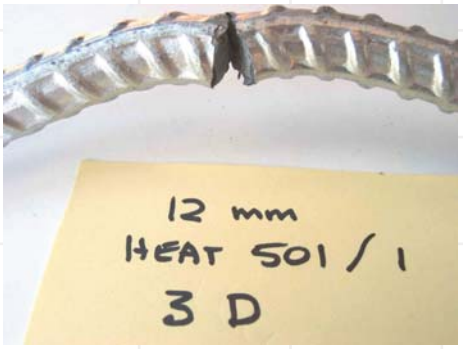
39 - GALVANIZING 500N GRADE REINFORCING BAR - TECHNICAL CONSIDERATIONS FOR DESIGNERS

INTRODUCTION

In the 1980's in Australia, new technology for manufacturing high strength steel reinforcing bar (rebar) was introduced that enabled the production of 410 MPa strength bar using a quenching and tempering process or alternatively micro-alloying of the steel. This grade of rebar was identified as 410Y Grade.



Micro-alloyed 12 mm 500n Grade reinforcing bar failed rebend testing around 3D radius

This technology replaced the cold-work processes that were previously used by the industry to obtain higher tensile levels for rebar. This cold-worked bar presented a barrier to hot dip galvanizing because of the high stresses involved in the cold working and subsequent bending to schedule.

This type of bar, identified as 410C Grade, was susceptible to embrittlement and required costly heat treatment after hot dip galvanizing to avoid the risk of brittle fracture in service.

All 500N Grade 32mm reinforcing bar passed the bend test if bent after galvanizing and AS 3600 specifications for bend radii were adhered to.

On its introduction, 410Y Grade rebar was subjected to extensive testing to validate its suitability for hot dip galvanizing without requiring any special post-treatment. The satisfactory results from this test program resulted in the galvanized rebar option being incorporated into the standards, codes and practice notes that have been used as reference documents for the reinforced concrete industry since the mid-1980's.

In the early 2000's, Australian rebar manufactures modified their processes to increase the tensile rating of standard grades of high-tensile rebar to nominally 500 MPa, with the grade designation of 500N. Some of the processing recommendations for hot dip galvanizing 500N Grade rebar appear to have been transposed from the 410Y Grade data.

500N Grade reinforcing bar presents no problems if galvanized after bending if AS3600 standards are complied with in the processing

In 2006, a number of inquiries were received from consultants requesting technical support information related to the hot dip galvanizing of 500N Grade rebar.

A literature search indicated that there had been no specific comprehensive test information published by the industry. It should be noted that no problems had been encountered with the galvanizing of 500N Grade rebar, where the processing procedures in accordance to AS/NZS 3600 standards had been implemented.

However, to validate the performance criteria for the galvanizing of 500N Grade rebar, a research project proposal was put to the International Zinc Association (IZA), through Nyrstar, one of its member companies, to fund this project.

PROJECT PARTICIPANTS

The project participants included OneSteel Pty Ltd, major manufacturer of 500N Grade rebar, Nyrstar Pty Ltd, Australian zinc producer and IZA member, Industrial Galvanizers Corporation (hot dip galvanizer) and Mount Townsend Solutions Pty Ltd, metallurgical consultancy.

PROJECT DEVELOPMENT

Initial tests were done on standard uncoated lengths of 500N Grade rebar to determine the typical

actual yield strength compared to the nominal 500 MPa specified for the grade. These tests were undertaken by Amdel Laboratories. Two sets of three samples each of 24 mm bar, from two separate heats were supplied by OneSteel. One set of samples from each heat was galvanized by Industrial Galvanizers (Newcastle) to evaluate the effect of hot dip galvanizing on the mechanical properties of the 500N Grade rebar, before and after galvanizing.

This series of tests showed that the actual yield stress was approximately 600 MPa, with that of the galvanized samples being slightly higher than that of the as-rolled samples (average 605 MPa versus 592 MPa or 2.2%). The galvanized samples had higher elongation than the as-rolled samples (10.8% versus 10.15%).
For practical purposes, these preliminary tests indicated that the hot dip galvanizing process had no significant effect on the mechanical properties of the 500N Grade rebar.

TYPICAL STEEL CHEMISTRY
The specification for cast analysis given in AS/NZS 4671 for this product is as follows (% max);

C - 0.22
P - 0.050
Si - 0.050
Ceq* - 0.44

* Carbon equivalent

Note: Carbon Equivalent Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15

The typical chemical composition (in % by mass) of the OneSteel TEMPCORE product is as follows;

C - 0.20
P - 0.013
Mn - 0.80
Si - 0.20
S - 0.020
Ni - 0.06
Cr - 0.10
Mo - 0.02
Cu - 0.20

For OneSteel micro-alloyed bar, the typical composition is;

C - 0.15
P - 0.013
Mn - 1.16
Si - 0.27
S - 0.020
Ni - 0.06
Cr - 0.10
Mo - 0.03
Cu - 0.21
V - 0.073

TESTING STRATEGY
A test program was developed to evaluate the performance of hot dip galvanized rebar that was

galvanized before and after bending, and to test sections that were bent in contravention of the existing recommended minimum bend radii recommendations, in addition to sections bent in accordance to the AS 3600 requirements.

The decision to test rebar bent to tighter than recommended radii was made to better define likely failure end-points and to recognise that some manufacturers providing fabricated elements containing 500N Grade rebar frequently exceeded the bend radii limitations in contravention of rebar manufacturers recommendations. (e.g. rebar welded to protection angles and other fabricated structures embedded in concrete)

The technical information published by OneSteel for its Grade 500PLUS rebar with respect to AS 4671 and AS 3600 bending limits is as follows:

Table 1 – Bending Properties

Diameter	AS4671 requirements	AS3600 Limits	TEMPCORE 500PLUS Capability	Micro-alloyed 500PLUS capability	Galvanized Bars*
≤ 16 mm	Not stated	5d generally but 4d for fitments	2d x 180 deg.	3d x 180 deg.	5d x 180 deg.
≥ 20 mm	4d x 180 deg.	5d generally but 4d for fitments	3d x 180 deg.	Not produced	8d x 180 deg

* Bending limits shown in this table have been specified in AS3600 to minimise spalling of the galvanized coating.

Table 2 – Re-bending properties.

Diameter	AS4671 requirements	TEMPCORE 500Plus Capability	Micro-alloyed 500Plus capability	AS3600 Limits
≤ 16 mm	4d	4d	4d	4d
20 ≥ d ≤ 24 mm	Not specified	5d		5d
28 ≥ d ≤ 36 mm	Not specified	6d		6d

The manufacturer's literature also states:

Rebending bars that have been bent prior to galvanizing.

This operation is currently not recommended, as cracking on the inside of the original bend may result. If it must be performed, careful checking for cracking should be carried out, and the largest diameter possible used for the initial bend but, in any case, not less than 5d for bars up to 20 mm diameter and 8d for larger diameter bars.

TEST RESULTS

A test program involving 176 samples from various steel heat numbers selected at random in 12 mm, 24 mm and 36 mm diameters was developed to include bend diameters from 1d to 8 d, bent both before and after galvanizing.

Each sample was individually ID tagged to ensure its identity was retained throughout the test program.

The test program included hardness testing samples of each section across the bend zone after bending to determine the degree of work hardening arising due to the cold working of the steel.

The samples were galvanized at Industrial Galvanizers (Newcastle) plant in accordance with AS/NZS 4680 hot dip galvanizing procedures.

Amdel Laboratories undertook the bending and hardness testing of the samples in accordance with the test schedule.

Any visible cracking of the rebar was deemed to be a failure and is reported as such in the test tables.

One bar was taken from each heat number/size and hardness tested across the bend by sectioning the bar and measuring the Rockwell B harness at the centre and the edge of the bar to determine the degree of hardening to which the sections are subjected during cold bending.

An approximate conversion relating hardness to tensile strength has been applied to the test results, based on hardness conversion tables provided by OneSteel. Unless otherwise marked, all bends were 90o. Samples bent through 1800 are identified in the tables.

A series of samples from two heats of 12 mm micro alloyed rebar failed the 3D rebend tests after being pre-galvanized (Test sheets N5033/6A and N5033/8A). A similar set of samples galvanized after the initial bend passed the 3D rebend tests (Test sheets N5033/5A and N5033/7A).Given that these results were contrary to expectations, a set of re-tests on micro alloyed rebar was undertaken, using 16 mm material. (12 mm micro alloyed bar samples were not available in a timely manner to complete the test program)

The pre-galvanized samples passed both the 3D and 5D rebend tests. However, the samples galvanized after the initial bend all failed the 3D and 5D rebend tests. This reflects the recommendations made in the OneSteel 500 Plus Rebar bending properties documentation.

SUMMARY

These tests to evaluate the limitations related to the hot dip galvanizing of 500N Grade steel reinforcing bar have supported the manufacturers' recommendations related to the processing of 500N Grade steel reinforcing bar, both prior to and after hot dip galvanizing.

These results also support the recommendations of the relevant concrete codes; specifically AS 3600 -2001 Concrete Structures and Concrete Institute of Australia's Current Practice Note Number 17 - 2002: The Use of Galvanized Reinforcement in Concrete.

It should be noted that bending reinforcing bar outside these guidelines either before or after galvanizing is not recommended.

It should also be noted that cold bending of 500N Grade reinforcing bar results in a significant increase in hardness in the cold-worked area. Re-bending practices should comply with manufacturers' recommendations to prevent the risk of strain age embrittlement of excessively cold-worked 500N Grade rebar.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01 - SPECIFIERS MANUAL — THIRD EDITION

Industrial Galvanizers Australian Galvanizing Division (IGAG) operates nine galvanizing plants around Australia, ranging in size from large structural galvanizing facilities to specialised small plants designed to process small parts.

The Australian Galvanizing Division has galvanized in excess of 2 million tonnes of steel products in Australia since its first plant was commissioned in 1965 and is recognized for its ability to handle complex and difficult projects, as well as routine contracts.

This experience has been collated in the Specifiers Design Manual, to assist those involved in the design of steel products and projects to better understanding the galvanizing process and allow the most durable and cost-effective solutions to be delivered to these products and projects. All sections of this Third Edition have been completely updated and additional sections have been included to provide additional technical information related to the use of hot dip galvanized steel.

In addition to its Australian Galvanizing operations, Industrial Galvanizers Corporation has a network of manufacturing operations in Australia, as well as galvanizing and manufacturing businesses throughout Asia and in the USA.

The company's staff in all these locations will be pleased to assist with advice on design and performance of hot dip galvanized coatings and products. Contact details for each of these locations are located elsewhere in this manual.

This edition of the Industrial Galvanizers Specifiers Manual has been produced in both html and .pdf formats for ease of access and distribution and all documents in the Manual are in .pdf format and can be printed if paper documents are required.

The Specifiers Manual is also accessible in its entirety on the company's web site at www.ingal.com.au.

Additional copies of the Specifiers Manual are available on CD on request.

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