Department of
Building and Housing
Te Tari Kaupapa Whare

Report on Grade 500E Steel Reinforcement

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Executive summary

In response to concerns raised by Dr Barry Davidson of the University of Auckland and other members of industry about the performance of Grade 500E reinforcing steel, the Department of Building and Housing carried out an investigation, which included:

- surveying ACENZ members on problems with 500E steel
- commissioning a report on the compatibility of the various Standards covering the manufacture, design, welding and handling of Grade 500 steel
- commissioning a series of tests on bars nominally sold as Grade 500E, both locally manufactured and imported product
- reviewing the available evidence of problems arising from the Auckland University tests.

The above tests and investigations identified some key issues affecting the use of Grade 500E, as follows.

Manufacturing and supply issues

- Local versus imported product.
- Identification markings – uniqueness and suitability.
- Deformations – compliance with New Zealand Standards.

Design issues

- Design practice – knowledge, bending, welding, reporting of failures.
- Auckland tests and cyclic effect.

Fabrication and construction issues

- General handling and reported failures.
- Welding – advisability of butt, lap and tack welding.
- Bending – ability to withstand without significant detriment to physical properties.
- Re-bending – inadvisability of allowing this.

New Zealand Standards issues

Consistency and coverage of New Zealand Standards for manufacture/design/welding/handling.

Detailed recommended actions are given in section 5 of this report and fall into the following categories.

- General education, advice and warnings to the industry on the properties of Grade 500E and its limitations and benefits.
- Research to provide better information on key issues.
- Specific advice to designers on implications for design.
- Specific advice to fabricators and constructors on the need for care in handling reinforcing steel, in particular Grade 500 steel.
- Amendments to New Zealand Standards.
  - Changes to requirements.
  - Inclusion of information about limitations regarding Grade 500E steel.

1 Introduction and background

Concerns were raised in 2003 by Dr Barry Davidson (of the University of Auckland and President of the Structural Engineering Society) that Grade 500E reinforcing steel might not be fit for its purpose as reinforcing when subject to design earthquake loading in ductile reinforced concrete structures. This followed some failures of bars under simulated earthquake loading at Auckland University. There were also reports of bars breaking when handled on site. John Scarry did not refer directly to Grade 500E steel in his Open Letter to the Building Industry Authority in December 2002, but mentioned concerns about the bending and rebending of reinforcing steel in general.

The Department of Building and Housing responded by investigating the concerns and the detailed issues behind them. These investigations included:

- asking ACENZ members to report any problems with Grade 500E steel and reviewing available data on specimens that had been referred to Pacific Steel as the manufacturer
- commissioning a report from Beca Consultants on the compatibility of the various Standards covering the manufacture, design, welding and handling of Grade 500E steel
- commissioning a series of tests by SGS on bars nominally sold as Grade 500E, both locally manufactured and a sample of imported product, to determine their physical properties
- reviewing the available evidence of problems arising from the Auckland University tests
- investigating the parameters that govern allowable bend diameters.

2 Summary of investigations

2.1 Reported problems

The Department was provided with a table of samples that had been referred to Pacific Steel for their investigation. To this the Department has added the limited feedback from ACENZ members. Results are presented in Appendix 1. It is clear from this table that reported concerns are not widespread and that the bulk of them relate to improper handling, particularly bending, of the steel.

Further evidence was obtained from a former builder who had developed a device for bending bars to the correct diameter. This had been prompted by concerns from builders regarding breakages during the bending process and the recognition that such bending was tighter than allowed by NZS 3101 and NZS 3109.

2.2 Report on Standards

(Refer Appendix 2, "The Use of Grade 500E Reinforcing Steel in New Zealand: A Review of Current Standards", Beca Consultants)

The Beca review of Standards covered:

- AS/NZS 4671: 2001 Steel Reinforcing Materials
- AS/NZS 1554.3: 2002 Welding of Reinforcing Steel
- NZS 3101: 1995 Concrete Structures Standard
- NZS 3109: 1997 Concrete Construction.

The report recommended that:

- there be a differentiation in identification markings for microalloy and quenched and tempered steels
- there be a requirement in AS/NZS 4671 for a test to confirm strain capability after bending, for bars of 20 mm diameter or greater
- minimum bar bending diameters specified in NZS3101 be reviewed to ensure adequate margin against fracture of Grade 500E steel
- warnings be issued that:
  - quenched and tempered (QT) steel must not be welded
  - AS/NZS 1554.3 requires a high level of workmanship well beyond that common on construction sites
  - suitable electrodes to weld Grade 500E steel and to develop the full strength of the bar in the upper characteristic range have not been adequately verified.

The Beca report has been copied to Standards New Zealand and the Department will be working with them as required to address the recommendations.

2.3 Physical testing of sample products

The Department commissioned SGS New Zealand Ltd, a specialist testing organisation in Auckland, to carry out a range of physical tests on sample reinforcing bars from local and imported sources. Tests included tensile tests (determining yield stress, ultimate stress and uniform elongation), rebend tests, hardness tests, and examination of deformations for compliance with AS/NZS 4671. Some of the results of the SGS report (Appendix 3) have been incorporated into a wallchart for easy reference. This wallchart is being finalised for publication.

It is very important to note that as the tests were based on a small sample size, there may be sources of imported steel that were not included in the test programme that may exhibit different characteristics. For all reinforcing steel, designers and contractors must satisfy themselves that the reinforcing steel they use complies with the requirements of AS/NZS 4671.

The tests showed compliance of almost all samples with the requirements of AS/NZS 4671.[1] Failure of some imported samples in some tests related to low yield stress, low ratio of ultimate to yield stress, low uniform elongation and incorrect bar markings and configurations. Such failure does not necessarily represent non-compliance, as AS/NZS 4671 allows re-testing when a single failure occurs.

One of the two samples of 16 mm bar from Amsteel failed the rebend test. A 12 mm bar from Siam Construction Steel Co failed the yield stress criteria and a 32 mm bar failed the elongation criteria. These results have been passed on to the distributor and manufacturer who are carrying out further testing.

Results of other tests on Grade 500E steel reinforcement made available to the Department indicated the same general trends, but there were instances of uniform elongation slightly below the required 10 percent, and some instances of uniform elongation around 20 percent and more, indicating a wide variation. Locally made Grade 500E steel showed compliance with AS/NZS 4671.

All samples of 16 mm diameter or less, except the initial Amsteel 16 mm sample, passed the rebend test as prescribed in AS/NZS 4671. The samples from all manufacturers, of 20 mm or greater bar, passed the bend test required by AS/NZS 4671 (bend through 180 degrees). In addition the bars of 20 mm and greater were subject to a rebend test (90 degree bend and straighten), although this is not required by AS/NZS 4671. Many samples showed signs of cracking following this test, indicating that such treatment produces unacceptably high strains.[2] It should be noted that heating the steel when rebending can reduce the strains; however, this may compromise other properties of the bar depending on the method of manufacture.

[1] Note that AS/NZS 4671 sets out requirements for sampling and testing reinforcing steel. It is based on a long-term sampling regime incorporating many test samples. The Department tests are based on a very small sample size and care should be taken when using any results, as they may not accurately represent the total population characteristics.

[2] The bend and rebend tests carried out to AS/NZS 4671 specify tighter bend diameters than those required in the material standards NZS 3101 and NZS 3109.

The hardness tests showed consistent hardness through the cross-section of the microalloyed samples. The QT samples showed a markedly softer core reflecting the characteristics of the quenching and tempering process. The hardness values showed no significant variation along the length of the bars. The relative hardness values also did not show a strong correlation to the yield stress or uniform elongation values.

Deformations were shown to comply with AS/NZS4671 in all cases.

2.4 Auckland University tests

The failure of some Grade 500E bars during testing of beam-column assemblies at The University of Auckland prompted the current investigation. Further tests on beam-column assemblies, using the same reinforcement, have now been carried out and investigations made into the failures. There is now no significant concern about the integrity of Grade 500E steel as produced. The main concern is that it be handled carefully.

Although there is no longer serious concern about the integrity of the Grade 500E material, the failures in the tests at Auckland University have not been fully explained. Further tests and investigations are being carried out at Auckland University, first to review the metallurgy of the failed bars and secondly to test the possible influence of the buckling effect brought about by the beam elongation. A postgraduate project is also under way at Auckland University to examine the notch ductility of Grade 500E steel at various temperatures. Results of this work are not currently available and the Department will continue to follow up to ensure the industry is informed of the test results.

2.5 Effects of bending

The reported problems of Grade 500 reinforcing bars failing when bent (or re-bent) prompted Department staff to examine the issues more closely and to request an extension to the report on Standards it commissioned to address this issue.

It was recognised that similar concerns had been expressed in the 1970s when Grade 380 steel (yield stress = 380 MPa) was introduced. At that time studies showed that the strains produced during bending of a deformed reinforcing bar are very high and near the limit of capability of the material. Minimum bend diameters were increased as a result of studies of the strains induced and the metallurgical properties of the steel.

It is recognised that an increase in yield strength of these steels will result in reduced tolerance to the strains induced during bending. Since the 1970s steels with yield stresses of 430 MPa and 500 MPa have been introduced, with no revision to the minimum bend diameters when Grade 500 was introduced. A review of required bend diameters in past New Zealand Standards was made, resulting in Appendix 4. Significantly this shows increases to 8 d and 10 d in 1980 for Grade 380 steel, but a reversion to tighter diameters in 1995. This coincided with the introduction of Grade 430 steel (a microalloy steel designed to have improved ductility) to replace Grade 380 (a plain carbon steel). The Commentary to NZS 3101: 1995 points out that the bend diameters required are twice those required of the bend test in NZS 3402. In 2001, NZS 3402 was replaced by AS/NZS 4671 and required diameters for the bend test were increased. No changes to the required site bend diameters were made when Grade 500E steel was introduced. The report on Standards has been sent to Standards New Zealand for consideration and includes a recommendation to review the minimum bend diameters for reinforcing steel.

The key questions are what, if any, adjustments to allowable bending diameters should be made to allow for the increase in yield stress to 500 MPa from 430 MPa? If adjustments should be made, what is the basis for making a change?

No definitive answers to these questions were evident from recent enquiries and research. The relationship between yield stress and an acceptable bending strain could not be clearly defined. Work is needed to provide a definitive relationship that can be used to determine suitable minimum bending diameters for steels of various types and yield stress levels.

There is ongoing metallurgical research at Auckland University that will help answer these questions and resolve some of the practical concerns about the performance of Grade 500E steel. Further detailed discussion on bending capability is given in section 4.

3 Summary of key issues identified

During the course of the above tests and investigations, a number of key issues affecting the use of Grade 500E steel reinforcement emerged. These are outlined below.

3.1 Manufacturing and supply issues

- Local versus imported product.
  - Microalloy vs. in-line quenched and tempered.
  - Compliance with New Zealand Standards.
  - Verification of properties through mill certificates.
- Intrinsic stress/strain characteristics of Grade 500E and other steels, particularly as they affect the ability of reinforcement to be bent without detriment to its physical properties.
- Identification markings – uniqueness and suitability.
- Deformations – compliance with New Zealand Standards.

3.2 Design issues

- Design practice – knowledge, bending, welding, reporting of failures.
- Auckland tests and cyclic effect.
- Market preferences and availability of Grade 430 steel.

3.3 Fabrication and construction issues

- General handling and reported failures.
- Welding – advisability of butt, lap and tack welding.
- Bending – ability to withstand without significant detriment to physical properties.
- Re-bending – inadvisability of allowing this.

3.4 New Zealand Standards issues

Consistency and coverage of New Zealand Standards for manufacture/design/welding/handling.

In section 4, brief comments are made on the outcome of the Department's investigations and conclusions presented on key issues.

4 Comment and conclusions on key issues

4.1 Manufacturing and supply issues

4.1.1 Local vs imported product

Microalloyed vs quenched and tempered

The imported steel tested came from Malaysia, Singapore and Thailand. This product is produced either as a microalloy or by a different process ('In-line quenched and tempered' or 'QT') that relies on quenching with water to provide the requisite strength and ductility. The strength from the quenching process can be reduced by hot working the material as occurs when welding, and therefore NZS 3101 does not allow it to be welded. It is vitally important that users are aware of the type of steel they are being supplied with and its characteristics. While the imported steel used in these tests came from Malaysia, Singapore and Thailand, the Department understands that steel is also being imported in small quantities from other sources.

Locally produced Grade 500E steel reinforcement is manufactured by Pacific Steel in Auckland to meet AS/NZS 4671 Steel Reinforcing Materials. The requisite strength and ductility is achieved by the addition of microalloys such as vanadium. This produces steel reinforcement with uniform metallurgical properties throughout the cross-section, allowing it to be welded under controlled conditions.

About 80 percent of New Zealand requirements for reinforcing steel are made in New Zealand, while the remainder is imported. Most of the reinforcing steel used in New Zealand is Grade 500E.

Compliance with New Zealand Standards

The imported steel tested came from Amsteel in Malaysia, National Steel in Singapore and Siam Construction Steel Co in Thailand. Amsteel and Siam Construction Steel Co advise that they make their product to comply with AS/NZS 4671. Reinforcement from National Steel is made to comply with Singapore Standard No 2, which does not refer to Grade 500E steel.

Generally, these steels and the local steel complied with the requirements of AS/NZS 4671. However, some of the Amsteel bars failed the strength and ductility tests and the rebend tests for 16 mm bars. Some samples of the National Steel and Siam Construction Steel Co bars failed the test for yield stress, ratio of ultimate stress to yield stress and the required elongation. Refer to section 2.3 on physical testing of bars and the test report by SGS New Zealand. Locally produced bars passed all tests.

The failure of some imported product, and the fact that the Natsteel product is not manufactured specifically to meet AS/NZS 4671, raises doubts about its consistency and therefore its suitability as Grade 500E. All material should clearly identify the Standard that it is manufactured to and contractors and consultants should inspect the mill certificates for compliance with the New Zealand Standard. For example, Grade 500E steel requires a uniform elongation of 10 percent, whereas Grade 500N only requires 5 percent.

The Department believes that some imported reinforcing steel sold as Grade 500E needs to be viewed with caution, because properties could vary considerably depending on the selection process. As with all such products, the steel should have evidence that its properties meet AS/NZS 4671 requirements for Grade 500E, particularly those for minimum uniform elongation, yield stress, ultimate to yield ratio and rebending.

Apart from the Siam Construction Steel Co product, the imported steel was not uniquely marked as Grade 500E in the same way as the locally made product. This provides a further reason for control testing of imported product. Contractors and other users of steel should also pay particular attention to the steel supplied and ensure it is correctly identified so it can be correctly placed.

Verification through mill certificates

It is vital that designers, fabricators and constructors check the origin of reinforcing steel as supplied. Even then, there is room for doubt that the product is demonstrably suitable. Information on some mill certificates for imported reinforcing steel does not always provide all the information necessary to demonstrate compliance with relevant New Zealand Standards. More importantly, the nature of the documentation for imported steel does not promote confidence that the mill certificate matches the actual product in question.

In one case, a bundle of one of the imported bars was not tagged in a way that enabled correlation to the mill certificates. In a building application it would be difficult to relate test results to the mill certificates and this limits the ability to trace bundles on site to specific production batch runs. Steel suppliers must tag and identify their product in accordance with the requirements of AS/NZS 4671.

The Department strongly recommends that specifiers and users of Grade 500E steel satisfy themselves as to the veracity and completeness of information on mill certificates, and if there is any doubt that they call for independent physical testing and chemical analysis. Particular attention should be paid to the need for 10 percent uniform elongation, the attainment of the requisite yield stress, compliance with bend and rebend test requirements and confirmation of the mode of manufacture – microalloyed or quenched and tempered.

Bending

4.1.2 Stress-strain Characteristics and Effect of The Department investigations indicated that little rational analysis has gone into the determination of suitable bend diameters for reinforcing, or for determining suitable bend tests for AS/NZS 4671. The report on Standards commissioned by the Department calls for a review of both these aspects.

The manufacturing Standard, AS/NZS 4671, calls for a bend and rebend test on bars of 16 mm diameter or less, consisting of a bend through 90 degrees followed by a controlled rebend to straight. The bend is required to be around a mandrel of 4 times the diameter of the bar.

Compliance with AS/NZS 4671 requires that there is no visible cracking at the end of the bend and rebend test.

For bars greater than 16 mm diameter, the bend test in AS/NZS 4671 is simply a 180 degree bend around a mandrel of 4 times the diameter of the bar, with no rebend requirement. Bars tested for the Department passed this test, but frequently failed a bend and rebend test.

Bending around a 4 d mandrel produces a strain in the outer extremity of the bar of about 20 percent, without taking account of stress concentrations due to deformations. This compares with the required minimum ductility (uniform elongation) for Grade 500E steel of 10 percent and for Grade 500N of only 5 percent. On the face of it, the bars do not have the requisite ductility to undergo bending of this severity.

However, there is a key difference in these two strains that is not widely recognised or understood. The 10 percent and 5 percent figures are the required *uniform elongation* to be attained by a bar under a specified tensile test. As the name suggests, the uniform elongation occurs as a strain over the full length of the test piece. Beyond this level of elongation, strain becomes concentrated in a section of bar about 2 diameters long. Thus, any further elongation of the test piece is not uniform and a ‘necked’ section develops within which the strains are very high before fracture occurs. Tests done for the Department indicate that the level of strain within the necked region is of the order of 30 percent. Thus, there is a reasonable, but not excessive, margin available over the 20 percent imposed by the bend test. However, it is clear that during even normal bending, the material is being strained well beyond the strains required to attain commonly required structural ductility.

The relative values (approximately 30 percent capability versus approximately 20 percent imposed strain) point to the potential for problems if the bars are bent around a smaller mandrel, or are rebent, even under controlled conditions. The reported instances of bars breaking when bent (usually around too tight a diameter) are consistent with these relative values. For example, a bar bent around a mandrel of 2 times the bar diameter would produce strains in the region of 33 percent.

This subject was investigated in the 1970s when Grade 380 bar was introduced and problems were encountered of bars breaking during bending. Papers by Erasmus and Pussegoda [1, 2] provide valuable insights, but there is little to tie the choice of allowable bend diameters to nominal yield strength of the steel.

When Grade 500 steel was introduced as acceptable in NZS 3101, there was no revision to the required bend diameters that had been set for Grade 430 steel. The interrelationships between steel grade and bend diameter are complex. A rational investigation and analysis is needed to determine a practical basis for determining appropriate bend diameters for each of the various steel strengths available.

The overall conclusion is that Grade 500E material passes the bend tests of AS/NZS 4671 and that there is no justification to change the required bend diameters. It is far more important to ensure that the proper bend diameters are being achieved in practice, and it is the Department’s intention to focus on this.

To promote improved compliance, the Department intends to issue a set of discs that will allow contractors and inspectors to determine the correct diameter for any size of bar and application.

This will be supplemented by the production of a wallchart summarising the key properties and New Zealand Standard requirements of Grade 500E steel.

Rebending

It is clear from the test results and the reported problems that incorrect rebending of Grade 500E bars is highly likely to result in reduction or complete loss of strength and ductility of the material.

The Department believes that for all practical purposes rebending of reinforcing bars should not be allowed and that designers should use proprietary inserts and connectors in preference. It is possible to bend and rebend bars 16 mm and less, but this requires strict control of procedures and a greater quality control requirement that is often not applied on site.

4.1.3 Identification markings

Grade 500E steel made by Pacific Steel has unique markings that clearly distinguish the grade of product. These markings are included as a requirement in AS/NZS 4671 and it should be possible for site personnel to positively verify that the correct material is being used. The steel produced by Siam Construction Steel Co also clearly distinguishes the grade, ductility class, manufacturer and diameter.

The same cannot be said of the other imported products examined by the Department. They have different markings that are not included in AS/NZS 4671 and the Department received no evidence that correlated the markings with the steel properties. More work is needed to provide the industry with information that will enable site personnel to easily and accurately identify the grade, ductility class and method of manufacture of reinforcing steel on site.

Deformations

Deformations on reinforcing steel are required by AS/NZS 4671 to have particular dimensions and characteristics. Limited tests carried out for the Department confirmed that all of the samples met these requirements. Although the appearance of the imported bars is completely different from that of the locally made bars, there is no reason to doubt that bond characteristics are adequate.

4.2 Design issues

There are a number of design issues that require attention.

4.2.1 Designer knowledge

Seminars organised by CCANZ and Reinforcing New Zealand in 2003 did much to improve the knowledge of designers and territorial authority building officials on the properties of Grade 500E steel reinforcement. In particular, the unsuitability of QT steel for welding was emphasised. The undesirability of welding even microalloy Grade 500E reinforcing was also highlighted.

The recent issue of CCANZ information bulletin IB79 is generally helpful regarding bending and rebending bars. However, it does show photos of bar bending using a ‘dogbar’ which is not recommended by the Department.

4.2.2 Choice of steel grade

Some contractors and subcontractors report a tendency for designers to specify Grade 500 steel when it is not required. Because it is required in one part of the building, the pragmatic decision is frequently taken to make all steel the same grade to avoid possible mix-ups. However, what happens in practice is that suppliers offer alternatives in order to reduce costs, with the result that a mix of steels is supplied.

Designers and inspectors need to recognise the possibility of mix-ups, not just between Grades 500N and 500E, but between Grade 500 and other grades such as Grade 300. Designers need to better understand the suitability of the various reinforcing steels and specify accordingly, noting where the consequences of using the wrong grade could be significant.

As an example, designers should be aware that the on-site substitution of Grade 500 for Grade 300 might have implications for overstrength of beams relative to columns. Additionally, they should think twice before specifying Grade 500 steel when the additional strength and ductility are not required as, for example, when a more important consideration is the weldability to achieve electrical continuity.

4.2.3 Overstrength factors

Tests carried out for the Department on samples of local and imported product indicated significant differences in the ratio of ultimate stress to yield stress. This ratio is used to provide a degree of certainty in the overstrength factor used in capacity design. The minimum ratio required by AS/NZS 4671 is 1.15 with a maximum of 1.40. The tested values for local product were typically 1.23 to 1.28, while the imported steel showed values of 1.11 to 1.26. Consultants, designers and contractors should therefore check to ensure that the steel being used meets the minimum requirements of the Standard.

Designers should note that factors for overstrength are given in NZS 3101. However, these factors are based on tests carried out on Pacific Steel product and may not apply to other manufacturers’ product. Designers must ensure they use the appropriate overstrength factors for the particular product and ensure that consistency is carried through to the materials used on site in construction.

4.2.4 Suitability for welding

Butt-welding

The report on Standards indicated there may not be suitable electrodes for butt-welding microalloy steel. The electrodes called for in AS/NZS 1554.3: 2002 cannot be relied upon to provide sufficient overstrength to match the large difference between yield and ultimate stress of the bars. This is the reason that NZS 3101 prohibits full-strength welded splices in reinforcement with a yield stress greater than 450 MPa unless yielding can be shown not to occur, or proof testing demonstrates that failure will occur away from the weld.

It is desirable that a suitable electrode be identified to overcome this drawback. However, unless welding is carried out in controlled conditions, butt-welding of Grade 500E steel, even with suitable electrodes, is unlikely to provide the level of confidence required.

The Department recommends against butt-welding of Grade 500E steel. Proprietary jointers are to be preferred but, in any case, no jointing should be made in regions where the full strength and/or ductility of the bar are required.

Tests carried out for the Department by SGS confirmed that QT steels are not suitable for welding, including butt-welding.

The Department understands that HERA is working on welding procedures for high strength bars and further information may become available in the future.

Welding generally

The premature failures of reinforcing steel in tests at Auckland University, together with the problems reported to Pacific Steel, clearly indicate that the inappropriate welding operations can adversely affect the performance of Grade 500E steel. This means that special efforts are needed to educate designers, contractors, sub-contractors and inspectors of the serious consequences of what might otherwise be regarded as acceptable.

Welding of microalloy Grade 500E steel may be acceptable provided special efforts are made to conform to all of the requirements of the welding procedure, such as preheating and sheltering, but the Department is not confident that such conditions can be met on site.

Welding of QT Grade 500E steel should not be allowed under any circumstances. This includes welding of bars to achieve electrical continuity. For such applications, it is unlikely that Grade 500E steel will be required and other more weldable steels should be chosen.

In summary, designers should not rely on welding of Grade 500E steel and fabricators/contractors should not allow welding of this material.

4.2.5 Availability of other grades of steel, particularly Grade 430

There appears to be a perception amongst designers that Grade 430 steel is no longer available. In fact Pacific Steel have links with a mill in Fiji that is rolling a Grade 430 steel to a Fijian standard and, subject to sufficient demand, could supply this grade to the New Zealand market. Unfortunately, Grade 430 was dropped from NZS 3101, when Grade 500E steel reinforcement was introduced, giving the impression that it was no longer available.

Recent comment by Esli J Forrest, structural engineer and editor of the *SESOC Journal*, suggests that the economics of using Grade 500E steel may not be as advantageous as generally assumed.

Based on recent work on this issue, the Department considers that the decision to remove Grade 430 from NZS 3101 unnecessarily constrained market choice. The Department believes that Standards New Zealand should consider reinstating Grade 430 steel as an option, provided that Pacific Steel confirms their ability and willingness to manufacture Grade 430 for the New Zealand market.

4.2.6 Reporting of failures and problems

Informal reports of problems with Grade 500E steel far outweigh the formally reported evidence. This suggests that there are a significant number of unreported problems and failures. It is important that a much higher proportion of problems are formally reported so that concerns can be properly analysed and put into context.

Designers, fabricators, contractors and inspectors should be on the lookout for evidence of concerns and take special efforts to see it is reported to the manufacturers, importers and to the Department. Where possible, reports should include a sample of the bar in question and a description of the conditions in which it was being placed – weather, location, handling practices.

4.2.7 Auckland University Tests

Initial concerns cast doubt on the integrity of Grade 500 steel reinforcement. Tests for the Department on samples, plus the existence of other influences such as welding, have all but removed concerns about the product.

The main cause of premature failure appears to be the existence of welds, but it has been suggested that buckling of the bars between lateral reinforcement may be a significant contributing factor. It is important that this possibility be investigated by the industry to establish whether or not some modification to design parameters is needed.

4.3 Fabrication and construction issues

4.3.1 General handling and reported failures

Reported instances of failure, plus a body of informal evidence, indicates that almost all problems with or failures of Grade 500E steel are due to improper handling or treatment, particularly bending too tightly, rebending or welding. This effect will not be confined to Grade 500E, but that grade is more sensitive than most other steels used for reinforcement.

The Department believes that stricter control and better education of designers, inspectors, fabricators and construction personnel is needed to reduce non-compliance and thus concerns regarding possible reduction in strength and ductility.

4.3.2 Welding – butt, lap and tack

Welding of any kind to QT steel will reduce its strength and must not be attempted.

Butt-welding of Grade 500E microalloy steel is possible under controlled conditions. However, the electrodes specified in AS/NZS 1554.3 will not always be sufficient to match the ultimate strength of the bar. This means that butt-welding should not be used in situations where the steel could undergo significant yielding, such as under earthquake loading. Butt-welding of this reinforcing requires careful preparation and controlled conditions and the Department strongly recommends that site welding should be avoided.

Some designers opt for single lap welds to splice reinforcing bars. The potential for unzipping due to the combination of imperfections in the weld and the eccentricity of connection make this type of weld undesirable. Therefore, until further testing shows otherwise, it is recommended that such welds should not be considered, except in non-critical situations where the mobilisation of the full strength of the bar is not required. In situations where welding cannot be avoided, such as in circular hoops, it is recommended that Grade 300 steel be used.

Tack welds can seem almost insignificant to the site operative. They simply help to add stability to a cage, or facilitate placement. However, placement of weld material on Grade 500E steel (microalloyed or QT) may well lead to premature failure of the bar. The tests at Auckland University support this. Reported failures of bars include those due to application of welding and due to inadvertent damage from gas cutting equipment.

The Department strongly recommends against any tack welding of Grade 500E steel, and urges vigilance by designers, fabricators, contractors and inspectors to avoid damage that could jeopardise the safety of the structure.

4.3.3 Bending

Grade 500E has shown itself to be sensitive to the high strains induced in the bending process. It is not tolerant of bending to diameters tighter than the minimum bend diameters specified in NZS 3101.

Formal and informal reports indicate that bend diameters are frequently less than the minimum specified, and that this leads to problems and/or failure. The Department believes that a concerted effort is needed to promote awareness of the need to comply with New Zealand Standards in this regard. The concern is not so much with bars that fail during bending (and are therefore replaced), but with those that are bent to the point of failure and are built into the structure.

The Department is producing a set of discs aimed at raising awareness of this issue and providing those on site with the means to simply determine the correct diameter of bend for a particular size of bar.

The Department is encouraging correct practice on site as a result of learning of the existence of an improved hand-operated reinforcing bar bender that produces the correct bend diameter for bars up to 16 mm. Information on this was published in *BIA News* in June 2004. Provided the requirements of the New Zealand Standard are met, there is no reason to doubt the integrity of Grade 500E steel that has been bent.

4.3.4 Rebending

Rebending of reinforcing steel is a major concern, especially but not exclusively for Grade 500E steel. Over the years designers have come to rely on starter bars from precast units being bent for transport and rebent (straightened) for inclusion in the structure. Bending for rebending is almost always done without due control and to tighter diameters than required. This practice could be placing at risk some important elements of the structure and is difficult to justify for any grade of steel reinforcing.

Given the low tolerance of Grade 500E steel to bending, the Department strongly believes that reliance on bending and rebending should cease. Designers should be required to use alternatives such as cast-in connectors or specify steel with a lower yield stress. The Department does not agree with the endorsement of rebending bars as shown in Figure 5 of CCANZ IB79.

4.4 New Zealand Standards issues

4.4.1 Action items from the review

The following sections highlight the items requiring action by Standards New Zealand and/or the industry, all of which resulted from the review of relevant Standards.

Manufacture

The bend and re-bend tests required by AS/NZS 4671 need to be reviewed. To support this, more research is needed into the properties of Grade 500E steel, particularly its capability to be bent without significant reduction in physical properties.

The NZS 3101 committee should review bend diameters for Grade 500 and other grades for future development.

There should be marking differentiation between steels produced by microalloy process and the QT process. A clear method of distinguishing the ductility class of the steel should be provided.

Design

Minimum bending diameters for reinforcement should be reviewed to ensure they are sufficiently large to provide adequate margin against fractures in the bending zone.

Welding

Warnings are needed in NZS 3101 to emphasise that lap welds may not provide a sufficient margin against failure. Designers and contractors should take note of the limitations on lap welding covered in NZS 3109 and NZS 3101.

Suitable electrodes for butt-welding Grade 500E steel may not be available and warnings should be given in NZS 3101.

Construction

Welding requirements of AS/NZS 1554.3 imply high standards of workmanship. Every opportunity should be taken to emphasise this, notably in NZS 3109.

NZS 3109 should warn of the higher degree of care required when handling Grade 500 steel compared with the previously available Grade 430 steel.

5 Recommended actions

The required actions fall into the following categories.

- General education of the industry on the properties of Grade 500E and its limitations and benefits.

  Action on this is primarily up to industry organisations to implement. It is noted that the industry has carried out some work in this regard with seminars provided by CCANZ and the Reinforcing Association and information bulletins through CCANZ. The Department has a strong role to play by encouraging such education and providing seed funding when warranted.

- Advice and alerts to industry about limitations and benefits of the product and the variation to be expected in suppliers, bar markings and weldability.

  Action is primarily up to industry organisations, but the Department can have a strong role in endorsing such alerts through formal advice to industry.

- Research to provide better information on key issues.

  Action can be supported by industry organisations. The Department should play a strong role in helping identify worthwhile research topics and facilitating funding of the work.

- Specific advice to designers on implications for design.

  Action on this should be a joint effort between the design organisations (IPENZ, ACENZ, SESOC, NZSEE) and the Department. Work to date in this area includes the provision of seminars for designers and amendments to Standard NZS 3101 Concrete Structures.

- Specific advice to fabricators and constructors on the need for care in handling reinforcing steel, in particular Grade 500 steel.

  Action on this should be a joint effort between the Department and industry organisations such as CCANZ and Reinforcing New Zealand.

- Amendments to New Zealand Standards.
  - Changes to requirements.
  - Inclusion of information about limitations regarding Grade 500E steel.

  Action required is for the Department to advise Standards New Zealand of the need for changes and the reasons behind them. The Department should then support Standards New Zealand and encourage them to take decisive action. Note that recent amendments to NZS 3101 and NZS 3109 have addressed some issues relating to the use of Grade 500 reinforcing steel.

References

1 Erasmus L A, Pussegoda L N. 'Strain Embrittlement of Reinforcing Steels'. *New Zealand Engineering*, Vol 32 No 8, August 1977.

2 Erasmus L A, Pussegoda L N. 'Safe Bend Radii for Deformed Reinforcing Bar to Avoid Failure by Strain Age Embrittlement'. *New Zealand Engineering*, Vol 33, No 8, August 1978.

3 Cement and Concrete Association New Zealand. 2004. *IB79 Recommended Industry Practice on Bending and Re-bending Reinforcing Bars*,

Appendices

- Appendix 1: Grade 500E Steel Reinforcement: Summary of reported failures and problems with Grade 500E reinforcing steel. Compiled by the Department of Building and Housing with data from Pacific Steel and ACENZ members. July 2004.
- Appendix 2: The Use of Grade 500E Reinforcing Steel in New Zealand: A review of current Standards. Report by Beca Consultants for the BIA. July 2004.
- Appendix 3: Investigation to Clarify Properties of Grade 500E Reinforcing Steel Bar. Report by SGS New Zealand. August 2004 and January 2005.
- Appendix 4: Review of Bend Diameters for Reinforcing in Successive New Zealand Standards. Prepared by the Department of Building and Housing with assistance from Standards New Zealand.

Appendix 1: Grade 500E Steel Reinforcement: Summary of reported failures and problems with Grade 500E reinforcing steel

Compiled by the Department of Building and Housing with data from Pacific Steel and ACENZ members

ID	Date	No of failures	Problem description	Cause(s)	Comment
1	21.08.02	1 minimum	12mm Starter Bars snapping in precast elements during bending of bars for transport.	None specifically found. Reverse bent. Initial bend radius was 4d c.f. 5d specified. Corrosion?	Broken bar was bent/reverse bent/tensile tested and met Gr500. Tests of bars passed spec.
2	26.08.02	1	16 mm Pl Breaking galvanised bars	Cock bent on 1d pin & then galvanised. Cracks due to Hydrogen embrittlement of highly strained region.	3101 specifies 2d min. bend for non galvanised bars. Bending after galvanising is recommended. If bent before galvanising we would recommend 5d.
3	11.09.02	1	10 mm def'd. Bars tested - incorrect bend	Bent on 2d pin on off-coil bender.	Tight bends to form stirrups. Second bend was restrained by the first bend - second bend broke. Minimum 4d required by 3101.
4	25.09.02	1	20 mm def'd	Reverse bent.	Small sample received. Analysis in spec. Failed from base of flattened deformation.
5	24.10.02	1	A 25 mm bar in pile cage fractured.	Fracture at gas cut during "straightening".	The bars broke during cold straightening after damage by digger bucket. The fracture initiated at a 10 mm deep gas cut in the bar caused when cutting adjacent stirrup.
6	31.10.02	1	25 mm bar fractured on reverse bend (pile cage).	Fracture at previous tack weld during "straightening"	As 574 but initiated at tack weld between support ring and bar.
7	23.01.03	1	Bar Fractured in beam during placement.	Bar bend around 2.4d pin - bending error.	Hook at end of pre-cast beam broke during "adjustment" to get beam into place. 60 mm bend radius used c.f. 125 mm specified.

8	09.04.03	1	25 mm Reidbar broke at bend	Deformed bar used as lifting hook.	Cold formed lifting hook used to lift precast pipes. Fracture initiated at base of deformation.
9	14.07.03	1	10 mm PI 500 - bar breaking on off-coil bender.	Under investigation.	
10			16 mm def'd breaking in test beam	Welded sample fractured at heat affected zone under arc strike.	Fracture initiated at arc strike at end of weld. Weld performed using MIG welder with 1 mm wire (low energy input). Hardness of 490 Hv under arc strike.
11	29.07.03				Query re availability and properties with respect to Grade 430
12	21/07/03				Comments that problem is not new in high strength steels
13	15/07/03				interested in findings
14	21/07/03				unaware of specific problems, but gives example of questionable supply practice in Tauranga
15	16/07/03	3	3 of 25 galvanised bars failed in brittle fracture in pullout test		Effect of galvanising? At what strength did the bars fail? Were Pacific notified.
16	19/08/03	1 minimum	hd16 rods breaking when being bent for footing/starter bars	bars being bent with a tool from Placemakers that had a 35mm diameter instead of 80mm	
17	22/07/03	1 minimum	starter bars from balcony panels breaking when being rebent on site after transport	incorrect pin diameter used in initial bending and incorrect procedure used for rebending	information and photos available if required
18	29/07/03				Paper on problems with 500N in Australia
19	21/07/03	3	12mm starter bar bent by hand near the bend, 12mm starters prebent adjusted by hand, starters welded to steel beam broke by the bend	In third case the welding occurred near the bend	Cold air temperatures 4-5 degrees

20	21/07/03	1	Bar return on a 25mm starter from a foundation was knocked off		bar knocked with a plate compactor
21	21/07/03	2	HD12 bar starter was bending bar and snapped in hands, two occurrences		
22	17/07/03				No specific problems to date but are concerned over results of UoC tests.
23	18/07/03	1 minimum	Some problems with high strength plain bars		
24	6/06/2004	1 minimum	rag bars for stair support breaking on rebending (note positive seating still provided to stairs)	bending/rebending insufficient diameters, incorrect steel grade being used and welded	No action taken by contractors, Pac steel not contacted

Appendix 2: The Use of Grade 500E Reinforcing Steel in New Zealand: A review of current Standards

Report by Beca Consultants for the BIA

Building Industry Authority
P O Box 11846
WELLINGTON

20 July 2004

Our Ref: 2711141

Error! Reference source not found.*RDJ45R01.DOC*

Attention: Mr David Hopkins

Dear Sir

The Use of Grade 500E Reinforcing Steel in New Zealand - A Review of Current Standards

Please find enclosed our revised report (rev D) presenting key issues relating to the use of Grade 500E Reinforcing Steel in New Zealand.

In this revision of the report we have incorporated responses to the comments raised in your Email dated 30 May 2004.

Yours faithfully
Rob Jury
Technical Director - Structural Engineering

on behalf of
Beca Carter Hollings & Ferner Ltd

Direct Dial: +64-4-471 5511

Email: rjury@beca.co.nz

Revision History

Revision Nº	Prepared By	Description	Date
A	Rob Jury	1st Draft	18/03/04
B	Rob Jury	2nd Draft	28/04/04
C	Rob Jury	3rd Draft	17/05/04
D	Rob Jury	4th Draft	20/07/04

Document Acceptance

Action	Name	Signed	Date
Prepared by	Rob Jury		
Reviewed by	....		
Approved by	Rob Jury		
on behalf of	**Beca Carter Hollings & Ferner Ltd**		

Table of Contents

Appendices

Executive Summary

This review has been prepared to identify key issues relating to the use of Grade 500E reinforcing steel and to provide confidence that the available Standards are consistent and applicable for use with this product.

The key issues identified are:

- Unexpected failures of Grade 500E reinforcing steel experienced in Auckland University tests (these are still under investigation) raise the possibility that there may be an issue with the quality control of the Grade 500E micro alloy steel produced in New Zealand. The investigations of these failures should be completed with some urgency to remove this issue as an area of uncertainty for designers and specifiers.
- The construction industry in New Zealand needs to be rapidly trained to be aware of the higher degree of workmanship required for Grade 500E reinforcing steel. Some industry training has already been carried out and it is understood that more is planned which should resolve this issue.
- The industry sector was inadequately prepared (by seminars, training, etc) in advance of the introduction of Grade 500E and prior to the withdrawal of Grade 430 reinforcement. This has relevance to introduction of other new products in the future.
- There should be a requirement for a marking differentiation of micro alloy steel and Quenched and Self-tempered (Q&ST) produced product in AS/NZS 4671.
- There should be a requirement in AS/NZS 4671 for a simple confirmatory test to confirm ductility (strain capability) after bending, for larger (ie greater than 20mm diameter) bar sizes.
- The requirements for ribs/indentations in AS/NZS 4671 should be reviewed to see if bond issues in beam/column joints can be addressed. This is not an issue of the adequacy of the Standards but whether more efficient use can be achieved with the material.
- AS/NZS 1554.3 implies that lap welds are possible with Grade 500E reinforcing steel but testing suggests that lap welding to the Standard specified requirements does not provide a sufficient margin against failure of the weld before failure of the bar. This has been addressed in the amendment to NZS 3101 but warnings regarding the expected performance of this detail should be given in this Standard.
- AS/NZS 1554.3 implies that pre-qualified butt welding of Grade 500E reinforcing steel is possible. However suitable welding electrodes are not currently available to provide confidence that failure will always occur in the bar if the bar is required to yield at overstrength. This is addressed in the amendment to NZS 3101 by restricting welding to materials with a design yield stress less than or equal to 450 Mpa,. but warnings should also be given in this Standard.
- Minimum bar radii specified in NZS 3101 should be reviewed, as there is the suggestion that they may not be sufficiently large to provide an adequate margin against fractures in the bending zone of a bent 500E reinforcing bar.
- NZS 3109 should warn of the lower tolerance to misuse of Grade 500E reinforcement compared with the previously available Grade 430 reinforcing steel and should reiterate the requirement given in NZS 3101 that Q&ST reinforcing steel must not be welded.

1 Introduction

This report has been prepared for the Building Industry Authority (BIA) to examine the various Standards that impact on the quality and performance of Grade 500E reinforcing steel and its use in construction, and to identify key issues that should be followed up to provide confidence that the standards are consistent and applicable for use with 500E reinforcing.

The standards reviewed were:

- AS/NZS 4671:2001 Steel Reinforcing Materials
- AS/NZS 1554.3:2002 Welding of Reinforcing Steel
- NZS 3101:1995 Concrete Structures Standard including Amendment No 3
- NZS 3109:1997 Concrete Construction including Amendment No 2

This review has been a desktop exercise.

The agreed brief for this work is presented in Appendix A:

2 Background

Grade 500E reinforcing steel was introduced into the New Zealand market in 2001 in tandem with the introduction of the joint standard, AS/NZS 4671. Grade 500E replaced the previously available Grade 430 reinforcing steel. The standard covering Grade 430 reinforcing steel has now been withdrawn.

As well as achieving harmonisation with international practices, the introduction of the higher strength Grade 500E reinforcing steel was seen as an opportunity to achieve economies and reduce reinforcing cage congestion. It was also thought that the cost of reinforced concrete would become more attractive as a result (1).

Grade 500E reinforcing steel is intended to be a 'ductile' high yield steel suitable for use in construction of structures in regions susceptible to earthquake shaking.

The Grade 500 E reinforcing steel manufactured in New Zealand is a micro-alloyed steel. Micro-alloyed bars produced in New Zealand gain their strength from the addition of vanadium alloy. They are produced by the hot-rolled process and are cooled in air to produce a 'normalised' grain structure. The mechanical properties of the micro alloyed reinforcing are not significantly affected by the application of heat provided that the rate of cooling is controlled.

Quenched and self-tempered (Q&ST) Grade 500 reinforcing steel manufactured overseas is also available in New Zealand. The most common sources are Malaysia and Singapore. These products are supplied to the New Zealand market on the basis of either having been produced to AS/NZS 4671:2001or being equivalent to this Standard. The availability of QS&T Grade 500E reinforcing steel in New Zealand is uncertain but considered possible, as testing(10) has shown that it would not be difficult for the QS&T steel to meet the Grade 500E requirements as specified in AS/NZS 4671. The Q&ST reinforcing gains its strength from heat treatment. Therefore heating of the reinforcement due to processes such as welding, galvanising and hot bending is likely to reduce the strength of Q&ST reinforcing.

Since introduction there has been anecdotal and documented evidence of Grade 500E reinforcing bars fracturing after re-bending and some evidence of bars fracturing unexpectedly during Auckland University load testing. It is suspected, but not confirmed, that these failures have been experienced with the micro alloy, New Zealand produced, reinforcing steel. The University test failures are still under investigation.

The instances of failure do not appear to be large but are of a sufficient number to be cause of concern to designers and regulators.

The majority of the failures appear to be due to mishandling and poor workmanship rather than a problem with quality control of the steel itself, however this is not conclusive.

It is worth noting that Grade 500 steel (Q&ST) has been in use in Australia for some time with little evidence of on-going problems. The grades of steel in use in Australia are typically 500L and 500N which are notionally less ductile than 500E. Use of Grade 500L reinforcing steel is not permitted in New Zealand.

Key general issues that arise are:

- Unexpected failures of Grade 500E reinforcing steel experienced in University tests raise the possibility that there may be an issue with the quality control of the Grade 500E micro alloy steel produced in New Zealand. The investigations of these failures must be completed with urgency to remove this issue as an area of uncertainty for designers and specifiers.

- The construction industry in New Zealand needs to be rapidly trained in awareness of the higher degree of workmanship required for Grade 500E reinforcing steel. Some industry training has already been carried out and it is understood that more is planned, which should resolve this issue.
- The industry sector was inadequately prepared (by seminars, training, etc) in advance of the introduction of Grade 500E and prior to the withdrawal of Grade 430 reinforcement. The opportunity to address this has passed for Grade 500E steel but it has relevance to the introduction of other new products in the future.

Review of Standards

General

The following standards impacting on the quality and performance of Grade 500E reinforcing, and its use in construction were reviewed:

- AS/NZS 4671:2001 Steel Reinforcing Materials
- AS/NZS 1554.3:2002 Welding of Reinforcing Steel
- NZS 3101:1995 Concrete Structures Standard including Amendment A3
- NZS 3109:1997 Concrete Construction including Amendment A2

The review is discussed below.

AS/NZS 4671:2001 Steel Reinforcing Materials

This standard specifies requirements for the chemical composition and the mechanical and geometrical properties of reinforcing steel, including Grade 500E.
Key issues arising from this standard, relating to the use of Grade 500E reinforcing steel, are:

- There is no requirement for differentiating between the bar marking identification of micro alloy steel and the Q&ST produced product in this Standard. It is considered essential that there is some means of differentiating between these products on New Zealand sites, other than sole reliance on reference back to the steel producers documentation. The imported product does not appear to provide a unique mark on the reinforcing steel to identify the producer, as is required by the Standard. It is noted that the Pacific Steel steel produced Grade 500E reinforcing steel is identifiable by a product mark on the bar.
- There is no requirement for a rebend test for bars with diameters greater than 20 mm. While such a test may be inappropriate for larger bars, the lack of an appropriate simple sampling test procedure to confirm some measure of ductility and fracture resistance (after bending) is available is considered a major deficiency in the standard. It is recommended that consideration be given to including a simple test in the Standard to confirm that Grade 500 reinforcing bars with diameters greater than 20mm have adequate resilience.
- There is evidence to suggest that there may be some difficulties with maintaining bond of horizontal yielding Grade 500E beam reinforcement within beam column joints and as a result significant restrictions have been specified for bar sizes and columns widths in the current amendment to NZS 3101 [7]. This suggests that the requirements for bar ribs/indentations specified in this standard may be insufficient for the efficient use of the higher yield bars. Although the amendments to NZS 3101[7] are intended to address this issue it is recommended that the current deformation pattern requirements specified in AS/NZS 4671 be reviewed to see if the performance of 500E Grade reinforcing steel in beam/column joints can be improved.

AS/NZS 1554.3:2002 Welding of Reinforcing Steel

This standard specifies requirements for the welding of reinforcing steel used in concrete structures that are designed and constructed in accordance with NZS 3101.
The standard covers materials (parent and backing materials and welding consumables), connection details, qualification of welding personnel and procedures, welding techniques and qualification of welding by testing and inspection.

We have reviewed this Standard on the basis of whether it is likely that the requirements presented will lead to an adequate performance for welded Grade 500E reinforcing steel. There are issues as to whether it adequately warns fabricators of the lower tolerance to welding of Grade 500E compared with Grade 430 but it is considered that this is better dealt with in a Standard Commentary or as part of NZS 3109.

Key issues and questions that arise relating to application of this standard to Grade 500E reinforcing steel are:

- Q&ST Grade 500 reinforcing can not be welded without strength loss. It is recommended that a suitable warning be added to the Standard to this effect. This is covered in the amendment to NZS 3101(7)
- The standard implies that lap welds are possible with Grade 500E but testing suggests that lap welding to the Standard specified requirements does not provide a sufficient margin against failure of the weld before failure of the bar(2). This is addressed in NZS 3101, however, it is recommended that appropriate amendments also be made to AS/NZS 1554.3 to warn specifiers/designers/constructors of the likely performance of this detail.
- The Standard implies that butt-welding of Grade 500 E reinforcing steel is possible but is silent on the performance expected. Discussion at the recent seminars on Grade 500E reinforcing steel (2) indicated that currently there may not be a suitable welding electrode available to provide confidence that failure will always occur in the steel rather than the weld when the bars are at the higher end of the maximum tensile strength range allowable in AS/NZS 4671 and the bars containing the weld are required to yield at overstrength. Although this issue is covered in the amendment to NZS 3101, it is essential that it is also addressed in AS/NZS 1554.3 as butt-welds complying with the Tables in this Standard are deemed to be pre-qualified and could be assumed to be capable of developing the strength of the bar, unless warnings are given to the contrary.

NZS 3101:1995 Concrete Structures Standard

This Standard sets out minimum requirements for the design of reinforced and prestressed concrete structures in New Zealand.

Amendment N° 3 of this Standard(7) has now been released. One of the primary reasons for the amendment to the Standard is to address the issue of Grade 500E reinforcing steel and its use in concrete construction.

The issues arising from the use of Grade 500E reinforcing steel that have been addressed in the amendment include;

- Allowance for over strength
- Restrictions on the use of Q & ST reinforcing bars (eg no welding, no tack welding)
- Reference to AS/NZS 4671
- Reference to AS/NZS 1554.3
- Restrictions on the use of full strength welded lap splices
- Restrictions on the use of full strength butt-welded splices
- Restrictions on size of Grade 500 beam reinforcement passing through beam column joints.
- Minimum bend radii for galvanised Grade 500E reinforcing.

There is anecdotal evidence that, even when Grade 500 E reinforcing steel is bent to the bend radii currently specified in the Standard, steel fracture in the bend zone can still occur, albeit infrequently. We are not aware of any fracture assessment of Grade 500E reinforcing bars having been completed, although simple geometrical calculations (Appendix B describes an assessment of the strain requirements in reinforcing bar bends) would suggest that the tensile strains in the currently specified bends are well in excess of those required from the confirmatory testing in AS/NZS 4671. Evidence that an adequate margin against bar fracture exists with the currently specified bend diameters is urgently required.

NZS 3109:1997 Concrete Construction

This Standard provides minimum requirements for the construction of concrete structures including reinforced concrete structures.

A second amendment of the standard (Amendment N° 2)[9] has now been released.
This amendment addresses issues arising from the use of Grade 500E reinforcing steel including;

- Reference to AS/NZS 4671:2001
- Reference to AS/NZS 1554.3:2002
- Requirement to hot bend pre-bent micro alloy Grade 500E reinforcement
- Requirement to inspect re-bent areas for cracking.
- Restrictions on location of tack welds from bends.
- Warnings regarding welding of reinforcement

The amendment appears to adequately address these issues, although the warning regarding welding should reiterate the requirements of NZS 3101 which prohibit welding of Q&ST reinforcing steel.

References

1. “Shake it up”, Progressive Building, Issue 43, Dec 2003/Jan 2004.
2. Grade 500 Reinforcement Design Construction & Properties Seminar Notes, Presented by The Cement and Concrete Association of New Zealand & Reinforcing New Zealand Inc 2003.
3. AS/NZS 4671:2001 Steel Reinforcing Materials, Joint Australian and New Zealand Standard.
4. AS/NZS 1554.3:2002 Structural Steel Welding Part 3: Welding of Reinforcing Steel, Joint Australian and New Zealand Standard.
5. NZS 3101: Part 1:1995 Concrete Structure & Standard Part 1 – The Design of Concrete Structures, New Zealand Standard.
6. NZS 3101: Part 2:1995 Concrete Structures Standard. Part 2 – Commentary on The Design of Concrete Structures, New Zealand Standard.
7. Amendment Nº 3 to NZS 3101:1995 Public Comment Draft, New Zealand Standard.
8. NZS 3109:1997 Concrete Construction, New Zealand Standard.
9. Amendment Nº 2 to NZS 3109:1997 Public Comment Draft, New Zealand Standard.
10. Private communication with the New Zealand Building Authority.

Appendix A

Investigation Brief

Our Ref: 344.1
Your Ref: W3:15315-RDJ39L05.Doc

03 OCT 2003

Building Industry Authority

02 October 2003

Beca Carter Hollings and Ferner
PO Box 3942
Wellington

Attention: Rob Jury

Dear Rob

Grade 500E Reinforcing Steel – Desk Top Study

Thank you for your proposal on the above topic dated 19 September, received 23 September 2003.

Your proposal is accepted as to Scope, Methodology and Commercial Terms. Please take this letter as an instruction to commence work. We anticipate completion of the report by no later than 24 October 2003.

Thank you for your attention to this matter. Please do not hesitate to contact us should you require any further information or direction.

Yours sincerely

David Hopkins
Consultant Technical Advisor

Building Industry Authority
PO Box 11 846
WELLINGTON

19 September 2003
Our Ref: 5000017/020
W3:40397-RDJ55L04.DOC

Attention: Dr David Hopkins

Dear Sir

Grade 500E Reinforcing Steel

We provide the following Scope of Work and Methodology for the Grade 500E Reinforcing Steel investigation in response to your e-mail dated 10 September 2003.

Scope of Work

The intention is to examine the various standards that impact on the quality and performance of Grade 500E reinforcing steel and identify key issues that should be followed up to provide confidence that the standards are consistent and applicable for use with 500E reinforcing. It is intended that this be a brief desk-top exercise.

The standards to be reviewed are:

- AS/NZS 4671:2001 Steel Reinforcing Materials
- NZS 3101:1995 Concrete Structures Standard
- NZS 3109:1997 Concrete Construction
- AS/NZS 1554.3 Welding of Reinforcing Steel

Amendments are currently being proposed for NZS 3101 (DZ 3101 A3) and NZS 3109 (DZ 3109 A2). These amendments will also be included in the review.

Methodology

The following process is proposed;

- Review the relevant standards and proposed amendments for consistency and in light of the information presented at the recent seminar on 500E reinforcing steel.
- Prepare a list of major issues relating to the use of 500E reinforcing steel.
- Discuss the issues with others (eg Beca metallurgist) in order to form an opinion of the degree with which they are addressed in the standards and recommendations for use.
- Identify those issues that will require additional research in order to provide confidence of the acceptability of 500E reinforcing steel.

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Fax +64-4-471 5501
www.beca.co.nz

- Prepare a brief report outlining results of the review.

Yours faithfully
Rob Jury
Technical Director - Structural Engineering

on behalf of
Beca Carter Hollings & Ferner Ltd
Direct Dial: +64-4-471 5511
Email: rob.jury@beca.com

Appendix B

Assessment of Strain Requirements in Reinforcing Bar Bends

Calculation of Strains within Reinforcing Bar Bends

It can be shown from simple assessment of bend geometry that the strain in the outer and inner fibers of a bar bend can be approximated as;

$\varepsilon = d/(D+d)$……………………………………………………………….eqn B1

where d is the diameter of the bar
D is the diameter of the bend

The resulting strains for 16, 25 and 32mm diameter bars are shown in Table B.1.

The method of Lubahn and Sachs(B.1) (as also used by Erasmus and Pussegoda (B.3)), as presented in eqn B2, predicts almost identical strains as can be seen in Table B.1.

$\varepsilon = (1-K)/(1+K)$…………………………………………………………….eqn B2

where $K = (D/d)/(1+ [(D/d)^2 + 2D/d]^{0.5})$
d and D are as defined above.

Table B.1 Predicted Bend Strains

Bar Diameter, d mm	Bend Diameter, D Mm	ε = d/(D+d)	ε = (1-K)/(1+K)	Predicted Notch Strain
16	**5d**	**17%**	**16%**	**20%**
25	**6d**	**14%**	**14%**	**18%**
32	**6d**	**14%**	**14%**	**20%**

These strains need to be enhanced to account for the notch effect at the crushed deformations in compression side of the bar. The equation to allow for this, which was presented by Erasmus(3), appears in error, however recourse to the various plots in the Erasmus paper indicates the following enhancements might be appropriate;

16mm dia 15%
25mm dia 30%
32mm dia 40%

From these indicative enhancements the following bend notch strains are predicted;

16mm dia D = 5d strain = 17% x 1.15 = 20%
25mm dia D = 6d strain = 14% x 1.30 = 18%
32mm dia D = 6d strain = 14% x 1.40 = 20%

These are also shown in Table B.1

Assessment of Acceptable Bend Strains

The way to assess acceptable bend strains is though an appropriate fracture (toughness) assessment, ie as carried out by Erasmus(2,3).

It is of interest to consider the alternative method used to suppress brittle fracture in structural steel sections presented in NZS 3404 (Section 2.6), the notch ductile method. This method would suggest that for steel grades covered by this Standard only small diameter bars could be subjected to strains approaching anywhere near 20%.

The uniform elongation as obtained from the standard tensile test is not considered to provide a realistic assessment of the strain capability of reinforcing bars. However, we understand that it is common to restrict the bend strains in a structural member to the strain achieved in a standard tensile test (5). A true strain test (accounting for the reduction in area of the specimen as it necks) would provide a more appropriate measure. The specified minimum uniform elongation for Grade 500E reinforcing steels in AS/NZS 4671 is 10%.

We could find no evidence that a fracture assessment has been completed for Grade 500E reinforcing bar bends. The desirability of such an assessment requires informed comment and discussion.

Additional References for Appendix B

B.1. Lubahn, J D and Sachs, G, Bending of an Ideal Plastic Material, Transactions of the ASME, Vol 72 p201, February 1950.

B.2. Erasmus, L A and Pussegoda L N, Strain Embrittlement of Reinforcing Steels, New Zealand Engineering, Vol 32 No 8, August 1977.

B.3. Erasmus, L A and Pussegoda L N, Safe Bend Radii for Deformed Reinforcing Bar to Avoid Failure by Strain Age Embrittlement, New Zealand Engineering, Vol 33, No 8, August 1978.

B.4. NZS 3404:1997, Steel Structures Standard, New Zealand Standard.

Private communication with Hera.

Appendix 3: Investigation to Clarify Properties of Grade 500E Reinforcing Steel Bar.

Report by SGS New Zealand

PROJECT REPORT

SGS FILE REFERENCE:	INZ1564810
REPORT:	Investigation to Clarify Properties of Grade 500E Reinforcing Steel Bars
CLIENT:	Building Industry Authority
CONTACT:	David Hopkins
DATE:	18th August 2004

REPORTED:	Leonard Kong - Materials Engineer - BE Chem & Mats
REVIEWED:	Dean Currie - Business Manager - NDT & Materials Services
DATE:	31st August 2004

Executive Summary

The Building Industry Authority (BIA) had awarded the contract to SGS New Zealand Limited to carry out an "Investigation to Clarify the Properties of Grade 500E Reinforcing Steel Bars" following the concerns raised by many parties with regards to the adequacy of Grade 500E steel for use in New Zealand ductile structures.

The scope of the project is to study the deformed type of this grade of reinforcing steel bars through a series of mechanical tests in accordance with AS/NZS 4671:2001. The tests include tensile testing, rebend testing followed by tensile testing on the same specimens, and hardness testing. These results were reported in File Ref INZ1564806 dated 18th March 2004.

Following the variation to the original contract, further testing were included to study the weldability of these rebar, surface geometry study, addition of 32mm size bars for the completeness of the study, and the 180° bend test as per standard requirement for bars more than 20mm size. Results were added to the report and is finalised as report reference INZ1564810, which is intended to replace all previous reports.

Rebars were sourced from Pacific Steel (New Zealand), Natsteel (Singapore), and Amsteel (Malaysia) through various local distributors to represent good sampling spread within the New Zealand market.

Results obtained from the tests showed concluding remarks and highlighted some issues such as mill certificate accuracy, bar markings and their uniqueness, and physical property trends.

Table of Content

1.0 Introduction

As the name implies, reinforcing steel is defined in the standard *AS/NZS 4671:2001 – Steel Reinforcing Materials* “steel with a circular or practically circular cross section suitable for the reinforcement of concrete”. There are several types of reinforcing steel and are classified by their shape, strength grade, relative ductility and size.

Grade 500E reinforcing steel bars are so designated as having the strength grade of 500Mpa and ductility class of ‘Earthquake’ (seismic) grade. It has come onto the New Zealand market recently in the past few years to replace its predecessor Grade 430E of *NZS 3402:1989*. Studies conducted by the University of Auckland and other sources have raised concerns over the performance of Grade 500E steel, especially in the one instance, when based on the observation of a single bar, that the hardness of the steel can vary significantly over a typicallength of bar.

The Building Industry Authority (BIA) has been carrying out the project to address these concerns by confirming or otherwise the adequacy of Grade 500E steel for use in ductile structures. This was achieved by testing a representative sample of product to examine any evidence of variation of properties. SGS was invited the tender and was awarded the contract to perform this investigation to clarify the properties of the Grade 500E steel.

2.0 Scope

The scope of work involves obtaining a representative sample of Grade 500E reinforcing steel bars available in New Zealand from various local distributors. Three reinforcing steel manufacturers were nominated, one being the local manufacturer Pacific Steel New Zealand while others were sourced from Natsteel Singapore and Amsteel Malaysia.

The tests to be carried out as the original scope are listed as follows:
- Tensile tests in accordance with AS/NZS 4671 Clause 7.2.2
- Rebend tests in accordance with AS/NZS 4671 Clause 7.2.3 followed by tensile tests on the bars after they have undergone the rebend test.
- Hardness tests on the bar cross-section traversing from core to edge using the Vickers Hardness method.

2.1 Variation to the original scope

Further tests were added as variation to the original scope and these can be summarised as follows:
- Variation to original scope to study bar markings and surface geometry in accordance with AS/NZS 4671 Clause 7.4 & Clause 9.
- Variation added to carry out tensile testing of 12mm size bars for further study of total elongation after fracture.
- Variation added to carry out bend testing of all bar size above 20mm through the 180° bends as per Clause 7.2.3.
- Variations added to carry out tensile testing of welded rebars on selected samples for the study of weldability effects on the tensile properties.
- Variations added to carry out testing on 32mm size rebar for the completeness of the study.

The tests were carried out in three places along the same bar. The sampling of specimens can be referred to in *Table 2.1* below.

			Original Scope			Variation to Original Scope			
Bar Size (mm)	No. of Suppliers	No. of Bars per Supplier	Tensile Tests per Bar	Rebend and Tensile Tests per Bar	Hardness Tests per Bar	Bar Marking and Surface Geo-metry	Total Elong-ation Test per Bar	180° Bend Test per Bar	Weld-ability Study
12	3	2	3	2	3	1	1	-	-
16	3	2	3	2	3	1	-	-	2
20	3	2	3	2	3	1	-	2	6
25	3	2	3	2	3	1	-	2	2
32 Added	2	2	3	2	3	1	-	2	-
Total Tests			84	56	84	14	6	32	10

Table 2.1: Scope of Test Specimens

Wherever possible, each of the two bars from the same supplier is opted to be of different production batch. However, some bars sourced from Natsteel and Amsteel have not been able to meet this requirement given the timing of tests and stock availability. Therefore two bars from the same production batch were tested on Nasteel 12mm, 16mm, 20mm, 25mm and Amsteel 25mm bars.

3.0 Samples Identification

Due to large number of tests and specimens, and in the hope of easy referencing each test specimens were identified using the following system:

“Manufacturer-Heat/Batch no.-(Tensile/Bend/Hard)(sample no.)” e.g. PAC-30471-T1.

Where two re-bars were of the same batch like those from Natsteel, the specimens were designated as NAT-S34140-T1.1 for the first bar while NAT-S34140-T2.1 for the second.

Reporting of testing results were tabulated base on each bar size per page per type of test. Each test report number will end with three digits bar size number e.g. INZ15648-report no.- 012 for 12mm diameter bar.

Analysis of data where individual specimens cut from the same bar when taken average would be designated, for example, as PAC-30471-12 for the 12mm diameter bar.

4.0 Mechanical Testing

All Pacific Steel rebars arrived in 6m lengths while the Natsteel bars arrived in 6m lengths already pre-cut in halves. The Amsteel bar however arrived in 3m lengths. Test specimens for a length of bars were cut at three places i.e. 2 at each end and 1 at mid section along the same bar as shown in *Figure 1* below.

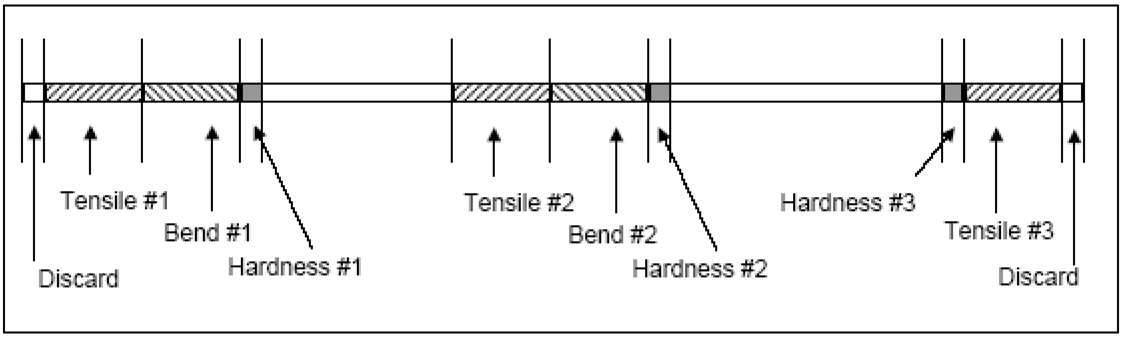

Figure 1: Test specimen location along a bar

4.1 Bar Markings and Surface Geometry

Bar markings and surface geometry of the rebars were identified in accordance with the standard clause already specified in the above scope. Bar markings was assessed visually to confirm presence of the bar unique identification system, which shall enable the steel producer and/or the strength grade to be identified.

The surface geometry testing was carried out to study its bond strength characteristics with concrete through the criterion of specific projected area f_R as set out in the standard. One of each of the different size bar samples from each supplier was studied for this surface geometrical property.

4.2 Tensile Testing

Tensile testing of rebars was conducted in accordance with the standard clause already specified in the above scope. The properties that can be obtained from the test are the yield stress (R_{eL}), the ultimate tensile stress (R_m) and the uniform elongation (A_{gt}). The A_{gt} of each tensile specimen was determined in accordance with ISO 10606. Note that A_{gt} is relatively recent with many specifications only requiring the generic elongation method such as in the previous specification NZS 3402. The later, i.e. the total elongation after fracture was carried out on the 12mm bar sizes as a variation to the original scope to study its trend.

All of these tensile values are used to determine if the bars comply with the characteristic mechanical properties as set out in Table 2 of AS/NZS 4671:2001.

Three tensile specimens were cut using the cut off saw at places shown in *Figure 1* above. After taken into account of minimum clearance and gauge length as stated in ISO 10606, the total length for each tensile specimen was 500mm except for 32mm size bar the length is 850mm. Gauge length of 50mm at interval of 25mm along the free length of the specimen was used.


Figure 2: Tensile test set up

Figure 2 above shows an example that all specimens were subject to full section longitudinal tensile stress. Notice the white gauge markings along the length of the specimen.

The yield stresses of the steel bar were determined through observation of yield phenomena that fluctuates the tensile machine scale.

4.3 Rebend Tests Followed by Tensile Testing

Reverse bend tests were conducted in accordance with the standard clause specified in the above scope using the guided bend test method. Reverse bend tests for the 20mm and 25mm bars were not tested in accordance with the standard clause as will be explained later. The test involves the initial bending of test specimen according to mandrel size and bending angle as set out in Table 4 of AS/NZS 4671:2001. The specimen was then aged in 100ºC bath for 1 hour, left to cooled to room temperature before subjecting it to reverse bend (straightened) in the same initial angle.

After the reverse bends there shall be no visible evidence of cracking on the surface of the test bar. At the end of these, the straightened bars were subject to tensile test to study if there were any changes to the mechanical properties.

It was not required in the standard to rebend the 20mm, 25mm and 32mm bars after the initial 180º bend. However, for the purpose of this study, initial trials to rebend the 180º angle were attempted but leading only to bars fracturing during straightening. For this reason, it was varied from the standard that the initial bending angle be the same as 12mm and 16mm bar i.e. 90º angles.

Later as testing progresses, there was variation added to the original scope to carry out the full 180° bend test on all 20mm, 25mm and 32mm size bars as per the standard for compliance requirements.

Two bend test specimens were cut off at two places along the same length of a single bar as shown in *Figure 1* previously. *Figure 3* and *4* shows the set up of guided bend and rebend test. It consists of a mandrel pushing down against the bar supported by a set of two rollers. The rebend jig set up is just the reverse of the guided bend. It consists of sandwich plates on both sides of the bar. The bar is seated on the rolling plates.

Figure 3: Guided bend jig set up

Figure 4: Reverse guided bend jig

4.4 Welding of Rebar for Tensile Testing

The effect of welding of this bar grade on the tensile properties was studied. 10 different combinations of bar sizes and manufacturers were nominated and welded in accordance with *AS/NZS 1554.3:2002 – Structural steel welding Part 3: Welding of reinforcing steel*.

As per standard requirement for prequalified welding procedures, the parameters used for welding the rebar were specified as follow:

- Type BD-3a joint preparation for double-V butt splice
- E5518 and E6218 welding consumables selected for the weld metal's minimum tensile strength of 550MPa and 620MPa respectively. Due to no stock availability of this type of welding electrode, the American equivalent electrodes were used for this test i.e. the AWS A5.5 E8015-B3L to replace the E5518 while AWS A5.5 E9016-B3 replaces the E6218.
- Welder's skill qualification to NZS4711 were employed to carry out the welding
- Supervision during joint preparation and welding was carried out to ensure consistency of testing.

The bars selected for welding were as follows:

- 2 no's of 16mm bars from Pacific Steel,
- 2 no's of 20mm bars from each of the 3 suppliers, and
- 2 no's of 25mm bars from Pacific Steel.

Each 5 bars out of the 10 were used for welding with the respective 550MPa and 620MPa electrodes.

4.5 Vickers Hardness Testing

Although it was not specified in the AS/NZS 4671 standard that hardness test is necessary, previous investigation raised this as an issue to further investigate and verify the distribution of hardness along the same length of bars. The hardness distribution was obtained by traversing the cross section of the rebar specimens from core to edge at four intervals as shown in *Figure 5* below.

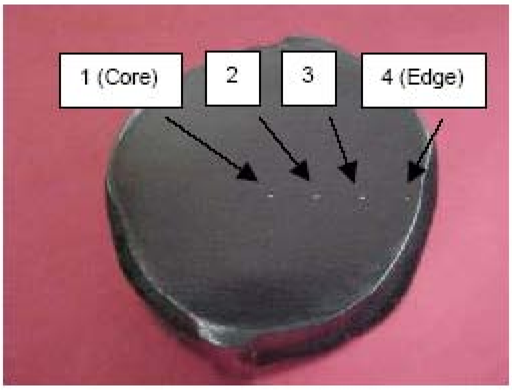

Figure 5: Hardness traverse from core to edge

The method of hardness test adopted was the Vickers scale and was carried out in accordance with AS1817. The indentation load of 10kg was selected for the range of this anticipated steel hardness. The hardness test specimens were nominated at three places along the length of a single bar as shown in *Figure 1* earlier.

5.0 Results and Findings

Bar markings, surface geometry, tensile, bending, welding and hardness results were tabulated and presented as Appendices of this report.

5.1 Bar Markings and Surface Geometry

Bar markings unique to each manufacturer can be shown in *Figure 6, 7* and *8* below.

Figure 6: Amsteel bars consist of two rows of crescent shaped transverse ribs reversing in direction on opposite sides of the bar with two additional longitudinal ribs on one side. On the other side there is one longitudinal mark joining two consecutive ribs, spaced at 1m apart.

Figure 7: Natsteel bars consists of two rows of transverse ribs reversing in direction on opposite sides of the bar with 3 additional longitudinal ribs - one on one side and two on the other. On the sides with two longitudinal ribs, there are two longitudinal marks deformed in between two consecutive ribs, spaced at 1m apart.

Figure 8: Pacific Steel bars can be identified by two rows of uniform height transverse ribs reversing in direction on opposite sides of the bar and have on one sides, two missed deformations adjacent to two additional longitudinal bars joining two consecutive ribs. There is alphanumerical marking "SEISMIC 500" adjacent to the missed deformations spaced at 1m apart.

Results for the surface geometry were tabulated in the *Appendix Test Report No. INZ1564808*. Note that the non-compliance to acceptance criteria is highlighted in red.

5.2 Tensile Results

Tensile results are reported in the *Appendix Test Report No. INZ1564801* series. Yield stress (R_{eL}) and the ultimate tensile stress (R_m) values for all the tensile specimens were plotted in *Chart 1*. As can be seen, specimen AM-120388-T3 of 20mm bar has the lowest test values corresponding to R_{eL}=497MPa while the maximum R_{eL}= 583MPa is observed from specimen NAT-RGB77-T3 of 32mm bar.

In *Chart 2, 3, and 4*, the values of the 3 test specimens representing the same bar were averaged. These averaged results were plotted in comparison with the respective mill values and the minimum acceptance criteria. *Chart 2* plots the average values of Yield Stress (R_{eL}) and Ultimate Tensile Stress (R_m) for each bar. *Chart 3* plots the average values of Tensile Stress Ratio (R_m/R_{eL}) while Chart 4 shows the average values of Uniform Elongation (A_{gt}).

5.3 Reverse Bend Results

Reverse bend results can be viewed from the *Appendix Test Report No. INZ1564802* series. All 12mm and 16mm bars comply with the standard requirements without significant findings before and after bending.

However, all of 25mm, 32mm and majority of 20mm size bars tested developed surface cracks after reverse bends. Note that there is no compliance requirement as per standard for these sizes for the reverse bend test.

There is only one of each of the 25mm and 32mm bars that fractured during the re-bending process as shown in *Figure 9*. *Figure 10* shows typical surface cracks that are generally found at the region of bends, along and underneath both sides of a rib mark that extend to about 3-5 ribs. Maximum crack lengths are normally up to 20mm.

Figure 9: Fracture during straightening

Figure 10: Example of surface cracks

Severe cracks up to 6mm deep were observed in 32mm bars after reverse bends. *Figure 11* and *Figure 12* shows the relative size of cracks in the 32mm bars. All the 32mm bars tested have combination of cracks along the bend region i.e. from just surface cracks at the outer region of bend radius like those shown in *Figure 10* to deep cracks at the highest strained region, except that NAT-RGB77-B1 and NAT-S42770-B1 showed only minor surface cracks.

Apart from all these, there are no other significant findings on the bars after the initial bend. The full 180° bend test for bar size above 20mm have also complied with the criteria.

Figure 11: Crack profile

Figure 12: Surface cracks and deep cracks

5.4 Tensile Properties after Reverse Bends

Further studies of tensile properties of those bars after undergone the reverse bend test were presented in *Chart 6, 7, 8* and *9* to compare the values from the previous charts i.e. the initial tensile specimen results. Each chart respectively shows the comparison of UTS (R_m), Yield Stress (R_{eL}), Stress Ratio (R_m/R_{eL}), and Uniform Elongation (A_{gt}) before and after reverse bend test.

The location of fracture in relation to the bend and rebend region is reported in the *Appendix Test Report No. INZ1564804* series.

5.5 Tensile Properties after Welding

Tensile results after welding are reported in *Appendix Test Report No. INZ1564809*. The fracture locations of the welded bars were also reported.

The tensile properties were plotted in *Chart 10, 11, 12, and 13* for comparison of trends with their respective bar average values from *Chart 2, 3, and 4*.

5.6 Hardness Results

Vickers hardness traverse plots for 12mm, 16mm, 20mm, 25mm and 32mm bars were shown in *Chart 14, 15, 16, 17* and *18* respectively. These charts plot the individual hardness readings for all the specimens traversing from core to edge. *Chart 19* plots the averaged of these core-to-edge values for all the specimens stated. The raw data can also be referred to in *Appendix Test Report No. INZ1564803* series.

6.0 Results Discussion

6.1 Bar Markings and Surface Geometry

Pacific Steel bars complied with the standard requirement of alphanumerical and unique characteristics of deformation patterns. Both Natsteel and Amsteel have some form of characteristic deformation patterns but they do not have the alphanumerical markings. Despite the commercial claims that both Natsteel and Amsteel have bar markings that are unique to their range of imported products in the New Zealand market, it is not easily distinguishable, as they look somewhat similar to some other grades in the *AS/NZS 4671* standard. For instance, both Natsteel and Amsteel when compared casually would look like the New Zealand grade 500N. The lack of alphanumerical markings would also prove difficult for construction site workers to identify the strength grade.

The surface geometry test of all 3 suppliers and sizes was carried out mainly for the purpose of confirming the adequacy of bond strength to concrete through the calculation of specific projected area f_R, and that all complies with the minimum requirement of 0.056. There are other minor non-compliances with the deformation parameters and these include the longitudinal rib height requirement of Natsteel bars, and rib inclination angle requirement of Natsteel and 16mm Pacific Steel bars.

6.2 Tensile Properties Comparison with Mills and Acceptance Criterion

Referring to *Chart 2*, while all bars passed the minimum yield stress of 500MPa except for the 20mm AM-120388-20, the consistency of both the R_{eL} and R_m as compared to the mill values is not very obvious. This might lead to a concern that raises the question if the mill certificates were supplied accurately. Despite the differences, most bars tested are showing average stresses lower than those reported in the mill certificate except for only few of the large size bars.

In *Chart 3,* it is found that most Natsteel bars did not conform to the minimum acceptable ratio of 1.15 as per standard requirement. In line with this, the corresponding mill certificates are also reporting values just marginally over the minimum requirements. All other bars tested comply, although AM-120838-16 bar is showing mill values that did not comply.

The minimum acceptance criterion for the uniform elongation (A_{gt}) required by the standard is 10%. All bars tested passed the criteria as shown in *Chart 4*. Note that some mill certificates reported only the total elongation instead of the required A_{gt} values; therefore these values are left blank in the graph. Hence, further studies on the total elongation of the 12mm bars were carried out to confirm the mill values. *Chart 5* plots the total elongation (A) comparison. Note that Natsteel bars are consistent with mill values whereas the Amsteel bars show differential values of up to 9%.

6.3 Tensile Properties Comparison Before and After Reverse Bend

Chart 6, 7 and *8* each shows respectively the UTS (R_m) and yield stress (R_{eL}) comparison before and after reverse bend. There is no significant difference between these values for bar size 12mm and 16mm. As for the bigger size bars i.e. the 20mm 25mm and 32mm the only significant differences in the values of UTS, Yield and hence the Tensile Stress Ratio (R_m/R_{eL}) are noticeable on the bars that have premature failure due to large cracks.

Chart 9 shows the uniform elongation (A_{gt}) comparison. Note that all A_{gt} values were lower than the A_{gt} before bending and the minimum acceptance criterion. This has been expected because of the fact that the original gauge marks (L_o) were only taken after the bars had undergone some stage of work hardening or plastic deformation during the reverse bend process.

One finding is that most bars that had undergone the reverse bend, when subject to tensile tests they break at the region outside the bent section as can be shown in *Figure 13*. Note that the bent section is in the middle section of the bars in the Figure.

There are however, some specimens that fractured inside the bent section where there is presence of surface cracks. It is believed that these cracks may have directly affected the fracture location. *Figure 14* shows a close up of the typical fracture lips of a specimen due to surface cracks.

Figure 13: Examples of fracture location and cracks region as marked in white relative to bent section in the middle.

Figure 14: Cracks leading to fracture as marked

For specimens with fracture location outside the bent section, it is believed that this is the location where that section of the bar have not been deformed plastically therefore giving rise to yield point phenomena as observed. This may explain the small differences in R_m and R_{eL} values discussed earlier.

6.4 Tensile Properties Comparison Before and After Welding

Out of the 10 bars welded, all the 2 Natsteel bars and 1 Amsteel bars fractured at weld joint fusion line. All others fractured at parent metal. One of Natsteel bars fractured with the 550MPa electrode whereas the other Natsteel and the one Amsteel fractured with the 620MPa electrode.

Although there were 3 welded bars that fractured at the weld joints, *Chart 11* shows that their respective yield values (R_{eL}) are very close to the original unwelded samples with all having exceeded the minimum R_{eL} requirement. Only the AM-120388-20 bar that did not comply with the original R_{eL} as discussed in the earlier tensile section. Maximum differential yield stress is 15MPa.

Chart 10 showed that all welded bars, including the 3 samples that fractured at weld joint, passed the original bar minimum UTS requirement of 575MPa and the respective electrode minimum UTS. Only the weld joint failure of AM-120396-20 sample that it did not passed the minimum electrode UTS of 620MPa.

Studying only the UTS values in *Chart 10* may be misleading and conclusion should not be drawn to pass the welding procedure. *Chart 12* confirms this argument that the one important parameters of seismic grade reinforcing bars i.e. the R_m/R_{eL} ratio is greatly different from the original unwelded bar especially seen on the Natsteel bars. *Chart 13* also shows significant differential A_{gt} values of up to 7%.

The overall trend suggested that the choice of welding consumables might play an important role in the strength of the reinforcing bars. The two types of electrode used may suit Pacific Steel bars very well and part of Amsteel bars. They may not suit the Natsteel bars but can only be confirmed with more test samples.

6.5 Hardness Properties

From *Chart 14* to *Chart 18*, notice the trend for each of the bar sizes that hardness distribution are generally increasing from core to edge, although there are some scattering of hardness readings from core to edge. Pacific Steel bars generally showed better uniformity of hardness distribution than Natsteel and Amsteel.

As can be seen from *Chart 19*, the average traverse results showed small variations of hardness throughout a length of bars, although only a few that is scattering. Pacific Steel and Natsteel bars showed better uniformity of hardness regardless of bar size. Amsteel however has significant hardness trends.

These can reasonably confirmed that the rebars hardness is consistent along the lengths, but varied quite significantly within the cross sections. Nevertheless, the trend seems to be improving towards the larger size bars.

6.6 Comments on the Seismic Grade Reinforcing Steel

Part of the design of the seismic grade of reinforcing bars with the requirement of minimum R_{eL}, R_m/R_{eL} ratio, and uniform elongation A_{gt} is to ensure that the reinforcing bars are able to cope with the huge seismic demand during severe earthquakes in order to control damage or to avoid catastrophic damage on civil structures. This can be achieved because the reinforcing steels are so designed that when loaded beyond yielding or plastic deformation, the yielding is not confined to that localised point where it first commences and therefore allowing greater ductility throughout the length of bars.

This phenomenon explains why some bars tested have fractured outside the bent region. Unlike the micro alloy process of Pacific Steel, the in-line quench and temper Natsteel and Amsteel do not show such consistent trends due to the nature of its microstructure directly affecting the failure mode.

7.0 Conclusion

- In line with the scope of this project to carry out an investigation to clarify properties of Grade 500E reinforcing steel bars, conclusions are drawn only based on the results and findings.

- The local reinforcing steel complies with the bar markings requirement but not the imported ones.

- Surface geometry study reveals that all bars tested comply with the minimum specific projected area fR but there are some other parameter requirements that have not been met to reflect the adequacy of bond strength characteristics to concrete.

- All bars tested passed minimum yield stress (R_{eL}) requirement, but there are some that do not comply with the uniform elongation (A_{gt}) and stress ratio (R_m/R_{eL}) requirements.

- All bars tested have some tensile results varied quite significantly with mill certificate.

- All 12mm and 16mm bars tested comply with reverse bend requirements without visible surface cracks developing. There are no compliance requirements for the 20mm, 25mm and 32mm bars even though majority of these developed surface cracks.

- All bars tested for the full 180° bend comply with the standard requirement.

- All tensile results of bars after the reverse bend tests have similar values to the original bars in R_m and R_{eL} except for bars that have severe cracks. All A_{gt} values were lower than the original bars. The fracture locations were identified with majority of the bars breaking outside the bent section.

- All welded bars tested exceeded the parent metal minimum UTS, but there are some bars that did not fully comply with other requirements of stress ratio and uniform elongation.

- Vickers hardness readings indicated variation of hardness at the cross sections but acceptable consistency throughout the lengths of the bar.

8.0 Recommendations

- For bars that do not fully comply with the surface geometry requirements, it is recommended that the actual bond test performance on concrete be carried out as set out in the AS/NZS 4671 standard.

- Independently test the new reinforcing steel shipments that arrive in New Zealand to validate the accuracy of mill certificates.

- The weldability studies of imported reinforcing bars should be carried out more extensively to include larger number of bars as well as choices of welding consumables.

- Further the metallurgical condition of the material such as grain size and refinement is likely to have a significant impact on performance and hence the resulting physical properties. This relationship should also be considered.

- Expand existing testing regime to include greater number of sample batches to further validate some possible trend from the data obtained.

TEST REPORT No.: INZ1564801-012

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile:

Type: Full Section
Specimen Axis: Longitudinal

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_o=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments C - Complies, DNC - Does Not Comply
PAC-30471-T1	12	527	655	1.24	50	14.3	
PAC-30471-T2	12	529	653	1.23	50	12.3	
PAC-30471-T3	12	529	653	1.24	50	11.3	
PAC-31077-T1	12	527	656	1.24	50	12.5	
PAC-31077-T2	12	529	654	1.24	50	11.3	
PAC-31077-T3	12	529	654	1.24	50	12.3	
NAT-S34140-T1.1	12	508	562	1.11	50	11.3	DNC Ratio only
NAT-S34140-T1.2	12	503	559	1.11	50	11.3	DNC Ratio only
NAT-S34140-T1.3	12	508	562	1.11	50	10.3	DNC Ratio only
NAT-S34140-T2.1	12	500	561	1.12	50	11.3	DNC Ratio only
NAT-S34140-T2.2	12	504	562	1.12	50	12.3	DNC Ratio only
NAT-S34140-T2.3	12	503	561	1.11	50	12.3	DNC Ratio only
AM-116784-T1	12	508	604	1.19	50	10.3	
AM-116784-T2	12	511	604	1.18	50	12.3	
AM-116784-T3	12	521	604	1.16	50	12.3	
AM-120820-T1	12	539	622	1.15	50	14.3	
AM-120820-T2	12	539	625	1.16	50	13.3	
AM-120820-T3	12	541	624	1.15	50	11.3	
Min.		500	559	1.11		10.3	
Max.		541	656	1.24		14.3	
Average		520	610	1.17		12.0	
Acceptance Criteria:	Minimum	500		1.15		10.0	

Tested By:	L Kong	Date:	14-Apr-04
Checked By:	D Currie	Date:	14-Apr-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.:	INZ1564801-016
Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile:

Type: Full Section

Specimen Axis: Longitudinal

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments C - Complies, DNC - Does Not Comply
PAC-30755-T1	16	537	684	1.27	50	13.3	
PAC-30755-T2	16	540	681	1.26	50	16.3	
PAC-30755-T3	16	540	684	1.27	50	15.3	
PAC-30756-T1	16	545	681	1.25	50	14.3	
PAC-30756-T2	16	542	681	1.26	50	14.3	
PAC-30756-T3	16	542	681	1.26	50	14.3	
NAT-S38526-T1.1	16	510	597	1.17	50	12.3	
NAT-S38526-T1.2	16	502	597	1.19	50	11.3	
NAT-S38526-T1.3	16	507	587	1.16	50	11.3	
NAT-S38526-T2.1	16	525	599	1.14	50	12.3	DNC Ratio only
NAT-S38526-T2.2	16	502	592	1.18	50	12.3	
NAT-S38526-T2.3	16	505	597	1.18	50	12.3	
AM-120829-T1	16	530	612	1.15	50	14.7	
AM-120829-T2	16	530	617	1.16	50	13.3	
AM-120829-T3	16	532	617	1.16	50	13.9	
AM-120838-T1	16	537	634	1.18	50	10.3	
AM-120838-T2	16	542	629	1.16	50	11.3	
AM-120838-T3	16	547	634	1.16	50	14.3	
Min.		502	587	1.14		10.3	
Max.		547	684	1.27		16.3	
Average		529	634	1.20		13.2	
Acceptance Criteria:	Minimum	500		1.15		10.0	

Tested By:	L Kong	Date:	14-Apr-04
Checked By:	D Currie	Date:	14-Apr-04

Amendments to this certificate are not allowed unless such amendments are approved and effected by SGS NEW ZEALAND LIMITED. Reproduction without permission is not allowable unless in full content.

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.: INZ1564801-020

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile:

Type: Full Section

Specimen Axis: Longitudinal

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments C - Complies, DNC - Does Not Comply
PAC-30076-T1	20	547	683	1.25	50	17.3	
PAC-30076-T2	20	546	681	1.25	50	14.3	
PAC-30076-T3	20	546	683	1.25	50	16.3	
PAC-31119-T1	20	543	681	1.26	50	15.9	
PAC-31119-T2	20	538	680	1.26	50	13.9	
PAC-31119-T3	20	538	683	1.27	50	15.3	
NAT-S35858-T1.1	20	567	653	1.15	50	10.3	
NAT-S35858-T1.2	20	568	651	1.146	50	11.3	DNC Ratio only
NAT-S35858-T1.3	20	567	651	1.149	50	9.3	DNC Ratio & Agt
NAT-S35858-T2.1	20	575	659	1.147	50	11.3	DNC Ratio only
NAT-S35858-T2.2	20	570	657	1.15	50	9.3	DNC Ratio & Agt
NAT-S35858-T2.3	20	576	659	1.14	50	10.3	DNC Ratio only
AM-120388-T1	20	498	602	1.21	50	14.7	DNC Yield only
AM-120388-T2	20	501	598	1.19	50	15.9	
AM-120388-T3	20	497	594	1.20	50	15.9	DNC Yield only
AM-120396-T1	20	499.7	602	1.20	50	15.3	DNC Yield only
AM-120396-T2	20	503	600	1.19	50	17.9	
AM-120396-T3	20	503	598	1.19	50	15.3	
Min.		497	594	1.14		9.3	
Max.		576	683	1.27		17.9	
Average		538	645	1.20		13.9	
Acceptance Criteria:	Minimum	500		1.15		10.0	

Tested By:	L Kong	Date:	14-Apr-04
Checked By:	D Currie	Date:	14-Apr-04

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Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.:	INZ1564801-025
Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile:

Type: Full Section

Specimen Axis: Longitudinal

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments C - Complies, DNC - Does Not Comply
PAC-30580-T1	25	530	666	1.26	50	14.3	
PAC-30580-T2	25	524	664	1.27	50	12.3	
PAC-30580-T3	25	522	664	1.27	50	13.3	
PAC-31128-T1	25	572	719	1.26	50	12.4	
PAC-31128-T2	25	572	725	1.27	50	12.4	
PAC-31128-T3	25	570	729	1.28	50	10.4	
NAT-S35830-T1.1	25	572	656	1.146	50	12.3	DNC Ratio only
NAT-S35830-T1.2	25	572	656	1.146	25	12.3	DNC Ratio only
NAT-S35830-T1.3	25	573	666	1.16	50	11.3	
NAT-S35830-T2.1	25	564	646	1.14	50	9.9	DNC Ratio & Agt
NAT-S35830-T2.2	25	563	644	1.14	50	10.3	DNC Ratio only
NAT-S35830-T2.3	25	564	646	1.14	50	10.3	DNC Ratio only
AM-123405-T1.1	25	568	672	1.18	50	10.3	
AM-123405-T1.2	25	574	676	1.18	50	10.3	
AM-123405-T1.3	25	570	672	1.18	50	10.3	
AM-123405-T2.1	25	574	676	1.18	50	10.3	
AM-123405-T2.2	25	577	680	1.18	50	11.3	
AM-123405-T2.3	25	574	676	1.18	50	11.3	
Min.		522	644	1.14		9.9	
Max.		577	729	1.28		14.3	
Average		563	674	1.20		11.4	
Acceptance Criteria:	Minimum	500		1.15		10.0	

Tested By:	L Kong	Date:	9-Aug-04
Checked By:	D Currie	Date:	9-Aug-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.: INZ1564801-032

Client: Building Industry Authority
Order No.: N/A
Sample Description: Reinforcing Bars
Sample Identification: As Listed Below
Material Specification: Grade D500E
Tested in accordance with: AS/NZS 4671:2001

Tensile:

Type: Full Section
Specimen Axis: Longitudinal

Conditions
a. Temperature: Ambient (23 $\pm$ 5 °C)
b. Uncertainty of Measurement: $\pm$ 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments C - Complies, DNC - Does Not Comply
PAC-25917-T1	32	515	658	1.28	50	12.7	
PAC-25917-T2	32	515	658	1.28	50	14.3	
PAC-25917-T3	32	520	666	1.28	50	13.3	
PAC-30979-T1	32	530	683	1.29	50	14.3	
PAC-30979-T2	32	528	681	1.29	50	13.3	
PAC-30979-T3	32	527	681	1.29	50	13.3	
NAT-RGB77-T1	32	581	705	1.21	50	10.4	
NAT-RGB77-T2	32	576	706	1.23	50	10.4	
NAT-RGB77-T3	32	583	706	1.21	50	9.95	DNC Elongation Only
NAT-S42770-T1	32	532	639	1.20	50	10.3	
NAT-S42770-T2	32	531	638	1.20	50	10.3	
NAT-S42770-T3	32	533	639	1.20	50	10.3	
Min.		515	638	1.20		10.0	
Max.		583	706	1.29		14.3	
Average		539	672	1.25		11.9	
Acceptance Criteria:	Minimum	500		1.15		10.0	

Tested By: L Kong Date: 30-Jun-04
Checked By: D Currie Date: 30-Jun-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.: INZ1564802-012

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	12mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Reverse Bend Tests

Conditions a. Type: Guided Bend
b. Axis: Longitudinal
c. Former Diameter: 4d (48mm)
d. Order: Bend to 90°, Age 100°C 1hr, Reverse bend to 90° (Straightened)

Specimen	Findings After 1st Bend	Findings After Reverse Bend	Results
PAC-30471-B1	Nil	No visible surface cracks	Complies
PAC-30471-B2	Nil	No visible surface cracks	Complies
PAC-31077-B1	Nil	No visible surface cracks	Complies
PAC-31077-B2	Nil	No visible surface cracks	Complies
NAT-S34140-B1.1	Nil	No visible surface cracks	Complies
NAT-S34140-B1.2	Nil	No visible surface cracks	Complies
NAT-S34140-B2.1	Nil	No visible surface cracks	Complies
NAT-S34140-B2.2	Nil	No visible surface cracks	Complies
AM-116784-B1	Nil	No visible surface cracks	Complies
AM-116784-B2	Nil	No visible surface cracks	Complies
AM-120820-B1	Nil	No visible surface cracks	Complies
AM-120820-B2	Nil	No visible surface cracks	Complies

Acceptance Criteria: AS/NZS 4671:2001 Sect 7.2.3

Tested by: L Kong Date: 14-Apr-04

Checked by: D Currie Date: 14-Apr-04

IAAF109

TEST REPORT No.: INZ1564802-016

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	16mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Reverse Bend Tests

Conditions
a. Type: Guided Bend
b. Axis: Longitudinal
c. Former Diameter: 4d (64mm)
d. Order: Bend to 90°, Age 100°C 1hr, Reverse bend to 90° (Straightened)

Specimen	Findings After 1st Bend	Findings After Reverse Bend	Results
PAC-30755-B1	Nil	No visible surface cracks	Complies
PAC-30755-B2	Nil	No visible surface cracks	Complies
PAC-30756-B1	Nil	No visible surface cracks	Complies
PAC-30756-B2	Nil	No visible surface cracks	Complies
NAT-S38526-B1.1	Nil	No visible surface cracks	Complies
NAT-S38526-B1.2	Nil	No visible surface cracks	Complies
NAT-S38526-B2.1	Nil	No visible surface cracks	Complies
NAT-S38526-B2.2	Nil	No visible surface cracks	Complies
AM-120829-B1	Nil	Surface cracks at ribs developing	Does not comply
AM-120829-B2	Nil	Surface cracks at ribs	Does not comply
AM-120838-B1	Nil	Surface cracks at ribs developing	Does not comply
AM-120838-B2	Nil	Surface cracks at ribs developing	Does not comply

Acceptance Criteria: AS/NZS 4671:2001 Sect 7.2.3

Tested by: L Kong Date: 14-Apr-04

Checked by: D Currie Date: 14-Apr-04

IAAF109

TEST REPORT No.: INZ1564802-020

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	20mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Reverse Bend Tests

Conditions
a. Type: Guided Bend
b. Axis: Longitudinal
c. Former Diameter: 4d (80mm)
d. Order: Bend to 90°, Age 100°C 1hr, Reverse bend to 90° (Straightened)
e. Exceptions: 90° bend instead of 180° as per standard

Specimen	Findings After 1st Bend	Findings After Reverse Bend	Results (See note)
PAC-30076-B1	Nil	Surface cracks at ribs	
PAC-30076-B2	Nil	Surface cracks at ribs	
PAC-31119-B1	Nil	Surface cracks at ribs	
PAC-31119-B2	Nil	No visible surface cracks	
NAT-S35858-B1.1	Nil	Surface cracks at ribs	
NAT-S35858-B1.2	Nil	Surface cracks at ribs	
NAT-S35858-B2.1	Nil	No visible surface cracks	
NAT-S35858-B2.2	Nil	Surface cracks at ribs	
AM-120388-B1	Nil	Surface cracks at ribs developing	
AM-120388-B2	Nil	No visible surface cracks	
AM-120396-B1	Nil	No visible surface cracks	
AM-120396-B2	Nil	Surface cracks at ribs developing	

Note: Compliance not applicable as per standard requirements

Acceptance Criteria:

Tested by: L Kong Date: 14-Apr-04

Checked by: D Currie Date: 14-Apr-04

IAAF109

TEST REPORT No.: INZ1564802-020

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	20mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Bend Tests

Conditions
a. Type: Guided Bend
b. Axis: Longitudinal
c. Former Diameter: 4d (80mm)
d. Order: Full 180° Bend
e. Exceptions: Nil

Specimen	Findings	Results
PAC-30076-B3	Nil Defects	Complies
PAC-30076-B4	Nil Defects	Complies
PAC-31119-B3	Nil Defects	Complies
PAC-31119-B4	Nil Defects	Complies
NAT-S35858-B1.3	Nil Defects	Complies
NAT-S35858-B1.4	Nil Defects	Complies
NAT-S35858-B2.3	Nil Defects	Complies
NAT-S35858-B2.4	Nil Defects	Complies
AM-120388-B3	Nil Defects	Complies
AM-120388-B4	Nil Defects	Complies
AM-120396-B3	Nil Defects	Complies
AM-120396-B4	Nil Defects	Complies

Acceptance Criteria: AS/NZS 4671:2001 Sect 7.2.3

Tested by: L Kong Date: 9-Jul-04

Checked by: D Currie Date: 9-Jul-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limit's discretion. Returning of samples to be advised in writing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF109

TEST REPORT No.: INZ1564802-025

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	25mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Reverse Bend Tests

Conditions
a. Type: Guided Bend
b. Axis: Longitudinal
c. Former Diameter: 4d (100mm)
d. Order: Bend to 90°, Age 100°C 1hr, Reverse bend to 90° (Straightened)
e. Exceptions: 90° bend instead of 180° as per standard

Specimen	Findings After 1st Bend	Findings After Reverse Bend	Results (See note)
PAC-30580-B1	Nil	Surface cracks at ribs	
PAC-30580-B2	Nil	Surface cracks at ribs	
PAC-31128-B1	Nil	Surface cracks at ribs	
PAC-31128-B2	Nil	Fracture during reverse bend	
NAT-S35830-B1.1	Nil	Surface cracks at ribs	
NAT-S35830-B1.2	Nil	Surface cracks at ribs	
NAT-S35830-B2.1	Nil	Surface cracks at ribs	
NAT-S35830-B2.2	Nil	Surface cracks at ribs	
AM-123405-B1.1	Nil	Surface cracks developing	
AM-123405-B1.2	Nil	Surface cracks developing	
AM-123405-B2.1	Nil	Surface cracks developing	
AM-123405-B2.2	Nil	Surface cracks developing	

Note: Compliance not applicable as per standard requirements

Acceptance Criteria:

Tested by: L Kong Date: 10-Aug-04

Checked by: D Currie Date: 10-Aug-04

IAAF109

TEST REPORT No.: INZ1564802-025

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	25mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Bend Tests

Conditions
a. Type: Guided Bend
b. Axis: Longitudinal
c. Former Diameter: 4d (100mm)
d. Order: Full 180° Bend
e. Exceptions: Nil

Specimen	Findings	Results
PAC-30580-B3	Nil Defects	Complies
PAC-30580-B4	Nil Defects	Complies
PAC-31128-B3	Nil Defects	Complies
PAC-31128-B4	Nil Defects	Complies
NAT-S35830-B1.3	Nil Defects	Complies
NAT-S35830-B1.4	Nil Defects	Complies
NAT-S35830-B2.3	Nil Defects	Complies
NAT-S35830-B2.4	Nil Defects	Complies
AM-123405-B1.3	Nil Defects	Complies
AM-123405-B1.4	Nil Defects	Complies
AM-123405-B2.3	Nil Defects	Complies
AM-123405-B2.4	Nil Defects	Complies

Acceptance Criteria:	AS/NZS 4671:2001 Sect 7.2.3		
Tested by:	L Kong	Date:	9-Jul-04
Checked by:	D Currie	Date:	9-Jul-04

IAAF109

TEST REPORT No.: INZ1564802-032

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	32mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Reverse Bend Tests

Conditions
a. Type: Guided Bend
b. Axis: Longitudinal
c. Former Diameter: 4d (128mm)
d. Order: Bend to 90°, Age 100°C 1hr, Reverse bend to 90° (Straightened)
e. Exceptions: 90° bend instead of 180° as per standard

Specimen	Findings After 1st Bend	Findings After Reverse Bend	Results (See note)
PAC-25917-B1	Nil	SC & Cracks - up to 3mm deep	
PAC-25917-B2	Nil	SC & Cracks - up to 3mm deep	
PAC-30979-B1	Nil	SC & Cracks - up to 6mm deep	
PAC-30979-B2	Nil	Fracture during reverse bend	
NAT-RGB77-B1	Nil	SC at ribs	
NAT-RGB77-B2	Nil	SC & Cracks - up to 2mm deep	
NAT-S42770-B1	Nil	SC at ribs	
NAT-S42770-B2	Nil	SC & Cracks - up to 4.5mm deep	
Abbreviation: SC - Surface Cracks			

Note: Compliance not applicable as per standard requirements

Acceptance Criteria:

Tested by: L Kong Date: 28-Jun-04

Checked by: D Currie Date: 28-Jun-04

IAAF109

TEST REPORT No.: INZ1564802-032

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	32mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Bend Tests

Conditions
a. Type: Guided Bend
b. Axis: Longitudinal
c. Former Diameter: 4d (128mm)
d. Order: Full 180° Bend
e. Exceptions: Nil

Specimen	Findings	Results
PAC-25917-B1	Nil Defects	Complies
PAC-25917-B2	Nil Defects	Complies
PAC-30979-B1	Nil Defects	Complies
PAC-30979-B2	Nil Defects	Complies
NAT-RGB77-B1	Nil Defects	Complies
NAT-RGB77-B2	Nil Defects	Complies
NAT-S42770-B1	Nil Defects	Complies
NAT-S42770-B2	Nil Defects	Complies

Acceptance Criteria: AS/NZS 4671:2001 Sect 7.2.3

Tested by: L Kong Date: 9-Jul-04

Checked by: D Currie Date: 9-Jul-04

IAAF109

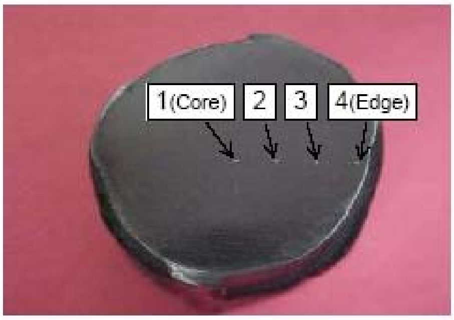
TEST REPORT No.: INZ1564803-012

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	12mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS1817

TEST - VICKERS HARDNESS

LOAD: 10 kg

Specimen	Sample No.	Hardness Vickers (HV10) (Traverse See Diagram Below) 1	2	3	4	Min.	Max.	Average
PAC-30471	H1	212	185	230	229	185	230	214
	H2	224	215	201	161	161	224	201
	H3	223	227	239	231	223	239	230
PAC-31077	H1	171	205	208	209	171	209	198
	H2	208	228	171	165	165	228	193
	H3	227	199	177	175	175	227	194
NAT-S34140	H1	149	150	152	178	149	178	157
	H2	147	137	189	205	137	205	169
	H3	152	132	157	192	132	192	158
NAT-S34140	H1	137	149	140	190	137	190	154
	H2	134	128	152	210	128	210	156
	H3	142	151	159	145	142	159	149
AM-116784	H1	170	170	186	197	170	197	181
	H2	142	167	174	192	142	192	169
	H3	163	166	143	218	143	218	173
AM-120820	H1	90	71	101	213	71	213	119
	H2	84	93	99	113	84	113	97
	H3	86	78	76	111	76	111	88



Acceptance Criteria:

Tested by: L Kong Date: 14-Apr-04
Checked by: D Currie Date: 14-Apr-04

IAAF107

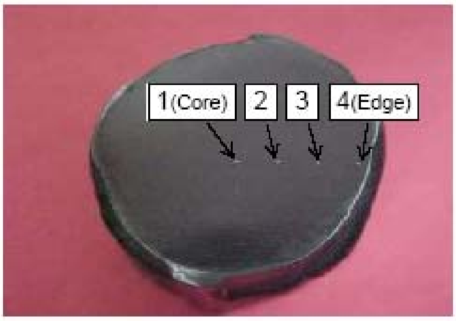
TEST REPORT No.: INZ1564803-016

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	16mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS1817

TEST - VICKERS HARDNESS

LOAD: 10 kg

Specimen	Sample No.	Hardness Vickers (HV10)						
		(Traverse See Diagram Below)						
		1	2	3	4	Min.	Max.	Average
PAC-30755	H1	215	223	216	220	215	223	218
	H2	191	216	224	221	191	224	213
	H3	160	166	228	223	160	228	194
PAC-30756	H1	252	249	252	251	249	252	251
	H2	210	234	177	232	177	234	213
	H3	220	197	192	228	192	228	209
NAT-S38526	H1.1	165	154	193	223	154	223	184
	H1.2	168	168	197	232	168	232	191
	H1.3	172	171	182	214	171	214	185
NAT-S38526	H2.1	158	166	140	202	140	202	166
	H2.2	166	167	168	250	166	250	188
	H2.3	137	173	161	189	137	189	165
AM-120829	H1	95	76	143	155	76	155	117
	H2	115	76	82	124	76	124	99
	H3	108	76	95	113	76	113	98
AM-120838	H1	95	61	83	139	61	139	95
	H2	93	92	86	112	86	112	96
	H3	96	72	87	129	72	129	96



Acceptance Criteria:

Tested by:	L Kong	Date:	14-Apr-04
Checked by:	D Currie	Date:	14-Apr-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limit's discretion. Returning of samples to be advised in writing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

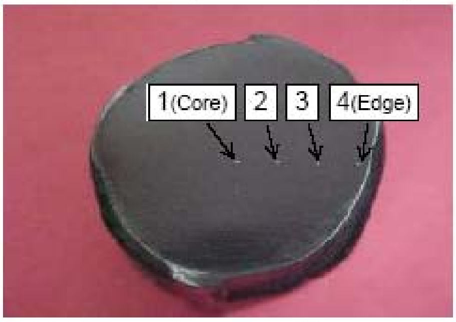
IAAF107

TEST REPORT No.: INZ1564803-020

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	20mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS1817

TEST - VICKERS HARDNESS
LOAD: 10 kg

Specimen	Sample No.	Hardness Vickers (HV10) (Traverse See Diagram Below)						
		1	2	3	4	Min.	Max.	Average
PAC-30076	H1	214	211	215	224	211	224	216
	H2	220	220	220	212	212	220	218
	H3	219	218	219	220	218	220	219
PAC-31119	H1	224	222	232	218	218	232	224
	H2	224	223	227	232	223	232	226
	H3	218	225	230	232	218	232	226
NAT-S35858	H1.1	179	183	205	289	179	289	214
	H1.2	176	181	187	215	176	215	190
	H1.3	172	179	201	243	172	243	199
NAT-S35858	H2.1	174	173	190	227	173	227	191
	H2.2	176	177	194	283	176	283	207
	H2.3	172	174	190	272	172	272	202
AM-120388	H1	72	63	76	123	63	123	84
	H2	108	68	96	117	68	117	97
	H3	159	72	74	92	72	159	99
AM-120396	H1	73	78	89	140	73	140	95
	H2	92	91	96	139	91	139	105
	H3	103	114	73	134	73	134	106



Acceptance Criteria:

Tested by:	L Kong	Date:	14-Apr-04
Checked by:	D Currie	Date:	14-Apr-04

IAAF107

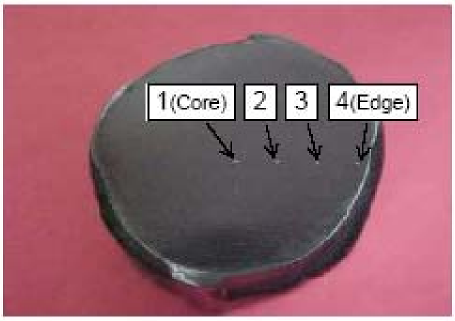
TEST REPORT No.: INZ1564803-025

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	25mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS1817

TEST - VICKERS HARDNESS

LOAD: 10 kg

Specimen	Sample No.	Hardness Vickers (HV10) (Traverse See Diagram Below) 1	2	3	4	Min.	Max.	Average
PAC-30580	H1	236	216	243	243	216	243	235
	H2	232	243	243	215	215	243	233
	H3	232	214	235	247	214	247	232
PAC-31128	H1	215	228	228	235	215	235	226
	H2	220	223	234	219	219	234	224
	H3	215	221	223	230	215	230	222
NAT-S35830	H1.1	172	176	203	229	172	229	195
	H1.2	179	179	184	253	179	253	199
	H1.3	151	172	182	220	151	220	181
NAT-S35830	H2.1	150	181	199	273	150	273	201
	H2.2	176	165	181	229	165	229	187
	H2.3	176	178	189	266	176	266	202
AM-123405	H1.1	175	235	243	417	175	417	267
	H1.2	197	200	237	354	197	354	247
	H1.3	190	195	231	352	190	352	242
AM-123405	H2.1	194	203	263	371	194	371	258
	H2.2	213	204	256	361	204	361	259
	H2.3	203	206	246	325	203	325	245



Acceptance Criteria:

Tested by:	L Kong	Date:	09-Aug-04
Checked by:	D Currie	Date:	09-Aug-04

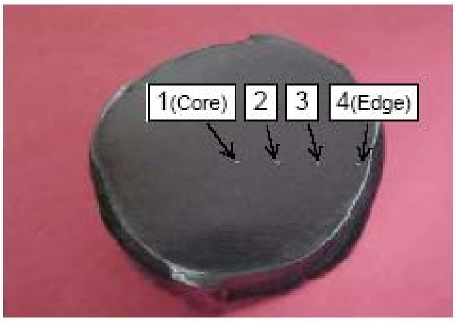
TEST REPORT No.: INZ1564803-032

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	32mm Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS1817

TEST - VICKERS HARDNESS

LOAD: 10 kg

Specimen	Sample No.	Hardness Vickers (HV10)						
		(Traverse See Diagram Below)						
		1	2	3	4	Min.	Max.	Average
PAC-25917	H1	212	219	216	213	212	219	215
	H2	217	212	217	215	212	217	215
	H3	220	213	217	220	213	220	218
PAC-30979	H1	224	227	227	224	224	227	226
	H2	227	224	228	228	224	228	227
	H3	220	222	224	225	220	225	223
NAT-RGB77	H1	182	185	197	299	182	299	216
	H2	192	190	202	270	190	270	214
	H3	163	186	203	281	163	281	208
NAT-S42770	H1	162	171	195	266	162	266	199
	H2	165	169	192	262	165	262	197
	H3	165	165	187	270	165	270	197



Acceptance Criteria:

Tested by:	L Kong	Date:	29-Jun-04
Checked by:	D Currie	Date:	29-Jun-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limit's discretion. Returning of samples to be advised in writing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF107

TEST REPORT No.: INZ1564804-012

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile Test after Reverse Bend

Type: Full Section
Specimen Axis: Longitudinal
Specimen Conditions: a. Gauge L_o after reverse bend
b. Bent section in central

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments Location of Fracture Outside/Within Bent Section
PAC-30471-B1	12	523	656	1.26	50	8.3	Outside
PAC-30471-B2	12	520	659	1.27	50	6.3	Outside
PAC-31077-B1	12	523	661	1.26	50	6.5	Outside
PAC-31077-B2	12	527	661	1.26	50	4.3	Outside
NAT-S34140-B1.1	12	502	550	1.10	50	7.8	Outside
NAT-S34140-B1.2	12	504	565	1.12	50	7.3	Outside
NAT-S34140-B2.1	12	504	568	1.13	50	7.3	Outside
NAT-S34140-B2.2	12	502	570	1.14	50	8.3	Outside
AM-116784-B1	12	513	606	1.18	50	9.3	Outside
AM-116784-B2	12	517	609	1.18	50	4.3	Outside
AM-120820-B1	12	539	623	1.16	50	5.3	Outside
AM-120820-B2	12	538	624	1.16	50	5.3	Outside
Min.		502	550	1.10		4.3	
Max.		539	661	1.27		9.3	
Average		518	613	1.18		6.7	

Acceptance Criteria: Not applicable as per standard after undergone reverse bend tests.

Tested By:	L Kong	Date:	14-Apr-04
Checked By:	D Currie	Date:	14-Apr-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.: INZ1564804-016

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile Test after Reverse Bend

Type: Full Section
Specimen Axis: Longitudinal
Specimen Conditions: a. Gauge L_o after reverse bend
b. Bent section in central

Conditions a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments Location of Fracture Outside/Within Bent Section
PAC-30755-B1	16	537	689	1.28	50	6.8	Outside
PAC-30755-B2	16	527	686	1.30	50	7.3	Outside
PAC-30756-B1	16	540	694	1.29	50	6.8	Outside
PAC-30756-B2	16	535	686	1.28	50	6.8	Outside
NAT-S38526-B1.1	16	522	607	1.16	50	7.3	Outside
NAT-S38526-B1.2	16	497	599	1.21	50	8.3	Outside
NAT-S38526-B2.1	16	500	592	1.18	50	11.3	Outside
NAT-S38526-B2.2	16	502	592	1.18	50	7.3	Outside
AM-120829-B1	16	530	617	1.16	50	6.3	Outside
AM-120829-B2	16	527	614	1.17	50	6.3	Outside
AM-120838-B1	16	545	634	1.16	50	3.3	Outside
AM-120838-B2	16	540	634	1.18	50	2.7	Outside
Min.		497	592	1.16		2.7	
Max.		545	694	1.30		11.3	
Average		525	637	1.21		6.7	

Acceptance Criteria: Not applicable as per standard after undergone reverse bend tests.

Tested By:	L Kong	Date:	14-Apr-04
Checked By:	D Currie	Date:	14-Apr-04

IAAF101 Rev 0

TEST REPORT No.: INZ1564804-020

Client: Building Industry Authority
Order No.: N/A
Sample Description: Reinforcing Bars
Sample Identification: As Listed Below
Material Specification: Grade D500E
Tested in accordance with: AS/NZS 4671:2001

Tensile Test after Reverse Bend

Type: Full Section
Specimen Axis: Longitudinal
Specimen Conditions: a. Gauge L_o after reverse bend
b. Bent section in central

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments Location of Fracture Outside/Within Bent Section
PAC-30076-B1	20	540	688	1.27	50	6.8	Outside
PAC-30076-B2	20	538	686	1.28	50	7.8	Outside
PAC-31119-B1	20	533	688	1.29	50	7.3	Outside
PAC-31119-B2	20	541	684	1.26	50	7.8	Outside
NAT-S35858-B1.1	20	562	648	1.15	50	8.3	Within
NAT-S35858-B1.2	20	567	656	1.16	50	7.3	Within
NAT-S35858-B2.1	20	567	653	1.15	50	7.3	Within
NAT-S35858-B2.2	20	560	645	1.15	50	8.3	Within
AM-120388-B1	20	495	600	1.21	50	4.3	Outside
AM-120388-B2	20	490	594	1.21	50	5.3	Outside
AM-120396-B1	20	498	602	1.21	50	5.3	Outside
AM-120396-B2	20	498	603	1.21	50	6.3	Outside
Min.		490	594	1.15		4.3	
Max.		567	688	1.29		8.3	
Average		532	645	1.21		6.9	

Acceptance Criteria: Not applicable as per standard after undergone reverse bend tests.

Tested By: L Kong Date: 14-Apr-04
Checked By: D Currie Date: 14-Apr-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.: INZ1564804-025

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile Test after Reverse Bend

Type: Full Section
Specimen Axis: Longitudinal
Specimen Conditions: a. Gauge L_o after reverse bend
b. Bent section in central

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments Location of Fracture Outside/Within Bent Section
PAC-30580-B1	25	511	670	1.31	50	6.3	Outside
PAC-30580-B2	25	509	670	1.32	50	5.3	Outside
PAC-31128-B1	25	564	725	1.29	50	4.4	Outside
PAC-31128-B2	25						Fracture during re-bend
NAT-S35830-B1.1	25	560	646	1.15	50	6.3	Within
NAT-S35830-B1.2	25		652		50	4.3	No yield phenomena noted
							& fracture at within
NAT-S35830-B2.1	25	568	652	1.15	50	7.3	Within
NAT-S35830-B2.2	25	560	644	1.15	50	7.3	Within
AM-123405-B1.1	25	572	674	1.18	50	9.3	Within
AM-123405-B1.2	25		674		50	9.3	No yield phenomena noted
							& fracture at within
AM-123405-B2.1	25	574	674	1.17	50	9.3	Within
AM-123405-B2.2	25	574	676	1.18	50	9.3	Within
Min.		509	644	1.15		4.3	
Max.		574	725	1.32		9.3	
Average		555	669	1.21		7.2	

Acceptance Criteria: Not applicable as per standard after undergone reverse bend tests.

Tested By:	L Kong	Date:	14-Apr-04
Checked By:	D Currie	Date:	14-Apr-04

Amendments to this certificate are not allowed unless such amendments are approved and effected by SGS NEW ZEALAND LIMITED. Reproduction without permission is not allowable unless in full content.

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IAAF101 Rev 0

TEST REPORT No.: INZ1564804-032

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile Test after Reverse Bend

Type: Full Section
Specimen Axis: Longitudinal
Specimen Conditions: a. Gauge L_o after reverse bend
b. Bent section in central

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments Location of Fracture Outside/Within Bent Section
PAC-25917-B1	32	512	666	1.30	50	4.3	Outside
PAC-25917-B2	32	518	674	1.30	50	3.3	Outside
PAC-30979-B1	32	532	647	1.21	50	4.3	In Crack
PAC-30979-B2	32						Fractured during re-bend
NAT-RGB77-B1	32		694		50	6.3	No Yield, In Crack
NAT-RGB77-B2	32		680		50	4.3	No Yield, In Crack
NAT-S42770-B2	32	599	638	1.06	50	9.3	In Crack
NAT-S42770-B2	32	603	632	1.05	50	9.3	In Crack
Min.		512	632	1.05		3.3	
Max.		603	694	1.30		9.3	
Average		553	661	1.19		5.9	

Acceptance Criteria: Not applicable as per standard after undergone reverse bend tests.

Tested By:	L Kong	Date:	11-Aug-04
Checked By:	D Currie	Date:	11-Aug-04

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Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.: INZ1564807-012

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile:

Type: Full Section
Specimen Axis: Longitudinal

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Total Elongation (%)	Comments C - Complies, DNC - Does Not Comply Mill Total Elongation
PAC-30471-T4	12	520	645	1.24	60	25.3	N/A
PAC-31077-T4	12	523	649	1.24	60	26.7	N/A
NAT-S34140-T1.4	12	502	555	1.11	60	25.3	26
NAT-S34140-T2.4	12	502	556	1.11	60	25.3	26
AM-116784-T4	12	504	594	1.18	60	26.3	23
AM-120820-T4	12	539	622	1.15	60	28.0	19
Min.		502	555	1.11		25.3	
Max.		539	649	1.24		28.0	
Average		515	604	1.17		26.2	
Acceptance Criteria:	Minimum	500		1.15		N/A	

Tested By:	L Kong	Date:	14-Apr-04
Checked By:	D Currie	Date:	14-Apr-04

Amendments to this certificate are not allowed unless such amendments are approved and effected by SGS NEW ZEALAND LIMITED. Reproduction without permission is not allowable unless in full content.

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of samples at client's expense.

IAAF101 Rev 0

TEST REPORT No.: INZ1564808

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Test: Surface Geometry

Manufacturer	AMSTEEL				NATSTEEL					PACSTEEL					Limits
Alpha-numerical Markings	Nil				Nil					SEISMIC 500					
Special Features	1 Longitudinal adjoining 2 adjacent transverse				2 longitudinal in between 2 adjacent transverse					2 missed transverse adjacent to 2 additional longitudinal					
Features Spacing	1 meter				1 meter					1 meter					Within 1.5 meter
Size, d	12	16	20	25	12	16	20	25	32	12	16	20	25	32	
No. of Transverse	2&R	2&R	2&R	2&R	2&R	2&R	2&R	2&R	2&R	2&R	2&R	2&R	2&R	2&R	2 < #
Beta Angle, b	66	56	56	54	79	76	62.5	62	64	67	71	67	70	66	45 < b < 70
Alpha Angle, a	58.95	53.81	62.72	53.51	65.16	61.36	62.06	51.07	65.56	60.98	61.94	47.58	58.62	50.68	45 < a
Rib Height, h	0.93	1.36	1.6	1.92	0.81	1.52	1.65	1.95	2.97	0.73	1.21	1.1	1.82	2.24	0.05d < h < 0.1d
Rib Spacing, C	7.3	9.6	12.5	16.2	7.7	10.5	13.8	17.3	21.9	7.7	10	14.25	16	23	0.5d < C < d
Crest Width, Wc	0.82	1.19	2.1	3.11	1.91	1.51	2.18	3.11	4.21	1.51	1.51	2.25	3.13	2.78	Wc < 0.3C
Longitudinal Rib Height, hL	0.915	1.085	0.525	0.645	0.435	0.29	0.325	0.745	0.725	0.3	0.78	0.545	1.345	1.65	0.025d < hL < 0.1d
Projected Area, fR	0.072	0.084	0.077	0.078	0.095	0.13	0.106	0.1	0.121	0.085	0.111	0.068	0.104	0.089	0.056 < fR

NB: R = Reverse RED =DNC

Acceptance Criteria:	AS/NZS4671:2001 Sect 7.4		
Tested by:	L Kong	Date:	09-Jul-04
Checked by:	D Currie	Date:	09-Jul-04

IAAF 109

TEST REPORT No.: INZ1564809

Client:	Building Industry Authority
Order No.:	N/A
Sample Description:	Reinforcing Bars
Sample Identification:	As Listed Below
Material Specification:	Grade D500E
Tested in accordance with:	AS/NZS 4671:2001

Tensile Weld:

Type: Full Section
Specimen Axis: Longitudinal
Welding Electrodes: AWS A5.5 E8015-B3L
AWS A5.5 E9016-B3

Conditions
a. Temperature: Ambient (23 ± 5 °C)
b. Uncertainty of Measurement: ± 1 MPa
c. Strain Rate Uncontrolled
d. L_e=50mm
e. Other: BS EN 10204 3-1B A1 1996

Specimen	Diameter (d) (mm)	Yield Stress (R_{eL}) (MPa)	Ultimate Tensile Strength (Rm) (MPa)	Ratio (Rm)/(ReL)	Original Gauge Length (L_o) (mm)	Uniform Elongation (A_{gt}) (%)	Comments Fracture Location P.M - Parent Metal
Electrode E8015 - 550MPa Equivalent							
PAC-30755-W1	16	535	679	1.27	50	15.3	P.M, 70mm from weld
PAC-30076-W1	20	547	688	1.26	50	17.3	P.M, 220mm from weld
NAT-S35858-W1	20	563	627	1.11	50	6.3	Weld Joints
AM-120388-W1	20	495	595	1.20	50	14.3	P.M, 135mm from weld
PAC-31128-W1	25	568	719	1.27	50	11.4	P.M, 100mm from weld
Electrode E9016 - 620 MPa Equivalent							
PAC-30756-W1	16	540	679	1.26	50	14.3	P.M, 90mm from weld
PAC-31119-W1	20	533	675	1.27	50	10.3	P.M, 120mm from weld
NAT-S35858-W2	20	559	633	1.13	50	6.3	Weld Joints
AM-120396-W1	20	503	595	1.18	50	9.3	Weld Joints
PAC-30580-W1	25	522	668	1.28	50	12.7	P.M, 65mm from weld
Min.		495	595	1.11		6.3	
Max.		568	719	1.28		17.3	
Average		536	656	1.22		11.8	
Acceptance Criteria:	Minimum	500	575	1.15		10.0	
	AS/NZS 1554.3: 2002 - Sect 8.3						

Tested By:	L Kong	Date:	31-May-04
Checked By:	D Currie	Date:	31-May-04

Samples will be retained for two (2) weeks after test date before disposal at SGS New Zealand Limited's discretion. Returning of samples to be advised in writing at the time of testing. Storage (when agreed by SGS New Zealand Limited) or return of sampl

IAAF101 Rev 0

CHART 1 - Plot of Tensile Stresses for all Test Specimens

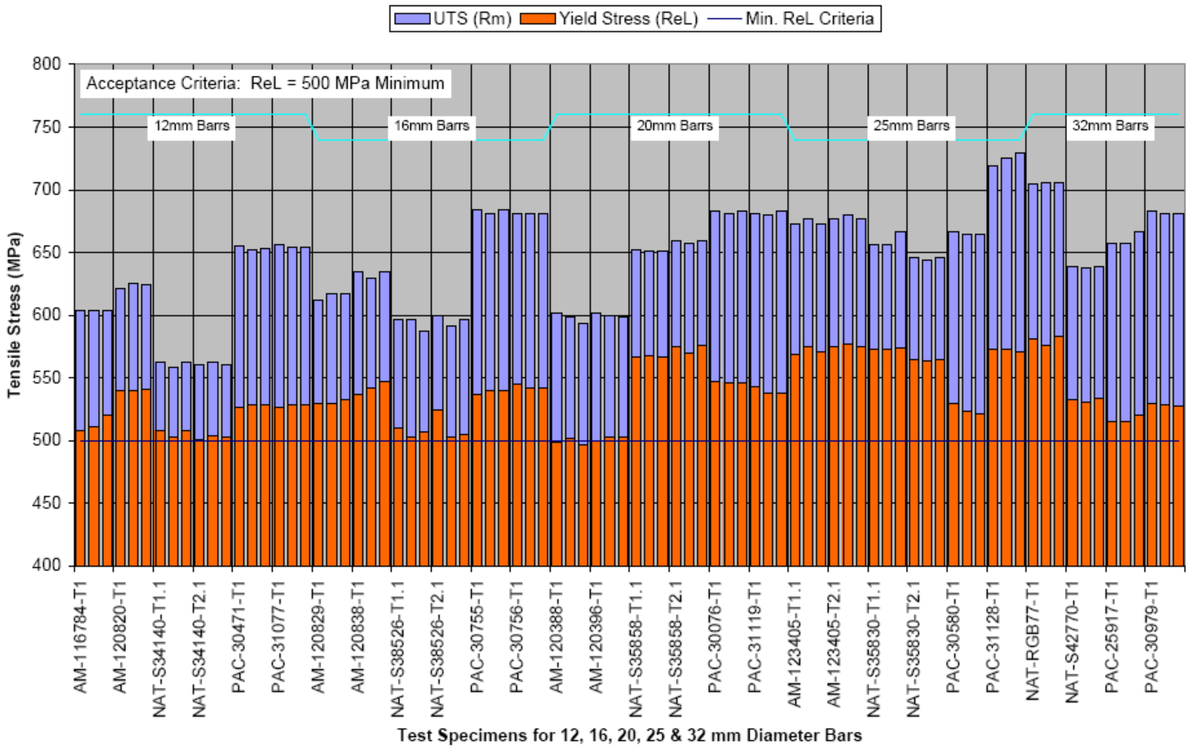

Chart1

File Ref: INZ15648

CHART 2 - Plot of Average Tensile Stresses for Tested Bars & Mill Values

Note: Values are average of 3 specimens representing the same bar length

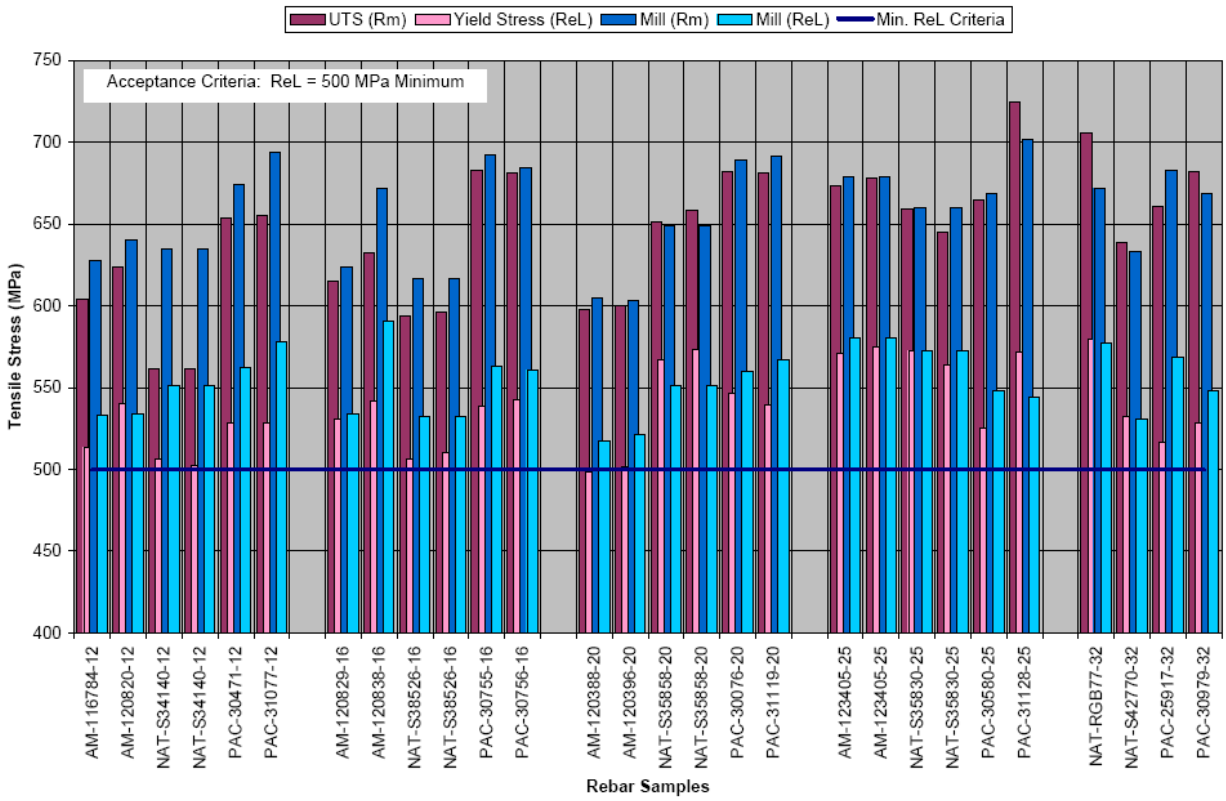

Chart2

File Ref: INZ15648

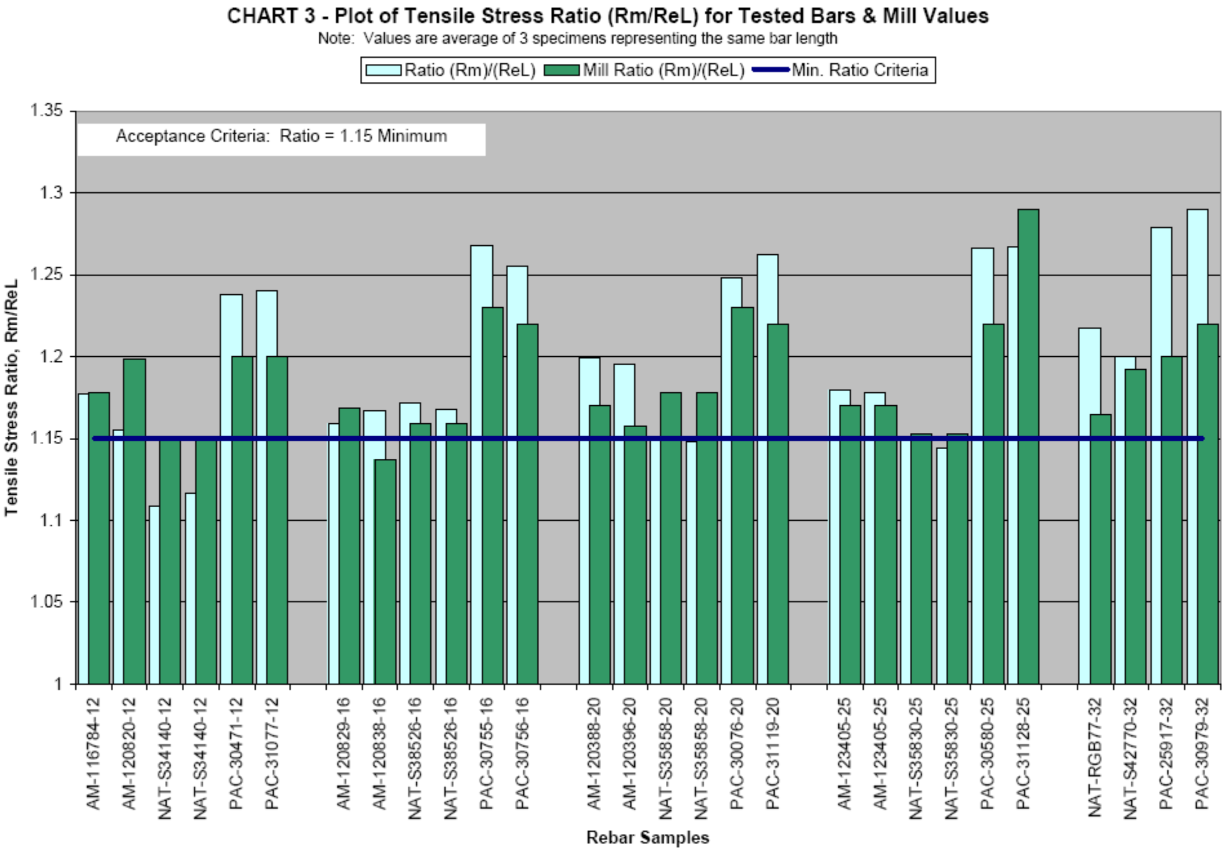

Chart3

File Ref: INZ15648

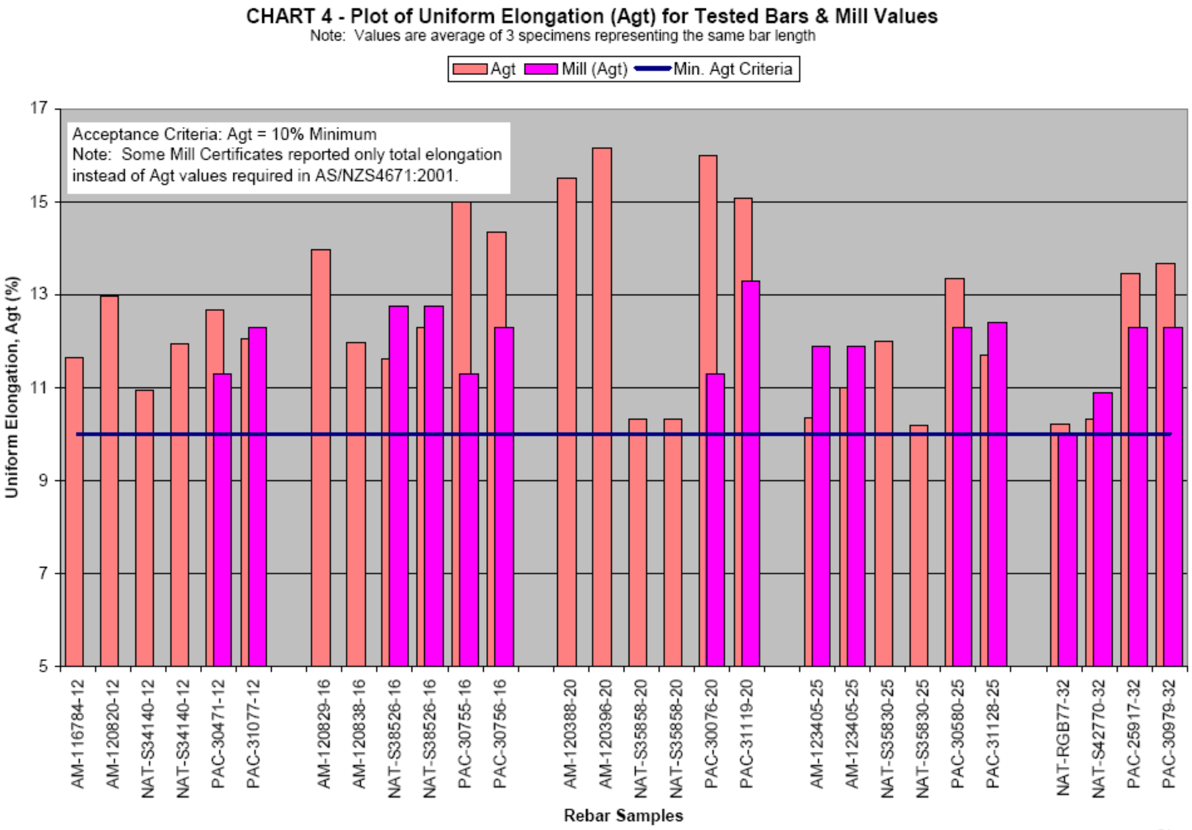

Chart4

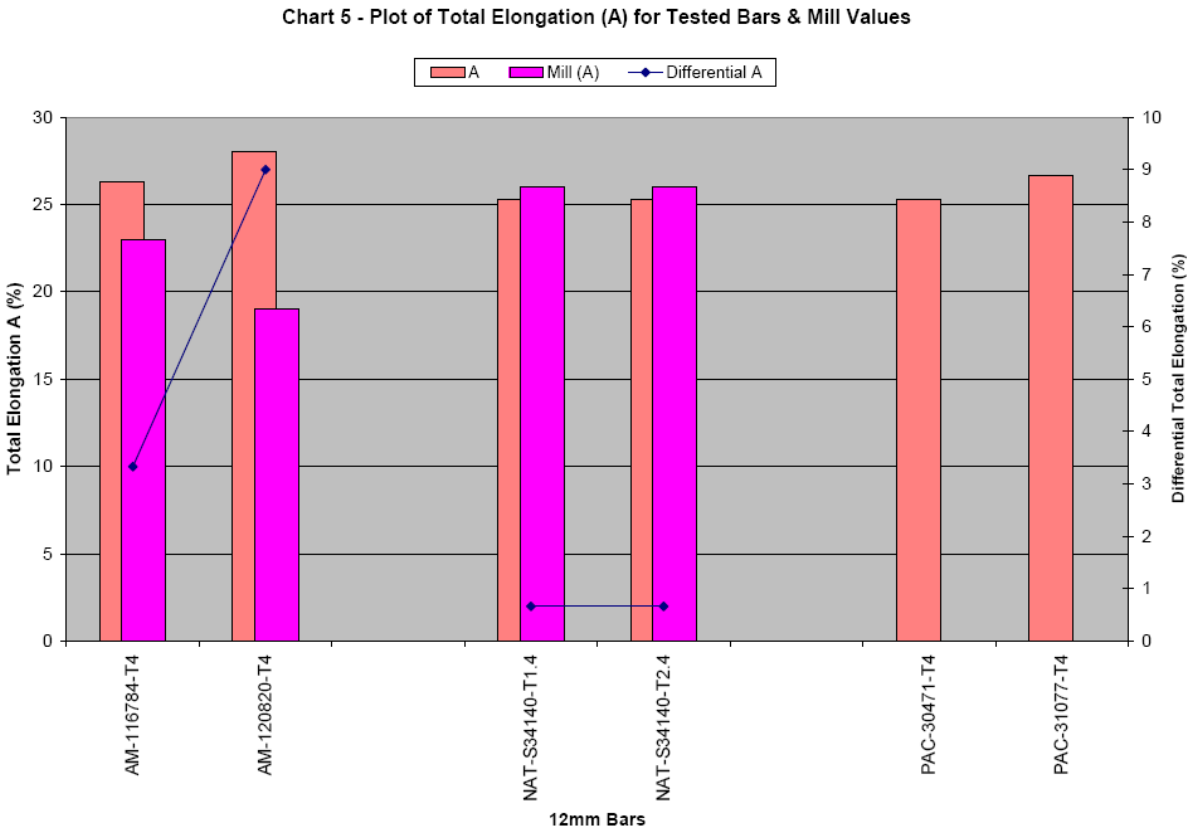

Chart5

File Ref: INZ15648

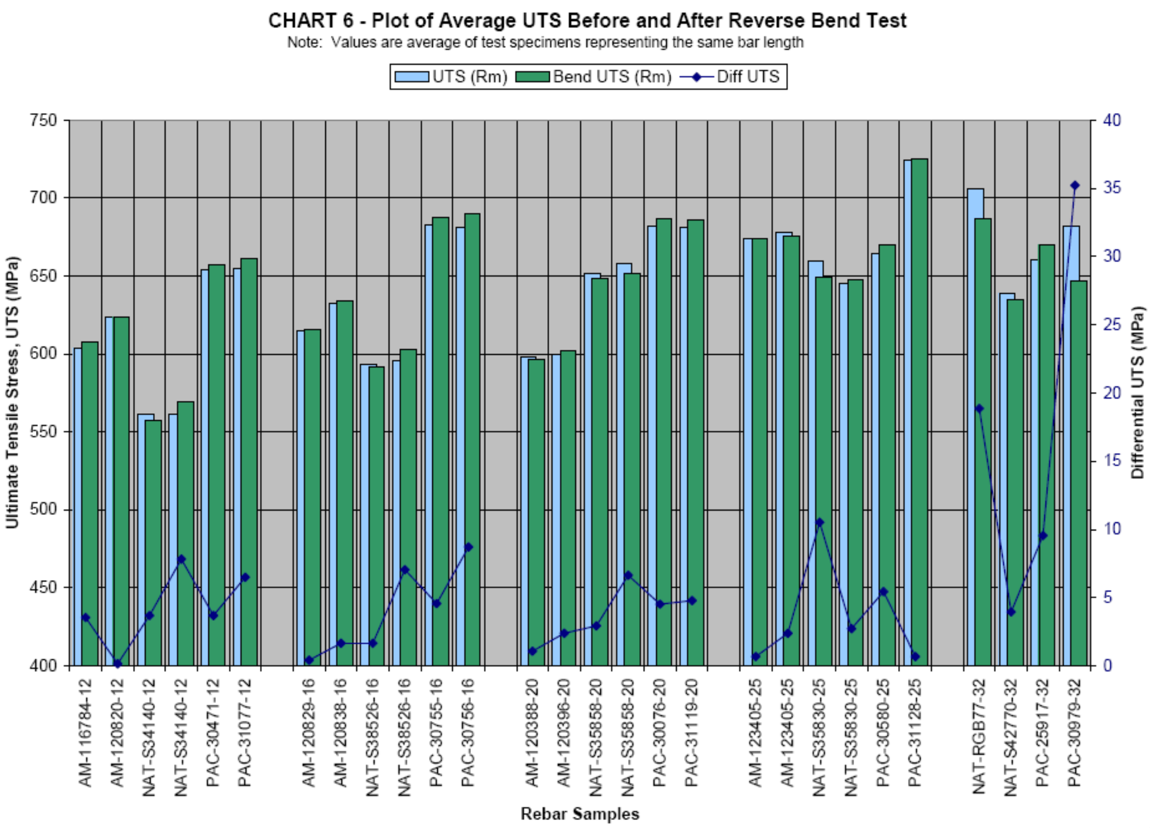

Chart6

File Ref: INZ15648

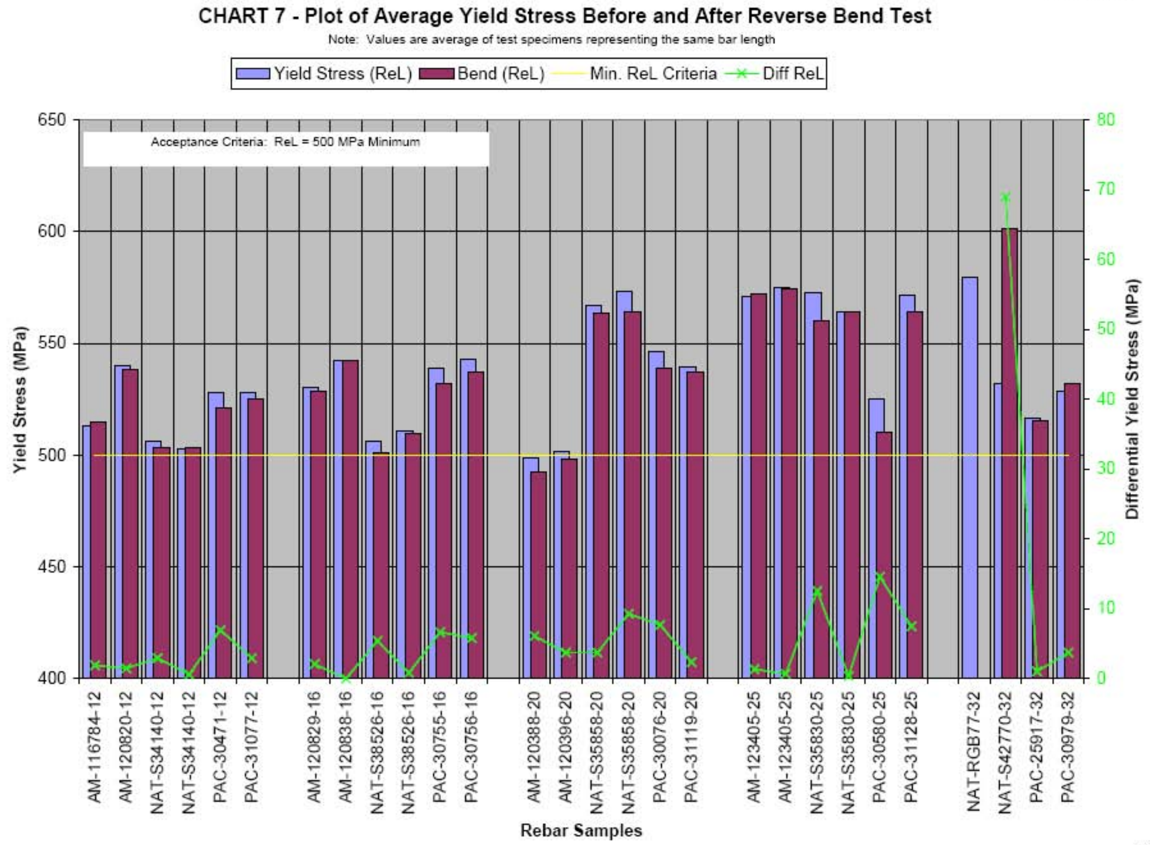

Chart7

File Ref: INZ15648

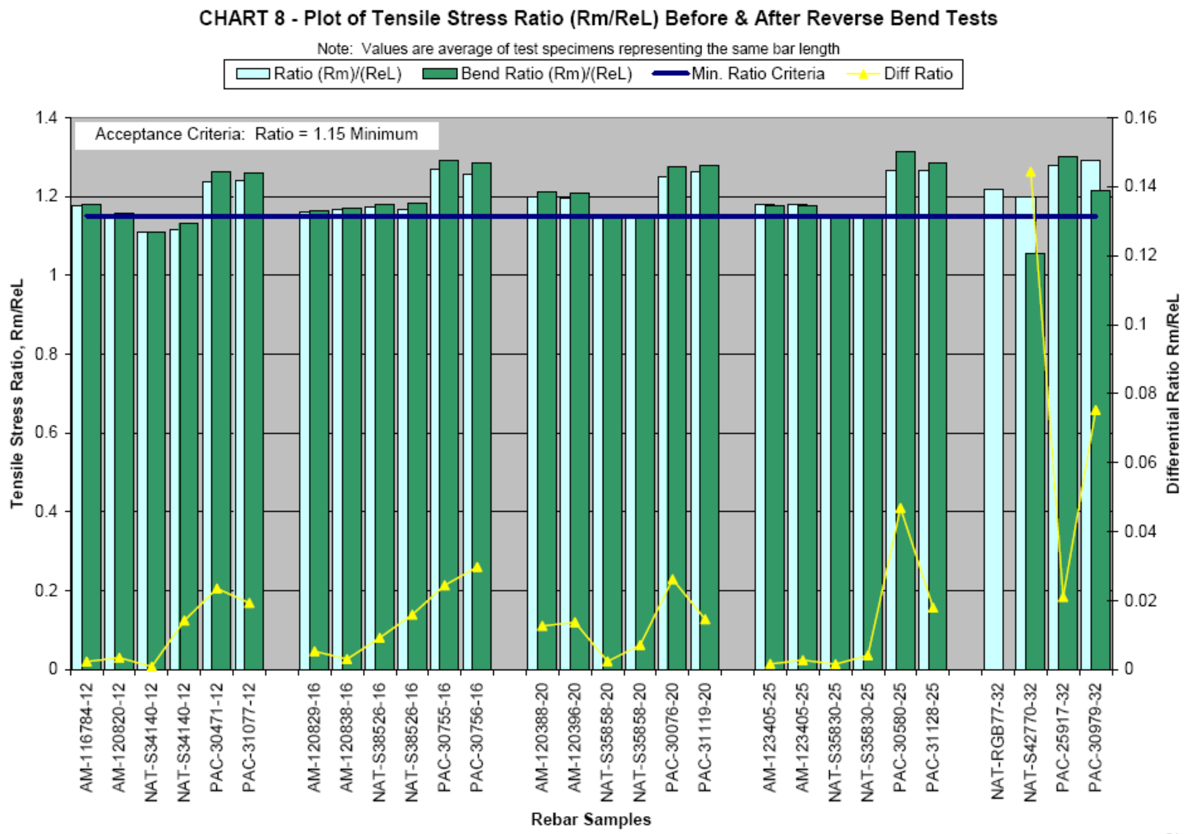

Chart8

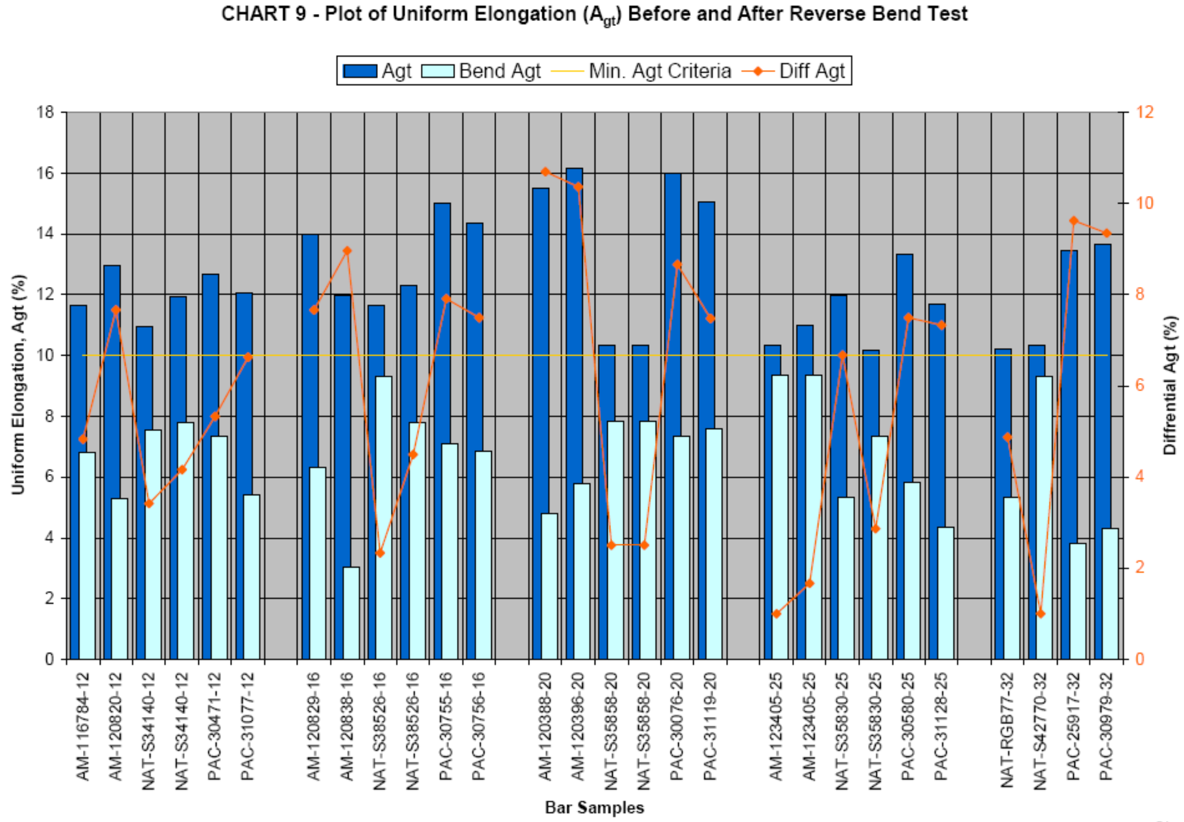
CHART 9 - Plot of Uniform Elongation (A_{gt}) Before and After Reverse Bend Test
Agt
Bend Agt
Min. Agt Criteria
Diff Agt
Uniform Elongation, Agt (%)
Diffrential Agt (%)
AM-116784-12
AM-120820-12
NAT-S34140-12
NAT-S34140-12
PAC-30471-12
PAC-31077-12
AM-120829-16
AM-120838-16
NAT-S38526-16
NAT-S38526-16
PAC-30755-16
PAC-30756-16
AM-120388-20
AM-120396-20
NAT-S35858-20
NAT-S35858-20
PAC-30076-20
PAC-31119-20
AM-123405-25
AM-123405-25
NAT-S35830-25
NAT-S35830-25
PAC-30580-25
PAC-31128-25
NAT-RGB77-32
NAT-S42770-32
PAC-25917-32
PAC-30979-32
Bar Samples

Chart9

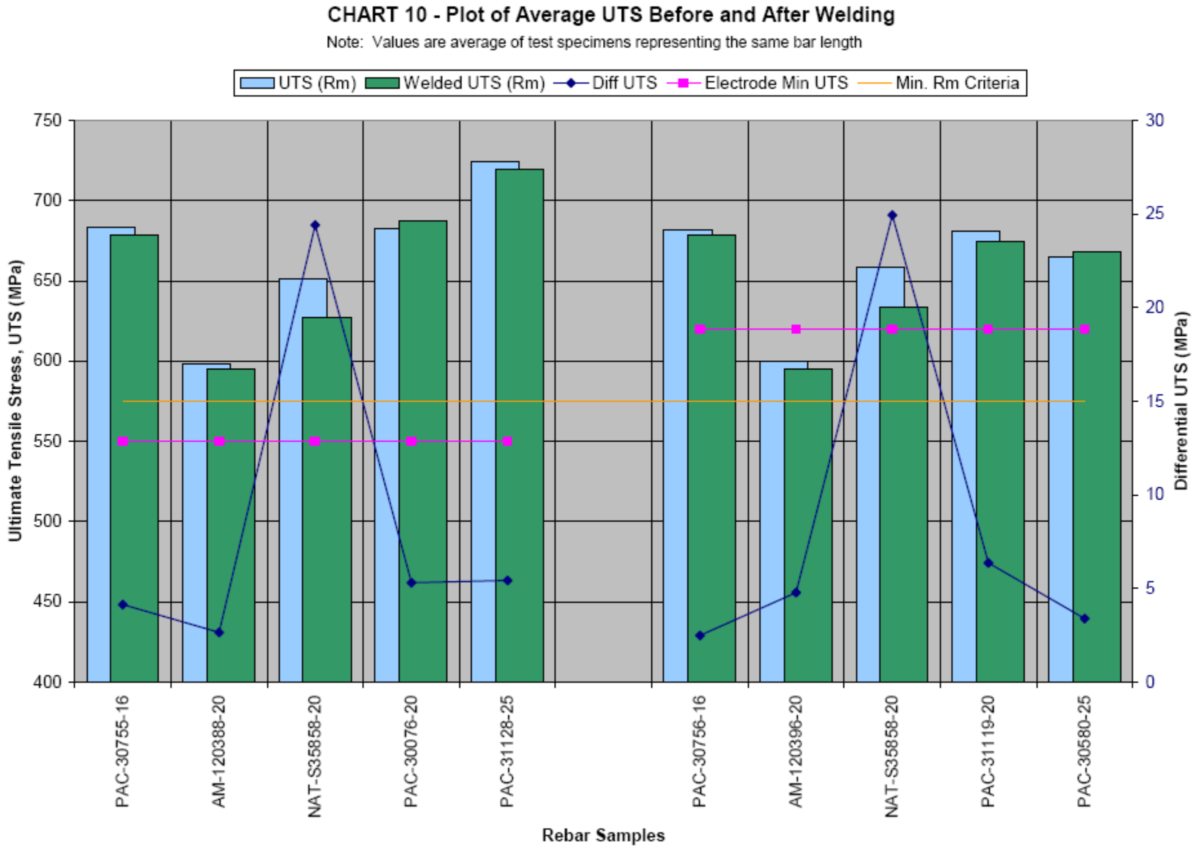
CHART 10 - Plot of Average UTS Before and After Welding
Note: Values are average of test specimens representing the same bar length
UTS (Rm)
Welded UTS (Rm)
Diff UTS
Electrode Min UTS
Min. Rm Criteria
Ultimate Tensile Stress, UTS (MPa)
Differential UTS (MPa)
PAC-30755-16
AM-120388-20
NAT-S35858-20
PAC-30076-20
PAC-31128-25
PAC-30756-16
AM-120396-20
NAT-S35858-20
PAC-31119-20
PAC-30580-25
Rebar Samples

File Ref: INZ15648

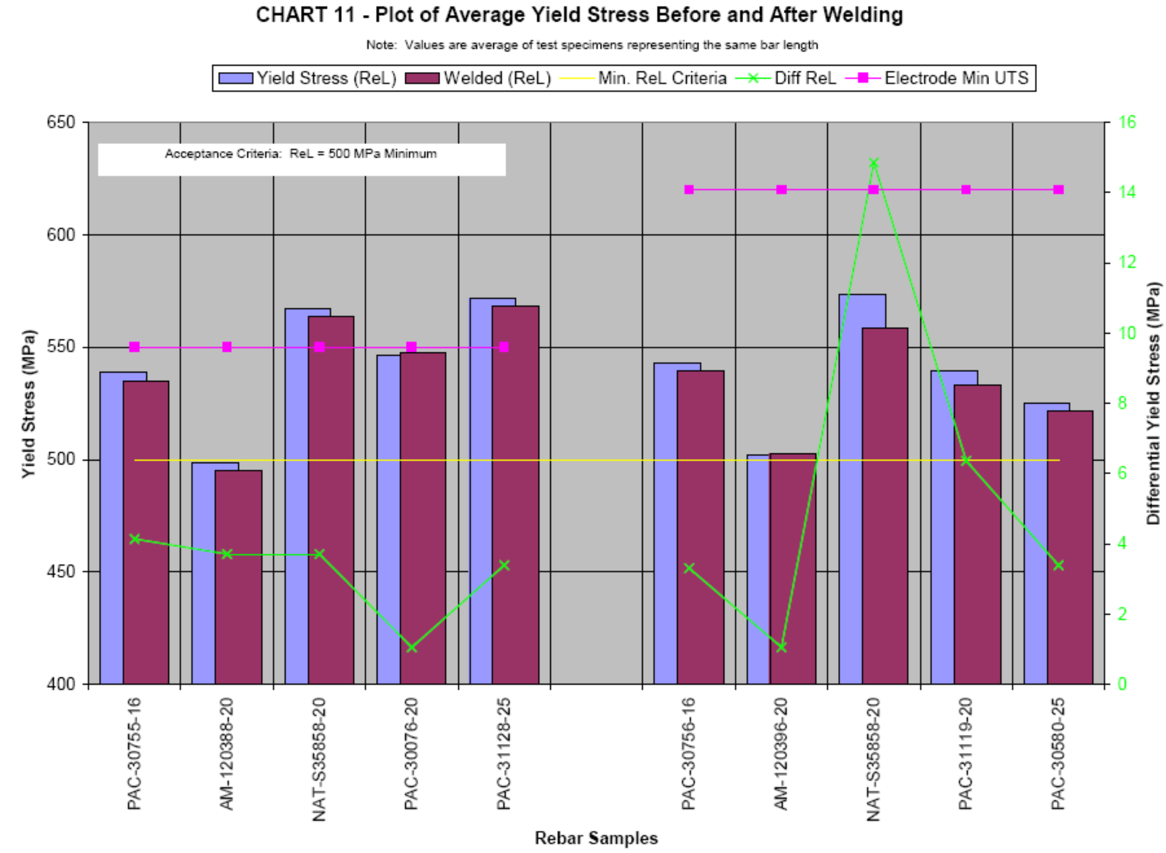

Chart11

File Ref: INZ15648

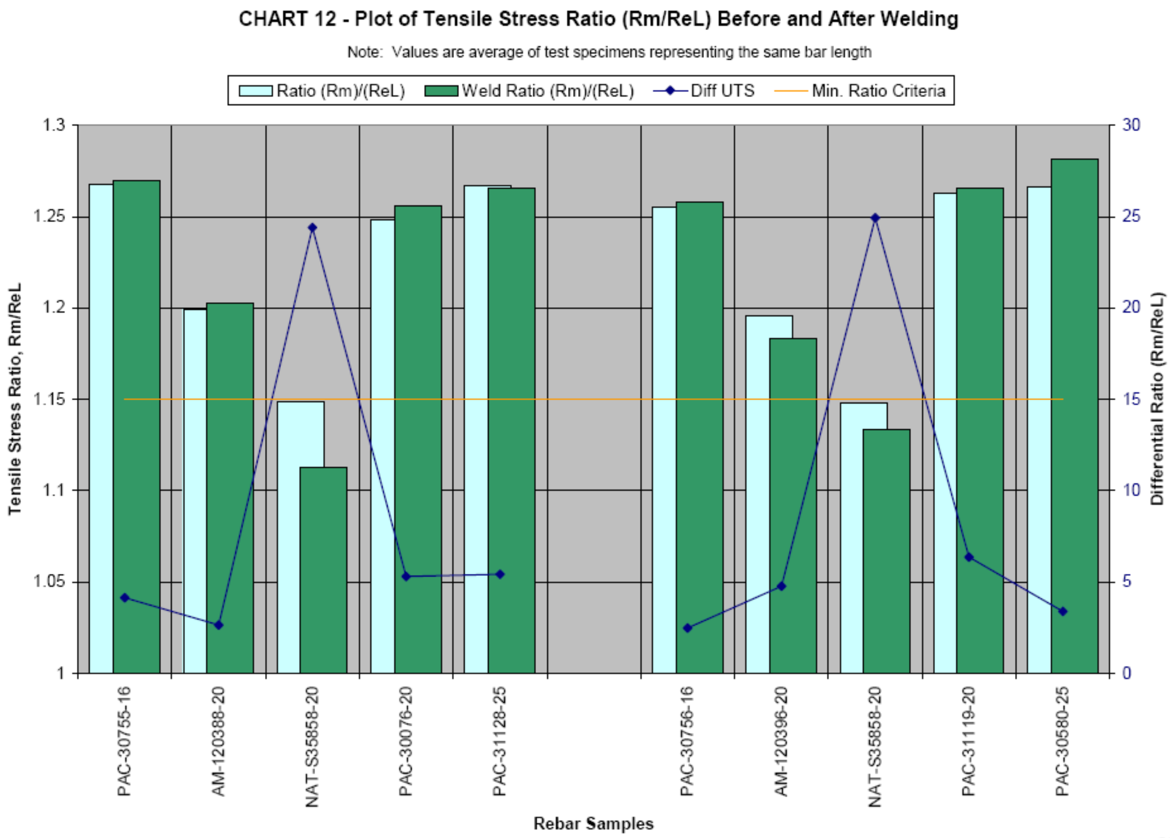

Chart12

File Ref: INZ15648

CHART 13 - Plot of Uniform Elongation (A_{gt}) Before and After Welding

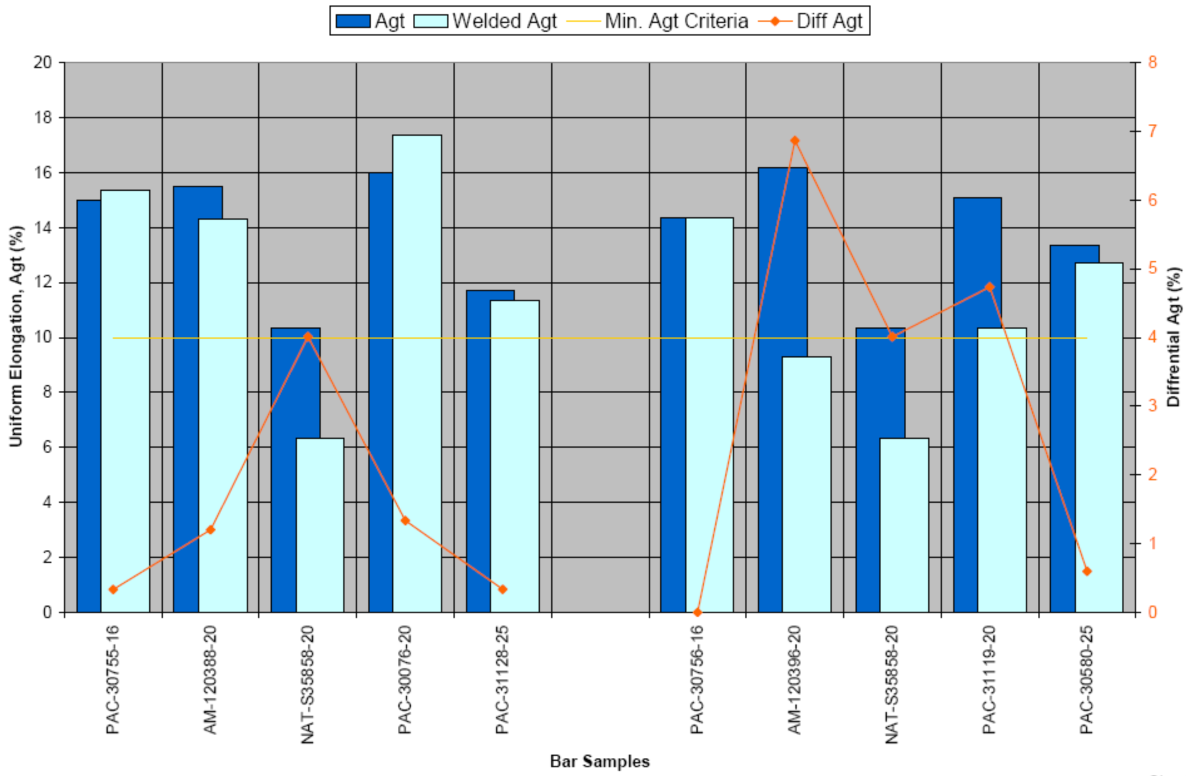

Chart13

File Ref: INZ15648

CHART 14 - Plot of Hardness Trend from Core to Edge for 12mm Bars

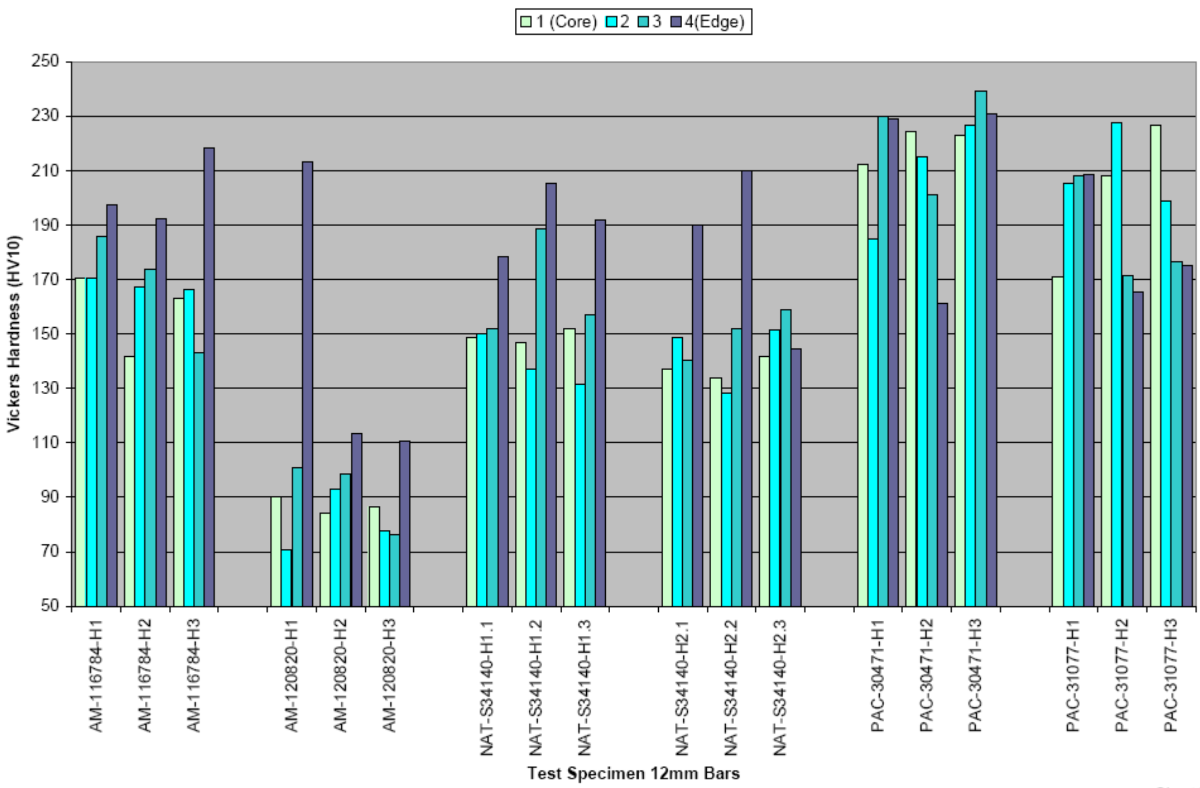

Chart14

File Ref: INZ15648

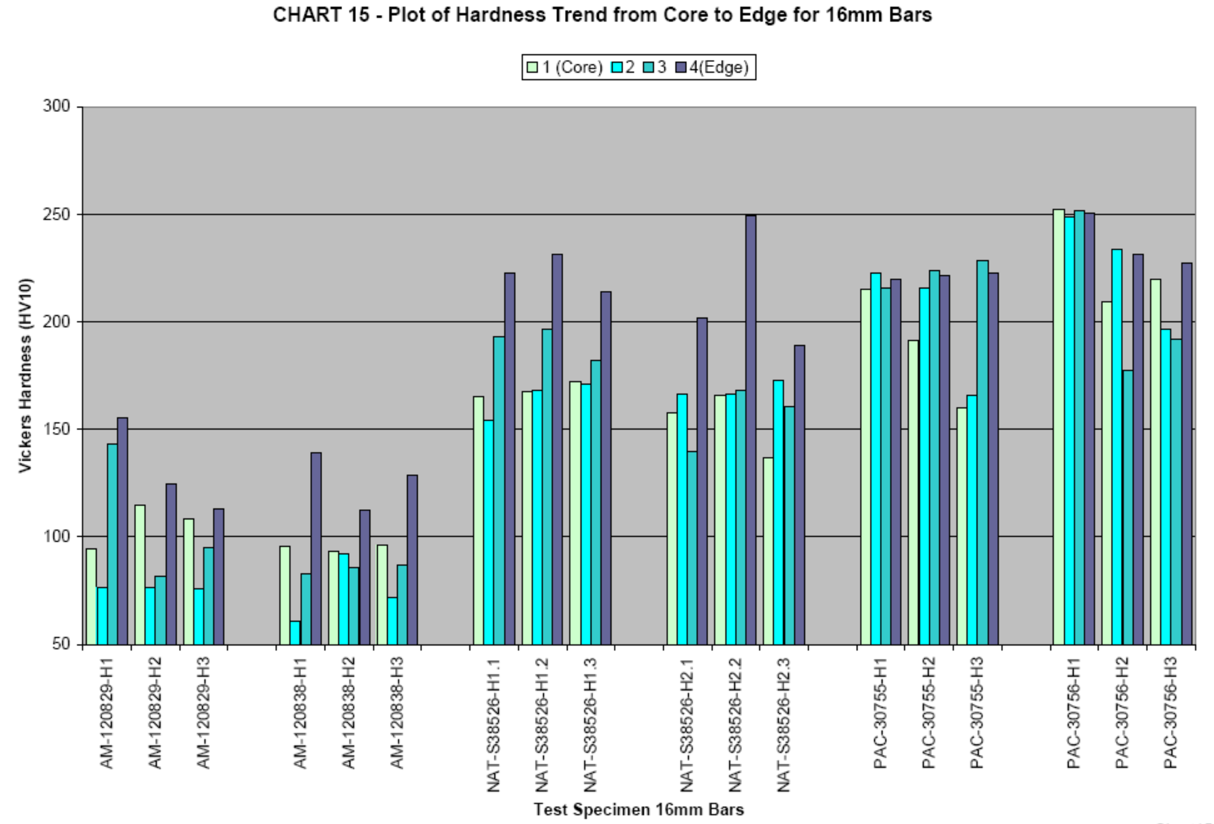

Chart15

File Ref: INZ15648

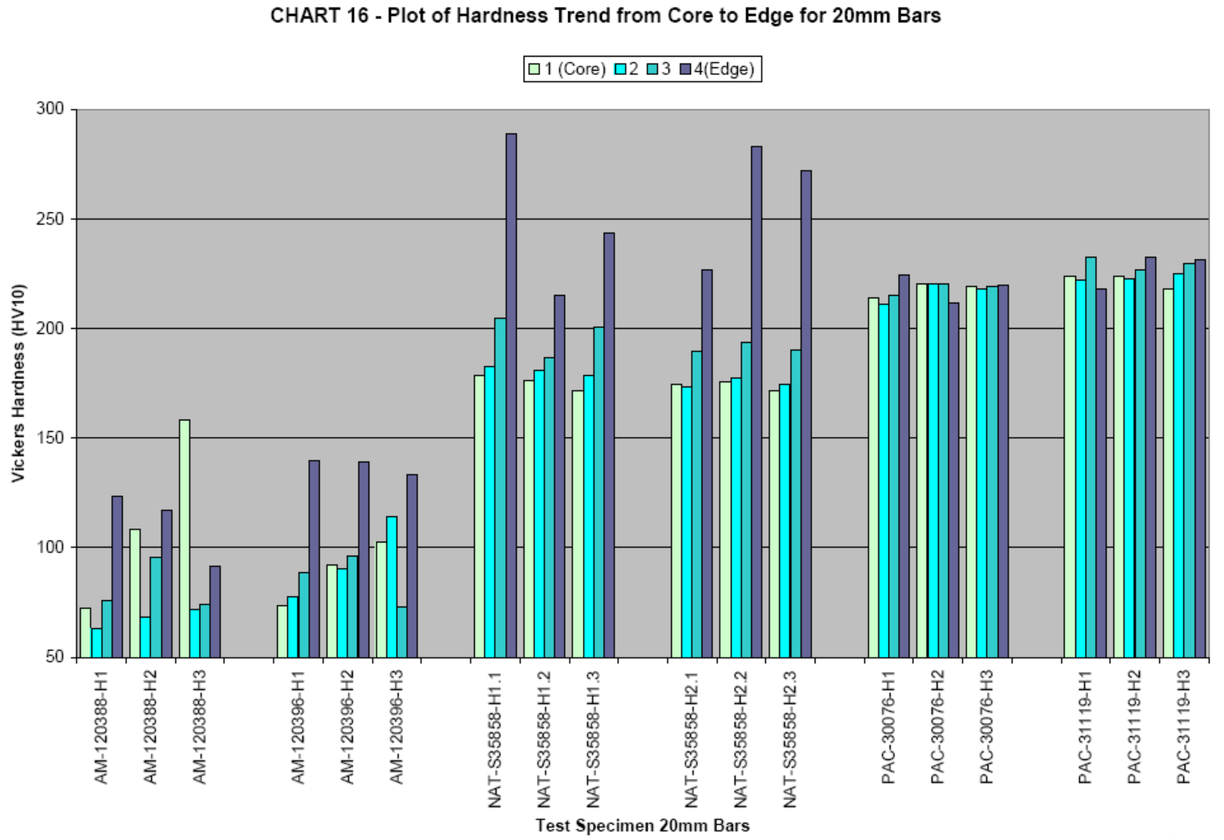

Chart16

File Ref: INZ15648

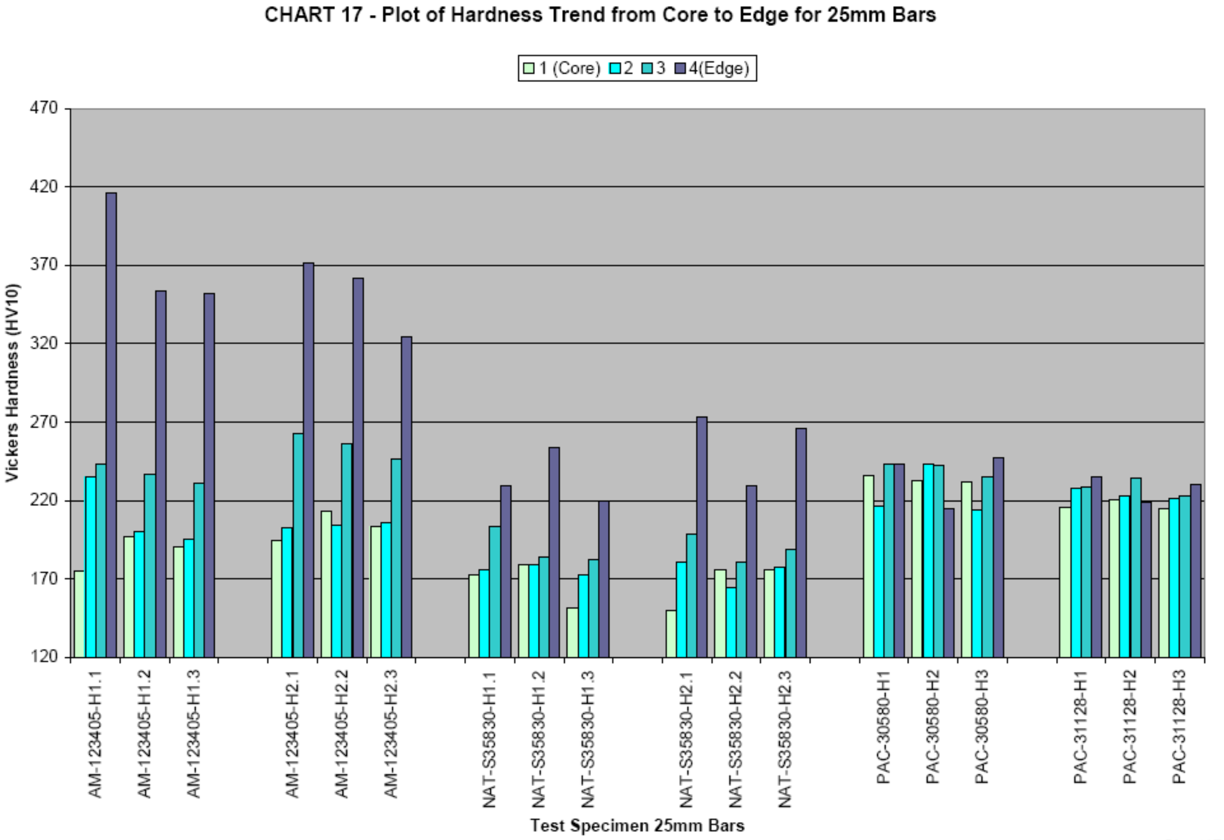

Chart17

File Ref: INZ15648

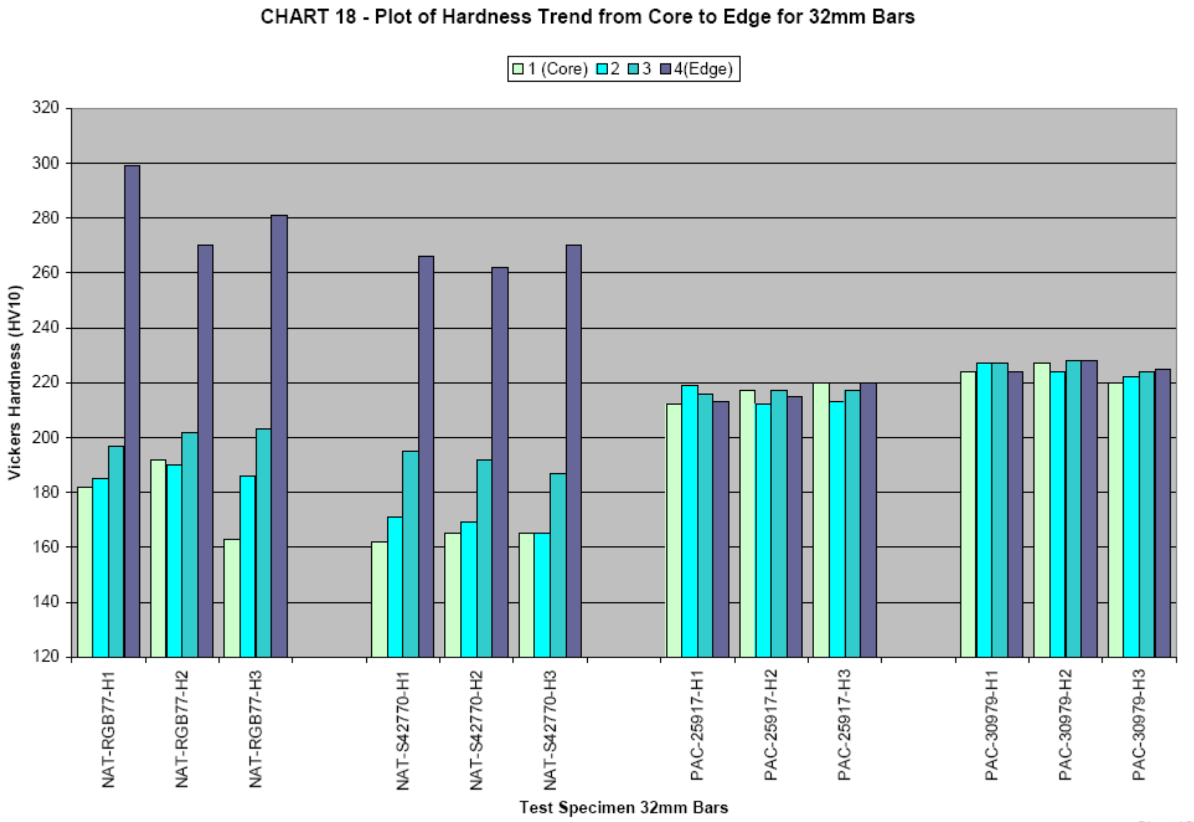

Chart18

File Ref: INZ15648

CHART 19 - Plot of Hardness Traverse Average for all Test Specimens

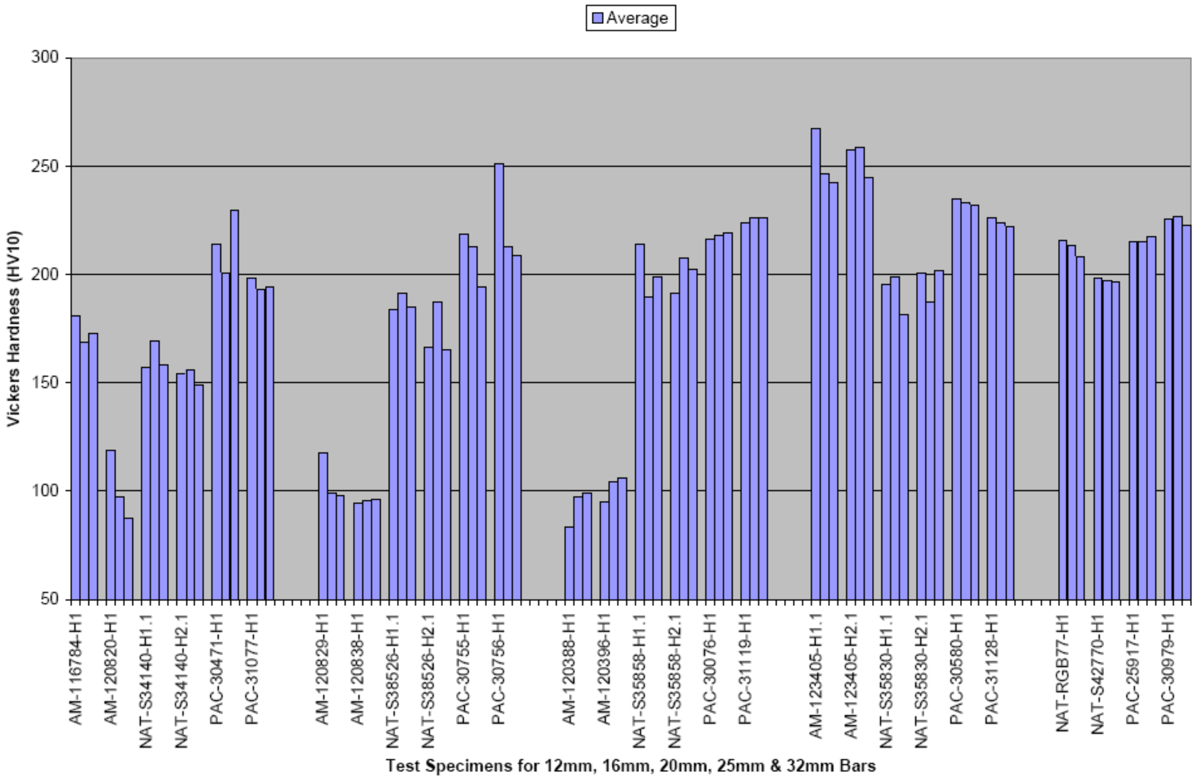

Chart19

AMSTEEL MILLS SDN BHD

A Member of The Lion Group

MILL TEST CERTIFICATE

ustomer: EURO CORPORATION LIMITED

ddres.:

Commodity: STEEL REINFORCING BARS FOR CONCRETE

Specification: AS/NZS4671 (2001) GRADE 500

Contract No.: SRB/EC/03/059

Certificate No: 71398/03

D/O No:

Date of Issue: 8/08/03

Size (mm)	Heat No	No of Pieces	Weight (Kg)	No of Bdl/Coil	Mechanical Properties			Bend Test (180°)	REBEND TEST	Chemical Composition (%)					
					Yield	Tensile	EL			C	Si	Mn	P	S	CE
					N/mm²	N/mm²	%			x 100			x 1000		x100
→ 12.0	116784				533	628	23	PASSED	PASSED	22	16	80	13	23	38
12.0	116786				545	626	21	PASSED	PASSED	19	11	80	16	35	37
16.0	116563				552	643	24	PASSED	PASSED	19	14	80	21	19	36
16.0	116516				520	613	24	PASSED	PASSED	21	8	80	12	33	36
16.0	117221				535	618	23	PASSED	PASSED	22	12	65	23	25	39
16.0	117220				535	613	23	PASSED	PASSED	18	14	60	21	23	34
						ITEM(S) =	6 ONLY								

Remarks:

We hereby certify that the material described herein has been made and tested in accordance with the above specification.

Aeck

AMSTEEL MILLS SDN BHD

A Member of The Lion Group

PO# 11533 **MILL TEST CERTIFICATE**

2/3/04

Customer: EURO CORPORATION LIMITED

Address: PO BOX 64-360
BOTANY TOWN CENTRE, EAST TAMAKI
AUCKLAND, NEW ZEALAND

Commodity: HIGH TENSILE DEFORMED BARS

Specification: AS/NZS 4671(2001) GRADE

Contract No.:

Certificate No: 89313/04

D/O No:

Date of Issue: 19/02/04

Size (mm)	Heat No	No of Pieces	Weight (Kg)	No of Bdl/Coil	Mechanical Properties			Bend Test (180°)	REBEND TEST	Chemical Composition (%)					
					Yield	Tensile	EL			C	Si	Mn	P	S	CE
					N/mm²	N/mm²	%			x 100			x 1000		X100
12.0	120960				572	662	19	PASSED	PASSED	17	14	66	16	25	31
12.0	120965				565	658	21	PASSED	PASSED	19	11	65	25	40	35
12.0	120820				534	640	19	PASSED	PASSED	21	12	66	16	14	36
16.0	120838				591	672	21	PASSED	PASSED	18	18	77	25	22	37
16.0	120837				593	679	21	PASSED	PASSED	21	19	66	26	35	38
16.0	120829				539	624	21	PASSED	PASSED	19	12	71	10	29	35
20.0	120388				517	605	22	PASSED	PASSED	19	13	69	12	30	35
20.0	120396				521	603	20	PASSED	PASSED	18	16	77	16	24	38
						ITEM(S) = 8 ONLY									

Remarks:

We hereby certify that the material described herein has been made and tested in ...

27.Jul. 2004 12:10 REDCO 09 5798787 No.7555 P. 1

15.Jul. 2004 8:49 EURO CORPORATIONS MARKETING No. 0615 P. 1/1

~~Mike~~

AMSTEEL MILLS SDN BHD (3077-A)

"ATTN : Quan"

A Member of the Lion Group

MILL TEST CERTIFICATE

12 metre Bar.

Fax 636-6054

Customer : EURO CORPORATION LIMITED

Address : PO BOX 64-360
BOTANY TOWN CENTRE, EAST TAMAKI
AUCKLAND, NEW ZEALAND

Commodity: HIGH TENSILE DEFORMED BAR

Specification: AS/NZS 4671 (2001) GRADE 500

Contract No.: HTD/EURO/04/043

Certificate No : 00510/04

D/O No :

Date of Issue : 10/06/04

Size (mm)	Heat No	ECSA (mm²)	Rolling Mass (Kg/m)	No of Bundle / Coil	TEST DATE	Mechanical Properties: Yield (N/mm²)	Tensile (N/mm²)	Stress Ratio	AGT %	Bend Test (180°)	Rebend Test	C (x 100)	Si (x 100)	Mn (x 100)	Chemical Composition (%): P (x 1000)	S (x 1000)	CE (X100)
12.0	123297	109.70	0.861		25/05/04	539	634	1.17	10.70	PASSED	PASSED	20	14	66	8	21	34
12.0	123289	109.80	0.862		20/05/04	528	612	1.16	10.40	PASSED	PASSED	19	11	66	16	24	33
16.0	122825	194.90	1.530		11/05/04	520	610	1.17	11.37	PASSED	PASSED	19	14	74	18	46	36
16.0	122617	195.80	1.537		11/05/04	531	619	1.16	15.31	PASSED	PASSED	21	18	58	15	35	36
20.0	122734	305.00	2.394		22/04/04	549	654	1.19	11.10	PASSED	PASSED	19	15	61	30	32	35
25.0	123206	475.67	3.734		02/06/04	557	659	1.18	10.50	PASSED	PASSED	16	16	62	9	17	31
25.0	123405	475.41	3.732		02/06/04	580	679	1.17	11.90	PASSED	PASSED	15	13	70	12	32	33
										ITEM(S) =	8 ONLY						

Remarks: ECSA = Effective Cross Section Area
CE = Carbon Equivalent

We hereby certify that the material described herein has been made and tested in accordance with the above specification.

MILL TEST CERTIFICATE

NatSteel

From 24/06/2003 To 24/06/2003 page : 1

CUSTOMER NAME : NAUHRIA BUILDING SUPPLIES LIMITED \

CONTRACT NO : C030249 CUSTOMER REF NO: S/LC/181/3

JOBSITE : EXPORT TO AUCKLAND, NEW ZEALAND

PRINT DATE : 26/01/2004 09:48:08

MC NO: 03060001

ORDER NO: 03061850

BBS NO: NAUHRIA-01

PO NO: NS03060001

SPECIFICATION SIZE	COMMODITY PCS/BDL	HEAT NO	QTY	WEIGHT MT	CHEMICAL COMPOSITION C	Si	Mn	P	S	Ce	TENSILE STRENGTH Yield Pt	Tens Str	Elong %	BEND TEST 180D	RE-BEND TEST	REMARKS
SS2 ; 1999 GRADE 500. 12MM X 12M DEFORMED	188	S34140	13	26.052	DEFORMED BAR 0.18	0.110	0.82	0.023	0.031	0.32	551.33	634.51	26.00	PASSED	PASSED	

SUBTOTAL BY PROD:	13	26.052
SUBTOTAL BY SPEC:	13	26.052
GRAND TOTAL:	13	26.052

MILL TEST CERTIFICATE

NatSteel

From 09/10/2003 To 09/10/2003 page : 1

CUSTOMER NAME: NAUHRIA BUILDING SUPPLIES LIMITED \

CONTRACT NO: C030463 CUSTOMER REF NO: S/HD/206/3

JOBSITE : EXPORT TO AUCKLAND, NEW ZEALAND

PRINT DATE: 10/10/2003 11:23:58

MC NO: 03100009

ORDER NO: 03100756

BBS NO: NAU01

PO NO: NS03100039

SPECIFICATION/COMMODITY SIZE	PCS/BDL HEAT NO	QTY	WEIGHT MT	CHEMICAL COMPOSITION C	Si	Mn	P	S	Ce	TENSILE STRENGTH Yield Pt	Tens Str	Elong %	AGT %	BEND/ REBEND TEST	REMARKS
SS2: PART 2: 1999 GRADE 500 16MM X 12M DEFORME	54 S38526	40	40.920	DEFORMED STEEL BAR IN 12M LENGTH 0.19	0.144	0.55	0.032	0.030	0.34	532.34	616.92	22.50	12.75	P/P	
										527.36	[illegible]	23.50	13.00	P/P	

SUBTOTAL BY PROD:	40	40.920
SUBTOTAL BY SPEC:	40	40.920
GRAND TOTAL:	40	40.920

NatSteel

NatSteel Ltd
22 Tanjong Kling Road, Singapore 628048. Telephone: 6265 1233.
Cable: NATSTEEL Telex: RS 21509 NSTEEL Fax: 6265 8317.

Jobsite :

MILL CERTIFICATE

Our ref : A/0/05/126

Contract No : S/HO/116/03

Buyer : NAUHRIA BUILDING SUPPLIES LIMITED

Commodity : DEFORMED STEEL BARS IN 12 METRES LENGTH

Specification : SS2:1999 STEEL GRADE 500

Date 05/05/2003

Sheet No.: 1

Destination : AUCKLAND,NEW ZEALAND

Size	No. of Bundle /Coils	Heat No.	No. of Pcs/ Bundle	Weight M/Tons	Chemical Composition C %	Si %	Mn %	P %	S %	CE %	Tensile Strength Yield [illegible]	Tensile [illegible]	Elong. %	Bend Test	Re-Bend Test	Remarks
25MM X 12M	7	536630	23		0.21	0.12	0.66	0.027	0.023	0.36	572.30	659.88	19.68	PASSED	PASSED	
	7	535631			0.19	0.10	0.56	0.028	0.034	0.33	570.25	659.88	20.60	PASSED	PASSED	
	14			14.890												

Dimension and Surface Conditions: GOOD

$$CE = C + \frac{Mn}{6} + \frac{Cr + V + Mo}{5} + \frac{Ni + Cu}{15}$$

THE QUALITY MANAGEMENT SYSTEM HAS BEEN CERTIFIED TO SS ISO 9002 : 1994

DATE/TIME OF PRINT-OUT: 06/05/2003 16:01:52

ISO 9000 PSB

CERT. NO. : 92-2-0581
SS ISO 9002 : 1994

NatSteel

NatSteel Ltd
22 Tanjong Kling Road, Singapore 628048, Telephone 6265 1233
Cable: NATSTEEL Telex: RS 21569 NSTEEL. Fax: 6265 8317.

AC/03/129
Our ref :

S/ND/116/03
Contract No :
NAUHIRA BUILDING SUPPLIES LIMITED
Buyer :
HIGH TENSILE DEFORMED BARS
Commodity :
SS2:1999 STEEL GRADE 500
Specification :

Jobsite :

MILL CERTIFICATE

05/05/2003
Date :
2
Sheet No.:
AUCKLAND,NEW ZEALAND
Destination :

Size	No. of Bundle /Coils	Heat No.	No. of Pcs/ Bundle	Weight M/Tons	C %	Si %	Mn %	P %	S %	CE %	Yield Pt N/mm²	Tens. Str. N/mm²	Elong %	Bend Test 180	Re-Bend Test	Remarks
20MM X 12M	5	S3[illegible]			0.20	0.11	0.8[illegible]	0.033	0.03	0.35	550.9[illegible]	640.13	22.8[illegible]	PASSED	PASSED	
	16			16.578												
25MM X 12M	7	S35850	23		0.21	0.12	0.56	0.027	0.028	0.36	572.30	653.8[illegible]	19.68	PASSED	PASSED	
	7	S35851			0.19	0.13	0.56	0.029	0.034	0.33	570.2[illegible]	659.0[illegible]	20.00	PASSED	PASSED	
	14			14.896												
32MM X 12M	12	S35568	1[illegible]		0.20	0.15	0.57	0.03[illegible]	0.01[illegible]	0.35	563.38	65[illegible].59	16.15	PASSED	PASSED	
	12			12.132												

Dimension and Surface Conditions: GOOD

$$CE = C + \frac{Mn}{6} + \frac{Cr + V + Mo}{5} + \frac{Ni + Cu}{15}$$

DATE/TIME OF PRINT-OUT: [illegible]

THE QUALITY MANAGEMENT SYSTEM HAS BEEN CERTIFIED TO SS ISO 9002 : 1994

MILL TEST CERTIFICATE

From 11/05/2004 To 11/05/2004 page : 2

CUSTOMER NAME: NAUHRIA BUILDING SUPPLIES LIMITED
MC NO: 04050020

CONTRACT NO: C040212 **CUSTOMER REF NO:** S/HD/121/4
ORDER NO: 04050351

JOBSITE : EXPORT TO AUCKLAND, NEW ZEALAND
BBS NO: NA

PRINT DATE: 12/05/2004 16:06:16
PO NO: NS04050002

SPECIFICATION/COMMODITY SIZE	PCS/BDL	HEAT NO	QTY	WEIGHT MT	C	Si	Mn	P	S	Ce	Yield Pt	Tens Str	Elong %	AGT %	BEND/ REBEND TEST	REMARKS
SS2:1999 GRADE 500				DEFORMED STEEL BAR												
[redacted]																
32MM X 12M DEFORME	14	RBG77	20	21.220	0.21	0.220	0.51	0.016	0.009	0.31	549.75	639.30	19.50	10.20	P/P	
											558.46	644.28	19.38	9.94	P/P	
											577.11	672.89	19.75	9.98	P/P	
SUBTOTAL BY PROD:			20	21.220												
[redacted]				[redacted]												

MILL TEST CERTIFICATE

From 28/04/2004 To 28/04/2004 page : 2

CUSTOMER NAME: NAUHRIA BUILDING SUPPLIES LIMITED
MC NO: 04040054

CONTRACT NO: C040163 **CUSTOMER REF NO:** S/HD/115/4
ORDER NO: 04042666

JOBSITE : EXPORT TO AUCKLAND, NEW ZEALAND
BBS NO: NA

PRINT DATE: 30/04/2004 15:44:14
PO NO: NS04040031

SPECIFICATION/COMMODITY SIZE	PCS/BDL	HEAT NO	QTY	WEIGHT MT	C	Si	Mn	P	S	Ce	Yield Pt	Tens Str	Elong %	AGT %	BEND/ REBEND TEST	REMARKS
SS2:1999 GRADE 500				DEFORMED STEEL BAR												
[redacted]																
32MM X 12M	14	342768	1	1.061	0.19	0.141	0.50	0.026	0.032	0.33	555.97	656.72	19.25	11.42	P/P	
											548.51	651.74	19.63	11.66	P/P	
											548.51	651.74	19.50	11.58	P/P	
		542770	19	20.159	0.18	0.141	0.47	0.027	0.033	0.31	559.70	651.74	18.25	10.98	P/P	
											531.09	633.08	18.38	10.90	P/P	
											578.36	669.15	17.75	10.58	P/P	
SUBTOTAL BY PROD:			20	21.220												
[redacted]				[redacted]												

ICATE OF TEST
CESS OF MANUFACTURE: BASIC ELECTRIC ARC

358049

STOMER STEELPLUS LTD

CUSTOMER O/No. 20482

WORKS O/No. 22148

DESCRIPTION ROUND S 12 SEISMIC 500 DEF 6M

SPECIFICATIONS AS/NZS 4671 G500E DEF

Invoice No: 262444 Page 1

Cast No	C %	MN %	SI %	S %	P %	T.C.EQ %	ULT/Y	YLD MPA	UELG %	RBEND
30460	0.18	1.21	0.33	0.030	0.014	0.43	1.20	552	13.3	PASS
30471	0.18	1.20	0.35	0.037	0.018	0.44	1.20	562	11.3	
30472	0.17	1.20	0.35	0.034	0.017	0.44	1.20	566	13.3	
31063	0.18	1.19	0.37	0.038	0.022	0.44	1.20	575	12.3	

Cont...

JAMES FLETCHER DRIVE, OTAHUHU, AUCKLAND, NEW ZEALAND.
P.O. BOX 22-201, OTAHUHU. PHONE (09) 276 1849. FAX (09) 276 1947.

CUSTOMER O/No.

DESTINATION

PACIFIC W/O No.

DATE	BARS BUNDLES	DELIVERY REFERENCE	PARTICULARS	TONNES	RATE	INVOICE TOTAL

CERTIFICATE OF TEST
PROCESS OF MANUFACTURE: BASIC ELECTRIC ARC

Invoice No: 262444 Page 2

358049
CUSTOMER STEELPLUS LTD
CUSTOMER O/No. 20482
WORKS O/No. 2214??
DESCRIPTION ROUND S 12 SEISMIC 500 DEF 6M
SPECIFICATIONS AS/NZS 4671 G500E DEF

Cast No	C %	MN %	SI %	S %	P %	T.C.EQ %	ULT/Y	YLD MPA	UELG %	RBEND
31074	0.19	1.20	0.35	0.031	0.018	0.44	1.21	557	12.3	
31077	0.17	1.19	0.38	0.029	0.021	0.44	1.20	578	12.3	

JAMES FLETCHER DRIVE, OTAHUHU, AUCKLAND, NEW ZEALAND.
P.O. BOX 22-201, OTAHUHU. PHONE (09) 276 1849. FAX (09) 276 1947.

Page 2
Tax Invoice No: 262444
Date 16/02/2004

358000
STEELPLUS LTD
P O BOX 58-749
GREENMOUNT

CUSTOMER O/No.
20482

PACIFIC W/O No.
221417

DESTINATION
23 Trugood Drive
East Tamaki
AUCKLAND

GST REG No.76 487 421

DATE	BARS BUNDLES	DELIVERY REFERENCE	PARTICULARS	TONNES	RATE	INVOICE TOTAL
Item 371226060			AS/NZS 4671 G500E DEF ROUND S 12 SEISMIC 500 DEF 6M			
1 02/04	3	Y800043564	6.0M	5.161		
14/02/04	11	Y800043576	6.0M	21.465		
14/02/04	7	Y800043577	6.0M	13.620		
			Total Tonnage	40.246		

CERTIFICATE OF TEST

PROCESS OF MANUFACTURE: BASIC ELECTRIC ARC

Invoice No: 261082 Page 1

358049

CUSTOMER STEELPLUS LTD

CUSTOMER O/No. 20131

WORKS O/No. 220423

DESCRIPTION ROUND M 16 SEISMIC 500 DEF 6M

SPECIFICATIONS AS/NZS 4671 G500E DEF

Cast No	C %	MN %	SI %	S %	P %	T.C.EQ %	ULT/Y	YLD MPA	UELG %
30755	0.19	1.30	0.35	0.026	0.012	0.46	1.23	563	11.3
30756	0.18	1.29	0.34	0.025	0.012	0.45	1.22	561	12.3

JAMES FLETCHER DRIVE, OTAHUHU, AUCKLAND, NEW ZEALAND.
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Tax Invoice No: 261082

Page 1
Date 12/12/2003

358000
STEELPLUS LTD
P O BOX 58-749
GREENMOUNT

CUSTOMER O/No.
20131

PACIFIC W/O No.
220423

DESTINATION
23 Trugood Drive
East Tamaki
AUCKLAND

GST REG No.76-487-421

DATE	BARS BUNDLES	DELIVERY REFERENCE	PARTICULARS	TONNES	RATE	INVOICE TOTAL
Item 381626060			AS/NZS 4671 G500E DEF ROUND M 16 SEISMIC 500 DEF 6M			
? '12/03	11	Y800041859	6.0M	21.005		
1?/12/03	6	Y800041860	6.0M	11.530		
			Total Tonnage	32.535		

CERTIFICATE OF TEST

PROCESS OF MANUFACTURE: BASIC ELECTRIC ARC

Invoice No: 261405 Page 1

358049

CUSTOMER STEELPLUS LTD

CUSTOMER O/No. 20234

WORKS O/No. 220657

DESCRIPTION ROUND M 20 SEISMIC 500 DEF 6M

SPECIFICATIONS AS/NZS 4671 G500E DEF

Cast No	C %	MN %	SI %	S %	P %	T.C.EQ %	ULT/Y	YLD MPA	UELG %
:0076	0.20	1.20	0.35	0.023	0.013	0.45	1.23	560	11.3

JAMES FLETCHER DRIVE, OTAHUHU, AUCKLAND, NEW ZEALAND.
P.O. BOX 22-201, OTAHUHU. PHONE (09) 276 1849. FAX (09) 276 1947.

Page 1

Date 7/01/2004

Tax Invoice No: 261405

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STEELPLUS LTD
P O BOX 58-749
GREENMOUNT

CUSTOMER O/No. 20234

PACIFIC W/O No. 220657

DESTINATION 23 Trugood Drive
East Tamaki
AUCKLAND

GST REG No.76-407-421

DATE	BARS BUNDLES	DELIVERY REFERENCE	PARTICULARS	TONNES	RATE	INVOICE TOTAL
Item 382026060			AS/NZS 4671 G500E DEF ROUND M 20 SEISMIC 500 DEF 6M			
6/01/04	3	Y800042241	6.0M	5.875		
			Total Tonnage	5.875		

CERTIFICATE OF TEST

PROCESS OF MANUFACTURE: BASIC ELECTRIC ARC

Invoice No: 262269 Page 1

358049

CUSTOMER STEELPLUS LTD

CUSTOMER O/No. 20356

WORKS O/No. 221024

DESCRIPTION ROUND M 20 SEISMIC 500 DEF 6M

SPECIFICATIONS AS/NZS 4671 G500E DEF

Cast No	C	MN	SI	S	P	T.C.EQ	ULT/Y	YLD	UELG	BEND
	%	%	%	%	%	%		MPA	%	
311191	0.18	1.28	0.34	0.026	0.012	0.44	1.22	567	13.3	PASS

JAMES FLETCHER DRIVE, OTAHUHU, AUCKLAND, NEW ZEALAND.
P.O. BOX 22-201, OTAHUHU. PHONE (09) 276 1849. FAX (09) 276 1947.

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Tax Invoice No: 262269

Date 11/02/2004

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STEELPLUS LTD
P O BOX 58-749
GREENMOUNT

CUSTOMER O/No. 20356

PACIFIC W/O No. 221024

DESTINATION
23 Trugood Drive
East Tamaki
AUCKLAND

GST REG No.76-487-421

DATE	BARS BUNDLES	DELIVERY REFERENCE	PARTICULARS	TONNES	RATE	INVOICE TOTAL
Item 382026060			AS/NZS 4671 G500E DEF ROUND M 20 SEISMIC 500 DEF 6M			
1 02/04	1	Y800043426	6.0M	2.140		
			Total Tonnage	2.140		

CERTIFICATE OF TEST

PROCESS OF MANUFACTURE: BASIC ELECTRIC ARC

Invoice No: 262434 Page 1

PACIFIC STEEL

358049

CUSTOMER STEELPLUS LTD

CUSTOMER O/No. 20234

WORKS O/No. 22065?

DESCRIPTION ROUND L 25 SEISMIC 500 DEF 6M

SPECIFICATIONS AS/NZS 4671 G500E DEF

Cast No	C %	MN %	SI %	S %	P %	T.C.EQ %	ULT/Y	YLD MPA	UELG %	BEND
30580	0.19	1.27	0.33	0.032	0.017	0.46	1.22	548	12.3	PASS
31126	0.17	1.25	0.34	0.028	0.015	0.47	1.29	544	12.4	PASS

17 FEB 2004

JAMES FLETCHER DRIVE, OTAHUHU, AUCKLAND, NEW ZEALAND.
P.O. BOX 22-201, OTAHUHU. PHONE (09) 276 1849. FAX (09) 276 1947.

PACIFIC STEEL

Page 1

Tax Invoice No: 262434

Date 16/02/2004

358000
STEELPLUS LTD
P O BOX 58-749
GREENMOUNT

CUSTOMER O/No.
20234

PACIFIC W/O No.
220657

DESTINATION
23 Trugood Drive
East Tamaki
AUCKLAND

GST REG No.76-487-421

DATE	BARS BUNDLES	DELIVERY REFERENCE	PARTICULARS	TONNES	RATE	INVOICE TOTAL
Item 392526060			AS/NZS 4671 G500E DEF ROUND L 25 SEISMIC 500 DEF 6M			
1 02/04	1	Y800043564	6.0M	1.848		
14/02/04	1	Y800043577	6.0M	1.755		
			Total Tonnage	3.603		

PACIFIC STEEL
PO Box 22 201, Otahuhu
Auckland
New Zealand

Ph: 64 9 276 1849
Fax: 64 9 276 1947
www.steelreinforcing.co.nz
A FLETCHER BUILDING LTD COMPANY

CERTIFICATE OF TEST

Customer Number:	320040
Customer Name:	FLETCHER REINF OLD ROD MILL
Delivery Address:	PACIFIC STEELS OLD ROD BLOCK 259 JAMES FLETCHER DRIVE OTAHUHU
Cast Number:	25917-03
Specification:	AS/NZS 4671 GRADE 500
Product:	ROUND L 32 SEISMIC 500 DEF 15M
Certificate Number:	419
Issue Date:	14/01/2003

Chemical Analysis (% by mass)

C (%)	Mn (%)	Si (%)	S (%)	P (%)	Al (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	Sn (%)	V (%)	N (%)	C + Mn/6 (%)	Ceq (%)	Cu:Sn
0.19	1.27	0.35	0.020	0.012	0.001	0.07	0.05	0.002	0.22	0.062	0.100	0.021	0.400	0.45	0.072

Mechanical Tests

Ultimate:Yield Rm/Re	Yield Strength Re (MPa)	Uniform Elong. Agt(%)	Bend Test	Mass/m (Kg/m)	Batch Conformance	Long term Conformance
1.20	569	12.3	Passed	6.210	Passed	Passed

We certify that the above information is in accordance with the records of the company and conforms to the specifications as stated.

Pacific Steel Authorised Signatory:

Keith Towl
Site Metallurgist

Attention:

Leonard Wong

This is the copy of the TEST CERT for the bar supplied to you.

Thanks
Regards,
Brend
30/06/04

CERTIFICATE OF TEST

PROCESS OF MANUFACTURE: BASIC ELECTRIC ARC

Invoice No: 261516 Page 1

PACIFIC STEEL

CUSTOMER 358049 STEELPLUS LTD

CUSTOMER O/No. 20079

WORKS O/No. 220214

DESCRIPTION ~~ROUND L 32 SEISMIC 500 DEF 12M~~

SPECIFICATIONS ~~AS/NZS 4671 G500E DEF~~

Cast No	C %	MN %	SI %	S %	P %	T.C.EQ %	ULT/Y	YLD MPA	UELG %	BEND
30979	0.20	1.33	0.34	0.029	0.015	0.47	1.22	548	12.3	PAS3

JAMES FLETCHER DRIVE, OTAHUHU, AUCKLAND, NEW ZEALAND.
P.O. BOX 22-201, OTAHUHU. PHONE (09) 276 1849. FAX (09) 276 1917.

PACIFIC STEEL

Tax Invoice No: 261516

Page 1
Date 13/01/2004

358000
STEELPLUS LTD
P O BOX 58-749
GREENMOUNT

CUSTOMER O/No. 20079

PACIFIC W/O No. 220214

DESTINATION
23 Trugood Drive
East Tamaki
AUCKLAND

GST REG No.76-487-421

DATE	BARS BUNDLES	DELIVERY REFERENCE	PARTICULARS	TONNES	RATE	INVOICE TOTAL
		Item 393226120	AS/NZS 4671 G500E DEF ROUND L 32 SEISMIC 500 DEF 12M			
1./01/04	1	Y800042440	12.0M	2.165		

Appendix 4: Review of Bend Diameters for Reinforcing in Successive New Zealand Standards

Review of Bend Diameters for Reinforcing in Successive NZ Standards

All figures are multiple of bar diameter unless noted otherwise

Standard	Grade	Bend Diameters: Deformed or Plain Bars 6	10	12	16	20	25	32	40		Stirrups and Ties	10	12	16	20	24	
NZS 1900 Chapter 9.3A 1970	All		5	5	6	6	6	8	8			2	2	2			Requirement was for bend to match diameter of main bar. Figure shown is an estimate
NZS 3101 P 1970	All		5	5	6	6	6	8	8			2	2	2			
NZS 3109 1980	275		5	5	5	5	5	6	6		Plain	2	2	2	2	2	
											Def	4	4	4	4	4	
	380		8	8	8	8	10	10	10		Plain	4	4	4			
											Def	8	8	8			
NZS 1900 Chapter 9.3 1981	275		5	5	5	5	5	6	6		Plain	2	2	2	2	2	
											Def	4	4	4	4	4	
	380		8	8	8	8	10	10	10		Plain	4	4	4			
											Def	8	8	8			
NZS3101 : 1982	275		5	5	5	5	5	6	6		Plain	2	2	2	2	2	
											Def	4	4	4	4	4	
	380		8	8	8	8	10	10	10		Plain	4	4	4	4		
											Def	8	8	8	8		
NZS 3109 1987	275		5	5	5	5	5	6	6		Plain	2	2	2	2	2	
											Def	4	4	4	4	4	
	380		8	8	8	8	10	10	10		Plain	4	4	4			
											Def	8	8	8			
NZS 3101: 1995	300		5	5	5	5	6	6	6		Plain	2	2	2	2	3	
	430		5	5	5	5	6	6	6		Def	4	4	4	4	6	
	500		5	5	5	5	6	6	6								
	Galvanised		5	5	5	8	8	8	8								