INTRODUCTION

The 1982 revision of AS 1302 formalised the introduction of Grade 410Y hot-rolled, high-strength deformed reinforcing bars and resulted in a phasing-out of the cold-worked Grade 410C deformed bars. The 1991 revision of AS 1302 changed the specification of hot-rolled bars to 400Y to conform to the requirements of AS 3600.

The hot-rolled bars offer considerable advantages over cold-twisted bars, particularly in terms of ductility after bending, galvanising and the fact that the carbon and carbon-equivalent limits are below those of Grade 250 bars.

Whilst the deformed reinforcing bars manufactured in Australia to AS 1302 are probably the best of their type anywhere in the world, they are still high-strength, low-carbon steels, and as such require appropriate care in their use. However, isolated instances of bar failure have occurred because of a misunderstanding of bar capabilities at the design stage and due to some bad on-site practices.

This Reinforcement Practice Note outlines recommended practices which will greatly minimise the incidence of bar failures on site after various operations. Much of the information given in the 1986 edition of these notes was adopted in AS 3600 and is not repeated here.

TYPES OF AUSTRALIAN-MANUFACTURED REINFORCING BARS

Three types of deformed reinforcing bars complying with AS 1302 are manufactured in Australia. Two are high-strength, hot-rolled deformed bars of Grade 400Y, and the third is low-strength Grade 250S.

Quenched and Tempered Bars

TEMPCORE™ reinforcing bar is a mill heat-treated and tempered product, the high strength being obtained during the rolling operation. TEMPCORE™ is manufactured by BHP Rod and Bar Division at several plants in four States. A quenched and tempered 400Y bar is also manufactured by Smorgon Steel in Victoria.

Identification of the bar type is from markings imprinted at regular intervals on the bar surface. TEMPCORE™ has a set of smaller half-height...
longitudinal or transverse ribs spaced approximately 250 mm on 12-mm (Y12) and 16-mm (Y16) bars, and 500 mm on Y20 to Y40 bars Figure 1. Each mill of manufacture has its own distinguishing mark.

Smorgon Steel 400Y bar has one normally-inclined transverse rib replaced by a 90° transverse rib at approximately one-metre intervals over the range Y12 to Y16 Figure 2.

- Micro-Alloy 400Y Bars

Micro-alloyed bars of Grade 400Y with sizes above Y40 can be made to special order. The high strength is obtained by the addition of small quantities of grain refining elements such as vanadium and niobium.

- Structural Grade

Grade 250S deformed bars, previously available from 12 to 36 mm are now made only as S12 bars. 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 250S is permitted for use in AS 2783[8], but it is not included in AS 3600 or AS 2870.1[4]. AS 2783 does not prevent the use of Grade 400Y bars or fabric.

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 10 mm or below, is straightened and bent for use as fitments.

BHP and Smorgon also produce 400Y bar in coil form. They are hot-rolled deformed bars produced either by quenching and tempering methods or micro-alloy methods. They are straightened, cut to length and bent to shape if needed by reinforcement supply companies. The sizes are limited to Y12 and Y16.

Identification of the coil type differs from that of bars because it is necessary that the section be as near circular as possible to assist de-coiling and bending on automatic bending machines. The longitudinal ribs of the straightened material display a spiral shape, but this is not detrimental to the properties of the bar.

TEMPCORE™ in coil has four longitudinal ribs as shown in Figure 3.

Smorgon’s bar from coil has a pattern as shown in Figure 4.
3 BENDS IN REINFORCEMENT

3.1 AS 1302 Bend Test Requirements.
A bend test is specified in AS 1302 as one of the quality-control tests for reinforcing bars during manufacture. The test requires that at room temperature, reinforcing bars can be bent around a former or pin of:
- \(3d_b\) (3 bar diameters) for Y12 and Y16 bars;
- \(4d_b\) for Y20 and above.

The bars comply if the test piece shows no evidence of cracking.

Bars with a diameter of 20 mm or less must be capable of meeting the requirements of a reverse-bend test which is now included as an appendix to AS 1302. The test comprises the following steps:
- Bend the test piece 90° around a \(3d_b\) former.
- Age the bent sample at 100°C for at least two hours.
- Cool and straighten the test piece at room temperature by applying a uniform force using an appropriate tool.

Any brittle 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 1302.

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 fitsments of Grade 400Y bars, \(3d_b\) for Grade 250R and for wire.

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, and becomes the responsibility of, the designer.*

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.*

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 36-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 over 20 mm in diameter requires considerable force.

In all bending/rebending operations, surface damage must be avoided. Impact blows, such as by a sledge hammer 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 cause the steel to display reduced bend ductility.

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

A pipe 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.

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 400 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 400Y 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.

Y12 and Y16 bars should be bent cold, because of their small size and the fact that heating cannot be controlled easily.

For Y20 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 1d 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 Y12 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.

4 WELDING REINFORCEMENT

4.1 General

Reinforcing bars manufactured to comply with AS 1302 Grade 400Y 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(10). A general summary of requirements for fusion-welded connections is as follows:

Preheat/Postheat: Not required.
Electrode type: Hydrogen controlled types recommended for butt 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.

In this Standard, a ‘tack weld’ means a short weld for assembly and fixing purposes only. It need not be consumed by future weld runs.

Flash-butt welding is used to obtain a bar length above that available from stock, and as a means of conserving steel off cuts. Normally only two lengths would be joined to form one longer-length bar. Where possible, the location of the welds should be staggered within the structure.

4.2 Welded Splices

The strength of welded splices in reinforcing bars is covered by AS 1554.3 and AS 3600.

Clause 8.3 of AS 1554.3 requires that the tensile strength of a butt splice must be at least 1.05 times the specified bar yield strength of the reinforcing steel. This equals 420 MPa for Grade 400Y bars. It was based on the minimum tensile strength requirements of AS 1302.

AS 3600 on the other hand specifies in clause 13.2.2 that a welded splice must be capable of developing a stress not less than 1.1 fy for the smaller bar at the splice. This equates to 440 MPa for Grade 400Y bars, around which this Standard is written. Bars complying with AS 1302 will meet both these requirements.

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 75 mm, and tack welds some 5 bar diameters, away from any previously bent portion of the bar except tack welding of main bars into the corner of fitments (see Clause 1.6.2 of AS 1554.3).

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.
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
AS 3600 specifies in Clause 13.2.2 that a mechanical splice must be capable of developing a stress not less than 1.1 f_y for the smaller bar at the splice. This equates to 440 MPa for Grade 400Y bars. Bars complying with AS 1302 will meet these requirements. Currently, there are two mechanical tension splices in common use in Australia:

ALPHA-SPLICES™ consist of one or more steel sleeves swaged to both bars by circumferential compression applied by a hydraulic press. In its simplest form, only one sleeve is used, but this generally means that the second pressing must be made on-site after one bar has been fixed or cast-in. A more common arrangement is to have two sleeves which are swaged to each bar. The other is threaded and is later joined by a separate piece with a screw-thread. It is not necessary to form a thread on the bars – the sleeve is pressed into the space between the bar deformations and the extent of the swaging can be inspected visually.

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.

Both coupling types are capable of developing the joint stress required by AS 3600 when used with grade 400Y bars. It is common for one bar to be embedded in concrete before the splice is made; because threads must be tightened, the orientation of the second bar can be difficult to satisfy if that bar is a bent one.

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(6).

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 1302. 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 250R and 250S 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.

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 bend diameters are recommended to minimise cracking or flaking of the coating:
  - 5d₀ for 12-mm and 16-mm bars;
  - 8d₀ 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 AS 1650 Appendix B.

- **Prebent bars (bending before galvanising)** As previously explained, this sequence of operations may reduce ductility in the bend region. An increase in bend diameter is therefore recommended to retain adequate bar properties:
  - 5d₀ for 12-mm and 16-mm bars;
  - 8d₀ 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 bend diameters for the initial bend are recommended, and used again for the rebend:
  - 5d₀ for 12-mm and 16-mm bars;
  - 8d₀ for 20-mm to 36-mm bars.

Rebending practice should be as outlined earlier in Clause 3.4, with an additional requirement that the amount of rebending should be minimised.

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(8).

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 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** Recent research overseas has shown that bond between concrete and the coating is reduced by some 20–30% of that of coated bars. ACI 318-89(8) requires the basic development length or splice to be multiplied by:
  - 1.5 for bars with cover less than 3d₀ or clear spacing between bars less than 6d₀;
  - 1.2 for all other conditions.

- **Bend Diameters** AS 3600, Clause 19.2.3.2 suggests bend diameters for bending as follows:
  - 5d₀ diameters for 12-mm and 16-mm bars;
  - 8d₀ diameters for 20-mm to 36-mm bars.

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 cranage, 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 1302 Steel Reinforcing Bars for Concrete Standards Australia, 1991.
5 AS 1554.3 Welding of Reinforcing Steel, Part 3 Standards Australia, 1983.
8 ACI 318-89 Building Code Requirements for Reinforced Concrete American Concrete Institute, November 1989.

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