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Evaluation of Molybdenum as a Surrogate for Iridium in Weld Development

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Abstract

The welding equipment used for welding iridium containers (clads) at Los Alamos National Laboratory is twenty five years old and is undergoing an upgrade. With the upgrade, there is a requirement for requalification of the welding process, and the opportunity for process improvement. Testing of the new system and requalification will require several welds on iridium test parts and clads, and any efforts to improve the process will add to the need for iridium parts. The extreme high cost of iridium imposes a severe limitation on the extent of test welding that can be done. The 2 inch diameter, 0.027 inch thick, iridium blank disc that the clad cup is formed from, is useful for initial weld trials, but it costs $5000. The development clad sets needed for final tests and requalification cost $15,000 per set. A solution to iridium cost issue would be to do the majority of the weld development on a less expensive surrogate metal with similar weld characteristics. One such metal is molybdenum. Since its melting index (melting temperature x thermal conductivity) is closest to iridium, welds on molybdenum should be similar in size for a given weld power level. Molybdenum is inexpensive; a single 2 inch molybdenum disc costs only $9.

In order to evaluate molybdenum as a surrogate for iridium, GTA welds were first developed to provide full penetration on 0.030 inch thick molybdenum discs at speeds of 20, 25, and 30 inches per minute (ipm). These weld parameters were then repeated on the standard 0.027 inch thick iridium blanks. The top surface and bottom surface (root) width and grain structure of the molybdenum and iridium welds were compared, and similarities were evident between the two metals. Due to material and thickness differences, the iridium welds were approximately 35% wider than the molybdenum welds. A reduction in iridium weld current of 35% produce welds slightly smaller than the molybdenum welds yet showed that current could be scaled according to molybdenum/iridium weld width ratio to achieve similar welds. Further weld trials using various thicknesses of molybdenum determined that 0.024 inch thick molybdenum material would best match the 0.027 inch thick iridium in achieving comparable welds when using the same welding parameters. Across the range of welding speeds, the characteristic weld pool shape and solidification grain structure in the two materials was

also similar. With the similarity of welding characteristics confirmed, and the appropriate thickness of molybdenum determined, it has been concluded that the use of molybdenum discs and tube sections will greatly expand the weld testing opportunities prior to iridium weld qualification.

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Introduction

Early in iridium container (clad) production, weld cracking was a significant issue. Prior to production at LANL, the cracking issues were mitigated through improvements in the iridium alloy production methods. The iridium production process was changed from a small batch drop-cast method to a larger batch electron beam and vacuum arc re-melting process. The new production process improved alloy cleanliness, homogeneity, and consistency, all factors which contributed to improved weldability. Early testing of welding with magnetic arc oscillation on the old crack sensitive alloy appeared to reduce cracking and thus it was implemented in the production welding procedure. Although subsequent investigations of arc oscillation with the improved iridium alloy are unclear on a benefit, the arc oscillator has been retained in production welding to the present day. Because the actual deflection of the arc cannot be accurately measured, the arc oscillator cannot be calibrated. Elimination of the arc oscillator is one factor being considered as a potential process improvement.

The iridium welding process and equipment is now 25 years old and undergoing an upgrade. With the upgrade, there is a requirement for requalification of the welding process, and the opportunity for process improvement. Testing of the new system and requalification will require several welds on iridium test parts and clads, and any efforts to improve the process will add to the need for iridium parts. The extreme high cost of iridium imposes a severe limitation on the extent of test welding that can be done. The 2 inch diameter, 0.027 inch thick, iridium blank disc that the clad cup is formed from, is useful for initial weld trials, but it costs $5000. The development clad sets needed for final tests and requalification cost $15,000 per set. A solution to iridium cost issue would be to do the majority of the weld development on a less expensive surrogate metal with similar weld characteristics. One such metal is molybdenum. Since its melting index (melting temperature x thermal conductivity) is closest to iridium, welds on molybdenum should be similar in size for a given weld power level. Molybdenum is inexpensive; a single 2 inch molybdenum disc costs only $9.

Having a similar melting index suggests that a given weld power level will result in similar weld size for equal thickness of molybdenum and iridium. When considering factors significant to maximizing weld ductility and minimizing hot cracking, establishing welding parameters to minimize weld size is of primary importance, but of secondary importance is the control of weld pool shape and solidification grain structure. A review of molybdenum weld microstructure suggests that this aspect is also very similar to iridium welds.

This report documents the results of experimental efforts to determine a correlation between molybdenum and iridium with respect to the weld size and solidification response to welding conditions. Assuming that the weld response of the materials is similar, the ultimate goal of this work was to determine the thickness of molybdenum that would result in welds closely matching those in the 0.027 inch thick iridium blank and final production clad.

Experimental Procedure

To begin the comparison of molybdenum with iridium, welding parameters were first developed to provide full penetration welds on 0.030 inch thick molybdenum. The goal was to produce a weld of minimum width, while maintaining adequate margin to avoid lack of penetration that could occur with normal process variation. For simplicity, the welding process was constant current GTA, and magnetic arc oscillation was not used. Because welding speed affects the shape of the molten pool, solidification grain structure, and cracking susceptibility and ductility of welds, a range of travel speeds were investigated; 30, 25, and 20 ipm. The upper limit of 30 ipm was chosen because this is the speed currently used in production of the clad weld, and based on a review published research and some prior weld trials done at LANL, welds at greater speeds tend to produce a teardrop shaped weld pool and a solidification grain structure with a distinct centerline that promotes hot cracking. A lower limit speed of 20 ipm was chosen because prior tests had shown it to produce an elliptical pool shape and desirable grain structure. Further reduction in speed below 20 ipm would likely just increase heat input, resulting in an increased heat affected zone, promoting grain growth and reduced ductility.

Following the development of suitable welds on molybdenum, three experimental iterations were completed on 0.027 inch thick iridium in order to determine the amperage required to produce welds most closely matching those on molybdenum. With the appropriate amperage determined for each welding speed on iridium, these parameters were then applied to three different thicknesses of molybdenum; 0.027, 0.023, and 0.019 inches thick, to determine the thickness of molybdenum that would result in welds most similar to those made on iridium.

The welding was performed within a helium atmosphere glovebox, with oxygen levels less than 10 ppm. The 2 inch diameter molybdenum and iridium discs were cleaned with ethanol prior to introduction into the glovebox for welding. The disc was mounted in the flat positon on a spring loaded fixture. This fixture clamped the disc along the length on either side of the linear weld path and provided tension on the disc transverse to the weld axis to counteract warping during welding. The welding process used a 1/8 inch diameter, 2% thoriated electrode with a 60° included angle and 0.010 inch diameter truncated point. The arc gap was set at 0.032 inch using a feeler gauge. Torch shielding gas was 75% helium/25% argon and was supplied at 30 cfh as read on the argon scale of the flow meter. The welding sequence control was provided by an AMET XM system. The welding power was provided by a Miller Maxstar LX 200 ampere DC power supply utilizing high frequency arc starting. Before the weld program was started, all parameters, weld number, and weld speed were recorded. The weld program was then started and the process was monitored through a shaded lens to watch for any issues while welding. Once completed, the disc was removed from the fixture and the weld was visually inspected. General characteristics of the weld were recorded with the information collected prior to the weld. The disc was then repositioned for a new weld, and the procedure repeated. Up to six different welds were positioned on each disc. The same process was used for both molybdenum and iridium.

Initial Testing Data Summary

Initial testing consisted of 41 welds on molybdenum and 13 welds on iridium. Appendix A lists the molybdenum weld data and Appendix B lists the iridium weld data. Table 1 lists the process settings and weld dimensions for the molybdenum welds at the three given speeds. Table 2 lists the iridium weld dimensions produced by using the same parameters as the molybdenum welds.

Table 1: Initial molybdenum welds

Thickness: 0.0292"	Molybdenum Disc #13		
Weld Speed (ipm)	20	25	30
Weld	Moly # 56	Moly #55	Moly #54
Top Width (inches)	0.099	0.097	0.102
Root Width (inches	0.063	0.054	0.060
Average Amperage	88	95	102
Dwell Time (sec)	0.3	0.3	0.3
Dwell Amperage	83	89	95
Length (inches)	1.3	1.3	1.3
Start Amperage	83	89	95
Final Amperage	93	101	110
Torch Gas	75% He/25% Ar		

Table 2: Initial iridium welds

Thickness: 0.0270”	New Disc #2 (L1-15-2)		
Weld Speed (ipm)	20	25	30
Weld	Ir #14	Ir #12	Ir #15
Top Width (inches)	0.151	0.157	0.156
Root Width (inches)	0.150	0.154	0.151
Average Amperage	88	95	102
Dwell Time (sec)	0.3	0.3	0.3
Dwell Amperage	83	89	95
Length (inches)	1.3	1.3	1.3
Start Amperage	83	89	95
Final Amperage	93	101	110
Torch Gas	75% He/25% Ar		

Initial Testing Data Analysis

A visual comparison of the molybdenum and iridium welds is shown in Figure 1. A plot of the dwell/start amperage, average amperage, and final amperage is shown in Figure 2.

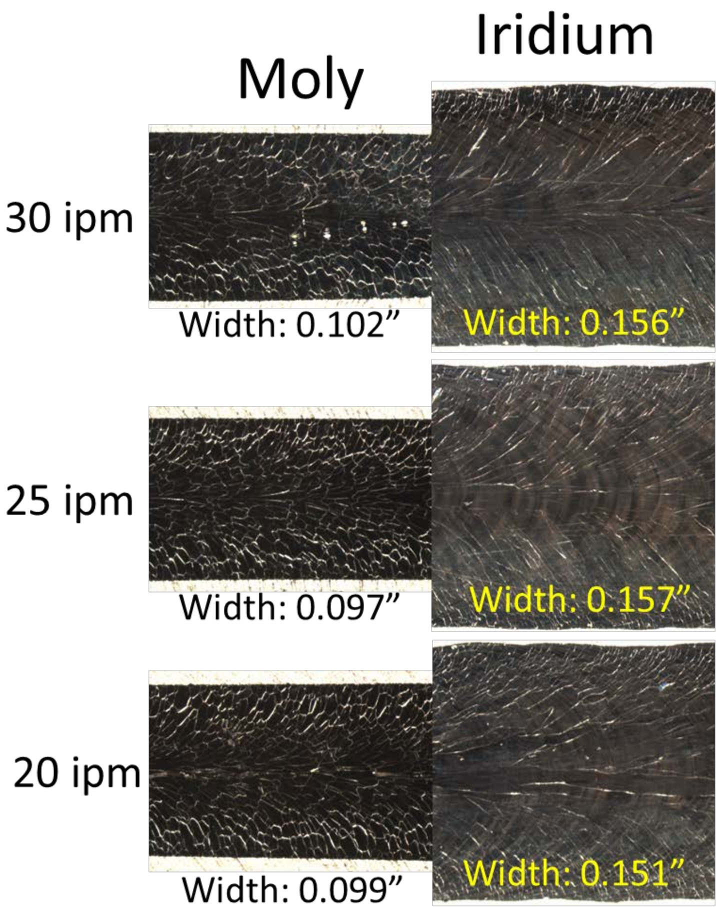

Figure 1: Initial comparison of molybdenum and iridium welds

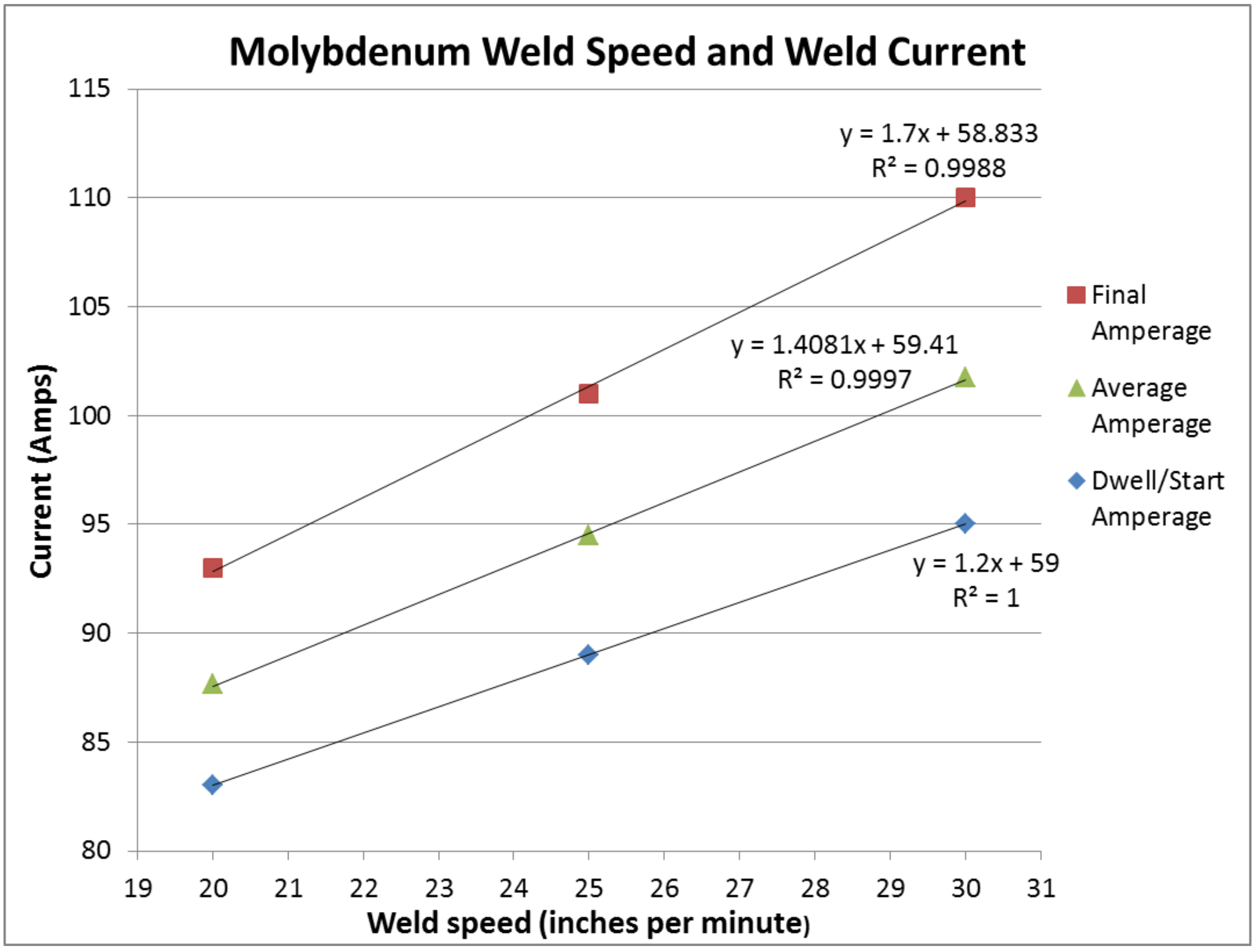

Figure 2: Plot of molybdenum amperages for welds at each travel speed

Comparing the widths of the molybdenum and iridium welds, it is clear that the iridium welds were consistently larger. The average molybdenum top width was 0.100 inches while the average iridium top width was 0.155 inches. This large difference in size attributed to both material differences and the thickness difference between the discs. The molybdenum discs used to develop the welding parameters were around 0.030 inches thick while the iridium discs are 0.027 inches thick. The difference is only 0.003 inches, but even small changes in thickness were found to affect the weld. With the goal of producing welds of minimal width, similar to the molybdenum welds, a ratio was developed based on the average top surface widths for the two materials. The ratio of molybdenum width divided by iridium width resulted in a value of approximately 0.65, thus reducing the iridium weld amperage by 35% should create welds that are similar to those on molybdenum. This ratio was tested and the results are discussed in the Subsequent Testing Data sections that follow.

Figure 2 shows that as the weld speed increases, a linear increase weld amperage is required to create similar sized welds. As the weld speed increases, more heat input is required to maintain the width and penetration along the weld. The increase in heat input is linear across the range when increasing the weld speed from 20 to 30 ipm. The dwell/start amperages and the final amperage had to be increased in a linear manner. Various previous welds showed that having too small or large of a change between start and final amperages resulted in welds with vary results. Welds with too small of a change either narrowed, lost penetration, or both. Welds with too large of a change either widened, began to gain penetration along the weld, or both. The sensitivity of these welds to small variations in the start and weld conditions was a challenging aspect of producing welds of fairly uniform width along their length. When finally achieving uniform welds of similar size to one another, these welds had a linear relationship between weld speed and weld amperages.

Subsequent Testing Data Summary

Additional welds were made on iridium implementing the ratio found from the original data. The new iridium welds were made by decreasing the amperage used for the molybdenum welds by 35%. The parameters for the welds at the three speeds are shown in Table 3.

Table 3: 35% reduced iridium welds

Thickness: 0.0270"	New Iridium Disc #2 (L1-15-2)		
Weld Speed (ipm)	20	25	30
Weld	Ir #14	Ir #12	Ir #15
Top Width (inches)	0.085	0.081	0.086
Root Width (inches)	0.061	0.047	0.057
Average Amperage	57	61	68
Dwell Time (sec)	0.3	0.3	0.4
Dwell Amperage	54	58	62
Length (inches)	1.3	1.3	1.3
Initial Amperage	54	58	62
Final Amperage	60	66	72
Torch Gas	75% He/25% Ar		

It is important to note that dwell time has a major influence on the success of the weld. Table 3 shows that the 30 ipm weld had a dwell time of 0.4 seconds while the other welds had a dwell time of 0.3 seconds. A 30 ipm weld with a dwell time of 0.3 seconds was made, but lacked penetration (shown in Appendix B). Increasing the dwell time by 0.1 seconds provided adequate penetration for the length of the weld.

Subsequent Testing Data Analysis

The reduction of amperage for the iridium welds by 35% resulted in welds that were slightly smaller than the molybdenum welds and indicated that the amperage had been reduced too much. However, the average top width of the reduced amperage welds was 0.084 inch, much closer to the molybdenum weld average width of 0.100 inch when compared to initial iridium welds with an average width of 0.155 inch. A visual comparison of top widths for the molybdenum and reduced amperage iridium welds is shown in Figure 3. Additionally, the linear relationships for the reduced amperage iridium welds are shown in Figure 4.

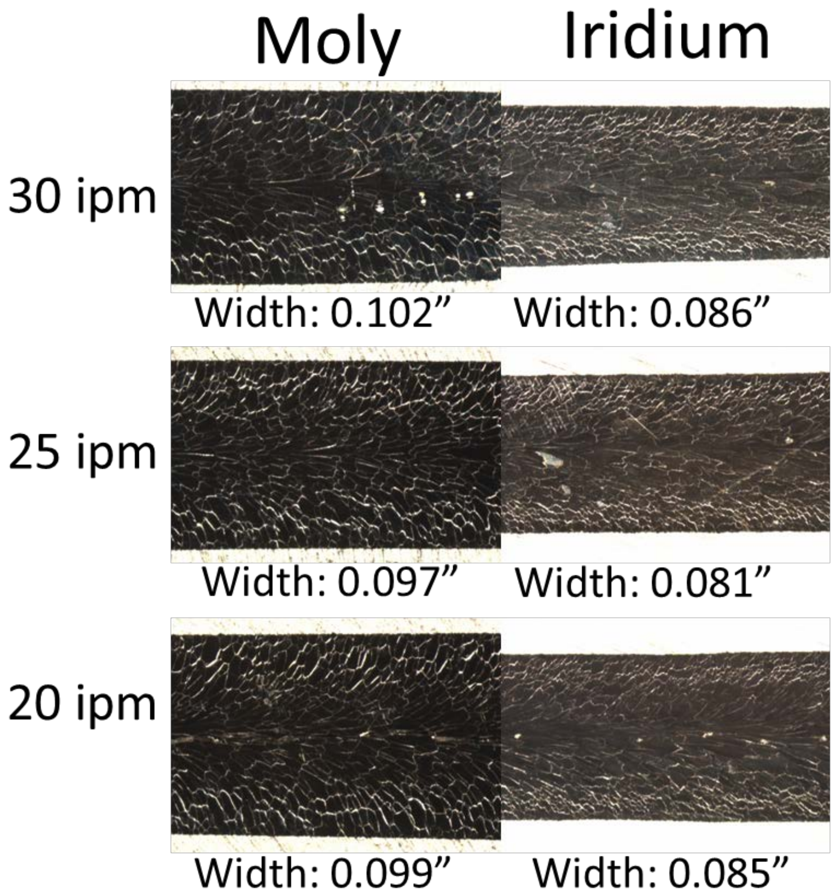

Figure 3: Comparison of molybdenum and 35% reduced amperage iridium welds

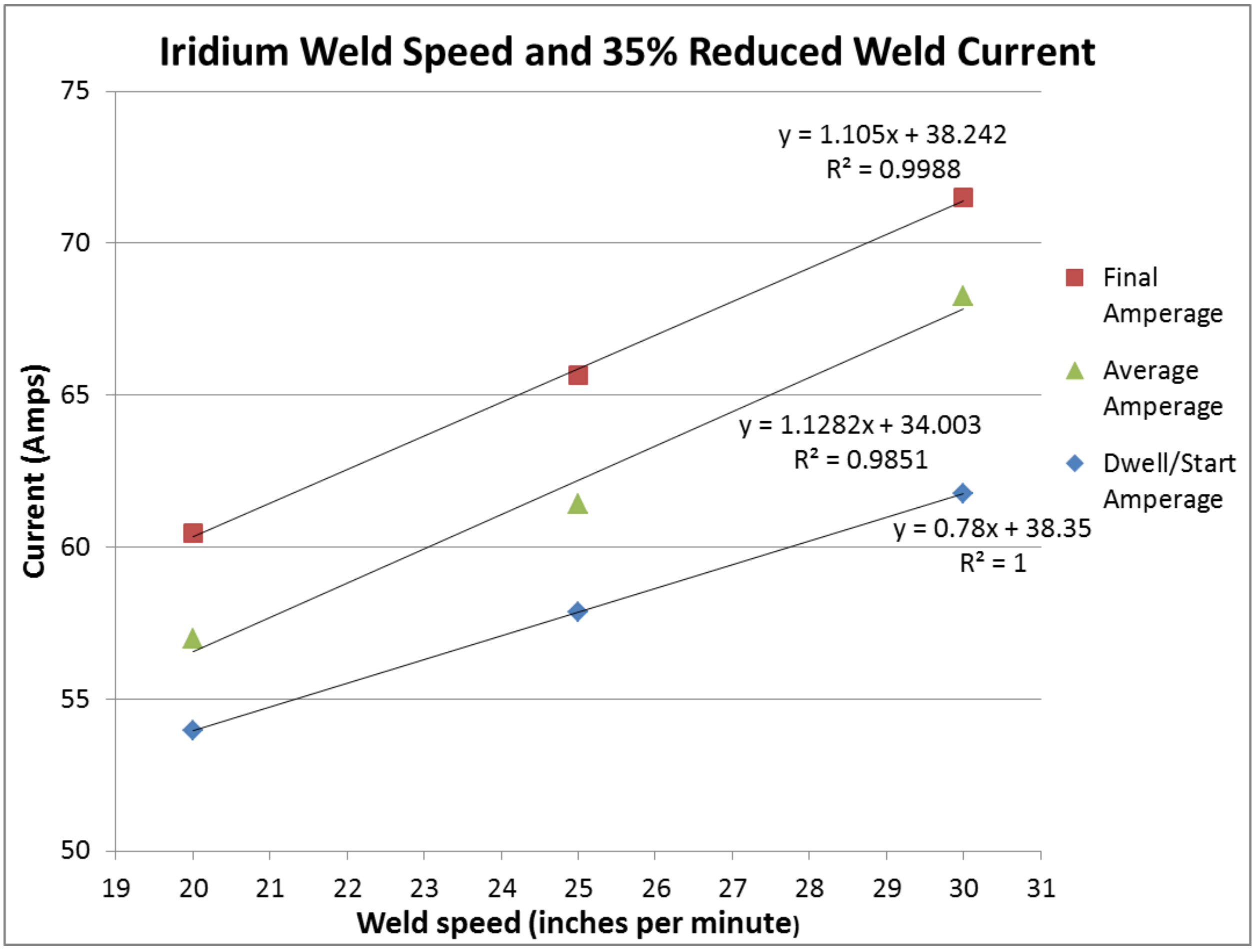

Figure 4: Plot of reduced iridium amperages for welds at each travel speed

Although the iridium top widths were smaller, the root widths were similar in size. The average molybdenum root width was 0.059 inches while the average iridium root width was 0.056 inches. Similar to what was found with the amperages for molybdenum welds, amperages for iridium welds scaled linearly with weld speed. The linear relationship for the average amperage is slightly off due to the change in dwell time by 0.1 seconds for the 30 ipm weld at the reduced current. The first weld at 30 ipm with a 0.3 second dwell time had lack of penetration at the start and that carried through the rest of the weld resulting in poor penetration. Increasing the dwell from 0.3 seconds to 0.4 seconds allowed for full penetration at the start and full penetration along the length of the weld.

Evaluation of Weld Pool Shape and Grain Structure

The molybdenum and iridium weld pool shape and solidification grain structures were compared using an optical microscope and images of the top and root side of welds at each speed were captured. The pool shapes at the different weld speeds are shown in Figure 5. The images of the pool shapes are from the welds on iridium with the molybdenum amperages. These welds were used because they best showed the shape of the weld pool for comparison.

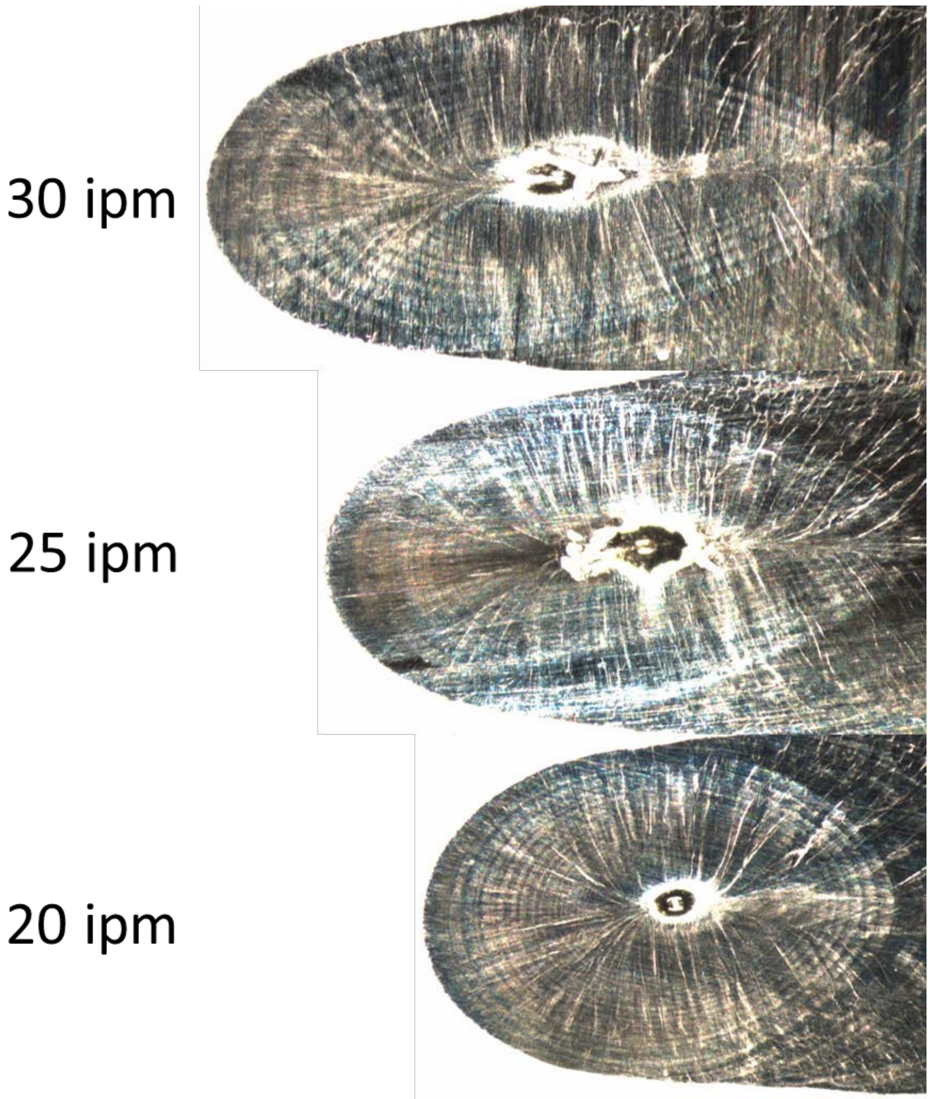

Figure 5: Weld pool shape at different weld speeds

The current production weld has a travel speed of 30 ipm. This speed tends to form a near teardrop shaped weld pool which is clearly seen in Figure 5. Welds with a teardrop shaped weld pool that have a sharp trailing edge are unfavorable due to the formation of long columnar grains which abut along the weld centerline. This solidification pattern promotes the concentration of low melting temperature solute along the weld centerline, contributing to weakness in the weld and potential cracking issues along the centerline. As the travel speed decreases from 30 ipm to 20 ipm the teardrop shape changes to an elliptical shape. At 25 ipm, the pool shape is transitioning from teardrop to elliptical. The elliptical pool shape of the 20 ipm weld is favorable because it promotes curved grain growth and a more homogenous solute distribution.

The comparison of the top grain structures for both molybdenum and iridium is shown in Figure 6. The comparison of the root grain structures is shown in Figure 7. These comparisons show the molybdenum welds and the 35% reduced amperage iridium welds.

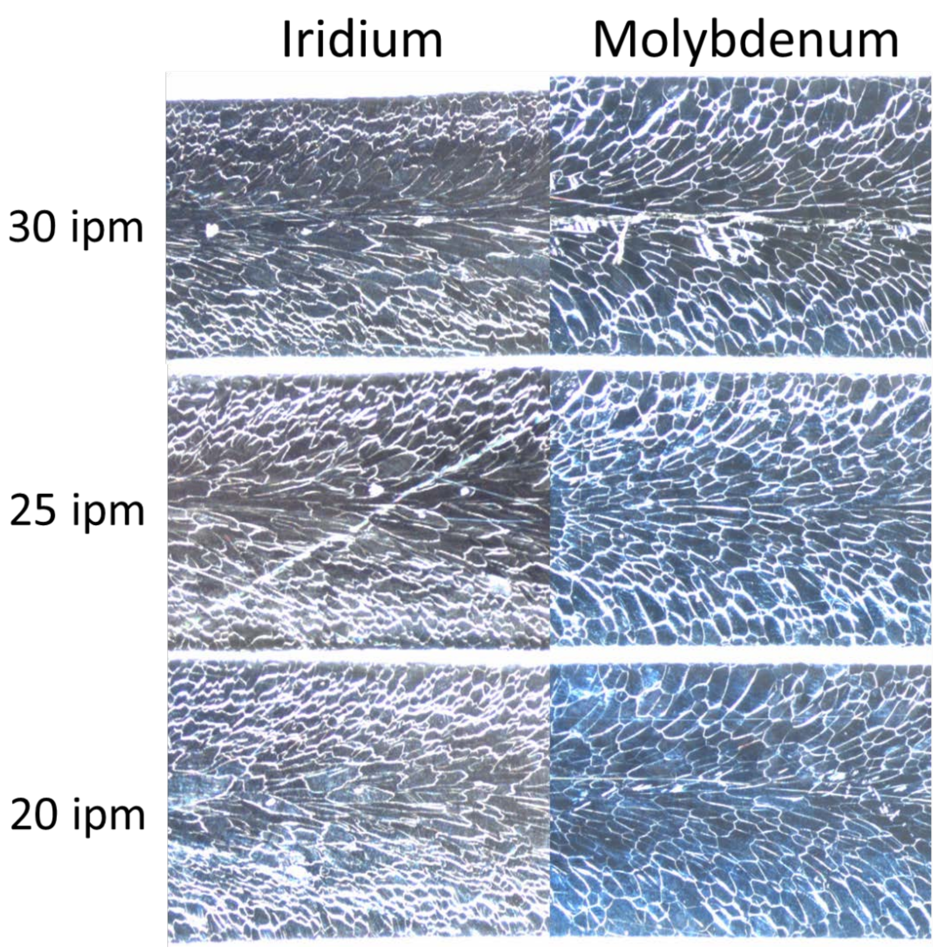

Figure 6: Molybdenum and iridium top grain structures

As expected, based on the teardrop weld pool shape, the 30 ipm welds for both molybdenum and iridium showed the formation of a distinct centerline along the weld. As the speed lowered to 25 and 20 ipm the centerline became less distinct in the top of the weld.

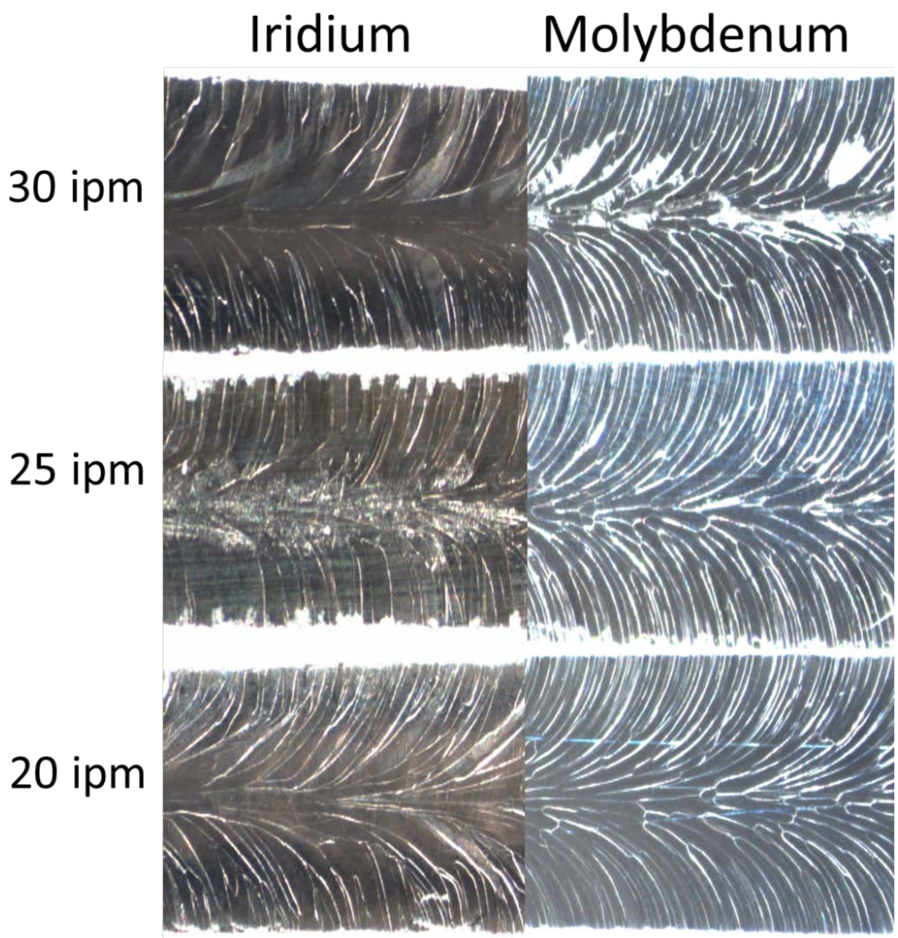

Figure 7: Molybdenum and iridium root grain structures

As Figure 7 shows, the root grain structures of the molybdenum and iridium very similar. At 30 ipm, the root structures are very columnar and form a distinct centerline. The molybdenum weld formed a centerline crack, while the iridium did not. As the weld speed decreased, the grains tend to curve resulting in a less distinct centerline. There is still an obvious centerline in the lower speed welds, but the grains tend to overlap much more than at 30 ipm. This was observed for both the iridium and molybdenum welds. Though both the top and root structures are not exactly identical for the metals, they are similar enough such that weld development analysis on the molybdenum would be a good representation of a corresponding iridium weld.

Molybdenum Thickness Determination

The previous research determined that scaling the molybdenum amperage parameters by 75% should result in comparable welds on iridium. A few iridium welds with the current reduced by 25% proved to be almost identical to the molybdenum welds. The first experiment used molybdenum discs that were roughly 0.029-0.031 inches thick, while the iridium discs were 0.027 inches thick. Though the difference is small in the thickness, it nonetheless has a large impact on the weld. With the initial correlation between the materials complete, further testing was done to determine the thickness of molybdenum that would most accurately represent the final iridium welds that had been established. The iridium welding parameters for 20, 25, and 30 ipm speeds, shown in Table 4, were used to make welds on three different thicknesses of molybdenum. A total of nine molybdenum welds were made; one weld for each speed on three molybdenum discs of 0.027, 0.023, and 0.019 inches thick. The top widths on each disc were measured and averaged. The measured and average top widths were plotted. The graph with data and trend line is shown in Figure 8.

Table 4: Welding parameters for thickness determination welds

Torch Gas:	75% He/25% Ar		
Weld Speed (ipm)	20	25	30
Dwell Time (sec)	0.3	0.3	0.4
Dwell Amperage	54	58	62
Length (inches)	1.3	1.3	1.3
Start Amperage	54	58	62
Final Amperage	60	66	72

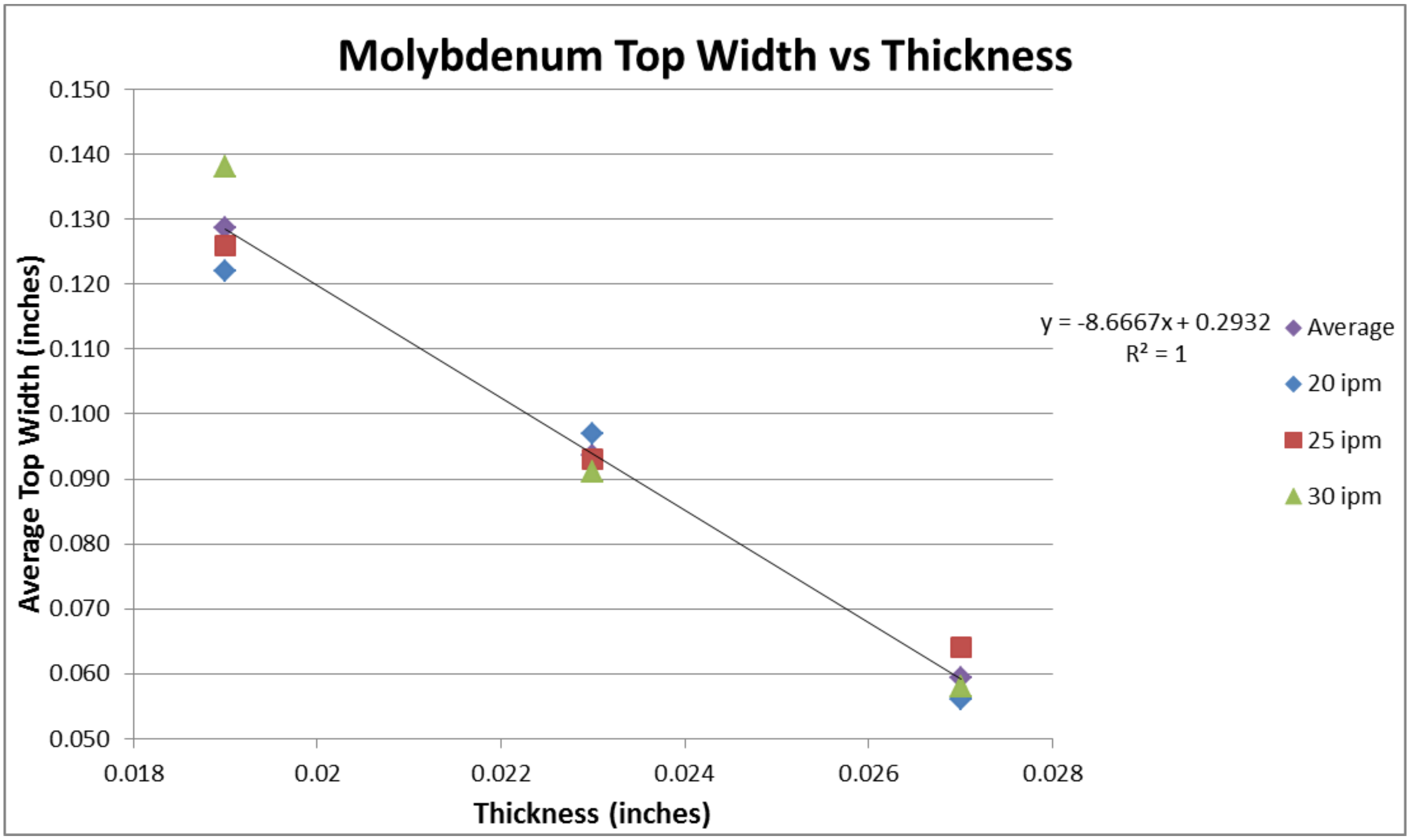

Figure 8: Relationship between average top width and thickness of molybdenum

A linear trend was found for the average widths of each thickness. The average is used because the welding parameters for each speed were developed to produce roughly the same size weld. The most variation in weld size occurred on the thinnest disc, and less variation was seen on the thicker discs. The largest variation is 0.016 inches which is between the 20 and 30 ipm welds on the 0.019 inch molybdenum disc. Based on the results at this set of welding parameters, a molybdenum thickness of 0.024 inches is predicted to result in welds that are most comparable to 0.027 inch thick iridium.

Conclusions

Based on the results of the flat position disc welds presented here, molybdenum was found to be a good surrogate for iridium welds, both in matching weld size for a given power and thickness, and for displaying similar weld pool shape and solidification structures as a function of welding speed.

First it was found that welding current could be scaled based on the ratio of molybdenum and iridium weld top surface widths and thus similar welds could be achieved even though initial test materials were a slightly different thickness. For molybdenum thicknesses between 0.029 and 0.031 inch, and iridium thickness of 0.027 inch, reducing the iridium weld current by 35% initially provided welds similar in size to molybdenum. A new reduction of 25% for iridium weld current improved the similarity in welds. Further experimentation with molybdenum of various thicknesses showed that for a given weld power, molybdenum at 0.024 inch thickness should result in welds that are most similar to those on 0.027 inch thick iridium.

When comparing molybdenum and iridium welds of similar width, over the range of weld speed tested, the weld pool shape and solidification grain structure were also very similar. Examining the weld pool shape and grain structures at each speed, the 30 ipm welds appear to be the least favorable. This is due to the tendency to produce a teardrop shaped weld pool that promotes columnar grain growth abutting along the weld centerline. This type of solidification produces a distinct weld centerline and can cause accumulation of lower melting temperature solute, both of which may contribute to lower ductility and possible centerline cracking. As the travel speed decreases from 30 ipm to 20 ipm the teardrop shape changes to an elliptical shape. At 25 ipm, the pool shape is transitioning from teardrop to elliptical. The elliptical pool shape of the 20 ipm weld is favorable because it promotes curved grain growth and a more homogenous solute distribution.

From the numerous welds on molybdenum and iridium, it was found that welds in both materials were very sensitive to the dwell time, the start amperage, and the final amperage. Slight variances in these values can result in poor welds at any speed. The similarity in the sensitivity of these materials to minor weld deviations is likely related to the relatively thin section thickness, but further points out the benefit of using low cost molybdenum surrogate for much of the preliminary weld development leading to iridium weld qualification

Future work with molybdenum and iridium welding will include experimentation with pulsed current welding to examine potential enhancement of grain refinement and solidification structure. This will include pulsed current welds at 20, 25, and 30 ipm for comparison to similar constant current welds. This will aid in determination of possible improvements to the current production welds. Additional future work will look to use molybdenum tube sections as a machine function test to verify welding machine consistency prior to production runs. This will help increase successful production welds by determining machine errors prior to using a costly production clad vent set. Testing will have to be done to determine how the horizontal position tube welds will compare to the flat position disc welds.

Appendix A

Molybdenum Disc #5					
Weld Speed (ipm)	25	25	25	25	25
Weld	Moly # 16	Moly #17	Moly #18	Moly #19	Moly #20
Average Amperage	91	96	101	89	94
Dwell Time (sec)	0.2	0.1	0.2	0.2	0.2
Dwell Amperage	83	88	93	80	86
Length (inches)	1.3	1.3	1.3	1.3	1.3
Start Amperage	83	88	93	80	86
Final Amperage	100	105	110	100	103
Torch Gas:	75% He/25% Ar				

Molybdenum Disc #6				
Weld Speed (ipm)	20	20	20	20
Weld	Moly # 21	Moly #22	Moly #23	Moly #24
Average Amperage	96	94	94	97
Dwell Time (sec)	0.2	0.2	0.2	0.2
Dwell Amperage	90	86	86	90
Length (inches)	1.3	1.3	1.3	1.3
Start Amperage	90	86	86	90
Final Amperage	103	103	103	105
Torch Gas:	75% He/25% Ar			

Thickness: 0.03190"	Molybdenum Disc #7			
Weld Speed (ipm)	20	20	20	20
Weld	Moly # 25	Moly #26	Moly #27	Moly #28
Average Amperage	101	102	102	102
Dwell Time (sec)	0.2	0.2	0.2	0.2
Dwell Amperage	93	100	96	96
Length (inches)	1.3	1.3	1.3	1.3
Start Amperage	93	100	96	96
Final Amperage	110	105	108	108
Torch Gas:	75% He/25% Ar			

Thickness: 0.03190"	Molybdenum Disc #8					
Weld Speed (ipm)	20	20	25	25	25	25
Weld	Moly #29	Moly #30	Moly #31	Moly #32	Moly #33	Moly #34
Average Amperage	96	96	96	99	98	97
Dwell Time (sec)	0.2	0.4	0.4	0.4	0.4	0.4
Dwell Amperage	90	90	90	90	90	90
Length (inches)	1.3	1.3	1.3	1.3	1.3	1.3
Start Amperage	90	90	90	90	90	90
Final Amperage	103	103	103	110	107	105
Torch Gas:	75% He/25% Ar					

Thickness: 0.03150"	Molybdenum Disc #9				
Weld Speed (ipm)	25	25	25	20	20
Weld	Moly # 35	Moly #36	Moly #37	Moly #38	Moly #39
Average Amperage	97	99	101	96	90
Dwell Time (sec)	0.4	0.3	0.3	0.4	0.4
Dwell Amperage	90	93	93	90	85
Length (inches)	1.3	1.3	1.3	1.3	1.3
Start Amperage	90	93	93	90	85
Final Amperage	105	107	110	103	95
Torch Gas:	75% He/25% Ar				

Thickness: 0.03120"	Disc #10				
Weld Speed (ipm)	20	20	20	20	20
Weld	Moly # 40	Moly #41	Moly #42	Moly #43	Moly #44
Average Amperage	90	90	90	90	90
Dwell Time (sec)	0.4	0.2	0.3	0.3	0.4
Dwell Amperage	85	85	85	85	85
Length (inches)	1.3	1.3	1.3	1.3	1.3
Start Amperage	85	85	85	85	85
Final Amperage	95	95	95	95	95
Torch Gas:	75% He/25% Ar				

Thickness: 0.03085"	Molybdenum Disc #11				
Weld Speed (ipm)	20	20	20	20	20
Weld	Moly #45	Moly #46	Moly #47	Moly #48	Moly #49
Average Amperage	90	89	89	89	89
Dwell Time (sec)	0.4	0.4	0.4	0.3	0.3
Dwell Amperage	85	86	85	85	85
Length (inches)	1.3	1.3	1.3	1.3	1.3
Start Amperage	85	86	85	85	85
Final Amperage	95	93	93	93	93
Torch Gas:	75% He/25% Ar				

Thickness: 0.03030"	Molybdenum Disc #12			
Weld Speed (ipm)	20	20	30	30
Weld	Moly #50	Moly #51	Moly #52	Moly #53
Average Amperage	89	88	110	104
Dwell Time (sec)	0.3	0.3	0.1	0.3
Dwell Amperage	85	83	100	95
Length (inches)	1.3	1.3	1.3	1.3
Start Amperage	85	83	100	95
Final Amperage	93	93	120	115
Torch Gas:	75% He/25% Ar			

Thickness: 0.0292"	Molybdenum Disc #13		
Weld Speed (ipm)	20	25	30
Weld	Moly # 56	Moly #55	Moly #54
Top Width (inches)	0.099	0.097	0.102
Root Width (inches	0.063	0.054	0.060
Average Amperage	88	95	102
Dwell Time	0.3 sec	0.3 sec	0.3 sec
Dwell Amperage	83	89	95
Length (inches)	1.3	1.3	1.3
Start Amperage	83	89	95
Final Amperage	93	101	110
Torch Gas	75% He/25% Ar		

Appendix B

New Iridium Disc #1 (L1-15-1)			
Weld Speed (ipm)	25	30	20
Weld	Ir #3	Ir #4	Ir #5
Average Amperage	94	102	88
Dwell Time (sec)	0.3	0.3	0.3
Dwell Amperage	89	95	83
Length (inches)	1.3	1.3	1.3
Start Amperage	89	95	83
Final Amperage	101	110	93
Torch Gas:	75% He/25% Ar		

Reused Iridium Disc # 1 (K3-3-3)			
Weld Speed (ipm)	25	20	30
Weld	Ir #6	Ir #7	Ir #8
Average Amperage	61	57	65
Dwell Time (sec)	0.3	0.3	0.3
Dwell Amperage	58	54	61
Length (inches)	1.3	1.3	1.3
Start Amperage	58	54	61
Final Amperage	65	60	71
Torch Gas:	75% He/25% Ar		

Reused Iridium Disc # 2 (K3-3-2)			
Weld Speed (ipm)	20	25	30
Weld	Ir #9	Ir #10	Ir #11
Average Amperage	57	62	66
Dwell Time	0.3	0.3	0.3
Dwell Amperage	54	58	62
Length (inches)	1.3	1.3	1.3
Start Amperage	54	58	62
Final Amperage	60	66	72
Torch Gas:	75% He/25% Ar		

New Iridium Disc #2 (L1-15-2)				
Weld Speed (ipm)	25	30	20	30
Weld	Ir #12	Ir #13	Ir #14	Ir #15
Average Amperage	62	66	57	66
Dwell Time (sec)	0.3	0.3	0.3	0.4
Dwell Amperage	58	62	54	62
Length (inches)	1.3	1.3	1.3	1.3
Start Amperage	58	62	54	62
Final Amperage	66	72	60	72
Torch Gas:	75% He/25% Ar			