

FABRICATION AND SITE HANDLING OF REINFORCING BARS

1 INTRODUCTION

An Australia/New Zealand Standard AS/NZS 4671 was published in 2001; a replacement for AS 1302; AS 1303 and AS 1304. The Standard formalised the introduction of 500 MPa yield strength steels. Rather than specify the steels by manufacturing process, the new Standard classifies by strength grade and ductility class (Low L, Normal N and Seismic E [NZ only]).

While higher strength steels were introduced, the Standard responded to designers' and builders' requests to maintain weldability and rebend characteristics, which are the cornerstones of Australian concrete construction technology. This has been achieved with only minimal changes in the Welding Standard AS 1554.3^[5].

Class N deformed reinforcing bars manufactured to comply with AS/NZS 4671 are high-strength, low-carbon steels. The compliance of both Australian manufactured and imported steel reinforcement is assured by one of two methods.

Firstly, by the Australian Certification Authority for Reinforcing Steels Ltd (ACRS). This is an industry-based, third-party product certification scheme for steel reinforcement and prestressing strand. If the product conforms to the relevant Australian Standards, it is permitted to display the ACRS 'mark' on its tags and other documents.

Alternatively, by compliance with ISO 9000 quality systems which guarantees that consistent processes developed by a company are being followed.

This Technical Note has several objectives:

- Give designers an understanding of reinforcing bar capabilities and limitations;
- Encourage good on-site practices in the handling, placing, rebending and adjusting of reinforcing steel;
- Provide commentary to the mandatory requirements of the Concrete Structures Standard AS 3600:2001^[2].

2 TYPES OF REINFORCING BARS AND THEIR IDENTIFICATION

Three types of deformed reinforcing bars complying with AS/NZS 4671 are available in Australia. Two are high-strength, hot-rolled deformed bars of Grade 500N and the third is low-strength Grade 250N.

2.1 Quenched and Self-Tempered Bars (QST) 500N

Most Grade 500N reinforcing bar is a mill heat-treated and tempered product. It is produced in straight lengths in diameters 12 mm, 16 mm, 20 mm, 24 mm, 28 mm, 32 mm and 36 mm.

General identification is by regular-spaced, inclined transverse ribs, two longitudinal ribs and a minimum of two (usually three) longitudinal marks in addition to the longitudinal ribs as, shown in **Figure 1**.

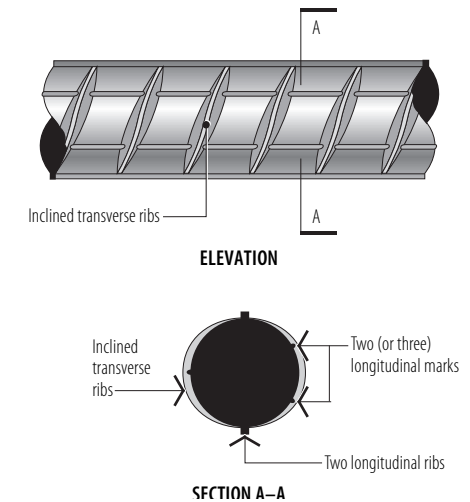
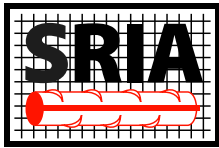


FIGURE 1 General Identification of QST (Straight) 500N Bars



2.2 Micro-Alloy 500N Bars

Micro-alloyed bars of Grade 500N, produced in coils, are available in sizes 10 mm, 12 mm and 16 mm. The high strength is obtained by the addition of small quantities of grain-refining elements such as vanadium and niobium.

Identification of the coil type differs from that of bars because it is necessary that the section be shaped to assist de-coiling and bending on automatic bending machines. Generally, off-coil 500N bars have four longitudinal ribs as well as uniformly-spaced, inclined transverse ribs (Figure 2). The longitudinal ribs of the straightened material may display a spiral shape, but this is not detrimental to the properties of the bar.

Micro-alloyed bars in sizes above N40 can be made to special order.

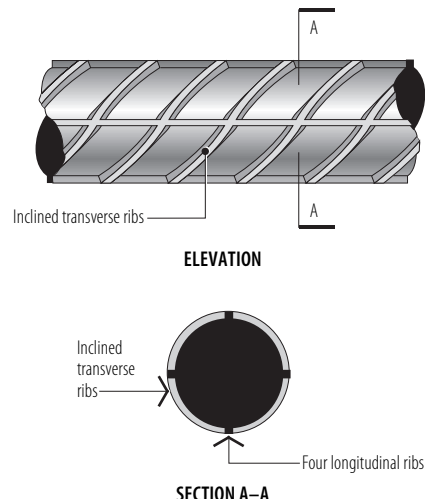


FIGURE 2 General Identification of Micro-Alloy (Off-Coil) 500N Bars

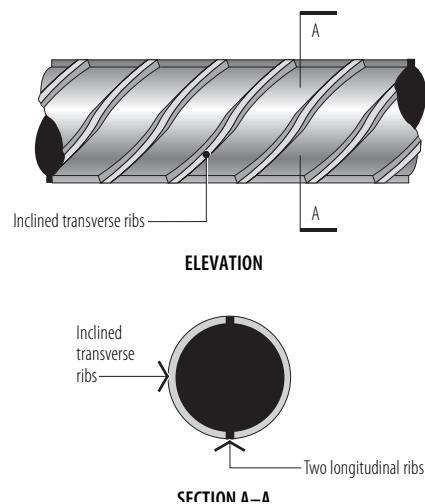


FIGURE 3 General Identification of Deformed 250N Bars

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2.3 Grade 250N Bars

Grade 250N deformed bars are available in a limited range of sizes. Their general identification is evenly-spaced, inclined transverse ribs and two longitudinal ribs (Figure 3).

Because it is 'softer' to bend into complex shapes on site, it is preferred by some steel-fixers for use in reinforced concrete swimming pools. Grade 250N is permitted for use in AS 2783^[3], but it is not included in AS 3600 or AS 2870^[4]. AS 2783 does not prevent the use of Grade 500N bars or 500L mesh.

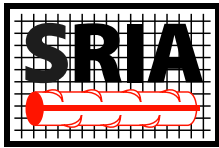
Plain round bars of low strength (250 MPa) have no distinguishing marks rolled on to the surface. In larger sizes they may be used as dowel bars. Note that the round-bar range of diameters differs from the deformed-bar sizes.

Coiled round rod, of Grade 250R, and in sizes R10 and R6, is straightened and bent for use as fitments.

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2.4 Identification Marks of Manufacturers

AS/NZS 4671 requires all deformed reinforcement bars to carry unique marks enabling the steel manufacturer to be identified.



3 BENDS IN REINFORCEMENT

3.1 AS/NZS 4671 Bend Test Requirements

A bend or rebend test is specified in AS/NZS 4671 as one of the quality-control tests for reinforcing bars during manufacture. The test requires that at room temperature, Class N reinforcing bars can be bent around a former or pin of $4d_b$.

For N20 bars and above, the bars are bent 180° . The bars comply if the test piece shows no visible evidence of cracking.

Class N bars with a diameter of 16 mm or less must be capable of meeting the requirements of a reverse-bend test. The test comprises the following steps:

- Bend the test piece 90° around a $4d_b$ former.
- Age the bent sample at 100°C for one hour.
- Cool and rebend the test piece 90° at room temperature by applying a uniform force using an appropriate tool.

Visual evidence of cracking is cause for rejection. Deformation compression cracking is acceptable provided the crack widths are less than the height of the deformation and the straightened test piece passes the tensile test requirements of AS/NZS 4671 after aging.

3.2 AS 3600 Bending Limitations

The ends of bars are often bent 90° or 180° to provide anchorage, or are bent to keep the bar within the confines of the concrete. To ensure that the bearing pressure between the steel bend and concrete is not excessive, reinforced concrete design standards specify a range of minimum bend internal-diameters.

Clause 19.2.3 of AS 3600 generally limits bend diameters to $5d_b$ for all grades, although a concession of a $4d_b$ pin is allowed for fitments of Grade 500N bars; and $3d_b$ for Grade 250N and for Class L material.

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3.3 Factory Bending Practices by Reinforcement Supply Companies

It is an industry practice that, unless instructed otherwise by the specifying engineer, the internal diameter of a bend will follow the structural design requirements of AS 3600, Section 19.

Bending is performed on purpose-made equipment which ensures consistent and accurate bend angles and causes little damage to the deformations both inside and outside the bend, provided that the internal diameter of the bend is five times the bar size or more. Bending hooks or cogs on large size bars imposes considerable stress on the deformations and bending pin because of the small lever arm available.

Bending to diameters less than any appropriate bend test requires special instruction in writing from, and becomes the responsibility of, the designer.

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FIGURE 4 Factory Bending around Pins of Specified Diameters

3.4 On-site Bending and Rebending Practices

This is a major cause of bar failures due to the use of inappropriate tools and methods.

Cold bending (the first bend)

A power bending tool, fitted with a forming mandrel of the correct size for the particular bar, or a manual bending tool similarly equipped, is required for all on-site bending operations.

A pipe is not recommended as this causes an extremely small effective bend diameter to be generated, resulting in extremely high localised stresses in the bend zone. This may lead to crushing of the ribs and cracking of the bar in the bend area, or to fracture of the bar if subsequent rebending is performed.

Figure 5 shows suitable manual bending tools while a hand-held power bender is illustrated in Figure 6, although these are not very common.

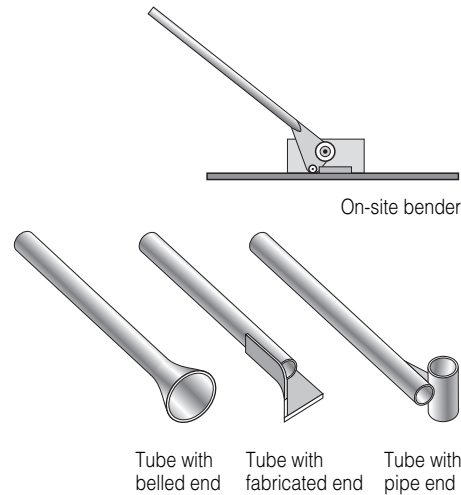


FIGURE 5 Manual On-Site Bending Tools



FIGURE 6 Hand-Held Power Bender

Cold rebending (the second bend)

In the general sense, this refers to any subsequent bending of a previously bent portion of the bar – ie forward or back. In practice, rebending usually applies to straightening a previously bent bar such as a pullout bar in slab and wall construction.

Clause 19.2.3.2(c) of AS 3600 gives the following minimum pin diameters for the first bend of bars which are intended to be subsequently straightened or rebent:

- $4d_b$ for 12-mm and 16-mm bars;
- $5d_b$ for 20-mm and 24-mm bars;
- $6d_b$ for 28-mm to 40-mm bars.

The same pin sizes apply for the rebend.

It is also stated there that any such straightening or rebending shall be clearly specified or shown in the drawings.

Cold bending of bars greater than 16 mm in diameter requires considerable force.

In all bending/rebending operations, surface damage must be avoided. Impact blows, such as by a sledge hammer, or power tools, to assist bending, should also be avoided as this may result in an uncontrolled bend diameter being produced, or the surface may be notched and damaged during clean out of the concrete, and cause the steel to display reduced bend ductility.

Where possible, a purpose-made power tool should be used for straightening and rebending. A typical hand straightening tool is shown in Figure 7.

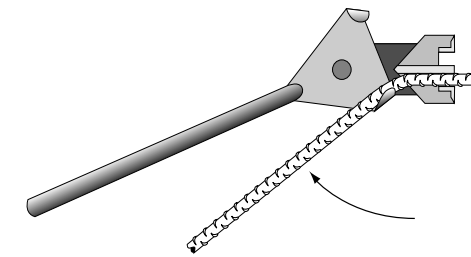
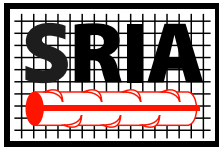


FIGURE 7 Manual Straightening Tool

A pipe, with an internal diameter not greater than $2d_b$, may be used to straighten a previously-bent bar provided that the necessary force is applied uniformly along the bar inside the pipe and not at the extreme end. The bending should be carried out with a single smooth continuous action. The pipe should not be less than 1.2 m long.

However, as previously stated, a pipe should not be used to create a new bend in any direction because the sharp edge can notch the bar.



Hot bending and rebending

The application of heat to a bar can significantly change the properties of hot-rolled reinforcing bars. Any change is irreversible. This operation should be avoided wherever possible.

If it is known or expected at the design stage that bars previously cast in concrete will need to be bent at a later stage, the details should be shown in the construction drawings. It is common for bending or rebending to be an unplanned operation and it is therefore important that it is properly supervised.

If heating is necessary, the following practice is recommended:

- Use a broad heating tip to ensure uniform heating along the length of the bend. Localised hot-spots must be avoided.
- Heat the cross-section of the bar uniformly along this length also.
- If the bar's design yield strength of 500 MPa must be utilised after bending, do not heat the bar above 450°C. This low temperature will require more bending force.

- If it is not essential that the full yield strength be maintained, the bar may be heated to a maximum of 600°C. However, if the temperature exceeds 450°C, then the maximum permitted strength is 250 MPa, since above this temperature the strength properties of Grade 500N bars can be reduced.
- Allow normal air cooling of the bar after heating and bending. Do not cool the bar by quenching with water.

Bar surface temperature can be checked by marking the surface with a thermal crayon immediately after heating. Bending should be performed as soon as the bar reaches the appropriate temperature (which of course is the lowest temperature at which bending can be performed). Care should be taken not to overheat the bar. As a rough guide only, 600°C corresponds to the first appearance of red in the bar, provided this is viewed in shade.

Thermal crayons (which change colour at a specific temperature) and similar temperature-measuring accessories can be obtained from building and welding supply companies.

N12 and N16 bars should be bent cold, because of their small size and the fact that heating cannot be controlled easily.

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For N20 and larger bars, power-operated bending tools are preferred, provided they can work in the confined space which often exists.

Bend diameters for hot-bending

Similar bend diameters and practices should be used for hot bending as for cold bending. See earlier clauses.

Kinks in rebent or straightened bars

It is generally not possible to rebend previously bent bars to perfect straightness; in fact attempts to do so could significantly reduce ductility and toughness. However, every attempt should be made to achieve adequate straightness without excessive cold-working or adjustment of the bar.

Deviations from linearity of the centreline up to 1db should be acceptable along with a directional change of 5°. This deviation is based on the same offset which occurs when a column bar is cranked for a compression splice.

Cutting bars on site

Bolt-cutters may be adequate for N12 bars, but above this size mechanical shears or oxy-acetylene equipment must be used. With the latter method, protection of nearby bars from hot-metal spatter is advisable. Because only the end of the bar is affected by heat, there is no reduction of strength or bond capacity.

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4 WELDING REINFORCEMENT

4.1 General

Reinforcing bars manufactured to comply with AS/NZS 4671 Grade 500N specification are the most 'weldable' high-strength reinforcing bars produced in the world. Some restrictions apply to these operations. These bars are particularly suitable for tack welding into prefabricated reinforcement components.

All forms of butt-welding, or tack- and lap-splice welds are permissible and the methods are given in AS 1554.3^[5]. A general summary of requirements for fusion-welded connections is as follows:

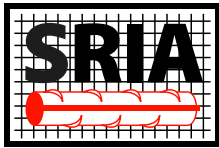
Preheat/Postheat: Not required.

Electrode type: Hydrogen-controlled types recommended for all welding.

Heat input: Control of heat input and weld inter-pass temperature is recommended for full strength butt and splice welds, to avoid changing metallurgical characteristics.

4.2 Welded Splices

Welded splices in reinforcing bars are covered by AS 1554.3.



4.3 Bending and Welding

Bending near an existing weld

Due to the possibility of residual stress near the weld zone, any subsequent bending should be positioned so that the start of any bend is at least 5 bar diameters away from the weld.

Welding near a previously-bent portion of a bar

The high temperatures that can accompany some welding operations may result in some strain ageing of previously cold-worked (eg bent) parts of the bar. Splicing welds should thus be positioned at least $2d_b$ from a bend. Clause 13.2.1(f) of AS 3600 requires a $3d_b$ spacing from a rebend. Locational tack welds are permitted on any bent portion of a bar.

Welding near a bend becomes critical when making fixings and connections for precast units. Careful detailing and explanation at the design stage should eliminate future problems.



FIGURE 8 Welding provides for safe, accurate assembly of column and beam reinforcement

Welding galvanised reinforcing bars

This is not recommended but if necessary reference should be made to *Galvanizers Association literature*^[6].

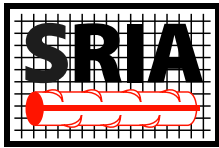
Welding epoxy-coated reinforcing bars

The coating prevents any form of welding and must therefore first be totally removed.

5 MECHANICAL SPLICES

LENTON SPLICES™ consist of a single sleeve with a tapered thread on the inside of both ends. A matching tapered thread is formed on each of the bars to be joined, and the bars are then screwed into the ends of the coupling.

500PLUS REIDBAR® is a continuous-threaded reinforcing bar system. The bar can be cut and joined at any point using a coupler. It is a 500N grade bar and it can be substituted for standard bars. This threaded bar system includes many accessories including couplers, lock nuts, threaded inserts, foot plates and grout sleeves.



6 GALVANISED REINFORCING BARS

6.1 General

The introduction of hot-rolled high-strength reinforcing bars in 1982 encouraged the use of galvanised coatings for enhanced corrosion protection of reinforcement, while still retaining adequate bar properties. Although there has been much debate on the value of galvanising

as a method of corrosion protection for reinforcement, there appears to be general acceptance that, with the possible exception of environments with high chlorides, a substantial improvement in corrosion protection is achievable with this process.

Galvanising provides a sacrificial anodic coating and is thus able to tolerate small discontinuities in the coating. The hard surface of the zinc also affords good protection against abrasion and mechanical damage after coating.

When determining the Exposure Classification of the surface of a member as set out in Section 4 of AS 3600, it should be noted that the concrete quality is selected for its own protection as much as for the benefit of the encased metals. Although the Note to Clause 4.3.1 states that protective surface coatings may be taken into account in the assessment of the exposure classification, this applies to a coating on the concrete, not on the bar. AS 3600 therefore does not permit any reduction in classification for the use of galvanised reinforcement. In practice, the concrete strength and associated covers are not to be reduced.

Wherever galvanised bars are used, it is essential that they be used throughout all parts of the structure where electric connectivity is possible. Interconnecting galvanised bars with uncoated tie-wire or other bars increases the sacrificial effect, and can reduce the assumed and expected protection. For more information see *Hot Dip Galvanizing* published by the Galvanizers Association of Australia^[5], and *Current Practice Note 17* published by Concrete Institute of Australia^[9].

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6.2 Effect on Bar Properties

Straight Bars

Galvanising has no significant effect on straight-bar properties.

Bent Bars

Galvanising may reduce the bar ductility marginally in the bend area but will still meet the requirements of AS/NZS 4671. A number of factors may cause this slight reduction in ductility:

- **Hydrogen embrittlement.** Some hydrogen may be picked up by the steel during acid pickling for scale removal prior to galvanising. The galvanised coating then 'locks' this hydrogen in the bar. Its effects will be most noticeable in the more highly-stressed region of a bend made before galvanising.
- **Strain ageing.** The high temperature of the galvanising bath (approximately 460°C), coupled with the cold-work in the bend zone, may result in strain ageing. This will slightly reduce ductility and slightly increase strength in the bend area. This effect is more noticeable with Grade 250N steels.
- **Brittle iron/zinc intermediate layer.** This small zone between the base steel and the zinc outer layer is quite hard, and may not tolerate as much additional cold deformation as would occur when rebending.

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6.3 Bending Galvanised Bars

Because bars can be galvanised either in their original straight condition, or after they have been bent to shape, a different effect can arise for each:

Pre-galvanised straight bar

As galvanising has little effect on properties of straight bars, bend diameters are governed by the requirements of bearing-pressure on the bend from concrete and the need to maintain adequate coating integrity after bending. The following minimum pin diameters are recommended to minimise cracking or flaking of the coating:

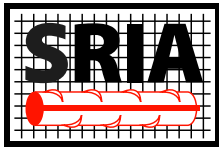
- $5d_b$ for 12-mm and 16-mm bars;
- $8d_b$ for 20-mm to 36-mm bars.

If excessive spalling in the bend area occurs, it should be repaired by application of a zinc-rich paint or a zinc-alloy repair rod, in accordance with Galvanizers Association Literature^[5].

Prebent bars (bending before galvanising)

As previously explained, this sequence of operations may reduce ductility in the bend region. An increase in pin diameter is therefore recommended to retain adequate bar properties:

- $5d_b$ for 12-mm and 16-mm bars;
- $8d_b$ for 20-mm to 36-mm bars.



6.4 Rebending Galvanised Bars

Once again the prior history of the bar is important:

Pre-galvanised straight bars bent, and rebent later

Although the rebending operation does not greatly affect the properties, repeated rebending will cause considerable flaking of the galvanised coating. This practice is not recommended.

Prebent bars galvanised, and rebent later

This is a more common practice, yet it is one of the major causes of bar failure on site for several of the reasons outlined earlier. Increased initial bend diameters are necessary to reduce the amount of possible work-hardening/strain-ageing in the bend zone, and to restrict flaking of the coating during rebending. The following minimum pin diameters for the initial bend are recommended:

- $5d_b$ for 12-mm and 16-mm bars;
- $8d_b$ for 20-mm to 36-mm bars.

Rebending is not recommended.

6.5 Repair

A zinc-rich paint may be applied to the bar after the surface has been wire brushed, as indicated in Galvanisers Association literature^[5].

7 EPOXY COATED REINFORCING BARS

7.1 General

When used correctly, this type of coating provides excellent protection against corrosion in all environments. This is achieved by providing an impermeable barrier between the steel and the environment. It is not a sacrificial coating and any discontinuities may allow substantial localised corrosion to occur. The coating is much softer than zinc coating on galvanised bars, and relatively gentle handling is required to avoid damaging the coating. At present only straight lengths can be coated effectively due to equipment limitations.

There is no Australian Standard for epoxy coatings on reinforcement. ASTM A775/A775M^[7] has been in use for many years but it is a constantly evolving document. Major concerns are adhesion between coating and bar, and the quantity of minute holes, or 'holidays', through the coating.

7.2 Effect On Bar Properties

Mechanical properties

Bars are heated typically to 220°C prior to coating; consequently, no change in bar properties occurs.

Anchorage length for stress development

Research overseas has shown that bond between concrete and the coating is reduced by some 20–30% to that of uncoated bars. ACI 318-02^[8] requires the basic development length or splice to be multiplied by:

- 1.5 for bars with cover less than $3d_b$ or clear spacing between bars less than $6d_b$;
- 1.2 for all other conditions.

Bend diameters

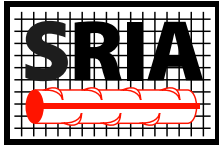
AS 3600, Clause 19.2.3.2 specifies bend diameters for bending as follows:

- $5d_b$ diameters for 12-mm and 16-mm bars;
- $8d_b$ diameters for 20-mm and greater.

7.3 Fabricating and Site Practices of Epoxy-Coated Bars

The principal requirement is to avoid surface damage to the coating during processing, fabrication, transport, handling and placing. The following guidelines should be noted:

- Bending should be performed around a non-abrasive former such as reinforced plastic or timber.
- During transport, bars should be secured so that abrasion will not damage the surface.
- For hoisting and craning, nylon or similar slings should be used. Such slings do not wear well and require careful application.
- Placing requires plastic or plastic-coated chairs, and plastic-coated tie-wire.
- Any loss of coating at cut ends, damaged areas, holidays, splices, heat-affected zones, etc, can be repaired by an appropriate epoxy-repair coating



8 REFERENCES

- [1] AS 3600:2001, *Concrete structures*, Standards Australia.
- [2] AS 2783:1992, *Use of reinforced concrete for small swimming pools*, Standards Australia.
- [3] AS 2870:1996, *Residential slabs and footings - Construction*, Standards Australia.
- [4] AS 1554.3:2002, *Structural steel welding - Welding of reinforcing steel*, Standards Australia.
- [5] *Hot Dip Galvanizing*, Galvanizers Association of Australia.
- [6] ASTM A775/A775M-02, *Epoxy-Coated Reinforcing Steel Bars*, American Society for Testing and Materials, Philadelphia, PA, 2002.
- [7] ACI 318-02, *Building Code Requirements for Reinforced Concrete*, American Concrete Institute, January 2002.
- [8] AS/NZS 4671:2001, *Steel reinforcing material*, Standards Australia.
- [9] CPN 17, *The Use of Galvanised Reinforcement in Concrete*, Concrete Institute of Australia, 2001.