ARNCO HARDBANDING SPECIFICATION

FOR THE PREPARATION, APPLICATION and INSPECTION

OF

ARNCO HARDBANDING PRODUCTS
(100XT™, 200XT™ and 300XT™)

VERSION 1.0
November 1, 2007
# TABLE OF CONTENTS

**MANUAL HIGHLIGHTS and SPECIFIC SECTION CHANGES**

**FOREWORD and DESCRIPTION OF ARNCO PRODUCTS**

**APPLICATOR RESPONSIBILITY** *(New Section)*

**POLICY STATEMENT**

**WARRANTY PROVISIONS AND LIMITATIONS**

Section 1: APPLICATION TYPES OF ARNCO HARDBANDING

- 1.1 Raised Hardbanding
- 1.2 Flush Hardbanding

Section 2: GENERAL PREPARATION GUIDELINES AND INFORMATION

- 2.1 General Hardband Application Information
- 2.2 Welding Equipment Requirements
- 2.3 Material Preparation Requirements
- 2.4 Welding Parameter Ranges
- 2.5 Wire Usage Chart
- 2.6 Temperature Conversion Chart

Section 3: SPECIFIC APPLICATION PROCEDURES

- 3.1 Hardbanding Applied onto AISI 4137 Steel Tool Joints
- 3.2 Hardbanding Applied onto AISI 4145-HT or AISI 1340-HT Steel Heavy Weight Drill Pipe, Drill Collars and Other Drilling Equipment
- 3.3 Hardband Re-Application Procedures

Section 4: INSPECTION CRITERIA FOR QC / THIRD PARTY INSPECTORS *(This section can be utilized as a separate inspection criteria)*

- 4.1 Pre Weld Equipment Inspection
- 4.2 Pre Weld Material Inspection
- 4.3 Post Weld Hardband Inspection

**CLOSING REMARKS**

**ATTACHMENTS**

Attachment 1: Hardband Equipment Set-Up Worksheet
Attachment 2: Temperature Conversion Chart
MANUAL HIGHLIGHTS

This manual, in the past, has been a “Recommended Procedures Manual” whereby the applicators have been asked to consider this as a guideline rather than a specification. In the future this new manual is to be considered a “Specification” and not a recommended procedures manual. This is in response to many customer requests to update the Arnco manual and require the applicators to operate strictly within the parameters set forth in this manual.

Applicators seeking certification in the future will be required to demonstrate the application of Arnco’s products to become a “Certified Applicator”. In the future, Applicators will be issued only one certificate to apply all Arnco products. Certification is valid for five (5) years. Certified applicators will need to re-certify before the certification expires. Re-certification can be as simple as furnishing a weld sample to Arnco for lab analysis. Most applicators will be able to meet this requirement easily based on past performance. Others may require an on-site visit by an Arnco representative in order to be certified. The determination to certify will be solely at Arnco’s discretion after consultation with the applicator. There are expense charges for certification or re-certification that will be invoiced to the applicator for the certification process.

This “Specification” includes procedures for all Arnco products, presently including 100XT, 200XT and 300XT. As most applicators already know, some procedural items are common to all Arnco wires, but some are not. All applications concerning proper preparation, pre-heat, welding parameters of a wire and slow-cooling must be performed in the same manner for each wire. Those commonalities and differences concerning the general aspects of each wire’s application and inspection are identified in this manual. Briefly they are:

- Both 300XT and 200XT produce cracking, whether Micro or Stress cracking, but 100XT does not produce visible cracking if applied properly.
- 100XT and 300XT requires the use of a shielding gas, but 200XT does not.
- Pre-heat temperatures for all wires differ regarding the type of parent metal steel being hardbanded. Pre-heat temperatures are now more specified than before for a particular OD or groups of OD sizes.
- The Inspection Section 4 has been revised to eliminate the discussion of causes of imperfections or reject criteria so that the Acceptance/Rejection Criteria can be utilized by any experienced Inspector, whether QC, QA or “Third Party”.
- The words “hardband” or “hardbanding” will apply to all product wires unless specifically noted otherwise.
- Specific changes to pages contained in the Sections are briefly listed on the next page.

All applicators are required to read this new manual and agree to the Applicator Responsibility section. They are free (and encouraged) to distribute it to all concerned personnel within their respective companies. They must discuss it with their management and operational personnel and then reply to Arnco Technology in Houston, Texas at the addresses below with any questions or comments they may have.

Arnco Technology Trust Limited
3657 Briarpark Drive, Houston, Texas 77042-5205, USA
Telephone: (01) 832-214-5200 Fax: (01) 832-214-5205
E-Mail: Arnco@arnnottech.com Website: www.arnnottech.com
SPECIFIC SECTION CHANGES

Section 1: Application Types of Hardbanding

1.1 Raised Hardbanding; Pages 9-11; Applied Thickness and Taper Groove Depth have changed. See text in Figure 1.1, page 10.

Section 2: General Preparation Guidelines and Information

2.1 General Hardband Application Information; Pages 13-14; Information regarding the necessity for proper Pre-Heating is added, as well as, the negative effects of utilizing cooling methods to rapid-cool tool joint ends after friction welding or to protect the internal plastic coating during hardband application onto used pipe.

2.2 Welding Equipment Requirements; Pages 15-17: Information has been added regarding the necessity for accurate calibration of volt and amp meters to determine actual applied voltage and amperage; proper position for offset to prevent welding in the molten puddle; increased “stick-out” distance of the torch tip; and the necessity for a wire straightener to remove the “cast” of the wire.

2.4 Welding Parameter Ranges; Page 19; Revised to indicate optimum ranges for equipment settings at start-up and during application.

2.5 Wire Usage Chart; Page 20; Revised for application of 4/32” (3.17mm) thickness per OD size.

Section 3: Specific Application Procedures

3.1 Hardbanding Applied onto AISI 4137 Steel Tool Joints; Pages 22-23; Preheat Temperature Ranges for grouped OD sizes have been revised.

3.2 Hardbanding Applied onto AISI 4145-HT or AISI 1340-HT Steel; Pages 24-25; Preheat Temperature Ranges for group OD sizes have been revised.

3.3 Hardband Re-Application Procedures; Pages 26-39; Information regarding application over un-like hardbanding wires; General and Specific Inspection of worn and re-applied hardbanding including more color photographs of examples; Information for acceptance/rejection of cracking; rejection for “Heat-Check” cracking of used/worn hardbanding and undercutting in weld beads.

Section 4: Inspection Criteria for QC / Third Party Inspectors

4.3 Post Weld Hardband Inspection: Pages 41-50; This section is completely re-written and can be utilized as an extracted, “stand-alone”, acceptance and rejection criteria.
FOREWORD

Since 1995 Arnco Technology has provided the hardbanding industry with the Arnco Technology Recommended Procedures Manual. The first manual was for Arnco 200XT, our original hardbanding product. We later, in the year 2000, added the Arnco 100XT manual and later, the Arnco 300XT. In the beginning there was a separate manual for each product and that has worked very well. Many of the procedures that were developed by Arnco were derived from the development of each particular hardbanding wire. Also, some of those procedures were developed with regards to AWS and industry standards and specifications. At that time, there were only a few “casing friendly” hardbanding products on the market. Today there are many and there are equally as many different ways to apply each product. Some of them are good; others not so good. What we see is a vast amount of confusion in the way that a certain hardbanding is to be applied. As always, experience is a good teacher and, as they say, hindsight is 20/20. With this in mind, Arnco Technology feels that the time has come to attempt to eliminate as much of the confusion as possible, AS FAR AS ARNCO PRODUCTS ARE CONCERNED.

With this new specification manual comes the time to consolidate all three Arnco hardbanding products into one manual. It is equally important to require that all three products be applied in a consistent manner, as specified by Arnco Technology, so that we eliminate the confusion between the Arnco hardbandings and all the other hardbandings currently on the market today. Not all hardbandings are the same and they are not all applied with the same procedures. Consequently this specification is for ARNCO PRODUCTS only.

As with the previous manuals, Arnco Technology hopes that this publication will facilitate the best understanding of Arnco hardbanding technology. Arnco Technology is constantly researching and developing new, improved products and applications and they will be introduced when they have been proven to work successfully in the field. Any questions about this manual or Arnco’s hardband products may be addressed to:

ARNCO TECHNOLOGY TRUST, LIMITED
3657 BRIARPARK DRIVE, HOUSTON, TEXAS 77042-5205, USA
Telephone: 1+ (832) 214-5200 Fax: 1+ (832) 214-5205
Email: Arnco@arncotech.com Website: www.arncotech.com
APPLICATOR RESPONSIBILITY

Upon attaining Arnco certification, the Certified Applicator agrees to the following;

1) To assume operational responsibility for making applications of Arnco wire per this Arnco Hardbanding Specification Manual. The applicator must confirm that this latest procedure is in their possession and is read and understood by all necessary personnel within his organization. Some of those personnel may be the;
   - Operations Manager and Supervisors
   - Hardbanding Supervisors and Operators
   - QA/QC Manager and Supervisors
   - QC Inspectors

2) To have a functioning Quality System to include an internal training program and Operator certification.

3) When an order is received by an Applicator, he should ensure that;
   - Sufficient quantity of wire and specified shielding gas is in stock
   - Sufficient test pieces are available for set-up
   - The Volt, Amp and gas flow gauges are in current calibration

4) A Pre-production meeting is held with all involved employees prior to starting the production of the order.

5) The Supervisor/Manager is to give the order to proceed with production only after successful equipment set-up is performed and test welds are accepted.

6) The Applicator should document the application welding parameters for each order they produce and keep records on file for future reference. They may also produce an internal QC Report. Those records should contain;
   - Name of Hardband Operator and Unit number
   - The Wire Batch (Lot/Mix) number and description of the applied wire
   - Preheat temperature range and periodically measured temperatures
   - Actual welding parameters for; Voltage, Amperage, Gas flow, Rotation speed, Oscillation speed, etc.
   - Inclusive dates of application
   - Complete description of pipe; size, weight, grade, tool joint description, etc
   - Number of joints/ends hardbanded
   - Visual and Dimensional Inspection
   - Pipe/Joint Serial numbers upon request by Customer
ARNCO TECHNOLOGY POLICY STATEMENT

Arnco Technology Trust Limited (Arnco) maintains this industry leading warranty for its current range of hardbanding products.

Arnco Technology is the world leader in drill string hardbanding products. However, as with any welding process, the adherence to the specified application parameters is critical to the integrity and performance of the finished product.

Customers and end users have continued to seek better ways to ensure that once the products are applied, they will work without failure.

Arnco Technology has developed this program to better ensure such a result, while giving our customers a warranty with great clarity. This warranty applies to all Arnco hardbanding wires when applied in full conformance with this Arnco Hardbanding Specification Manual*, and as witnessed and verified by Arnco personnel or an Arnco approved independent monitor.

This procedure will give our customers a verification that the Arnco specified parameters have been properly adhered to by monitoring the application to assure compliance with those specifications. Once verified and approved, the warranty provides that, in the unlikely event of any specific defect occurring in the Arnco hardbanding as a direct result of the technical performance of the Arnco product used, then Arnco will replace, in full, the faulty hardbanding at Arnco’s expense. Please see the following page for the specific provisions of the warranty and its limitations.

* The Arnco Hardbanding Specification Manual is available at no cost, direct from Arnco Technology by contacting the Arnco Technology website (www.ArncoTech.com) or an Arnco representative at one of the following Arnco contact numbers:

Arnco Technology Trust Limited
3657 Briarpark Drive, Houston, Texas 77042-5205, USA
Telephone: (01) 832-214-5200 Fax: (01) 832-214-5205
E-Mail: Arnco@arncotech.com Website: www.arncotech.com

Version 1.0, November 1, 2007 7
PROVISIONS AND LIMITATIONS

Provisions

1. Hardbanding must be applied by an Arnco Certified Applicator.

2. Arnco personnel or an Arnco approved monitor must witness the application. The cost of this service is to be negotiated between Arnco and the customer.

3. Hardbanding must be applied strictly in conformance with this current Arnco Hardbanding Specification Manual.

4. In the unlikely event that a hardbanding failure occurs, an independent failure analysis will be performed to determine the cause of the failure. If the failure is caused by the product or application, then Arnco will be responsible for the repair as stated. If it is caused by the drilling conditions, etc. then the cost of the repair will be the responsibility of the customer.

Limitations

1. Limited to the cost of removal of defective hardbanding, application of a butter pass and re-application of the new hardbanding only, including necessary inspections involved in the hardbanding application.

2. Not included is the potential loss of time or revenue of the customer in the event of defective hardbanding.

3. Not included is the cost of a third party monitor that might be required by the customer or end user. If they wish to have a monitor present during repair, it will be at their expense, not Arnco’s. Arnco will provide their own monitoring service as required.
SECTION 1: APPLICATION TYPES OF ARNCO HARDBANDING

1.1 RAISED HARDBANDING

Raised hardbanding is strongly recommended on all tool joints for maximum casing and tool joint protection.

1.1.1 When specified by the customer, an optional recess groove is machined into the 18° elevator shoulder and filled flush with the hardbanding. One layer is then applied raised on the tool joint O.D. for a specified length. Normally 3" (~76mm) of hardbanding is applied on the Box O.D. and, as a recommended option; 2" (~50mm) is applied on the Pin O.D. Instead of the full length of the tool joint contacting the inner surface of the casing or the open hole wall, the Arnco hardband makes the contact, thereby reducing casing wear AND tool joint wear. This raised application for tool joints is illustrated in Figure 1.1.

1.1.2 Application on the Pin O.D. is strongly recommended for extra-long tool joints. This will further ensure the entire tool joint area (Box and Pin) will have minimal contact with the inside surface of the casing or open hole wall. This is of concern when drilling or tripping in and out of the well bore.

1.1.3 Arnco hardbanding applied in this manner also reduces the possibility of heat checking occurring on the tool joint surface. Instead of the tool joint being damaged by heat checking, the hardband surface will absorb the load. The worst thing that could happen is that the hardband would be damaged and subsequently requires its removal and re-application. The drill string could then be salvaged and continue to be utilized.

1.1.4 When the hardbanding makes contact with the inside of the casing, the low coefficient of friction reduces the torque and drag experienced in extended reach or high-angle wells. As a result, this reduction in torque and drag should reduce fuel cost.

1.1.5 When application is performed on new or used tool joints in a non-mill application (as performed with portable field equipment), it is usually not necessary to apply or re-apply hardbanding to the 18° elevator shoulder. The shoulder area should be visually inspected to determine if it is in serviceable condition. This type of raised application for new or used tool joints in a non-mill application is illustrated in Figure 1.2.

Note: Refer to Section 2 and 3 of this manual for detailed information concerning application onto used material.
** Apply hardbanding flush on 18° shoulder, +0, - 1/32" (+0, -0,80mm);
The taper groove should be machined to a depth that equals the finished applied thickness (H) for the raised hardband on the OD.
When specified, the Taper Weld Bead width shall be a minimum of 3/4” (19mm)

<table>
<thead>
<tr>
<th>2&quot; (~50mm)</th>
<th>L_P</th>
<th>L_B</th>
<th>3&quot; (~76mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/32&quot;, +0&quot;, - 1/32&quot; (3,17mm, +0mm, -0,80mm)</td>
<td></td>
<td>H</td>
<td>4/32&quot;, +0&quot;, - 1/32&quot; (3,17mm, +0mm,-0,80mm)</td>
</tr>
</tbody>
</table>

*Figure 1.1*
ARNCO HARDBANDING

RAISED NON-MILL APPLICATION

On Box End, apply the hardbanding approximately 3/8", +/- 1/8"
from the 18° shoulder (9.52mm, +/- 3.17mm)

Figure 1.2
1.2 FLUSH HARDBANDING

1.2.1 Flush Hardbanding is recommended *only* if the maximum tool joint O.D. must be restricted so as not to cause interference with the casing inside diameter. *Any hardbanding* applied in this manner will not yield maximum results because the *tool joint O.D.* begins to wear simultaneously with the hardbanding.

1.2.2 For a Flush Hardband application, a recess groove is machined into the entire hardband area of the tool joint and filled with Arnco hardbanding flush with the O.D. of the tool joint. The hardband area normally includes the 18° elevator shoulder. This type of application for new, used or rebuilt tool joints is illustrated in Figure 1.3.

1.2.3 Application of hardbanding on the Pin O.D. is a recommended option.

*NOTE: Refer to Section 2 and 3 of this manual for detailed information concerning application on used material.*

**ARNCO HARDBANDING**

**FLUSH APPLICATION**

---

**Table 1.3**

<table>
<thead>
<tr>
<th>2&quot;</th>
<th>L_P</th>
<th>L_B</th>
<th>3&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/32&quot; +0, - 1/32&quot; <em>(2,38mm +/- 0,80mm)</em></td>
<td>D</td>
<td>3/32&quot; +0, - 1/32&quot; <em>(2,38mm +/- 0,80mm)</em></td>
<td></td>
</tr>
<tr>
<td>Flush with O.D., + 1/32&quot;, -0&quot; (+0,80mm,-0)</td>
<td>H</td>
<td>Flush with OD, + 1/32&quot;, -0&quot; (+0,80mm,-0)</td>
<td></td>
</tr>
</tbody>
</table>

*Apply hardbanding flush with 18° shoulder, +0, - 1/32" (+0mm, -0,80mm)*

*If not specified, the Taper Weld Bead width shall be a minimum of 3/4" (19mm)*

*Figure 1.3*
SECTION 2: GENERAL GUIDELINES AND INFORMATION

2.1 GENERAL HARDBAND APPLICATION INFORMATION

2.1.1 Hardband Width: It has become a common practice to order drill pipe with extra long tool joints. With the advent of the high torque type tool joints, the total length of the combined tool joints may be as much as 36" (914mm) in length. To increase the bearing effect of these long tool joints, Arnco recommends applying 2" (50mm) on the pin tool joint in addition to a 3" (76mm) or wider band on the box tool joint.

2.1.2 Weld Bead Width: Arnco recommends that the finished weld bead be 1-1/8" (~28.6mm) in width. This results in a smoother, more uniform bead. The unit operator should determine how well the equipment can produce the highest degree of workmanship to attain a flat or slightly convex weld bead profile. Oscillation width and adequate overlap, of 1/8" (3.17mm) can be adjusted to achieve the desired effect and meet the requirement for a specified, overall minimum hardband width. If applicators chose to apply a ~3/4" wide finished weld bead, they must pay close attention to the amount of overlap needed to attain the overall, minimum hardband width specified by the customer.

2.1.3 Pre-Heat: Proper preheating of the tool joint or drill collar must be performed regardless of the O.D. or ambient temperature of the steel. Inadequate preheating of the parent steel may cause undesirable cracking in the parent metal and/or weld metal.

2.1.3.1 An excerpt from Weldability of Steels, R.D. Stout, Welding Research Council, 4th Edition, © 1987, page 169, is provided herein concerning the benefits and necessity for preheating:

“Preheating is beneficial for four reasons: first, it lowers the cooling rates in the weld metal and heat-affected base metal, producing a more ductile metallurgical structure to resist weld cracking; second, the slower cooling rate provides an opportunity for any hydrogen that may be present to diffuse out harmlessly without causing cracking; third, it lowers the magnitude of shrinkage and fourth, it raises some steels above the temperature at which brittle fracture could occur in fabrication”.

2.1.3.2 Applicators shall refer to Section 3 of this manual for the specific preheat temperature ranges for the type of steel and OD size of the parent metal and ensure that the preheat is a “soak” heat and not a surface heat.

2.1.3.3 Customers and Applicators are advised that utilizing any method to cool internal plastic coating during hardbanding can cause embrittlement of the Heat Affected Zone (HAZ) below the weld and negatively affect the fusion bond of the hardband to the parent metal. Cooling the ID of pipe will not allow for proper preheat of the parent metal prior to hardbanding.
2.1.4 **Slow-Cooling:** The Applicator must "slow-cool" the hardbanded tool joints. To ensure the required slow cooling, the tool joints need to be wrapped immediately in thermally insulated blankets or canisters. The use of shop ventilation fans shall have the airflow directed away from the hardbanded tool joints during handling, wrapping and slow cool storage. The wrapping and subsequent slow cooling must take place in “still air”. The blankets or canisters shall remain on the tool joint ends until the tool joint has cooled down to less than 150°F (66°C).

   Note: Arnco has determined that any method utilized to cool tool joint ends to facilitate handling and inspection, after the Q&T process following friction weld, can negatively affect the hardband, especially 200XT and 300XT. Manufacturers that apply hardbanding should not use any method of cooling solely to handle or speed-up production. Adequate time must be allowed for the tool joint ends to slow cool naturally after the Q&T process.

2.1.5 **Grinding:** Repair grinding to contour overlap areas of the weld bead or to remove spatter or minor protrusions shall be performed as necessary after the tool joint has been cooled down to less than 150°F (66°C). Heavy, continuous grinding with stationary grinding wheels is not necessary and should not be performed.

2.1.6 **Elevator Shoulder:** When welding is required on the 18° elevator shoulder, the unit operator and inspector must pay close attention to the weld profile of the finished weld bead. If the weld bead height on the 18° elevator shoulder exceeds that of the tool joint shoulder itself, it is necessary to remove that excess height to make it flush with the tool joint shoulder. Any raised weld metal on the 18° elevator shoulder may result in interference with the elevator’s operation.

2.1.7 **Fingers:** When “fingers” are required on the 18° elevator shoulder, they also must be flush. They may be applied with the hardbanding unit or with hand-held welding equipment (i.e. MIG gun). If the tool joint has been previously hardbanded and has cooled to less than the required preheat temperature, the tool joint must be preheated again to the required temperature prior to application of the fingers. Arnco has no opinion on the use of fingers, but it has become more accepted that fingers with casing friendly hardbanding are not applied.
2.2 WELDING EQUIPMENT REQUIREMENTS

2.2.1 The welding equipment should consist of a Constant, Direct Current (DC) power supply capable of furnishing a current of 200-320 amperes and 24 - 30 volts, with the wire Positive (DCEP). Reverse polarity (DCEP) is to be utilized at all times, for all Arnco products, regardless of the type of steel that the hardband is being applied onto.

Note: Arnco has learned that equipment voltmeters, whether on the power supply itself or a remote meter at the Operators panel, need to be calibrated to the actual, applied voltage as measured as close to the torch head as possible. It is normal to have a “voltage line drop” of ~1 to 2-volts (sometimes more) from the power supply output to the torch head. This line-drop needs to be compensated for by having the voltmeter calibrated to the applied voltage at the torch head and not that of the output of the power supply.

2.2.2 The welding equipment should have a clean grounding system that will not resist the flow of electric current. The resistance can be seen as heat build-up in the welding lead or in its connection after a short weld time.

Note: Also, it is possible to see a varying resistance, by measuring voltage. When a voltmeter is utilized to measure the applied voltage the ground lead of the voltmeter is held directly onto the tool joint. If a good ground connection is not present, the measured voltage will widely vary upward from the applied voltage, as the electrode (the hardband wire) is “seeking ground”. When a good ground connection is present, the measured voltage should only vary approximately, +/-, 0.50 to 1.0 volt from the applied voltage.

2.2.3 The equipment should have the ability to grip and rotate the tool joint under the welding torch concentric to within .030” (0,76mm) and at a constant uniform speed of between 60 and 200 seconds per revolution. The tool joint O.D. is the factor that determines the speed at which to rotate the tool joint.

2.2.4 The equipment must have the ability to move the welding torch from vertical center so that welding takes place on the uphill side of the tool joint as it is being rotated. For this “Torch off-set”, refer to the Recommended Welding Parameters as illustrated in Figure 2.1. The torch offset distance changes slightly with each OD size. This offset adjustment is critical to have, so to attain a flat weld bead profile.

2.2.5 In addition, the equipment must have the ability to angle the welding torch, in the direction of the rotation, to between 17-19 degrees as measured from vertical center of the tool joint. For this “Torch Angle”, refer to the Recommended Welding Parameters illustrated in Figure 2.1.

NOTE: Machines that are not configured to adjust torch angle or offset, from vertical center, have normally demonstrated difficulty to produce a consistently flat, or slightly convex, weld bead profile. Not having both of these adjustments available becomes a greater disadvantage when welding on a tool joint smaller than 4-3/4” (~120mm) O.D.

Further, the offset adjustment must be positioned correctly so that the electrode wire, during welding, is NOT too far forward to top-dead-center and allows the welding arc to burn “within the molten puddle”. Welding within the molten puddle can cause porosity and lack of fusion with the parent metal.
2.2.6  The equipment must have the ability to oscillate the welding torch at a standoff or “stick-out” distance of 1” to 1-1/8” (25.4mm to 28.6mm), from the welding surface and at approximately 50 to 90 oscillations per minute. This distance is measured from the torch tip and not the nozzle cover. A stick-out distance less than 1” (<25.4mm) can sometimes cause turbulence of the gas flow, at the nozzle cover, which can cause porosity in the weld bead.

2.2.7  The equipment must be able to move the torch, parallel to the tool joint axis, for a minimum distance of 4” (~102mm). A longer distance, of 6” to 12” (~153mm-305mm) is preferred, especially when hardbanding drill collars or extra long tool joints.

2.2.8  Welding equipment should include a wire feed system capable of feeding the wire through the torch at a variable, uniform speed without damaging the surface or the shape of the wire. Special wire-feed rollers designed for feeding soft-skinned, flux-cored wire should be utilized. The wire feeder should also have a wire straightener to remove, as best as possible, the normal “cast” of the wire. The wire straightener can be installed before or after the wire feeder roller assembly. Having a straightener also reduces tip wear as the wire, when straightened, does not exit of tip in a curved fashion.

2.2.9  A shielding gas must be supplied to the arc when welding Arnco 100XT or 300XT. Arnco has learned from experience that either a Pure 100% Carbon Dioxide or a mixture of Argon and Carbon Dioxide gases can be utilized when welding. The specified Argon/CO₂ gas mixtures are; a) 82%Ar/18%CO₂ or b) 80%Ar/20%CO₂ or c) 75%Ar/25%CO₂. Other gas mixtures of Argon and Carbon Dioxide shall not be utilized as they may negatively affect the weld. The regulated flow for all gases must be controlled to deliver 30 to 35 CFH (14-16.5 LPM) to the arc area. During windy conditions, when operating portable hardband units in pipe yards or at rig locations, every precaution shall be taken to protect gas flow at the nozzle, inside the torch cabinet, from being blown away from the arc when welding. The Arnco 200XT wire does not need a shielding gas as the wire is manufactured as a “self-shielded” wire.

2.2.10  When welding is performed on the 18° elevator shoulder, the equipment must be able to tilt the tool joint or lift the joint of pipe in order to weld the shoulder on a flat plane.

2.2.11  The pre-heat equipment must have the ability to pre-heat any tool joint, center wear pad or drill collar, to a uniform temperature from 225°F to 675°F (107°C to 358°C). Refer to Section 3 of this manual for the specific preheat temperature ranges for the type of steel and OD size of the parent metal. The heat applied should be a soak heat rather than a surface heat.

2.2.11.1  To determine if a soak heat is being applied, perform this simple procedure:

a. Remove the tool joint from the heating device and immediately measure the temperature in the area to be hardbanded.

b. Immediately cover the tool joint with a canister or thermal blanket

c. Allow the tool joint to stand in still air for 4 minutes.

d. Then, again, measure the temperature of the tool joint.

e. If the temperature drops more than 50°F (10°C), the pre-heat applied is only a surface heat and not a soak heat.

f. If it is determined that it is a surface heat, continue preheating until the temperature drop is within the tolerances of a soak heat.
2.2.12 The Applicator must "slow-cool" the hardband areas in “still air”. In order to ensure the required slow cooling, the tool joints must be wrapped as immediately as possible in thermally insulated blankets or canisters. The use of shop ventilation fans shall have the airflow directed away from the hardbanded tool joints during application, handling, wrapping and slow cool storage. The subsequent slow cooling must take place in “still air”. The blankets or canisters shall remain on the tool joint ends (or hardband area) until the tool joint has cooled down to less than 150°F (66°C). Any grinding shall be done after the tool joint has cooled down to less than 150°F (66°C).

2.2.13 When hardbanding drill pipe tool joints, the ends of the drill pipe should be closed to prevent a draft, or “chimney effect”, through the drill pipe. This becomes extremely critical when hardbanding during windy or cold-air conditions, especially where portable equipment is utilized. The use of closed-end protectors, or applying tape over the wrench-hole openings on steel protectors, should be sufficient to prevent the drafting of air through the inside of the pipe.
2.3 MATERIAL PREPARATION REQUIREMENTS

NOTE: Preparation of the hardband area must be performed to minimize, if not eliminate, foreign matter becoming an impurity in the molten weld puddle and to ensure a good fusion bond with the parent metal. Preparation must be performed when applying hardbanding onto either new or used material.

2.3.1 General Material Preparation Information:

2.3.1.1 Visually inspect the weld surface of all tool joints or hardband areas to ensure they are clean and free of all foreign matter such as rust, dirt, grease, oil, paint or pipe coating.

2.3.1.2 Utilizing a side-grinder & cup-brush will usually produce a sufficiently clean weld surface for hardbanding new tool joints. Perform a visual inspection of the tool joint O.D. surface after buffing. “Buffing” of the tool joint surface does not always produce a clean weld surface, consequently, further cleaning may be necessary. Applicators are to determine the best method available to prepare the weld surface.

2.3.1.3 The threaded connections should be cleaned of all thread lubricants or storage compounds. This will ensure a much cleaner welding process and eliminate the probability of the lubricant or compound igniting during pre-heat.

2.3.1.4 When Raised hardbanding is required on new or used unhardbanded tool joints, it is sometimes necessary to machine a shallow, .015" (0.38mm), recess groove into the tool joint O.D. to give a clean, smooth and concentric weld surface.

2.3.1.5 Prior to hardbanding used unhardbanded drill pipe, the tool joints should be examined for eccentric wear caused by downhole drilling conditions. The concentricity of the tool joint should be within .030" (0.76mm) of the center axis in order to apply an even layer of hardbanding. If the eccentricity of the tool joint is greater than .030" (0.76mm) it may cause the welding arc to be erratic and/or produce an unacceptable weld bead of insufficient height over ~180° of the circumference of the hardband area. Refer to section 3 for more information regarding hardbanding Used drill pipe.

2.3.2 Application of Hardbanding onto Used hardbanded drill pipe: Refer to Sub-Section 3.3 for a more detailed application procedure of hardbanding used pipe.

NOTE: If you have any questions concerning application of any hardbanding over another, contact your Arnco representative prior to proceeding.

2.4 RECOMMENDED WELDING PARAMETERS: The welding parameters for the hardbanding wire are illustrated in Figure 2.1. Applicators should refer to this diagram for torch and welding equipment set-up.

2.5 WIRE USAGE CHART: Applicators should use Table 2.1, to determine the amount of hardbanding wire required to weld a particular O.D. tool joint, center wear pad or drill collar.

2.6 TEMPERATURE CONVERSION CHART: Applicators may use the enclosed temperature Conversion Chart (Attachment 2) to convert temperatures, either Fahrenheit to Celsius or vice versa.
**ARNCO HARDBANDING**  
**EQUIPMENT SETTINGS and WELDING PARAMETER RANGES**

"TORCH ALIGNMENT SETTINGS"

The Distance "X" is set to between ~.50" (12.7mm) to ~1.500" (38.1mm) depending on the OD of the tool joint, center wear pad or drill collar.

The total indicated run-out (TIR) should be within +/- 0.015" (+/- 0.38mm)

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>FCAW (AUTOMATIC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHIELDING GAS</td>
<td>See Procedures in Section 3</td>
</tr>
<tr>
<td>FILLER METAL</td>
<td>Only Mild Steel Wire</td>
</tr>
<tr>
<td>ELECTRODE SIZE</td>
<td>1/16&quot; (1.6mm) (or 5/64&quot; for 200XT)</td>
</tr>
<tr>
<td>PREHEAT</td>
<td>See Specific Procedure in Section 3</td>
</tr>
<tr>
<td>CURRENT TYPE / POLARITY</td>
<td>For all wires DCEP (REVERSE)</td>
</tr>
<tr>
<td>WIRE STICK-OUT DISTANCE</td>
<td>1.0&quot;-1.125&quot; (25.4mm to 28.6mm)</td>
</tr>
<tr>
<td>VOLTAGE RANGE</td>
<td>24 – 30 VDC</td>
</tr>
<tr>
<td>(Arnco recommends that Applied Voltage be set at 27-28Vdc)</td>
<td></td>
</tr>
<tr>
<td>AMPERAGE RANGE</td>
<td>200 – 320 amps</td>
</tr>
<tr>
<td>(Amperage to be adjusted to produce desired thickness of weld bead)</td>
<td></td>
</tr>
<tr>
<td>OSCILLATION SPEED</td>
<td>Approx. 50-90 Oscillations/minute</td>
</tr>
<tr>
<td>OSCILLATION WIDTH (without arc applied)</td>
<td>~.750&quot; (19, 0 mm) to 1.0&quot; (25, 4 mm)</td>
</tr>
<tr>
<td>(Arnco recommends the finished weld bead to be 1-1/8&quot; (28.6mm) in overall width)</td>
<td></td>
</tr>
<tr>
<td>WELD BEAD OVERLAP</td>
<td>.125&quot; (3, 17 mm)</td>
</tr>
<tr>
<td>(Arnco recommends overlap of weld beads to be 1/8” (3,17mm)</td>
<td></td>
</tr>
<tr>
<td>POST WELD TEMPERING</td>
<td>OPTIONAL</td>
</tr>
<tr>
<td>POST WELD COOL DOWN</td>
<td>COVERED, IN STILL AIR</td>
</tr>
<tr>
<td>INTERPASS TEMPERATURE</td>
<td>850°F (454°C) MAXIMUM</td>
</tr>
</tbody>
</table>

**Figure 2.1**
<table>
<thead>
<tr>
<th>Tool Joint Diameter</th>
<th>Pounds Per Linear Inch</th>
<th>.750&quot;</th>
<th>1.00&quot;</th>
<th>2.00&quot;</th>
<th>3.00&quot;</th>
<th>3.750&quot;</th>
<th>4.00&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1/2&quot;</td>
<td>.504</td>
<td>.378</td>
<td>.504</td>
<td>1.008</td>
<td>1.512</td>
<td>1.890</td>
<td>2.016</td>
</tr>
<tr>
<td>4-3/4&quot;</td>
<td>.531</td>
<td>.398</td>
<td>.531</td>
<td>1.062</td>
<td>1.593</td>
<td>1.990</td>
<td>2.124</td>
</tr>
<tr>
<td>5&quot;</td>
<td>.559</td>
<td>.419</td>
<td>.559</td>
<td>1.118</td>
<td>1.677</td>
<td>2.096</td>
<td>2.236</td>
</tr>
<tr>
<td>5-1/4&quot;</td>
<td>.586</td>
<td>.440</td>
<td>.586</td>
<td>1.172</td>
<td>1.758</td>
<td>2.198</td>
<td>2.344</td>
</tr>
<tr>
<td>5-1/2&quot;</td>
<td>.613</td>
<td>.460</td>
<td>.613</td>
<td>1.226</td>
<td>1.839</td>
<td>2.299</td>
<td>2.452</td>
</tr>
<tr>
<td>5-3/4&quot;</td>
<td>.641</td>
<td>.481</td>
<td>.641</td>
<td>1.282</td>
<td>1.923</td>
<td>2.404</td>
<td>2.564</td>
</tr>
<tr>
<td>6&quot;</td>
<td>.669</td>
<td>.502</td>
<td>.669</td>
<td>1.338</td>
<td>2.007</td>
<td>2.509</td>
<td>2.676</td>
</tr>
<tr>
<td>6-1/8&quot;</td>
<td>.684</td>
<td>.513</td>
<td>.684</td>
<td>1.368</td>
<td>2.052</td>
<td>2.565</td>
<td>2.736</td>
</tr>
<tr>
<td>6-1/4&quot;</td>
<td>.698</td>
<td>.524</td>
<td>.698</td>
<td>1.396</td>
<td>2.094</td>
<td>2.618</td>
<td>2.792</td>
</tr>
<tr>
<td>6-1/2&quot;</td>
<td>.728</td>
<td>.546</td>
<td>.728</td>
<td>1.456</td>
<td>2.184</td>
<td>2.734</td>
<td>2.912</td>
</tr>
<tr>
<td>6-5/8&quot;</td>
<td>.740</td>
<td>.555</td>
<td>.740</td>
<td>1.480</td>
<td>2.220</td>
<td>2.775</td>
<td>2.960</td>
</tr>
<tr>
<td>6-3/4&quot;</td>
<td>.753</td>
<td>.565</td>
<td>.753</td>
<td>1.506</td>
<td>2.259</td>
<td>2.824</td>
<td>3.012</td>
</tr>
<tr>
<td>7&quot;</td>
<td>.781</td>
<td>.586</td>
<td>.781</td>
<td>1.562</td>
<td>2.343</td>
<td>2.930</td>
<td>3.124</td>
</tr>
<tr>
<td>7-1/4&quot;</td>
<td>.809</td>
<td>.607</td>
<td>.809</td>
<td>1.618</td>
<td>2.427</td>
<td>3.034</td>
<td>3.236</td>
</tr>
<tr>
<td>7-1/2&quot;</td>
<td>.838</td>
<td>.629</td>
<td>.838</td>
<td>1.676</td>
<td>2.514</td>
<td>3.143</td>
<td>3.352</td>
</tr>
<tr>
<td>8&quot;</td>
<td>.894</td>
<td>.671</td>
<td>.894</td>
<td>1.788</td>
<td>2.682</td>
<td>3.353</td>
<td>3.576</td>
</tr>
<tr>
<td>8-1/4&quot;</td>
<td>.929</td>
<td>.697</td>
<td>.929</td>
<td>1.858</td>
<td>2.787</td>
<td>3.484</td>
<td>3.716</td>
</tr>
<tr>
<td>8-1/2&quot;</td>
<td>.964</td>
<td>.723</td>
<td>.964</td>
<td>1.928</td>
<td>2.892</td>
<td>3.615</td>
<td>3.856</td>
</tr>
</tbody>
</table>

NOTE: These figures are theoretical and based on deposition rates for 1/16" (1,6mm) diameter wire and 4/32" (3,17mm) thickness. It is advisable to perform your own tests to determine actual usage rates for your operation.
SECTION 3: SPECIFIC APPLICATION PROCEDURES

SPECIAL NOTATION FOR WELDING PROCEDURES

The following specific welding procedures can be used for developing your own particular written welding procedure. These procedures provide specific vital information for application of all Arnco Hardbanding Wires onto AISI 4137, 4145-HT and 1340 steels. Based on experience, Arnco has learned it is difficult to write a procedure for every conceivable application. We have included only those known and proven applications in this new manual. If you do not find a particular application or a specific requirement for an application, included in this manual, contact your nearest Arnco representative PRIOR TO WELDING. They will assist you in developing one to meet your specific requirement. The procedures on the following pages consist of those specifically for:

AISI 4137 STEEL TOOL JOINTS

- Hardbanding applied onto New or Used tool joints for OD sizes 3-1/8” to 8-1/2” (79.37mm to 215.90mm)

- Hardbanding applied onto Used tool joints and the limitations for application over Other Hardbandings

AISI 4145-HT STEEL AND AISI 1340-HT STEEL

- Hardbanding applied onto New or Used heavy weight drill pipe (Hevi-Wate or Spiral-Wate), drill collars and various other drilling equipment

- Hardbanding applied onto Used heavy weight drill pipe (Hevi-Wate or Spiral-Wate), drill collars and various other drilling equipment and the limitations for application over Other Hardbandings

AISI 4137, AISI 4145-HT STEEL AND AISI 1340-HT STEEL

- Hardbanding Re-Applied onto Used drill pipe tool joints, heavy weight drill pipe (Hevi-Wate or Spiral-Wate), drill collars and various other drilling equipment and the limitations for application over Other Hardbandings
3.1 HARDBANDING APPLIED TO AISI 4137 STEEL TOOL JOINTS

3.1.1 Before hardbanding tool joints of any size O.D., whether new or used, ensure that the necessary equipment and material preparation has been performed as recommended in Section 2 of this manual.

3.1.2 Applicators are strongly advised to use a “test piece” or ‘practice joint” of the same diameter, thickness and steel type to fine tune the welding equipment prior to starting production. Operators can utilize the Hardband Setup Worksheet (Attachment I) included with this manual to document the equipment settings necessary to hardband each size tool joint. The worksheets can then be used for future reference.

3.1.3 When welding new or used AISI 4137 Steel drill pipe tool joints, always utilize Reverse Polarity (DCEP). This will ensure the proper weld fusion, penetration and deposition of the Hardband onto the parent metal.

3.1.4 When welding with 100XT or 300XT, a shielding gas must be supplied to the arc. Arnco has learned from experience that either a Pure 100% Carbon Dioxide or a mixture of Argon and Carbon Dioxide gases can be utilized when welding. These gas mixtures are; a) 82%Ar/18%CO2 or b) 80%Ar/20%CO2 or c) 75%Ar/25%CO2. Other gas mixtures of Argon and CO2 shall not be utilized as they may negatively affect the weld. The regulated flow for all gases must normally be controlled to deliver between 30 to 35 CFH (14-16.5 LPM) to the arc area. During windy conditions, when operating portable hardband units in pipe yards or at rig locations, every precaution shall be taken to protect gas flow at the nozzle, inside the torch cabinet, from being blown away from the arc when welding. The Arnco 200XT wire does not need a shielding gas as the wire is manufactured as a “self-shielded” wire.

3.1.5 For a particular O.D. of tool joint, select the proper Preheat Temperature Range listed below:

<table>
<thead>
<tr>
<th>Tool Joint O.D.</th>
<th>Preheat Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1/8&quot; to 4-3/8&quot;</td>
<td>250°F, +/- 25°F; (~121°C, +/- -4°C)</td>
</tr>
<tr>
<td>4-3/4&quot; to 5-1/4&quot;</td>
<td>350°F, +/- 25°F; (~177°C, +/- -4°C)</td>
</tr>
<tr>
<td>5-1/2&quot; to 6-1/4&quot;</td>
<td>450°F, +/- 25°F; (~232°C, +/- -4°C)</td>
</tr>
<tr>
<td>6-3/8&quot; to 6-5/8&quot;</td>
<td>525°F, +/- 25°F; (~275°C, +/- -4°C)</td>
</tr>
<tr>
<td>6-7/8&quot; to 7-1/4&quot;</td>
<td>575°F, +/- 25°F; (~302°C, +/- -4°C)</td>
</tr>
<tr>
<td>7-7/8&quot; to 8-1/2&quot; (nom.)</td>
<td>625°F, +/- 25°F; (~330°C, +/- -4°C)</td>
</tr>
<tr>
<td>8&quot; to 8-1/2&quot; (w/5&quot;id.)*</td>
<td>575°F, +/- 25°F; (~302°C, +/- -4°C)</td>
</tr>
</tbody>
</table>

(* The wall thickness for this id size is much less than normal tool joints)

It is strongly recommended that preheat temperatures be measured with a digital, electronic pyrometer. The minimum acceptable requirement is the use of two tempstiks; one for each of the minimum and maximum temperatures of the range. The unit operator must ensure that the desired, preheat temperature range is controlled. Experience has taught us that excessive preheat can sometimes distort the weld bead profile and insufficient preheat can negatively affect the metallurgy of the weld as well as the parent metal.

NOTE: Arnco does not recommend the use of tempstiks, as they are not always utilized correctly. However, if tempstiks are used on the prepared hardband surface, the residue left by the tempstik must not be excessive. If the residue is excessive, it must be removed prior to welding. If not, the residue can become an impurity that may affect the fusion bond of the hardbanding to the prepared surface.
3.1.6 The Maximum Interpass Temperature for all hardbanding procedures is 850°F (454°C).

3.1.7 The unit operator should adjust the hardband equipment to attain a flat or slightly convex weld profile as illustrated in Figure 4.3.1, contained in the Post-Weld Material Inspection section of this manual. Each weld bead should overlap the previous weld bead ~1/8" (~3.17mm) and consistently "tie-in" with the edge of the preceding weld bead. In addition, unless specified by the customer, each weld bead should meet the required hardband height (dimension H) as shown in Figures 1.1, 1.2 and 1.3, in Section 1 of this manual.

3.1.8 When welding the 18° elevator shoulder, the unit operator must ensure that the weld bead is consistently tied into the side of the recess groove in the tool joint shoulder. In addition, the weld bead shall not exceed the surface of the adjacent elevator shoulder as explained in paragraph 2.1.6 of this manual.

3.1.9 The Applicator must maintain slow-cooling of the hardbanded tool joints. In order to ensure the required slow cooling, the tool joints need to be wrapped immediately in thermally insulated blankets or canisters. The use of shop ventilation fans shall have the airflow directed away from the hardbanded tool joints during handling, wrapping and slow cool storage. The wrapping and subsequent slow cooling must take place in “still air”. The blankets or canisters shall remain on the tool joint ends until the tool joint has cooled down to less than 150°F (66°C). Any grinding shall be done after the tool joint has cooled down to less than 150°F (66°C).

3.1.10 When the 300XT is applied, “micro cracking” will appear in the layer. When applied properly, this micro cracking has not been found to be detrimental to the integrity of the 300XT. Also, when 200XT is applied, "stress cracking" will appear in the layer. Likewise, when applied properly, this stress cracking has not been found to be detrimental to the integrity of the 200XT.

3.1.11 To maintain the preferred amount of micro cracking, the 300XT can be applied over itself and over 100XT, but not over some other hardbandings, including Arnco 200XT.

3.1.12 Likewise, 200XT should never be applied over 100XT nor 300XT. It can be applied over itself only if the worn layer is in serviceable condition.

3.1.13 Post-Weld Tempering of the 200XT or 300XT on AISI 4137 tool joints is not required but optional.
3.2 HARDBANDING APPLIED TO AISI 4145-HT STEEL OR AISI 1340-HT STEEL

3.2.1 Prior to hardbanding AISI 4145-HT or AISI 1340-HT Steel, whether new or used, ensure that the necessary equipment and material preparation has been performed as recommended in Section 2 of this manual.

3.2.2 As with AISI 4137 Steel, applicators are urged to use a “test piece” or “practice joint” of the same size and steel type to fine tune the welding equipment prior to starting production. In addition, the unit operator should utilize the Hardband Setup Worksheet (Attachment I) to document the equipment settings for future reference.

3.2.3 When welding new or used AISI 4145-HT Steel, always utilize Reverse Polarity (DCEP). This will ensure the proper weld fusion, penetration and deposition of the hardband onto the parent metal.

3.2.4 When welding with 100XT or 300XT, a shielding gas must be supplied to the arc. Arnco has learned from experience that either a Pure 100% Carbon Dioxide or a mixture of Argon and Carbon Dioxide gases can be utilized when welding. These gas mixtures are; a) 82%Ar/18%CO2 or b) 80%Ar/20%CO2 or c) 75%Ar/25%CO2. Other gas mixtures of Argon and CO2 shall not be utilized as they may negatively affect the weld. The regulated flow for all gases must be controlled to deliver 30 to 35 CFH (14-16.5 LPM) to the arc area. During windy conditions, when operating portable hardband units in pipe yards or at rig locations, every precaution shall be taken to protect gas flow at the nozzle, inside the torch cabinet, from being blown away from the arc when welding. The Arnco 200XT wire does not need a shielding gas as the wire is manufactured as a “self-shielded” wire.

3.2.5 For AISI 4145-HT or AISI 1340-HT Steel of a particular O.D., select the proper Preheat Temperature Range listed below:

<table>
<thead>
<tr>
<th>Tool Joint/Center Wear Pad/Drill Collar O.D.</th>
<th>Preheat Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 4-1/2&quot;</td>
<td>300°F, +/- 25°F; (149°C, +/-, -4°C)</td>
</tr>
<tr>
<td>4-3/4&quot; to 5-1/4&quot;</td>
<td>350°F, +/- 25°F; (177°C, +/-, -4°C)</td>
</tr>
<tr>
<td>5-1/2&quot; to 6-1/4&quot;</td>
<td>450°F, +/- 25°F; (232°C, +/-, -4°C)</td>
</tr>
<tr>
<td>6-3/8&quot; to 6-5/8&quot;</td>
<td>550°F, +/- 25°F; (288°C, +/-, -4°C)</td>
</tr>
<tr>
<td>6-7/8&quot; to 7-1/4&quot;</td>
<td>600°F, +/- 25°F; (316°C, +/-, -4°C)</td>
</tr>
<tr>
<td>8&quot; to 8-1/2&quot;(nom.)</td>
<td>650°F, +/- 25°F; (344°C, +/-, -4°C)</td>
</tr>
<tr>
<td>8&quot; to 8-1/2&quot;(w/5&quot;id.)*</td>
<td>600°F, +/- 25°F; (316°C, +/-, -4°C)</td>
</tr>
</tbody>
</table>

* The wall thickness of this size tool joint is much less than normal tool joints

3.2.6 It is strongly recommended that the preheat temperature be measured with a digital, electronic pyrometer. The minimum acceptable requirement is the use of two tempstiks; one for each of the minimum and maximum temperatures of the range. The unit operator must ensure that the desired, preheat temperature range is controlled. Experience has taught us that excessive preheat can sometimes distort the weld bead profile and insufficient preheat can negatively affect the metallurgy of the weld as well as the parent metal.

NOTE: Arnco does not recommend the use of tempstiks, as they are not always utilized correctly. However, if tempstiks are used on the prepared hardband surface, the residue left by the tempstik must not be excessive. If the residue is excessive, it must be removed prior to welding. If not, the residue can become an impurity that may affect the fusion bond of the hardbanding to the prepared surface.
3.2.7 The Maximum Interpass Temperature for all Hardbanding procedures is 850°F (454°C).

3.2.8 The unit operator should adjust the hardband equipment to attain a flat or slightly convex weld profile as illustrated in Figure 4.3.1, contained in the Post-Weld Material Inspection section of this manual. Each weld bead should overlap the previous weld bead ~1/8" (~3.17mm) and consistently “tie-in” with the edge of the preceding weld bead. In addition, unless specified by the Customer, each weld bead should meet the required hardband height (dimension H) as shown in Figures 1.1, 1.2 and 1.3 in Section 1 of this manual.

3.2.9 When welding the 18° elevator shoulder, the unit operator must ensure that the weld bead is consistently tied into the side of the recess groove in the tool joint shoulder. In addition, the weld bead shall not exceed the surface of the adjacent elevator shoulder as explained in paragraph 2.1.6, of this manual.

3.2.10 With AISI 4145-HT Steel, a slow cool-down, after hardbanding is extremely critical. These types of material are used in a transition zone between pieces of drilling equipment that have widely varied wall thickness' and areas of high stress concentration. The result of rapid cool-down is usually catastrophic. For this reason the Applicator must control the cooling rate of the hardbanded tool joints. In order to ensure the required slow cooling, the tool joints need to be wrapped immediately in thermally insulated blankets or canisters. The use of shop ventilation fans shall have the airflow directed away from the hardbanded tool joints during handling, wrapping and slow cool storage. The wrapping and subsequent slow cooling must take place in “still air”. The blankets or canisters shall remain on the tool joint ends until the tool joint has cooled down to less than 150°F (66°C). Any grinding shall be done after the tool joint has cooled down to less than 150°F (66°C).

NOTE: The center wear pad of the heavy weight drill pipe is one of the most critical areas for application of any hardbanding. Great care and special attention must be given to this area to ensure that the welding and post-weld procedures are strictly adhered to. Failure to do so may result in failure of the joint of drill pipe.

3.2.11 When the 300XT is applied, micro cracking will appear in the new layer. When applied properly, this micro cracking has not been found to be detrimental to the integrity of the 300XT. Also, when 200XT is applied, “stress cracking” will appear in the layer. Likewise, when applied properly, this stress cracking has not been found to be detrimental to the integrity of the 200XT.

3.2.12 To maintain the preferred amount of micro cracking, the 300XT can be applied over itself and over 100XT, but not over some other hardbandings, including Amco 200XT.

3.2.13 Likewise, 200XT should never be applied over 100XT nor 300XT. It can be applied over itself only if the layer is in serviceable condition.

3.2.14 Post-Weld Tempering of the hardband area is optional, but not required. If tempering of the hardband area is desired, the following parameters are recommended:

a) Post weld heat treat to 1075°F (580°C), +/- 50°F (10°C) for a maximum of 2 hours.

b) Slow cool down to ambient temperature following PWHT process.
3.3 HARDBAND RE-APPLICATION PROCEDURES

3.3.1 General Information

3.3.1.1 When the hardbanding on used drill pipe has been worn to the point that reapplication is necessary, the existing hardband layer must first be cleaned and inspected. This is necessary to determine if the existing layer is intact and serviceable prior to the application of a new layer hardbanding. Acceptable hardband areas can then have a new layer of hardbanding applied per the specified application procedures for 4137, 4145HT and 1340HT steels as contained within this manual.

3.3.1.2 Arnco has determined, from previous testing and experience, that some Arnco hardband products can be reapplied over the same type of the existing layer of worn hardbanding. Previously that same testing and experience had found that some, but not all, of the other types of hardbanding were found to have limited metallurgical compatibility with Arnco’s products. However, over the past few years, Applicators have had problems with applications when applying one type of hardbanding over another. The only Arnco hardband products that can be reapplied over themselves or other compatible Arnco products are;

- Arnco 100XT over 100XT
- Arnco 200XT over 200XT
- Arnco 300XT over 300XT
- Arnco 300XT over 100XT

Note: Arnco 100XT or 300XT can NOT be applied over Arnco 200XT.

3.3.1.3 The owner of the drill pipe, as well as the applicator, should also note then when different hardbanding wires are applied one over another, the latest application, even if applied correctly, is only as good as the previous applied layer. If the previous layer was not applied per the manufacturer’s procedures (with respect to preheat, application or slow-cooling) spalling of the newly applied layer from the previous layer, as well as spalling at the fusion line from the parent metal, can occur.

3.3.1.4 THEREFORE, ARNCO TECHNOLOGY STRONGLY DOES NOT RECOMMEND THE APPLICATION OF ONE UNLIKE HARDBANDING DIRECTLY OVER ANOTHER. This is due to the fact that, while they may be “metallurgically” compatible, there may be a lack of quality in the previous hardbanding that may cause the two hardbandings to be incompatible and may fail. If there are cracks, porosity or other defects in the original unlike hardbanding, they will most likely propagate up into the new layer being applied. This is not acceptable to customers of Arnco.

3.3.1.5 Owners of drill pipe and Arnco Certified Applicators should consult Arnco before applying any Arnco Hardbanding wire over any other type of hardbanding.

3.3.2 Cleaning of the Existing Hardband Area

3.3.2.1 Cleaning of the hardband area must be performed to remove all drilling mud, dirt, rust, oil, grease, thread compound, paint, etc. Utilizing a side-grinder & cup brush will usually produce a sufficiently clean surface for inspection and welding.

3.3.2.2 Washing of the hardband area with a soap or solvent solution may be necessary to ensure a clean surface, especially when an oil based mud was utilized during drilling operations.
3.3.3 General Inspection of the Existing Hardband Area

3.3.3.1 It is important to remember that hardbanding is a simple process and the inspection of hardbanding is equally simple. This inspection criteria consists of Visual and Dimensional inspection. It is also very easy for an Inspector to be overly critical with acceptance and rejection criteria. Inspectors should have experience in the inspection of hardbanding and should utilize common sense when making judgments regarding this criteria.

3.3.3.2 A hardband is considered acceptable if the general appearance and the dimensional requirements are within the guidelines explained elsewhere in this document or as required by the owner of the drill pipe. Some customers have their own hardband inspection criteria that may exceed the requirements of this manual. In that case, the customer's criteria shall take precedence.

3.3.3.3 If Inspectors or customers have questions regarding the interpretation or intent of this inspection criteria they should contact Arnco immediately.

3.3.3.4 The hardband area shall be visually inspected for existing crack widths, spalling, chipping, flaking and porosity and to identify the existing hardband. In addition, dimensional measurements should be taken and recorded to verify if a new layer of hardbanding is needed to meet the customer’s requirements.

3.3.3.5 As best as possible, the existing hardband needs to be identified to ensure compatibility with the new layer of hardbanding to be applied. **If the existing layer’s identity is unknown or found not to be compatible with the new hardbanding wire, then all the hardbanding must be removed and the hardband area rebuilt before application of the new layer is applied.** Traceability records provided by the owner and/or the applicator can help provide information regarding the previous hardbanding.

3.3.3.6 Magnetic Particle Inspection (MPI-wet or dry) or Liquid-Penetrant Inspection (LPI) of the hardband area is usually performed during the inspection of the pipe ends to check for cracks that may have propagated from the edges of the hardband into the parent metal. Care should be taken when a “dry” MPI is performed so to not “mask” any cracks that may have propagated into the parent metal.

*Cacks in the hardband area not visible to the naked eye, yet seen by MPI or LPI, are not relevant for rejection, unless they extend from the hardband into the parent metal.*
3.3.4 Specific Acceptance and Rejection Criteria for Used/Worn Hardbanding

3.3.4.1 Existing Cracks: Weld bead cracks have become the utmost concern to Customers. If 100XT is applied properly, there should be no cracks visible to the naked eye. However, 200XT and 300XT does normally crack. The 200XT produces “stress cracking” and the 300XT produces “micro cracking”. Each hardbanding has its own acceptance or rejection criteria when concerning the visible cracking.

3.3.4.1.1 Criteria for 100XT Cracks:

A) **If cracks are visible, then the entire hardband area is considered reject.**

B) The hardband area will need to be completely removed and the area rebuilt with a mild steel wire before a new layer of 100XT is applied.

C) **As stated before, cracks in the hardband area not visible to the naked eye, yet seen by MPI or LPI, are not relevant for rejection, unless they extend from the hardband area into the parent metal.**

D) Typical, acceptable, 100XT hardbanding is shown in the photos below;

Acceptable 100XT Hardband-“Non-Mill” Application

Acceptable 100XT Hardband with 18° Taper Weld Bead Applied
3.3.4.1.2 Stress-Crack Criteria for 200XT:

A) *A weld bead with No weld stress cracks is reject.*

B) Cracks that are oriented perpendicular to the weld bead and normally as close as 1/2” or as far as 3” apart are considered acceptable.

C) A circumferential crack, located in the center of a single weld bead, is not desired and is reject. For tool joints smaller than 7” O.D., the crack shall not extend more than 45° around the tool joint’s circumference. For tool joints larger than 7” O.D., the crack shall not extend more than 3” around the tool joint’s circumference. However, if a circumferential crack crosses over to an adjacent weld bead, *at any point prior to 45° or 3” in length*, it is considered acceptable.

D) Oblique cracks occur, and are acceptable, as they may intersect perpendicular or circumferential cracks. Sometimes, they are a continuation of a perpendicular crack.

E) Any crack found that is wider than 1/16” shall be rejected as this may be an indication of rapid-cooling of the hardbanding after application.

F) Typical 200XT acceptable crack patterns are shown in the photos below;
3.3.4.1.3 **Micro-Crack Criteria for 300XT:**

A) Crack widths within the existing 300XT hardband area are acceptable if less than .010" (0.25mm) in width.

B) The number of, and spacing between, cracks can vary from joint to joint. There is no definite crack pattern that can be expected. A crack pattern with numerous cracks shall not be a cause for rejection. Usually the cracks that were visible at the hardband surface, after application, are not always visible after the 300XT has become worn.

C) Cracks can be oriented in any direction; longitudinal, oblique or circumferential. Usually any circumferential cracks that may be seen are less than 2.0" (50mm) in length. However, a single circumferential crack that may or may not be intersected by a longitudinal or oblique crack and centered in the middle of the weld bead shall be rejected; as this indicates rapid-cooling of the hardband when previously applied.

D) Typical acceptable 300XT crack patterns are shown in the photos below. On the following page crack patterns are shown under “black-light” for reference only.

Acceptable Worn 300XT Crack Pattern

Acceptable New 300XT Crack Pattern (also shown under black-light on next page)
Acceptable 300XT Crack Pattern (also shown on previous page)

Acceptable 300XT Crack Pattern

Tool Joints with Acceptable 300XT Crack patterns
3.3.4.2 Heat-Check Cracking

3.3.4.2.1 This type of cracking is not normally seen on existing used hardbanding. Therefore, some Applicators and Inspectors may not be aware of the detrimental effects it can have when attempting to reapply a new layer of hardbanding over the existing layer.

3.3.4.2.2 This type of cracking, commonly known as “Heat-Checking”, is the result of high axial loading during drilling against the hardband area. This causes a high amount of friction and heat on the hardband. When it occurs, the hardband area develops small cracks, usually oriented longitudinal, across the entire hardband surface.

3.3.4.2.3 Heat-Checking must definitely be rejected. The existing layer of hardbanding must be removed and the hardband area rebuilt before a new layer of hardbanding is applied.

3.3.4.2.4 The photo below is a good example of “Heat Checking”. All Inspectors need to become familiar with this type of cracking and not confuse it with acceptable cracking exhibited by the cracking-type hardbandings.
3.3.4.3  **Spalling:** Spalling within the existing hardband area **shall** be rejected. Some examples of spalling are shown in the photographs below. The photo on the right also has porosity which contributed to the spalling in small areas.

![Spalling at Fusion Line](image1) ![Spalling from Porosity](image2)

*Note: Do not confuse spalling with flaking or chipping. Spalling occurs when the hardband layer separates at the fusion line with the parent metal. Flaking or chipping occurs only within the thickness of the hardband layer.*

3.3.4.4  **Chipping or Flaking:** Minor chipping or flaking of the existing Hardband layer is acceptable only if the affected area is less than one square inch (1.0 in² or 25.4mm²) and contained within the thickness of the hard metal layer. Chipped or flaked areas of 100XT or 300XT (but not 200XT) can be ground smooth by hand-grinding to remove any sharp edges. If desired, a patch repair application of the same hardbanding (i.e. 100XT over 100XT or 300XT over 300XT) over the ground area is acceptable if applied per this specified procedures manual. The photograph shown below is an example of reject flaking that has areas that are larger than one square inch.

![Flaking Within the Thickness of a 300XT Hardband Layer](image3)
3.3.4.5 Porosity: The inspection of porosity to determine if acceptable, or reject, must include a decision based on the overall quality and workmanship of the previous application. Therefore, the inspector needs to have some basic knowledge of the hardband application process and what specifically causes porosity during welding.

3.3.4.5.1 There are various interpretations of what is considered to be “excessive” porosity. Further, experience has proven that even when porosity was found “acceptable”, and when a new layer of hardbanding was applied, that more porosity then became visible. That is, it is possible that porosity can be contained within an existing layer and is not all visible at the surface.

3.3.4.5.2 A common rejection criteria of some manufacturers and end-users is if the hole is “greater than 1/8” (3,17mm) in width and 1/16” (1,6mm) in depth”, it is reject. Or, if more than 5 holes are visible within a single 120° view of the hardband area, the hardband is reject. Some end-users have more strict reject/accept criteria established. Applicators should take note of any specific criteria established by their customer.

3.3.4.5.3 In addition, experience has also proven that hardband areas that had excessive porosity do not always cause the hardband to chip, flake or spall. There has been hardbanding found that was inspected in the past that excessive porosity was not detected after application and/or was sometimes ignored during inspection. Such hardbanding remained intact and continued to wear flush to the OD of the tool joint.

3.3.4.5.4 The criteria that follows is Arnco’s interpretation/definition of reject vs. acceptable porosity. In all cases, the root cause of the porosity should be investigated by the Applicator and an attempt be made to eliminate it. **Applicators shall refer to Section 4 of this manual for the accept/reject criteria for porosity as inspected by their QC Inspectors.**

A) Excessive porosity, that is continuous and contained in all of the hardbanding, is usually caused by the total absence or interruption of gas flow at the arc during welding. This type of porosity shall be rejected.

B) Sporadic or intermittent porosity that is “clustered”, and/or appears intermittently in clusters, around the hardband circumference, is usually caused by interrupted or insufficient gas flow during welding. This type of porosity shall be rejected.

C) Porosity that is found to be continuous or in multiple clusters around the circumference of the weld bead, and is shallow in depth with holes less than 1/32” (0,79mm) deep, is also usually caused by interrupted or insufficient gas flow during welding. However, the porosity did not propagate as deep. Trying to repair it by patch welding is virtually impossible. This type of porosity shall be rejected.

D) A single clustered porous area that appears only once or twice within the hardband area may be caused by an interruption of gas flow for a short period of time. If the area is less than one square inch (1.0 in² or 25,4mm²) it should not necessarily be rejected. It has been known to be possible, but not always, to remove a clustered area by hand-grinding and then make a patch repair of over that area.

E) The specific cause of isolated (single-hole) porosity is not definitely known. It may be caused by an instantaneous interruption of gas flow. It may occur at random, sometimes only one to three times or so, within the circumference of a weld bead but is not clustered or continuous. This type of porosity should not necessarily be rejected.
Note: If either single-cluster or isolated porosity is accepted, and as stated previously, if during the reapplication of a new layer of hardbanding, the hardband Operator sees more porosity that has formed at the surface of the new layer, the new hardband layer shall be rejected. The hardband area shall then be removed and the area rebuilt with a mild steel wire before application of a new layer of hardbanding.

3.3.4.5.5 The photographs shown below are some examples of reject excessive, sporadic and isolated porosity found in existing hardbanding layers as well as new applied layers of 300XT.
3.3.4.6 **Blow-holes and Voids:** Sometimes “Blow-Holes” and Voids in the weld bead are sometimes associated with porosity. This is not always the case. Even with sufficient gas flow, blow-holes can be the result of the welding arc being “blown back” when the arc passes over an area that may not have been sufficiently cleaned or may have had a high amount of residual magnetism contained in the tool joint.

3.3.4.6.1 Voids are areas where no welding had occurred, such as at the end of a weld bead tie-in. Both will show an absence of weld metal as parent metal can be easily seen. They are rarely seen on used or worn hardbanding because the hard-metal area surrounding the blow-hole or void has been worn during use. They can be seen after application of the new applied layer.

3.3.4.6.2 Blow-holes and voids are usually confined to one blow-hole or void area and shall be rejected, regardless of size, unless they are repaired with a spot or patch weld while the tool joint remains hot at sufficient temperature. Therefore, the hardband Operator should inspect the entire 360° circumference of the Hardband weld beads for any blow-holes or voids immediately after application while the tool joint is still placed in the chuck assembly and is at sufficient temperature.

3.3.4.6.3 The photographs shown below are some examples of Blow-Holes and Voids found in new applied layers of 300XT. The photo on the left is hardband found reject due to numerous blow-holes. The hardband was removed and the area rebuilt prior to a new layer being applied. The photo on the right was patch welded and made acceptable.
3.3.4.7 **Undercutting:** Undercutting of the weld bead shall be rejected. Depending on the severity, it is possible to repair undercutting by hand-grinding or machining. However, if the undercutting is severe and cannot be repaired, then the hardband needs to be removed and the area rebuilt with a mild steel wire before a new layer of hardbanding is applied. If not repaired, undercutting cause a stress riser area that can possibly fracture the tool joint and/or hardband area while in use down hole. The photo below shows an example of undercutting at the bottom of the 18° taper weld bead. These particular tool joint ends were repaired by machining the taper weld to remove the undercut area.

![Undercutting at Bottom of 18° Taper Weld Bead](image)

3.3.4.8 **Application of 18° Taper Weld Bead onto Taper Shoulder:** When welding is required on the 18° elevator shoulder, the unit operator and inspector must pay close attention to the weld profile of the finished weld bead. If the weld bead height on the 18° elevator shoulder exceeds that of the tool joint shoulder itself, it is necessary to remove that excess height to make it flush with the tool joint shoulder. Any raised weld metal on the 18° elevator shoulder may result in interference with the elevator’s operation. Removing the excess height can be performed by hand-grinding the hardband. The photos below show an acceptable and reject taper weld bead.

![Acceptable “Flush” Taper Weld Bead](image) ![Reject Taper Weld Bead](image)
3.3.4.9  **Application of OD Weld Bead Adjacent to 18° Taper Shoulder:** When welding onto the OD of tool joint ends or onto Center Wear Pads of heavy weight drill pipe, the unit Operator must pay close attention to not apply the hardband too close to the shoulder. The diagram shown in Section 1, Figure 1.2, indicates the hardband should be placed 3/8” from the taper shoulder. If placed too close to the shoulder interference with the elevator bowl will occur when closing the elevator latch so to lift the pipe. The photo below shows a reject OD weld bead that is too close to the shoulder. This can be repaired by hand-grinding the edge of the weld bead so to provide the proper clearance within elevator bowl. When hand-grinding the edge of the weld bead, the overall required hardband width must not be reduced. The unit Operator should align the torch head, when oscillating but before welding, to the proper distance from the edge of the taper shoulder to eliminate this problem.

Interference of OD Weld Bead with Taper Shoulder
3.3.5  Removal and Rebuild of the Hardband Area

3.3.5.1 The following methods shall be utilized when it is found that the existing layer of used hardbanding needs to be removed when found to be reject or not compatible with the new hardbanding to be applied. The Applicator can utilize any removal method listed below. The methods listed are in order from the most to the least preferred by Amco. They are;

A) By machining with a composite or ceramic type of tooling on a conventional lathe or CNC equipment.

B) By grinding with stationary grinding equipment.

C) By plasma-arc gouging equipment.

D) By carbon-arc gouging equipment.

3.3.5.2 The Applicator should consult the manufacturer of the material (if known) for any required dimensions that may be affected during repair. As an example, one most important dimension is the Minimum Hardband Area Diameter after the removal of hardbanding. That is, the wall thickness of the remaining material in the hardband area should be sufficient so that the Heat Affected Zone (HAZ) of the mild steel application does not penetrate to the ID of the area being rebuilt. Experience has taught us that usually the HAZ will penetrate to ~.375” (9.52mm) into the parent metal. A minimum wall thickness of .750” (19mm) is usually required so to allow for the HAZ to be no closer than .375” (9.52mm) to the ID of the material after welding. If a remaining wall thickness of less than .750” (19mm) may be realized, then careful consideration should be made when removing the reject hardbanding and applying the mild steel layer. Specifically, only remove the hardbanding to just below the surface of the parent metal; Do not remove any excess parent metal than is needed.

3.3.5.3 The Applicator must utilize a mild steel wire for rebuild that is compatible with the parent metal steel. Some suggested commonly used wires are Lincoln L-70 or ESAB ER70-S6. The rebuilt surface shall be welded up to the existing tool joint OD and be clean and free of slag.

3.3.5.4 The Applicator shall have a Magnetic Particle or Liquid Penetrant Inspection performed after application of the mild steel wire and weld surface preparation to ensure the layer is free of cracks.

3.3.6  Application of New Hardband Layer

3.3.6.1 Application of the new layer of Hardbanding shall be per the specified procedures contained in this manual for 4137, 4145HT and 1340HT Steels.

3.3.6.2 As stated previously, the Hardband Operator should inspect the entire 360° hardband area immediately after application of the Hardband for blow-holes or voids that can be repair welded while the tool joint is still hot, as well as for any porosity that may be visible.

3.3.7  Final Inspection of the New Hardband Layer

3.3.7.1 Final Inspection of the new applied layer of Hardbanding shall be per the accept/reject criteria stated in Section 4 of this manual.
SECTION 4: INSPECTION CRITERIA FOR APPLICATOR QC / THIRD PARTY INSPECTORS

4.1 Pre-Weld Equipment Inspection

4.1.1 Ensure that the proper wire feed assembly (for soft-skinned cored wire) and torch tip are installed, clean and in proper working order.

4.1.2 Ensure that the hardband wire is properly loaded into the wire feed assembly. In addition, ensure that only an adequate amount of tension is applied to the wire-feed rollers to feed the wire through to the torch assembly.

4.1.3 Ensure that the torch is set at the proper angle and offset to achieve the correct weld bead profile and deposition for the size and type of material being hardbanded.

4.1.4 Ensure that the correct positive polarity (DCEP), voltage, amperage, wire feed, rotation and oscillation parameters are set per the welding procedures. These adjustments are based on the hardbanding equipment and operators’ ability to attain the required weld profile, height, thickness and deposition.

4.1.5 Ensure that the shielding gas is of good quality and, if a mixture, is the correct mixture for use with hardbanding wire. Ensure that the flow of gas can be accurately regulated.

4.2 Pre-weld Material Inspection

4.2.1 Ensure that the material to be hardbanded is clean and free of all foreign matter such as dirt, rust, oil, grease, paint or thread compound.

4.2.2 Ensure that the part (tool joint or drill pipe) is set properly in the hardband machine so that the weld area is as level and concentric as possible to within .030” (0.76mm).

4.2.3 If existing hardbanding has been removed and rebuilt with mild steel wire, ensure that the weld area is free of all slag and debris.

4.2.4 The surface of the area where a “butter pass” of a mild steel wire has been applied shall be free of any cracks. Suggested inspections may include bi-directional wet or dry magnetic particle inspection of that surface area. This eliminates the possibility of welding over pre-existing cracks or defects. Experience has taught us that many times when existing hardbanding, especially tungsten carbide, is removed, it creates heat checking (small surface cracks) in the body of the steel. Heat checking can also be caused by high axial loading against the tool joints during drilling operations and has nothing to do with existing hardbanding. **With either situation, when cracks in the mild steel layer are welded over during the hardband application, it most likely will cause these cracks to propagate into the parent metal.** Therefore, it is very important that a critical tool joint inspection be performed after removal of existing hardbanding and prior to hardbanding or re-hardbanding a tool joint.
4.3 Post-Weld Hardband Inspection

4.3.1 General Information

4.3.1.1 It is important to remember that hardbanding is a simple process and the inspection of hardbanding is equally simple. This inspection criteria consists of Visual and Dimensional inspection. It is also very easy for an Inspector to be overly critical with acceptance and rejection criteria. Inspectors should have experience in the inspection of hardbanding and should utilize common sense when making judgments regarding the criteria.

4.3.1.2 A hardband is considered acceptable if the general appearance and the dimensional requirements are within the guidelines explained elsewhere in this document or as required by the owner of the drill pipe. Some customers have their own hardband inspection criteria that may exceed the requirement of this document. In that case, the customer’s criteria shall take precedence.

4.3.1.3 If Inspectors or customers have questions regarding the interpretation or intent of this inspection criteria, they should contact Arnco immediately.

4.3.2 Visual Inspection of the Hardband Area

4.3.2.1 Workmanship and Cleanliness

4.3.2.1.1 No slag, spatter, high spots at step-over areas or minor protrusions shall remain on weld area. Spatter and minor protrusions are considered reject unless removed by grinding.

4.3.2.1.2 Overlap and step-over areas should be ground to conform to the overall hardband profile and dimensional requirement.

4.3.2.2 Weld Bead Profile

4.3.2.2.1 The weld bead profile shall be flat to only, slightly convex and consistent throughout the entire hardband area.

4.3.2.2.2 If the weld profile is severely “humped” in the middle of the weld bead, the hardband is reject.

4.3.2.2.3 If the weld bead profile is concave and/or insufficient in overall hardband height, the hardband area is reject.

4.3.2.2.4 The unacceptable, acceptable and preferred (flat) weld bead profiles are illustrated below in Figure 4.1.

![Figure 4.1](image-url)

Version 1.0, November 1, 2007 41
4.3.2.3 **Tie-ins**

4.3.2.3.1 Tie-ins with adjacent weld beads should be consistent to prevent deep furrows or voids between weld beads. If separation between weld beads is seen, the hardband is reject. Some customers have their own criteria regarding furrows such that if the width of the furrow exceeds 1/8” in width and 1/16” in depth, it is considered reject.

4.3.2.3.2 For a Flush Application, the “tie-in” with the edges of the parent metal (recessed area) must be consistent throughout the circumference of that hardband area. If the tie-in is not consistent, the hardband area may be a reparable reject.

4.3.2.4 **Voids and” Blow-holes” (the absence of hardband)**

4.3.2.4.1 An area that is void of hardbanding such that the parent metal can be seen is considered a reparable reject.

4.3.2.4.2 A blow-hole that is void of hardbanding such that the parent metal can be seen is considered a reparable reject. If numerous blow-holes are seen, the hardband is reject.

4.3.2.4.3 The photos below are typical examples of a void and blow-hole areas.

| Numerous Blow-Holes-Hardband Rejected | Void Area-Only Acceptable After Repair |
4.3.2.5  **Stress-Crack Accept/Reject Criteria for 200XT:**

4.3.2.5.1 *A weld bead with No weld stress cracks is reject.*

4.3.2.5.2 Cracks that are oriented perpendicular to the weld bead and normally as close as 1/2" or as far as 3" apart are considered acceptable.

4.3.2.5.3 A circumferential crack, located in the center of a single weld bead, is not desired and is reject. For tool joints smaller than 7" O.D., the crack shall not extend more than 45° around the tool joint’s circumference. For tool joints larger than 7” O.D., the crack shall not extend more than 3” around the tool joint’s circumference. However, if a circumferential crack crosses over to an adjacent weld bead, *at any point prior to 45° or 3” in length*, it is considered acceptable.

4.3.2.5.4 Oblique cracks occur, and are acceptable, as they may intersect perpendicular or circumferential cracks. Sometimes, they are a continuation of a perpendicular crack.

4.3.2.5.5 Any crack found that is wider than 1/16“ shall be rejected as this may be an indication of rapid-cooling of the hardbanding after application.

4.3.2.5.6 Typical 200XT acceptable crack patterns are shown in the photos below;

![Existing Worn 200XT Layer](image1)

![New 200XT Layer Applied Over Worn Layer](image2)

![New 200XT Layer with 18° Taper Weld Bead Applied](image3)
4.3.2.6 Micro Crack Criteria for 300XT

4.3.2.6.1 CRACKING IS DEFINED AS “VISIBLE TO THE NAKED EYE” ONLY. ANY CRACKS DETECTED BY MAGNETIC PARTICLE OR LIQUID PENETRANT INSPECTION, AND/OR NOT VISIBLE TO THE NAKED EYE, ARE NOT RELEVANT OR REJECTABLE UNLESS THEY EXTEND INTO THE PARENT METAL.

4.3.2.6.2 Once 300XT hardbanding is applied, “micro-cracking” of the hardband area will occur. The following criteria applies to this type of cracking.

4.3.2.6.3 The micro-cracks may be oriented longitudinal, oblique and circumferential to the tool joint axis.

4.3.2.6.4 The spacing between the cracks can vary at intervals around the circumference.

4.3.2.6.5 A visible, single circumferential crack, not intersected by a longitudinal or oblique crack and centered in the middle of the weld bead is reject.

4.3.2.6.6 Cracks, regardless of orientation, shall not be wider than .010” (0,25mm).

4.3.2.6.7 A typical acceptable, new and used 300XT crack patterns are shown in the photographs below.

![New Layer of 300XT](image1)

![Used Layer of Worn 300XT](image2)
4.3.2.7 Crack Criteria for 100XT

4.3.2.7.1 If cracks are visible to the naked eye, then the entire hardband area is reject.

4.3.2.7.2 As stated before, cracks in the hardband area not visible to the naked eye, yet seen by MPI or LPI, are not relevant for rejection, unless they extend from the hardband area into the parent metal.

4.3.2.7.3 Typical, acceptable, 100XT hardbanding is shown in the photos below;

Acceptable 100XT Hardband—“Non-Mill” Application

Acceptable 100XT Hardband with 18° Taper Weld Bead Applied
4.3.2.8 Heat Check Cracking

4.3.2.8.1 This type of cracking is not normally seen on existing used hardbanding. Therefore, some Applicators and Inspectors may not be aware of the detrimental effects it can have when attempting to reapply a new layer of hardbanding over the existing layer.

4.3.2.8.2 This type of cracking, commonly known as “Heat-Checking”, is the result of high axial loading during drilling against the hardband area. This causes a high amount of friction and heat on the hardband. When it occurs, the hardband area develops small longitudinal cracks across the entire hardband surface.

4.3.2.8.3 Heat-Checking must definitely be rejected. The existing layer of hardbanding must be removed and the hardband area rebuilt before a new layer of hardbanding is applied.

4.3.2.8.4 The photo below is a good example of “Heat Checking”. All Inspectors need to become familiar with this type of cracking and not confuse it with acceptable cracking exhibited by the cracking-type hardbandings.
4.3.2.9 **Porosity**

4.3.2.9.1 The inspection of porosity to determine if acceptable, or reject, must include a decision based on the overall quality and workmanship of the hardband area. The formation of porosity can be a cluster (concentration) of holes, a “run” of continuous holes, an isolated hole or a “pin” hole.

4.3.2.9.2 Two clusters (or concentration) of porosity that are no more than 1” (25.4mm) in length, as measured in a circumferential direction, for either 3/4” (19mm) or 1” (25.4mm) wide weld beads, in the total hardband area are allowed. However, any hole within the cluster, larger than 1/8” (3.2mm) in diameter and 3/32” (2.4mm) in depth must be repaired to be acceptable.

4.3.2.9.3 In addition to the two allowed clusters, a maximum of five (5) holes that are visible within a single 120° view of the hardband area, are also allowed. Again, any hole in the view larger than 1/8” (3.2mm) in diameter and 3/32” (2.4mm) in depth must be repaired to be acceptable.

4.3.2.9.4 For the total hardband surface, porosity holes that are less than 1/16” (1.6mm) in diameter are not relevant and should be neglected.

4.3.2.9.5 The photographs shown below are some examples of reject clustered, continuous and pin-hole porosity found in existing hardband layers as well as new applied layers of 300XT™.
4.3.2.10 **Spalling**

4.3.2.10.1 Spalling occurs when the hardband layer separates at the fusion line with the parent metal.

4.3.2.10.2 **Spalling of the weld bead or hardband area is reject.** Some examples of spalling are shown in the photographs below. The photo on the right also has porosity which contributed to the spalling in small areas.

![Spalling At Fusion Line](image1)

![Spalling From Porosity](image2)

4.3.2.11 **Chipping or Flaking**

4.3.2.11.1 Chipping or Flaking occurs only within the thickness of the hardband layer. It is not to be confused with spalling. Chipped or flaked areas usually will not be of minimum required thickness, therefore must be repaired to be acceptable.

4.3.2.11.2 Minor chipping or flaking of the existing Hardband layer is acceptable only if the affected area is less than one square inch (1.0 in² or 25.4mm²) and contained within the thickness of the hard metal layer. For areas larger than one square inch (1.0 in² or 25.4mm²), the chipped or flaked areas of 100XT or 300XT (but not 200XT) are considered reparable reject.

4.3.2.11.3 The reparable area can be ground smooth by hand-grinding to remove any sharp edges and if desired, a patch repair application of the same hardbanding (i.e. 100XT over 100XT or 300XT over 300XT) can be made over the ground area. The repaired area shall be re-inspected after hand-grinding to make sure the area is concentric with the existing hardbanding.

4.3.2.11.4 The photograph shown below is an example of reject flaking that has areas that are larger than one square inch.

![Flaking Within the Thickness of a 300XT Hardband Layer](image3)
4.3.2.12 **Undercutting:** Undercutting of the weld bead shall be rejected. If not repaired, undercutting can cause a stress riser area that can possibly fracture the tool joint and/or hardband area while in use down hole. The photo below shows an example of undercutting at the bottom of the 18° taper weld bead.

![Undercutting at Bottom of 18° Taper Weld Bead](image)

4.3.2.13 **Application of 18° Taper Weld Bead onto Taper Shoulder:**

4.3.2.13.1 When welding is required on the 18° elevator shoulder, the Inspector must pay close attention to the weld profile of the finished taper weld bead. If the weld bead height on the 18° elevator shoulder exceeds that of the tool joint shoulder itself, it is necessary to remove that excess height to make it flush with the tool joint shoulder.

4.3.2.13.2 Any raised weld metal on the 18° elevator shoulder may result in interference with the elevator’s operation. Removing the excess height can be performed by hand-grinding the hardband. The photos below show an acceptable and reject taper weld bead.

![Acceptable “Flush” Taper Weld Bead](image) ![Reject Taper Weld Bead](image)
4.3.2.14 Application of OD Weld Bead Adjacent to 18° Taper Shoulder:

4.3.2.14.1 When hardbanding is applied to the OD of tool joint ends or onto Center Wear Pads of heavy weight drill pipe, the Inspector must pay close attention to the height of the hardband and distance the hardband is to the taper shoulder. The diagram shown in Section 1, Figure 1.2, indicates the hardband should be placed 3/8” from the taper shoulder. If placed too close to the shoulder interference with the elevator bowl will occur when closing the elevator latch so to lift the pipe.

4.3.2.14.2 The photo below shows a reject OD weld bead that is too close to the shoulder. This is considered a reparable reject only after hand-grinding the edge of the weld bead so to provide the proper clearance within elevator bowl.

4.3.2.14.3 After hand-grinding the edge of the weld bead, the area shall be re-inspected to ensure proper clearance will be attained, and, that the overall required hardband width has not been reduced. If the overall hardband width has been reduced, the Customer or Arnco will have the final decision whether or not to accept the hardband.

4.3.3 Dimensional Inspection of the Hardband Area

4.3.3.1 For either Raised or Flush applications, the dimensions of the hardbanded area and the thickness (height) of the hardband layer shall conform to the diagrams illustrated in Section I of this Specified Procedures Manual or to Customer requirements.

4.3.3.2 The Inspector shall check flatness of the weld bead profiles across the entire hardband area for high and low areas in weld beads. Excessive high areas, such as at the weld bead tie-ins, shall be repaired by hand-grinding because those areas exceed the tolerance for the maximum specified height of the hardband area. Likewise, excessive low areas may be cause for repair or rejection if they exceed the tolerance for the specified minimum height or thickness of the hardband layer.
CLOSING REMARKS

As before, we urge all users of this manual to read and become very familiar with the specified parameters and procedures. If a customer or an applicator chooses to create his own hardbanding procedures manual, it is strongly recommended that you keep all procedures within the parameters set forth by Arnco Technology in this manual. If you stay within these recommended parameters, you can be assured of a quality hardband application. To *not* do so may cause you to have an unacceptable Arnco Technology hardband product.

We express our special thanks to all our end users, applicators and inspectors for their cooperation and input into the creation of this revised specification.

In closing, we at Arnco Technology assure you all Arnco Technology hardbanding products can be extremely effective in reducing casing wear and tool joint wear if applied properly and used to its optimum potential. While we recognize the fact that they are somewhat different to apply than other hardbandings, they are no more difficult to apply *if* these procedures are strictly followed. *It is usually when applicators operate outside the Arnco specifications that they experience difficulties.*

If a situation arises where any Arnco Technology hardbanding product must be applied outside the Arnco specified parameters, **CALL US FIRST!**

**Thank you!**

ARNCO TECHNOLOGY TRUST, LTD.
3657 Briarpark Drive, Houston, Texas 77042-5205, USA
Telephone: (01) 832-214-5200 Fax: (01) 832-214-5205
E-Mail: Arnco@arncotech.com **Website:** www.arncotech.com
## HARDBAND EQUIPMENT SET-UP WORKSHEET

<table>
<thead>
<tr>
<th>UNIT #</th>
<th>LOCATION</th>
<th>DATE</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>TOOL JOINT O.D.</th>
<th>TYPE OF WIRE</th>
<th>SIZE</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>TYPE OF STEEL:</th>
<th>AISI 4137</th>
<th>AISI 4145HT</th>
<th>AISI 1340HT</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>APPLICATION TYPE:</th>
<th>RAISED</th>
<th>FLUSH</th>
<th>HARDBAND HEIGHT</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>PROCESS:</th>
<th>FCAW</th>
<th>GMAW</th>
<th>Type FLUX</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>CURRENT POLARITY:</th>
<th>DCEN (Straight)</th>
<th>DCEP (Reverse)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>AMPERAGE</th>
<th>VOLTS</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>SHIELDING GAS:</th>
<th>Mixture</th>
<th>Flow Rate</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>TORCH SETTINGS:</th>
<th>Angle</th>
<th>Offset from TDC</th>
<th>Distance from Part</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>OSCILLATION:</th>
<th>Width</th>
<th>Speed</th>
<th>Dwell</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>ROTATION SPEED:</th>
<th>Minutes / Seconds per Revolution</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>PREHEAT TEMPERATURE RANGE</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>INTERPASS TEMPERATURE:</th>
<th>Maximum allowed</th>
<th>Actual</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>SPECIFIED COOL-DOWN PROCESS:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>NOTES:</th>
</tr>
</thead>
</table>

---

*Attachment 1*
# TEMPERATURE CONVERSION CHART

(A) To use, locate “given temperature” in “given temperature” column (coloured GREY) whether \( ^\circ \text{C} \) or \( ^\circ \text{F} \).

(B) If “given temperature” is in degrees Celsius (\(^\circ \text{C}\)), read degrees Fahrenheit (\(^\circ \text{F}\)) in right hand column.

(C) If “given temperature” is in degrees Fahrenheit (\(^\circ \text{F}\)), read degrees Celsius (\(^\circ \text{C}\)) in left hand column.

(D) **Example:**

(i) Given temperature is \(35^\circ \text{C} = 95^\circ \text{F} \) from right hand column.

(ii) Given temperature is \(35^\circ \text{F} = 1.7^\circ \text{C} \) from left hand column.

<table>
<thead>
<tr>
<th>( ^\circ \text{C} )</th>
<th>( ^\circ \text{F} )</th>
<th>( ^\circ \text{C} )</th>
<th>( ^\circ \text{F} )</th>
<th>( ^\circ \text{C} )</th>
<th>( ^\circ \text{F} )</th>
<th>( ^\circ \text{C} )</th>
<th>( ^\circ \text{F} )</th>
<th>( ^\circ \text{C} )</th>
<th>( ^\circ \text{F} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-320 to -27</td>
<td>28 to 77</td>
<td>78 to 235</td>
<td>240 to 485</td>
<td>490 to 2400</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(-196)</td>
<td>(-32^\circ \text{C})</td>
<td>2.2</td>
<td>78.2</td>
<td>25.6</td>
<td>78.2</td>
<td>172.4</td>
<td>116</td>
<td>240</td>
<td>464</td>
</tr>
<tr>
<td>(-184)</td>
<td>(-40^\circ \text{C})</td>
<td>1.7</td>
<td>82.4</td>
<td>25.6</td>
<td>79.7</td>
<td>174.2</td>
<td>118</td>
<td>245</td>
<td>473</td>
</tr>
<tr>
<td>(-172)</td>
<td>(-50^\circ \text{C})</td>
<td>1.1</td>
<td>86.6</td>
<td>26.7</td>
<td>80.0</td>
<td>176.0</td>
<td>121</td>
<td>250</td>
<td>482</td>
</tr>
<tr>
<td>(-160)</td>
<td>(-60^\circ \text{C})</td>
<td>0.6</td>
<td>90.8</td>
<td>27.2</td>
<td>81.7</td>
<td>178.8</td>
<td>124</td>
<td>255</td>
<td>491</td>
</tr>
<tr>
<td>(-148)</td>
<td>(-70^\circ \text{C})</td>
<td>0.0</td>
<td>95.0</td>
<td>27.8</td>
<td>82.4</td>
<td>180.6</td>
<td>127</td>
<td>260</td>
<td>500</td>
</tr>
<tr>
<td>(-136)</td>
<td>(-80^\circ \text{C})</td>
<td>0.6</td>
<td>100.0</td>
<td>28.9</td>
<td>84.2</td>
<td>182.6</td>
<td>130</td>
<td>265</td>
<td>509</td>
</tr>
<tr>
<td>(-124)</td>
<td>(-90^\circ \text{C})</td>
<td>1.1</td>
<td>108.3</td>
<td>31.2</td>
<td>89.0</td>
<td>189.6</td>
<td>137</td>
<td>272</td>
<td>518</td>
</tr>
<tr>
<td>(-112)</td>
<td>(-100^\circ \text{C})</td>
<td>1.7</td>
<td>114.0</td>
<td>34.2</td>
<td>93.0</td>
<td>194.0</td>
<td>143</td>
<td>279</td>
<td>527</td>
</tr>
<tr>
<td>(-100)</td>
<td>(-110^\circ \text{C})</td>
<td>2.2</td>
<td>126.6</td>
<td>39.0</td>
<td>100.0</td>
<td>201.0</td>
<td>150</td>
<td>286</td>
<td>536</td>
</tr>
<tr>
<td>(-90)</td>
<td>(-120^\circ \text{C})</td>
<td>2.7</td>
<td>139.6</td>
<td>44.0</td>
<td>106.0</td>
<td>208.0</td>
<td>157</td>
<td>293</td>
<td>545</td>
</tr>
<tr>
<td>(-80)</td>
<td>(-130^\circ \text{C})</td>
<td>3.3</td>
<td>153.6</td>
<td>50.0</td>
<td>112.0</td>
<td>215.0</td>
<td>164</td>
<td>300</td>
<td>554</td>
</tr>
<tr>
<td>(-70)</td>
<td>(-140^\circ \text{C})</td>
<td>4.0</td>
<td>169.6</td>
<td>57.0</td>
<td>120.0</td>
<td>222.0</td>
<td>171</td>
<td>307</td>
<td>563</td>
</tr>
<tr>
<td>(-60)</td>
<td>(-150^\circ \text{C})</td>
<td>4.7</td>
<td>187.2</td>
<td>65.0</td>
<td>128.0</td>
<td>229.0</td>
<td>178</td>
<td>314</td>
<td>572</td>
</tr>
<tr>
<td>(-50)</td>
<td>(-160^\circ \text{C})</td>
<td>5.5</td>
<td>207.2</td>
<td>74.0</td>
<td>136.0</td>
<td>236.0</td>
<td>186</td>
<td>321</td>
<td>581</td>
</tr>
<tr>
<td>(-40)</td>
<td>(-170^\circ \text{C})</td>
<td>6.4</td>
<td>229.0</td>
<td>84.0</td>
<td>144.0</td>
<td>243.0</td>
<td>194</td>
<td>328</td>
<td>590</td>
</tr>
<tr>
<td>(-30)</td>
<td>(-180^\circ \text{C})</td>
<td>7.4</td>
<td>253.0</td>
<td>95.0</td>
<td>152.0</td>
<td>250.0</td>
<td>202</td>
<td>335</td>
<td>600</td>
</tr>
<tr>
<td>(-20)</td>
<td>(-190^\circ \text{C})</td>
<td>8.5</td>
<td>280.0</td>
<td>107.0</td>
<td>160.0</td>
<td>257.0</td>
<td>210</td>
<td>342</td>
<td>609</td>
</tr>
<tr>
<td>(-10)</td>
<td>(-200^\circ \text{C})</td>
<td>9.8</td>
<td>310.0</td>
<td>120.0</td>
<td>168.0</td>
<td>264.0</td>
<td>218</td>
<td>350</td>
<td>618</td>
</tr>
<tr>
<td>(0)</td>
<td>(-210^\circ \text{C})</td>
<td>11.2</td>
<td>344.0</td>
<td>135.0</td>
<td>176.0</td>
<td>271.0</td>
<td>226</td>
<td>358</td>
<td>627</td>
</tr>
<tr>
<td>(10)</td>
<td>(-220^\circ \text{C})</td>
<td>12.9</td>
<td>381.0</td>
<td>152.0</td>
<td>184.0</td>
<td>278.0</td>
<td>234</td>
<td>366</td>
<td>636</td>
</tr>
<tr>
<td>(20)</td>
<td>(-230^\circ \text{C})</td>
<td>15.0</td>
<td>422.0</td>
<td>171.0</td>
<td>192.0</td>
<td>285.0</td>
<td>242</td>
<td>374</td>
<td>645</td>
</tr>
<tr>
<td>(30)</td>
<td>(-240^\circ \text{C})</td>
<td>17.4</td>
<td>467.0</td>
<td>192.0</td>
<td>200.0</td>
<td>292.0</td>
<td>250</td>
<td>382</td>
<td>654</td>
</tr>
<tr>
<td>(40)</td>
<td>(-250^\circ \text{C})</td>
<td>20.2</td>
<td>516.0</td>
<td>215.0</td>
<td>208.0</td>
<td>299.0</td>
<td>258</td>
<td>390</td>
<td>663</td>
</tr>
<tr>
<td>(50)</td>
<td>(-260^\circ \text{C})</td>
<td>23.5</td>
<td>570.0</td>
<td>240.0</td>
<td>216.0</td>
<td>306.0</td>
<td>266</td>
<td>398</td>
<td>672</td>
</tr>
<tr>
<td>(60)</td>
<td>(-270^\circ \text{C})</td>
<td>27.3</td>
<td>630.0</td>
<td>267.0</td>
<td>224.0</td>
<td>313.0</td>
<td>274</td>
<td>406</td>
<td>681</td>
</tr>
<tr>
<td>(70)</td>
<td>(-280^\circ \text{C})</td>
<td>31.7</td>
<td>696.0</td>
<td>296.0</td>
<td>232.0</td>
<td>320.0</td>
<td>282</td>
<td>414</td>
<td>690</td>
</tr>
<tr>
<td>(80)</td>
<td>(-290^\circ \text{C})</td>
<td>36.7</td>
<td>771.0</td>
<td>327.0</td>
<td>240.0</td>
<td>327.0</td>
<td>290</td>
<td>422</td>
<td>700</td>
</tr>
</tbody>
</table>

**CONVERSION FACTORS**

**DEGREES FAHRENHEIT TO CELSIUS**

\[ \left( ^\circ \text{F} - 32 \right) \times \frac{5}{9} = ^\circ \text{C} \]

**DEGREES CELSIUS TO FAHRENHEIT**

\[ ^\circ \text{C} \times \frac{9}{5} + 32 = ^\circ \text{F} \]

**ATTACHMENT 2**

Version 1.0, November 1, 2007

53