ELECTRIC POWER RESEARCH INSTITUTE

Guidelines and Specifications for High-Reliability Fossil Power Plants: Best Practice Guideline for Welding Root Without Purge Gas Using the Gas Metal Arc Welding Process

2019 TECHNICAL REPORT

Guidelines and Specifications for High-Reliability Fossil Power Plants: Best Practice Guideline for Welding Root Without Purge Gas Using the Gas Metal Arc Welding Process

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Euroweld

NOTE

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ABSTRACT

For nearly two decades, purgeless root pass welding of creep-strength-enhanced ferritic (CSEF) steels has been used in the fabrication of large-diameter piping systems in supercritical, pulverized coal power plants and heat recovery steam generators (HRSGs). The processes for making purgeless root pass welds have included the following:

- Waveform-controlled gas metal arc welding short-circuit (GMAW-S)
- Open-root shielded metal arc welding (SMAW)
- High-deposition metal transfer, semiautomatic hot-wire gas tungsten arc welding (GTAW)

The waveform-controlled GMAW-S process has been the predominant method. Industry experience has shown clear instances of successful adoption of purgeless root pass welding using GMAW-S, as well as some outcomes that were regarded as either marginal or complete failures. Successful outcomes require the adoption of comprehensive programs that embrace the nuances of the welding processes and procedures. This report identifies best practices and realistic expectations for using waveform-controlled GMAW-S for purgeless root pass welding. The emphasis is on American Society of Mechanical Engineers (ASME) P-No. 15E (9Cr-1Mo-V) steels, which constitute a considerable fraction of the state-of-the-art, large-diameter, high-temperature piping systems in supercritical power plants and HRSGs. However, the general recommendations can be extended to other materials.

Keywords

Creep-strength-enhanced ferritic (CSEF) steels
Grade 91 steel
Grade 92 steel
P-No. 15E steel
Purgeless root pass welding
Waveform-controlled gas metal arc welding short-circuit (GMAW-S)

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PRIMARY AUDIENCE: Corporate engineers responsible for asset management

SECONDARY AUDIENCE: Designers and maintenance planners

KEY RESEARCH QUESTION

A *purgeless root pass welding technique* is defined as any welding process that avoids having to fill the inside diameter of a pressure vessel or piping system with an inert gas, such as argon. Purgeless root pass welding for creep-strength-enhanced ferritic (CSEF) steels in the fabrication of large-diameter piping systems in supercritical, pulverized coal power plants and heat recovery steam generators has been used for nearly two decades. Reported approaches for making purgeless root passes have included waveform-controlled gas metal arc welding short-circuit (GMAW-S); open-root shielded metal arc welding (SMAW); and high-deposition metal transfer, semiautomatic hot-wire gas tungsten arc welding (GTAW). The most commonly used method is the GMAW-S process, which has been specified and implemented in dozens of new build power plant piping systems. However, significant variability has been reported, and there exists a general lack of appreciation regarding the complexity of the process and the need for a thorough welding program to implement and maintain the engineering and welding expertise associated with the approach.

RESEARCH OVERVIEW

This report identifies best practices and realistic expectations for using waveform-controlled GMAW-S for purgeless root pass welding. The emphasis is on American Society of Mechanical Engineers P-No. 15E steels, including Grade 91 and Grade 92 (Code Case 2179). These materials constitute a majority of the recent applications of the GMAW-S welding process for the root pass in state-of-the-art, large-diameter, high-temperature piping systems. Generally, the recommendations can and should be extended to other materials (such as mild steel, low-alloy steel, or stainless steel piping systems), although details in the document may require specific consideration of the material composition and weldability.

KEY FINDINGS

Waveform-controlled GMAW welding, including the purgeless root pass process, is a proven method that can provide considerable benefit to the cost and schedule while maintaining strict quality standards. This is by no means a new welding process; however, it is an approach that is generally underutilized due to the complexity of the technology and historic variability in the power generation industry. Potential implementation of the technology must embrace a welding program that, at a minimum, addresses the following:

- Roles and responsibilities of all personnel
- Definition of welding variables and development of welding procedure specifications (WPSs)
- Importance of following the WPS
- Details and variables that are not required by Code but are critical and provided in specific technique sheets or incorporated into the WPS

- Groove geometry, fit-up, and cleanliness criteria
- Equipment operation and maintenance
- Filler metal procurement
- Training and supervision

Economic benefit or schedule enhancement will ultimately depend on how well the welding program is managed and maintained. Organizations new to the process with programs in their infancy will have growing pains. Lessons will be learned and some modifications must be made to suit the individual users. Beyond these initial hurdles lies the potential for schedule and monetary success, provided managers are willing to maintain the welding program.

WHY THIS MATTERS

The waveform-controlled GMAW-S process has been the predominant purgeless root welding method adopted in the power generation industry for welding large-bore piping systems. Although industry experience has shown clear instances of successful implementation, countless outcomes are regarded as either marginal or complete failures. Successful outcomes require the adoption of a comprehensive welding and training program that embraces the nuances of the welding processes and procedures.

HOW TO APPLY RESULTS

This report should be used to help responsible staff make critical decisions regarding the acceptance of the GMAW-S process for purgeless root pass welding of large-bore piping systems; it also provides a framework for training. Appendices provide guidance for filler metal procurement, writing WPSs, target welding parameters, and exemplar welding procedure qualifications. The results provided in this report are presented on a practical level with clear guidance to not only inform stakeholders in the fabrication and construction process but also minimize the risk to future issues that can arise when using a sophisticated welding process.

LEARNING AND ENGAGEMENT OPPORTUNITIES

A wide range of opportunities exist to discuss issues or concerns associated with advanced waveform-controlled GMAW processes. Typically, these discussions include engagement with the appropriate stakeholders in the electricity supply industry through the CSEF steel Interest Group meetings, expert workshops and conferences, and the Program 87 Technology Transfer Week. Details of these opportunities are available through www.epri.com.

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PROGRAM: Materials and Repair, P87

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BACKGROUND ON THE APPLICATION OF "PURGELESS" ROOT PASS WELDING

Use of purgeless root pass welding[1] for creep strength enhanced ferritic (CSEF) steels in the fabrication of large diameter piping systems in supercritical, pulverized coal power plants and heat recovery steam generators (HRSGs) has been utilized for nearly two decades. Reported approaches for making purgeless root passes have included:

- Waveform controlled gas metal arc welding short-circuit (GMAW-S) process[1]
- The use of an open-root shielded metal arc welding (SMAW) procedure and
- More recently the high deposition metal transfer (HDMT®), semiautomatic hot-wire gas tungsten arc welding (GTAW), such as by the TIPTIG® without backing gas.

The application of purgeless root pass welding has been largely dominated by the waveform controlled GMAW-S process. A brief summary of the application of purgeless welding of piping systems (and without specific reference to CSEF steels) is summarized here [1]:

- The first application of waveform controlled GMAW-S procedure on a commercial scale occurred in the year 2000 in a large Canadian oil project. Procedures, including procedure qualification records (PQRs) and welding procedure specifications (WPSs) were developed for carbon steel (P-No. 1), 5Cr-0.5Mo (P-No. 5) and austenitic stainless steel (P-No. 8). This effort required onsite training of 40 welders who performed ~3,000 total welds to the following requirements:
  - 1,800 carbon steel welds to ASME B31.3
  - 170 carbon steel welds to ASME B31.1
  - 400 5Cr-0.5Mo welds to ASME B31.3
  - 850 austenitic stainless steel welds to ASME B31.3

  Overall, the rejection rate for this project was 1.9%. Although not utilized in the process of fabricating the piping systems, additional PQRs and WPSs were qualified for 9Cr-1Mo (P-No. 5B) and 9Cr-1Mo-V (P-No. P15E).

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[1] In this report, the phrase 'purgeless welding method' refers specifically to a gas metal arc welding (GMAW) procedure which utilizes a waveform controlled short-circuit transfer mode to transfer material across the arc. These methods are referred to commercially by Lincoln Electric as 'STT®' (Surface Tension Transfer) or Miller Electric as 'RMD™' (Regulated Metal Deposition) or Fronius as 'CMT' (Cold Metal Transfer). *STT, STT II, Power Wave and Power Wave STT* are trademarks of the Lincoln Electric Company. *Field Pro, Pipe Pro, Pipe Worx, RFC and RMD* are trademarks of Miller Electric Company.

- A second Canadian project in the oil sands in the same timeframe referenced above required the welding of 1,000 austenitic stainless steel welds to ASME B31.3. A 3-day training program for onsite welder training was developed as part of the effort. As before, additional PQRs and WPSs had been qualified but were not implemented; the qualified materials included carbon steel (P-No. 1) and 5Cr-0.5Mo (P-No. 5). The rejection rate for this project was <1%. This case study provided the basis for a *Welding Journal* article published in December 2002 [2].
- Early adoption of the waveform controlled GMAW-S process occurred in the power generation industry in the early 2000s. In one of the first case studies in 2003, a total of 63 welds were made in Grade 91 steel (P-No. 15E) with a 0% rejection rate. The welds included a range in outside diameters of 14 to 24 inches (356 to 610 mm) and wall thicknesses of 0.969 to 1.781 inches (24.6 to 45.2 mm). The PQR and WPS specified an ER90S-B9 filler wire with increased Si (0.34 wt. %), a preheat temperature of 430°F (220°C) and a shielding gas mixture of 86%He-14%CO_2 at a flow rate of 45 cfh. The basis for the development of the welding procedure and subsequent implementation are detailed in [3].
- Open root weld passes have been performed using the SMAW process [4]. In the documented case study from 2003, a consumable marketed by then Bohler Thyssen with the trade name "Chromo T 91" and conforming to the AWS specification E9018-B9-H4 was utilized for the root pass. All fill passes were deposited with an E9015-B9 electrode. Deposition of the root pass included a vertical-uphill progression using direct current and straight polarity. Direct current and reverse polarity were utilized for the balance of the fill passes. A total of 28 welds were made in 18 inch (457 mm) OD X 1.781 inch (45.2 mm) WT piping to ASME B31.1. One rejection, incomplete penetration at closure tie-in, was documented. The total documented cost savings in this project was reported to be $56,560 with the largest savings associated with elimination of man hours. For a conventional fabrication using the GTAW process, these man hours would be needed to install purge dams, clean surfaces and waiting for the oxygen to be reduced to an acceptable level to initiate welding.
- A large refinery project in the UK in 2006 qualified the waveform controlled GMAW-S process for carbon steel (P-No. 1), 5Cr-0.5Mo (P-No. 5) and austenitic stainless steel (P-No. 8) welds. A total of 83 welds were made; direct testimony from the lead site welding engineer stated that the 83 welds were produced at an average rate that was 3X faster than conventional approaches.

Although the listed projects above provide clear examples where adoption of a purgeless root pass approach can be regarded as successful, it is important to emphasize that the adoption of the waveform controlled GMAW-S process (due to its widespread implementation) has experienced an equal or greater number of instances where the outcome was marginal or regarded as a complete failure [5]. Success can only be achieved where a comprehensive program, which embraces the nuances of the welding process and procedure, is implemented.

The purpose of this report is to identify the best practices and realistic expectations when implementing a waveform controlled GMAW-S approach for making purgeless root passes in P-No. 15E material. Although the emphasis of this document is for P-No. 15E steels, which constitute a considerable fraction of the state-of-the-art large diameter, high temperature piping systems in the power generation industry supercritical power plants and HRSGs, the general recommendations provided in this document can be extended to other materials. The important components of such a welding program will be identified and detailed.

2
BACKGROUND SUPPORTING "PURGELESS" ROOT PASS WELDING

The primary driver for specifying the use of the waveform controlled GMAW-S processes is cost-reduction and an increase in productivity. The following information will review examples where these two aspects have been assessed. It should be emphasized that a primary driver for success in implementing a waveform controlled GMAW-S process is the access to skilled labor. It is thus the objective of this section to not only demonstrate the merit in the waveform controlled GMAW-S process, but also to illustrate that a portion of the cost savings should be invested in obtaining the most skilled welders. This, naturally, will require a higher hourly rate than what might typically be specified for manual field welding. When waveform controlled GMAW-S processes are well-executed on a field erection site, the cost differential for a higher skilled pool of welders is dwarfed by the economic impact on the overall job performance.

The obvious advantage of the waveform controlled GMAW-S processes is the elimination of purge gas in the inside diameter (so-called 'backing gas' or 'back purge'). In large bore piping systems, such as main steam and hot reheat piping systems where extensive field welding is required, the ability to make a weld with no back purge has the potential to save thousands, or even millions, of dollars in direct costs. These costs are defined by the needed purge gas, the labor required to prepare and monitor the weld for the purging procedure, and the down time associated with establishing an acceptable purge prior to welding.

A documented example provided by a large piping fabricator in [6] provides perspective on one economic case study. Two supercritical power plants, including >1,100 welds, were fabricated in the late 2000s with two different approaches:

1. One unit was fabricated with a conventional GTAW root pass and SMAW fill
2. The second unit was fabricated with a waveform controlled GMAW-S root pass and SMAW fill

The comparison of cost for the plant 1 and 2 was >$600,000 versus $166,000, respectively for the shielding gas cost alone. Additional cost savings which were described but not fully monetized, included reduced man hours (50% savings on CSEF large diameter piping), reduced root pass deposition time by 80% and reduced cost for weld preparation (e.g. purge dams).

A second example which monetizes the costs associated with purge gas is provided in Table 1 for two identical hydrogen cracker projects at a Gulf Coast facility. One was assembled using traditional welding methods requiring an argon purge to be maintained at all times. The other used a waveform controlled GMAW-S method for root passes, where possible. A savings of over $1 Million was observed and is illustrated in Table 2-1.

Table 2-1
Comparison of Purge Gas Cost and Cylinder Fees for Two Hydrogen Cracker Projects [7]

Case	Purge Gas Cost	Cylinder Fees	Total
Cracker A (Purge-less)	$943,000	$84,000	$1,027,000
Cracker B (Traditional)	$1,727,000	$480,000	$2,207,000 (+114%)

The savings in labor alone can be significant. One example is given below for welding P91 piping for the following scenarios in Table 2-2:

1. Waveform controlled GMAW-S process for the root and then performing the remaining fill passes with the GMAW-P process
2. GTAW process for the root and FCAW process for the fill passes
3. GTAW process for the root and SMAW process for the fill passes.

Table 2-2
Comparison of Welding Time versus Welding Process for a 24 inch (610 mm) Outside Diameter and 1.218 inch (30.9 mm) Thick Girth Weld [7]

Case	Root Pass	Fill Passes	Total Weld Time (hours)
1	Waveform controlled GMAW-S	GMAW-P	18.95
2	GTAW	FCAW	27.91 (+47%)
3	GTAW	SMAW	48.15 (+154%)

Costs for labor should also be considered in light of the needed, skilled labor to perform the work. Proper training and utilization will be needed to implement a waveform controlled GMAW-S root pass approach and require increased labor rates. However, and as illustrated in Table 2-3 for 58 thick-section welds made in P-No. 5A material (Grade 22), there is still the opportunity for considerable cost savings even when paying a ~25% premium over 'typical' labor rates for a less-skilled pool of available welders.

Table 2-3
Demonstration of Cost Savings in a Case Study of 58 Thick-section Welds in Grade 22 and even Paying an Increased Bill Rate for Access to Higher Skilled Welders to Perform the Waveform Controlled GMAW-S root pass and GMAW-P fill passes [7]

Case	Root Pass	Fill Passes	Total Time (hours)	Bill Rate (/hour)	Total Cost	Cost/dia. inch
1	Waveform controlled GMAW-S	GMAW-P	3,611	$74	$267,177	$162.51
2	GTAW	FCAW	7,773	$60	$466,380	$283.69

Additional savings is realized in other areas such as onsite logistics and safety. Being able to execute work quickly and effectively the first time reduces re-work and therefore reduces additional expenditures. In the case where re-work begins to put considerable constraint on scheduling, there exists a higher risk to accidents. Using less gas not only saves in the gas cost itself, but means moving fewer cylinders, taking fewer deliveries and reducing labor.

In addition to monetary savings, safety is inherently increased through a reduction in the volume of needed inert gases (e.g. primarily Argon), which are heavier than air. Asphyxiation is a very real danger when working with heavy gases in confined areas, such as construction sites or industrial complexes.

Each application is unique and savings over the use of traditional methods will vary. Potential savings on many large projects is considerable, easily offsetting the cost of training and capital equipment investment. One must accept that some projects, specifically those with limited applications for purge-less methods, may not see a significant savings or may in fact see a cost increase when factoring in training and equipment costs. This is illustrated by the summary of considerations given in Table 2-4.

Table 2-4
Considerations for Cost Comparison of the manual GTAW process and the waveform controlled GMAW-S process for performing Root Passes in Piping Systems

Consideration		GTAW	Waveform controlled GMAW-S
Equipment	Power Source	$ (Transformer-rectifier or Inverter, Constant Current. If engine driven, higher cost)	$$ (Inverter, Constant Voltage, with purge-less root capability)
	Wire Feeder	None (manual)	Yes
	Cables	Ground + Welding	Ground + Welding + Feeder
	Gas Supply and Control	Bottle/system handling Purge and shield	Bottle/system handling Torch shielding only
	System Consumables	Torch collet & cup	Tips, gun liners, torch cups,
Mobilization	Transportation [Teamster]	Bulk Purge Gas	Not after original install
	Lifting [Operating Engineer]	Bulk Purge Gas	Not after original install
	Install [Electrician]	Not after original install	Not after original install
	Environmental Shelter [Carpenters and Laborers]	Yes, wind breaks, tents, etc.	Yes, wind breaks, tents, etc.
	Scaffold [Craft, etc.]	Minimal	May need for feeder
	Shop vs. Field	Both (manual GTAW)	Both & Shop Friendly
	Deposition Rate	A function of Operating Factor and Actual Conditions	
	Operator Factor	A function of Actual Conditions	

Table 2-4 (continued)
Considerations for Cost Comparison of the manual GTAW process and the waveform controlled GMAW-S process for performing Root Passes in Piping Systems

Consideration		GTAW	Waveform controlled GMAW-S
Costs	Cost/lb. Deposited, raw	Depends on number or welds, lbs. deposited, and schedule gain/loss	
	Cost/lb. Deposited, adjusted	Depends on number or welds, lbs. deposited, and schedule gain/loss	
	MH/lb. Deposited, raw	1X (manual GTAW)	2-3X
	MH/lb. Deposited, adjusted	Depends on number or welds, lbs. deposited, and schedule gain/loss	
	Automation Possible?	Yes	Yes
	Maintenance	Minimal – Tungsten, gas lenses, Cups	Minimal - Tips, Nozzles, Liners
	Consumable Storage and Handling	Minimal	Minimal if vacuum packed
	Skill Required	GTAW Open Root	Downhill Open Root
	Economical for isolated work	Yes	No
	Portability	Yes	Less

Regardless of the benefits demonstrated by the waveform controlled GMAW-S process, this process is stilled considered inferior and might be adversely prone to failures. Some of the confusion and initial technical issues related to the process are summarized in a review article published by the National Board in 1985 [8]. Much of the aversion to the GMAW-S process can be attributed to many weld failures associated with offshore oil applications in the 1980's. GMAW-S was utilized in welding heavy sections of structural steel and piping including the entire through-thickness of the weld. The relatively low energy of the weld combined with poor welding technique produced welds with considerable amounts of lack of fusion. Upon service exposure, the integrity of these weldments was poor and resulted in many failures.

Documented experience has shown that limitations must be introduced for the waveform controlled GMAW-S process. First, this process is for the root pass only. The remaining thickness of the weld is deposited using other welding processes that have long been accepted, such as SMAW, flux core arc welding (FCAW) or pulse GMAW (GMAW-P). Second, the process has been tailored to this specific task and simply will not work outside the narrow window of parameters for which it was designed. Lack of fusion is unlikely provided care is taken to machine proper groove geometries including sufficient fit-up, the machine settings are not allowed to vary outside of the ranges listed in the WPS and sound welding technique are used (e.g. training is mandatory to reinforce best habits). The balance of this document will address these fundamental issues.

3

BACKGROUND ON WAVE FORM CONTROLLED GAS METAL ARC WELDING SHORT-CIRCUIT TRANSFER MODES

Currently, there are at least six unique suppliers of unique GMAW short-circuit transfer modes: EWM, Daihen, Merkle, Fronius, Lincoln Electric and Miller. The primary means for control of these unique short-circuit transfer processes is by means of software, e.g. so-called 'waveform controlled GMAW welding process.' The Fronius cold metal transfer (CMT) process achieves a similar result by means of hardware manipulation; as soon as the short-circuit is detected the wire feed is manipulated to retract at this moment.

With respect to field construction, the two primary processes utilized in the fabrication of power piping systems in new power plant construction are the *Lincoln Electric STT*[2] (Surface Tension Transfer) and the *Miller Electric RMD*[3] (Regulated Metal Deposition). Both are software controlled short-circuit transfer methods. The representation of the conventional short-circuit transfer mode is given in Figure 3-1. The STT and RMD processes were originally developed to reduce spatter and bridge gaps in sheet metal welding applications. Some soon realized it worked very well for root passes in pipe. Through software and microprocessor control, the welding current and voltage output can be adjusted at a rapid rate to stabilize the arc and weld pool to a level that is not possible with the traditional GMAW-S process.

The stability of the welding arc and weld pool is the primary advantage of the waveform controlled GMAW-S process and a key attribute for the welding of root passes. Optimized, tapered gas nozzles also aid in directing shielding gas through the root gap and towards the back of the weld pool. This greatly reduces the susceptibility to the formation of oxide on the inside diameter (ID) of the root and makes it possible to deposit the root with no back purge.

The processes work by controlling the voltage and amperage very closely. In a traditional GMAW-S process, the wire electrode approaches and eventually shorts out on the base metal, Figure 3-1. As this happens, the arc voltage decreases to zero and current begins to climb rapidly. As the current climbs, the wire electrode becomes super-heated from the high electrical resistance and begins to neck down and eventually burn off, also known as "pinching". Once the wire has pinched off, the plasma or arc column is restored in a somewhat violent and instantaneous fashion due to the very high current and voltage. This typically results in high amounts of weld spatter, one of the original deficiencies with this transfer mode.

[2] *STT, STT II, Power Wave and Power Wave STT* are trademarks of the Lincoln Electric Company.
[3] *Field Pro, Pipe Pro, Pipe Worx, RFC and RMD* are trademarks of Miller Electric Company.

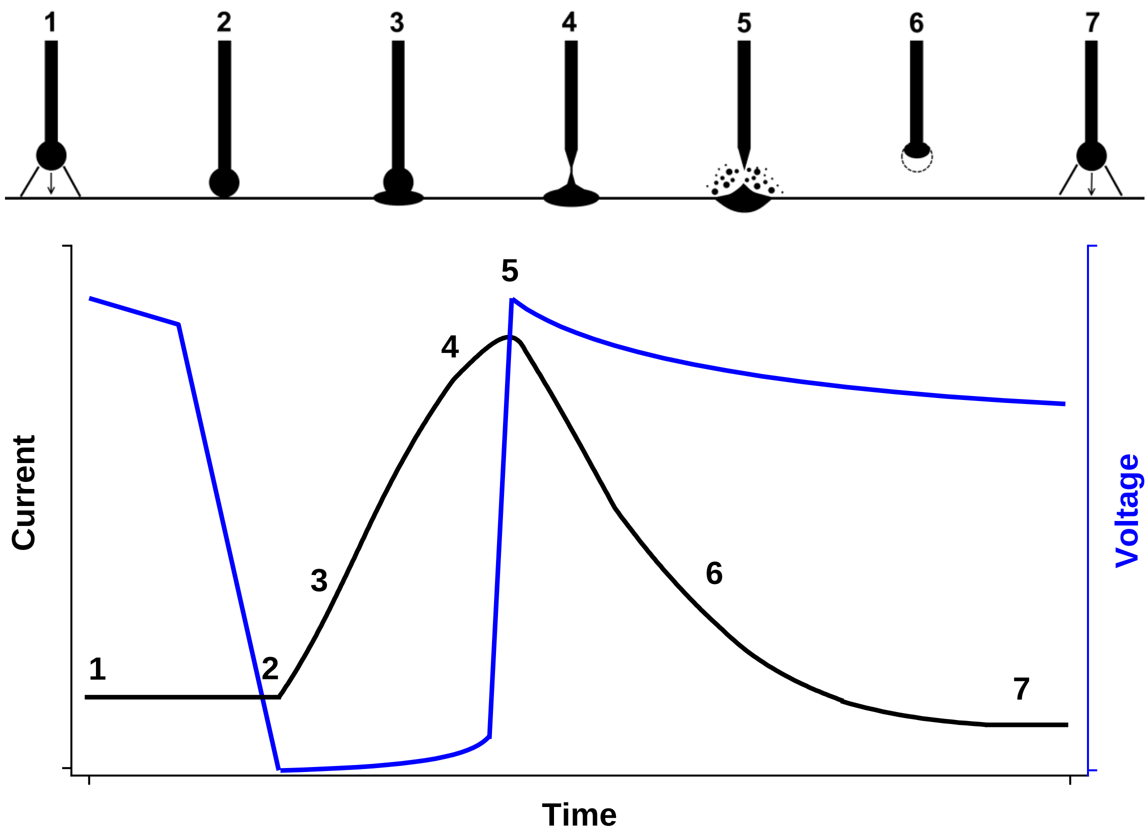

Figure 3-1
Schematic for current and voltage as a function of time for the conventional short-circuit transfer mode and as linked to the sequence of weld deposition in the weld (steps 1-7)

The controlled waveform GMAW-S processes work differently by monitoring the arc and anticipating when the “pinch” will occur. As the electrode begins to neck down and separate for the molten drop, the power source will momentarily reduce or cut power to the arc. This reduces the otherwise violent and explosive clearing of the short with traditional GMAW-S process. Following the separation of the drop, electrical power is restored to form the plasma column and begin the process over again. Enhancements are made to electrical characteristics to manipulate the plasma column, allowing for wider to narrower beads, more or less penetration as well as adjustments to arc length. Figure 3-2 and Figure 3-3 illustrate the electrical characteristics of both Lincoln STT and Miller RMD, respectively. A normalized current-time plot for the conventional short-circuit transfer mode and the Miller RMD process is given in Figure 3-4.

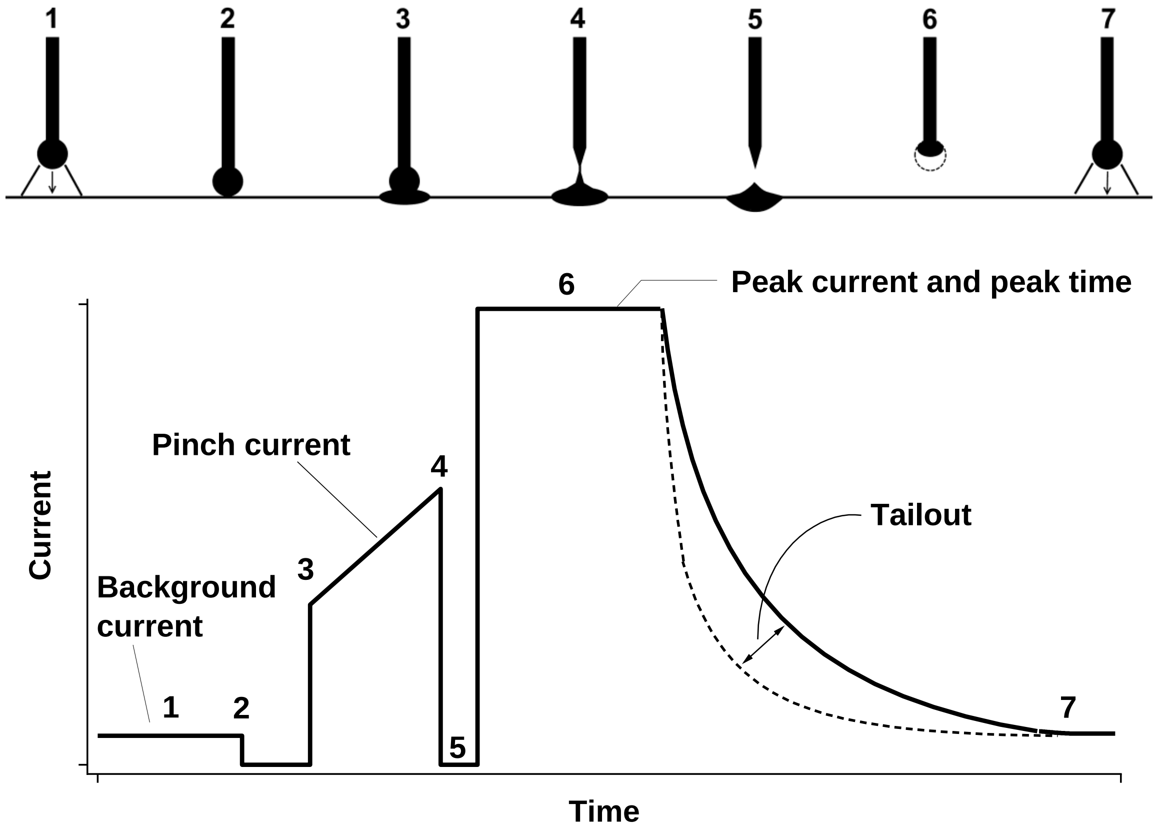

Figure 3-2
Schematic of the current, time and weld deposition for the Lincoln Surface Tension Transfer (STT) advanced Waveform for Depositing Root Passes using the GMAW-S process

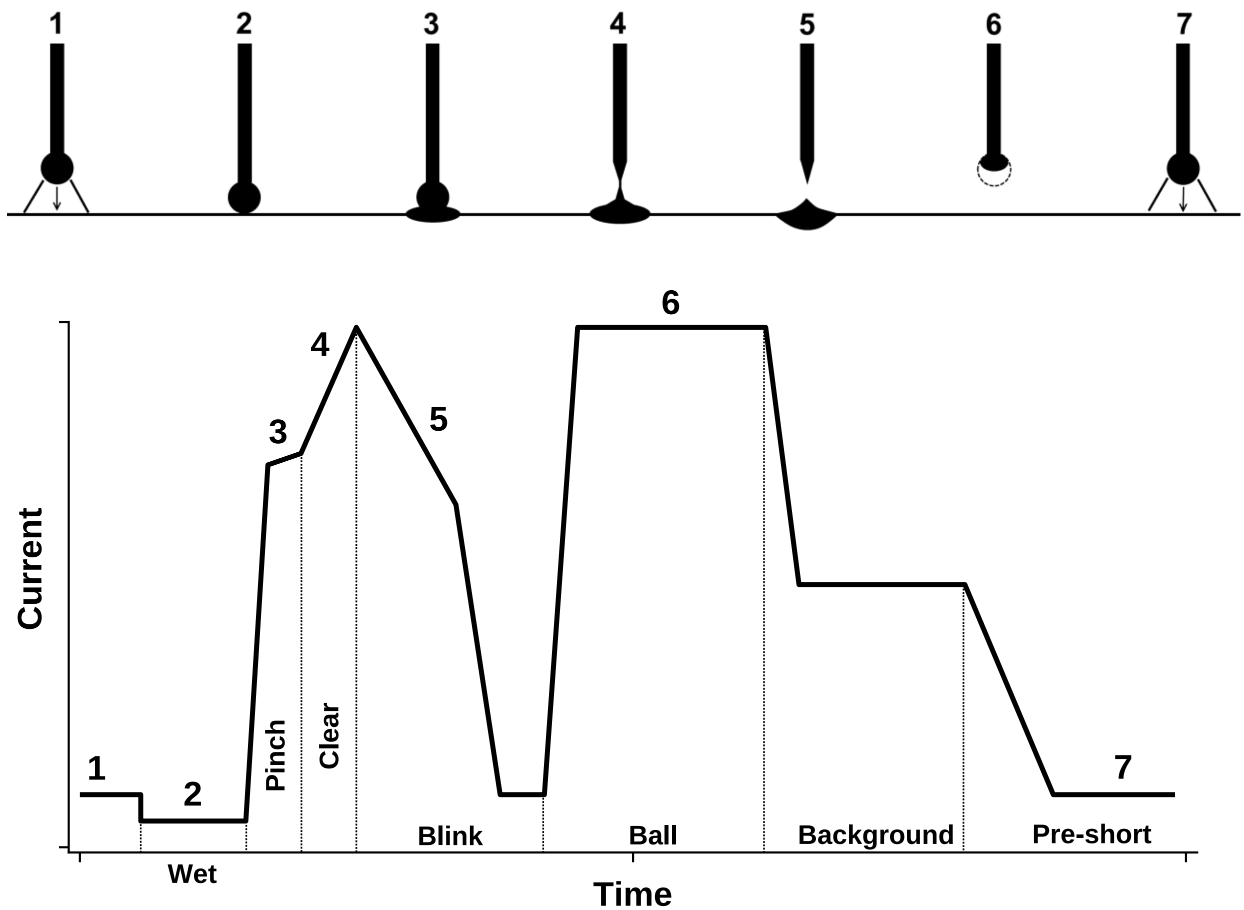

Figure 3-3
Schematic of the current, time and weld deposition for the Miller Regulated Metal Deposition (RMD) advanced Waveform for Depositing Root Passes using the GMAW-S process

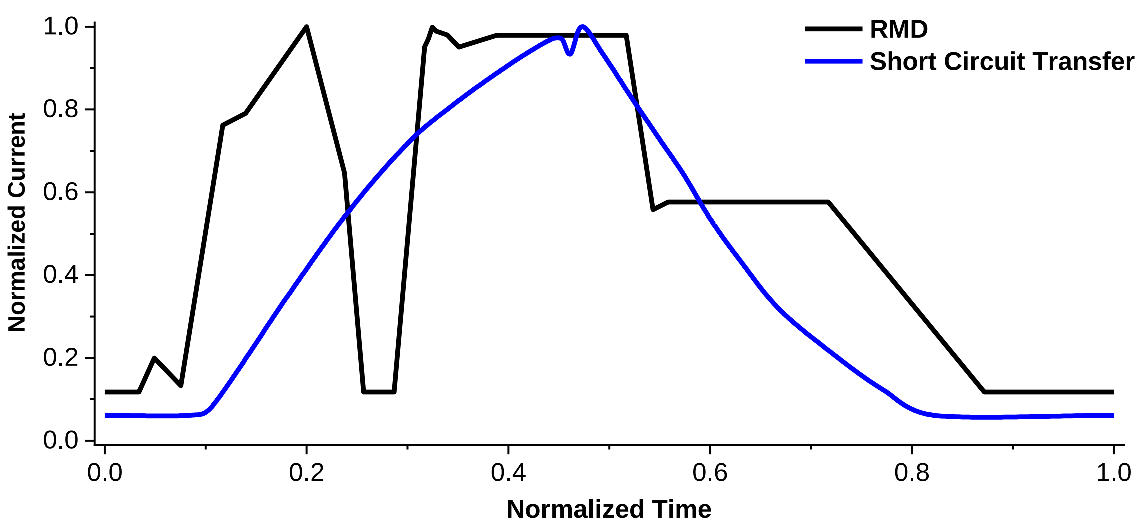

Figure 3-4
Comparison of the normalized current versus time profiles for the Miller Regulated Metal Deposition (RMD) process and conventional short-circuit transfer process

4
COMPONENTS OF A "PURGELESS" ROOT PASS WELDING PROGRAM

Because the waveform controlled GMAW-S process can offer considerable advantages in cost and schedule, management and procurement is often quick to demand such methods be used for a given project. Depositing root passes using this process may sound simple in the initial contracting stage, and indeed conversations with the fabricator may reinforce this sentiment, but the large variability in documented results in the power generation industry is directly attributed to the lack of appreciation for the challenges that are inherent to the process.

The waveform controlled GMAW-S process and required power supply and supporting equipment are fundamentally different to the traditional means of making root passes in large bore girth welds (e.g. typically open root with the GTAW process or less-commonly with a backing ring and the SMAW process). There are many additional variables that must be considered, any of which can negatively impact the chances of success. Special consideration needs to be given to these variables and how they are communicated to the craft performing the work. This is not simply a different welding process that can fall under a traditional welding program. A dedicated program is required to be successful and must include training. Elements of this program must include:

1. Roles and responsibilities
2. Definition of welding variables and development of WPSs
3. Equipment
4. Filler metal procurement
5. Training
6. Supervision

Each of these fundamental aspects will be reviewed in the following sections.

Roles and responsibilities

Management

Executives and management must realize the waveform controlled GMAW-S process is not a “silver bullet” and does have limitations. Many craft personnel and their supervision have never used such a process. Thus, management must be committed to the creation and implementation of a welding program that includes recommended guidelines detailed in this document. In many cases, an initial support from management is provided, but without a proper perspective on the initial cost required to implement and sustain the welding program. With successful implementation, subsequent costs can be reduced and minimized, but it is important to emphasize the need to support a decision to utilize a waveform controlled GMAW-S process with a welding program that must include a robust and sustained training effort.

Welding Engineer/Technical Specialist

The Welding Engineer or Technical Specialist must make the initial economic and technical evaluation to determine that the waveform controlled GMAW-S process offers tangible benefits before proceeding. This consideration should include the potential costs of developing, implementing and sustaining a welding program dedicated to this process. The access to skilled labor able to perform the specific work should also be verified to ensure sufficient, capable welders can be employed during the fabrication of the required component systems.

The technical personnel must be very familiar with the process, methods and equipment. The initial implementation of such a program will come with many questions and inquiries from the stakeholders involved in the process. Fielding questions and solving problems in a quick and efficient manner is necessary so that confidence in the process is not lost. A designated person, whether a Welding Engineer, Welding Specialist or other, should be appointed as the technical authority for the process. This person should possess hands on welding skills and train with equipment manufacturer's technical specialists. In many cases this individual may need to be an active participate in training Supervision and Welders. Lastly, it is a primary responsibility for the Welding Engineer to write and maintain clear Welding Procedure Specifications and supporting materials which are considered vital to the success of a waveform controlled GMAW-S process.

Oversight and Supervision

The supervisory role is typically a person who is in the field, monitoring the ongoing work. This person acts as a liaison between the technical authority and the craft. They may be considered a foreman or team lead. It is imperative that the person in this role is a skilled welder who has received similar in-depth training on the equipment, process and procedures. This person must be viewed as an asset and is expected to contribute to efficient production by trouble shooting, leading the team and working as a first line quality inspector.

Welder

Execution of the welding program.

Definition of Welding Variables and Development of Welding Procedure Specification

Correct application of the process and technique is key. Engineers and welding supervision need to be selective when implementing this technology. Many of the critical variables necessary for successful implementation are <u>NOT</u> regarded as 'essential variables' by ASME B&PV Code Section IX Table QW-255 nor are these variables recognized in Section QW-400 "Variables." Examples include: specific details on groove geometry, cleanliness, make/model of equipment or software identification and revision (specific to major changes in software). Software changes have been found to not affect the arc. ASME B&PV Code Section IX has partially recognized the complexity in waveform controlled GMAW-S processes in the Nonmandatory Appendix H "Waveform Controlled Welding," which provides very basic guidance on determining heat input, new procedure qualification, existing qualified procedures and performance qualifications. The critical variables necessary to ensure a consistent welding procedure is implemented are reviewed here as these may not be provided in a traditional WPS. (See Table 4-1 and Appendix C.)

Limitations on Section Size

It is generally recommended that GMAW processes are reserved for piping that is 6 inches (150 mm) OD and larger when out of position due to the degree of difficulty in angle change and difficulty in manipulating the welding torch. Smaller diameter piping down to 1.5 in (38 mm) have been successfully field welded. Again, the key is additional training must be completed including welder training, qualification and mock-ups performed prior to production welding. For section sizes larger than this, it is highly recommended to perform an engineering and economics evaluation specific to the application. In some applications, where the pipe dimensions and numbers of welds do not provide sufficient economic justification, specification of the waveform controlled GMAW-S process may not offer any benefit and may cost more considering procurement of equipment and training costs. This is generally true in a fabrication shop setting where setting up a purge is simple, or applications where there are a relatively small number of welds to make.

Filler Metal Selection

Optimized filler materials must be procured when performing waveform controlled GMAW-S root passes. The primary concern for the filler metal composition, whether it be for stainless, carbon steel or CSEF applications, is the silicon (Si) content. Si must be at an elevated level to ensure the weld pool will wet and exhibit sufficient fluidity. Fortunately, many non-CSEF steels are available in a high Si classification and designated with "Si". Others, such as ER90S-B9 (this classification becomes ER90S-B91 in the next revision of A/SFA-5.28), do not have an elevated Si designation. However, there are select wire manufacturers that do produce ER90S-B9 with a Si content near the upper limit of the classification for use in this specific application. ER90S-B9 has an upper Si limit of 0.50 wt. %. Generally, a wire with 0.35 wt. % Si or higher will be sufficient for the waveform controlled GMAW-S process discussed herein for Grade 91.

Most waveform controlled GMAW-S welding utilizes 0.035 in (0.9 mm) or 0.045 in (1.2 mm) diameter wires. The smaller diameter wire appears to offer the most flexibility for purgeless root passes in Grade 91. Success can be achieved using the larger diameter wire but normally requires additional skill. Satisfactory results have been obtained with either diameter wire on other alloys. However, the welder should train using the diameter that will be used in production.

Wire surface should be free of excessive lubricant, slivers or tears. Excessive lubricant can result in unsatisfactory porosity while slivers or tears in the surface adversely affect wire feed and tip wear. Commercially available GMAW wires are normally acceptable, chemical composition notwithstanding.

Electric Characteristics and Heat Input

Where heat input and toughness testing are of concern, special methods and equipment for determining heat input must be employed. Traditional analog heat input measurement equipment and the calculation in QW-409.1(a) is not accurate when working with waveform controlled power sources. ASME B&PV Code Section IX, QG-109, provides the following definitions:

- *Waveform controlled welding*: A welding process modification of the voltage and/or current wave shape to control characteristics such as droplet shape, penetration, wetting, bead shape or transfer mode(s).
- *Instantaneous power or energy*: As used for waveform controlled welding, the determination of power or energy using the product of current and voltage measurements made at rapid intervals which capture brief changes in the welding waveform.

The upcoming revision of AWS A3.0, Standard Terms and Definitions … (proposed and pending) provides the following definitions:

- *Average instantaneous power* (AIP): The average of products of amperages and voltages determined at sampling frequencies sufficient to quantify waveform changes during a welding interval.
- *Total instantaneous energy* (TIE): The sum of products of amperages, voltages, and time intervals determined at sampling frequencies sufficient to quantify waveform changes during a welding interval.

At some future time, it can be expected that ASME B&PV Code Section IX will be revised to reflect the AWS A3.0 definitions.

Power sources discussed herein for depositing purgeless root passes operate in a waveform controlled mode. ASME B&PV Code Section IX provides four approaches for determining heat input:

> QW-409.1 An increase in heat input, or an increase in volume of weld metal deposited per unit length of weld, for each process recorded on the PQR. For arc welding, the increase shall be determined by (a), (b), or (c) for nonwaveform controlled welding, or by (b) or (c) for waveform controlled welding. See Nonmandatory Appendix H. For low-power density laser beam welding (LLBW), the increase shall be determined by (d).
>
> *(a)* Heat input [J/in. (J/mm)]
>
> $$= \frac{Voltage \times Amperage \times 60}{Travel\ Speed\ [in/\min\ or\ mm/min]}$$
>
> *(b)* Volume of weld metal measured by
>
> *(1)* an increase in bead size (width × thickness), or
>
> *(2)* a decrease in length of weld bead per unit length of electrode
>
> *(c)* Heat input determined using instantaneous energy or power by
>
> *(1)* for instantaneous energy measurements in joules (J) *Heat input [J/in. (J/mm)]*

$$= \frac{Energy\ (J)}{Weld\ Bead\ Length\ [in.\ or\ mm]}$$

(2) for instantaneous power measurements in joules per second (J/s) or Watts (W) *Heat input [J/in. (J/mm)]*

$$= \frac{Power\ \left(\frac{J}{s}\ or\ W\right) \times arc\ time\ (seconds)}{Weld\ Bead\ Length\ (in.\ or\ mm)}$$

(d) LLBW Heat input [J/in. (J/mm)]

$$= \frac{Power\ (W) \times 60}{Travel\ speed\ (in/\min\ or\ mm/\min)}$$

where Power is the power delivered to the work surface as measured by calorimeter or other suitable methods.

Nonmandatory Appendix H offers some commentary and guidance specific to this subject. Fortunately, many of the newer equipment models have software included that can assist in determining the actual heat input. Stand-alone measurement devices for monitoring in accordance with QW-409.1 (c) (see 4.2.3) are offered, such as: Euroweld (JouleBox2), Fluke (345), Lincoln Electric (Arc Tracker Data Monitor) and The Validation Center, UK (Weld Data Logger). Typically, the heat input is calculated by measuring the arc energy used through the duration of depositing a weld bead. That energy value can be divided by the length of the bead to document a value with the units in J/inch or J/mm. Meeting requirements for impact properties is typically not difficult with controlled waveform processes. Where ferrite is a consideration (such as for non-CSEF steel alloys), the ferrite content is generally consistent due to the narrow operating parameters.

Shielding Gas

Although the initial application of the waveform controlled GMAW-S process involved many different shielding gas mixtures, including 86%He-14%CO_2, 75%Ar-25%CO_2, 90%Ar-7.5%He-2.5%CO_2 and 75%Ar-25%CO_2, the most commonly utilized gas mixtures are 75%Ar-25%CO_2 and 90%Ar-10%CO_2 with the latter mixture perhaps being the most popular for root passes only. The two-part mixtures are also more economical than the three- or four-component gas mixtures. Guidance for ordering shielding gas can be found in ASME Section IIC, SFA-5.32.

Joint Fit-Up

The root geometry (land and gap) must be uniform and use of machining equipment, stationary or portable, is necessary. Training weld coupons should exhibit fit-up similar to what will be encountered in production. Components of differing wall thickness may require different land size(s) in the weld joint. In general, the joint fit-up should be controlled to similar criterion that would be used for root pass welding with the GTAW process. (See Appendix C for fit-up guidelines.)

Documentation of Critical Welding Variables

As mentioned above, the WPS will require considerable attention. Because ASME Section IX does not address the additional critical variables, it is recommended to develop a "technique sheet" to accompany the WPS. Variables specific to the process and equipment will be detailed for proper set-up of the machine. At a minimum, the welding variables in Table 4-1 should be considered and detailed.

Table 4-1
Important Welding Variables which should be Documented and Included in Training Whether these are Explicitly Addressed in ASME B&PV Code Section IX QW-255

Welding Variable		Addressed in QW-255	Category
Equipment manufacturer	Power supply	No	
	Wire feeder	No	
	Gun assembly	No	
	Software version[1]	No	
	Weld program and/or mode	No	
[Specific to Miller RMD process][3]	Arc length[2]	No	
	Arc control	No	
[Specific to Lincoln STT/STT II process][3]	Trim	No	
	Tail out	No	
	Hot start	No	
	UltimArc	No	
	Background current	No	
	Peak current2	No	
Joint design	Bevel	QW-402.1	Nonessential
	Land thickness	QW-402.1	Nonessential
	Root gap	QW-402.10	Nonessential
Shielding gas mixture		QW-408.2	Essential
Filler metal diameter		QW-404.6	Nonessential
Wire feed speed		No	
Weld metal composition		QW-404.27	Essential
Cup or nozzle size		QW-410.3	Nonessential
Electrode extension		QW-410.8	Nonessential
General notes and useful schematics for welding		No	

Notes:

1. Changes in software need to be evaluated. It is reported that many software changes correct internal bugs, enhance starting plus arc stability and have little to no effect on the arc. Where compatibility with former qualification is in question, it is recommended that a test be conducted with the "old" parameters and examine the results.
2. Arc length is not constant with short circuit transfer. Very little difference may be observed when altering this setting. Arc current is also not steady state (see Figure 4-2 and Figure 4-3). These values are controlled by the complex waveform software. Once the panel setting is made, the software adjusts other values according to the programmed algorithms.
3. Values in these rows are specific to the equipment manufacturer indicated. These are examples for the equipment shown herein. It is anticipated that as new models and apparatus are introduced, so will such terms. If a PQR/WPS uses terms specific to a manufacturer, multiple WPS will more than likely be required where multiple manufacturers' equipment is used and should be highlighted during training.

For reference parameters see Appendix C for "Example Process Baseline Root Parameters".

Equipment

As mentioned in the Section 2, the primary equipment used in the fabrication of piping systems in the power generation industry for waveform controlled GMAW-S root pass deposits are manufactured by Lincoln Electric and Miller Electric. Both manufacturers have several generations of equipment, and substantial improvements continue to be made over previous models. Other manufacturers market and sell similar systems and their popularity could increase in the future.

The first field-friendly and capable piece of equipment was offered from Lincoln Electric, and identified as the *STT II*. This machine worked well but at times setting parameters and refining the arc could be challenging due to the many controls and adjustments that were available to the welder. It is worth noting that many *STT* users still use the *STT II* equipment regardless of the fact there is newer equipment available. This is due to the inherent customization of the welding program and procedure that was necessitated by the equipment, and many users prefer these customized settings/programs. Many users began their respective welding and training program and accompanying procedure development with the *STT II* equipment and it has continued to serve them well as time goes on.

Newer generation *STT* capable equipment is based on the *Power Wave* series of equipment. Certain models can be fitted with a module that will make the *Power Wave STT* capable. This allows for a machine that is capable of many processes, not just *STT*. A single module can be fitted to any compatible Power Wave power supply, offering some flexibility in equipment utilization. The advanced features and weld ready programs of the *Power Wave* take some technical work out of setting the equipment and has simplified the controls. In any case, these machines have been used in the field and shop settings with success.

Figure 4-1
Lincoln STT Equipment; Left: STT Module for New Generation of Equipment; Middle: Newest Generation Power Wave Power supply, the S500; Right: STT II (original offering of STT-capable power supply) (Lincoln Electric Co.)

Miller Electric has produced several power supplies with the trademarked "*RMD* capability". The first was the *Pipe Pro RMD*. This was primarily a shop oriented machine but some did use it in the field. This was followed by the *Pipe Worx* 400. This was an improvement over the PipePro with refined wave forms and a very simple user interface. It is also multi-process capable. This too, is a shop oriented machine. The latest *RMD* capable power supply is the *FieldPro*. As its name states, it is designed for *RMD* field applications and is multi-process capable. Its compact size is ideal for portability and the simple user interface carries over from other equipment.

Like any Lincoln or Miller product, this equipment is available for purchase through their distributors. The manufacturer suggested retail price (September 2018) will approach $10,000 to $12,000 for a field ready power source, appropriate wire feeder and torch/gun. Much of this equipment is also available through welding equipment rental services. This is an attractive alternative to buying equipment for those who may only use it occasionally or would like to explore the capabilities without having to make a capital purchase.

CAUTION: Most modern waveform controlled power sources and systems have incorporated special shielding measures to assure that the equipment does not "talk" to each other. These power sources are essentially large signal generators. However, there have been instances where these power sources "talked" to other power source designs and models, creating unsatisfactory welding situations. This can be especially true where all equipment shares a common electrical buss and/or grounding system. Consult the manufacturer when this occurs if systematic powering down equipment (to identify the offender) does not resolve the problem.

Figure 4-2
Miller RMD Equipment; Left: FieldPro; Right: PipeWorx 400 (Miller Electric Co.).

One of the most beneficial features of the modern power supplies is their ability to run multiple processes. In many cases, this allows for a nearly seamless transition from the root pass to fill and cap passes. In many cases, a root can be deposited with the RMD/STT process and then can be filled using GMAW-P using the same solid wire and shielding gas. This “one wire, one gas” approach saves a great deal of time by simplifying logistics. The likelihood of using an incorrect wire or gas is reduced. However, success is also reported by contractors who chose to deposit the root with one wire and shielding gas (GMAW-S) and deposit the fill and cap passes using FCAW wires and a different shielding gas.

This document is not intended to provide specific details of the equipment or options available. The Reader should consult the manufacturer’s literature or a representative for specific information.

5
FILLER METAL PROCUREMENT

As with any critical filler metal procurement process, AWS A5.01 *Welding Consumables – Procurement of Filler Metals and Fluxes,* is a resource that can assist obtaining what is required. In addition, *Appendix A – Procurement Specification for Solid Wire Welding Consumables for use with Pulsed Gas Metal Arc Welding (GMAW) and Purgeless Root Deposit.* These details should be considered and specified to the filler metal supplier. Finally, it is crucial the responsible technical person plays a role in the procurement process. Leaving details to a procurement department generally leads to the purchase of a generic, low cost filler metal that will not perform as required.

6
TRAINING

Like any welding application, the most important part is the skill level of the craft personnel. Successful programs utilize welders with demonstrated experience and a proven track record using semi-automated welding processes such as the GMAW process. Typically, 40 hours of training is adequate. Using the same type of filler wire, diameter, groove design, fit-up, torch/nozzle and base metal that will be used in production is generally preferred. Tacking and making repairs should also be included in the training. However, as the technology has matured, some users have found the use of exact or comparable base materials to be unnecessary because they do not feel there is a significant difference in operating characteristics between materials within a general grouping, e.g. ferritic steel versus stainless steel. This decision must be made carefully by experienced supervision.

The waveform controlled GMAW-S process is no more difficult to use than other semi-automatic wire feed processes, but does require time to become familiar with the equipment and proper technique. In most cases, a welder who is proficient in other wire feed processes will require approximately 40 hours of training. Much of this can be done using carbon steel materials to save cost. Typically, it is only necessary to use matching production alloys for critical applications, or towards the end of training once the welder has become competent using less expensive carbon steel. 6 inch SCH 80 coupons are sufficient for most applications. Thinner or thicker wall pipe may be used to match production joints more closely or allow for more practice with fill passes (heavier wall). Generic elements of a 40-hour training program are itemized in Table 6-1 and include, but are not limited to:

- Overall outline of the program
- Review of the Welding Procedure Specification (WPS)
- Highlight details and variables that are not required by Code but are critical and provided in specific technique sheets
- Importance of following the WPS
- Fit-up and cleanliness criteria

Table 6-1
Recommended 40-hour Training Program

Hours[1]	Task/Topic	Recommended Attendees	Responsibility
4	Classroom including familiarization with WPS	Engineers, supervision and welders	Owner/Fabricator[2]
4	Equipment familiarization	Engineers, supervision and welders	Manufacturer
16	Training on mild steel coupons	Welders	Fabricator[2]
8	Training on actual material coupons and mock-ups	Welders	Fabricator[2]
8	Qualification and review of results	Welders	Owner/Fabricator[2]

Notes:

1 Additional 16-20 hours training and qualification required for diameters <6 inches.

2 Contractor, Service Vendor, Installer, etc.

Equipment Familiarization/Troubleshooting

- Review the features and controls of the welding power source and wire feeder
- Learn how to set the equipment (electric and mechanical parameters) to meet the criteria specified in the WPS and supplementary technique sheets
- Proper equipment grounding and sensing lead attachment(s)
- Understand equipment maintenance and what parts require change out on a routine basis (gun liners, torch tips, drive rolls, etc.)
- Become familiar with the shielding gas delivery system, gas regulators, and overall gun/cable/liner/nozzle, tip relationships
- Be aware of when the liner needs to be changed
- Be aware of when there are issues with the sensing leads

Training on Coupons - Preliminary

- Initial training conducted on mild steel (6 inch SCH 80, minimum) coupons unless determined otherwise by supervision
- Groove geometry to be as close to production conditions as possible
- Train in the 2G and 5G positions
- Tacking and through-wall repair of the root shall be conducted for each position
- Visual inspection to be identical to that imposed on production work

- Test coupons may be evaluated by bend testing to verify soundness
- Guidance to be provided by experienced personnel from the fabricator, contractor and/or equipment manufacturer's representative.
- Where limited access or special issues such as small diameters will be involved, mock-ups should be part of the training program.

Training on Actual Material Coupons

- Train on the actual alloy to be welded in production (6 inch SCH 80, minimum) unless determined otherwise by supervision
- Groove geometry to be as close to production conditions as possible
- Train in the 2G and 5G positions
- Tacking and through-wall repair of the root shall be conducted for each position
- Visual inspection to be identical to that imposed on production work
- Test coupons may be evaluated by bend testing or other suitable method to verify soundness
- Guidance to be provided by experienced personnel from the fabricator, contractor and/or equipment manufacturer's representative.

Qualification

- Welder performance qualification tests should be administered in at least the 6G position or as required by the code of construction.
- Test(s) shall be conducted on the actual base metal and weld metal to be used in production (6 inch SCH 80, minimum).
- All test coupons should be subjected to bend testing. Alternatively, ultrasonic testing (preferably phased array) may provide satisfactory results with skilled technicians. Note that due to the orientation of lack of fusion flaws, radiography may not find such flaws.

It is worth noting that occasionally, equipment manufacturers promote these technologies as a means for achieving productivity utilizing low skilled labor. This is not always an accurate statement when it comes to critical welds in high-energy piping systems. Many will claim to have taken a person with minimal welding experience, given minimal guidance, and had this individual depositing root passes using a waveform controlled GMAW-S process in no more than a few minutes. As in all welding processes, there is no one method that presents a cure-all for an absent skill set. Such rationale typically leads to failure. Most of the horror stories with this process are due to lack of skill or knowledge, not the process. This approach should be one that can make a good welder a more productive welder. There must be an appreciation of the potential complexity in field welding that includes pipe-to-pipe fabrication which necessitates welding out-of-position, confined spaces, obstacles and other issues that are not easily duplicated in a laboratory environment.

Beyond training and certification is the need to retrain the skilled welders. Traditionally, these highly skilled welders are terminated at the end of a project, moving on to the next one. Time and again, contractors are faced with having to retrain welders, assuming qualified welders are available. The cost and logistics of re-training or training new welders is expensive and time consuming, taking away from the advantages of the waveform controlled GMAW-S process. To minimize this, contractors have begun to assemble specialty welding teams that are retained from project to project when possible. This has the potential to reduce staffing challenges while maintaining the welders' skills and continuity. The welder also benefits from the standpoint of steady employment.

Even when retained on a long duration project, a successful program will require that a welder undergo retraining and/or requalification if the welder has not used a waveform controlled GMAW-S process within the last 30 days. This may appear excessive until the impact of repair and/or rework is considered on the cost and schedule of the project. Retraining may only require four (4) hours of practice plus four (4) hours to test, depending on the proficiency of the welder.

In addition to the welders being trained, support staff such as supervisors, foreman, superintendents, quality personnel and necessary engineering staff must have a functional knowledge of the equipment use in a field and/or shop setting. There will be subtle work practice difference from traditional methods. Having this knowledge throughout the organization helps teams make informed decisions and understand limitations of the process. The following practical items need to be included in any familiarization program:

- Power source and wire feeder controls, what they do and how to set the machine. This information should be obtained from the Operation/Owner Manual and/or a Manufacturer's Representative.
- Maintenance of all equipment, including teardown of the gun/torch and wire feeder (Figure 6-1)
- Understanding when cable liners, tips and wire feeder drive rolls require replacement.
- The importance of fit-up, joint geometry consistency, and cleanliness.
- Emphasis on work flow and implementation differences between shop and field operations.

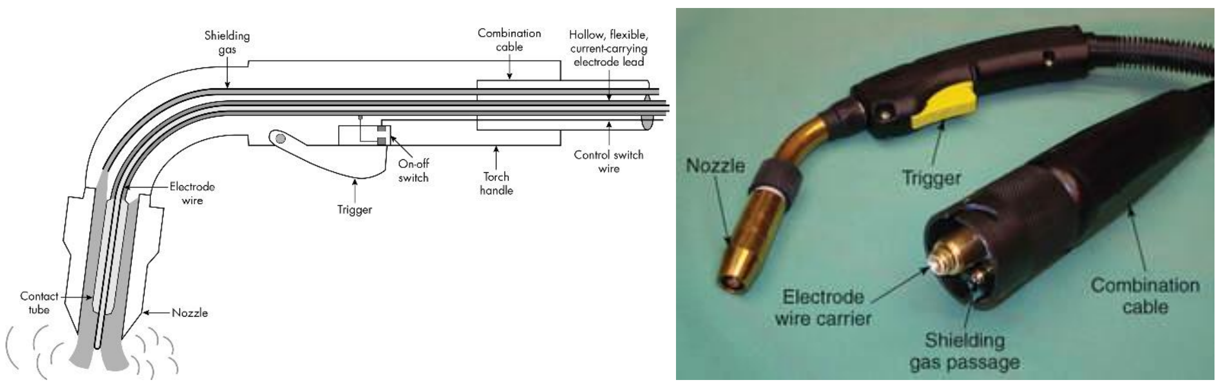

Figure 6-1
Generic gas metal arc weld gun assembly

Technical assistance from the manufacturers is readily available. Each has a team of skilled and experienced personnel who can provide valuable assistance in equipment familiarization, procedure development and training. Details should be worked out between parties directly.

7 CONCLUSION

Waveform controlled GMAW welding including purgeless root pass processes are a proven method that can benefit cost and schedule while maintaining strict quality standards. This is by no means a new welding technology; however, it is a technology that is generally underutilized due to the complexity of the technology and historic variability of industry success.

Potential implementation of the technology must embrace a welding program which, in the minimum, addresses:

- Roles and responsibilities of all personnel
- Definition of welding variables and development of WPSs
- Importance of following the WPS
- Highlight details and variables that are not required by Code but are critical and provided in specific technique sheets or are incorporated into the WPS
- Groove geometry, fit-up and cleanliness criteria
- Equipment operation and maintenance
- Filler metal procurement
- Training
- Supervision

Economic benefit or schedule enhancement will ultimately depend on how well the welding program is managed and maintained. Organizations new to the process with programs in their infancy WILL have growing pains. Lessons will be learned and some modifications must be made to suit the individual users. Beyond these initial hurdles is the potential for schedule and monetary success.

8
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A

PROCUREMENT SPECIFICATION FOR SOLID WIRE WELDING CONSUMABLES FOR USE WITH PULSED GAS METAL ARC WELDING (GMAW-P) AND WAVEFORM CONTROLLED SHORT CIRCUIT TRANSFER ROOT PASS WELDING

1. PURPOSE and BACKGROUND

1.1 Purpose

This specification provides instructions for procurement of solid wire welding consumables for use with pulsed Gas Metal Arc Welding (GMAW-P) and Waveform Controlled Short Circuit Transfer Root Pass Welding. (Also known as Lincoln Surface Tension Transfer (STT) and Miller Regulated Metal Deposition (RMD)).

This document provides requirements for the procurement of welding consumables to join low carbon steels, chrome moly steels, creep strength enhanced ferritic (CSEF) steels (Grade 91, modified 9% Chrome-Moly steels) and austenitic stainless steels for power generation boiler and piping components. Only selected alloy classifications are addressed.

1.2 Background

GMAW, using solid wires, has characteristically not been utilized for welding power plant components due to lack of fusion issues in the past. This is especially true when GMAW was deployed in the short circuit mode (short arc). Most of these issues were encountered decades ago when power sources were traditionally very simple constant voltage transformer-rectifier designs. Wire feeding systems were equally simple and had no ability to interact with the power source or changing arc fluctuations.

The welding industry has evolved where power sources and wire feed systems have become quite sophisticated. Some systems rely on communication through feedback circuitry between the power source and wire feeder while other systems rely on a “smart” power source or wire feeder. Where the wire feeder is “smart”, a variety of different power sources from simple constant voltage designs up to and including waveform controlled models may be utilized. For field installation or repair applications, use of a pulse-capable inverter power source coupled with a “smart” wire feeder is a preferred approach.

Although flux cored arc welding (FCAW) is considered a form of GMAW in ASME Section IX, it is not addressed herein.

It is understood that the information contained in the ASME Code represents a set of minimum requirements. These minimum requirements are not guaranteed to be sufficient for the long term reliable operation of the components. The ultimate serviceability of the component or system relies on augmentation with additional criteria. This is especially true for high quality welds utilizing GMAW-P or GMAW Modified Short Circuit Transfer mode.

The requirement for addition criteria is alloy specific. Low carbon steel welding wires are typically more forgiving in their composition than those used for elevated temperature applications such as for the CSEF steels. Where required for successful implementation, additional criteria more than code specifications are provided herein.

2. DEFINITIONS

2.1 **Certificate of Compliance** – in manufactured products, a document that states that the product was manufactured, sampled, tested, and inspected in accordance with the requirements of the specification (including year of issue) and any other requirements specified in the purchase order or contract, and has been found to meet such requirements. Signatures are not required to appear on certificates of compliance. Objective evidence of compliance with the requirements of the material specification shall be maintained in the records of the material manufacturer or supplier.

2.2 **Certificate of Conformance** – for welding products, a test report documenting that the product meets the requirements of the AWS specification/classification.

The reported results shall be in the form of a single set of tests run at the same time, using representative material/product, and may be for a specific size (diameter) or for all sizes (diameters) required to be tested for classification. Actual test values for all tests required for the AWS classification shall be reported and include a date showing when these actual tests were completed. The report shall not consist of averages, ranges, or single random or “representative” values. It is not usually specific to the actual material shipped.

2.3 **Certified Mill Test Report (CMTR)** – *AWS,* A test report where there is specific reference to the tests being conducted on the actual material supplied. The CMTR may contain results of some or all the tests required for classification, or other tests as agreed upon by the purchaser and supplier.

2.4 **Lower Critical Transformation Temperature** – The temperature at which a change in phase occurs in steel. This term is sometimes used to denote the limiting temperature of a transformation range. The following symbols are sometimes used; A1, T_{crit}, Ac_1.

3. CODES, REFERENCES & STANDARDS

3.1 American Society of Mechanical Engineers

3.1.1 ASME Boiler and Pressure Vessel Code

3.1.1.1 Section I - Power Boilers

3.1.1.2 Section II - Materials

3.1.1.3 Section IX - Welding, Brazing and Fusing Qualifications

3.1.2 ASME Section I Code Case # 2192 (Latest Revision)

3.1.3 ASME B31.1 Power Piping

3.2 American Society for Testing Materials (ASTM)

3.2.1 ASTM A1091 Standard Specification for Steel Castings, Creep Strength Enhanced Ferritic Alloy, for Pressure Containing Parts, Suitable for High Temperature Service

3.3 American Welding Society, AWS

3.3.1 ANSI/AWS A/SFA 5.01 (Filler Metal Procurement Guidelines)

3.3.2 A/SFA 5.9 Specification for Bare Stainless Steel Welding Electrodes and Rods

3.3.2.1 ER308LSi

3.3.2.2 ER316LSi

3.3.3 A/SFA 5.18 Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding

3.3.3.1 ER70S-6

3.3.4 A/SFA 5.28 Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding

3.3.4.1 ER80S-B2

3.3.4.2 ER90S-B3

3.3.4.3 ER90S-B9

3.4 European Standards

3.4.1 ISO EN 10204 3.1

4. TECHNICAL REQUIREMENTS

4.1 General

4.1.1 All welding consumables shall meet the requirements of the A/SFA specification and specific classifications plus additional criteria as noted herein.

4.1.2 All welding consumables shall be supplied with a CMTR for the material shipped in accordance with A/SFA 5.01 (and/or EN 10204 3.1). Actual chemical composition shall be reported (Schedule H & K) unless specifically noted herein. Typical mechanical test data is satisfactory (Schedule F or G).

4.1.3 The Purchase Order shall specify:

- A/SFA specification and classification
- Schedule of Testing per A/SFA 5.01
- Provide CMTR (when required) per A/SFA 5.01
- Diameter & spool size
- Quantity
- Packaging (weight, etc.)

4.2 Stainless Steel – Stainless steel welding consumables shall be supplied to meet classifications ER308LSi or ER316LSi. The elevated silicon classification is required to address successful process implementation.

4.3 Low Carbon Steel – Low carbon steel welding consumables shall be supplied to meet specification A/SA 5.18, classification ER70S-6. Chemical composition may be in accordance with Schedule F or G.

4.4 Low Alloy Steel

4.4.1 ER80S-B2 and ER90S-B3 shall be supplied to meet specification A/SA 5.28. Chemical composition shall be in accordance Schedule H.

Some contracts or Owner Specifications may also impose the following optional criteria.

Bruscato or X- Factor < 15; where:

$$X = \frac{(10\,P + 5\,Sb + 4\,Sn + As)}{100} \text{ (elements in ppm)}$$

4.5 Grade 91 Welding Filler Metal Requirements (CSEF)

4.5.1 Welding filler metals for Grade “B9” or Grade "B91" shall be procured in accordance with ANSI/AWS A5.01, “Schedule K”.

4.5.2 Certified Material Test Reports (CMTR’s) are required.

4.5.3 Filler metals shall have a chemical composition within the specified ranges, determined by current EPRI research, shown in Table 1. The values shown in Table 1 are more restrictive than A/SFA 5.28 and latest EPRI guidelines (December 2016).

Filler metal compositions outside of the ranges listed in Table 1 may be used in special circumstances or when conforming materials are not available only after review and written acceptance by responsible parties.

Table A-1
Chemical Composition Ranges for Grade 91 Filler Metals

Elements[1,2]	**GMAW**
C	0.07 to 0.13
Mn	0.40 to 1.00
Si	**0.35 to 0.50**
P	0.010
S	0.010
Ni	0.80
Cr	8.0 to 9.5
Mo	0.85 to 1.20
V	0.15 to 0.30
Cu	0.20
Al	0.02
Cb (Nb)	0.02 to 0.10
N[3]	0.04 to 0.07
As	0.010
Sn	0.010
Sb	0.003
Mn+Ni	1.00[4]

[1] Element ranges are provided in weight percent. (Result of EPRI programs and research.)

[2] Element expressed as a single value represent the maximum allowed content with no lower minimum limit

[3] N/Al > 2

[4] This composition limitation is required to maximize the potential range permissible for post weld heat treatment and to enhance creep performance at elevated temperature.

Ref. *Guidelines and Specifications for High-Reliability Fossil Power Plants, 2nd Edition: Best Practice Guideline for Manufacturing and Construction of Grade 91 Steel Components.* EPRI, Palo Alto, CA: 2015. 3002006390.

B
SUPPLEMENTAL TECHNIQUE SHEET EXAMPLE (TO BE ATTACHED OR INCORPORATED INTO PQRS AND WPSS)

Supporting WPS		**Date**	
Welding Process		**Equipment Model**	
Equipment Manufacturer		**Torch/gun**	
Power Source		**Nozzle**	
Wire Feeder		**Shielding Gas**	
Software Revision		**Wire Size**	
Welding Program / Mode		**Arc Control/UltimArc**	
Arc Length / Trim		**Weld Progression**	
Wire Feed Speed		**Torch Position**	
Joint Design:			
Notes:			

Approved by:	**Name:**	**Title:**

C

PROCESS BASELINE ROOT PARAMETERS FOR MILLER ELECTRIC RMD P91 ROOT PASS WELD

Supporting WPS:	RMD P91 Root	**Date:**	
Welding Process:	RMD	**Equipment Model:**	Field Pro
Equipment Manufacturer:	Miller	**Torch/gun:**	Bernard
Power Source:	XMT 350 Field Pro	**Nozzle:**	Tapered Style 3/8 in.
Wire Feeder:	Arc Reach Smart Feeder	**Shielding Gas:**	90% Ar – 10% CO_2
Software Revision:		**Wire Size:**	0.035 inch
Welding Program/Mode:	Carbon Steel	**Arc Control/ UltimArc:**	-0.5 to 1.0
Arc Length/Trim[1]:	-0.5 to 1.0	**Weld Progression:**	Downhill
Wire Feed Speed:	120 to 145 IPM	**Torch Position:**	10 to 15° drag
Joint Design: 37.5° bevel V-groove (75° included); 5/32-inch Root Gap; 1/16-inch Root Face/Land			

Notes:

1. One successful contractor routinely operates with a wire feed speed of 180 to 250 ipm

Approved by:	**Name:**	**Title:**

D

PROCESS BASELINE ROOT PARAMETERS FOR LINCOLN ELECTRIC STT P91 ROOT PASS WELD

Supporting WPS:	STT P91 Root	**Date:**	
Welding Process:	STT	**Equipment Model:**	PowerWave S350
Equipment Manufacturer:	Lincoln Electric	**Torch/gun:**	Tweco/Lincoln style
Power Source:	PowerWave S350	**Nozzle:**	Tapered Style 3/8 inch
Wire Feeder:	Power Feed 25M	**Shielding Gas:**	75% Ar – 25% CO_2
Software Revision:		**Wire Size:**	0.035 inch
Welding Program/Mode:	STT II Mode 345	**Background:**	40 to 65
Peak:	230 to 270	**Hot Start:**	3 to 6
Tailout:	0 to 3	**Weld Progression:**	Downhill
Wire Feed Speed:	160 to 180 IPM	**Torch Position:**	10 to 15° Drag
Joint Design: 37.5° bevel V-groove (75° included); 1/8-inch Root Gap; 1/32-inch Root Face/Land			
Notes:			
Approved by:	**Name:**	**Title:**	

E

EXAMPLE OF A NEW CONSTRUCTION PROCEDURE QUALIFICATION RECORD IN GRADE 91 STEEL USING A MATCHING FILLER MATERIAL, THE WAVEFORM CONTROLLED GMAW-S PROCESS FOR THE ROOT PASS, THE GMAW-P PROCESS FOR THE FILL PASSES AND POST WELD HEAT TREATMENT

MAVERICK TESTING LABORATORIES, INC.
10001 Porter Rd, Suite 100 La Porte, Texas 77571
Ph. 281-888-8210 Fax. 281-888-8212
Welding Procedures - Welder Performance - Materials Testing
Where Personal Service & Quality Meet

American Welding Society
Sustaining Company Member

Client:	Contact: Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR: -	Date Due:	11/02/2018
	WPS: -	PO No.:	18-123
	Quote: 18-0445.3	Lab No.:	PQ18-0381

Welding Procedure Qualification per ASME Section IX for 1.5" SA-387 Gr. 91 Welded To SA-387 Gr. 91 Process 1: GMAW-RMD, ER90S-B9 (Root) Process 2: GMAW-P, ER90S-B9 (Balance)

Visual Testing (VT)

Acceptable – No relevant indications noted
Pat Patrick - 10/29/2018

Post-Weld Heat Treatment

Heat treatment conducted @ 1350°F for 2.0 hours.
Heating rate: 600°F/Hr. (Max) above 600°F to soak Cooling rate: 600°F/Hr. (Max) from soak to 600°F

Transverse Cross Weld Tensile Tests

Specification: ASME Section IX, QW-150 / QW-462.1(a) Test Method: QW-152

Specimen	Width Thickness	Area (in²)	.2% Offset Yield, Lbs.	.2% Offset Yield Strength (ksi)	UTL, Lbs.	UTS (ksi)	(%) EL.	(%) RoA	Fracture Location / Type
T1	.756 x 1.450	1.096	80,300	**73.3**	110,300	**100.6**	26.8	47.3	Base / Ductile
T2	.750 x 1.448	1.086	79,200	**72.9**	108,500	**99.9**	29.8	49.4	Base / Ductile

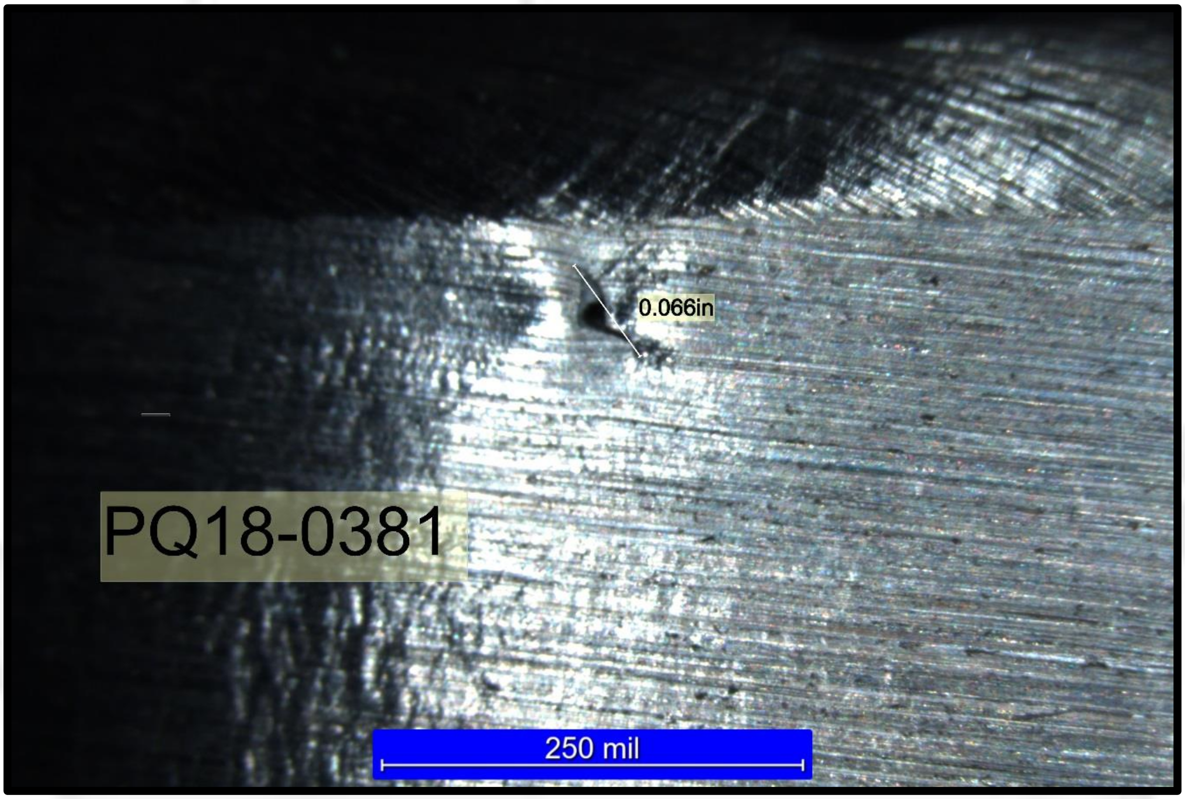
Transverse Side Bend Tests

Specification: ASME Section IX; QW-160 Mandrel Size (in.): 1.5

Side Bend 1	Side Bend 2	Side Bend 3	Side Bend 4
Acceptable	Acceptable	Acceptable	Acceptable

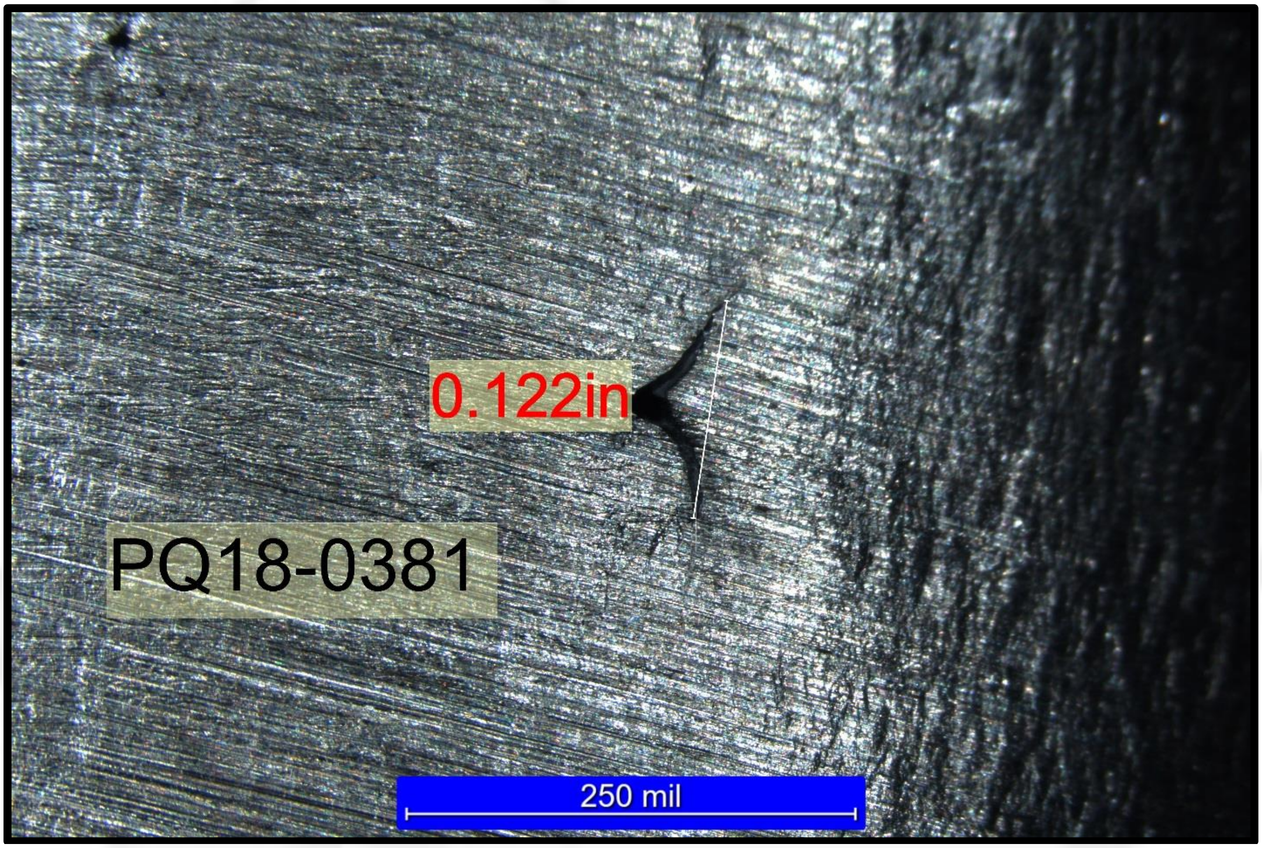
Client:	Contact:	Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR:	-	Date Due:	11/02/2018
	WPS:	-	PO No.:	18-123
		Quote: 18-0445.3	Lab No.:	PQ18-0381

Bend Specimen Discontinuity – 0.066 in.



Client:	Contact:	Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR:	-	Date Due:	11/02/2018
	WPS:	-	PO No.:	18-123
		Quote: 18-0445.3	Lab No.:	PQ18-0381

Bend Specimen Discontinuity – 0.122 in.



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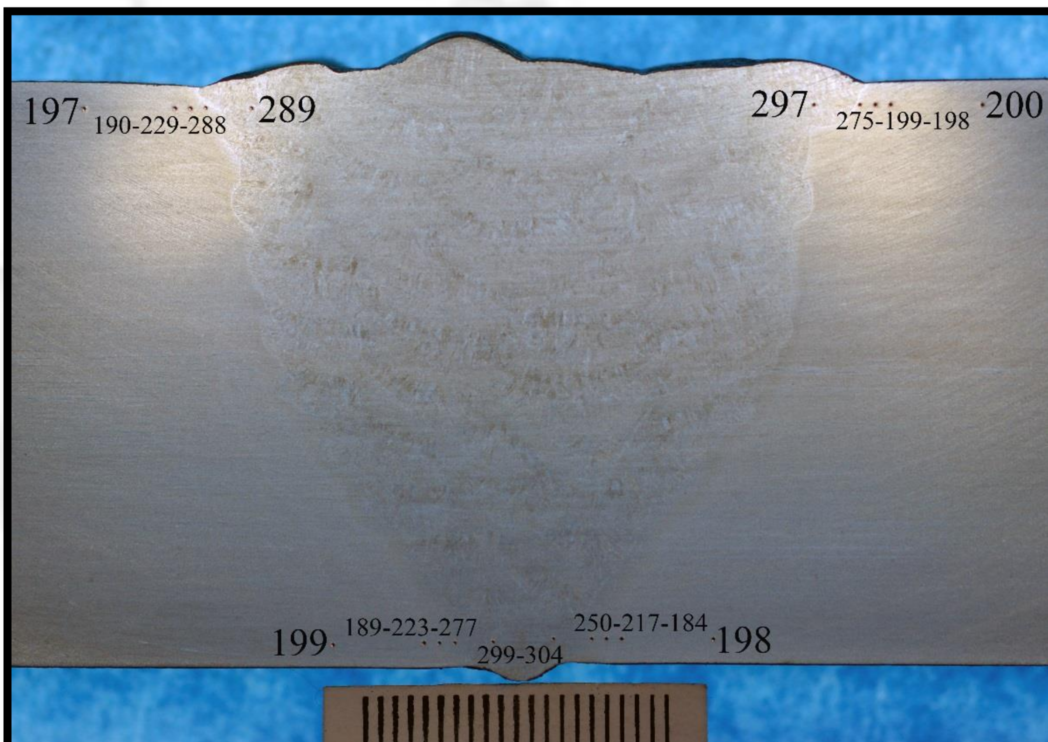
Client:	Contact: Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR: -	Date Due:	11/02/2018
	WPS: -	PO No.:	18-123
	Quote: 18-0445.3	Lab No.:	PQ18-0381

Vickers Hardness Survey

Specification: API RP 934E
Hardness Scale: 10Kg

Magnification: Scale
Test Method: ASTM E384

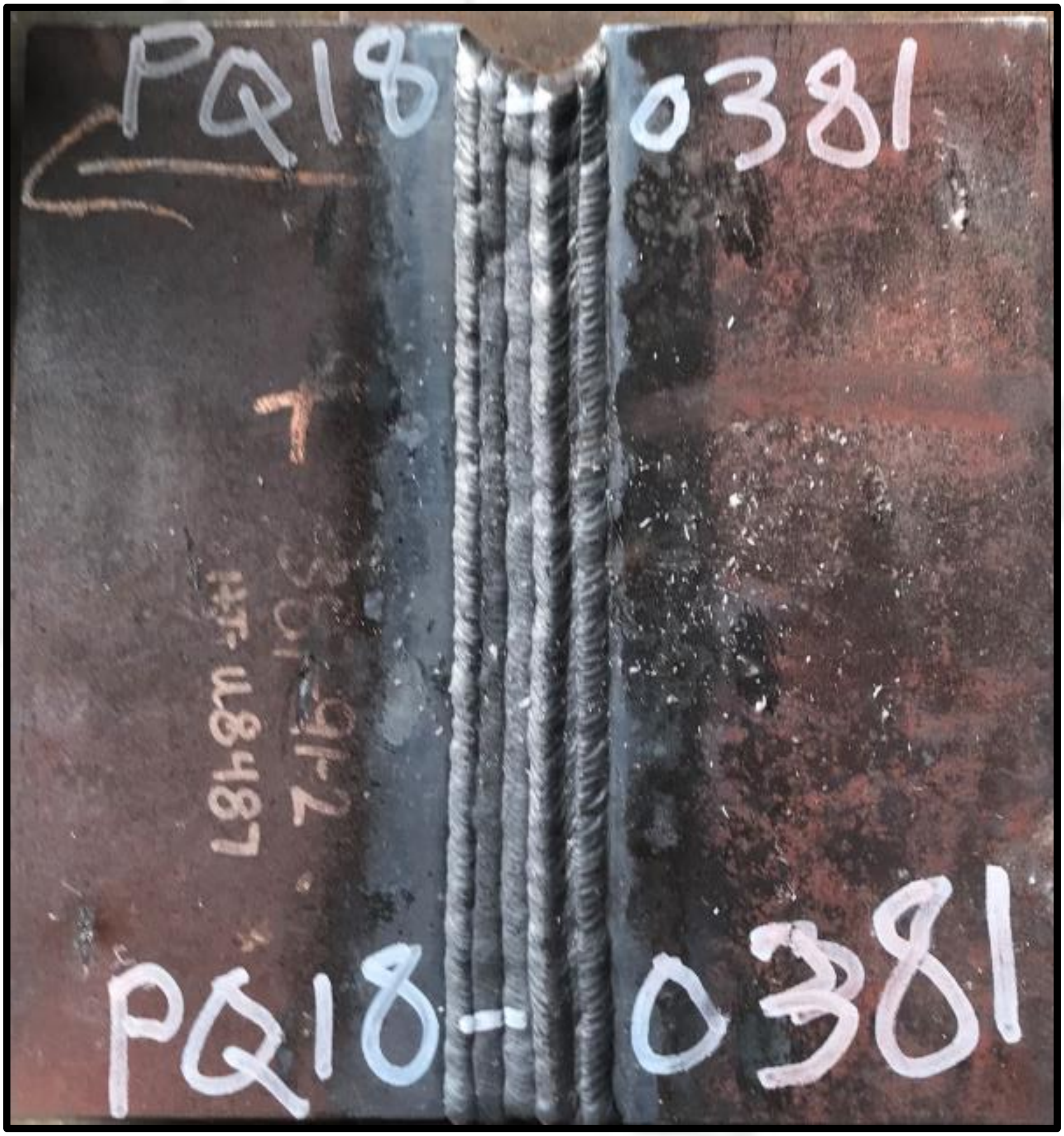
Location	Base	HAZ	Weld	HAZ	Base
Punch #	**1**	**2-3-4**	**5-6**	**7-8-9**	**10**
Cap	197	190-229-288	289-297	275-199-198	200
Punch #	**11**	**12-13-14**	**15-16**	**17-18-19**	**20**
Root	199	189-223-277	299-304	250-217-184	198



Specimen etched with Vilella's Reagent. Scale in mm.

Client:	Contact: Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR: -	Date Due:	11/02/2018
	WPS: -	PO No.:	18-123
	Quote: 18-0445.3	Lab No.:	PQ18-0381

Welded Coupon



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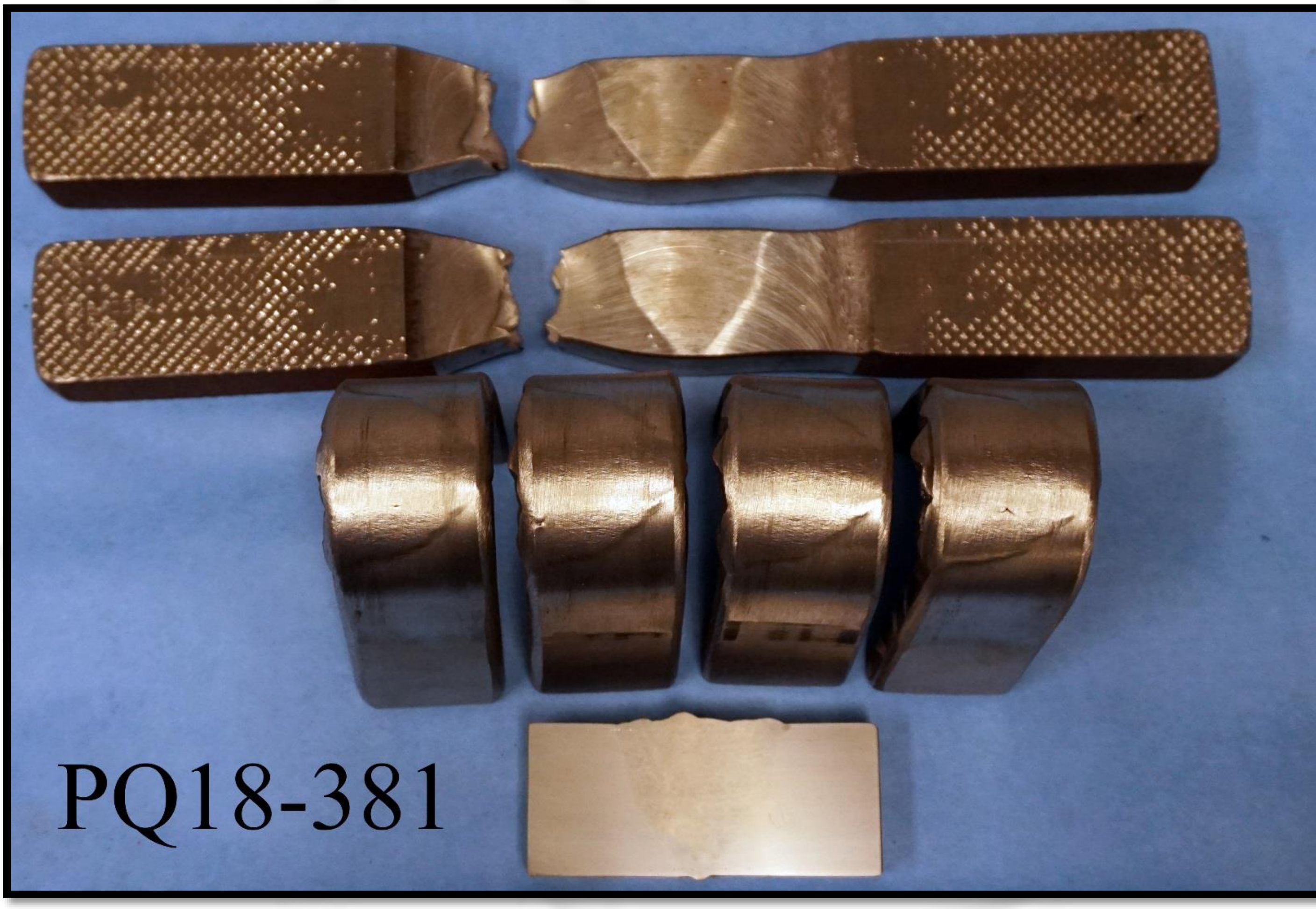
Client:	Contact: Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR: -	Date Due:	11/02/2018
	WPS: -	PO No.:	18-123
	Quote: 18-0445.3	Lab No.:	PQ18-0381

Test Specimens



Maverick Testing Laboratories, Inc. Representative

Brad Berglan

Rev 1. 29 September 2018

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ASME SECTION IX WELDING RECORD

Lab Number/ PQR Number	PQ18-0381	WPS record number	***Client to Determine***	Revision	0
Date	10/31/2018	Customer name			
Standard/Specification(s)	ASME IX, NBIC	and tested:	With PWHT		

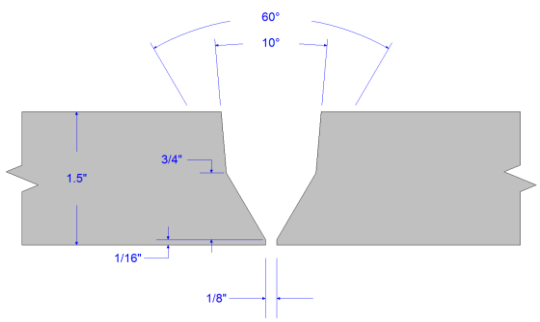
Base Metals (QW-403)

	Product form	Specification (type or grade)	P No.	Grp. No.	Size (in.)	Sch.	Thick. (in.)	Dia. (in.)
1	Plate	SA387-91-2	P15E	1	-	-	1.500	-
Welded to: 2	Plate	SA387-91-2	P15E	1	-	-	1.500	-

Heat Number(s):	Base Metal 1: U8487	Base Metal 2: U8487
PWHT Information:	PWHT per ASME B31.3 (331.1.1), controlled heating/ cooling from 600°F to 600°F	Temp. / Soak Time: 1350° F 2 Hrs. Soak
Notes:	No Backing Purge Shall be Used. RMD Root - Pulse Balance.	

Joints (QW-402)

Joint design	Single Vee Groove - Compound 3.5° x 3/4" 10° Balance	Welders Name	Craig Spindler
Backing:	Without	Identification Number	3198
Retainers	None	Stamp	-
Groove angle (deg.)	See Below		
Root opening (in.)	1/8"		
Root face (in.)	1/16"		

Weld Joint Detail	Weld Bead Sequence
	See Attached Drawing

Welding Processes

Welding Processes	GMAW - RMD	GMAW - Pulse	-
Type	Semi-Automatic	Semi-Automatic	-

Filler Metals (QW-404)

SFA specification	5.28		5.28		-	
AWS classification	ER90S-B9		ER90S-B9		-	
Filler metal F-number	6		6		-	
Weld metal A-number	5		5		-	
Filler metal product form	Solid Wire		Solid Wire		-	
Filler metal trade name	Bohler Thermanit MTS 3 Lni		Bohler Thermanit MTS 3 LNi		-	
Wire / Flux AWS Classification	N/A		N/A		-	
Flux Trade Name / Type	N/A		N/A		-	
Filler metal size (in.)	.035"	-	.035"	-	-	-
Filler metal Heat / Lot number	102920	-	102920	-	-	-
Deposited thickness (in.)	0.121"		1.379"		-	
Maximum pass thickness (in.)	0.121"		0.250"		-	
Weld deposit chemistry	CrMo		CrMo		-	
Supplemental filler metal	None		None		-	
Supplemental filler metal volume (ft^3)	None		None		-	
Recrushed Slag	N/A		N/A		-	

Form 1.0
Rev. 2

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ASME SECTION IX WELDING RECORD

Position (QW405) PQ18-0381

Position	1G	1G	-
Weld progression	N/A (Flat)	N/A (Flat)	-

Preheat (QW-406)

Preheat temperature (°F)	308°F	364°F	-
Maximum interpass temperature (°F)	364°F	426°F	-
Preheat Soak Time (M)	-	-	-
Post Weld Bake Out (^{0}F/M)	-	-	-

Gas (QW-408)

Shielding gas:	Type	90% ARGON, 10% CO2	90% ARGON, 10% CO2	-
	Flow rate (cfh)	35	35	-
Trailing gas:	Type	-	-	-
	Flow rate (cfh)	-	-	-
Backing gas:	Type	NONE	NONE	-
	Flow rate (cfh)	-	-	-

Electrical (QW-409)

Pass	Filler metal size (in.)	Process	Amperes	Volts	Travel speed (in./min)	Wire feed speed (in./min)	Maximum heat input (kJ/in.)
Root (1)	0.035	GMAW-RMD	95 - 100	17.7 - 18.4	5.3 -	200	20.83
Hot (2)	0.035	GMAW-Pulse	87 - 94	21.0 - 21.8	6.7 - 6.9	240	18.35
Fill (3)	0.035	GMAW-Pulse	87 - 95	20.9 - 21.3	5.0 - 5.2	240	24.28
Fill (4)	0.035	GMAW-Pulse	85 - 96	21.0 - 22.3	5.0 - 5.8	240	25.69
Fill (5)	0.035	GMAW-Pulse	85 - 100	21.2 - 25.9	4.1 - 7.5	240	37.90
Fill (6)	0.035	GMAW-Pulse	85 - 100	21.3 - 23.5	3.8 - 6.1	240	37.11
Fill (7)	0.035	GMAW-Pulse	89 - 100	21.3 - 22.0	4.3 - 5.0	240	30.70
Fill (8)	0.035	GMAW-Pulse	87 - 99	21.3 - 22.0	4.5 - 5.5	240	29.04
Fill (9)	0.035	GMAW-Pulse	86 - 104	21.2 - 22.4	4.1 - 6.3	240	34.09
Fill (10)	0.035	GMAW-Pulse	89 - 102	21.3 - 22.4	4.4 - 8.0	240	31.16
Cap (11)	0.035	GMAW-Pulse	87 - 101	21.3 - 22.1	3.8 - 5.7	240	35.24
			-	-	-		
			-	-	-		
			-	-	-		
			-	-	-		
			-	-	-		

Tungsten size (in.)	N/A	N/A	-
Tungsten type	N/A	N/A	-
Current/polarity	DCEP (Reverse)	DCEP (Reverse)	-
DC pulsing current	None	Yes	-
Arc transfer mode	Modified Short Circuit	Pulse Spray	-

Technique (QW-410)

String or weave	String	String & Weave	-
Orifice/gas cup size	1/2"	1/2"	-
C.T.W.D (in.)	1/4"	3/4"	-
Multi.single electrode	Single	Single	-
Multi/Single pass per side	Single	Multi/Bead Width 1/2" Maximum	-
Peening	None	None	-
Initial/interpass cleaning	Hand Brush,Grinding,Power Brushing	Hand Brush,Grinding,Power Brushing	-
Back gouging method	None	None	-

NOTES:

1. Preheat & Interpass temperature were monitored using a currently calibrated pyrometer. S/N 4240
2. Initial & Interpass cleaning was performed using mechanical wire brushing and by grinding to clean base material/ weld metal.
3. After Root Pass, Hot pass shall be split into two passes for the layer.
4. All subsequent weld passes shall be welded from the outside of the weld joint, into the center of the weld in order to temper the HAZ.
5. Welding parameters were monitored using a calibrated weld data logger S/N 000204

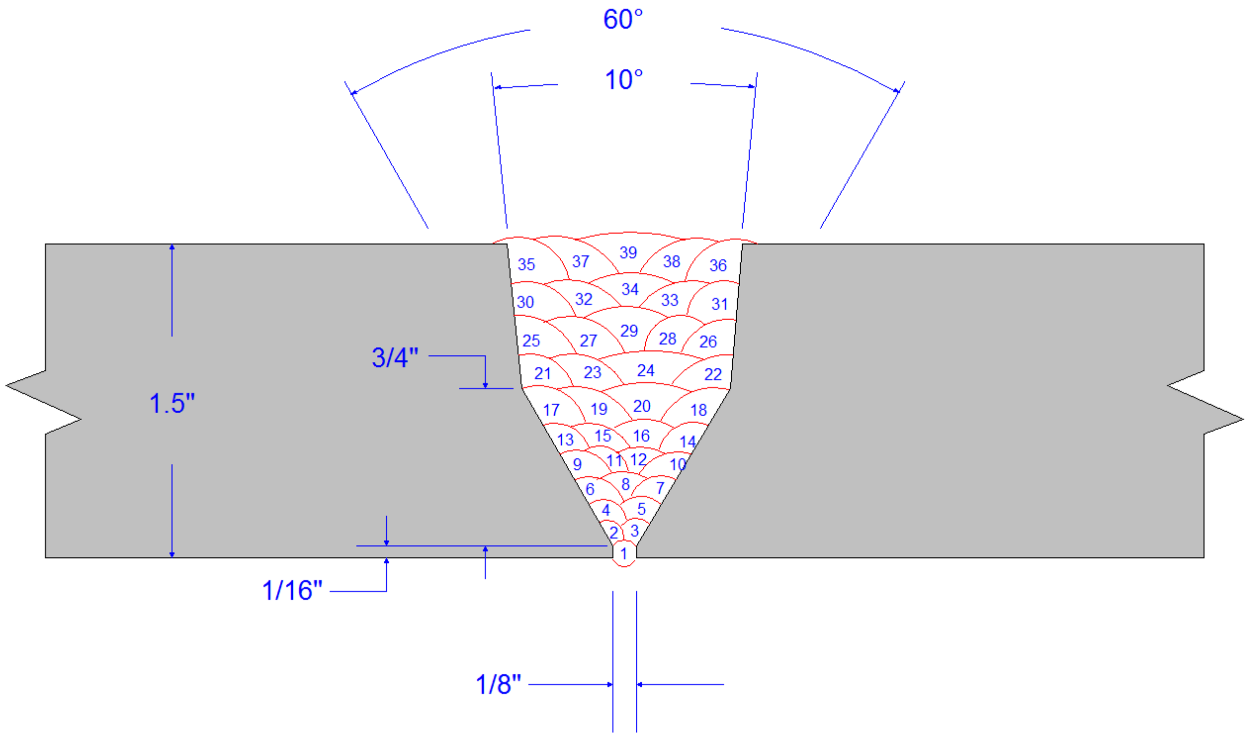
Maverick Testing Laboratories, Inc. Representative:

Scott Witkowski 11/9/2018

Signature Date

Form 1.0
Rev. 2

PQ18-0381



Welders' Name: Craig Spindler SS#3198

- Pass 1 Layer 1 GMAW – RMD .045"
- Passes 2 – 39 Layer 2 - 11 GMAW – Pulse .045"

Contact Info	Print date	Page	Certificate Identification
NOE ALVAREZ	11/01/2018 10:31	1/2	HTNOV111

TGR INDUSTRIAL SERVICES

HEAT TREATMENT CERTIFICATE

CERTIFICATE IDENTIFICATION

Project Registration Number
HTNOV111

GENERAL INFORMATION

Company / Customer	Customer Contact	Phone Number
ALS / Maverick Testing	PAT PATRICK	N/A

Site / Job Location La Porte, Tx	**Job Number** HEAT# U8487 / U8487
Method Of Heat Treatment Low Voltage Resist	**Type Of Heat Treatment** Preheating
Material GR 91 / GR 91	**Purchase Order Number** 3702

HEAT TREATMENT PROCEDURE

Part list

Drawing Number	Weld Number	T/C	Dia / Size	Wps Number	Notes
PQ18-0381	HN# U8487	TC 13	1.5" PLATE		GR 91
PQ18-0381	HN# U8487	TC 14	1.5" PLATE		GR 91

PROJECT INFORMATION

Start Of Heating	End Of Heating	Duration Of Heating	Used Energy Total
10/31/2018 08:30:55	10/31/2018 19:24:59	10h 54m 04s	0.0000 kWh

List Of Units

Nr.	Type	Serial Nr.	Calibration Date	Calibration Nr.	Sensor
1	Ice Star ISQi controller	463	-		

Description and Notes

SUPERVISOR ACCEPTANCE

Supervisor Signature	Approved Date

CUSTOMER ACCEPTANCE

Customer Signature	Approved Date

Contact Info	Print date	Page	Certificate Identification
NOE ALVAREZ	11/01/2018 10:31	2/2	HTNOV111

HEAT TREATMENT DIAGRAM

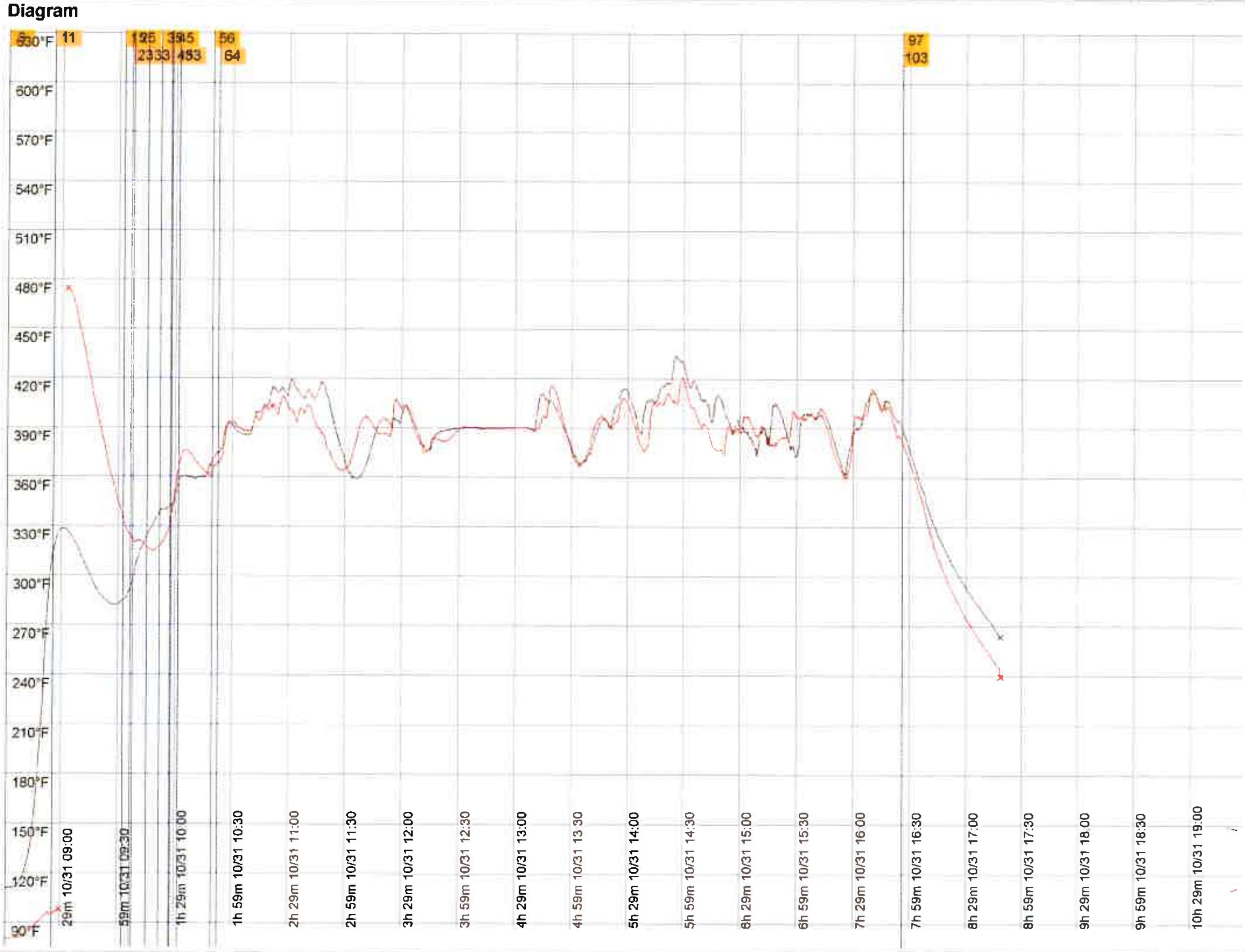
Phase List

Phase	Set Value	Measured Value Avg (Min-Max)	Duration
3 Heating	600°F/h > [300°F]	264°F/h 95°F > 204°F	24m 47s
11 Holding	300°F > MN	335.3°F (204.6°F - 401.1°F)	37m 08s
15 Heating	600°F/h > [320°F]	-8°F/h 309°F > 308°F	3m 39s
23 Holding	320°F > MN	308.6°F (308.4°F - 309.0°F)	57s
25 Heating	600°F/h > [340°F]	89°F/h 308°F > 320°F	7m 52s
33 Holding	340°F > MN	323.7°F (320.5°F - 328.6°F)	6m 35s
35 Heating	600°F/h > [360°F]	95°F/h 328°F > 336°F	5m
43 Holding	360°F > MN	337.6°F (336.5°F - 339.9°F)	53s
45 Heating	600°F/h > [370°F]	343°F/h 339°F > 361°F	3m 50s
53 Holding	370°F > MN	364.6°F (361.0°F - 368.2°F)	17m 37s
56 Heating	600°F/h > [390°F]	78°F/h 366°F > 370°F	3m 10s
64 Holding	390°F > USER	392.5°F (360.5°F - 426.0°F)	6h 03m 49s
97 Heating	600°F/h > (S 385°F)	-324°F/h 385°F > 385°F	02s
103 Cooling	400°F/h > 100°F.	-85°F/h 385°F > 129°F	2h 58m 36s

Point List

463:TC 13 463:TC 14

Diagram



SUPERVISOR ACCEPTANCE

Supervisor Signature | Approved Date

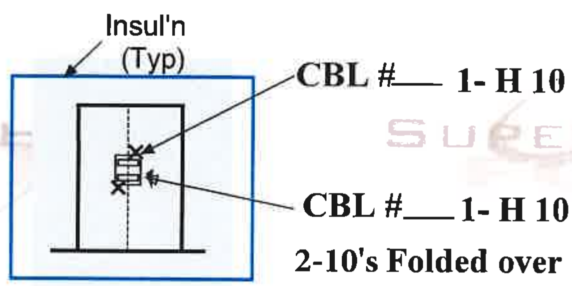
CUSTOMER ACCEPTANCE

Customer Signature | Approved Date

Standard Wrapping Specifications Sheet

TGR INDUSTRIAL SERVICES	1.5" to 1.5" Plate	Drawing #3
	Customer / Location: ALS / Maverick Test Lab	
	Line#: PQ18-0381 / Heat# U8487	Line#: PQ18-0381 / Heat# U8787
	300 Deg. Preheat / PO 3702	Material: Gr. 91 / Gr.91

Heaters Needed: 2- H 10's



Note:

- Insulation standard 1" thickness - 6 # density
- Insulation to extend Min 6 inches beyond heating element.
- **X** - Denotes T/C

Contact Info	Print date	Page	Certificate Identification
NOE ALVAREZ	11/02/2018 10:06	1/2	HTNOV117

HEAT TREATMENT CERTIFICATE

CERTIFICATE IDENTIFICATION

Project Registration Number
HTNOV117

GENERAL INFORMATION

Company / Customer	Customer Contact	Phone Number
ALS / Maverick Testing	PAT PATRICK	N/A

Site / Job Location	Job Number
LA PORTE, TX	HEAT# U8487 / U8487
Method Of Heat Treatment	**Type Of Heat Treatment**
Low Voltage Resist	PWHT
Material	**Purchase Order Number**
GR 91 / GR 91	3702

HEAT TREATMENT PROCEDURE

Part list

Drawing Number	Weld Number	T/C	Dia / Size	Wps Number	Notes
PQ18-0381	HN# U8748 / U8747	TC 27	1.5" PLATE		GR 91

PROJECT INFORMATION

Start Of Heating	End Of Heating	Duration Of Heating	Used Energy Total
10/31/2018 17:56:00	11/01/2018 05:17:10	11h 21m 10s	0.0000 kWh

List Of Units

Nr.	Type	Serial Nr.	Calibration Date	Calibration Nr.	Sensor
1	Ice Star ISQi controller	507	05/09/2018 11:34	507 516 4	TYPE_K

Description and Notes

SUPERVISOR ACCEPTANCE

Supervisor Signature	Approved Date

CUSTOMER ACCEPTANCE

Customer Signature	Approved Date

Contact Info	Print date	Page	Certificate Identification
NOE ALVAREZ	11/02/2018 10:06	2/2	HTNOV117

HEAT TREATMENT DIAGRAM

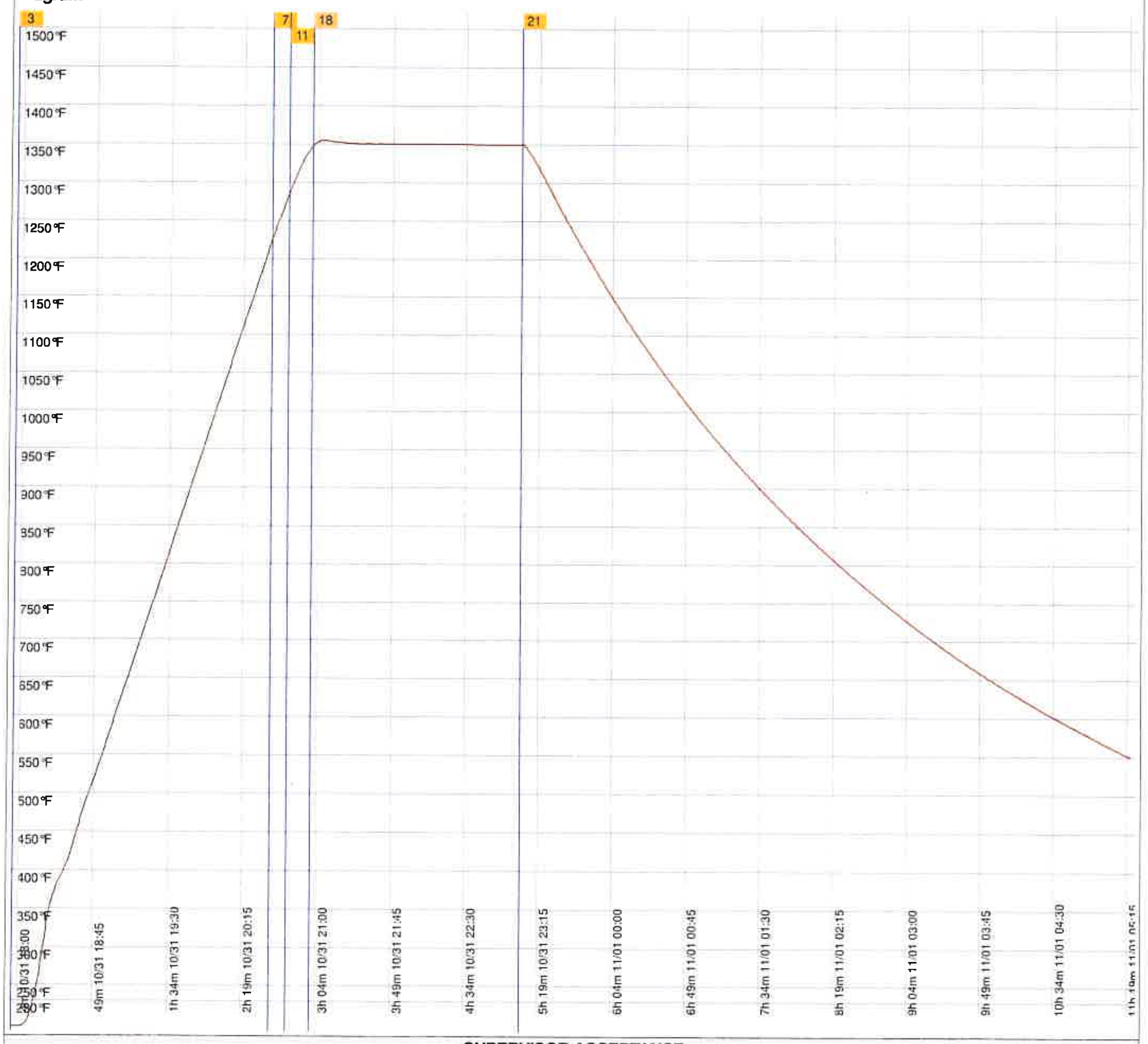
Phase List

Phase	Set Value	Measured Value Avg (Min-Max)	Duration
3 Heating	400°F/h > (1225°F)	397°F/h 196°F > 1225°F	2h 35m 16s
7 Heating	350°F/h > (1286°F)	353°F/h 1225°F > 1286°F	10m 20s
11 Heating	300°F/h > [1350°F]	259°F/h 1286°F > 1347°F	14m 18s
18 Holding	1350°F	1350.8°F (1347.8°F - 1355.0°F)	2h 07m 28s
21 Cooling	400°F/h > 550°F.	-128°F/h 1350°F > 550°F	6h 13m 09s

Point List

507:TC 27

Diagram



SUPERVISOR ACCEPTANCE

Supervisor Signature	Approved Date

CUSTOMER ACCEPTANCE

Customer Signature	Approved Date

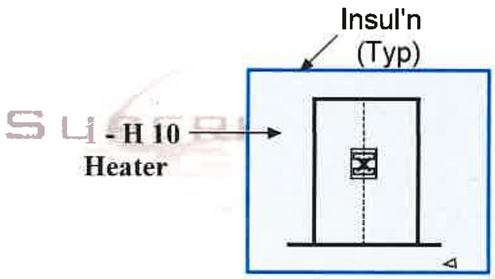
Standard Wrapping Specifications Sheet

TGR INDUSTRIAL SERVICES	1.5"Plate	Drawing #: 11
	Customer / ALS Maverick Test Lab	
	Line: PQ18-0381	
	PWHT / PO 3702	Material: Gr. 91

Weld #:________

PWHT cycles 1350º for 2 hours

Heaters Needed: 1- H 10's



Note:
- Insulation standard 1" thickness - 6 # density
- Insulation to extend Min 6 inches beyond heating element.
- **X** - Denotes T/C

11/01/2016 From: AMERICAN ALLOY STEEL, INC. To: MAVERICK TESTING LABRATORIES LLC
P.O.#: 1034 S.O.#: 557291 AA PL#: A96530
Item: 2 (10 PC) 1-1/2" X 6" X 24"
DOR = 6"

ARCELORMITTAL PLATE LLC

TEST CERTIFICATE

PAGE NO: 01 OF 02
FILE NO: 0284-01-32
MILL ORDER NO: 63598-002
MELT NO: U8487
SLAB NO: 8
DATE: 09/06/16

SHIP TO:
AMERICAN ALLOY STEEL
BNSF TR 7226 MILE 66.4
LN SEG 492
6230 N HOUSTON ROSSLYN RD
NORTH HOUSTON TX 77091

SOLD TO:
AMERICAN ALLOY STEEL, INC
P. O. BOX 40469
HOUSTON TX 77240-0469

SEND TO:

01-C

STEEL PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	1.5"	96"	480"	RECTANGLE	19602#

CUSTOMER INFORMATION

CUSTOMER PO: 108454

PART NO. 8

SPECIFICATION(S)

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE ORDER REQUIREMENTS AND SPECIFICATION(S).

ASME SA387 REV ED YR 07 GR 91 CL 2
ASTM A387 06A GR.91 CLASS 2
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2008 (CERTIFICATE NO. 30130) AND ISO 14001:2004 (CERTIFICATE NO. 49009).

CHEMICAL COMPOSITION (WT%) FOR ALL ELEMENTS EXCEPT H (PPM)

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:U8487	.09	.53	.011	.002	.10	.26	.13	8.40	.93

	V	TI	B	AL	ZR	CB	N
MELT:U8487	.214	.002	.0001	.006	.001	.078	.0409

MANUFACTURE

FINELINE - VACUUM DEGASSED

Certified a true copy of the original, retained in our file.
AMERICAN ALLOY STEEL, INC.
Reviewed By:
JP 9/23/2016

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PL/TEST	NORMALIZE	1925F	271	AIR COOL
PL/TEST	TEMPER	1450F	129	AIR COOL

AMERICAN ALLOY
PLATE # A96530

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Caroline McCormick
SUPERVISOR - TEST REPORTING
CAROLINE MCCORMICK

11/01/2016 From: AMERICAN ALLOY STEEL, INC. To: MAVERICK TESTING LABRATORIES LLC
P.O.#: 1034 S.O.#: 557291 AA PL#: A96530
Item: 2 (10 PC) 1-1/2" X 6" X 24"
DOR = 6"

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0284-01-32
MILL ORDER NO: 63598-002
MELT NO: U8487
SLAB NO: 8
DATE: 09/06/16

TENSILE PROPERTIES

SLAB NO.	LOC	DIR	YIELD STRENGTH PSI X 1000	TENSILE STRENGTH PSI X 1000	ELONGATION AFTER FRACTURE GAGE LGTH	%
8	BOT.	TRANS.	72	95	2.00"	24.0

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED
FOR SULFIDE SHAPE CONTROL.
TEST CERTS. ARE PREPARED IN ACCORD. WITH PROCEDURES
OUTLINED IN EN10204:2004 TYPE 3.1
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.USA.ARCELORMITTAL.COM/PLATE

B/L #02486 ATW 164028

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Caroline McCormick
SUPERVISOR – TEST REPORTING
CAROLINE MCCORMICK

voestalpine Bohler Welding USA Inc.

voestalpine Bohler Welding USA Inc.
10401 Greenbough Drive, Stafford, Texas 77477
Tel: +1 281-499-1212
Fax: +1 281-499-4347

Website www.voestalpine.com/welding

Euroweld, LTD.

255 Rolling Hills Rd
28117 Mooresville
USA

Certificate Schedule F

as per : ASME/AWS A5.01
No. : 2017-2025238475-900001-004
Rev. 0

PO no.	PO17-73	of	15.05.2017
Order no.	1025163729		
Delivery note/pos./splitt	2025238475/000010/900001	of	16.05.2017
Product	GMAW wire electrode		277433
Trade name	**THERMANIT MTS 3 LNi**		21835
Standard designation	AWS A5.28: ER90S-B9		1C77500G 0251
Dimension	0,9 mm		
Heat no.	102920		
Quantity	44,9 KG		

Chemical composition in % of the product

C	Si	Mn	P	S	Cr	Mo	Ni	V	Cu	Al	Nb	N		
0,10	0,38	0,64	0,005	0,001	8,78	0,91	0,04	0,20	0,02	< 0,01	0,06	0,04		

The product supplied shall meet the requirements of the applicable AWS filler metal specification, when tested in accordance with that specification.

Town	Date		Authorized representative
Stafford	17.05.2017	This certificate was issued by DP-equipment and does not require signature.	Russel Fuchs

voestalpine

PARTEK LABORATORIES

Phone 985-851-5310 Watts
1-800-445-4619
Fax 985-851-5312
www.parteklab.com
e-mail:
brenda@parteklab.com

PROFESSIONAL ENGINEERING
REG NO. C-01441

225 South Hollywood Road
Houma, LA 70360-2716

METALLURICAL TESTING – FAILURE ANALYSIS – WELD CONSULTING AND TESTING – CHEMISTRIES – HEAT TREATING

CERTIFICATE
OF
CALIBRATION

The measurements reported in this certificate were carried out using equipment whose measured values are traceable to National Standards.

All procedures employed and results reported are in conformance to the requirements of the original manufacturer.

The performance of the instrument was determined by comparison with the manufacturer's specification as found in the instrument handbook or other technical publications.

INSTRUMENT:	ALX II RS	SERIAL NO: 000204
MANUFACTURE:	The Validation Centre (TVC) Limited	
DATE OF CERTIFICATE:	May 10, 2018	
CALIBRATION DUE DATE:	May 10, 2019	
CERTIFICATE NO:	58889	
JOB NO:	N/A	
COMPANY:	Partek Laboratories 225 South Hollywood Road Houma LA 70360	

CALIBRATED BY: DOUG DONALDSON

SIGNED: Doug Donaldson

Partek LABORATORIES

Phone 985-851-5310 Watts
1-800-445-4619
Fax 985-851-5312
www.parteklab.com
e-mail:
brenda@parteklab.com

PROFESSIONAL ENGINEERING
REG NO. C-01441

225 South Hollywood Road
Houma, LA 70360-2716

METALLURICAL TESTING – FAILURE ANALYSIS – WELD CONSULTING AND TESTING – CHEMISTRIES – HEAT TREATING

A.L.X WELD MONITOR CALIBRATION REPORT

Calibration Conditions

Ambient Temperature during calibration: 70°F

Relative Humidity: 30%

Instruments used:

Type	Certificate #	Serial #
250 Turn Coil	28511	TVCIC28511
1705 DMM	FM20695	322370
DM 3058 MM	DM30581230003330	DM3L123000330
6614C PSU	6614CMY43000994	My43000994
TSX 3510 PSU	FM20695	347089
Fluke 714	CO-25385-1	1461074
WF Calibrator	0164.11	TVCTC27911
Gas Flow Calibrator	0321.11	GFC29211

PARTEK LABORATORIES

225 South Hollywood Road
Houma LA, 70360
985-851-5310

A.L.X. Weld Monitor Calibration report

General Condition:
Good

CLAMP	mV	0.4	mV	0.4	Temp	70	Humidity	30%

CURRENT

	Before	After
1000	1001	1000
750	752	750
500	502	500
375	376	375
250	248	250
125	126	125
50	51	50

VOLTAGE

	Before	After
100	100.4	100.0
75	75.4	75.0
50	50.2	50.0
25	25.0	25.0
5	4.9	5.0

ENERGY CHANNEL

	Before	After
80V,150A	602	600
60V'150A	451	450
40V,150A	301	300
20V,150A	151	150
25V50A	64	64

EQUIPMENT

Case:	OK
Controls:	OK
Meter:	OK
Connectors:	OK
Cables:	OK
Battery:	OK
Model #:	ALXII RS 0204
Date:	5/10/2018

COMMENTS:

Unit has passed calibration specifications as by the original manufacturer.

Signature: ______________________ Date: ____________

The Meter Shop, Inc
6934 Signat Dr.
Houston Texas 77041 www.metershop.com

Certificate of Calibration

For Instrument: Tempil Estick Thermometer
Serial Number: 4240
Certification/Asset Number: 12132
Measurement Standards : NIST

RMA / Work Order: 3071-DD
P.O.:

CUSTOMER: Maverick Testing Labs
10001 Porter Rd., Suite 100
La Porte TX 77571

The Meter Shop certifies that the above listed instrument meets or exceeds all specifications as stated in the referenced procedure unless otherwise noted). It has been calibrated using measurement standards traceable to the National Institute of Standards and Technology (NIST), or to NIST accepted intrinsic standards of measurement, or derived by the ratio type of self-calibration techniques. This calibration complies with MIL-STD-45662A and ANSI/NCSL Z540.3-2013. and ISO/IEC 17025: 2005. All calibrations are done in-house unless other wise noted.

Where applicable,the expanded uncertainty of measurement at the time of test is given in the following pages. They are calculated in accordance with the method described in the ISO Guide to the Expression of Uncertainty (GUM). The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k, such that the confidence level approximates 95%.

This report may not be reproduced, except in full, unless permission for the publication of an approved abstract is obtained in writing from The Meter Shop Inc issuing this report. See attached report of Calibration for data results.

CALIBRATION INFORMATION

Cal Date:	13 Jun 2018	Temperature	23.0°C	Pass	Y	Revision	
Next Cal Due:	13 Jun 2019	Humidity	45 %	Seals OK		Tech:	John

Remarks: FOUND-LEFT
Cal Procedure: Met/Cal: Digital Temperature:(1 yr)CAL VER/5500

STANDARDS USED FOR CALIBRATION

Asset Number	Description	Cal. Date	Due Date
5000	Fluke 5500A calibrator	23 Mar 2018	23 Mar 2019

Approved by: John Brown Lab Manager

Signed: JOHN BROWN

F

EXAMPLE OF A REPAIR PROCEDURE QUALIFICATION RECORD IN GRADE 91 STEEL USING ER80S-B8 FILLER MATERIAL, THE WAVEFORM CONTROLLED GMAW-S PROCESS FOR THE ROOT PASS, THE GMAW-P PROCESS FOR THE FILL PASSES AND NO POST WELD HEAT TREATMENT

MAVERICK TESTING LABORATORIES, INC.

10001 Porter Rd, Suite 100 La Porte, Texas 77571
Ph. 281-888-8210 Fax. 281-888-8212
Welding Procedures - Welder Performance - Materials Testing
Where Personal Service & Quality Meet

American Welding Society
Sustaining Company Member

Client:	Contact:	Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR:	-	Date Due:	11/02/2018
	WPS:	-	PO No.:	18-123
		Quote: 18-0433.4	Lab No.:	PQ18-0382

Welding Procedure Qualification per ASME Section IX
for 1.5" SA-387 Gr. 91 Welded To SA-387 Gr. 91
Process 1: GMAW-RMD, ER80S-B8 (Root)
Process 2: GMAW-P, ER80S-B8 (Balance)

Visual Testing (VT)

Acceptable – No relevant indications noted
Pat Patrick - 10/29/2018

Transverse Cross Weld Tensile Tests

Specification: ASME Section IX, QW-150 / QW-462.1(a) Test Method: QW-152

Specimen	Width Thickness	Area (in²)	.2% Offset Yield, Lbs.	.2% Offset Yield Strength (ksi)	UTL, Lbs.	UTS (ksi)	(%) EL.	(%) RoA	Fracture Location / Type
T1	.754 x .1.441	1.087	82,100	**75.5**	109,100	**100.4**	31.7	47.2	Base / Ductile
T2	.750 x 1.444	1.083	81,200	**75.0**	108,300	**100.0**	31.0	48.6	Base / Ductile

Transverse Side Bend Tests

Specification: NBIC Part 3 S8.4 (14% Elongation) Mandrel Size (in.): 2.3

Side Bend 1	Side Bend 2	Side Bend 3	Side Bend 4
Acceptable	Acceptable	Acceptable	Acceptable

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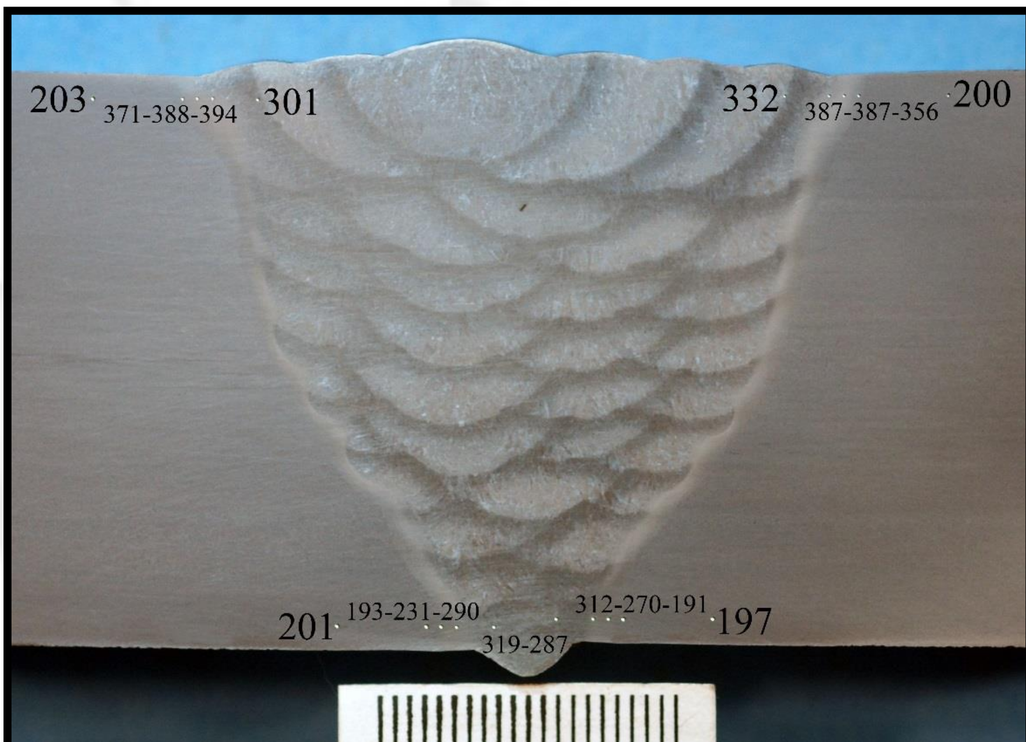
Client:	Contact:	Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR:	-	Date Due:	11/02/2018
	WPS:	-	PO No.:	18-123
	Quote:	18-0433.4	Lab No.:	PQ18-0382

Vickers Hardness Survey

Specification: API RP 934E
Hardness Scale: 10Kg

Magnification: Scale
Test Method: ASTM E384

LOCATION	BASE	HAZ	WELD	HAZ	BASE
Punch #	**1**	**2-3-4**	**5-6**	**7-8-9**	**10**
Cap	203	371-388-394	301-332	387-387-356	200
Punch #	**11**	**12-13-14**	**15-16**	**17-18-19**	**20**
Root	201	193-231-290	319-287	312-270-191	197



Specimen etched with Vilella's Reagent. Scale in mm.

MAVERICK TESTING LABORATORIES, INC.

10001 Porter Rd, Suite 100 La Porte, Texas 77571

Ph. 281-888-8210 Fax. 281-888-8212

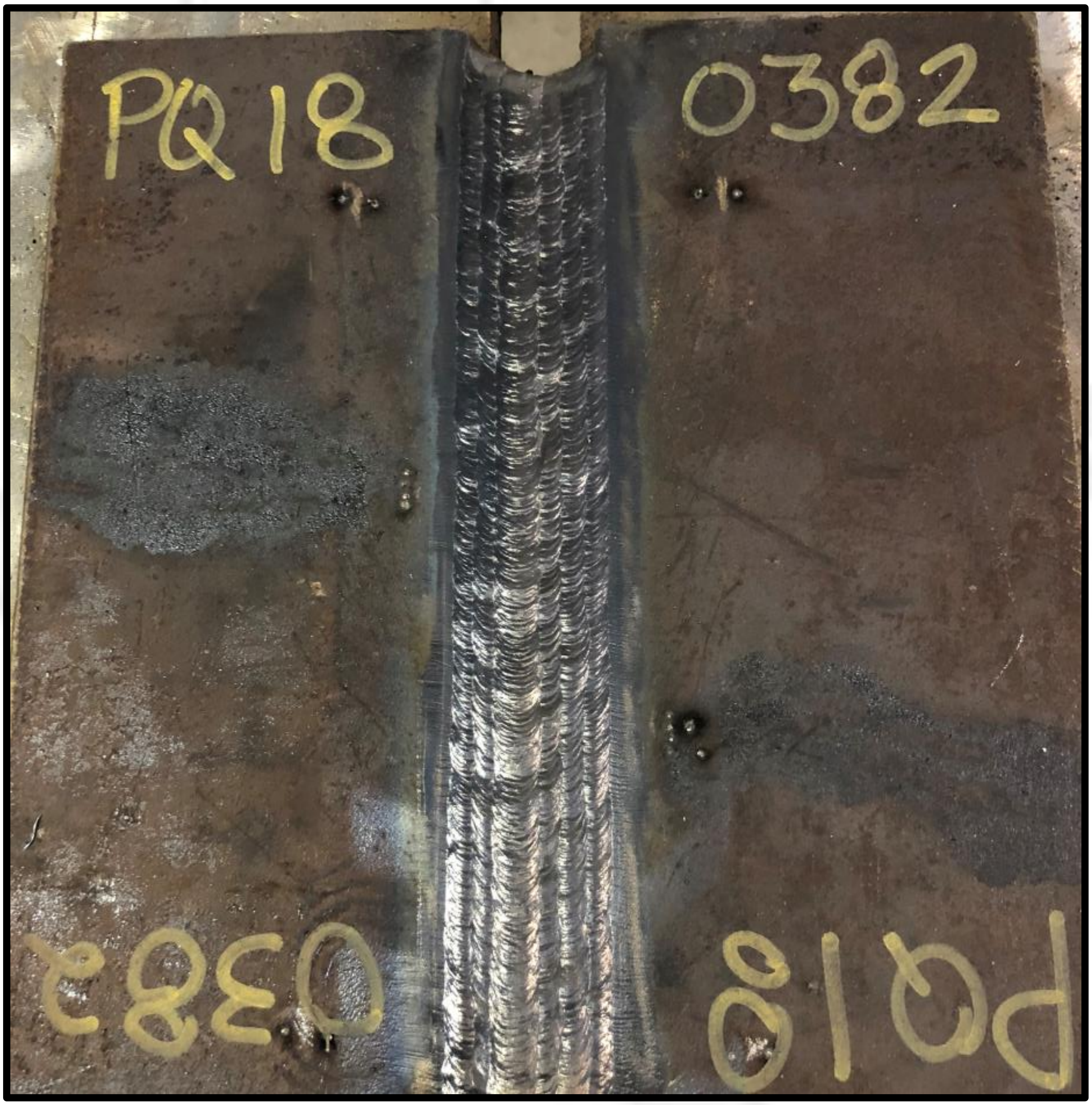
Welding Procedures - Welder Performance - Materials Testing

Where Personal Service & Quality Meet

American Welding Society
Sustaining Company Member

Client:	Contact: Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR: -	Date Due:	11/02/2018
	WPS: -	PO No.:	18-123
	Quote: 18-0433.4	Lab No.:	PQ18-0382

Welded Coupon



Rev 1. 29 September 2018

MAVERICK TESTING LABORATORIES, INC.

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Welding Procedures - Welder Performance - Materials Testing
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American Welding Society
Sustaining Company Member

Client:	Contact: Bill Newell / John Siefert	Date Rec'd	10/29/2018
	PQR: -	Date Due:	11/02/2018
	WPS: -	PO No.:	18-123
	Quote: 18-0433.4	Lab No.:	PQ18-0382

Test Specimens

Maverick Testing Laboratories, Inc. Representative

Brad Berglan

Rev 1. 29 September 2018

MAVERICK TESTING LABORATORIES,INC.
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ASME SECTION IX WELDING RECORD

Lab Number/ PQR Number	PQ18-0382	WPS record number	***Client to Determine***	Revision	0
Date	11/1/2018	Customer name			
Standard/Specification(s)	ASME IX, NBIC	and tested:	Without PWHT		

Base Metals (QW-403)

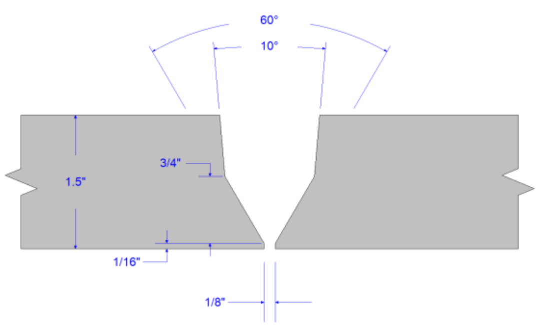
	Product form	Specification (type or grade)	P No.	Grp. No.	Size (in.)	Sch.	Thick. (in.)	Dia. (in.)
1	Plate	SA387-91-2	P15E	1	-	-	1.500	-
Welded to: 2	Plate	SA387-91-2	P15E	1	-	-	1.500	-

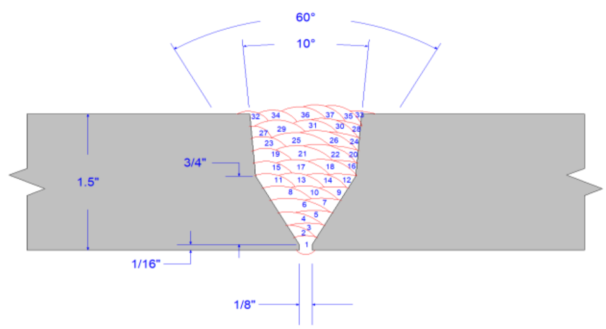
Heat Number(s):	Base Metal 1: U8487	Base Metal 2: U8487
PWHT Information:	No PWHT performed	Temp. / Soak Time: -
Notes:	No Backing Purge Shall be Used. RMD Root - Pulse Balance.	

Joints (QW-402)

Joint design	Single Vee Groove - Compound 3.5° x 3/4" 10° Balance	Welders Name	Craig Spindler
Backing:	Without	Identification Number	3198
Retainers	None	Stamp	-
Groove angle (deg.)	See Below		
Root opening (in.)	1/8"		
Root face (in.)	1/16"		

Weld Joint Detail	Weld Bead Sequence





Welding Processes

Welding Processes	GMAW - RMD	GMAW - Pulse	-
Type	Semi-Automatic	Semi-Automatic	-

Filler Metals (QW-404)

SFA specification	5.28		5.28		-	
AWS classification	ER80S-B8		ER80S-B8		-	
Filler metal F-number	6		6		-	
Weld metal A-number	5		5		-	
Filler metal product form	Solid Wire		Solid Wire		-	
Filler metal trade name	EUROWELD		EUROWELD		-	
Wire / Flux AWS Classification	N/A		N/A		-	
Flux Trade Name / Type	N/A		N/A		-	
Filler metal size (in.)	.045"	-	.045"	-	-	-
Filler metal Heat / Lot number	12/899-90802	-	12/899-90802	-	-	-
Deposited thickness (in.)	.165"		1.335"		-	
Maximum pass thickness (in.)	.165"		0.2500		-	
Weld deposit chemistry	CrMo		CrMo		-	
Supplemental filler metal	None		None		-	
Supplemental filler metal volume (ft³)	None		None		-	
Recrushed Slag	N/A		N/A		-	

Form 1.0
Rev. 2

MAVERICK TESTING LABORATORIES,INC.
10001 Porter Rd, Suite 100 La Porte, Texas 77571
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Welding Procedures - Welder Performance - Materials Testing
Where Personal Service Quality Meet

American Welding Society
Sustaining Company Member

ASME SECTION IX WELDING RECORD

Position (QW405) PQ18-0382

Position	1G	1G	-
Weld progression	N/A (Flat)	N/A (Flat)	-

Preheat (QW-406)

Preheat temperature (°F)	305°F	357°F	-
Maximum interpass temperature (°F)	357°F	438°F	-
Preheat Soak Time (M)	-	-	-
Post Weld Bake Out (^{0}F/M)	-	-	-

Gas (QW-408)

Shielding gas:	Type	90% ARGON, 10% CO2	90% ARGON, 10% CO2	-
	Flow rate (cfh)	35	35	-
Trailing gas:	Type	-	-	-
	Flow rate (cfh)	-	-	-
Backing gas:	Type	NONE	NONE	-
	Flow rate (cfh)	-	-	-

Electrical (QW-409)

Pass	Filler metal size (in.)	Process	Amperes			Volts			Travel speed (in./min)			Wire feed speed (in./min)	Maximum heat input (kJ/in.)
Root (1)	.045"	GMAW-RMD	116	-	126	15.9	-	16.5	6.7	-			18.62
Hot (2)	.045"	GMAW-Pulse	110	-	122	20.9	-	28.1	10.4	-	12.6		19.78
Fill (3)	.045"	GMAW-Pulse	110	-	118	20.5	-	21.2	8.0	-	8.7		18.76
Fill (4)	.045"	GMAW-Pulse	107	-	113	21.3	-	21.5	6.9	-	6.9		21.13
Fill (5)	.045"	GMAW-Pulse	105	-	112	21.2	-	21.6	6.5	-	8.3		22.33
Fill (6)	.045"	GMAW-Pulse	103	-	112	21.2	-	21.7	5.8	-	9.1		25.14
Fill (7)	.045"	GMAW-Pulse	103	-	114	21.1	-	21.6	5.5	-	6.5		26.86
Fill (8)	.045"	GMAW-Pulse	103	-	116	21.1	-	21.6	5.0	-	6.3		30.07
Fill (9)	.045"	GMAW-Pulse	101	-	112	21.2	-	21.3	5.4	-	6.2		26.51
Fill (10)	.045"	GMAW-Pulse	98	-	112	21.1	-	21.9	5.0	-	6.0		29.43
Cap (11)	.045"	GMAW-Pulse	96	-	110	21.1	-	22.2	4.8	-	6.6		30.53
				-			-			-			
				-			-			-			
				-			-			-			
				-			-			-			
				-			-			-			

Tungsten size (in.)	N/A	N/A	-
Tungsten type	N/A	N/A	-
Current/polarity	DCEP (Reverse)	DCEP (Reverse)	-
DC pulsing current	None	Yes	-
Arc transfer mode	Modified Short Circuit	Pulse Spray	-

Technique (QW-410)

String or weave	String	String & Weave	-
Orifice/gas cup size	3/8"	5/8"	-
C.T.W.D (in.)	1/4"	3/4"	-
Multi.single electrode	Single	Single	-
Multi/Single pass per side	Single	Multi/Bead Width 1/2" Maximum	-
Peening	None	None	-
Initial/interpass cleaning	Hand Brush,Grinding,Power Brushing	Hand Brush,Grinding,Power Brushing	-
Back gouging method	None	None	-

NOTES:

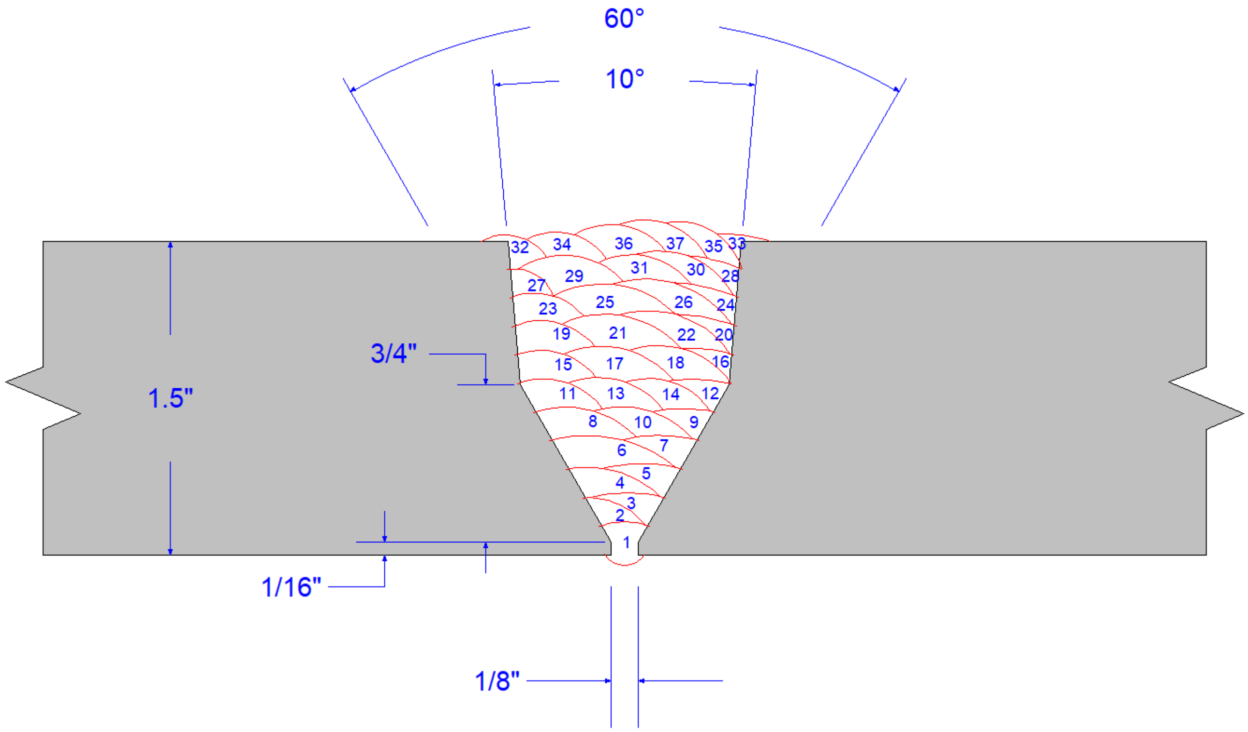
1. Preheat & Interpass temperature were monitored using a currently calibrated pyrometer. S/N 4240
2. Initial & Interpass cleaning was performed using mechanical wire brushing and by grinding to clean base material/ weld metal.
3. After Root Pass, Hot pass shall be split into two passes for the layer.
4. All subsequent weld passes shall be welded from the outside of the weld joint, into the center of the weld in order to temper the HAZ.
5. Welding Parameters were monitored using a calibrated weld data logger S/N 000204
6. 4T Bends per NBIC

Maverick Testing Laboratories, Inc. Representative:

Scott Witkowski — 11/9/2018

Signature — Date

Form 1.0
Rev. 2



Welders' Name: Craig Spindler SS#3198

- Pass 1 Layer 1 GMAW – RMD .045"
- Passes 2 – 37 Layer 2 - 10 GMAW – Pulse .045"

Contact Info	Print date	Page	Certificate Identification
NOE ALVAREZ	11/01/2018 14:03	1/2	HTNOV123

TGR INDUSTRIAL SERVICES

HEAT TREATMENT CERTIFICATE

CERTIFICATE IDENTIFICATION

Project Registration Number
HTNOV123

GENERAL INFORMATION

Company / Customer	Customer Contact	Phone Number
ALS / Maverick Testing	PAT PATRICK	N/A

Site / Job Location	Job Number
La Porte, Tx	HEAT# U8487 / U8487
Method Of Heat Treatment	**Type Of Heat Treatment**
Low Voltage Resist	Preheating
Material	**Purchase Order Number**
GR 91 / GR 91	3702

HEAT TREATMENT PROCEDURE

Part list

Drawing Number	Weld Number	T/C	Dia / Size	Wps Number	Notes
PQ18-0382	HN# U8487	TC 7	1.5" PLATE		GR 91
PQ18-0382	HN# U8487	TC 8	1.5" PLATE		GR 91

PROJECT INFORMATION

Start Of Heating	End Of Heating	Duration Of Heating	Used Energy Total
11/01/2018 06:46:26	11/01/2018 14:02:35	7h 16m 09s	0.0000 kWh

List Of Units

Nr.	Type	Serial Nr.	Calibration Date	Calibration Nr.	Sensor
1	Ice Star ISQi controller	767	05/24/2018 11:01	767 693 5	TYPE_K

Description and Notes

SUPERVISOR ACCEPTANCE

Supervisor Signature	Approved Date

CUSTOMER ACCEPTANCE

Customer Signature	Approved Date

Contact Info	Print date	Page	Certificate Identification
NOE ALVAREZ	11/01/2018 14:03	2/2	HTNOV123

HEAT TREATMENT DIAGRAM

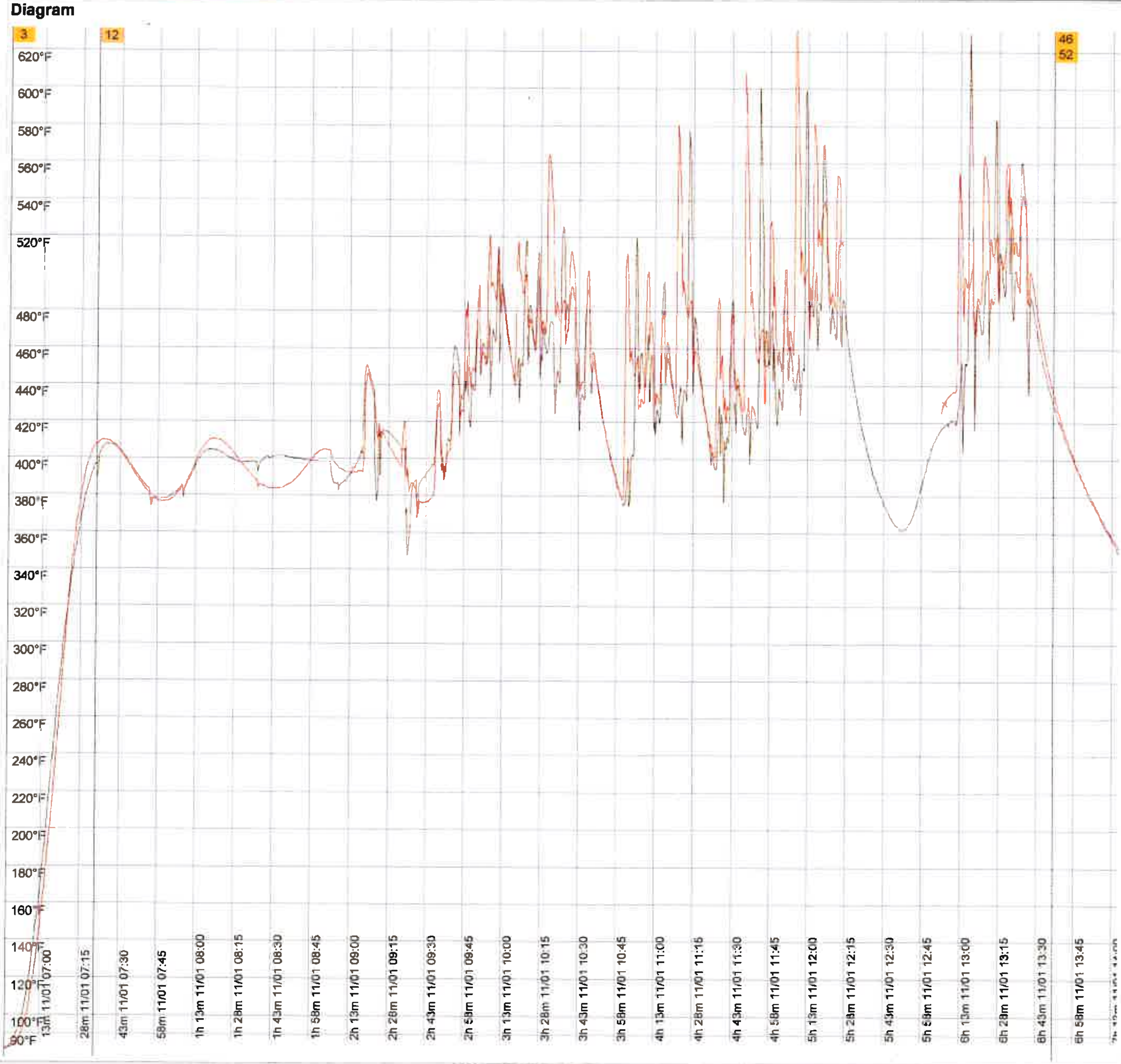
Phase List

Phase	Set Value	Measured Value Avg (Min-Max)	Duration
3 Heating	600°F/h > [400°F]	549°F/h 81°F > 398°F	34m 36s
12 Holding	400°F > USER	438.9°F (361.5°F - 565.5°F)	6h 15m 47s
46 Cooling	400°F/h > (432°F)	-648°F/h 432°F > 432°F	01s
52 Cooling	400°F/h > 100°F.	-189°F/h 432°F > 351°F	25m 40s

Point List

767:TC 8 767:TC 9

Diagram



SUPERVISOR ACCEPTANCE

Supervisor Signature	Approved Date

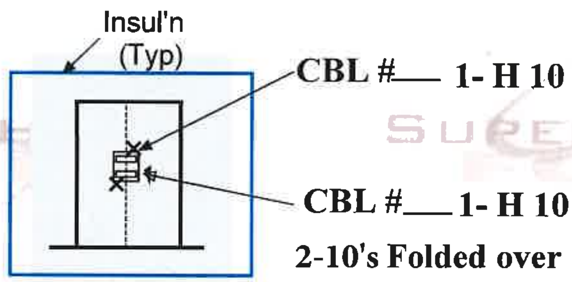
CUSTOMER ACCEPTANCE

Customer Signature	Approved Date

Standard Wrapping Specifications Sheet

TGR INDUSTRIAL SERVICES		
	1.5" to 1.5" Plate	Drawing # 9
	Customer / Location:ALS / Maverick Test Lab	
	Line#: PQ18-0382 / Heat# V8487	Line#: PQ18-0382 / Heat# V8487
	300 Deg. Preheat / PO 3702	Material: Gr. 91 / Gr.91

Heaters Needed: 2- H 10's



Note:
- Insulation standard 1" thickness - 6 # density
- Insulation to extend Min 6 inches beyond heating element.
- **X** - Denotes T/C

11/01/2016 From: AMERICAN ALLOY STEEL, INC.		To: MAVERICK TESTING LABRATORIES LLC
P.O.#: 1034	S.O.#: 557291	AA PL#: A96530
Item: 2 (10 PC) 1-1/2" X 6" X 24" DOR = 6"		

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

SHIP TO:
AMERICAN ALLOY STEEL
BNSF TR 7226 MILE 66.4
LN SEG 492
6230 N HOUSTON ROSSLYN RD
NORTH HOUSTON TX 77091

PAGE NO: 01 OF 02
FILE NO: 0284-01-32
MILL ORDER NO: 63598-002
MELT NO: U8487
SLAB NO: 8
DATE: 09/06/16

SOLD TO:
AMERICAN ALLOY STEEL, INC
P. O. BOX 40469
HOUSTON TX 77240-0469

SEND TO:

01-C

STEEL PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	1.5"	96"	480"	RECTANGLE	19602#

CUSTOMER INFORMATION

CUSTOMER PO: 108454

PART NO. 8

SPECIFICATION(S)

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE ORDER REQUIREMENTS AND SPECIFICATION(S).

ASME SA387 REV ED YR 07 GR 91 CL 2
ASTM A387 06A GR.91 CLASS 2
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2008 (CERTIFICATE NO. 30130) AND ISO 14001:2004 (CERTIFICATE NO. 49009).

CHEMICAL COMPOSITION (WT%) FOR ALL ELEMENTS EXCEPT H (PPM)

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:U8487	.09	.53	.011	.002	.10	.26	.13	8.40	.93

	V	TI	B	AL	ZR	CB	N
MELT:U8487	.214	.002	.0001	.006	.001	.078	.0409

MANUFACTURE

FINELINE - VACUUM DEGASSED

Certified a true copy of the original, retained in our file.
AMERICAN ALLOY STEEL, INC.
Reviewed By:
J.P. 9/23/2016

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PL/TEST	NORMALIZE	1925F	271	AIR COOL
PL/TEST	TEMPER	1450F	129	AIR COOL

AMERICAN ALLOY
PLATE # A96530

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Caroline McCormick
SUPERVISOR - TEST REPORTING
CAROLINE MCCORMICK

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0284-01-32
MILL ORDER NO: 63598-002
MELT NO: U8487
SLAB NO: 8
DATE: 09/06/16

TENSILE PROPERTIES

SLAB NO.	LOC	DIR	YIELD STRENGTH PSI X 1000	TENSILE STRENGTH PSI X 1000	ELONGATION AFTER FRACTURE GAGE LGTH	%
8	BOT.	TRANS.	72	95	2.00"	24.0

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED FOR SULFIDE SHAPE CONTROL.
TEST CERTS. ARE PREPARED IN ACCORD. WITH PROCEDURES OUTLINED IN EN10204:2004 TYPE 3.1
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO WWW.USA.ARCELORMITTAL.COM/PLATE

B/L #02486 ATW 164028

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Caroline McCormick
SUPERVISOR – TEST REPORTING
CAROLINE MCCORMICK

Certificate of Analysis

Date: 6/15/2009

EUROWELD, Ltd.
255 Rolling Hill Road
Mooresville, NC 28117 USA
704/662-3993 FAX:704/662-9820
http://www.euroweld.com
E Mail: euroweld@pobox.com

Sold To:	Ship To:

ITEM	SIZE	GRADE	LOT/HEAT NO.	QUANTITY
1	1.2mm (.045”)	ER80S-B8	12/899-90802	

SPECIFICATION: AWS A5.28-96 / ASME SFA 5.28 ER80S-B8

CERTIFIED MATERIAL TEST REPORT (CMTR) ACTUAL CHEMICAL ANALYSIS (%) AWS A5.01, Schedule H

C	Mn	Si	S	P	Cr	Ni	Mo	Nb	N
0.05	0.50	0.39	0.006	0.009	8.82	0.09	1.02		
O_2	**Ti**	**Al**	**V**	**Cu**	**Fe**	**As**	**Sn**	**Sb**	**Total**
				0.14	Bal.				Others < 0.50

ADDITIONAL TEST RESULTS

Ferrite:
Hardness:
X-Ray:

	As-Welded	Heat Treatment	Remarks
Bends:			
Toughness:			
Tensiles:			
Yield:			
Tensile			
Elong.			
Red. Of Area			

OTHER INFORMATION

33 Lb (15 Kg) Level Layer Wound Spools

We certify that the above material has been tested in accordance with the listed specification and is in conformance with all requirements.

Euroweld, Ltd.

PARTEK LABORATORIES

Phone 985-851-5310 Watts
1-800-445-4619
Fax 985-851-5312
www.parteklab.com
e-mail:
brenda@parteklab.com

PROFESSIONAL ENGINEERING
REG NO. C-01441

225 South Hollywood Road
Houma, LA 70360-2716

METALLURICAL TESTING – FAILURE ANALYSIS – WELD CONSULTING AND TESTING – CHEMISTRIES – HEAT TREATING

CERTIFICATE OF CALIBRATION

The measurements reported in this certificate were carried out using equipment whose measured values are traceable to National Standards.

All procedures employed and results reported are in conformance to the requirements of the original manufacturer.

The performance of the instrument was determined by comparison with the manufacturer's specification as found in the instrument handbook or other technical publications.

INSTRUMENT:	ALX II RS	SERIAL NO: 000204
MANUFACTURE:	The Validation Centre (TVC) Limited	
DATE OF CERTIFICATE:	May 10, 2018	
CALIBRATION DUE DATE:	May 10, 2019	
CERTIFICATE NO:	58889	
JOB NO:	N/A	
COMPANY:	Partek Laboratories 225 South Hollywood Road Houma LA 70360	

CALIBRATED BY: DOUG DONALDSON

SIGNED: Doug Donaldson

Partek LABORATORIES

Phone 985-851-5310 Watts
1-800-445-4619
Fax 985-851-5312
www.parteklab.com
e-mail:
brenda@parteklab.com

PROFESSIONAL ENGINEERING
REG NO. C-01441

225 South Hollywood Road
Houma, LA 70360-2716

METALLURICAL TESTING – FAILURE ANALYSIS – WELD CONSULTING AND TESTING – CHEMISTRIES – HEAT TREATING

A.L.X WELD MONITOR CALIBRATION REPORT

Calibration Conditions

Ambient Temperature during calibration: 70°F

Relative Humidity: 30%

Instruments used:

Type	Certificate #	Serial #
250 Turn Coil	28511	TVCIC28511
1705 DMM	FM20695	322370
DM 3058 MM	DM30581230003330	DM3L123000330
6614C PSU	6614CMY43000994	My43000994
TSX 3510 PSU	FM20695	347089
Fluke 714	CO-25385-1	1461074
WF Calibrator	0164.11	TVCTC27911
Gas Flow Calibrator	0321.11	GFC29211

PARTEK LABORATORIES

225 South Hollywood Road
Houma LA, 70360
985-851-5310

A.L.X. Weld Monitor Calibration report

General Condition:
Good

CLAMP	mV	0.4	mV	0.4	Temp	70	Humidity	30%

CURRENT

	Before	After
1000	1001	1000
750	752	750
500	502	500
375	376	375
250	248	250
125	126	125
50	51	50

VOLTAGE

	Before	After
100	100.4	100.0
75	75.4	75.0
50	50.2	50.0
25	25.0	25.0
5	4.9	5.0

ENERGY CHANNEL

	Before	After
80V,150A	602	600
60V'150A	451	450
40V,150A	301	300
20V,150A	151	150
25V50A	64	64

EQUIPMENT

Case:	OK
Controls:	OK
Meter:	OK
Connectors:	OK
Cables:	OK
Battery:	OK
Model #:	ALXII RS 0204
Date:	5/10/2018

COMMENTS:

Unit has passed calibration specifications as by the original manufacturer.

Signature: ____________________ Date: ____________

The Meter Shop, Inc
6934 Signat Dr.
Houston Texas 77041 www.metershop.com

Certificate of Calibration

For Instrument: Tempil Estick Thermometer

Serial Number: 4240
Certification/Asset Number: 12132
Measurement Standards : NIST

RMA / Work Order: 3071-DD
P.O.:

CUSTOMER: Maverick Testing Labs
10001 Porter Rd., Suite 100
La Porte TX 77571

The Meter Shop certifies that the above listed instrument meets or exceeds all specifications as stated in the referenced procedure unless otherwise noted). It has been calibrated using measurement standards traceable to the National Institute of Standards and Technology (NIST), or to NIST accepted intrinsic standards of measurement, or derived by the ratio type of self-calibration techniques. This calibration complies with MIL-STD-45662A and ANSI/NCSL Z540.3-2013. and ISO/IEC 17025: 2005. All calibrations are done in-house unless other wise noted.

Where applicable,the expanded uncertainty of measurement at the time of test is given in the following pages. They are calculated in accordance with the method described in the ISO Guide to the Expression of Uncertainty (GUM). The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k, such that the confidence level approximates 95%.

CALIBRATION INFORMATION

Cal Date:	13 Jun 2018	**Temperature**	23.0°C	**Pass**	Y	**Revision**	
Next Cal Due:	13 Jun 2019	**Humidity**	45 %	**Seals OK**		**Tech:**	John

Remarks: FOUND-LEFT
Cal Procedure: Met/Cal: Digital Temperature:(1 yr)CAL VER/5500

STANDARDS USED FOR CALIBRATION

Asset Number	Description	Cal. Date	Due Date
5000	Fluke 5500A calibrator	23 Mar 2018	23 Mar 2019

Approved by: John Brown Lab Manager

Signed: JOHN BROWN

Program:

Materials and Repair

3002015042

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com