What is it?

Corrosion is a process of restoring natural balance. In steel the iron content is chemically changed to a more stable iron oxide or iron salt.

The corrosion of metals is defined according to ISO8044 [1 p188]

"Corrosion is a physiochemical reaction between a metal and its environment which results in changes in the properties of the metal and which may often lead to an impairment of the function of that metal, the environment, or the technical system of which these form a part. The interaction is usually of an electrochemical nature."

In neutral or alkaline environments, dissolved oxygen plays an important role and corrosion only occurs if dissolved oxygen is present in the electrolyte. The most familiar corrosion of this type is the rusting of iron, when exposed to a moist atmosphere or water to form ferric hydroxide, which dries to form ferric oxide. Rusting requires an environment containing at least 1% each water and oxygen." [1 p188 Vernon]

The corrosion products of rusting steel bars occupy a volume of three or more times the volume of the steel section consumed. This volume increase will produce sufficient internal stresses to disrupt the surrounding grout or concrete.

Over time corrosion will reduce the effective section of the steel.

"There are three broad areas that generally define the type of corrosion. These are uniform or generalised corrosion, localised corrosion and cracking due to either stress corrosion or hydrogen embritlement.

Ground water with variable pH can create an electrolysis type corrosion cell.

Corrosion Protection of Grade 500 Reidbar™

Reidbar™ is often used in harsh or corrosive environments and in these areas some form of corrosion protection will need to be considered.

Reducing the effects of corrosion basically require isolating the iron from the environment in which it is to be used. Manufacturers of iron and steel products achieve this by combining the iron with alloys to form a more stable or corrosion resistant material.

For the past 10 years in NZ Reidbar™ has been produced as a micro alloyed steel and will have slightly better corrosion resistance than mild steel. The majority of Reidbar™ fittings are cast in Ductile Iron and these will corrode at about 30% of the rate for mild steel.[5] The exception to this is the marine environment where the corrosion rates are similar.

The corrosion products of Ductile Iron are not expansive.

The nature of corrosion is complex and the performance of corrosion protection systems can be extremely variable. The designer needs to thoroughly investigate local conditions before deciding on the protection method.

Common methods of corrosion protection include

- Applying a corrosion inhibiting medium
- Electro plating
- Hot metal spraying and Hot Dip Galvanising
- Painting and other surface coatings
- Encapsulating in a protective inert barrier

Each of these methods will offer differing degrees of protection. The selection of protection grade is dependant on the application, the application environment, the design life and the consequences of failure.

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Corrosion of Reidbar™

reid™
CONSTRUCTION SYSTEMS

The following paragraphs describe two of the protection alternatives for Reidbar™ together with their likely performance.

Hot Dip Galvanising

Reidbar™ and Reidbar™ fittings are galvanised to meet the requirements of AS/NZS 4680 with the nominal coating mass on Reidbar™ being 600gm/m^2. This equates to a surface zinc thickness of approximately 0.10 millimetres (100 microns).

To remove excess zinc, Reidbar™ fittings are spun in a centrifuge after galvanising and the resulting nominal coating thickness will be around 0.04~0.06 millimetres.

Since zinc coatings protect the steel by the sacrificial erosion of itself, the protective life of a metallic zinc coating is roughly proportional to the mass of zinc per unit of surface area. This is regardless of the method of application.

The Galvanising Association Handbook gives the anticipated life of 600 gm/m^2 of hot dipped coating at 50 years in a mild coastal environment and 25 years in a marine environment.

Some environment limitations are noted as follows:

Galvanising will give minimal protection for pH values less than 6.5 to 7.0. [1 p 179]

Unprotected galvanised systems should not be used with acid solutions below pH 6.0 or alkaline solutions above pH 12.5 [2p 21]

Additional protection is required when galvanised steel is in contact with chemically treated timber.

Cement grouts or concrete provide an environment where the pH is typically 9.5 to 13.5 in which a passive film forms on the steel that protects it from corrosion. However the loss of this protective alkalinity around the steel, or the presence of aggressive ions, notably chloride, in the grout or concrete, can lead to corrosion. [4 clause 8.2.3 para 6]

Hot Dip Galvanising will have no significant effect on the development length of reinforcing bars. [2 page 31]

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Surface Coatings

Surface coatings that are designed to resist corrosion simply enclose the metal component in an impervious barrier to exclude the corrosion causing elements. An effective coating needs toughness to resist abrasion and mechanical damage, proper substrate adhesion to resist corrosion migration at damage sites and be chemically inert.

An extremely effective method of providing this impervious barrier is coating the metal component with fusion bonded epoxy. In this process finely ground, fully cured epoxy powder, is applied to the hot surface of a clean grit blasted metal component. The residual heat of the component melts and fuses the epoxy powder to the component. The cured epoxy coating is flexible, abrasion resistant and almost impossible to remove.

The corrosion protection performance of fusion-bonded epoxy is further enhanced by pre coating the bar or fitting with a zinc rich fusion bonded epoxy.

Reidbar™ and Reidbar™ components can be coated with either fusion-bonded epoxy applied directly to the metal or first coated with the zinc rich fusion bonded epoxy and then over coated with fusion bonded epoxy.

The trade names of the epoxy products used are Black Beauty and Zinc Shield and are produced by Orica Powder Coatings.

Both the epoxy powder and the application and testing procedures meet the requirements of ASTM A775/A775M-97

Epoxy coatings will reduce the effective bonding of reinforcing bars in concrete. For the additional development length required, typically 1.2L_d to 1.5L_d, the designer should refer to the appropriate design literature.

How do you measure the effectiveness of a corrosion protection system?

The accurate simulation of actual long term performance on site during testing is virtually impossible. However a series of accelerated corrosion tests have been undertaken to provide a comparison of the relative performance of hot dip galvanising and fusion bonded epoxy.

The tests show that in the accelerated corrosion environment fusion bonded epoxy continues to provide corrosion protection for at least 20 times longer than a hot dipped galvanised surface.

These tests were carried out in a Q-Fog Cyclic Corrosion Tester (salt spray cabinet) in accordance with the test method ASTM B 117.[3]

The fusion bonded epoxy top coat was applied over a zinc rich fusion bonded epoxy base coat to give a combined total coating thickness of 270 microns. This coating system provided corrosion protection for at least 10,000 hours.

The hot dipped galvanised surface showed serious distress at 350 hours and was completely destroyed at 500 hours.

The tests showed that the difference in corrosion resistance between the fusion bonded epoxy only coating and the zinc rich plus fusion bonded epoxy coating was only apparent after 5000 hrs. At this time small blisters of 0.5mm diameter started showing on the bar surface but still no rusting.

Fusion bonded epoxy's are affected by ultraviolet radiation. Where part of an embedded bar is required to remain exposed some powdering may become evident.

The ultraviolet light in normal sunlight will degrade Fusion Bonded Epoxy coatings at approximately 2 microns per year.

Where Fusion Bonded Epoxy coatings are required to remain exposed to sunlight throughout a long working life then they should be overcoated with a 2 pack polyurethane paint system approximately 60 microns thick.

Due to the coating flexibility straining of up to 75% of the bar yield will not crack the epoxy coating. At these high loads there may be some damage to the coating surfaces within the nut.

References

1. Australian Tunneling Conference, Sydney Australia, August 1997
2. After Fabrication Hot Dip Galvanising, Galvanising Association of NZ
3. Orica Powder Coatings lab report # 0096 of 18 March 2002
4. BS 8081 British Standard Code of Practice for Ground Anchorages
5. A.S.T.M. Atmospheric Corrosion data Table 3.40

Double Protection for Permanent Ground Support

In ground support engineering the corrosion variables are complicated by a bewildering array of both ground types and ground water acidity.

The choice of the protection class required is the responsibility of the designer. That choice depends on such factors as consequence of failure, the aggressiveness of the environment and the cost of the protection. [4 cl 8.2.1]

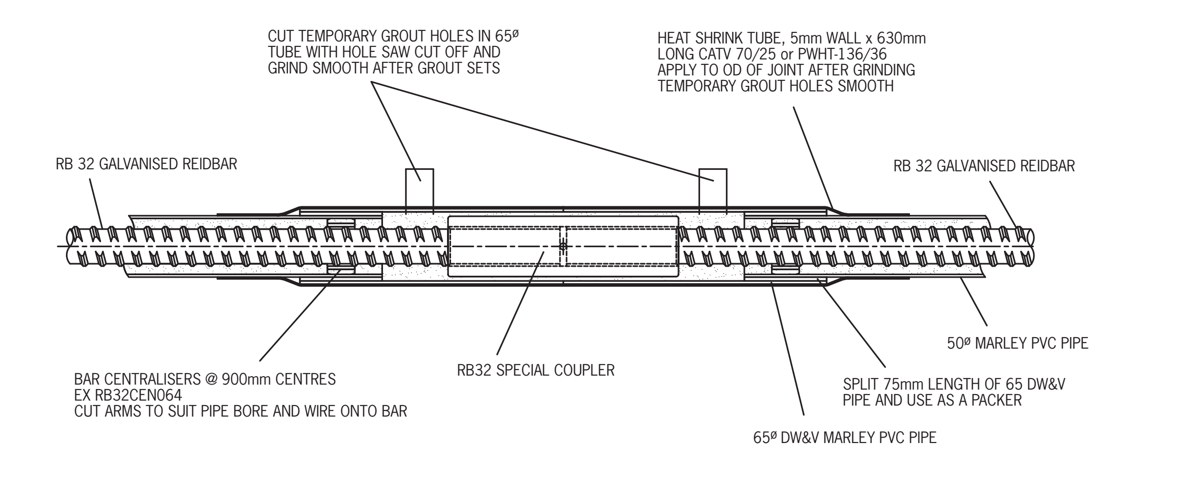
Permanent support bolts generally require double layer protection.

Because of the indeterminate nature of ground movement and the inability to ensure complete encapsulation of the bar, ground anchoring standards do not include the cement grout, or resin grout if used and insitu placed to bond the bolt, as a protection layer [4 clause 8.2.3 para 3 1 p 180.]

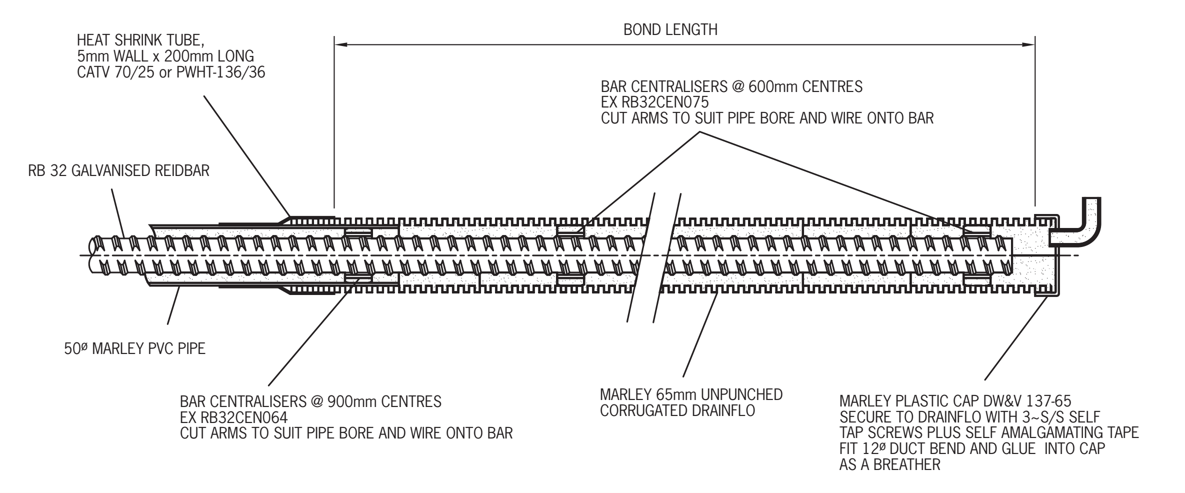
In ground anchoring the use of ribbed bar tendons (deformed reinforcing bar) has been shown to control the frequency of cracking of cement grouts within a corrugated duct encapsulation to such an extent that the crack widths are less than 0.1mm [4 clause 8.2.3 para 6]

Details 42 and 43 show typical arrangements of a double protected ground anchor, based on the requirements of BS 8081 and using standard off the shelf drainage materials

Detail 42.



Detail 43.



Features and benefits

Reidbar™ systems are designed to eliminate or reduce the need to weld reinforcing bars. Site conditions can often make it difficult to control both welding procedures and proper consumable selection.

References, standards

AS1554 Part 3 1983 and the WTIA technical note 1.

Joint design

Refer to AS1554 Part 3

Choice of welding process

This grade of steel is readily weldable by either metal manual arc (MMA) or semi-automatic and automatic (SUBARC) or inert gas shielded (MIG) processes.

Optimum results are obtained with MIG and automatic processes.

Consumables

When using MMA welding processes, we recommend the use of Hydrogen Controlled electrodes.

Note: Reidbar™ is manufactured in both New Zealand and Australia.

Prior to 2006 Reidbar™ of NZ origin has been a micro alloyed bar and could be welded using the procedures outlined for micro alloyed bar. In 2006 it is possible that Reidbar™ in NZ will be produced using a quenched and tempered process similar to that used in Australia. If this change occurs Reidbar™ should then be welded using the process outlined for quenched and tempered bars.

Grade 500E (Micro Alloyed)

Concrete reinforcing and welding

Careful design, process specification, qualification and control is vital for the integrity of weldments.

Welding processes can produce undesirable metallurgical defects in the steels being welded and in other adjacent materials subject to arc strikes and weld spatter. Defects introduced during welding can embrittle steel and create sites that act as stress concentrators, causing unexpected modes of failure. For this reason some codes prohibit or restrict the welding of reinforcing bars used in concrete construction.

As a general rule we do not recommend welding of reinforcing bars – especially on site where the required level of quality and supervision can be difficult to maintain. Where welding is required it should be critically supervised and carried out under carefully controlled conditions by suitably qualified welders using acceptable welding processes. Where bars are to be positioned in pre-fabricated cages, consideration should be given to tying rather than welding bars. Mechanical connection of bars using the benefits of Reidbar™ provide effective alternatives for joining bars both in the factory and on site.

Effect of heating on mechanical properties

There are two methods for achieving the required mechanical strengths of reinforcing bars:

- Addition of alloying elements to the steel
- Thermally treating the bar (cold water quenching and tempering)

Bars which are cold worked or thermally treated to increase their strength lose mechanical strength after heating. These bars cannot be heated before bending and can be adversely affected by welding processes. Great care and control must be exercised when applying heat to such bars to ensure that they do not exceed the critical heating temperature at any point. This is recognised by AS3600 Clause 19.2.3.1 which limits the design strength to 250MPa for bars heated in excess of 450°C.

Micro alloyed 500E Reidbar™ retains its full strength and ductility on cooling after being heated to temperatures in excess of 600°C.

Micro alloyed 500E Reidbar™ may be heated to assist bending without risk of reducing the mechanical properties, unlike cold worked or thermally treated bars.

See Freqently Asked Questions, pages 18 - 21.

Welding arc energy (heat input)

We recommend that a minimum welding arc energy of 2kJ/mm be used for all processes.

The use of well controlled high heat input processes is especially important for tack welds to reduce the risk for undesirable hardening in the heat affected zones adjacent to the welds.

Choose the largest diameter electrode possible for the job.

The electrode chosen should never be less than 3.2mm

As a guide the following minimum electrode sizes should be used for all welds including tack welds:

Table 32. Electrode Diameters.

Reidbar™ Diameter	Minimum Electrode Diameter
12, 16, 20	3.25
25, 32	4
over 32	5-6

Grade 500E (Micro Alloyed) continued

Preheating

Heating of steels prior to welding reduces the risk of cracking in the heat affected zones.

Regardless of the grade of steel, the best welds are achieved when the steel temperature prior to welding is at least 20-25°C.

Welds should never be attempted at temperatures below 0°C without preheating. In cold weather where such temperatures are expected it is essential to preheat the steel to 20-25°C.

Whilst good quality welds can be achieved in many steels at ambient temperatures above 0°C, the weldability and resistance to cracking depends on the steel chemistry and a number of factors which influence the rate of cooling from the welding temperature. These include the initial temperature of the steel, the physical size and mass of the pieces being joined, the size and shape of the weld, the welding heat input and the ambient temperature.

No additional preheat is required for any size of Reidbar™ when the welding arc energy exceeds 2kJ/mm.

Bars of 32mm diameter and larger require higher levels of preheat only when welded with arc energies less than 2kJ/mm. In practice it is unlikely that such low arc energies would be used for welding bars of this size.

Table 33.

Hydrogen controlled electrodes (E15XX, E16XX, E18XX, E28XX, E48XX)
or semi-automatic and automatic welding processes

	Electrode diameter				
	3.25	4	4	5	6
Arc energy kJ/mm E	$1 < E \leq 1.5$	$1.5 < E \leq 2.0$	$2.0 < E \leq 2.5$	$2.5 < E \leq 3.5$	$3.5 < E$

Bar diameter	Preheat temperature °C		
< 25	<	Preheat not required	
32	25	Preheat not required	
40	50		
50	75	50	Preheat not required

Metal manual arc welding with non-hydrogen controlled electrodes
(E10XX, E11XX, E12XX, E13XX, E14XX, E20XX, E24XX, E27XX)

	Electrode diameter				
	3.25	4	5	6	

Bar diameter	Preheat temperature °C		
< 25	Preheat not required		
32	50	Preheat not required	
40	75	50	
50	100	75	Preheat not required

Grade 500E (Quenched and Tempered)

500E Reidbar™ produced by the quenched and tempered method must have a carbon equivalent (CE) less that 0.39 (Australia Only). Consequently it requires no preheating prior to welding.

Hydrogen controlled electrodes must be used and matching strength electrodes will be required for full strength butt welds.

General Rules

Welding of reinforcing steel is not encouraged in New Zealand because of the high likelihood of strength or ductility loss in the heat affected zones. Localised weakened reinforcement could have dramatic effects on a reinforced concrete structure's response to seismic loadings.

If welding of reinforcement is undertaken it must conform to the requirements of ASNZS 1554 part 3.

Preheat

Not required

Post Heat

Not required

Electrode Type

- Hydrogen controlled welding processes and electrodes such as GMAW (MIG), FCAW and low hydrogen MMAW (sticks) must be used for all weld types. Correct control, storage and drying of electrodes is essential.
- Matching strength W55X (E55XX) or W62X (E62XX) type consumables are required for all load bearing butt welds.
- Under-matching W50X (E48XX) and W41 (E40XX) electrodes may also be used for lap and other weld types with appropriate weld lengths as shown in the following sections.
- Select electrode diameter to be compatible with size of bars being joined.

Interpass Temperature

This should be limited to 200°C maximum for all joints.

Welding Technique & heat Input

Best results are achieved using stringer beads where heat input will generally not exceed 2.5kj/mm. Weaving is not recommended.

Welding Practice Notes

- Observe 200°C maximum limit on interpass temperatures.
- For multiple welds, interpass temperature rise can be minimised by laying weld beads on separate joints in sequence thus allowing each weld to cool between runs. As interpass temperatures are likely to increase throughout, check the interpass temperature prior to commencing each weld run.
- Balance welding on each side of joint as required to minimise distortion.
- For butt welds, back grind root run prior to completing the joint.
- Clean and dress each weld run prior to deposition of subsequent runs.
- Refer to electrode manufacturer's recommended current ranges and shielding gasses.

General Notes

Non-symmetric joints such as lap welds may not be suitable for use in seismic applications – specialist advice should be sought in such cases.