	Stainless steel	AA 1100	AA 5056	AA 6063	
Field exposure test (ASTM G50-10)	BD Head quarter (9/F)	6	✓✓✓	✓✓✓	✓✓✓	--	--	--	✓	✓	✓	12
		12	✓✓✓	✓✓✓	✓✓✓	--	--	--	✓	✓	✓	12
		24	✓✓✓	✓✓✓	✓✓✓	✓	✓	✓	✓	✓	✓	15
	Yuen Long EPD	6	✓✓✓	✓✓✓	✓✓✓	--	--	--	✓	✓	✓	12
		12	✓✓✓	✓✓✓	✓✓✓	--	--	--	✓	✓	✓	12
		24	✓✓✓	✓✓✓	✓✓✓	✓	✓	✓	✓	✓	✓	15
	Sai Ying Pun EPD	6	✓✓✓	✓✓✓	✓✓✓	--	--	--	✓	✓	✓	12
		12	✓✓✓	✓✓✓	✓✓✓	--	--	--	✓	✓	✓	12
		24	✓✓✓	✓✓✓	✓✓✓	✓	✓	✓	✓	✓	✓	15

* Denotes window component samples from three different suppliers

Appendix M

Summary of Incident and MWIS Audit Report

Audit Reports				
No.	**District**	**Building age**	**Approx. distance from sea (m)**	**Defects found**
1	Wong Tai Sin	58	2,500	• Moderate corrosion of rivets • Missing rivet
2	Yau Tsim	56	800	• Moderate to slightly serious corrosion of rivets • Missing rivet
3	Southern	43	100	• Moderate corrosion of rivets • Missing rivet
4	Tuen Mum	35	100	• Moderate corrosion of rivets
5	Wont Tai Sin	30	2,000	• Moderate to slightly serious corrosion (bedroom)
Incident Reports				
No.	**District**	**Building Age**	**Approx. Distance from sea (m)**	**Defects found**
6	Southern	53	100	• For window associated with incident (CW1) in the bedroom, there's white powder around rivet holes but the degree of corrosion cannot be ascertained • Moderate corrosion of rivets
7	Sham Shui Po	61	1,500	• Rivet missing/loosen
8	Wan Chai	54	700	• Rivet corrosion moderate in general, one window on balcony serious. • Rivets and screws missing/broken in various locations
9	Mong Kok	55	1,000	• Corrosion and rust stain slightly more serious for window with incident • Remaining windows conditions are fair with moderate corrosion,
10	Wong Tai Sin	61	1,500	• Moderate corrosion of rivets • Missing rivet • Loosen/corroded hinge
				•

Corrosion Research Window Samples				
No.	**District**	**Building Age**	**Approx. Distance from sea (m)**	**Defects found**
HT01	Western	32	100	• Moderate to serious corrosion of rivets
HY01	Eastern	36	1,500	• Moderate to serious corrosion of rivets
HY02	Southern	33	<100	• Moderate to serious corrosion of rivets
HY03	Southern	33	<100	• Moderate corrosion of rivets
HT04	Yau Ma Tei	49	1,000	• Moderate to serious corrosion of rivets
HT05	Yau Ma Tei	49	1,000	
HT06	Yau Ma Tei	49	1,000	• Moderate corrosion of rivets
HT07	Yau Ma Tei	49	1,000	

Appendix N

Chemical Composition of Samples for Field Exposure Test

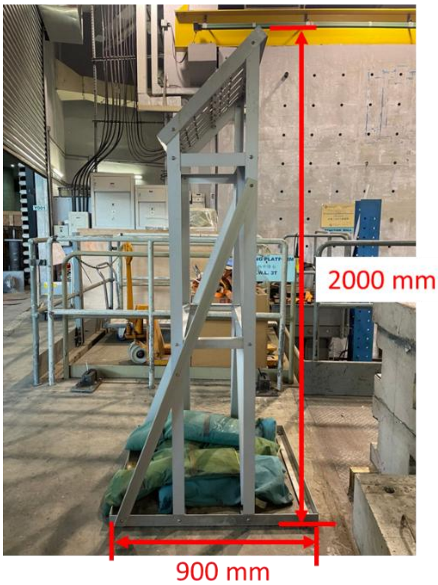
Sample types		Chemical composition (wt%)											
		Fe	Zn	Cu	Si	W	Al	Cr	Mg	Mn	Ni	C	O
Coupons	Carbon steel	**99.57**			0.13	0.30							
	Zinc	0.27	**96.4**	3.33									
	Galvanised steel	**99.57**			0.14	0.30							
	AA 1100	0.46					**97.73**						1.82
	AA 5056	0.57			0.75		**94.34**	0.22	2.09				2.03
	AA 6063	0.42		0.18	0.62		**95.97**	0.19	0.77	0.12			1.73
frame (AA6063)	Hangyue	0.18			0.54		**97.29**						2.00
	Sunwell	0.21			0.49		**97.18**						2.13
	Sunshine	0.22			0.48		**96.82**						2.48
Hinge (SS)	Hangyue	**71.99**			0.44	0.28		**19.06**			**8.19**		
	Sunwell	**72.22**			0.49	0.29		**18.90**			**8.10**		
	Sunshine	**72.09**			0.43	0.35		**19.03**			**8.10**		
screw (SS)	Hangyue	**69.24**		2.38	0.46	0.33	0.23	**19.09**			**8.26**		

	Window frame thickness (mm)	**Glazing frame thickness (mm)**
Sunshine	2.27	2.02
Hangyue	2.01	1.70
Sunwell	1.93	1.47

Appendix O

Proposed Location of Rack for Field Exposure Test

a) Overall view



b) Side view

c) Front view

Test programme of accelerated corrosion tests

Test type	Test duration (days)	Window samples			Plates						Total samples
		Frame*	Hinge*	Screw/rivet*	Carbon steel	Zinc	AA 1100	AA 5056	AA 6063	SS 304	
Neutral salt spray test (ISO 9227)	1	--	--	--	✓	✓	✓	✓	✓	✓	6
	3	--	--	--	✓	✓	✓	✓	✓	✓	6
	10	--	--	--	✓	✓	✓	✓	✓	✓	6
	21	--	--	--	✓	✓	✓	✓	✓	✓	6
	30	✓✓✓	✓✓✓	✓✓✓	✓	✓	✓	✓	✓	✓	15

Note: Salt spray test will be conducted according to ISO 9227 with 5% NaCl solution.

* Denotes window component samples from three different suppliers

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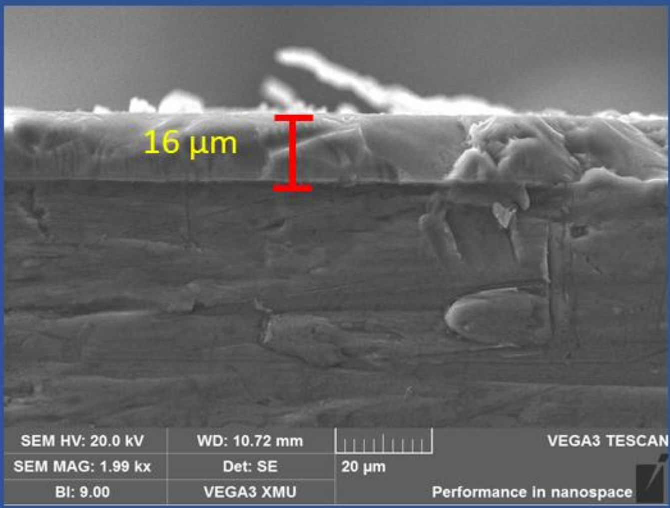
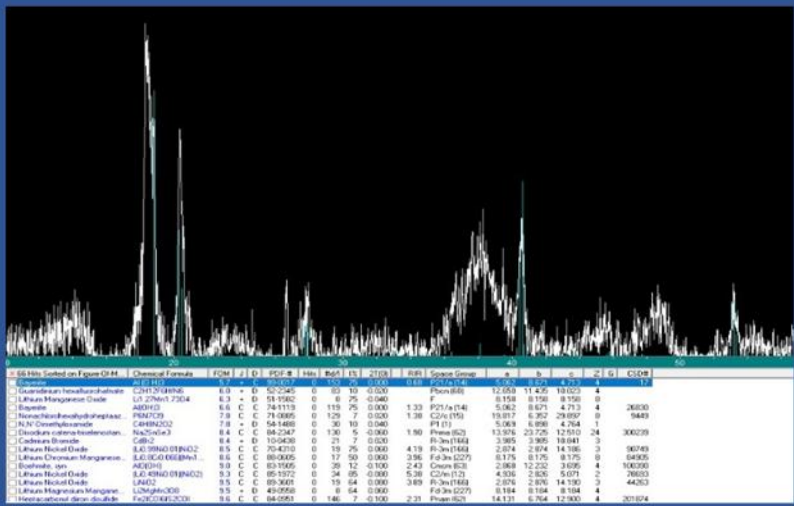
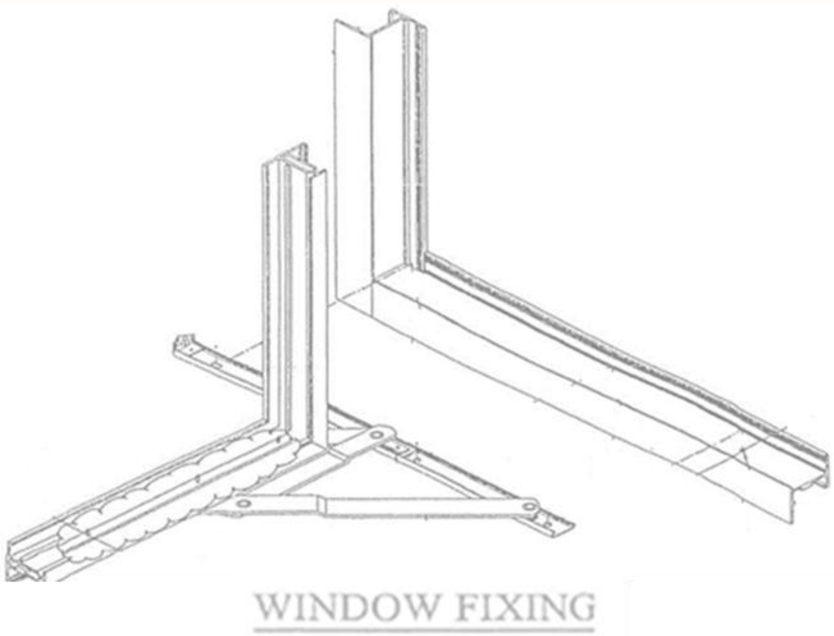
屋宇署
BUILDINGS DEPARTMENT





Technical Report on Corrosion of Aluminum Windows



Greater Bay Area Modern Construction Technology

Hong Kong Experience on Aluminum Structures