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Replaceable Paddle Tip Fabrication and Testing for Saltstone Production Facility (SPF) Mixer - FY2020 Update

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May 2021

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EXECUTIVE SUMMARY

Report SRNL-STI-2019-00142 [Ref. 1] showed that the proposed replaceable tip designs (either flat or helical) for the READCO™ paddles could mechanically handle the expected loads in the mixer during processing. The major effort described in this document is the fabrication of the helical replaceable tip design, which also includes the heat treatment of the Astralloy-V to obtain the targeted mechanical properties by SRNL.

The hubs and tips fabricated by SRNL are not suitable for process use. Key distances for both the hubs and tips were not within tolerance and the heat treatment process caused warping of the wing sections of the tips. The fit up of both heat treated and non-heated tips to the hubs visually showed gaps between the mating surface, indicating that machining of the parts in themselves could be a contributor.

SRNL could not replicate the quenching READCO™ used in a vacuum furnace. To obtain the required hardness throughout, SRNL used the heat treatment curve provided by READCO™ but rather than using inert gas quenching, ice water was used. Because the environment in the furnace was oxidizing, a coating was used on the exposed surfaces during heat treatment to mitigate oxidation.

An SRNL heat treated/quenched sample was analyzed for toughness in two planes. The short-tranverse plane satisfied the toughness requirements. The longitudinal plane did not meet the fracture toughness criterion to the point where failure could occur along this plane if impacted with sufficient force. Such failures have been observed in the actual SPF READCO™ mixer.

The directions for making these hub and tips, starting from the incoming plates, EDM, and heat treatment have been provided. This method can be used for a starting point for future work, though a skimming approach to the final dimensions is needed.

A cyclical load test rig has been designed and fabricated and is ready for use.

Recommendations:

The fracture toughness results for the heat treated/quenched SRNL sample indicate highly non-isotropic conditions from impact, where failure could occur in one plane. SRNL recommends that a heat treatment process that removes this non-isotropic condition, or cross-rolled Astralloy-V be procured and tested, to determine if the material is more uniform and appropriate for use. This material would be used as baseline material for the hubs and tips.

If the properties of Astralloy-V can be made more uniform, SRNL further recommends hardening the contact surfaces on the tips using a carburization process.

Future mechanical testing should include Charpy testing in three planes to determine the uniformity and acceptance of the material.

Machining using the EDM will have to be modified so as to obtain the desired dimensions. Skimming operations will be required to obtain the final dimensions, especially for the surfaces where the hub and tip make contact with each other.

More advanced EDM techniques, such as plungers can be used to make cylindrical shapes for accepting the socket head cap screws. EDM can occur after heat treatment. Another attribute in using the plunger,

is the hub section where the socket head cap screw is secured, the plunger could be used such that the hole to be threaded would not have to be completely bore out, hence reducing potential pathways for the salt solution/grout to enter the threaded section.

The above recommendations will be pursed by SRNL and a second report will be issued. External vendors will be used to execute these efforts under the direction of SRNL. If successful, cyclic testing will be performed and the results will be in the second report.

If the properties of Astralloy-V cannot be made more uniform, it is recommended that an alternative material be selected that can satisfy the uniformity issue as well as the requirements for use in the READCO™ mixer. SRNL has procured five erosion resistant materials to support this effort, if needed. Additional funding will be required for this activity and the results from this testing would be in a third report.

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LIST OF ABBREVIATIONS

DSS	Decontaminated Salt Solution
EDM	Electric Discharge Machine
RPM	revolutions per minute
SHCS	Socket Head Cap Screws
SPF	Saltstone Production Facility
SRNL	Savannah River National Laboratory
SRR	Savannah River Remediation
TTR	Technical Task Request
W/P	water to premix ratio

1.0 Introduction

Details of the operations and issues related to the paddles used in the Saltstone Production Facility (SPF) employing the 10-inch READCO™-Kurimoto co-rotating dual shaft continuous mixer are provided in SRNL-STI-2019-00142 [Ref. 1].

Based on a recent effort performed by the Savannah River National Laboratory (SRNL) and funded by Savannah River Remediation (SRR), eight different replaceable paddle designs were proposed and the angled notched design was selected [Ref. 1] , Figure 1, for this study. This design was selected over the other designs due to its simplicity and its ability to meet the fitness of duty requirements (Table 3-1 of SRNL-STI-2019-00142, [Ref. 1]). There are two types of angled notched replaceable tip designs, one being flat (R-R4-Z-00016, [Ref. 2]) and the other helical (R-R4-Z-00013, [Ref. 3]). Either of these designs can be used for blending the premix with the salt solution. Stress calculations performed on this design (the use of the bolts and connections) are documented in M-CLC-Z-00137 [Ref. 4] showing it was suitable for use.

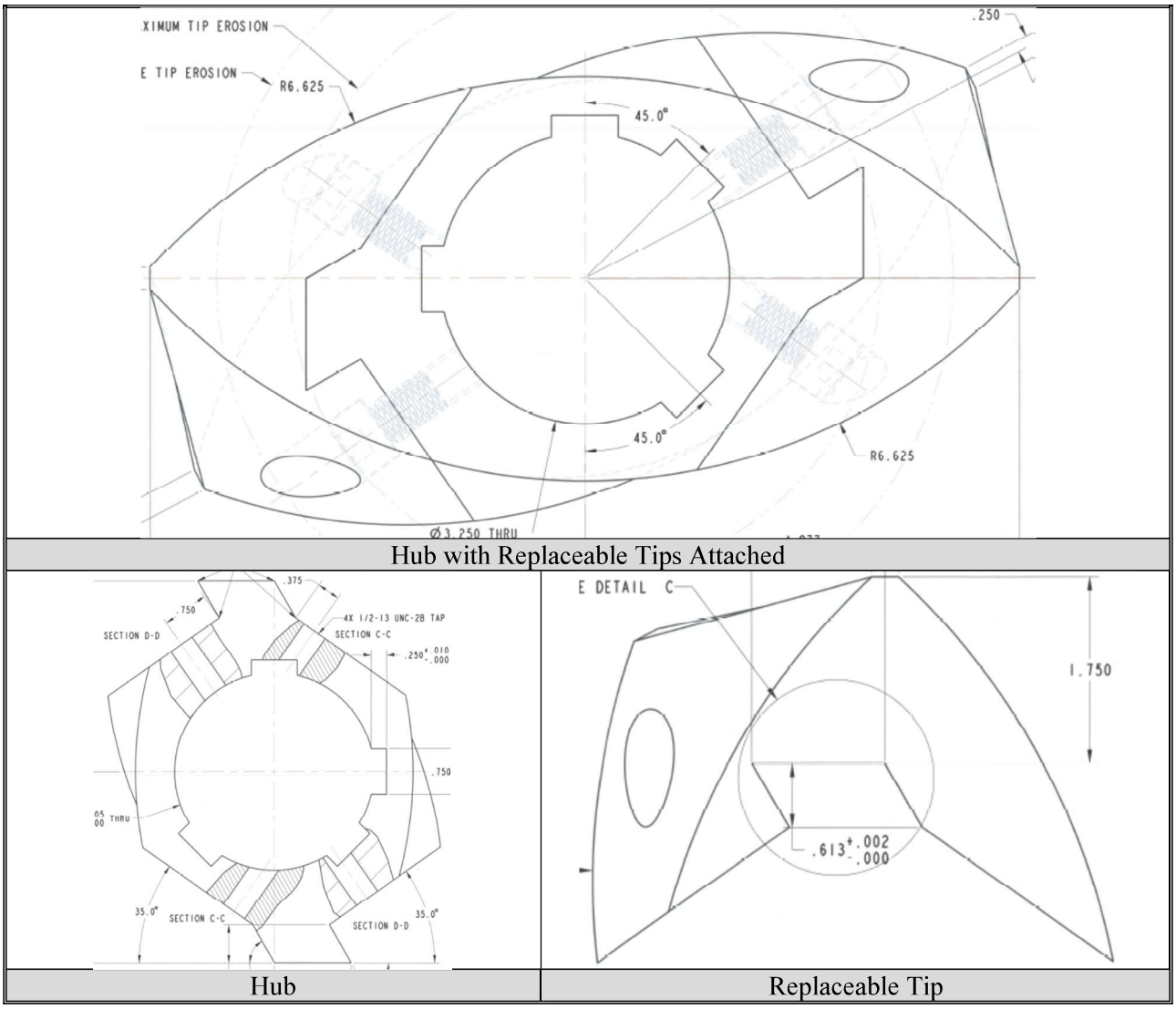

Figure 1 Helical Angled Notched Hub With Replaceable Helical Tips Paddle R-R4-Z-00013, [Ref. 3]

Based on the results from [Ref. 1], a Task Technical Request (TTR), M-TTR-Z-00019 [Ref. 5] was issued from SRR to the Savannah River National Laboratory (SRNL) with the following tasks:

1. Procure Astralloy-V materials. Procure sufficient materials to fabricate a total of 22 paddle hub/tips and an additional 22 replaceable tips. (20 for customer, 2 for testing). Procured materials must satisfy existing material specifications. (NOTE: SRNL has been provided a copy of SRR Acceptance Specifications for Astralloy-V paddles for an off-site vendor.)
2. Testing of the electric discharge machine (EDM) in cutting the paddle patterns using existing Astralloy-V material for proof of principle.
3. Fabricate paddles using EDM. Test sections of blocks to recertify material specifications. Verify bolting material satisfies design requirements; certification required.
4. Load testing to determine structural integrity of design. Load testing will be cyclical in nature.
5. Final report to include details on how to fabricate the paddles using EDM. Also include updated drawing showing the first seven paddles set contain replaceable tips. Report to include results from recertification testing.
6. Procure different (up to four (or five?)) materials for erosion characterization to determine if there are better materials for the replaceable tip as compared to Astralloy-V. Testing to be performed using the Miller machine.

Each of the items above will be discussed as well as the status of those items.

2.0 Experimental Procedure

2.1 Procurement of Astralloy-V Material

Sufficient quantities of as-received 2.125 inch thick x 5 inch wide x 20 inch long plates of Astralloy-V were procured. The quantity of Astralloy-V plates required are determined by overlaying hubs and tips onto a single plate to determine the quantity of hubs/tips that can be obtained from a single plate, the dimensions of the hub/tip are provided by drawing R-R4-Z-00013[Ref. 3]. The test specification(s) are compared to those of the plate used by READCO™ and differences greater than 10% are reported. Appendix A contains the test specification [Ref. 6] of recently procured Astralloy-V paddles from READCO™. The test specification are from Nucor, the company which produces the Astralloy-V alloy. A total of 22 hubs and 66 tips are required for fabrication.

2.2 Testing EDM – Proof of Principle

The as-received plates are 2.125" thick and are milled to 2" thick. EDMs, which uses a hot thin electrical wire carrying voltage/current, are used to cut the tips and hubs from the 2.125" thick milled Astralloy-V plates. Details from drawing R-R4-Z-00013 are programed into the EDMs for both the hubs and tips and these programs will be included in this report. Any changes required due to the limitations of the EDM are presented to SRR prior to making the necessary physical changes to the tips/hubs. If there are changes, such is reflected in a new drawing, R-R4-Z-00022 [Ref. 7].

2.3 Fabrication of Hubs and Tips

After the paddles are fabricated by READCO™, they are heat treated to satisfy the specifications in Table 2-1. An example of the reported hardness and fracture toughness data from READCO™ are provided in Appendix B. READCO™ also provided the heat treatment curve (in Appendix C) used to obtain the reported hardness and fracture toughness properties. The heat treatment occurred in a vacuum furnace and is forced cooled (quenched) using nitrogen gas. SRNL will initially follow this heat treatment curve for the

tips and samples. If SRNL cannot replicate this heat treatment curve to obtain the necessary hardness, the methods SRNL utilizes to obtain the required hardness are reported. The hubs will not be heat treated, given they will not observe wear. The reported hardness by READCO™ were obtained from the surfaces as visually observed by SRNL. It is unclear to SRNL in what plane the fracture toughness was obtained.

SRR has provided SRNL one sample of as-received (from Nucor) and one sample of heat treated Astralloy-V (from READCO™) for testing. Hardness measurements were performed using ASTM E18 [Ref. 8] on these samples, where both external and internal measurements are obtained to determine the uniformity of the hardness. SRNL prepared samples (and tips) and hardness measurements were performed on both the internal and external surfaces. A single sample fracture toughness measurement was made in two orthogonal planes. The fracture toughness measurement is obtained using an qualified external laboratory following ASTM E23 [Ref. 9].

Table 2-1. Recommended Material Property Acceptance Criteria for SPF Mixer Paddles Fabricated from Astralloy-V

Material Property	Specification		Testing Method	Required Documentation	Acceptance Criteria
	Min	Max			
Hardness [BHN/Rc]	480/51	512/54	ASTM E10 or E18	Mixer Vendor Inspection Report	Fail below min
Fracture Toughness [Ft-lbs at 32 ºF]	25	35	ASTM E23	Astralloy-V Vendor CMTR	Based on SRNL/SRR Review
Surface Roughness	10	100	Inspection or Topography	Mixer Vendor inspection report	Fail above max

Two hex bolts, ½ inch – 13 threads per inch, ¾ inch long, 316 stainless steel socket head cap screws (SHCS), with thread locking nylon patch are used for securing a tip to the hub. The SHCS used to secure the tips must have certifications that satisfies the dimensions per ASME B18.3 [Ref. 10] and chemical/mechanical properties per ASTM F837 [Ref. 11]. These hex bolts will have a nylon patch on the threads to keep the hex bolts from backing out. Hex bolts used for initial fit up or installation testing do not need to have certifications or the nylon patch.

Dimensional measurements of the finished hubs and caps are obtained and the distances are those identified on drawing R-R4-Z-00022, see appendix F. The drawing provides key physical dimensions with unique identifiers of the hub, tip and a combination of the tips installed onto the hubs. For the case where the tips are attached to the hub, the SHCS is torqued to 25 ± 3 ft-lbs (per M-CLC-Z-00137) for these measurements.

2.4 Cyclical Load Tester Rig

A cyclical load tester rig has been designed and fabricated. The load tester has the capability of producing the nominal and maximum loads specified in M-CLC-Z-00137. The number of cycles per minute is specified by the design. Bench top equipment cannot rotate at 238 RPM in a safe manner, hence a lower cycle rate will be used. Given the cycle rate, the total number of cycles will be used as a basis of operating time when this testing occurs.

2.5 Detail Fabrication of Paddles and Updating Drawings

Details of how the paddles were fabricated by SRNL, starting with the plate to the finished products, are provided in this report. This includes the EDM programing.

Tips/hubs issued to SRR for use will have recertification reports on each hub/tip that is provided. The SHCS used for the actual process will have certification as described in Section 2.3.

A drawing showing the first six sets of paddles after the pre-mix auger as replaceable tip paddles, consistent with drawing D274737 [Ref. 12] have been provided (Appendix N).

2.6 Procurement and Miller Testing of Alternative Materials

Up to four different metals that are used in erosion type environments have been procured. The chemical composition and mechanical properties, such as hardness and strength, will be measured when a decision to proceed with this activity is approved by the customer. Heat treatment might be required to obtain effective erosion properties prior to erosion testing based on the hardness results. Erosion testing measurements using the Miller Machine will be used to compare the erosion characteristics of these metals as compared to the baseline and heat treated Astralloy-V.

2.7 Quality Assurance

This work was requested via a Technical Task Request [Ref. 5] and directed by a Task Technical and Quality Assurance Plan, SRNL-RP-2019-00396 [Ref. 13]. The functional classification of this task is Production Support. This task is not waste form affecting and does not need to follow the quality assurance requirements of RW-0333P. Microsoft Excel was used to support this work. Data are recorded in the PerkinElmer E-Notebook under experiment C9827-00219-04 [Ref. 14]. Requirements for performing reviews of technical reports and the extent of review are established in Manual E7, Procedure 2.60 [Ref. 15]. This document, including all Microsoft Excel and JMP calculations, was reviewed by a Design Check. SRNL documents the extent and type of review using the SRNL Technical Report Design Checklist contained in WSRC-IM-2002-00011, Rev. 2 [Ref. 16].

3.0 Results and Discussion

3.1 Procurement of Astralloy-V

The number of hub and tips that can be obtained from a single plate are shown in Figure 3-1. A total of 25 plates were procured for testing and final fabrication purposes. Appendix D contains the Astralloy-V test specification for these plates and contain the material data sheets from Nucor. The plates were procured from Cheokee Steel Company and are 2.125 inch thick, 5 inch wide, and 20 inch long and were flame cut from stock. It must be noted that Astralloy-V is a proprietary alloy; hence there are no standards for which the alloy must specifically conform to. Comparing the specification from READCO (Appendix A) to that of the Astralloy-V SRNL procured, differences greater than 10% that are significant and worth noting include: (1) temper temperature hold time, (2) elongation, and (3) Charpy-V. Item (1) is controlled by Nucor. Subsequent heat treatment to the as-received Astralloy-V will impact items (2) and (3). If a non-inert environment is used during heat treatment, this could also impact the chemical/mechanical properties of surfaces that are exposed to an oxygen environment, creating an oxidized surface.

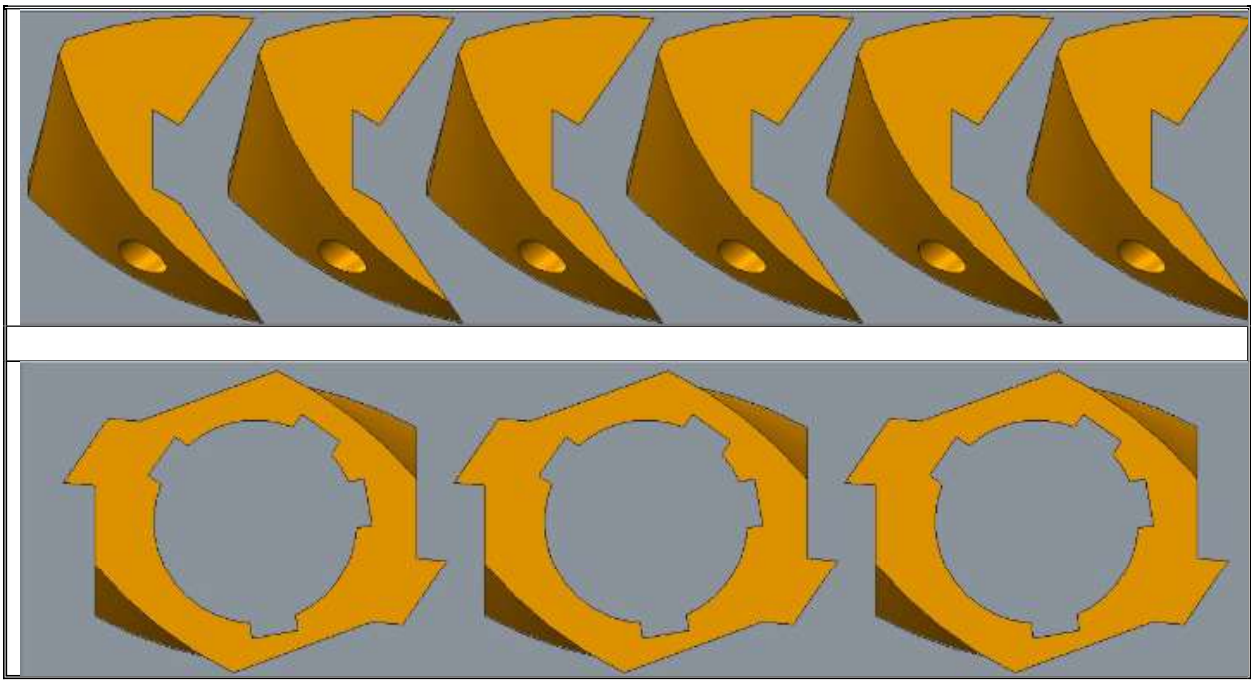

Figure 3-1. Tips and Hubs from a 5" wide x 20" Long Plate

3.2 Testing EDM – Proof of Principle

The EDM could fabricate the hub that holds the 27.5 degree helical tip. Multiple approaches in trying to fabricate the 27.5 degree helical tip were unsuccessful using the SRNL Machine Shop EDMs. An effort was taken to determine an acceptable angle which the EDM could cut tips and it was determined that a 20 degree angle was suitable for EDM fabrication. This information was relayed to SRR with a recommendation to reduce the angle to 20 degrees and was accepted. A new replaceable paddle drawing, R-R4-Z-00022 [Ref. 7] reflects these changes.

During this proof of principle approach, it was determined that the holes for the SHCS in the tips needed to be slightly increased given the available tooling. The holes through which the SHCS fits onto the hub were increased from 0.530 to 0.531 inches. The hole where the cap of the SHCS fits increased from 0.775 to 0.781 inches. Finally, the length of the threaded section was reduced from 1 inch to ¾ inch, given 1 inch was too long and could not be fully threaded onto the hub without making contact with the shaft. Per M-CLC-Z-00137, the minimum thread engagement is 0.29 inches, hence the ¾ inch threaded length is sufficient (actual thread engagement is 0.423 inches).

3.3 Results from the Fabrication of Hubs and Tips

Details of the fabrication process are provided in Section 3.5. The as-received Astralloy-V was used in the fabrication of the hubs using the EDM. The chemical and mechanical properties of the hubs are provided in Appendix D. No heat treatment is required of the hubs, given they are not expected to observe the erosive environment of the tips. A total of 22 hubs were fabricated.

For the tips, heat treatment is required to obtain the properties stated in Table 2-1 and the normalizing temperature (1450 ^{o}F) utilized by READCO^{TM} were used in most of the tests. Some tests used a normalizing temperature of 1650 ^{o}F. Normalizing temperatures were maintained for two hours. Quenching at the normalizing temperature was performed using different fluids such as gas, water and ice bath. After

quenching, the samples were tempered at 300 °F for two hours to remove residual stresses. Details of the heat treatments tests and material characterization efforts by SRNL are provided in SRNL-L3310-2020-00016 [Ref. 17], see Appendix E. Summarized below are the findings from that report. A total of 44 tips were fabricated and heat treated.

(1) Astralloy-V® is a proprietary alloy with limited available metallurgical data.
(2) READCO™ heat treated sample average Rockwell C hardness values were 47 on both the interior and exposed surface. These measurements did not satisfy minimum Rockwell C hardness requirements of 51.
(3) SRNL does not have vacuum furnaces that have sufficient quench rates. A local vendor could not reproduce the necessary quench rate using a high flow furnace. Measured Rockwell C hardness values for samples heat treated by SRNL and by the local were below the minimum requirement of 51.
(4) A coating (No Carb Green) was used to prevent oxidation on the exposed surface due to the environment in the furnace at temperature..
(5) Ice quenching was the only method that yielded Rockwell C hardness as specified in Table 2-1. The Rockwell C hardness was consistent internally and on external surfaces, see Table 3 in Appendix E.
(6) Charpy results of orthogonal measurements showed a large difference, 31.6 (short-transverse) and 8.3 (longitudinal) ft-lbs, respectively. The larger value satisfies the toughness requirement 25 to 35 ft-lbs. The lower value fails and indicates the material can easily fracture in that plane. Fracture failure was observed in the failure of SPF paddles.
(7) All the fabricated and heat treated/quenched tips satisfied the Rockwell C hardness values as measured on the exposed surface.
(8) Carburization (carburizing heat treatment) is recommended for the wetted parts of the tips to provide a superior wear resistance surface, while maintaining the toughness for impact resistance.

After the hubs and caps were fabricated, measurements (calipers were verified with M&TE block EA-306 prior to use) were made of the individual hubs and caps, but the number of measurements were limited when it was observed there were large variances in this small subset that were outside the tolerances. The distances measured are shown on R-R4-Z-00022 (Appendix F). This data is shown in Table 3-1 and measurements that were outside the tolerances are highlighted red. At this point, some of the caps were placed onto the hubs and it was observed that a significant gap existed (visually) between the contact surfaces of the tip and hub as observed in Figure 3-2. The wings of the tips were slightly deformed and pinched inward. This deformation was due to the ice quenching step in the heat treatment process. This cause does not explain the differences noted in Table 3-1.

SRNL then processed some of the heat treated tips by skimming away the inward pinch on the wings of the tip using the EDM. An aluminum hub (i.e., just the surface of the tip making contact with the hub) was used by the shop to determine if the skimming operation was acceptable. Additional tips that were not heat treated and not bored out (for the SHCS) were included in this activity. One H/T tip that was not skimmed was used for this activity. In this activity, each tip was placed on five different EDM and machined (threaded) hubs and three EDM and non-machined hubs (e.g. hubs that were not tapped and drilled). The tips were held in place on the diffenent hubs using hand pressure The mating surfaces between the hub and tip were visually observed for gaps and if none was present it was recorded. If a gap was present in both the front and back surfaces, this result was recorded. This activity examined if the tip/hub interface was consistent, and this consistency included comparing how each tip fit on each of the hub stubs (e.g., each hub has two stubs where a tip can fit) and on different hubs. The results from this activity are shown in Table 3-2. Figure 3-2 shows the location of the front and back surfaces that are referenced in this table and the two stubs. To interpet Table 3-2, lets use HUB # H-002 from the first hub connection that was measured as an example. In this case, both tips A and D had no gap between the tip and the hub. For tips B, C, 8, and 21, no gap was observed on the front surface (see Figure 3-2) of the tip/hub interface, but gaps were present on the back surface (hence not recorded). No tips made full contact with only the back surface. Finally,

tips 4 and 18 did not make full contact with either the front or back surfaces. For the vast majority (the None column), there were gaps present for most combinations. The front surface seemed to have better contact than the back surface. As expected, the tip that was heat treated but not skimmed had gaps on both sides and is the None column. Tips that were not even heat treated failed this test, indicating the EDM method of cutting needs to be reassessed. It is speculated that skimming will be required to obtain the required dimensions and tolerances.

Table 3-1. Key Measuring Distances for Fabricated Hubs and Tips

Hub #	Length			Bore					
	Specified	Tolerance	Actual: L1	Specified	Tolerance	Actual: L2	Actual: L3		
H-001	5.746"	±0.002"	5.750	3.253"	+0.002"	3.251	3.250		
H-002	5.746"	±0.002"	5.748	3.253"	+0.002"	3.250	3.252		
H-003	5.746"	±0.002"	5.760	3.253"	+0.002"	3.252	3.251		
Hub #	Keyway						Thickness		
	Specified	Tolerance	Actual: L4	Actual: L5	Actual: L6	Actual: L7	Specified	Tolerance	Actual: L8
H-001	.751"	+0.002"	0.750	0.750	0.751	0.750	2.000"	-0.002"	1.980
H-002	.751"	+0.002"	0.751	0.751	0.751	0.755	2.000"	-0.002"	2.004
H-003	.751"	+0.002"	0.750	0.750	0.751	0.750	2.000"	-0.002"	2.005
Tip #	Notch to Tip			Thickness					
	Specified	Tolerance	Actual: L9	Specified	Tolerance	Actual: L10			
T-001	2.000"	±0.002"	2.005	2.000"	-0.002"	2.015			
T-002	2.000"	±0.002"	2.002	2.000"	-0.002"	2.014			
T-003	2.000"	±0.002"	2.007	2.000"	-0.002"	2.002			
T-004	2.000"	±0.002"	2.004	2.000"	-0.002"	2.002			
T-005	2.000"	±0.002"	2.010	2.000"	-0.002"	2.010			
T-006	2.000"	±0.002"	2.005	2.000"	-0.002"	2.011			

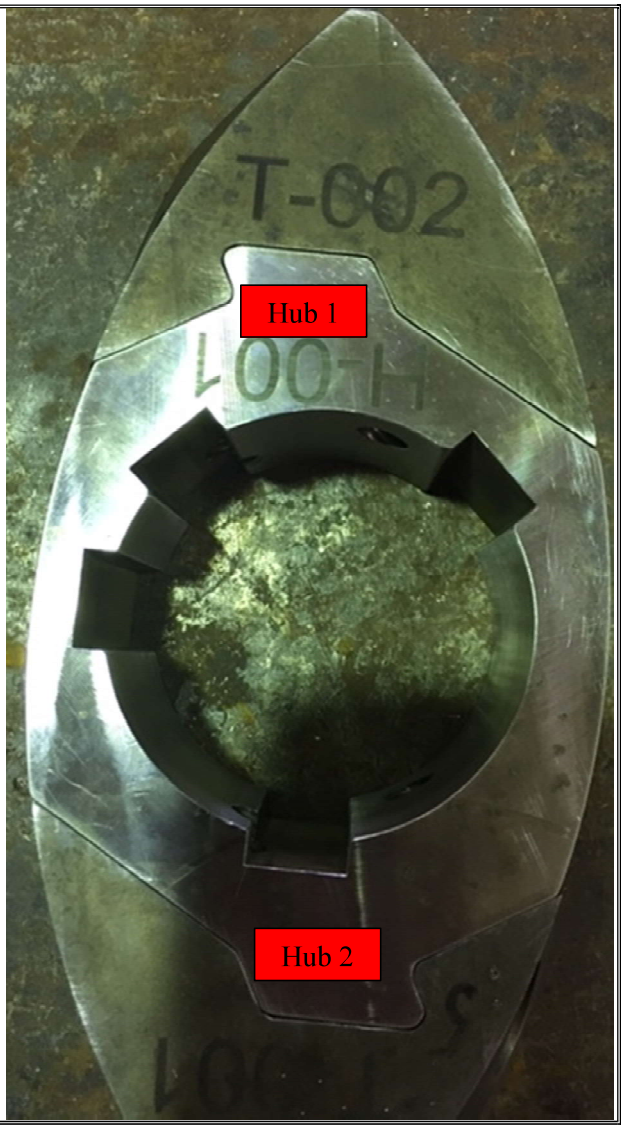

Figure 3-2. Visual Gap Between Seating Surface of Tip and Hubs

Table 3-2. Fit Up with Tips and Hubs

	TIP IDENTIFIERS	
EDM only	A, B, C, D	
EDM, machined, HT	4, 8, 18, 21	4 was not skimmed
	HUB IDENTIFIERS	
EDM, machined	2, 4,5, 9, 11	
EDM only	E, F, G	

Results from one of the hub connection

HUB #	Both, Tips	Count	Front, Tips	Count	Back, Tips	Count	None, Tips	Count
H-002	A,D	2	B,C,8,21	4			4,18	2
H-004			A,B,C,D,8,21	6			4,18	2
H-005					A,8	2	B,C,D,4,18,21	6
H-009	8	1	A,B,D,21	4			C,4,18	3
H-011			A,B,C,D,8,21	6			4,18	2
E			A,B,C,D,8,18,21	7			4	1
F			A,B,C,D,8,21	6			4,18	2
G					A,B,C,D	4	4,8,18,21	4
Total		**3**		**33**		**6**		**22**

Results from the other hub connection

HUB #	Both, Tips	Count	Front, Tips	Count	Back, Tips	Count	None, Tips	Count
H-002			A,B,D,8,21	5			C, 4,18	3
H-004	A,B,C,D,8,21	6					4,18	2
H-005	8	1	A,B,C,D,21	5			4,18	2
H-009	8	1	A,B,21	3			C,D,4,18	4
H-011			C,8,21	3			A,B,D,4,18	5
E	8	1	B,21	2			A,C,D,4,18	5
F	8	1	A	1	18,21	2	B,C,D,4	4
G					8,21	2	A,B,C,D,4,18	6
Total		**10**		**19**		**4**		**31**

3.4 Cyclical Load Tester

A cyclical load test rig was designed (Figure 3-3) and fabricated. The test rig applies a cyclical force to the tip of a replaceable paddle to determine if it would fail after a total number of cycles as determined by the user. The test rig can cycle a maximum of 60 revolutions (or cycles) per minute. Using a variable speed direct current motor, the cam shown in the top left figure in Figure 3-4, is repeatedly driven into the adjacent water filled hydraulic cylinder. The cam/hydraulic system can generate a force up to 3000 pounds, the maximum load specified in M-CLC-Z-00137, and is applied by the piston, shown in the top right figure in Figure 3-4. As the cylinder is compressed, it drives the piston into the tip of paddle as shown in the bottom left figure in Figure 3-4. The resulting pressure/force and the rate at which it is applied is recorded using a pressure transducer and a load cell. The data generated by these instruments is plotted in real time as shown in the bottom right figure in Figure 3-4. Testing of actual hub/tip combinations was not peformed due to fit up issues.

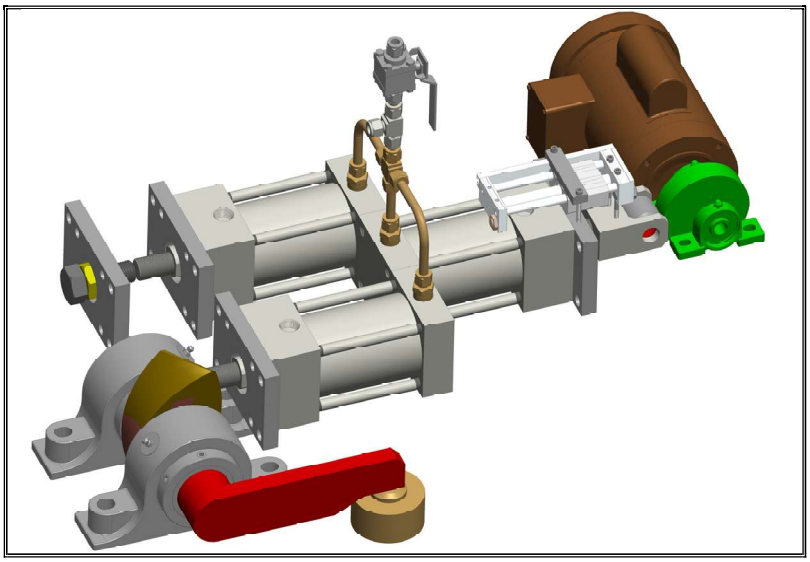

Figure 3-3. Design of Cyclical Load Tester For Hub and Tip

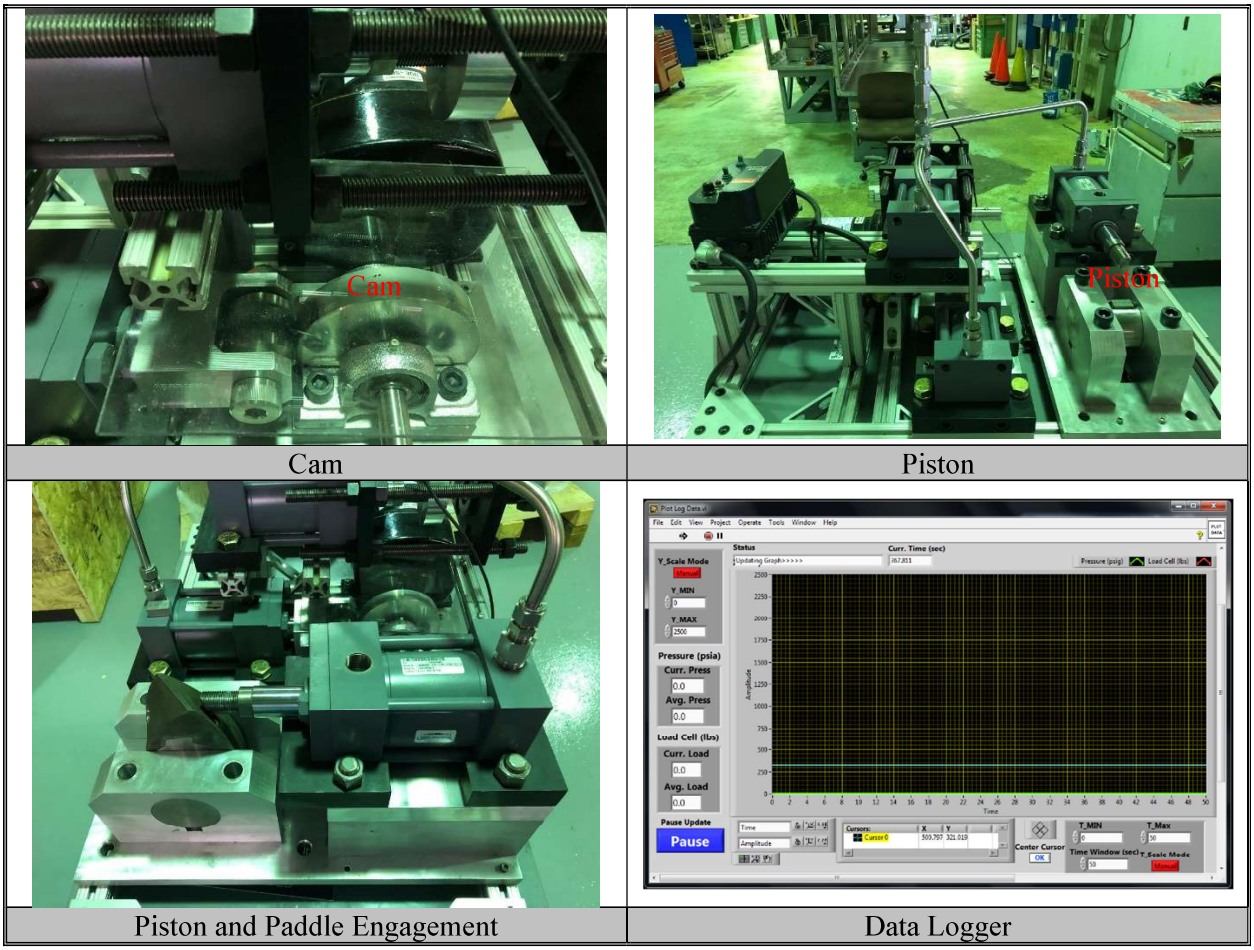

Figure 3-4. As-Fabricated Cyclical Load Tester

3.5 Detail Fabrication of Paddles and Updating Drawings

The steps used by SRNL machine shop follow:

(1) The as-received Astralloy-V plate thickness of 2.125 inches was milled to approximately 2.0 inches using a knee mill and the scaring was removed.
(2) The 5 inch sides were squared.

HUBS

(3) The Astralloy-V plates used for hubs were drilled ¼ inch in the center about 6 inches apart.
(4) The plates were cut into 6 inch sections
(5) The 6 inch section is placed into the EDM and secured. The ¼ inch hole is the reference point.
(6) The center section (shaft) and keyways were cut (EDM program, Appendix G).
(7) The EDM wire is started approximately ½ inch off the side of the hub just beyond the center, which gives the sufficient offset time and aligns with the helix on the side of the hub.
(8) The ends with angled keyed ends are cut and the hub removed. (EDM program, Appendix H)
(9) The hub is tapped and drilled for the ½ inch x 13 threads.

TIPS

(10) Plate is placed into and secured into the EDM and the EDM auto function finds the center line.
(11) First cutter path cuts the radial tip (EDM program, Appendix I)
(12) The wire direction is changed to permit the front (EDM program, Appendix J) and back side (EDM program, Appendix K) of the tip to be cut.
(13) The EDM wire to enter and exit fully for an offset to permit tip taper cut (EDM program, Appendix L)
(14) The tip was cut off with angled key cut (EDM program, Appendix M)
(15) Bolt Holes were milled using a Hass CNC mill and jig that matched the angled key shape from the tip.
(16) Heat treatment of the tips were performed as stated in SRNL-L3310-2020-00016.

A drawing for the layout of the replaceable tips as configured in the READCO™ mixer is provided in Appendix N. The final helical tip drawing in Appendix O.

Given there were no tips or hubs provided to the customer for use, no recertification document has been provided.

3.6 Procurement of Alternative Materials

Readily available roll or plate was procured from McMaster-Carr for Miller testing. The list of materials and use are provided in Table 3-3 and were selected due to having impact and/or wear resistance attributes. The chemical composition and density of these materials are shown in Table 3-4 with that of Stellite 12 and Astralloy-V. This list shown in Table 3-4 is by no means a comprehensive list of material that could be suitable for the in-line mixing process at Saltstone.

Miller testing was performed on as-received Astralloy-V and Ultimet test pieces. Hardness measurements on both the wear and non-wear surfaces were performed to determine if the Miller Machine work hardened the test pieces [Ref. 13]. The results indicated there was slight work hardening, but not to the point where it raised the hardness to the requirements in Table 2-1.

Table 3-3. Procured Metals from McMaster-Carr for Testing

Material	Use
4340	structural applications that involve extreme impact, heat, and wear
4140	hardened for increased abrasion and impact resistance
C300	excellent resistance to cracking from impact and compression
E52100	extremely hard and wear-resistant material
9310	superior strength, hardness, and fatigue resistance over other types of alloy steel

Table 3-4. Chemical Composition of Density of Procured Metals

		Material						
		4340	4140	C300	E52100	9310	Stellite 12	Astralloy V
Chemical Composition (%)	Fe	95.195 - 96.33	96.785 - 97.77	Balance	Balance	Balance	3.0	Balance
	Ni	1.65 - 2.00		18.5		3.00 - 3.50	3.0	4.00
	Cr	0.70 - 0.90	0.80 1.10		1.3 - 1.6	1.00 -1.40	30.0	2
	Mn	0.60 - 0.80	0.75 - 1.0	0.1	0.25 - 0.45	0.45 - 0.65		1.2
	C	0.37 - 0.43	0.38 - 0.43	0.3	0.98-1.10	0.08-0.13	1.55	0.29
	Mo	0.20 - 0.30	0.15 - 0.25	4.8		0.08-0.15	1.0	0.5
	Si	0.15 - 0.30	0.15 – 0.30		0.15-0.30	0.15-0.30	2.0	0.1
	S	0.04	0.04	0.1	0.025	0.025		0.01
	P	0.035	0.035		0.025	0.025		0.015
	Co			9.00			Balance	
	Tl			0.6				
	Al			0.1				
	W						8	
	Others						0.5	
Density (g/cc)		7.85	7.85	8.02	7.81	7.85	8.53	7.85

4.0 Conclusions

The hubs and tips fabricated by SRNL are not suitable for process use. Key distances for both the hubs and tips were not within tolerance and the heat treatment process caused warping of the wing sections of the tips. The fit up of both heat treated and non-heated tips to the hubs visually showed gaps between the mating surface, indicating that machining of the parts in themselves could be a contributor.

Testing showed that the heat treated READCO™ sample analyzed by SRNL did not satisfy the hardness requirements. This negative result was for both internal (samples were removed via EDM and analyzed) locations and from the surface.

SRNL could not replicate the quenching READCO™ used in a vacuum furnace. To obtain the required hardness throughout, SRNL used the heat treatment curve provided by READCO™ but rather than using inert gas quenching, ice water was used. Because the environment in the furnace was oxidizing, a coating was used on the exposed surfaces during heat treatment to mitigate oxidation..

An SRNL heat treated/quenched sample was analyzed for toughness in two planes. The short-tranverse plane satisfied the toughness requirements. The longitudinal plane did not meet the fracture toughness

criterion to the point where failure could occur along this plane if impacted with sufficient force. Such failures have been observed in the actual SPF READCO™ mixer.

The directions for making these hub and tips, starting from the incoming plates, EDM, and heat treatment have been provided. This method can be used for a starting point for future work, though a skimming approach to the final dimensions is needed.

A cyclical load test rig has been designed and fabricated and is ready for use.

Changes to the original helical angle from 27.5 to 20 degrees were determined via initial testing to support the use of the EDM to fabricate the tips. Without this change, the EDM could not make the tips. Additional changes for fitting the SHCS through the tips were made to match available tooling. The length of the SHCS as reduced from 1 inch to ¾ inch due to the threaded section being too long. The ¾ inch length satisfies the minimum thread engagement.

Drawings reflecting the changes to the hub/tip are shown in R-R4-Z-00022 (Appendix O). An additional drawing was supplied to SRR showing where the replaceable paddles would be installed on the shafts of the READCO™ mixer and is shown in Appendix N.

Five different metals that reportedly have impact and/or wear resistance attributes have been procured for future testing.

5.0 Recommendations, Path Forward or Future Work

The fracture toughness results for the heat treated/quenched SRNL sample indicates highly non-isotropic conditions from impact, where failure could occur in one plane. SRNL recommends that a heat treatment process that removes this non-isotropic condition or cross-rolled Astralloy-V be procured and tested to determine if the material is more uniform and appropriate for use. This material would be used as baseline material for the hubs and tips.

If the properties of Astralloy-V can be made more uniform, SRNL further recommends hardening the contact surfaces on the tips using a carburization process.

Future mechanical testing should include Charpy testing in three planes to determine the uniformity and acceptance of the material.

Machining using the EDM will have to be modified so as to obtain the desired dimensions. Skimming operations will be required to obtain the final dimensions, especially for the surfaces where the hub and tip make contact with each other.

More advanced EDM techniques, such as plungers, can be used to make cylindrical shapes for accepting the socket head cap screws. EDM can occur after heat treatment. Another attribute in using the plunger is the hub section where the socket head cap screw is secured, the plunger could be used such that the hole to be threaded would not have to be completely bore out, hence reducing potential pathways for the salt solution/grout to enter the threaded section.

The above recommendations will be pursed by SRNL and a second report will be issued. External vendors will be used to execute these efforts under the direction of SRNL. If successful, cyclic testing will be performed and the results will be in the second report.

If the properties of Astralloy-V cannot be made more uniform, it is recommended that an alternative material be selected that can satisfy the uniformity issue as well as the requirements for use in the

READCO™ mixer. SRNL has procured five erosion resistant materials to support this effort, if needed. Additional funding will be required for this activity and the results from this testing would be in a third report.

6.0 References

1. E.K. Hansen, K.R. Hera, W.T. Lozier, and C.A. McKeel, "Conceptual Design for Replaceable Paddle for the Saltstone Production Facility (SPF) Mixer," SRNL-STI-2019-00142, Rev. 0, 2019.

2. W. Lozier, "Saltstone Flat Paddle with Interchangeable Tips, Angled Notch Design Assembly and Details," R-R4-Z-00016, Rev. A, 2018.

3. W. Lozier, "Saltstone Helical Paddle, Interchangeable Tips Angled Notch Design Assembly and Details," R-R4-Z-00013, Rev. A, 2018.

4. C. McKeel, "Structural Analysis of Saltstone Mixer Paddle Replaceable Tips," M-CLC-Z-00137, Rev. 0, 2019.

5. S. Shah, "Mixer Split Design Paddle - Phase II SRNL Fabrication and Delivery," M-TTR-Z-00019, Rev. 0, 2019.

6. S. Shah, "8.0-Analysis and Design Reports," SRRA093893-000004, 2016.

7. W. Lozier, "Saltstone Helical Paddle, Interchangeable Tips Angled Notch Design Assembly and Details," R-R4-Z-00022, Rev. 0, 2019.

8. ASTM International, "Standard Test Methods for Rockwell Hardness of Metallic Materials," ASTM E18-19, 2019.

9. ASTM International, "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials ", ASTM E23-18, 2018.

10. ASME, "Socket Cap, Shoulder, Set Screws, and Hex Keys (Inch Series)," B18.3, 2012.

11. ASTM International, "Standard Specification for Stainless Steel Socket Head Cap Screws," ASTM F837-20, 2020.

12. READCO™ KURIMOTO, "Paddle Assembly 10 Cp," D274737, Rev. A, 2014.

13. E.K. Hansen, K.R. Hera, and K.J. Imrich, "Task Technical and Quality Assurance Plan to Fabricate and Test a Replaceable Paddle Design and Additional Erosion Testing of Harden Materials for the Saltstone Mixer," SRNL-RP-2019-00396, Rev. 0, 2019.

14. "Saltstone Paddle Design," Electron Laboratory Notebook C9827-00219-04, 2018.

15. Manual E7, "Conduct of Engineering, Procedure 2.60 - Technical Reviews," Savannah River Site, 2018.

16. "Savannah River National Laboratory - Technical Report Design Check Guidelines," WSRC-IM-2002-00011, Rev. 2, 2004.

17. K.J. Imrich, "Heat Treatment of Astralloy V for Saltstone Replaceable Mixer Paddles," SRNL-L3100-2020-00016, Rev. 0, 2020.

Appendix A. Astralloy-V Test Certificate, Dimensions, Weight, Chemical Composition, Heat Treatment, Brinell Hardness, Tensile Strength, and Charpy, Readco Material

OSR 45-11(Rev 10-22-2008)

Savannah River Site

Supplier Document Status

- ☐ 1.Work May Proceed
- ☐ 2.Submit Final Document - Work may proceed
- ☐ 3.Revise and Resubmit - Work may proceed subject to Resolution of Comments
- ☐ 4.Revise and Resubmit. Work may not Proceed.
- ☒ 5.Permission to proceed is not required.

Permission to proceed does not constitute acceptance or approval of design details, calculations, test methods, analysis or materials developed or selected by the supplier, and does not relieve supplier from full compliance with contractual obligations or release of any 'holds' placed on the contract.

Document ID	Revision
SRRA093893-000004	**A**

Document Category	Date
8.0-ANALYSIS AND DESIGN REPORTS	**2016-11-30 17:23:10 PM, EST**

Reviewer
SHAH, SATISH CHUNILAL

READCO PO 14813-00 PART # 274738 # 1

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO:

01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2008 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 009496).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

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PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
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BIRMINGHAM AL 35217

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TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

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CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

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TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

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ACID SOLUBLE ALUMINUM
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PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

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PART NO. 7

SPECIFICATION(S)

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	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
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PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

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MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

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SEND TO:

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1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

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CHEMICAL COMPOSITION

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MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

[redacted]

[redacted]

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738 # 5

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO:

01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2008 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 009496).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

[redacted]

[redacted]

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738 # 6

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO: 01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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AWT ASTRALLOY-V REV 7 YR 99 AP-1
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CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
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ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

[redacted]

[redacted]

[redacted]

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738 # 7

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO: 01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
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CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.			LAT.EXP.(INCH)		
BOT.	LONG.	+32F	FULL	35	37	40	.013	.015	.017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
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ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

[redacted]

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738 # 8

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO: 01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
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CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

[redacted]

[redacted]

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738 # 9

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO:

01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
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CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

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WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738 #10

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO: 01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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

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CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.			LAT.EXP.(INCH)		
BOT.	LONG.	+32F	FULL	35	37	40	.013	.015	.017

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ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

[redacted]

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738 # 11

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO: 01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2008 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 009496).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

[redacted]

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738 # 12

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO: 01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 30094

PART NO. 7

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2008 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 009496).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

[redacted]

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

READCO PO 14813-00 PART # 274738
TEST

T E S T C E R T I F I C A T E

ARCELORMITTAL PLATE LLC

PAGE NO: 01 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
RED HOLLOW ROAD
BIRMINGHAM AL 35217

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO:

01-C

P L A T E D I M E N S I O N S / D E S C R I P T I O N

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

C U S T O M E R I N F O R M A T I O N

CUSTOMER PO: 30094

PART NO. 7

S P E C I F I C A T I O N (S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
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C H E M I C A L C O M P O S I T I O N

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:C9229	.26	.91	.009	.004	.19	.25	3.39	1.46	.29

	V	AL	CB
MELT:C9229	.006	.026	.002

M A N U F A C T U R E

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE

H E A T T R E A T C O N D I T I O N

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	61	AIR COOL
PLT	TEMPER	450F	176	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

M E C H A N I C A L P R O P E R T I E S

SLAB - 8A - BRINELL PER E110 (HBW) - 437 435 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-01
MILL ORDER NO: 23965-001
MELT NO: C9229
SLAB NO: 8A
DATE: 01/13/14

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1620	2328	2.00"	9.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.	LAT.EXP.(INCH)
BOT.	LONG.	+32F	FULL	35 37 40	.013 .015 .017

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).
ACID SOLUBLE ALUMINUM
FOR MORE INFORMATION AND PROCESSING GUIDELINES, REFER TO
WWW.ARCELORMITTAL.COM/PLATEINFORMATION

B/L #40073 CUSTOMER'S TRUCK

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

Appendix B. Charpy and Hardness Results of Readco™ Heat Treated Astralloy-V

OSR 45-11(Rev 10-22-2008)

Savannah River Site

Supplier Document Status

- ☐ 1.Work May Proceed
- ☐ 2.Submit Final Document - Work may proceed
- ☐ 3.Revise and Resubmit - Work may proceed subject to Resolution of Comments
- ☐ 4.Revise and Resubmit. Work may not Proceed.
- ☒ 5.Permission to proceed is not required.

Permission to proceed does not constitute acceptance or approval of design details, calculations, test methods, analysis or materials developed or selected by the supplier, and does not relieve supplier from full compliance with contractual obligations or release of any 'holds' placed on the contract.

Document ID	Revision
SRRA093893-000006	**A**

Document Category	Date
8.0-ANALYSIS AND DESIGN REPORTS	**2016-11-30 17:23:10 PM, EST**

Reviewer
SHAH, SATISH CHUNILAL

LABORATORY TESTING INC.
2331 Topaz Drive, Hatfield, PA 19440
TEL: 800-219-9095 • FAX: 800-219-9096

Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 1

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

The services performed above were done in accordance with LTI's Quality System Program Manual Revision 20 dated 12/12/12 and ISO/IEC 17025. These results relate only to the items tested and this report shall not be reproduced, except in full, without the written approval of Laboratory Testing, Inc. L.T.I. is accredited by Nadcap for NDT and Materials Testing for the test methods and specific services as listed in the Scopes of Accreditation available at www.labtesting.com and www.eAuditNet.com. The results reported on this test report represent the actual attributes of the material tested and indicate full compliance with all applicable specification and contract requirements.

MERCURY CONTAMINATION: During the testing and inspection, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing devices employing a single boundary of containment.

NOTE: The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

LABORATORY TESTING INC.
2331 Topaz Drive, Hatfield, PA 19440
TEL: 800-219-9095 • FAX: 800-219-9096

Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT #2

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

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Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT #3

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

LABORATORY TESTING INC.
2331 Topaz Drive, Hatfield, PA 19440
TEL: 800-219-9095 • FAX: 800-219-9096

Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 4

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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MERCURY CONTAMINATION: During the testing and inspection, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing devices employing a single boundary of containment.

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

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TEL: 800-219-9095 • FAX: 800-219-9096

Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 5

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

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2331 Topaz Drive, Hatfield, PA 19440
TEL: 800-219-9095 • FAX: 800-219-9096

Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 6

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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QA Supervisor
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TEL: 800-219-9095 • FAX: 800-219-9096

Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 7

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

LABORATORY TESTING INC.
2331 Topaz Drive, Hatfield, PA 19440
TEL: 800-219-9095 • FAX: 800-219-9096

Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 8

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

The services performed above were done in accordance with LTI's Quality System Program Manual Revision 20 dated 12/12/12 and ISO/IEC 17025. These results relate only to the items tested and this report shall not be reproduced, except in full, without the written approval of Laboratory Testing, Inc. L.T.I. is accredited by Nadcap for NDT and Materials Testing for the test methods and specific services as listed in the Scopes of Accreditation available at www.labtesting.com and www.eAuditNet.com. The results reported on this test report represent the actual attributes of the material tested and indicate full compliance with all applicable specification and contract requirements.

MERCURY CONTAMINATION: During the testing and inspection, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing devices employing a single boundary of containment.

NOTE: The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

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Certified Test Report

IDI001-16-09-34103-1

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Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 9

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

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Certified Test Report

IDI001-16-09-34103-1

Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 10

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

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Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 11

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

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Certified Test Report

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Accredited Nadcap
Materials Testing Laboratory
Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMPACT # 12

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

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Certified Test Report

IDI001-16-09-34103-1

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Nondestructive Testing

CUSTOMER P.O.	CERTIFICATION DATE	SHIP VIA
4859	9/26/2016	EMAIL, UPS GROUND

DESCRIPTION

Quantity: 1
Part No.: 274738 CHARPY
Description: 2" THK x 5" x 7" Test Sample
Job No.: STOCK (1)

READCO PO 014813-00 PART # 274738 CHARPY IMAPCT # TEST

CHARPY V-NOTCH IMPACT TESTING:
SPECIMEN TYPE: Notched, 1/4 Thickness
APPLICABLE SPECIFICATIONS: ASTM E23-16b and Customer's Requirements
KEY: C - Conforms NC - Non-Conformance R-Report for Information

SAMPLE ID	(°F) TEMP	(FT-LBS.) ENERGY	(INCHES) LAT. EXP.	(%) SHEAR	SPECIMEN SIZE	KEY C/NC/R
Required	+ 32	25 MIN-35 MAX				
1		31	0.008	30	Full Size 10mm x 10mm	C
2		32	0.009	30	Full Size 10mm x 10mm	C
3		33	0.009	30	Full Size 10mm x 10mm	C

Procedures/Methods: MAS-CV-G, Rev. 12, General Procedure for Charpy Impact Testing

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NOTE: The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Cindy Heckler
QA Supervisor
[redacted]
Authorized Signature

OSR 45-11(Rev 10-22-2008)

Savannah River Site

Supplier Document Status

- ☐ 1.Work May Proceed
- ☐ 2.Submit Final Document - Work may proceed
- ☐ 3.Revise and Resubmit - Work may proceed subject to Resolution of Comments
- ☐ 4.Revise and Resubmit. Work may not Proceed.
- ☒ 5.Permission to proceed is not required.

Permission to proceed does not constitute acceptance or approval of design details, calculations, test methods, analysis or materials developed or selected by the supplier, and does not relieve supplier from full compliance with contractual obligations or release of any 'holds' placed on the contract.

Document ID	Revision
SRRA093893-000003	**A**

Document Category	Date
8.0-ANALYSIS AND DESIGN REPORTS	**2016-11-30 17:23:10 PM, EST**

Reviewer
SHAH, SATISH CHUNILAL

metlab
1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT #1

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	1
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 51.6 HRC

METLAB [redacted]
Quality Representative Rachel Piccari
MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 2

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	2
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari
MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 3

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	3
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari

MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
1000 E. Mermaid La., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 4

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	4
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari

MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 5

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	5
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari
MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
1000 E. Mermaid Ln., Wyndmoor (Philo.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 6

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	6
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

[redacted]

METLAB
Quality Representative Rachel Piccari

MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 7

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	7
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari

MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
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Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 8

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	8
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari
MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
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Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 9

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	9
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari

MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

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Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 10

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	10
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari
MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 11

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	11
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari
MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # 12

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	12
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari
MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

metlab
1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 14813-00 PART # 274738 HT # TEST

Certification

September 8, 2016

Metlab Shop Order:	93192
Purchase Order:	4816
Part Number:	274738
Heat Number:	13
Description:	2-1/8" x 6" x 10"
Material:	Astralloy V Alloy Steel
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above and conform to the specification requirements.

Results:

Surface Hardness: 52 HRC

METLAB [redacted]
Quality Representative Rachel Piccari

MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting

Appendix C. Final Heat Treatment Profile for Astralloy-V for Readco Paddles

metlab
1000 E. Mermaid La., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 17530-00 PART # 170862-7 # 1

Certification

May 2, 2019

Metlab Shop Order:	104513 /WO#3365-1
Purchase Order:	6017
Part Number:	170862
Quantity:	1 Piece
Weight:	28 Pounds
Material:	Astralloy V
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above with the following results

Results:

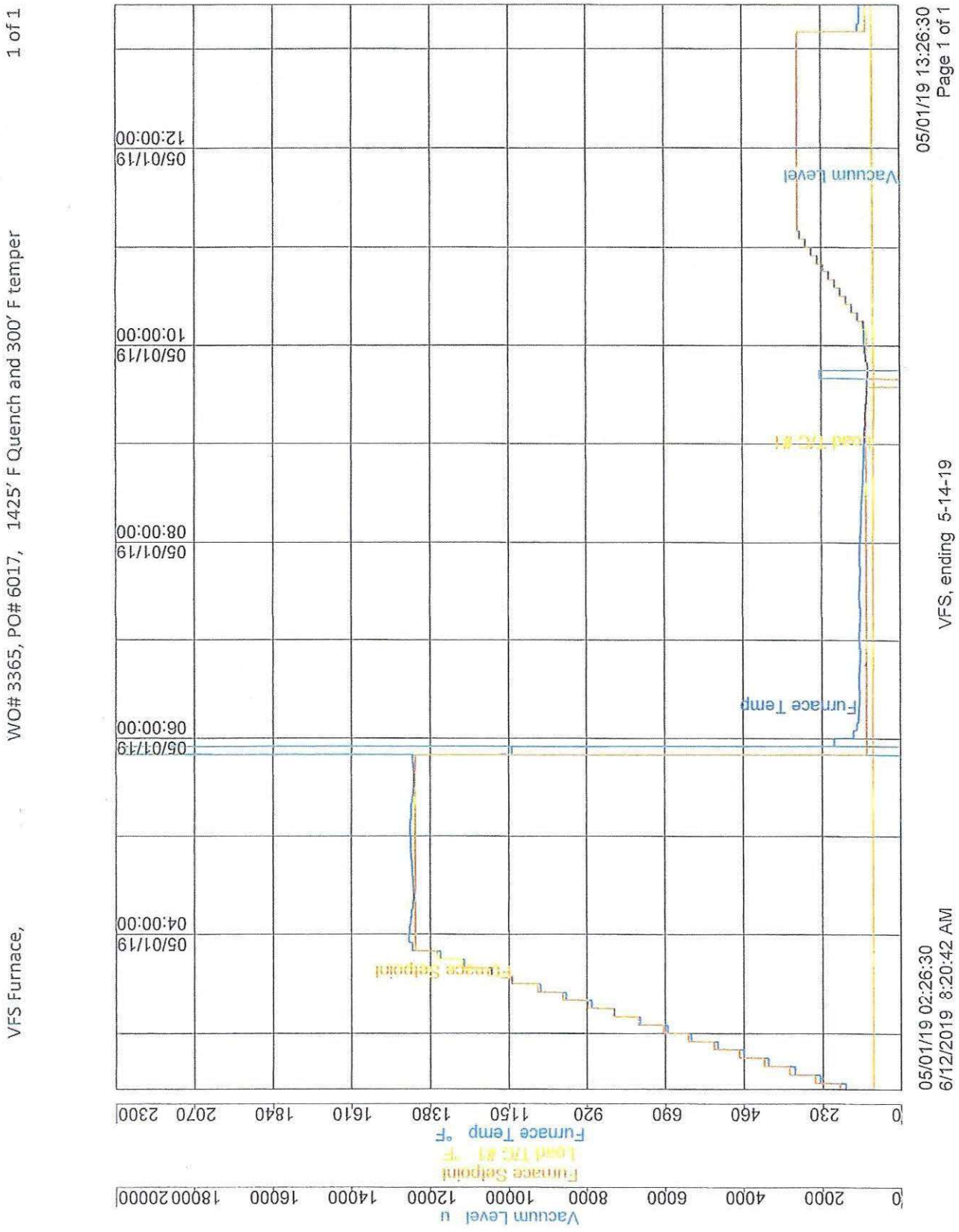
Surface Hardness: 51 HRC

See attached for heat treat cycle.

METLAB [redacted]
Quality Representative Mark Podob

MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting


VFS Furnace, WO# 3365, PO# 6017, 1425' F Quench and 300' F temper 1 of 1
05/01/19 13:26:30
Page 1 of 1
VFS, ending 5-14-19
05/01/19 02:26:30
6/12/2019 8:20:42 AM
Vacuum Level
Load TC #1
Furnace Temp
Furnace Setpoint
12:00:00
10:00:00
08:00:00
06:00:00
04:00:00
05/01/19
Vacuum Level u
0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000
Furnace Setpoint
Load TC #1 °F
Furnace Temp °F
0 230 460 690 920 1150 1380 1610 1840 2070 2300

Readco Kurimoto LLC summery of the heat treat conditions as provided on the Metlab documents "READCO PO 17530-00 Part# 170862-7 #1 "and "READCO PO 17530-00 Part# 170862-7 #2" contained in this document package are as below.

Parts Heat Treated

N017-170862-7 1

N017-170862-7 2

Heat Treat time and temp for both parts were

HT Description	Nom Temp F	Hold Minutes
Quench	1425	120
Temper	300	120

Appendix D. Astralloy-V Test Certificate, Dimensions, Weight, Chemical Composition, Heat Treatment, Brinell Hardness, Tensile Strength, and Charpy, SRNL Material

OCT. 6. 2011 3:44PM ASTRALLOY 205-520-2200 NO. 3371 P. 2/3

PO-710270
PN# 170862-X

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
1455 STANDARD AVENUE
MASURY OH 44438

PAGE NO: 01 OF 02
FILE NO: 0517-01-02
MILL ORDER NO: 38674-001
MELT NO: R2111
SLAB NO: 6A
DATE: 03/11/10

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

SEND TO: 01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 23998

PART NO. AV

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2000 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 006928).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:R2111	.26	.89	.009	.003	.15	.25	3.38	1.46	.28

	V	AL	CB
MELT:R2111	.004	.027	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE - MCQUAID-EHN GRAIN SIZE PER E112 - 7-8

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	57	AIR COOL
PLT	TEMPER	450F	234	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 6A - BRINELL PER E110 (HBW) - 444 444 - PLATE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]
SUPERVISOR - TEST REPORTING

PO-710270
PN#170862-X

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-02
MILL ORDER NO: 38674-001
MELT NO: R2111
SLAB NO: 6A
DATE: 03/11/10

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1647	2326	2.00"	10.0	52.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.			LAT.EXP. (INCH)		
BOT.	LONG.	+32F	FULL	43	44	44	.020	.021	.022

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).

B/L #05307 CUSTOMER'S TRUCK

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]
SUPERVISOR - TEST REPORTING
ELMORE ZABLITNY

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

PAGE NO: 01 OF 02
FILE NO: 0517-01-02
MILL ORDER NO: 41947-001
MELT NO: R4506
SLAB NO: 9G
DATE: 05/18/10

SHIP TO:
ASTRALLOY WEAR TECHNOLOGY CORP
1455 STANDARD AVENUE
MASURY OH 44438

SEND TO: PO# 710270 01-C

SOLD TO:
ASTRALLOY STEEL PRODUCTS INC
P. O. BOX 170974
BIRMINGHAM AL 35217

ITEM# 170863-X

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	2.125"	96"	240"	RECTANGLE	13885#

CUSTOMER INFORMATION

CUSTOMER PO: 24234

PART NO. AV

SPECIFICATION(S)

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

AWT ASTRALLOY-V REV 7 YR 99 AP-1
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2000 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 006928).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:R4506	.26	.90	.009	.002	.11	.25	3.35	1.47	.28

	V	AL	CB
MELT:R4506	.004	.031	.002

MANUFACTURE

ELECTRIC FURNACE QUALITY - VACUUM DEGASSED - FINE GRAIN PRACTICE - MCQUAID-EHN GRAIN SIZE PER E112 - 7-8

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

PO# 710270

ITEM# 170863-X

TEST CERTIFICATE

PAGE NO: 02 OF 02
FILE NO: 0517-01-02
MILL ORDER NO: 41947-001
MELT NO: R4506
SLAB NO: 9G
DATE: 05/18/10

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PLT	NORMALIZE	1650F	58	AIR COOL
PLT	TEMPER	450F	184	AIR COOL
TEST ONLY	NORMALIZE	1650F	64	AIR COOL
TEST ONLY	TEMPER	450F	128	AIR COOL

MECHANICAL PROPERTIES

SLAB - 9G - BRINELL PER E110 (HBW) - 429 429 - PLATE

TENSILE PROPERTIES

LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%	%R.A.
BOT.	TRANS.	1598	2272	2.00"	11.0	48.0

CHARPY V-NOTCH IMPACT RESULTS

LOC	DIR	TEMP	SIZE	FT. LBS.			LAT.EXP.(INCH)		
BOT.	LONG.	+32F	FULL	24	27	29	.009	.010	.014

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
BRINELL TESTING WAS PERFORMED USING A CARBIDE BALL (HBW).

B/L #11073 CUSTOMER'S TRUCK

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

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

[redacted]

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

Appendix E. SRNL-L3310-2020-00016, Heat Treatment of Astralloy V For the Saltstone Replaceable Mixer Paddles

SRNL SAVANNAH RIVER NATIONAL LABORATORY™

SRNL-L3310-2020-00016 Rev. 0

March 31, 2020

To: Erich Hansen
Actinide Materials Science and Technology
[redacted]

From: Kenneth J. Imrich & Stephen Crossland [redacted]
Applied Materials Engineering

Technical Reviewer: Bruce Wiersma [redacted]
Applied Materials Engineering

HEAT TREATMENT OF ASTRALLOY V FOR THE SALTSTONE REPLACEABLE MIXER PADDLES

Summary

The following conclusions are based on the available vendor literature and test results of heat treatments performed at SRNL:

1) Astralloy V® is a proprietary alloy with limited available metallurgical data. Time, Temperature Transition (TTT) diagrams were not available from the vendor making determination of the appropriate heat treatment extremely difficult.

2) SRNL could not produce a through-hardened, Rockwell C 50, part using the READCO heat treatment (normalizing, air quenching and tempering) schedule. An extremely fast quench rate, using ice water, was required to produce through-hardened, Rockwell C 50, parts when using the READCO 1425 °F normalizing temperature. This rapid quench rate introduces significant residual stresses and some distortion of the paddle tips.

3) The significant difference in Charpy impact data with respect to plate orientation was attributed to preferentially oriented microstructural features. This could result in catastrophic material failure when subjected to impact loading, which has been observed in previously installed paddles. The material specification should be modified to require the foundry or mill to cross-roll the plate. Depending on the amount of material required, the plate may have to be cut during the rolling process.

4) The preferred thermal process for as-machined paddles is to carburize the paddles at 1650 °F followed by an oil quench. This will produce a tough core, well over the SRNL specified 35 ft-lbs, and will provide a case-hardened surface (> HRC 60). Cryogenic cooling may further harden the case if deemed necessary.

5) Unless special precautions are taken during machining, all material should be stress relieved before machining. Stress relieving should be performed at 400 °F for two hours.

6) Stellite® 12 hard facing the auger flight edge is recommended. A dye penetrant test should be performed to ensure no cracks are present following hard facing. If two hard facing layers are applied, it is imperative that the initial layer be crack free before applying the second layer.

Background

Astralloy V® is the current material of construction for the Saltstone mixer paddles[1]. This is a high strength, abrasion resistant alloy steel that is "air-hardenable". It is a unique proprietary alloy only produced by Astralloy Steel Products Inc., which is a subsidiary of NUCOR®. Since Astralloy V® is a proprietary material, it is not governed by National Standard organizations such as the American Iron and Steel Institute (AISI), American Society of Automotive Engineers (ASME) or American Society for Testing and Materials (ASTM International). Because of this situation, the only published information concerning physical and mechanical properties, heat treating, machining and welding of Astralloy V® is available from Astralloy Steel Products Inc.[2] Engineering data and information is limited. Most importantly, a time, temperature, transformation (TTT) diagram, necessary for proper heat treatment, was not provided in the vendor supplied engineering data.

The primary property necessary for the Saltstone paddles is wear resistance. Generally, for a solid solution, carbide dispersed alloy such as Astralloy V®, the higher the hardness the better the wear resistance. Acceptance criteria for procurement of Astralloy V® paddles were developed from the Astralloy V® Engineering Data and product data sheet[3]. The maximum hardness range specified in these documents was Rockwell C (HRC) 51 – 54 and is obtained through heat treating and work hardening. This hardness range specified in the 2013 SRNL document[4] was from vendor literature. Although there are other metallurgical features, such as grain morphology and orientation and carbide size and distribution, that affect wear resistance, bulk hardness obtained by the Rockwell C test method[5] will be the primary mechanical test method addressed in this document. The following details the heat treating efforts that were performed by SRNL, using READCO's heat treating schedule as guidance (Attachment 1), to attain the as-quenched hardness range HRC 51 - 54. M&TE hardness block standards were used before each test for this work and the HRC values were always found to be within the range of the appropriate hardness block. Charpy[6] impact testing was performed on a single acceptable hardness heat treated SRNL sample to assess the toughness.

READCO Kuriomoto, LLC provided SRR the heat tracing profile[7] (see Attachment 1) for a fabricated paddle in a vacuum oven. A fabricated paddle is heated to 1425 °F for 120 minutes and

[1] M-DCF-Z-00499, Rev. 0, "Saltstone Mixer Paddles Configuration", 5/10/2017
[2] "Astralloy-V® Abrasion Resistant Wear Steel – Air Hardened Engineering Data" provided by Astralloy
[3] http://www.astralloy.com/files/pdf/Astralloy-V_Plates_EN.pdf
[4] Reigel, M. M. and Imrich, K.J., "Recommended Acceptance Criteria for Saltstone Mixer Paddles Materials of Construction", SRNL-L3100-2013-00047, Rev. 0, 2013
[5] ASTM E18, Standard Test Method for Rockwell Hardness of Metallic Materials
[6] ASTM A370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products
[7] Material Certification, READCO PO 17530-00 Part # 170862-7 #1, Metlab May 2, 2019

quenched to 150 °F using forced nitrogen gas at 5 psi[8]. The paddle is then reheated to 300 °F for 120 minutes for tempering and then cooled. This process successfully yielded a surface hardness HRC 51. Visual inspection of two READCO paddles provided by SRR were performed. Both paddles had hardness indents on the machined flat surfaces. Only one of the paddles had hardness measurements on the process-contacting wear surfaces. No hardness indents were observed on or near the tips from either of the two paddles. SRR provided SRNL as-received and heat treated Astralloy V® coupons from READCO for future assessments and these items will be discussed later.

Results

2.25" thick plates of Astralloy V® were procured to fabricate the replaceable paddles for the Saltstone mixer. The as-received plates had been mechanically sectioned into smaller pieces that were approximately 20 inches long by 5 inches wide. To evaluate the hardness of the as-received material, three 0.25" by 0.25" by 2.25" hardness test bars were electric discharge machined (EDM) from the large plate. The locations of the hardness test samples are shown in Figure 1 and were obtained from the edge, the center and near the edge of a plate. Measured hardness values were around HRC 40 (see Table 1). A larger test block 1.5" by 1.5" by 2.25" was also sectioned from the as-received plate (see Figure 1) and hardness values from various sides are shown in Figure 2. For this block the cut and ground surface, which is on the exterior side of the plate was found to have an HRC near 50.

In an attempt to obtain the minimum specified HRC 51 value, a series of heat treatment tests were initially performed using vacuum furnaces to mimic the READCO process. First a block of material 4.5" long by 1.5" wide by 2.5" tall was normalized at 1650 °F and held at this temperature for two hours in a vacuum furnace located in building 723-A. This size was selected because the thermal mass and cross-section is similar to the actual fabricated replaceable tip. Following the normalizing treatment, the block was quenched as fast as possible by injecting argon gas into the furnace. The average hardness obtained from this heat treatment was HRC 42, which was only slightly harder than the as-received plate, indicating the argon purge rate was insufficient in adequately quenching the block. A smaller Astralloy V® block (1.5 by 1.5 by 2.25 inches) was sent to an off-site heat treater located in Greer SC, Thermal Processing Services LLC. This company has a larger vacuum furnace with a significantly larger inert gas quenching system compared to the vacuum furnaced used at SRNL. Once again, the heat treatment only yielded an HRC hardness in the low forties. Based on these experiences and limitations on available equipment, SRNL determined a different approach was necessary in trying to obtain HRC 51 – 54 values.

Heat treatments were performed at SRNL using a small muffle furnace. These initial tests were performed in air, so oxidation on the exterior surfaces and decarburization of near-surface regions were expected during the 1650 °F normalization process. The block size for these tests were small (1.5 by 1.5 by 2.25 inches), and therefore, the thermal mass was smaller than the replaceable tip. The test blocks were placed in the furnace, ramped to the target temperature, and then held there for two hours. One sample was allowed to cool in air, as Astralloy recommended, and the other was water quenched. Small internal samples not exposed to air were EDM sectioned from the blocks and hardness tested. Results of these heat treatment processes again only yielded HRC hardness values in the low forties.

[8] Email from Debbie Bell, Setpoint Solutions, "FW: Conference Call", 8/21/19

The third test was performed in air at 1650 °F with the same 1.5” by 1.5” by 2.25” block size, however, this time the block was quenched in ice water. Figure 3 shows the hardness test sample that was EDM sectioned from the block and the location/orientation of the hardness measurements. HRC values are shown in Table 2. This quenching process yielded an average HRC 50 throughout the interior regions of the block. The surface HRC values of 40 were low and most likely due to decarburization.

The fourth heat treatment, using another 1.5” by 1.5” by 2.25” block, test was performed using the READCO normalizing temperature of 1425 °F. However, unlike READCO who uses a nitrogen quench, this block was ice water quenched and then tempered and stress relieved per the READCO thermal process at 300 °F for 2 hours. Two hardness test samples were EDM sectioned from this block, one following the normalizing and another after tempering. Both inner (not exposed to air in the furnace) and outer surfaces (exposed to air) were hardness tested. Figure 4 shows a schematic of the block and the EDM sections. Hardness tests were taken from the top to the bottom of the block in the locations indicated by the green arrows. Table 3 presents the HRC values at the various locations. Hardness measurements in the interior of the block that were not decarburized averaged HRC 50 or better.

The final heat treatment tests were performed in a small inert gas, high temperature furnace. Samples included a 1.5” by 1.5” by 2.25” block that had been EDM sectioned from the SRNL material and an irregularly shaped piece of scrap material recovered from one of the replaceable tips being machined at SRNL (Figure 5). EDM surfaces of the scrap material had been mechanically polished while the top and bottom surfaces were conventionally machined. The top and bottom surfaces of the 1.5 inch square block still had the original heavy mill scale while the other four sides were left in the as-EDM condition dark brown colored recast (re-solidified metal) layer (Figure 5A). No effort was taken to remove the recast layer from any of the as-EDM surfaces. These samples were coated with DuBois No Carb Green and allowed to thoroughly dry overnight (Figure 5B). This coating is intended to inhibit decarburization and oxidation. The two pieces were placed in the furnace at room temperature. The furnace was sealed and thoroughly purged with argon before turning on the furnace. The furnace was ramped to the normalizing temperature (1425 °F) in about 15 minutes. The pieces were held at this temperature for 2 hours after which time they were removed from the furnace and rapidly quenched in ice water. None of these test pieces were tempered at 300 °F. The post heat treated surfaces of each of the test samples are shown in Figure 5C. Surface hardness values for these samples following heat treating are presented in Table 4. Hardness values on the uncoated sample were in the twenties while the coated surfaces were all above HRC 50, clearly showing the effectiveness of this coating and the impact of decarburization.

As previously stated, READCO provided SRR two coupons of Astralloy, one that was heat treated according to READCO’s heat treating schedule and one that was not heat treated. These coupons were cylindrical in shape and from the center section of a paddle. The heat treated coupon was heat treated with the production paddles. These pieces including the pieces that were EDM sectioned for hardness testing are shown in Figure 6. The hardness of the non-heat treated material (designated as raw on identifying tag) was near HRC 40 while the heat treated material averaged HRC 47 (Table 5).

Charpy impact testing was performed to evaluate the toughness, impact resistance, of the SRNL heat treated Astralloy V® material. A 4.5" long by 1.5" wide by 2.5" tall block was EDM sectioned from the original bar. The longitudinal and short transvers directions are also indicated on the sketch (Figure 1). The block was coated with the DuBois No Carb Green, heated under an argon gas purge to 1425 °F and held there for 2 hours at which time it was ice water quenched. The block was reheated in air to 300 °F, held for 2 hours after which it was removed from the furnace and allowed to cool to room temperature. The heat treated block was sent to Applied Technical Services Inc. in Atlanta Georgia where six full-size Charpy v-notch samples were cut from the center of the block using an EDM (Figure 7). Three standard size Charpy test samples were cut with the v-notch oriented in the longitudinal direction and three oriented in the short transverse direction (Figure 7), these are orthogonal to the rolling direction. Charpy impact tests were performed in accordance with ASTM A370-19 at room temperature (70 °F). Results indicated the short transverse oriented samples had an absorbed energy 32 ft-lbs while longitudinally oriented samples were below 10 ft-lbs (Attachment 2). Photographs of the fractured Charpy bars are shown in figure 8. There is a distinct difference in the fracture surfaces and the amount of deformation between the two different orientations.

Surface hardness measurements for each individual replaceable tip following the heat treatment is presented in Table 6. Heat treatment was performed as that for the Charpy bars. Hardness values for the replaceable tips were HRC 50 or greater. Tempering had no impact on the resulting hardness.

Discussion

The Astralloy V® Engineering Data states that this alloy can be through-hardened to a Brinell Hardness (BHN) of 418 to 512. This equates to a Rockwell C (HRC) of approximately 45 to 52 using ASTM E140[9] conversion tables. According to the vendor's Astralloy V® Engineering Data, the highest as-quenched hardness is produced by normalizing this material at 1650 °F. This produces a fully austenitic structure and ensures all carbides are dissolved and placed back into solution prior to quenching. This is essential in order to attain the appropriate structure throughout the part upon quenching. Parts should be held at the normalizing temperature for at least an hour per inch of thickness. This soak time is a generally accepted practice in the heat treatment industry. When lowering the normalizing temperature, a much longer soak time may be required to produce the fully austenitic structure and to completely dissolve all the carbides. If the normalizing temperature is lowered too much, the austenite formation may not go to completion. In addition, the existing carbides will not be placed back into solution. Both are metallurgically necessary to attain the desired hardness and abrasion resistance following quenching. The vendor literature states that 1425 °F is the temperature at which the austenite transformation is complete upon heating. This is true if sufficient time is given to complete the transformation. The vendor also states that hot forming below 1450 °F will result in lower hardness and abrasion resistance. The latter statement infers that it would be impossible to produce a hardness of HRC 50 or greater, which is the maximum attainable hardness, using the READCO heat treating schedule. In fact, this was the case since the average HRC measurements from both the outer diameter and the core averaged 47. No

[9] ASTM E140-12b, Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness

measurements were above HRC 49. SRNL used a quench rate (ice bath) to obtain the targeted hardness, where such a method was not discussed in Astralloy's Engineering Data.

The appropriate quenching rate is required to produce the maximum as-quenched hardness at room temperature. Since a TTT diagram was not available, several test pieces had to be heat treated at various temperatures and quench rates to understand how Astralloy V® would respond metallurgically. The quenching rate is critical in order to produce a fully martensitic structure and appropriate carbide size/distribution at room temperature. For this alloy the temperature at which austenite begins to transform to martensite is around 650 °F. Without a TTT diagram the cooling rate necessary to produce the desired microstructure from the normalizing temperature to 650 °F is not known. Thickness and surface area will greatly affect the cooling rate. Parts with greater thermal mass and less surface area will be harder to quench rapidly. Rapid quenching rates can also produce residual stresses that can distort as-fabricated parts (as observed in some of the as-machined parts and in the heat treated tips) or in severe cases can result in crack formation. Metal parts exposed to an oxygen containing environment, as is present in a muffle furnace without atmospheric control, will be prone to decarburization and oxidation. If decarburization of the near surface region occurs, the martensite and the carbides will not form, resulting in lower hardness and wear resistance in the affected region.

Astralloy V® is reported to be an air-hardenable material. However, after several attempts to obtain HRC 50 using different types of furnaces, (vacuum, air muffle and inert gas) with different quenching techniques (inert gas, air, room temperature water, and ice water), it was determined that only an inert gas furnace (with No Carb coated parts) followed by an ice water quench would produce the desired through hardness when using the READCO normalizing temperature of 1425 °F. Note, a Rockwell hardness value of 50 or greater could not be produced at SRNL using the READCO normalizing temperature of 1425 °F with a gas (nitrogen or air) quench. This process would effectively eliminate decarburization and oxidation thus ensuring adequate surface hardness and avoiding dimensional changes from oxidation. Oil quenching was not attempted because it was not approved for use in SRNL. Ice water quenching of the 1.5" by 1.5" by 2.25" block of material was successful in producing a through hardened, HRC 50, part (Figure 3 and Table 2). This data indicates that a martensitic structure with needle-shaped lathes was most likely produced throughout the part. Although this microstructure yields the hardest, highest strength condition, it would have the lowest toughness. Tempering is necessary to transform the needle shaped lath structure to a more rounded martensitic structure, which makes crack initiation and propagation more difficult, thereby increasing toughness. Tempering will also change the size and distribution of the carbides. While tempering increases toughness, the hardness and ultimately wear resistance are reduced. This is the dilemma for the Saltstone mixer paddles. The READCO tempering temperature (300 °F) is so low that it is doubtful that it would change the mechanical properties significantly and probably only provide a moderate amount of stress relief, there was no observable change in toughness. Vendor literature shows that tempering at 450 °F will lower the yield strength slightly but has little effect on the tensile strength. Generally, hardness coincides with the tensile strength, therefore, tempering at very low temperatures would not produce any significant change in the as-quenched hardness. This was the case as no significant hardness change was observed between the as-quenched and the tempered conditions for the 26 replaceable tips (Table 6). Other physical properties such as tensile and yield strengths have not been measured for this heat treatment process.

Astralloy V® can also be work hardened at room temperature. The vendor data sheet shows that this material is work hardenable to a BHN in excess of 550 (HRC 54). Therefore, under certain severe loading conditions, such as grinding and turning during machining, this material can be hardened. The conventionally machined surface shown in figure 5A was HRC 50 before heat treating. It is possible that the paddles will work harden in-situ while the premix (cement/slag/fly ash) and low-level liquid waste are being blended in the Saltstone mixer. However, to date worn paddles from the mixer have not been metallurgically evaluated. To avoid work hardening an EDM was used to harvest samples for hardness testing from the various heat treated blocks. The EDM uses an electrically charged 0.010 inch wire to melt the metal. A high-pressure water flush rapidly cools the molten particles and metal block while flushing the particles from the kerf (slit made by the EDM during cutting). Since the test sample is only locally heated and rapidly cooled, EDM sectioning only has a minimal effect on the mechanical properties (i.e., hardness) of the material.

Two READCO production paddles were visually inspected with the unaided eye. Hardness indents were observed on the flat, mechanically machined sides of both production paddles. Only one of the paddles had indents on the slurry-contacting surfaces, however no indents were observed on or near the tips where wear is the most severe. The hardness indents appeared shallow and consistent with an HRC 50 indent. It must be noted that the flat sides exhibited evidence of a mechanical machining process. This means that the hardness measurements may have been influenced by work hardening and not by the heat treatment. If hardness readings are taken on the curved surface, the paddle must be orthogonally aligned with the indenter and it must be securely held while the 100 kg load is applied during the test. Any rocking of the paddle during the test would dramatically affect the test, thus producing erroneous hardness values. Since all the Rockwell C hardness values were not provided on the READCO's CMTRs, the variability and accuracy of the hardness tests could not be determined.

Charpy impact data indicated that there was a significant difference in toughness with the lowest toughness, 8 ft-lbs, orientated in the longitudinal, assumed rolling, direction (Figure 1). Materials with a fracture toughness below 22 ft-lbs are considered brittle and subject to catastrophic failure when impact loaded. The fracture surfaces from the different orientations also exhibited a vastly different morphology. The fracture surfaces from the short transverse samples appeared to have an irregular surface contour while the longitudinal samples appeared to be much flatter and uniform. The longitudinal samples also exhibited significantly less lateral expansion indicating the material was less ductile and crack propagation required less energy in this orientation. For this to occur there must be a significant microstructural difference (preferred orientation) between the two directions. This should not exist if the plate was manufactured properly for the mixer paddles in Saltstone. It is unlikely that this metallurgical condition was produced by the heat treating at SRS. That is, because all samples and paddles heat treated at SRS were adequately supported while in the furnace and the ice water was agitated vigorously when the parts were rapidly cooled. These practices ensured that heat transfer was uniform and therefore, would not produce the microstructural difference that resulted in the variation in toughness. The most likely cause was the rolling practices performed at the mill. The vendor's Astralloy V® Engineering Data states in the Fabrication Practices section that cross grain forming is preferred but not necessary. This suggests that cross rolling during plate fabrication would be advantageous because it would produce grains that are equiaxed and not directionally oriented. If a plate is not cross rolled during hot forming, the grains would become elongated in the rolling direction and narrow in the transverse and short

transverse directions. This would still be the case even with the fine grain practice used by the foundry. Carbides may also become oriented with the rolling direction. Preferentially oriented grains and carbides could produce a variation in toughness similar to that observed in the SRS material. Only a high normalization heat treatment at or above 1650 °F with a long soak time could produce a plate with a more equiaxed microstructure. Since a metallographic evaluation or examination of the fracture surfaces on the Charpy test specimens were not performed, the exact cause of the variation in toughness could not be determined.

An observation that was discussed during a meeting with representatives from Saltstone Engineering concerned the appearance of several paddles and loud noises coming from the mixer. One inspection revealed that several paddles had large chunks missing on the tips of the paddle (Figure 9). At the time the photograph was taken there were two paddle tips that had large sections, irregular chunks, missing. Their appearance was not characteristic of a uniform wear mechanism and was not at all similar to surrounding paddle tips. The fracture surface of one of the tips was significantly worn while the fracture surface on the other tip was more irregular and jagged. The difference in surface morphology was most likely due the amount of processing time following the initial fracture. The tip that fractured first would be expected to have worn more, effectively erasing all evidence of the initial fracture surface. However, the time between when the noise was heard and when the mixer was dismantled and documented is unknown. If the READCO paddles have a similarly oriented microstructure to that suspected in the SRS material, they could be subject to catastrophic fracture if shock loaded. Shock loading could occur during the initial start-up if paddles impact residual grout that has set up inside the mixer after it has been idled for a while or by impact with a large foreign object, such as a non-ferrous bolt or rock that enters the mixer with the dry premix. The large piece of material missing from the tip of the paddle may have resulted from an impact with the fracture surface subsequently eroded producing the polished surface and physically removing all evidence of the initial failure. It appears highly unlikely that only one or two paddle tips in one specific region of the mixer would be significantly degraded by erosion while the others are only slightly worn. A metallurgical examination of the failed paddle would be necessary to assess if a preferentially oriented microstructure existed, which could have resulted in the catastrophic failure of the paddle tip and loud noise heard originating within the mixer.

Carburization

Another way to obtain a compromise between toughness for impact resistance while maintaining superior wear resistance on the surface of an Astralloy V® part is to perform a carburizing heat treatment. Astralloy V® Engineering Data states that this alloy can be carburized. The carburizing process can be performed on an as-machined part in a sealed furnace where the carbon potential can be controlled. It may be possible to perform a one-step heat treatment to normalize and carburize the part. This would be followed by a rapid quench. Quenching rate would need to be determined to minimize distortion while obtaining the appropriate mechanical properties, core toughness and case hardness profile. Hot oil, room temperature oil or air may be used to quench the parts. Further hardening could be obtained by cryogenically cooling in liquid nitrogen. Case hardened depths can range between 0.002 to 0.350 inches depending on the alloy, the carbon potential, and the temperature/time for the carburizing process. According to the Astralloy V® Engineering Data this alloy can be oil quenched from 1600 °F and then tempered at 1000 °F to produce a room temperature toughness of 100 ft-lbs. This is the maximum attainable toughness which is much higher than that

required for the Saltstone application. So, the final tempering process could possibly be eliminated or performed at a lower temperature in order to avoid softening the case-hardened surface. This would still be expected to produce a core toughness well above 30 ft-lbs. This would have to be verified by testing.

Auger Stellite® 12 Overlay

The READCO mixer consists of a series of paddle and auger sections. Auger sections are located both upstream and downstream of the paddles. The auger sections located upstream of the paddles is where the dry feed is introduced into the mixer. Low-level liquid waste is added in the last set of auger flights just before the first set of paddles. During a meeting with Saltstone Engineering, there was a concern raised about wear of the auger in the dry and wetted regions. A recommendation was made to overlay the flight tips with Stellite® 12 using a conventional welding process. Stellite® 12 is a carbide dispersed cobalt-based alloy that has excellent wear resistance. It has an HRC hardness that can range between the mid-forties to the lower fifties and is brittle with a toughness of only 7 ft-lbs. Although Stellite® 12 can be cast to form various shapes, it is not practical for many applications because of its low impact resistance. Therefore, Stellite® 12 is normally used as an overlay when wear or abrasion resistance is required. It is generally applied on a lower cost, more ductile material, such as an austenitic stainless steel. There are issues associated with application of a Stellite® 12 hard facing including thermal distortion and cracking. Distortion can be minimized by using a thermal spray process rather than a conventional welding process. Stellite® 12 overlays are prone to cracking. Minimizing heat input into the part is critical. Dye penetrant testing (PT) is recommended after each overlay pass to ensure integrity. Generally, one overlay pass is sufficient to provide adequate wear resistance, however, multi-pass coatings are possible. Once again, care must be given to maintain a crack free surface prior to depositing subsequent layers because subsurface cracks can propagate in service as the part is cycled between compression and tension. Subsurface cracks may result in localized failure of the overlay.

Recommendations

The Saltstone mixer environment requires the material possess excellent abrasion resistance along with moderate toughness and minimal corrosion resistance. Astralloy V® is an adequate choice for this application. However, the specification for the fabrication of the as-supplied plate from the mill should be modified to require cross rolling to avoid preferential orientation of the grains..
There are several options that could be used to heat treat paddles. The options are, 1) heat treating parts in an air or inert furnace that have already been machined to tolerance, 2) heat treating parts in an air or inert furnace that have not been machined to tolerance. 3) parts that will be carburized and 4) parts that will not be heat treated and used in the as-supplied by the mill or foundry condition:

1) Heat treatment for parts that are machined to tolerance.

    A) Clean fabricated parts (parts that have been machined to final tolerances) with alcohol or other approved solvent to remove residual organics including oil and grease.

B) Coat exposed surfaces of fabricated parts with DuBois No Carb Green and allow to completely dry overnight.

C) Place parts in an inert gas (argon) furnace using adequate support to ensure even heat transfer on all sides, heat to 1650 °F and hold for a minimum of 2 hours.

Note: Oxygen may still present in an inert gas furnace so the use of the DuBois No Carb Green is still recommended.

D) Remove part from the furnace while providing adequate support to ensure even heat transfer during air cooling. Faster cooling rates may be required depending on the part geometry and thermal mass. This should produce a part with a through-hardness in the upper forties or higher.

E) Reheat to 400 °F in an inert gas or air furnace and hold at temperature for at least two hours to stress relieve the part.

F) Air cool the part.

2) Parts that have not been fabricated to final tolerances can be heated in an air furnace without the DuBois No Carb Green. When machining parts from as-received hot-rolled plate or from heat treated stock, EDM cuts should be made outside the final dimensions to relieve residual stresses. Once the residual stresses have been minimized, final to-tolerance cuts can be performed

3) Heat treatment for parts that are machined to tolerance and will be carburized to obtain a case-hardened layer (HRC 60 or better) on the surface.

A) Clean all fabricated parts (parts that have been machined to final tolerances) with alcohol or other approved solvent to remove residual organics including oil and grease.

B) Place the part in a furnace capable of carburizing and using adequate support to ensure even heat transfer on all sides, heat to 1650 °F while carburizing and hold for a minimum of 2 hours.

C) Quench in oil ensuring the oil is continuously agitated during cooling.

D) Clean parts in an approved degreaser.

E) If the fracture toughness is lower than 35 ft-lbs currently specified, then temper the part at 1000 °F for 2 hours. Tempering must be performed in a vacuum furnace.

4) As-supplied material that is not heat treated must still be carefully machined due to residual stress that may have resulted during the slow cooling of the large plate.

In-field hardness measurements should be performed on the paddle tips when they are initially installed in the mixer and after the mixer is disassembled for maintenance. This will help understand if Astralloy V® work hardens under actual loading conditions in the mixer.

Finally, the Saltstone Astralloy V® material specification should be modified to require the foundry/mill to cross-roll the plate to eliminate preferred orientation of microstructural features within the plate.

To minimize the impact of startup loads (e.g. cured grout) in the Saltstone mixer, it would be advantageous to flush the mixer thoroughly with water prior to shutting it down. If this is not possible, run the mixer for several hours after the feed has been shut off. This might allow for the residual grout in the region of interest to flatten out between the gap (between the tip and barrel) and potentially set so there would be no buildup of grout that would protrude into the mixing zone of a paddle during restart.

Conclusions

The following conclusions are based on the available vendor literature and test results of heat treatments performed at SRNL:

1) Astralloy V® is a proprietary alloy with limited available metallurgical data. Time, Temperature Transition (TTT) diagrams were not available from the vendor making determination of the appropriate heat treatment extremely difficult.

2) SRNL could not produce a through-hardened, Rockwell C 50, part using the READCO heat treatment (normalizing, air quenching and tempering) schedule. An extremely fast quench rate, using ice water, was required to produce through-hardened, Rockwell C 50, parts when using the READCO 1425 °F normalizing temperature. This rapid quench rate introduces significant residual stresses and some distortion of the paddle tips.

3) The significant difference in Charpy impact data with respect to plate orientation was attributed to preferentially oriented microstructural features. This could result in catastrophic material failure when subjected to impact loading, which has been observed in previously installed paddles. The material specification should be modified to require the foundry or mill to cross-roll the plate. Depending on the amount of material required, the plate may have to be cut during the rolling process.

4) The preferred thermal process for as-machined paddles is to carburize the paddles at 1650 °F followed by an oil quench. This will produce a tough core, well over the SRNL specified 35 ft-lbs, and will provide a case-hardened surface (> HRC 60). Cryogenic cooling may further harden the case if deemed necessary.

5) Unless special precautions are taken during machining, all material should be stress relieved before machining. Stress relieving should be performed at 400 °F for two hours.

6) Stellite® 12 hard facing the auger flight edge is recommended. A dye penetrant test should be performed to ensure no cracks are present following hard facing. If two hard facing layers are applied, it is imperative that the initial layer be crack free before applying the second layer.

Distribution:

Alex Cozzi	999-W
Rudolph Jolly	704-Z
Marissa Reigle	773-A
Satish Shah	704-30S

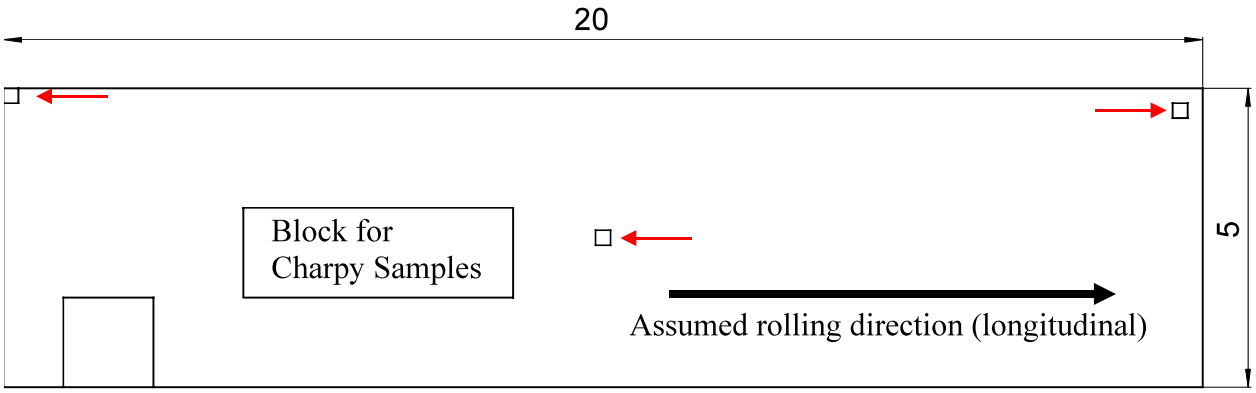


Figure 1. Sketch showing the location of the hardness test samples from as-received 20" long by 5" wide by 2.25" thick bar. Three 0.25" by 0.25" by 2.25" long samples were EDM sectioned from the large bar at the following locations, the edge, the center and 0.25 inch from the edge (small red arrows). **Notes:** 1) All exterior surfaces of this large bar were mechanically cut and/or ground while the top and bottom surfaces were left with the heavy oxide scale that resulted from the hot rolling operation at the mill. 2) The assumed rolling direction is shown by the long black arrow and the short transvers direction would be into the page.

Table 1. Rockwell C hardness values for the test samples from the as-received bar that is being used to fabricate the replaceable paddle tips and the hubs (values left to right are top to the bottom on the sample). Note: Small arrows in Figure 1 indicate the side the hardness tests were taken.

Location	Rockwell C																												Avg
Edge	34	40	42	40	41	43	42	42	43	43	43	43	42	41	43	41	41	42	42	42	42	41	40	39	38	38	34	31	35	40
Center	41	42	43	43	44	43	43	42	44	43	44	43	43	43	42	43														43
1/4" from Edge	34	40	42	40	41	43	42	42	43	43	43	43	42	41	43	41	41	42	42	42	42	41	40	39	38	38	34	31	35	40

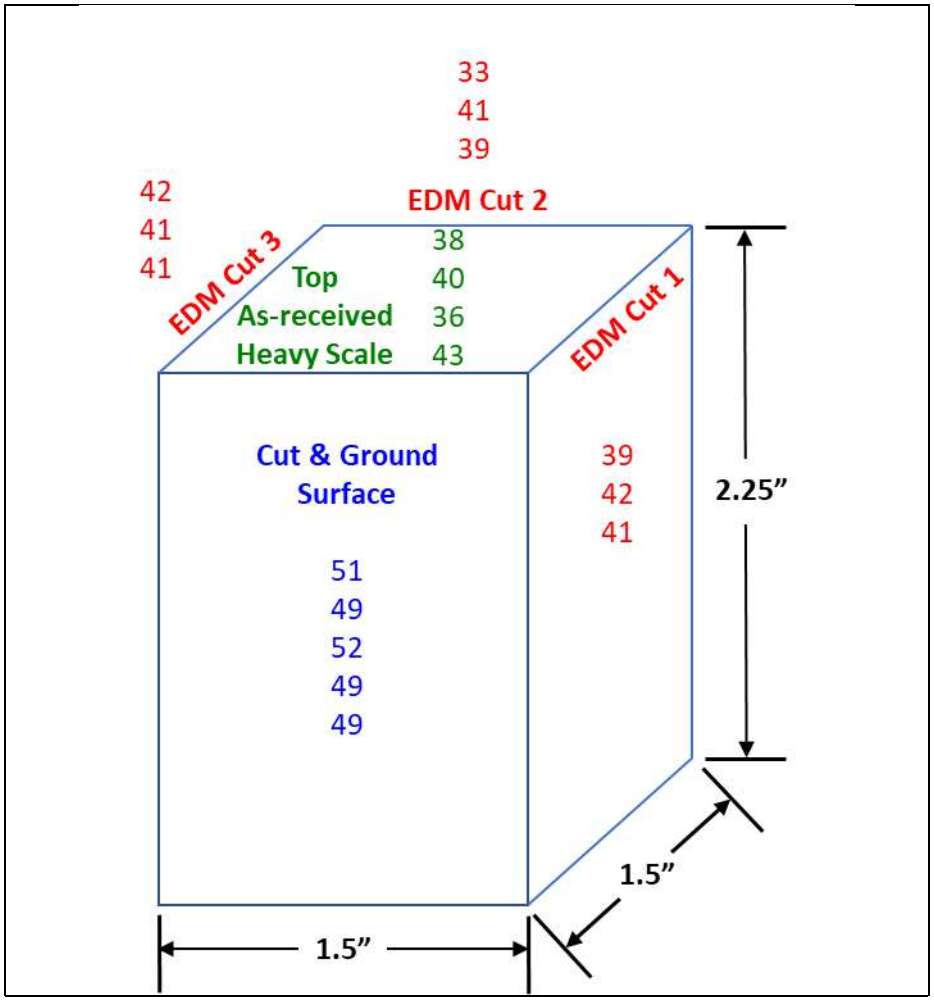


Figure 2. Rockwell C hardness values of the sides from the 1.5” by “1.5” by 2.25” test block EDM sectioned from the as-received heat treated bar (see figure 1 for location). Note: the cut/ground surface had an HRC of near 50 while the as-heat treated surface (top) was in the upper thirties.

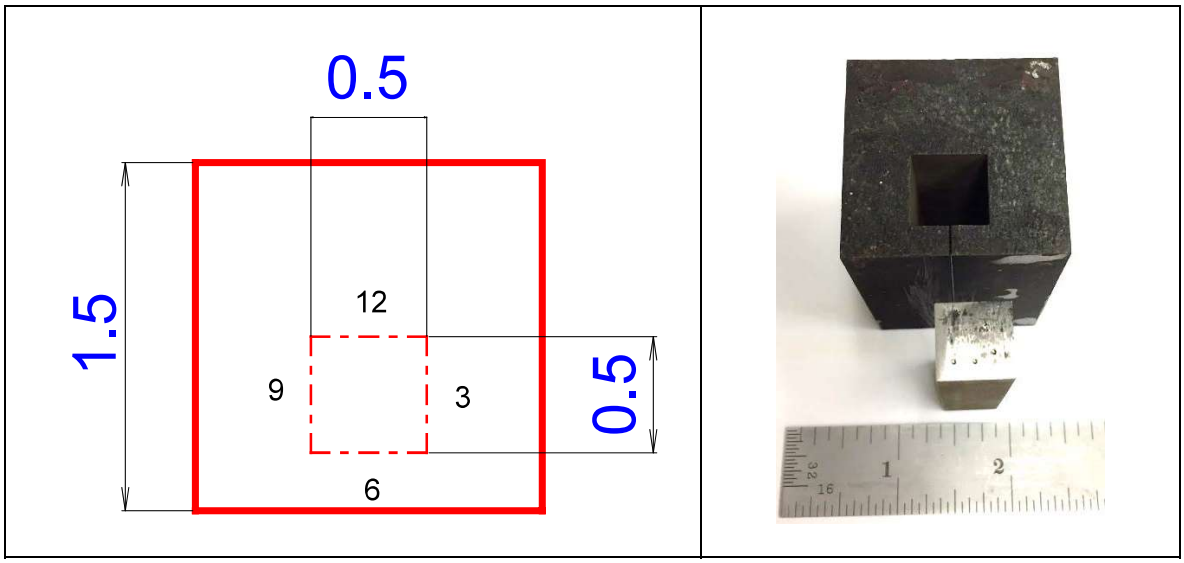


Figure 3. Location of hardness test sample (0.5” by 0.5” by 2.25”) EDM sectioned from the heat treated block (normalized 1650 ºF in air and ice water quenched).

Table 2. Hardness values for the test block that was normalized at 1650 ºF and ice water quenched.

Sample Name	Indent Location	Rockwell C							Average HRC
1650 °F Ice Water Quench	Top*	42	41	40	NT	NT	NT	NT	41
	Bottom+*	42	40	38	40	NT	NT	NT	40
	3 o'clock	49	50	51	51	51	50	49	50
	6 o'clock	49	50	51	51	51	50	50	50
	9 o'clock	49	51	50	52	51	50	50	50
	12 o'clock	48	50	52	52	51	52	50	50

* NT = Not Tested
EDM cut surface was exposed to air while in the furnace. The lower surface hardness resulted from decarburization.

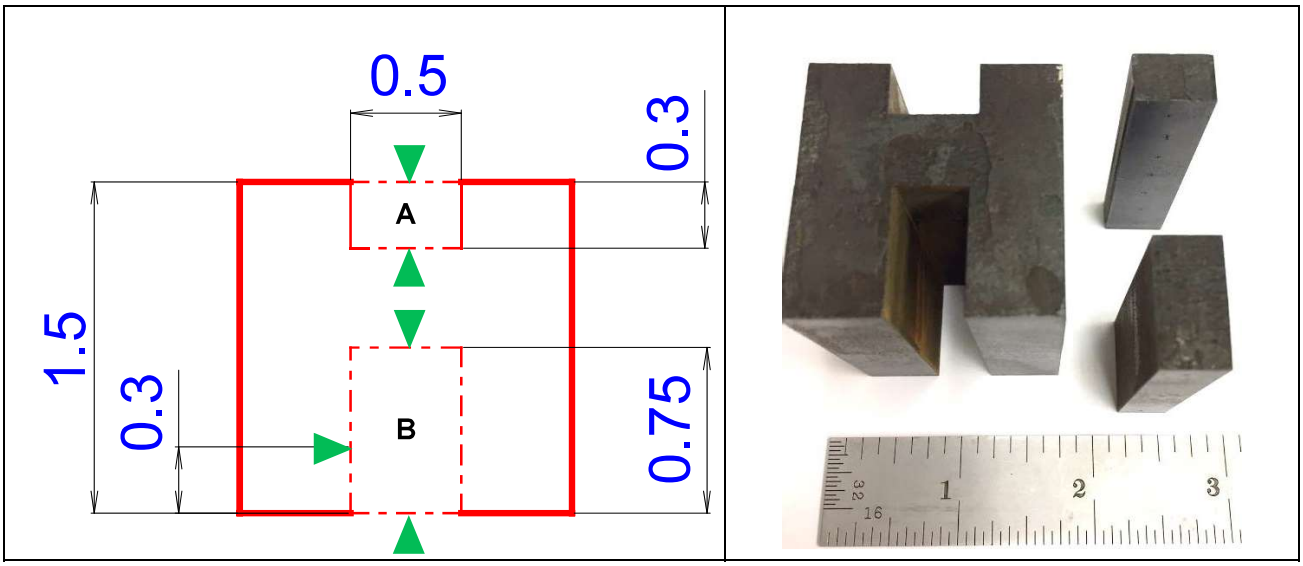


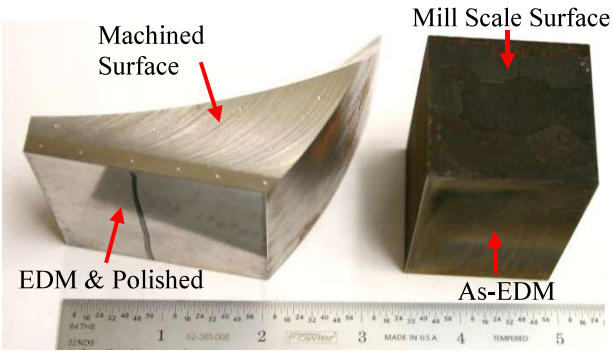
Figure 4. Location of hardness sectioned EDM test samples. Green triangles indicate hardness indent locations: Block, A after normalized at 1425 ºF for two hours and ice water quenched and Block B includes tempering at 300 ºF for two hours.

Table 3. Hardness values for the test block that was normalized at 1425 ºF in air, ice water quenched (A in figure 4) and tempered at 300 ºF (B in figure 4).

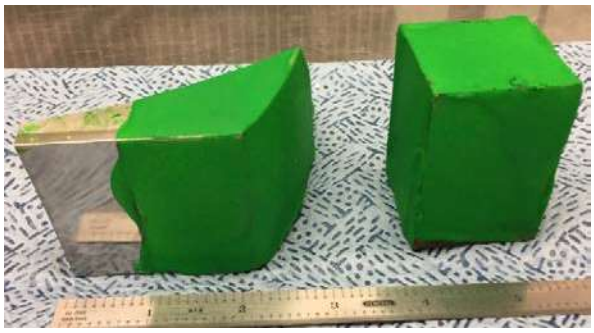
Sample Name	Indent Location	Rockwell C							Average HRC
1425 °F Ice Water Quench	Outside (EDM cut)*	35	37	38	37	37	40	40	38
	3/10" into material	48	50	52	51	52	52	50	51
1425 °F Ice Water Quenched & 300 °F Temper	Outside (EDM cut)*	35	36	37	NT	NT	NT	NT	36
	Center	51	51	51	52	51	51	50	51
	3/10" into block	49	49	50	50	50	51	50	50

NT = Not Tested

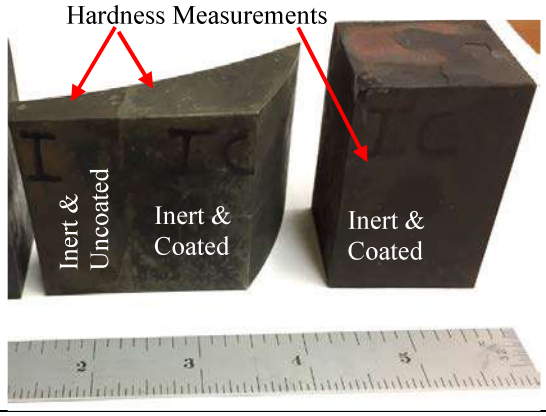
* Surface was EDM cut before heat treatment and was exposed to air while in the furnace resulting in lower hardness due to decarburization.



A - Surface finishes, as-EDM and polished, conventionally machined and as-EDM



B - Surfaces coated with DuBois No Carb Green

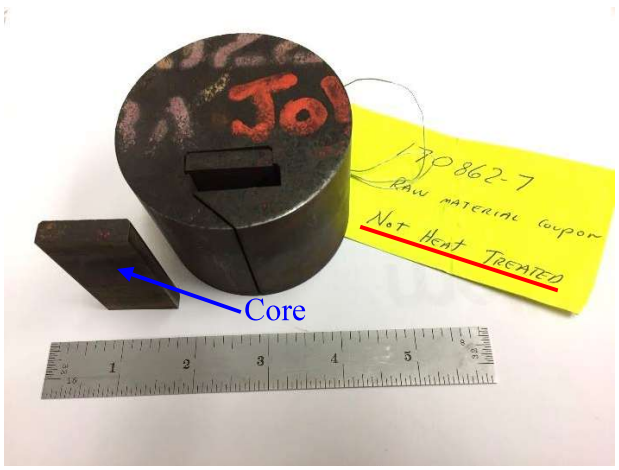


C - Surfaces following heat treating at 1425 °F for two hours and ice water quenched. Arrows indicate hardness measurements locations

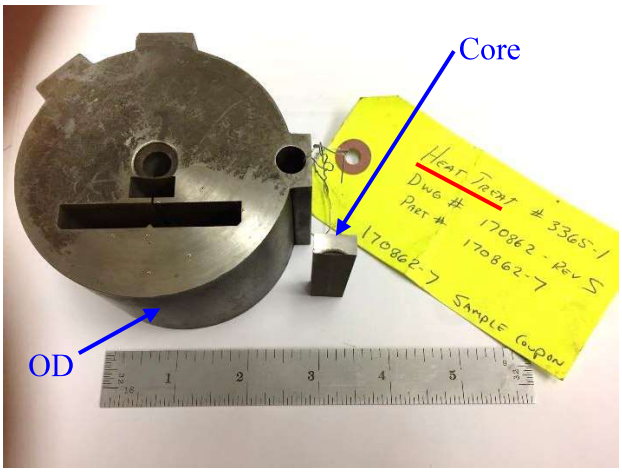
Figure 5. EDM test block and EDM replaceable tip scrap (SRNL material).

Table 4. Rockwell C hardness values for the EDM test blocks and EDM replaceable tip scrap (SRS material) following heat treatment at 1425 °F for two hours in an argon purged furnace and ice water quenched.

Sample Name	Rockwell C					Average HRC
Paddle Tip Scrap Uncoated Region	22	27	28	29	29	27
Paddle Tip Scrap Coated Region	54	54	52	51	54	53
1 1/2" Block Coated Region	51	52	51	52	53	52



A - Raw material that had not been heat treated with the production paddles



B - scrap material from the center of a paddle that was heat treated with the production paddles

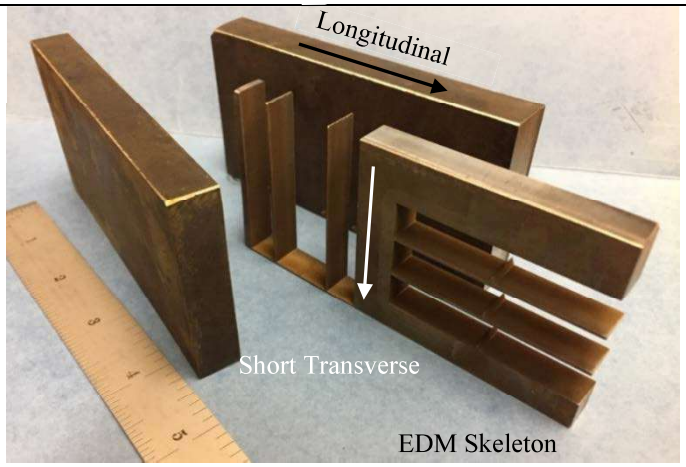
Figure 6. READCO supplied material. Arrows indicate location of hardness measurements

Table 5. Rockwell C hardness values for the READCO supplied raw material (not heat treated with the paddles) and the scrap metal that was heat treated with the paddles.

Sample Name	Location	Rockwell C					Average HRC
170862-7 Raw Material	Outer Diameter	38	40	40	39	NT	39
107862-7 Ht#: 3365-1 Scrap Heat Treated with Paddles	Outer Diameter	48	47	48	49	45	47
	Core Profile*	47	46	49	49	45	47

NT = Not Tested

* Surface not exposed to the furnace environment inside the cross-section of the part.



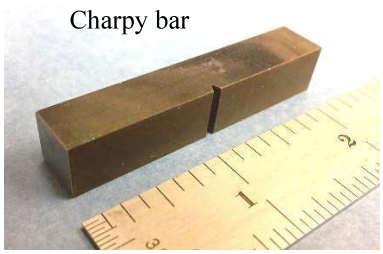
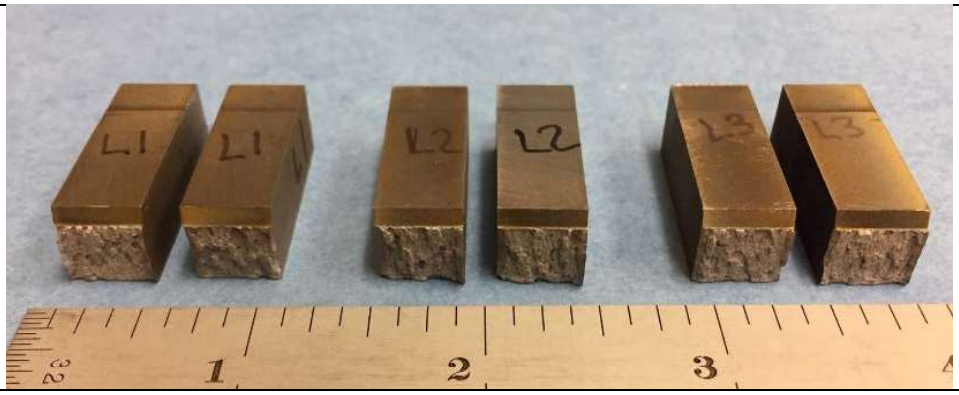
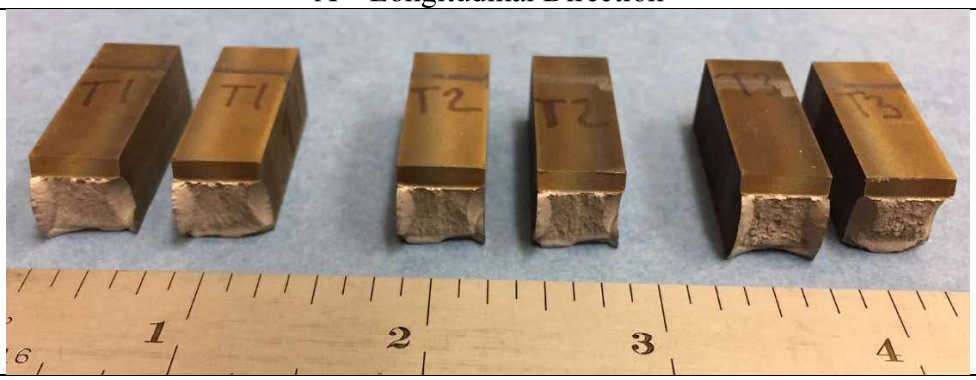


Figure 7. Heat treated block after the Charpy bars were removed using an EDM. The skeleton in the center of the block shows where the Charpy bars were cut and the orientation of the notches with respect to the rolling (longitudinal) and short transverse directions. As-machined Charpy bar shown on the right.



A – Longitudinal Direction



B – Short Traverse Direction

Figure 8. Charpy bars following impact testing. Note the shear on the sides of the Charpy bar tested in the short transverse direction (B) indicating a tougher more ductile material.

Figure 9. Saltstone mixer paddles showing large chunks of metal missing from the tips. Note: The surfaces are when the picture was taken but this amount of erosion at the tip is not characteristic of small particle erosion (see areas circled).

Table 6. Average Rockwell C hardness values the Saltstone mixer replaceable tip 1) before heat treating, 2) after heat treating at 1425 ºF and ice water quenching and 3) following tempering at 300 ºF.

Paddle Tip	**Average Rockwell C Hardness**		
ID	Before Heat Treatment	After 1425 ºF Heat Treatment/Ice Water Quenching	After 300 ºF Temper
1	41	NT	52
2*	44	NT	NT
3	NT	53	52
4	43	54	52
5	41	51	51
6	46	53	51
7	43	54	52
8	39	51	51
9	43	52	51
10	43	52	51
11	44	52	52
12	47	52	50
13	43	53	52
14	42	53	50
15	44	53	51
16	43	53	52
17	45	53	53
18	43	54	52
19	44	52	52
20	45	54	52
21	44	53	50
22	43	51	51
23	40	51	53
24	44	53	51
25	43	52	51
26	43	52	51

NT = Not Tested
* Tip 2 was heat treated at 1650 ºF and severely distorted during quenching

Attachment 1

READCO PO 17530-00 PART # 170862-7, HARDNESS CERTIFICATION

metlab
1000 E. Mermaid Ln., Wyndmoor (Phila.) PA 19038-8093
Tel. (215) 233-2600 Fax (215) 233-5653

READCO PO 17530-00 PART # 170862-7 # 1

Certification

May 2, 2019

Metlab Shop Order:	104513 /WO#3365-1
Purchase Order:	6017
Part Number:	170862
Quantity:	1 Piece
Weight:	28 Pounds
Material:	Astralloy V
Specifications:	Harden and temper to 51-54 HRC.

This is to certify that the above parts were processed as indicated above with the following results

Results:

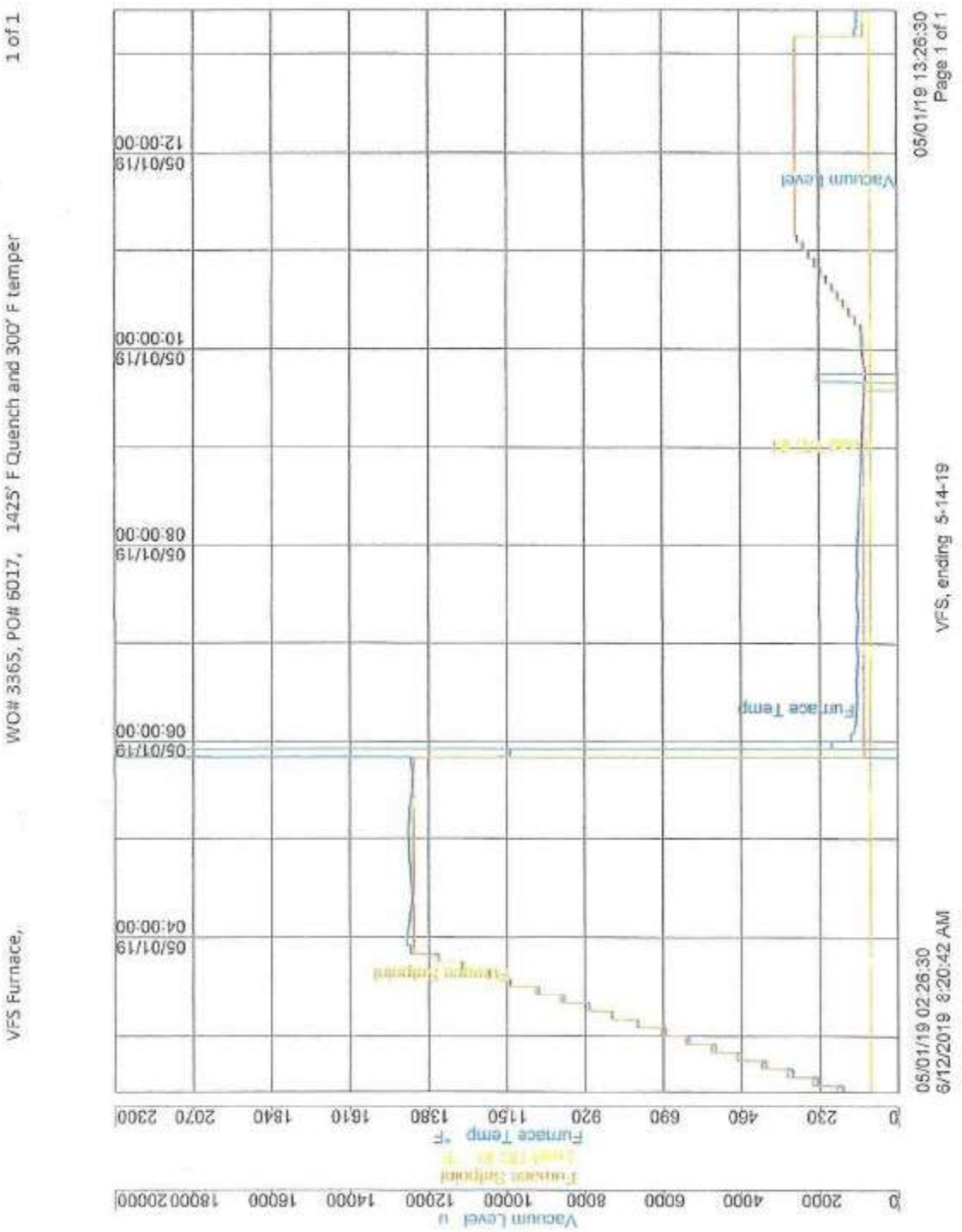
Surface Hardness: 51 HRC

See attached for heat treat cycle.

METLAB _____
Quality Representative Mark Podob

MERCURY CONTAMINATION: During the heat treating process, testing and inspections, the product did not come in direct contact with mercury or any of its compounds nor with any mercury containing device.

Heat Treating and Metallurgical Consulting



Notes:

1) Parts heated in vacuum furnace to 1425 °F and held at this temperature for 2 hours.
2) Thermocouple was in contact with the part.
3) Forced gas quench using 5 psi nitrogen until the part reached 150 °F
4) Reheated to 325 °F for two hours

Attachment 2 – Charpy Test Results

APPLIED TECHNICAL SERVICES, INCORPORATED

1049 Triad Court, Marietta, Georgia 30062 • (770) 423-1400 Fax (770) 424-6415

MATERIALS TEST REPORT

Ref. 326055 **Date** December 6, 2019 **Page** 1 **of** 1

Joyce Attucks
Savannah River Nuclear Solutions, LLC
Savannah River Site
Aiken, SC 29808

Purchase Order #: 0000453808

Test Procedure

Shear	☐	Material: Astralloy-V
Load	☐	
Impact	☒	Specifications: None Provided
Density	☐	
Bend	☐	
Other	☐	
Shear	☐	

Test Results

Part Identification	Quantity	Results			Remarks
		Absorbed Energy (ft-lbs)	Lateral Exp.(mils)	% Shear	
1425					Full-size (0.394" x 0.394") Charpy v-notch samples were tested per ASTM A370-19e1 at room temperature (70°F). The specimens were cut out using EDM. The notch was machined by EDM. Testing was performed in accordance with ATS Quality Manual Rev. 16 dated 10/01/2018.
1T	1	30	14	0	
2T	1	32	14	0	
3T	1	33	16	0	
1L	1	8	5	0	
2L	1	9	5	0	
3L	1	8	5	0	

ISO 9001

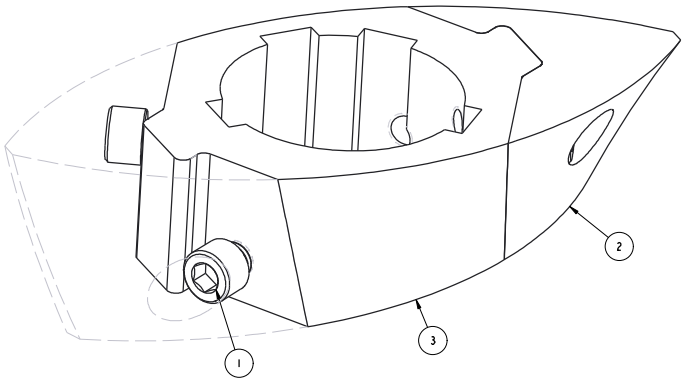
Prepared by: [redacted] Candice May
Materials Testing

Approved by [redacted] W. R. Allen
Materials Testing

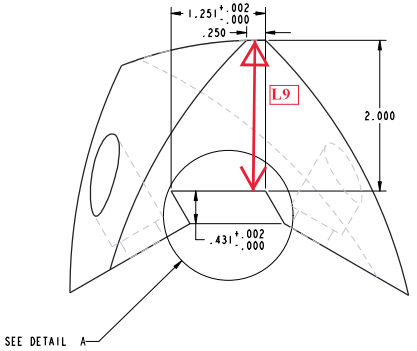
ATS 904, 01/2010

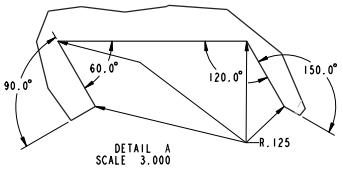
Appendix F. R-R4-Z-00022, Dimensional Measurements On Hubs and Tips

REV	REV	DATE	REVISION DESCRIPTION	PREP	ENGR	CHKD	DSGR	CUSTOMER OTHER	CUSTOMER OTHER
N/A	0	10/1/2019	ISSUED FOR CONSTRUCTION						

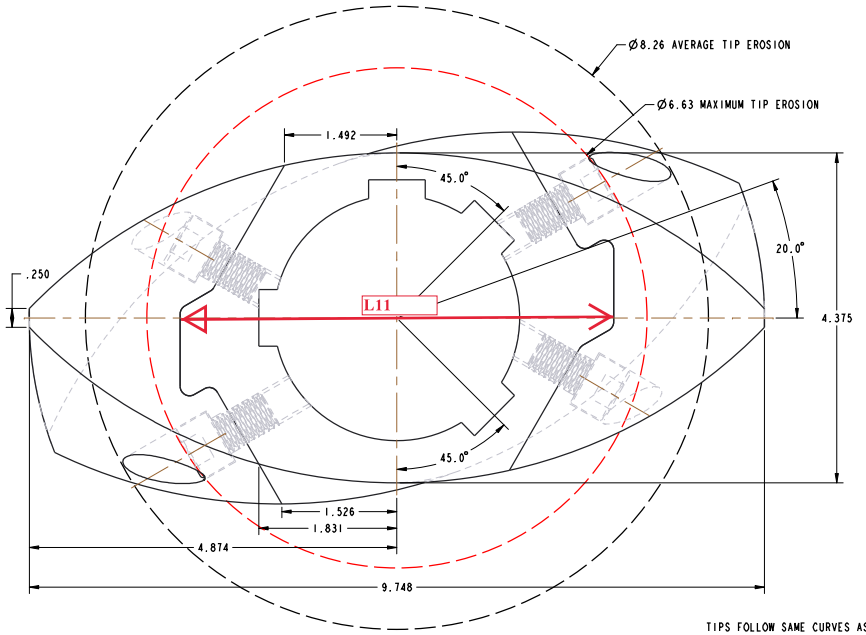


ITEM	PART AND DRAWING NO.	REQD PER ASSEMBLY	DESCRIPTION
3	R-R4-Z-00022-C	1	HUB - ASTRALLOY V FROM VENDOR BASE MATERIAL
2	R-R4-Z-00022-B	2	TIP - ASTRALLOY V, HEAT TREATED
1	COML	4	1/2-13 316 SST SHCS, 3/4" LG W/ THREAD LOCKING NYLON PATCH



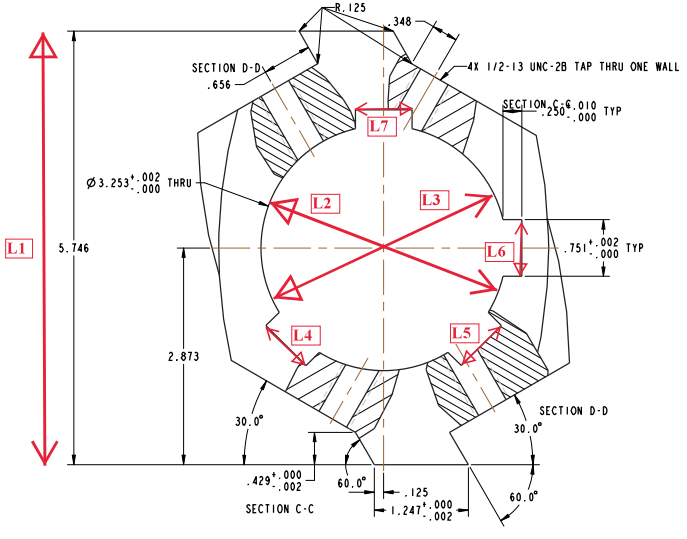


TIP - ASTRALLOY V, HEAT TREATED
MATL: ASTRALLOY "V" REQD: 2
R-R4-Z-00022-B
SCALE: 16" = 1'-0



TIPS FOLLOW SAME CURVES AS HUB

HELICAL PADDLE, INTERCHANGEABLE TIPS, 20 DEG TWIST
R-R4-Z-00022-A
SCALE: 16" = 1'-0



NOTCH AND HOLE FEATURES ARE MIRRORED ACROSS PART

HUB - ASTRALLOY V FROM VENDOR BASE MATERIAL
MATL: ASTRALLOY "V" REQD: 1
R-R4-Z-00022-C
SCALE: 16" = 1'-0

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TOLERANCES ARE: FRACTIONAL ±1/16" DECIMAL .X ± 0.03 .XX ± 0.01 .XXX ± 0.005 ANGULAR ± 2° THIRD ANGLE PROJECTION UNLESS OTHERWISE SPECIFIED: DO NOT SCALE DRAWING BREAK ALL SHARP EDGES .015 MAX. FINISH ALL SURFACES 63

INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M

RESPONSIBLE ENGINEER	W. LOZIER
ENGINEERING MANAGER	J. KINNEY
DRAWING ORIGINATOR	W. LOZIER

REFERENCE DRAWINGS

568997	PDMLINK DRAWING
568350	PDMLINK ASSEMBLY

REFERENCE STANDARDS

SITE CLEARANCE NO.	BUILDING NUMBER	DRAWING NUMBER	REV
N/A	704-Z	R-R4-Z-00022	0
DESIGN AUTHORITY	DESIGN GROUP	SCALE / JOB NUMBER	SHEET
N/A	SRNL R&DE	SHOWN 23694	1 OF 1

UNITED STATES DEPARTMENT OF ENERGY
SAVANNAH RIVER SITE

Savannah River National Laboratory™
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

TITLE

SALTSTONE HELICAL PADDLE, INTERCHANGEABLE TIPS ANGLED NOTCH DESIGN ASSEMBLY AND DETAILS

Appendix G. EDM Program – Hub Inside (shaft side) Cut

```
%
L10010/HUB ID
H01=.007
M20
M78M78
E1271F.02
G90G92X0.Y0.
M80M82M84
G1G42X-1.5055Y0.6467M90
G3X-1.5029Y0.6465R0.015
X-1.4891Y0.6555R0.015
G2X-0.1066Y1.6235R1.627
G3X-0.0928Y1.6359R0.015
G1X-0.0506Y1.8754M90
X0.689Y1.7449M90
X0.6467Y1.5055M90
G3X0.6465Y1.5029R0.015
X0.6555Y1.4891R0.015
G2X1.0726Y1.2234R1.627
G3X1.0825Y1.2197R0.015
X1.0911Y1.2224R0.015
G1X1.2903Y1.3619M90
X1.721Y0.7467M90
X1.5218Y0.6072M90
G3X1.5154Y0.5949R0.015
X1.5165Y0.5895R0.015
G2X1.627Y0.R1.627
X1.2234Y-1.0726R1.627
G3X1.2197Y-1.0825R0.015
X1.2224Y-1.0911R0.015
G1X1.3619Y-1.2903M90
X0.7467Y-1.721M90
X0.6072Y-1.5218M90
G3X0.5949Y-1.5154R0.015
X0.5895Y-1.5165R0.015
G2X0.Y-1.627R1.627
X-1.6235Y-0.1066R1.627
G3X-1.6359Y-0.0928R0.015
G1X-1.8754Y-0.0506M90
X-1.7449Y0.689M90
M01
X-1.5055Y0.6467M90
G40
M83M85M81
M30
%
```

Appendix H. EDM Program – Hub Outside (Tip side) Cut

```
%
L10020/OUTSIDE PROFILE
H01=.007
M20
M78M78
E1271F.02
G90G92X1.0Y-3.0
M80M82M84
G1G42X1.1192Y-2.2498M90
X2.3217Y-0.8167M90
G2X2.3747Y-0.7796R0.125
G1X2.7398Y-0.6467M90
G3X2.8202Y-0.5509R0.125
G1X2.9864Y0.3919M90
G3X2.9883Y0.4136R0.125
X2.8633Y0.5386R0.125
X2.8206Y0.531R0.125
G1X2.6771Y0.4788M90
G2X2.6343Y0.4713R0.125
X2.5169Y0.5535R0.125
G1X1.9313Y2.1622M90
X2.0Y3.0M90
X-1.0M90
X-1.1192Y2.2498M90
X-2.3217Y0.8167M90
G2X-2.3747Y0.7796R0.125
G1X-2.7398Y0.6467M90
G3X-2.8202Y0.5509R0.125
G1X-2.9864Y-0.3919M90
G3X-2.9883Y-0.4136R0.125
X-2.8633Y-0.5386R0.125
X-2.8206Y-0.531R0.125
G1X-2.6771Y-0.4788M90
G2X-2.6343Y-0.4713R0.125
X-2.5169Y-0.5535R0.125
G1X-1.9313Y-2.1622M90
M01
X-1.75Y-3.0M90
M83M85M81
M30
%
```

Appendix I. EDM Program – Tip Radius

```
%
L10001/TIP RADIUS
H01=.007
M20;
M78M78;
E1271F.05
G90G92X4.0Y3.0;
M80M82M84;
N10G41;
N15G01X3.8413;
N20G02Y-3.0I-3.8413J-3.0;
N25M83;
N30M85;
N35M81;
N40M30;
%
```

Appendix J. EDM Program - Tip Front (leading edge) Taper Cut

```
%
L10011/FRONT TAPER CUT;
H01=.007;
M20;
M78M78;
E1299F.01;
G90G92X-2.5Y-3.0;
M80M82M84;
N10G01G42X-1.9313Y-2.1622U-0.209V0.5742;
N15X-1.8324Y-2.1782U-0.2185V0.548;
N20X-1.7333Y-2.1927U-0.2276V0.5217;
N25X-1.634Y-2.2058U-0.2364V0.4952;
N30X-1.5344Y-2.2174U-0.2448V0.4686;
N35X-1.4347Y-2.2275U-0.2528V0.4419;
N40X-1.3349Y-2.2361U-0.2604V0.415;
N45X-1.235Y-2.2433U-0.2676V0.388;
N50X-1.1349Y-2.249U-0.2744V0.3609;
N55X-1.0348Y-2.2533U-0.2808V0.3336;
N60X-0.9347Y-2.256U-0.2869V0.3063;
N65X-0.8345Y-2.2573U-0.2925V0.2788;
N70X-0.7343Y-2.2571U-0.2977V0.2513;
N75X-0.6341Y-2.2554U-0.3025V0.2236;
N80X-0.534Y-2.2522U-0.307V0.1959;
N85X-0.4339Y-2.2476U-0.311V0.168;
N90X-0.3339Y-2.2414U-0.3146V0.1401;
N95X-0.2339Y-2.2338U-0.3178V0.1122;
N100X-0.1342Y-2.2248U-0.3206V0.0841;
N105X-0.0345Y-2.2142U-0.323V0.056;
N110X0.065Y-2.2022U-0.3249V0.0279;
N115X0.1642Y-2.1887U-0.3265V-0.0003;
N120X0.2633Y-2.1738U-0.3276V-0.0285;
N125X0.3622Y-2.1574U-0.3284V-0.0568;
N130X0.4608Y-2.1395U-0.3287V-0.0851;
N135X0.5591Y-2.1202U-0.3286V-0.1134;
N140X0.6571Y-2.0994U-0.3281V-0.1417;
N145X0.7548Y-2.0772U-0.3271V-0.17;
N150X0.8522Y-2.0535U-0.3258V-0.1984;
N155X0.9492Y-2.0284U-0.324V-0.2267;
N160X1.0458Y-2.0019U-0.3218V-0.255;
N165X1.142Y-1.974U-0.3192V-0.2833;
N170X1.2378Y-1.9446U-0.3162V-0.3116;
N175X1.3332Y-1.9139U-0.3127V-0.3399;
N180X1.4281Y-1.8817U-0.3089V-0.3681;
N185X2.0Y-3.0U0.V0.;
G40;
N190M83;
N195M85;
N200M81;
N205M30;
%
```

Appendix K. EDM Program -Tip Back (lagging edge) Taper Cut

```
%
L10012/BACK TAPER CUT;
H01=.007;
M20;
M78M78;
E1299F.01;
G90G92X2.5Y3.0;
M80M82M84;
N10G01G42X1.9313Y2.1622U0.209V-0.5742;
N15X1.8294Y2.1786U0.2188V-0.5472;
N20X1.7273Y2.1935U0.2282V-0.5201;
N25X1.6249Y2.2069U0.2372V-0.4928;
N30X1.5224Y2.2187U0.2458V-0.4654;
N35X1.4196Y2.2289U0.254V-0.4378;
N40X1.3168Y2.2376U0.2617V-0.4101;
N45X1.2138Y2.2447U0.2691V-0.3823;
N50X1.1107Y2.2502U0.276V-0.3543;
N55X1.0075Y2.2542U0.2825V-0.3262;
N60X0.9043Y2.2565U0.2886V-0.298;
N65X0.8011Y2.2574U0.2943V-0.2696;
N70X0.6979Y2.2566U0.2995V-0.2412;
N75X0.5946Y2.2543U0.3043V-0.2127;
N80X0.4915Y2.2504U0.3087V-0.1841;
N85X0.3884Y2.245U0.3127V-0.1554;
N90X0.2854Y2.2379U0.3162V-0.1266;
N95X0.1825Y2.2293U0.3193V-0.0977;
N100X0.0798Y2.2192U0.3219V-0.0688;
N105X-0.0228Y2.2075U0.3242V-0.0398;
N110X-0.1252Y2.1942U0.3259V-0.0108;
N115X-0.2273Y2.1794U0.3273V0.0182;
N120X-0.3292Y2.163U0.3282V0.0473;
N125X-0.4309Y2.1451U0.3286V0.0765;
N130X-0.5323Y2.1256U0.3287V0.1056;
N135X-0.6334Y2.1046U0.3282V0.1348;
N140X-0.7341Y2.082U0.3274V0.164;
N145X-0.8345Y2.0579U0.3261V0.1932;
N150X-0.9345Y2.0323U0.3243V0.2224;
N155X-1.0341Y2.0052U0.3221V0.2516;
N160X-1.1333Y1.9766U0.3195V0.2808;
N165X-1.232Y1.9464U0.3164V0.3099;
N170X-1.3303Y1.9148U0.3129V0.339;
N175X-1.4281Y1.8817U0.3089V0.3681;
N180X-2.0Y3.0U0.V0.;
G40;
N185M83;
N190M85;
N195M81;
N200M30;
%
```

Appendix L. EDM Program - Tip Taper Cut (Wings)

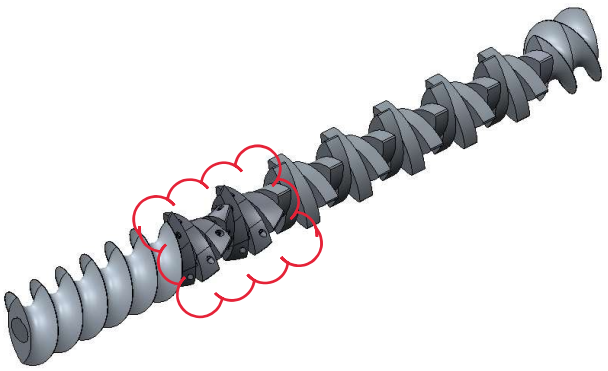
```
%
L10002/tip taper cut;
H01=.008
M20;
M78M78;
E1299F.02
G90G92X2.0Y3.0;
M80M82M84;
N10G01G41X1.9313Y2.1622U0.209V-0.5742;
N15X2.0328Y2.1442U0.1969V-0.5999;
N20X2.1339Y2.1247U0.1844V-0.6255;
N25X2.2347Y2.1037U0.1716V-0.6507;
N30X2.3352Y2.0811U0.1584V-0.6758;
N35X2.4353Y2.057U0.1449V-0.7006;
N40X2.5351Y2.0314U0.131V-0.7251;
N45X2.6345Y2.0043U0.1168V-0.7494;
N50X2.7334Y1.9757U0.1022V-0.7734;
N55X2.8319Y1.9456U0.0873V-0.7972;
N60X2.9299Y1.914U0.0721V-0.8207;
N65X3.0274Y1.8809U0.0565V-0.8439;
N70X3.1245Y1.8464U0.0406V-0.8668;
N75X3.2209Y1.8103U0.0245V-0.8895;
N80X3.3169Y1.7728U0.008V-0.9118;
N85X3.4122Y1.7339U-0.0089V-0.9339;
N90X3.5069Y1.6935U-0.026V-0.9556;
N95X3.6011Y1.6517U-0.0434V-0.9771;
N100X3.6945Y1.6085U-0.0611V-0.9982;
N105X3.7873Y1.5638U-0.079V-1.0191;
N110X3.8795Y1.5178U-0.0973V-1.0396;
N115X3.9709Y1.4703U-0.1158V-1.0598;
N120X4.0616Y1.4215U-0.1346V-1.0797;
N125X4.1515Y1.3713U-0.1537V-1.0992;
N130X4.2406Y1.3197U-0.173V-1.1185;
N135X4.329Y1.2668U-0.1926V-1.1374;
N140X4.4165Y1.2126U-0.2124V-1.156;
N145X4.5033Y1.157U-0.2325V-1.1742;
N150X4.5891Y1.1001U-0.2528V-1.1921;
N155X4.6741Y1.0419U-0.2733V-1.2096;
N160X4.7582Y0.9825U-0.294V-1.2268;
N165X4.8414Y0.9218U-0.315V-1.2437;
N170X4.9236Y0.8598U-0.3362V-1.2602;
N175X5.0049Y0.7966U-0.3576V-1.2763;
N180X5.0853Y0.7321U-0.3791V-1.2921;
N185X5.1646Y0.6665U-0.4009V-1.3075;
N190X5.243Y0.5996U-0.4229V-1.3226;
N195X4.8201Y0.723U0.4229;
M01;
N200X4.764Y0.6415U0.4007V-1.3079;
N205X4.7068Y0.5609U0.3787V-1.2928;
N210X4.6484Y0.4811U0.3569V-1.2774;
N215X4.5888Y0.4022U0.3353V-1.2616;
N220X4.5281Y0.3241U0.3139V-1.2454;
N225X4.4663Y0.2469U0.2926V-1.2289;
N230X4.4034Y0.1707U0.2716V-1.212;
N235X4.3393Y0.0954U0.2508V-1.1948;
```

```
N240X4.2742Y0.021U0.2302V-1.1772;
N245X4.2079Y-0.0525U0.2099V-1.1593;
N250X4.1407Y-0.1249U0.1897V-1.141;
N255X4.0723Y-0.1964U0.1699V-1.1224;
N260X4.003Y-0.2669U0.1502V-1.1035;
N265X3.9326Y-0.3363U0.1308V-1.0842;
N270X3.8612Y-0.4047U0.1117V-1.0645;
N275X3.7888Y-0.4721U0.0928V-1.0446;
N280X3.7154Y-0.5384U0.0742V-1.0243;
N285X3.6411Y-0.6036U0.0558V-1.0037;
N290X3.5659Y-0.6678U0.0378V-0.9828;
N295X3.4897Y-0.7308U0.02V-0.9615;
N300X3.4126Y-0.7927U0.0025V-0.94;
N305X3.3346Y-0.8535U-0.0147V-0.9181;
N310X3.2557Y-0.9132U-0.0316V-0.8959;
N315X3.176Y-0.9717U-0.0482V-0.8735;
N320X3.0955Y-1.029U-0.0645V-0.8507;
N325X3.0141Y-1.0851U-0.0805V-0.8277;
N330X2.9319Y-1.1401U-0.0961V-0.8043;
N335X2.8489Y-1.1938U-0.1115V-0.7807;
N340X2.7651Y-1.2464U-0.1265V-0.7568;
N345X2.6806Y-1.2977U-0.1411V-0.7326;
N350X2.5953Y-1.3478U-0.1555V-0.7082;
N355X2.5093Y-1.3966U-0.1695V-0.6834;
N360X2.4226Y-1.4442U-0.1831V-0.6585;
N365X2.3353Y-1.4905U-0.1964V-0.6332;
N370X2.2472Y-1.5355U-0.2093V-0.6078;
N375X2.1585Y-1.5792U-0.2219V-0.5821;
N380X2.0692Y-1.6217U-0.2341V-0.5561;
N385X1.9793Y-1.6628U-0.2459V-0.5299;
N390X1.8888Y-1.7026U-0.2574V-0.5035;
N395X1.7977Y-1.7411U-0.2685V-0.4768;
N400X1.7061Y-1.7783U-0.2791V-0.45;
N405X1.6139Y-1.8141U-0.2895V-0.4229;
N410X1.5212Y-1.8486U-0.2994V-0.3956;
N415X1.4281Y-1.8817U-0.3089V-0.3681;
M01
N420X1.0Y-3.0U0.V0.;
N425M83;
N430M85;
N435M81;
N440M30;
%
```

Appendix M. EDM Program - Tip Key and Cutoff (final cut)

```
%
L10003/TIP KEY AND CUTOFF
H01=.007
M20
M78M78
E1271F.05
G90G92X2.0Y3.0
M80M82M84
G1G42X1.9313Y2.1622M90
X2.5169Y0.5535M90
G3X2.6343Y0.4713R0.125
X2.6771Y0.4788R0.125
G1X2.8206Y0.531M90
G2X2.8633Y0.5386R0.125
X2.9883Y0.4136R0.125
X2.9864Y0.3919R0.125
G1X2.8202Y-0.5509M90
G2X2.7398Y-0.6467R0.125
G1X2.3747Y-0.7796M90
G3X2.3217Y-0.8167R0.125
G1X1.1192Y-2.2498M90
M01
X1.0Y-3.0M90
M83M85M81
M30
%
```

Appendix N. Saltstone Paddle Assembly with SRNL Helical Replaceable Paddles



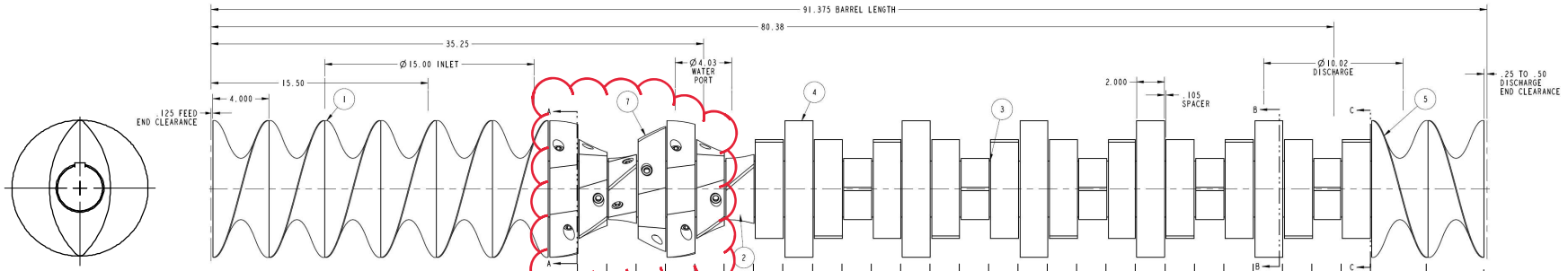
OPERATING CLEARANCE AT AMBIENT TEMPERATURE

PADDLE TO PADDLE	- .095" TO .155"
FEED SCREW TO FEED SCREW	- .020" MIN.
SCREW AND PADDLE TO BARREL RADIUS	- .110" TO .140"
FEED END CLEARANCE	- .115" TO .145"
DISCHARGE END CLEARANCE	- .250" TO .500"

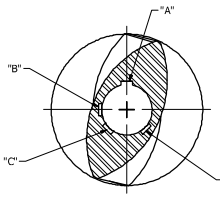
NOTES:
1. PADDLE ORIENTATION IS SHOWN FOR LEFT SHAFT AS VIEWED FROM THE DISCHARGE END OF PROCESSOR.
2. NO. REQD IS THE TOTAL FOR (1) SHAFT.
3. ASSEMBLE THE FIRST FEED SCREW SO THAT THE CHAMFERED END OF THE SCREW BORE IS SHOULDERED ON THE SHAFT. THE CHAMFER IS FOR CLEARANCE WITH THE RADIUS ON THE SHAFT. NOTE: ALL FORWARD (LH HELIX) FEED SCREWS HAVE A BEVEL ON ONE END OF THE BORE. THE ABOVE ONLY APPLIES TO THE FIRST FEED SCREW ON THE SHAFT.
4. THIS PADDLE ASS'Y NOTES CHANGES MADE TO MIXER S/N 108639. PLEASE REFER TO DWG. D274198 FOR ORIGINAL PADDLE ASS'Y.

ITEM	QTY	PART NUMBER	DWG. NUMBER	MATERIAL	DESCRIPTION	MASS
1	6	N027-274206	D274206	316L	FEED SEC. HARD TIP, (FWD) LH HELIX, 8 LEAD, 4 PITCH	25,21
2	1	N027-274738	C274738	ASTRALLOY V	HELICAL PADDLE KY POS A, B, C, &D	12,00
3	29	N027-174343-5	A174343	316L	SPACER	0,15
4	21	N017-170862	D170862-7ABC	ASTRALLOY V	FLAT PADDLE KY POS A, B, & C	12,07
5	2	N027-274207	D274207	316L	FEED SEC. HARD TIP, (REV) RH HELIX, 8 LEAD, 4 PITCH	25,22
6	1	N027-273832-1	B273832	316	PADDLE SHAFT KEY	9,80
7	6	R-R4-Z-00022-A	R-R4-Z-00022	ASTRALLOY V	REPLACEABLE TIP HELICAL PADDLE BY SRNL	11,65

TOTAL WT. (1) SHAFT = 551.2 LBS.

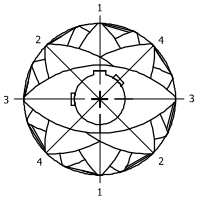


PADDLE NO.							1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28		
PADDLE ITEM NO.	1	1	1	1	1	1	7	7	7	7	7	7	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5
PADDLE POSITION	1	1	1	1	1	1	1	4	3	2	1	4	3	2	1	4	3	2	1	4	3	2	1	4	3	2	1	4	3	2	1	4	1	1
KEYWAY POSITION							A	D	B	C	A	D	B	C	A	C	B	C	A	C	B	C	A	C	B	C	A	C	B	C	A	C		

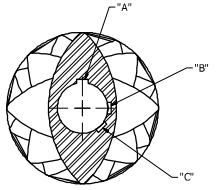


AS VIEWED FROM DISCHARGE END

SECTION A-A



SECTION C-C



SECTION B-B

METHODS REF. D270519, D273787, D274198

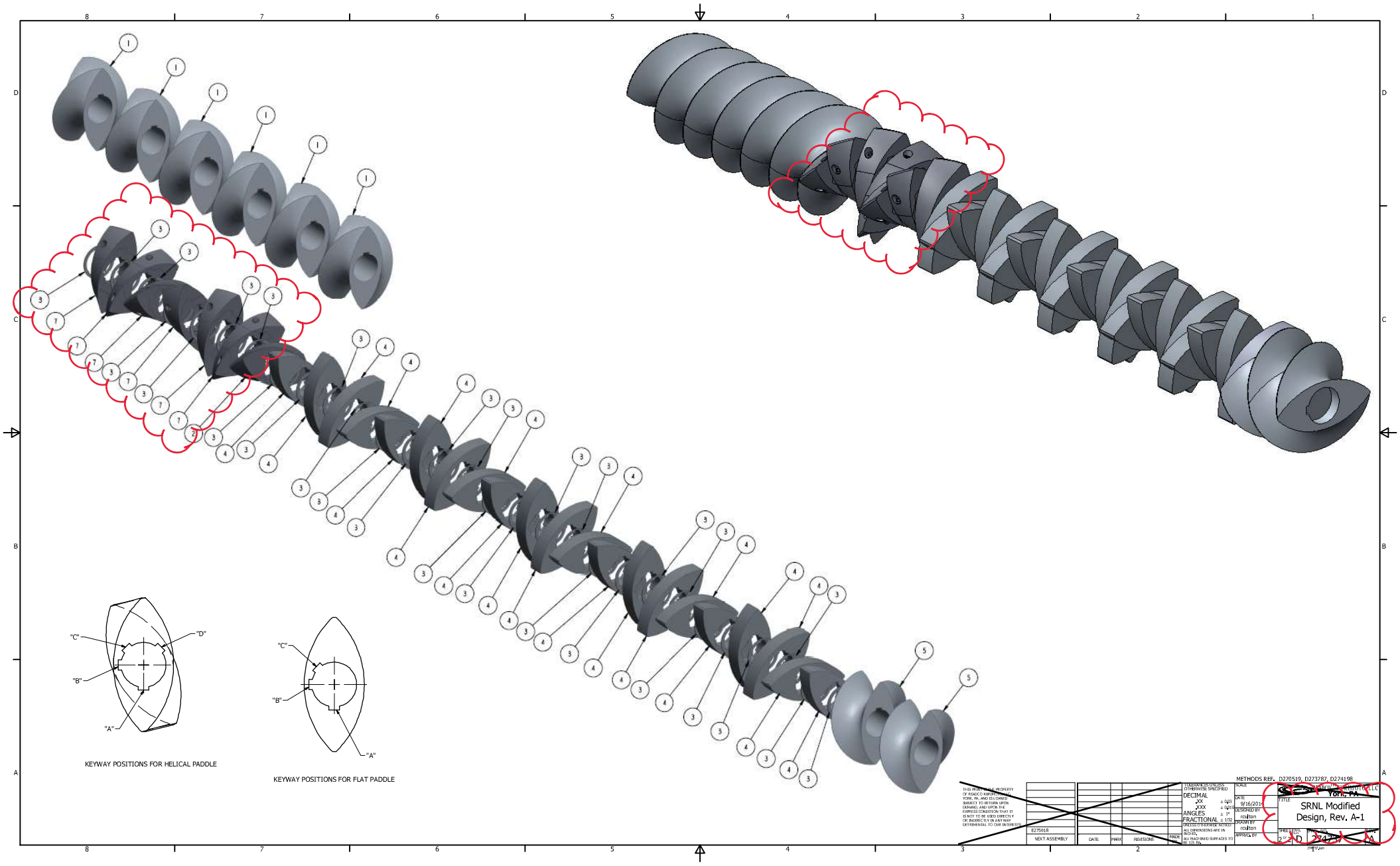
E275018 NEXT ASSEMBLY	9-8-14 DATE	A MARK	DCN6120 REVISIONS	NRL INITIALS

UNDIMENSIONED UNLESS OTHERWISE SPECIFIED
DECIMAL XX ± .020 XXX ± .010
ANGLES ± 1°
FRACTIONAL ± 1/32
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE IN INCHES
ALL MACHINED SURFACES TO BE 125 RX

SCALE 1:4
DATE 9/16/2014
DESIGNED BY roulton
DRAWN BY roulton
APPROVED BY

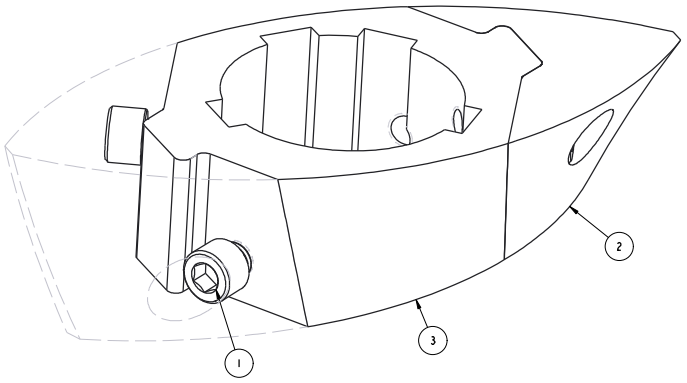
SRNL Modified Design, Rev. A-1

SIZE D | DWG NO. 274198 | REV A
SHEET 1 OF 1

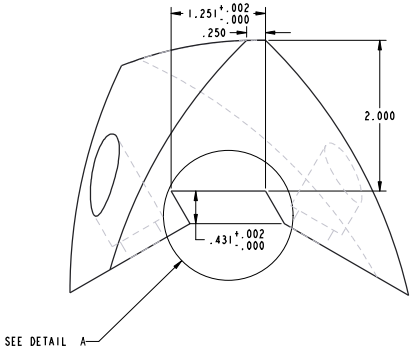

"C"
"D"
"B"
"A"
KEYWAY POSITIONS FOR HELICAL PADDLE
"C"
"B"
"A"
KEYWAY POSITIONS FOR FLAT PADDLE
METHODS REF. D270519, D273787, D274198
York, PA
SRNL Modified
Design, Rev. A-1
D 274198
A

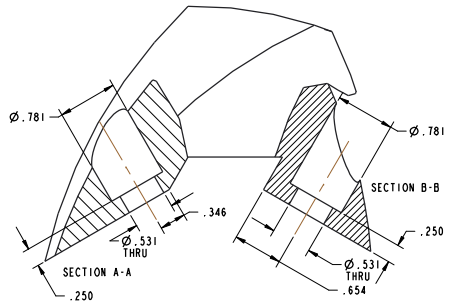
Appendix O. R-R4-Z-00022 Saltstone Helical Paddle Interchangeable Tips Angled Notch Design Assembly and Details

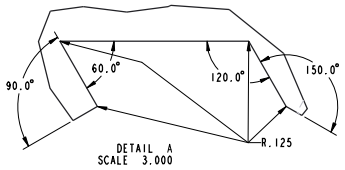
PROJ	REV	DATE	REVISION DESCRIPTION	PREP	ENGR	CHKD	DSNR	CUSTOMER OTHER	CUSTOMER OTHER
N/A	0	10/1/2019	ISSUED FOR CONSTRUCTION						



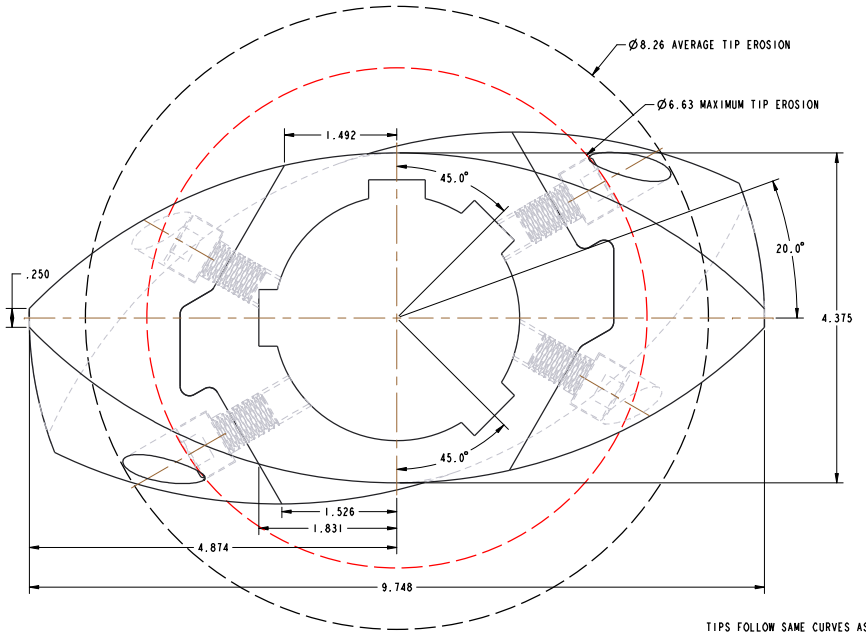
ITEM	PART AND DRAWING NO.	REQD PER ASSEMBLY	DESCRIPTION
3	R-R4-Z-00022-C	1	HUB - ASTRALLOY V FROM VENDOR BASE MATERIAL
2	R-R4-Z-00022-B	2	TIP - ASTRALLOY V, HEAT TREATED
1	COML	4	1/2-13 316 SST SHCS, 3/4" LG W/ THREAD LOCKING NYLON PATCH





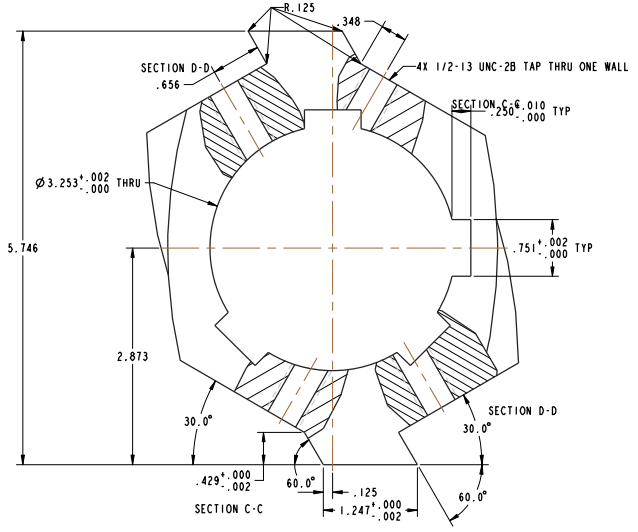


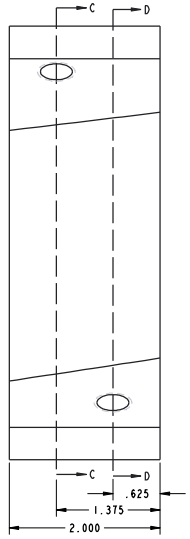
TIP - ASTRALLOY V, HEAT TREATED
MATL: ASTRALLOY "V" REQD: 2
R-R4-Z-00022-B
SCALE: 18" = 1'-0



TIPS FOLLOW SAME CURVES AS HUB

HELICAL PADDLE, INTERCHANGEABLE TIPS, 20 DEG TWIST
R-R4-Z-00022-A
SCALE: 18" = 1'-0





NOTCH AND HOLE FEATURES ARE MIRRORED ACROSS PART

HUB - ASTRALLOY V FROM VENDOR BASE MATERIAL
MATL: ASTRALLOY "V" REQD: 1
R-R4-Z-00022-C
SCALE: 18" = 1'-0

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SITE CLEARANCE NO.	BUILDING NUMBER	DRAWING NUMBER			REV
N/A	704-Z	R-R4-Z-00022			0
DESIGN AUTHORITY	DESIGN GROUP	SCALE	JOB NUMBER		SHEET
N/A	SRNL R&DE	SHOWN	23694		1 OF 1

TOLERANCES ARE: FRACTIONAL ±1/16 ANGULAR ± 2° DECIMAL .X ± 0.03 .XX ± 0.01 .XXX ± 0.005
THIRD ANGLE PROJECTION
UNLESS OTHERWISE SPECIFIED: DO NOT SCALE DRAWING BREAK ALL SHARP EDGES .015 MAX ALL SURFACES 63
INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M

RESPONSIBLE ENGINEER	W. LOZIER
ENGINEERING MANAGER	J. KINNEY
DRAWING ORIGINATOR	W. LOZIER

REFERENCE DRAWINGS

568997	PDMLINK DRAWING
568350	PDMLINK ASSEMBLY

REFERENCE STANDARDS

UNITED STATES DEPARTMENT OF ENERGY
SAVANNAH RIVER SITE
Savannah River National Laboratory™
OPERATED BY SAVANNAH RIVER NUCLEAR SOLUTIONS

TITLE
SALTSTONE HELICAL PADDLE, INTERCHANGEABLE TIPS ANGLED NOTCH DESIGN ASSEMBLY AND DETAILS