CONSTRUCTION FIXINGS association

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CFA Guidance Note: Fixings and Corrosion

1 INTRODUCTION

A significant proportion of fixings are inappropriately specified from the corrosion point of view. The consequences of poor specification range from unsightly staining to structural damage and costly repairs with the potential for risk to human life.

The most common mistake is the use of zinc plated carbon steel anchors for medium to long term use in external applications or those where significant humidity is present. Normal zinc plating is suitable only for dry internal use or short term use where humidity is present. However the specification of stainless steel, while ideal for most external applications, also has limitations in certain critical applications, which are discussed below.

The purpose of this Guidance Note is to give an introduction to the conditions leading to corrosion, to summarise the protection level offered by different materials and finishes and to outline the ways in which corrosion can be avoided.

This guidance is necessarily restricted in scope. More detailed discussions of all aspects can be found in the references in the bibliography. Some members of the Association have published comprehensive guidance on corrosion with respect to fixings.

Neither the Construction Fixings Association, nor its members, can be held responsible for any liability as a result of readers following this guidance. Readers are recommended to check the suitability of any specification with the manufacturer.

2 SUMMARY

The following table sets out appropriate anchor materials for typical exposure conditions where the fixture is in all cases compatible with the anchor material. (See section 3.3 Galvanic corrosion.)

It is a rough guide only; refer to the main text for a more detailed discussion of the various influencing factors.

Table 1	**Anchor material for required duration**		
Application condition	Short term	Medium term	Long term
Internal - Dry	Fe-Zn		
Internal humid, no chlorides or acid condensates	Fe-Zn	HDG	SS A2
External -Rural/Urban	HDG	HDG	SS A2
External – industrial or coastal	HDG	SS A2	SS A4
Special applications	Special consideration (see 6)		

Fe-Zn = Zinc plated carbon steel
HDG = Hot dip galvanised carbon steel.
SS A2 = Stainless steel Grade A2 (AISI 304)
SS A4 = Stainless steel Grade A4 (AISI 316)
Approximate duration:
Short = < 2 yrs, Medium = < 10 yrs, Long = < 50 yrs.

In the above summary table "External" applications involve normal conditions with no exceptional pollutants.

The most significant point to be made in the above table is that ordinary plated carbon steel fixings are inappropriate for anything other than long term use in dry internal conditions or short term use in humid internal conditions (see section 7).

3 TYPES OF CORROSION

There are many different types of corrosion mechanism. Here we discuss six which may affect fixing applications. They are discussed only in sufficient detail to enable specifiers to identify applications where they may occur and take the appropriate avoiding action.

Atmospheric corrosion

Pitting corrosion

Galvanic corrosion

Crevice corrosion

Stress corrosion cracking

Stainless steels under high temperatures

The potential influencing factors include types of metal, humidity, pollutants, temperature, stresses, design features including small gaps, and contamination.

3.1 Atmospheric corrosion

Most metals occur naturally as oxides and oxidation, which occurs in the presence of oxygen and water, is just the natural tendency to revert to that condition. In iron and steel "Rusting" is an aggressive phenomenon producing prodigious growth which, in the case of unprotected components contained within a structure, can exert forces sufficient to crack certain building materials. Unplated wall ties are quite capable of cracking mortar and lifting complete brick courses (hence wall ties are all at least galvanised which may also disappear leading to corrosion and damage thus Codes of Practice point to stainless steel which is mandatory for stone cladding).

The oxidation of aluminium occurs immediately it is exposed to the atmosphere producing a protective layer hence the dull patina and apparent corrosion resistance of this material. Stainless steel benefits from a similar protection mechanism in the development of a chromium based passive protection layer.

The corrosion of zinc, when exposed to the atmosphere, results in zinc carbonate (white rust) which develops at a rate of about one tenth that of red rust.

Avoidance

Depending on the durability required, and the degree of pollution, fixings of hot dip galvanised carbon steel may be considered but for most atmospheric exposure situations stainless steel will be the answer in grade A2 for long term rural and urban exposure with low chloride concentrations or Grade A4 for urban locations with higher chloride concentrations and industrial or coastal exposure. See Table 1.

3.2 Pitting corrosion

Pitting corrosion is the local breakdown of the passive layer on passively protected materials, such as stainless steel and aluminium, and results in pitting which can affect appearance, may cause some staining and, depending on section thickness, can eventually lead to complete perforation. It can be initiated by chemical contamination including seawater and other chlorides or even by steel fragments from non-stainless tools.

Avoidance
Ensure suitable thickness of fixing components. Avoid contamination from foreign corrosive matter e.g. mild steel tooling or machine swarf. Specify grade A4 stainless for polluted external conditions, see table 1. For applications involving more aggressive chemical attack consider using a "special" alloy grade of stainless steel – see section 4.5.

3.3 Galvanic corrosion

Often also referred to as "Bi-metallic corrosion" this occurs when two dissimilar metals are in electrical contact in the presence of an electrolyte e.g. rainwater.
Effectively a small cell is set up rather like a very inefficient battery. The metal which is less noble on the galvanic series will corrode faster than it otherwise would have done while the other is protected. This effect is one reason why zinc plating is used to protect steel. When the zinc plating is scratched or removed over a discrete area the zinc, which is less noble than steel, corrodes faster while corrosion of the steel is slowed and thus it is protected. (When plating is removed over a large area normal atmospheric corrosion takes place.)
The greater the potential difference between the two metals the faster the corrosion. The phenomenon is also area related so careful choice of metals can minimise the effect. If the more noble metal has a relatively large area the less noble will corrode more quickly. The effect on the rate of corrosion of fixings when in contact with other metals is illustrated in table 2 below for exposure in rural and urban areas. For more detailed consideration see [1].

Relative nobility of key metals:

Least noble
Zinc
Aluminium
Carbon steel & Malleable cast iron
Brass
Stainless steel
Most noble

Avoidance
Choose materials of fixing and fixture which are identical or have the ✔ rating in the table below. If this is not possible then either exclude water completely from the joint or isolate the materials electrically using neoprene or other non-metallic washers and sleeves (the latter is difficult to ensure and needs a high level of site supervision).

Table 2 Galvanic effect on the rate of corrosion of fixings

Fixing ► / Fixture ▼	Zinc Plated steel	HD Galvanised	Carbon steel (unplated)*	Brass	Stainless steel
Zinc Plated steel	✔	✔	✔	✔	✔
HDG coated Brackets etc	✔	✔	✔	✔	✔
Aluminium	✘	✚	✔	✔	✔
Structural steel (unplated)	✘	✘	✔	✔	✔
Cast Steel (unplated)	✘	✘	✘	✔	✔
Stainless steel	✘	✘	✘	✘	✔

Effect on rate of corrosion of the fixing:
✔ Insignificant or no increase in rate of corrosion
✚ Moderate increase in rate of corrosion
✘ Significant increase in rate of corrosion
* Additional protection must be applied to unplated carbon steel fixings for use in anything other than dry applications. (No member of the CFA supplies unprotected fixings.)
From this table it can be seen that fixing aluminium window frames with stainless steel fixings for instance will not be a problem. It also explains why the stainless steel expander clips used by some manufacturers on carbon steel plated anchors do not cause a problem as both the zinc plating and carbon steel anchor body have greater areas. Another potential problem arises with stainless fixings used in seawater (special alloys are best in sea water anyway see 4.5), or any other aggressive medium. If contact is allowed between the stainless fixing and reinforcing bars significant corrosion of the bars may take place; electrical isolation must be provided. This is most easily achieved with resin anchors where isolation occurs naturally but in cases of aggressive solutions then the corrosion resistance of the resin must be considered - see 4.6.

3.4 Crevice corrosion

Crevice corrosion occurs in chloride containing solutions where narrow gaps or crevices restrict the access of oxygen while allowing access for the solution and can even affect stainless alloys with good resistance to atmospheric corrosion. The crevices which allow this can be those that exist between washers and nuts (or bolt heads) and fixtures. Deposits on the fixings of e.g. mortar, sand, iron or accumulated dirt can eventually lead to crevice corrosion. The use of isolating washers does not prevent crevice corrosion.

Avoidance
Ensure no contamination by mortar, sand or other particles. Avoid stagnant solutions.
The most resistant materials are special alloys of stainless steel (see 4.5).

3.5 Stress corrosion cracking

A combination of very specific conditions leads to this problem. Standard austenitic stainless steels such as A2 and A4, when stressed, are particularly susceptible in the presence of chlorides and in temperatures in excess of 60°C. Hence swimming pool roof spaces are particularly prone to this type of corrosion. The stresses involved may be direct stresses, as in a tightened or loaded fixing, or simply the residual stresses from cold working or thermal cycles involved in the welding of fabricated bracketry. The result is not visible to the naked eye as it takes the form of fine cracks, which may lead to sudden catastrophic failure.

Avoidance

A2 and A4 material should not be used in conditions susceptible to stress corrosion cracking. Special high alloy grades may be suitable (see .4.5 Stainless Steels).

The traditional advice for suspension type applications common to swimming pools has been to use carbon steel components with organic coatings. This means care must be taken to maintain such coatings and ensure they cannot crack or be damaged.

3.6 High temperatures and stainless steel

The corrosion resistance of A2 and A4 stainless steels can be compromised by the high temperatures generated by grinding operations if not properly controlled and by welding.

Avoidance

Stainless fixings should not be welded. Never grind components involved in the functioning of the fixing. If grinding is used to remove excess stud length remove grinding products thoroughly - do not allow them to come into contact with other stainless components.

4 ANCHOR MATERIALS AND CORROSION RESISTANCE

4.1 Malleable cast iron

Usually zinc plated this material is restricted to use in shield anchors. Its corrosion resistance is slightly better than that of carbon steel but is treated the same.

4.2 Carbon steel

Severe rusting will occur with any unprotected components exposed to humidity or usual external conditions. Should only be used in plated or hot dip galvanised condition.

4.3 Zinc plated malleable cast iron or carbon steel

The protection against atmospheric corrosion offered by the zinc plating is directly proportional to its thickness. In the case of fixings this is typically 5 – 10mm (microns) and can only be relied upon for long term use in dry internal conditions. Durability is affected by factors which may remove the zinc carbonate produced by normal atmospheric corrosion such as the degree of exposure and regularity of washing. This means the following durability estimates are very approximate. Typically in external urban areas the plating would disappear in less than two years and in seawater in a matter of months.

Chromate passivation

This additional finish applied to zinc plating, which is commonly a yellow/gold colour but occasionally “Blue” (effectively clear) is only applied to prevent corrosion of the zinc due to chemicals contained in packaging materials and has no significant benefit in terms of atmospheric or other corrosion conditions.

Note: Some continental manufacturers use the term “Galvanised” for what we refer to as electroplated. When referring to “Hot dip galvanised” they will use that term in full. Check the plating thickness to see which they actually mean.

4.4 Hot dip galvanised (HDG) carbon steel

As for ordinary plated components the zinc coating thickness governs durability. Thicknesses used on fixings range from 45 - 60µm so protection in urban areas is in the order of 10 – 12 years while in seawater only around 3 years can be expected. Remember that the galvanising may be damaged or removed on some fixing types during installation e.g. throughbolts when hammered into the hole in concrete. If in doubt stainless steel versions should be considered.

4.5 Stainless steel

Austenitic stainless steel derives its corrosion resistance from Chromium, Nickel and in some grades, Molybdenum. Refer to BSEN 10088 for grade compositions and BSENISO 3506 for fasteners.

Grade A2 (303 and 304 etc)

Contains 17 – 19.5% Chromium and 8 – 10.5% Nickel.

The passive layer resists normal atmospheric corrosion in unpolluted rural areas but is susceptible to pitting and crevice corrosion in aggressive environments, such as industrial and coastal locations and may stain in polluted urban atmospheres. Many manufacturers are dropping this grade in favour of A4.

Old references such as grades 303 and 304 are being replaced with new references e.g. 1.4301 corresponds fairly closely in chemical composition and characteristics to 304S31.

Grade A4 (316)

Contains 16 – 18.5% Chromium, 10.5 – 14% Nickel, 2.5 – 3.0% Molybdenum.

The molybdenum improves the resistance to pitting corrosion. This grade of stainless steel is suitable for long term use in the most aggressive conditions normally encountered i.e. industrial coastal and marine environments including total immersion in seawater (not splash zone see 6.0). It has good resistance to pitting and crevice corrosion at normal temperatures.

New references for A4 316 include 1.4401, 1.4571 & 1.4436.

Special alloys of stainless steel.

Some manufacturers can make available fixings using these alloys which offer increased resistance to pitting and crevice corrosion compared with A4. They contain higher percentages of Chromium and Nickel and at least 6.0% Molybdenum. One such grade has the reference 1.4529 which contains 19.0 – 21.0% Chromium, 24.0 – 26.0% Nickel and 6.0 – 7.0% Molybdenum.

Special alloys of stainless steel are readily available in the form of threaded rods for resin anchor systems and a limited range of expansion anchors but can be supplied to special order for other systems. They may be considered for even more aggressive applications including those with high chloride exposure such as power station chimneys, desulphurisation plants and road tunnels where de-icing salts are drawn into the tunnels but not washed away by the rain. Depending on exact conditions these alloys may be considered for use in safety critical applications in swimming pool roof areas - refer to the manufacturer.

4.6 Resins and aggressive solutions

Resin formulations vary significantly so the following comments are a generalisation and may not apply to all resins. Check the resistance of a particular resin for a specific corrosion situation with the manufacturer, many of whom supply tables of corrosion resistance for a wide range of chemicals of varying concentrations.
Most resins are resistant to chlorides, including sea water, and to weak solutions of acids. They are generally not resistant to lubricating oils, strong acids, acetone and cleaning solvents (most solvents will evaporate before exposure can have an effect on the bond). It must also be born in mind that the exposure of the resin is usually limited to that close to the surface and deterioration of that portion of the bond may have little effect on the overall strength of the anchorage.

5 CORROSION AND APPROVALS

Approvals for anchors to be used in safety critical applications within Europe can now be issued according to the requirements of ETAG 001[2] This Guideline approves carbon steel zinc plated anchors (minimum plating thickness 5µm) only for long term use in dry internal applications and approves the use of stainless steel grade A4 for internal applications with humidity and all external applications where no particularly aggressive conditions exist. Other finishes may be approved if sufficient evidence of durability is provided during the approval process.
This policy of the ETAG does not mean that other materials/finishes such as hot-dip galvanised carbon steel or Grade A2 stainless are not suitable for certain applications depending on the actual corrosion conditions pertaining and the durability required.

6 SPECIAL APPLICATIONS

Most general purpose, and even safety critical applications, where no special corrosion conditions exist, are covered in Table 1. Where particularly aggressive environments exist or under conditions where there is a risk of a particular corrosion mechanism occurring e.g. crevice corrosion or stress corrosion cracking, then these become the governing factors and the avoidance measures recommended for those factors should be taken. Certain special situations are discussed below:

Sea water: Immersion in sea water is an aggressive condition for which special high alloys should be considered, especially in the splash zone.
Road Tunnels: Heavy atmospheric pollution plus de-icing salts used in road tunnels, or on their approaches, can cause severe corrosion so fixings likely to be affected should be specified as Grade A4 stainless steel or, in extreme cases, special high alloy stainless steel grades.
Industrial Chimneys. Combustion products are highly corrosive and grade A4 stainless steel is the minimum requirement for applications exposed to them. In some cases the conditions for stress corrosion cracking may exist so special alloys of stainless steel should be used.
Waste water treatment plants. Stainless steel grades A2 and A4 should be considered depending on chloride levels, refer to the manufacturer.
Chemical plants. Where strong acids may be present stainless steels may be attacked, refer to the manufacturer for advice regarding the particular conditions.
Swimming pool roof spaces – see section 3.5
Contact with rebar – see section 3.3

7 TEMPORARY FIXINGS

When fixings are used externally for short or medium term applications consideration must be given to how they are to be dealt with after their use is complete. If fixings cannot be removed from the structure but will be left in place, or ground off flush with the surface, then carbon steel anchors should be avoided as they may rust and cause structural damage, in this case fixings should be specified as for long term use.

8 INSPECTIONS

In certain cases where it is difficult to ensure adequate protection or where the extent of corrosion effects are difficult to predict then it is worth designing means for inspection into the structure and regular inspections into the maintenance schedule of the building.

References

[1] PD 6484 Commentary on corrosion at bi-metallic contacts and its alleviation. BSI www.bsi-global.com
[2] Guideline for European Technical Approval 001 Metal anchors for use in Concrete. www.eota.be

Other useful references:

- ❏ CFA Guidance Note: European Technical Approvals for Construction Fixings.
- ❏ Report C524 Cladding fixings – good practice guidance. CIRIA Tel 020 7222 8891 www.ciria.org.uk
- ❏ Curtain wall connections to steel frames. (Contains advice on how to isolate components of dissimilar metals.) P101. Steel Construction Institute. www.steel-sci.org
- ❏ Structural design of Stainless Steel. P291. Steel Construction Institute.

Other sources of advice:
British Stainless Steel Association -
Stainless Steel Advisory Service Email enquiry@bssa.org.uk
Tel 0114 224 2240. Online :- www.bssa.org.uk

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