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SEI Welding Investigation

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Abstract

The process of deciding on a method for welding the BSC support table, downtube/optics table, and the HAM optics and support tables is presented. The weld prototype and micrographs therefrom are discussed. Suggestions for new weld preps are illustrated. Results of a cursory check of residual stresses are presented. A stress relief cycle was performed on the coupons and the resulting warpage incurred is reviewed.

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LIGO PROJECT

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1. Introduction

In order to obtain sufficiently high natural resonances the optics table portion of the BSC downtube and the HAM optics and support tables were designed to use a fabricated honeycomb construction. There are essentially 2 types of weld joints that will be used in fabricating these tables. See Figure 1.

Since the program required an extremely flat optics table plus low residual stresses in the structure, it was decided to construct a weld prototype to investigate whether the contemplated design was adequate. Process Systems International (PSI) of Massachusetts and Nosmas Machine and Maintenance, Inc. of Florida were each selected to build one prototype.

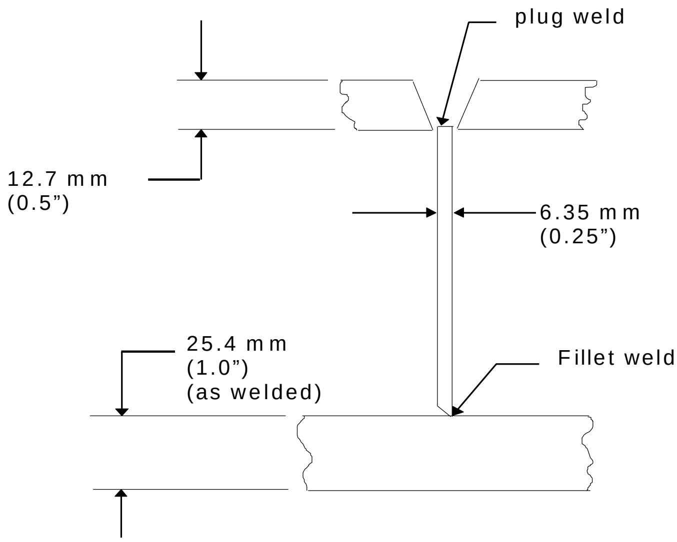

Figure 1. Typical optics table weld joints

The design of the weld prototype is shown in Figure 2. Essentially, it is a representative section of the HAM optics table, with a tube welded to the 12.7 mm (0.5”) plate to simulate the welding of the BSC downtube to the top side of the optics table.

In order to approximately determine the level of residual stresses, vendors were required to cut a 25.4 mm (1”) wide section from the weldment, as shown in Figure 2. They measured the length of the section prior to cutting it. HYTEC measured the length as received. See paragraph 2.3 for the results.

Vendors were also required to stress relieve the weldment, both pre and post machining. Measurements were taken during the fabrication and subsequent stress relief cycle to assess the movement and hence the residual stresses in the plate. Changes in surface flatness were recorded during the fabrication process.

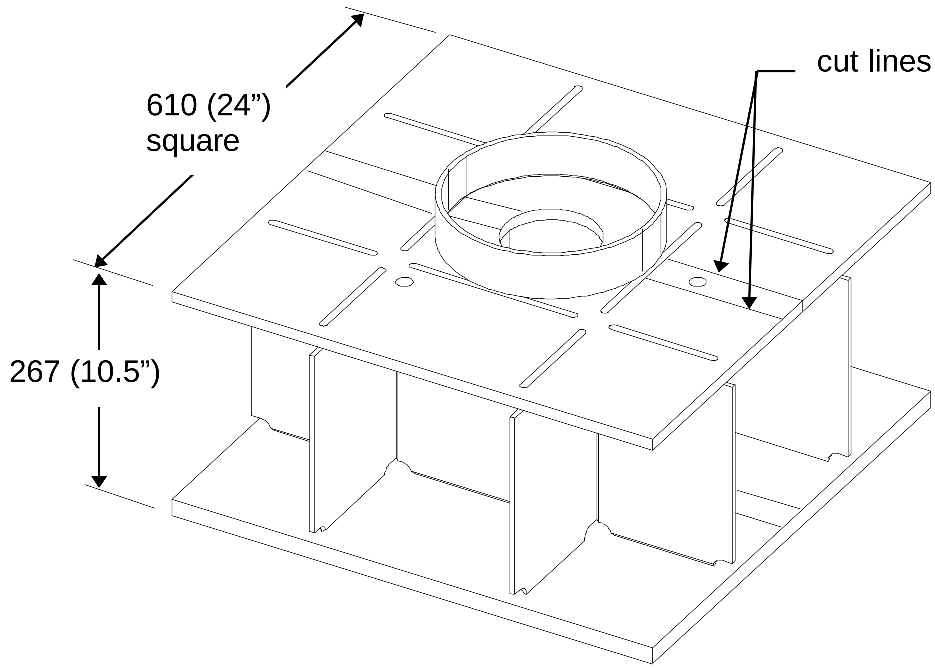

Figure 2. Weld prototype

2. Discussion

2.1 Fillet weld

The design of the weld prep on the fillet weld initially used a small land of 4.8 mm (.187") and a 45^o chamfer. This was patterned after recommendations in a Stanford Linear Accelerator Center (SLAC) document. Neither of the 2 shops was able to achieve a full penetration weld through the 4.8 mm (.187") land, thereby leaving a virtual leak. It is felt that the SLAC recommendation was based on stainless steel, a poor heat conductor. Figure 3 shows the attempts by Nosmas and PSI respectively. Notice the virtual leaks on each of the macrographs.

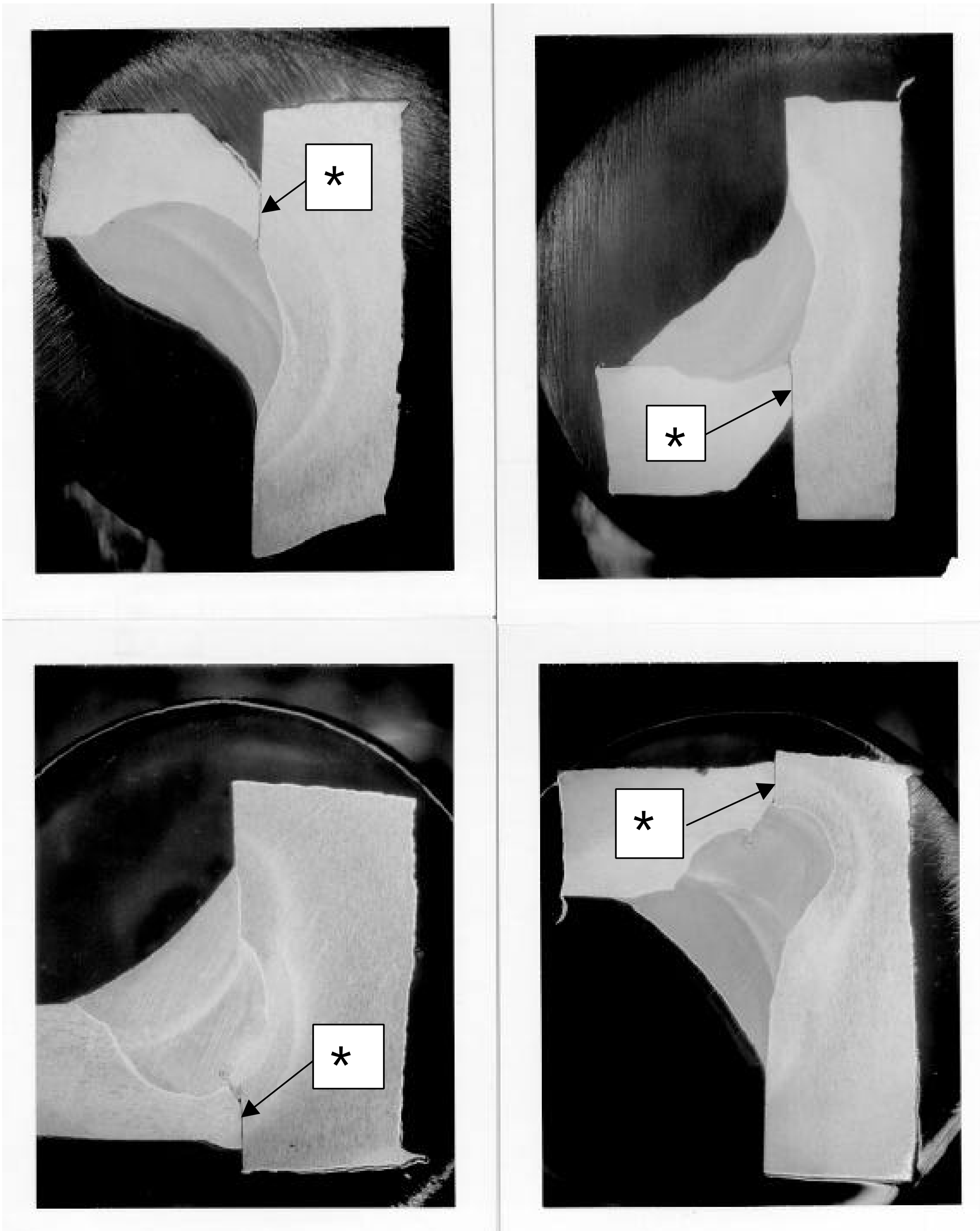

Figure 3. Fillet welds: Upper 2 by Nosmas, Lower 2 by PSI (magnification: 5x)

* = Virtual leak

This aluminum structure permitted heat to be rapidly diverted into the 1" plate. New samples were made with the weld prep coming to a sharp edge. Both vendors achieved penetration, although not necessarily with acceptable results. See Figures 4 through 8.

Note the pronounced virtual leak in the top photo of Figure 4. The weld penetrated the 1/4" plate, but did not fuse with the 1" plate. The lower left photo shows a number of very small shrinkage voids in the weld bead. Very small pores and some shrinkage were identified near the weld surface, as shown in the lower right photo.

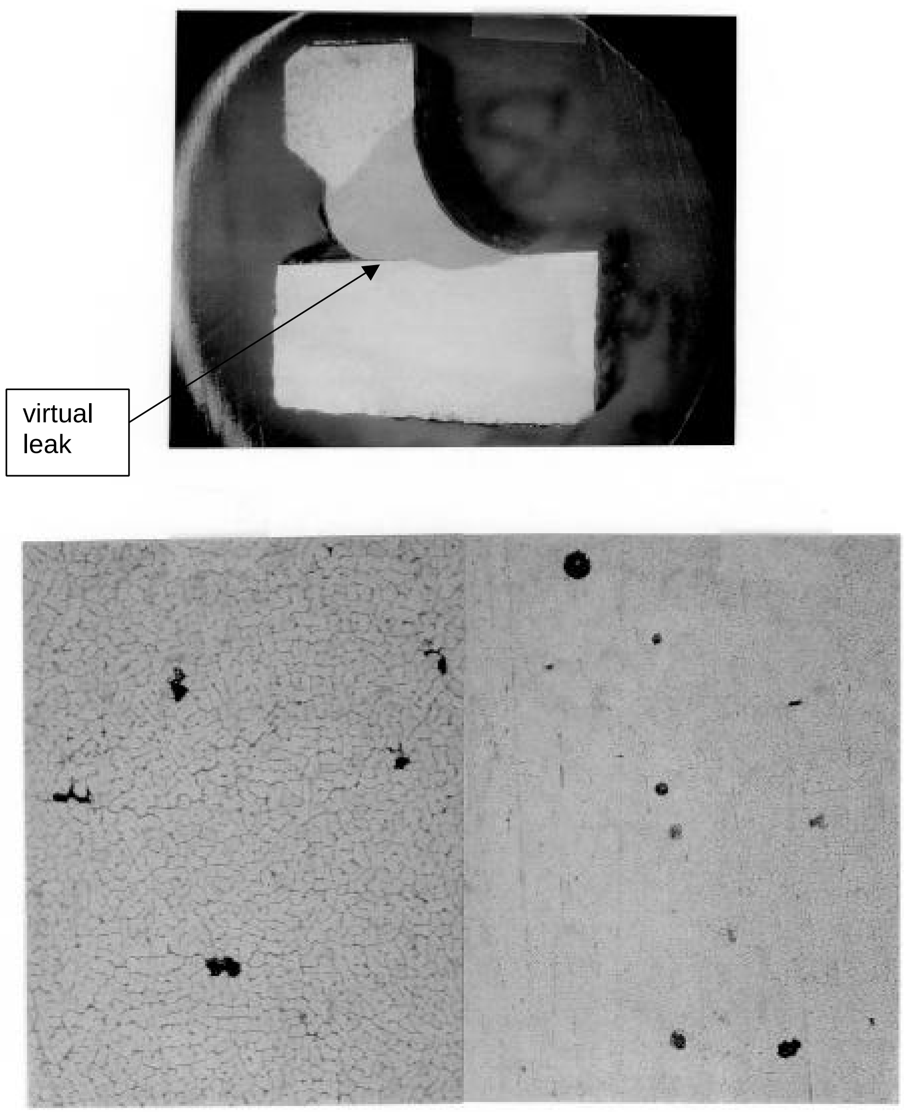

Figure 4. Nosmas 2nd attempt (magnification: top 5x, bottom left 200x, and bottom right 100x)

Figure 5 shows a double fillet weld done with a double beveled weld prep. Significant undercut at the weld surface is noted at one side resulting in a thinner cross-section at the weld than the thickness of the 1/4" plate. Interpenetration of the 2 fillet welds is almost complete except for a small central defect area. Also note the large heat affected zone adjacent to the fillet with the undercut, as shown in the upper photo. A small crack extending to the root area of both welds ending in void areas is seen in the lower left photo. A number of small pores were also identified. The lower right photo is typical.

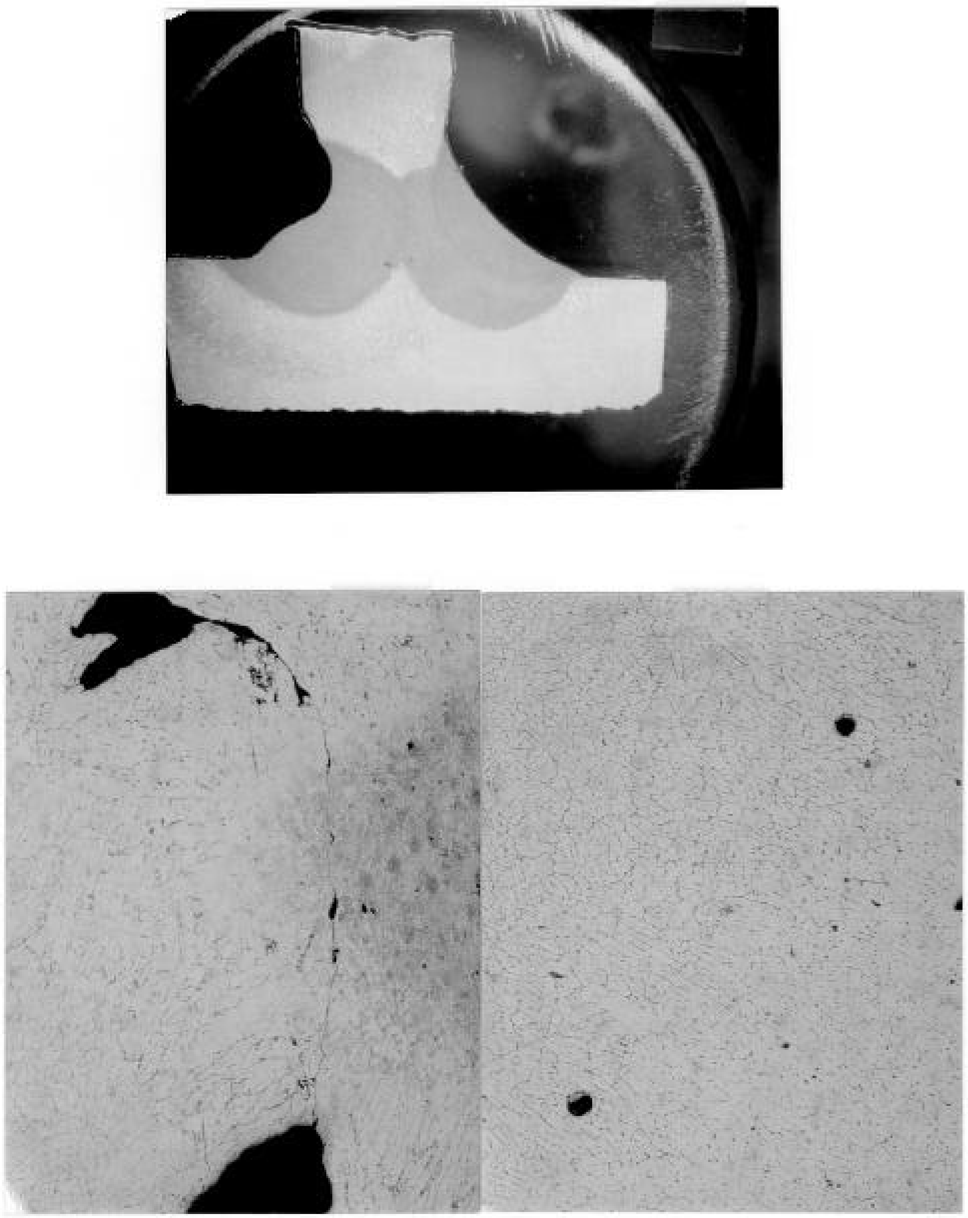

Figure 5. PSI's 2nd attempt. (magnification: top 5x, bottom 100x)

Shown below in Figure 6 is another PSI specimen. The weld prep was a 30^o chamfer on one side, with welding on both sides. The welds have fully penetrated the beveled plate with no evidence of remaining unwelded areas. The lower photo shows some of the many small pores scattered throughout the fillet welds.

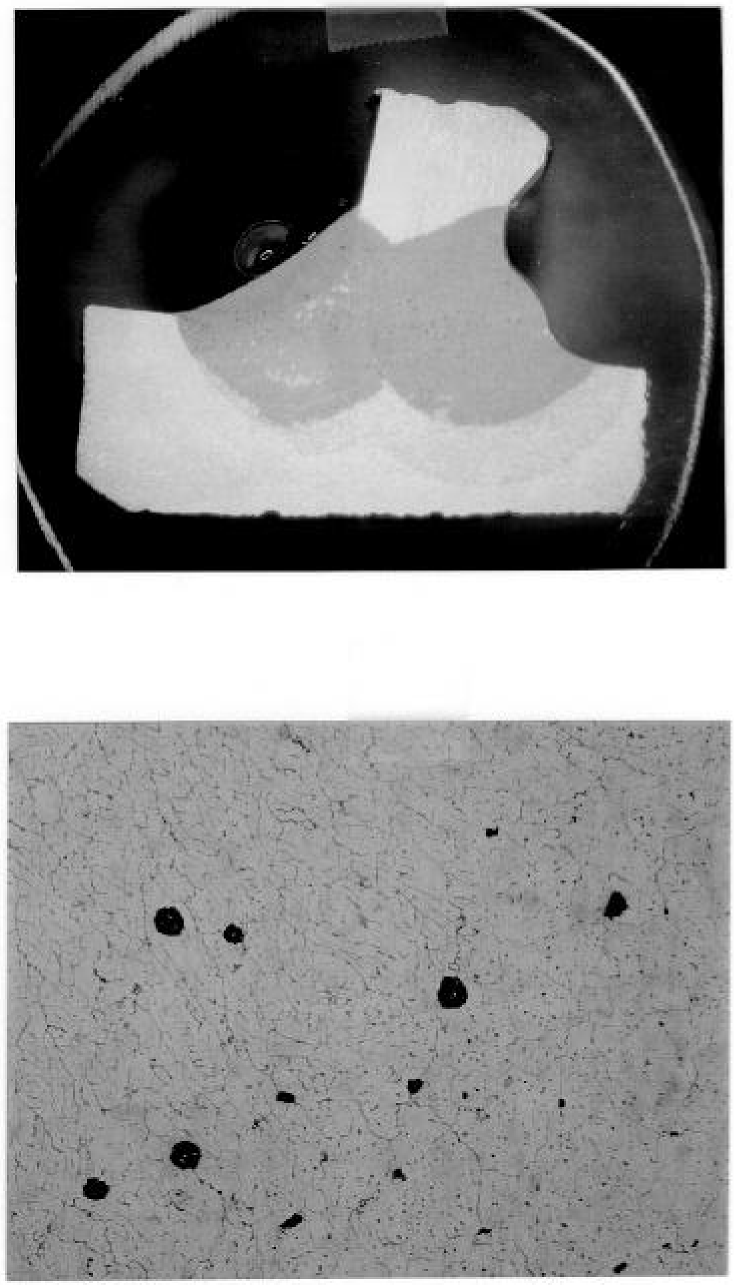

Figure 6. PSI specimen (magnification: upper 5x, lower 100x)

Figure 7 shows a single chamfered weld prep with a fillet weld on one side. The weld shows a lack of penetration in the weld root and porosity in the top run which is highly concave, as seen in the top photo. The lack of penetration is clearly seen in the lower left photo with a small shrinkage crack extending into the weld that has a pore attached. Porosity in the top weld run is prevalent and illustrated in the lower right photo.

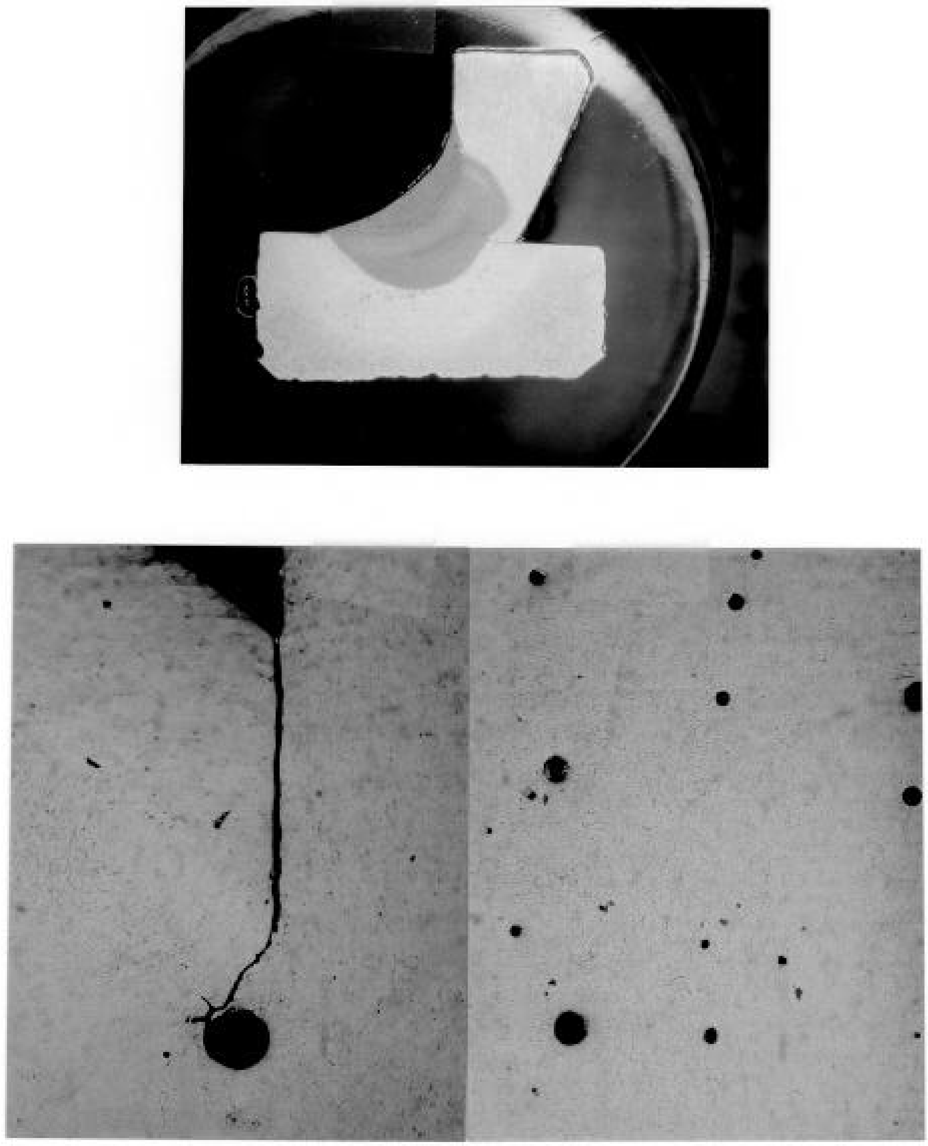

Figure 7. Another weld coupon by PSI (magnification: top 5x, bottom 50x)

Figure 8 shows the result of using a single chamfered weld prep and a fillet weld on the side opposite the chamfer. The weld is flat topped and displaced toward the thicker material, as shown in the upper photo. Some lack of fusion is present in the weld root. The lower left photo shows a small crack extending from this lack of fusion area. The weld also contains very fine porosity in the top run of the weld, as presented in the lower right photo.

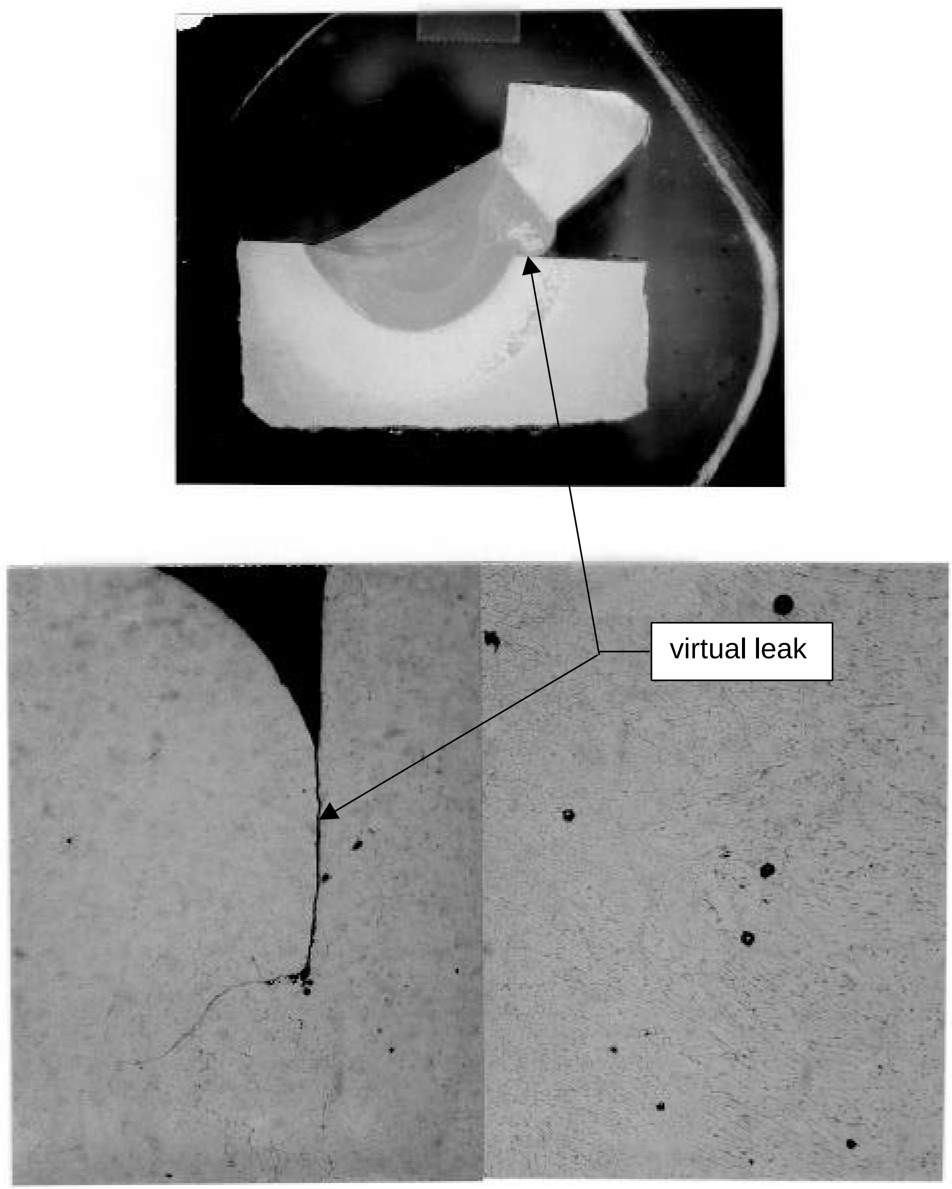

Figure 8. A PSI weld specimen using a single chamfer weld prep. (magnification: top 5x, lower left 50x, lower right 100x)

Subsequent discussion with Dr. Thomas W. Eagar of M.I.T. brought forth the recommendation that that a small land be left on the weld prep, lest the sharp corner bite into the thicker plate during welding. The latter was observed upon examining the second set of samples that had the sharp corner. Figure 9 shows Dr. Eagar's suggestion for the fillet weld. He also suggested that the first pass be autogenous DC, straight polarity, with a 50/50 argon/helium mix. The second pass should be AC with 4043 filler. Dr. Eagar further stated that, inasmuch, as welding is an art, the welder is given the freedom to explore alternatives that achieve the quality of weld that is desired. Additional weld specimens will be required to prove this design.

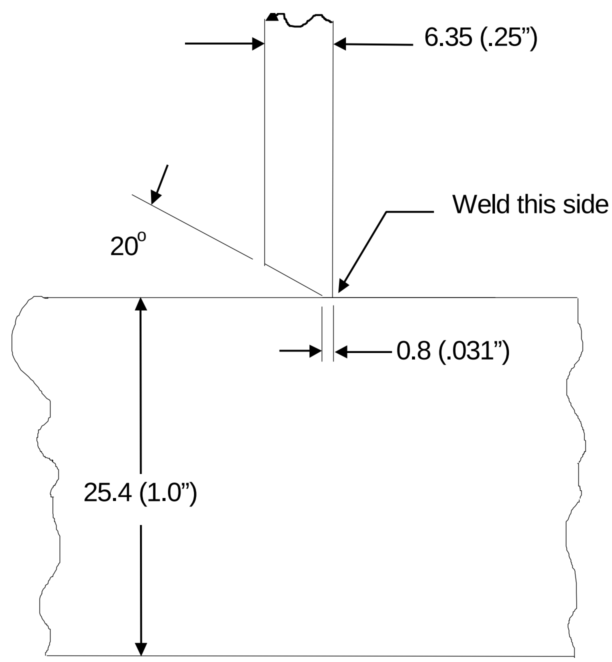

Figure 9. Suggested fillet weld design

2.2 Plug weld

The initial design of the plug weld at the bottom of the HAM optics table and the top of the BSC optics able is shown in Figure 10. The phantom lines indicate where both vendors requested opening the slot to improve welding access.

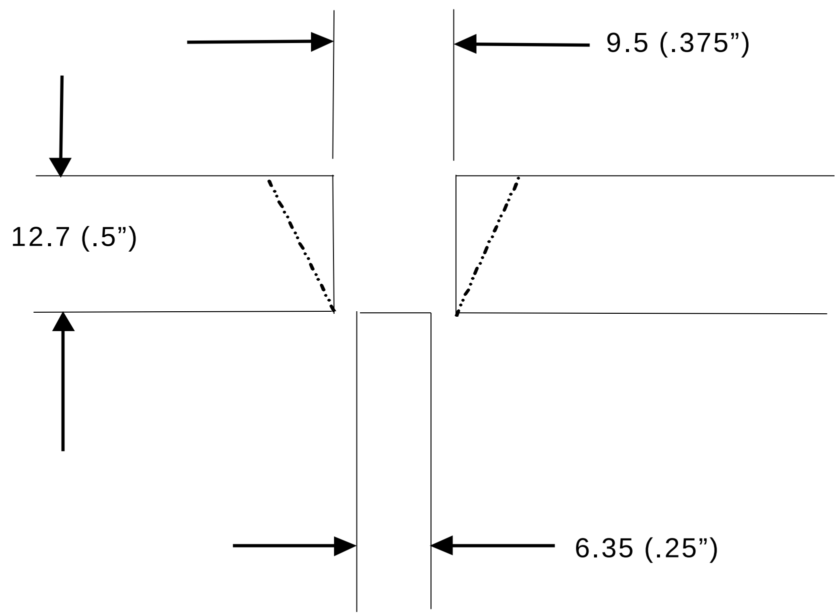

Figure 10. Initial design of the plug weld

Unfortunately, both vendors allowed the smaller plate to protrude excessively into the slot. The results were large virtual leaks. See Figure 11.

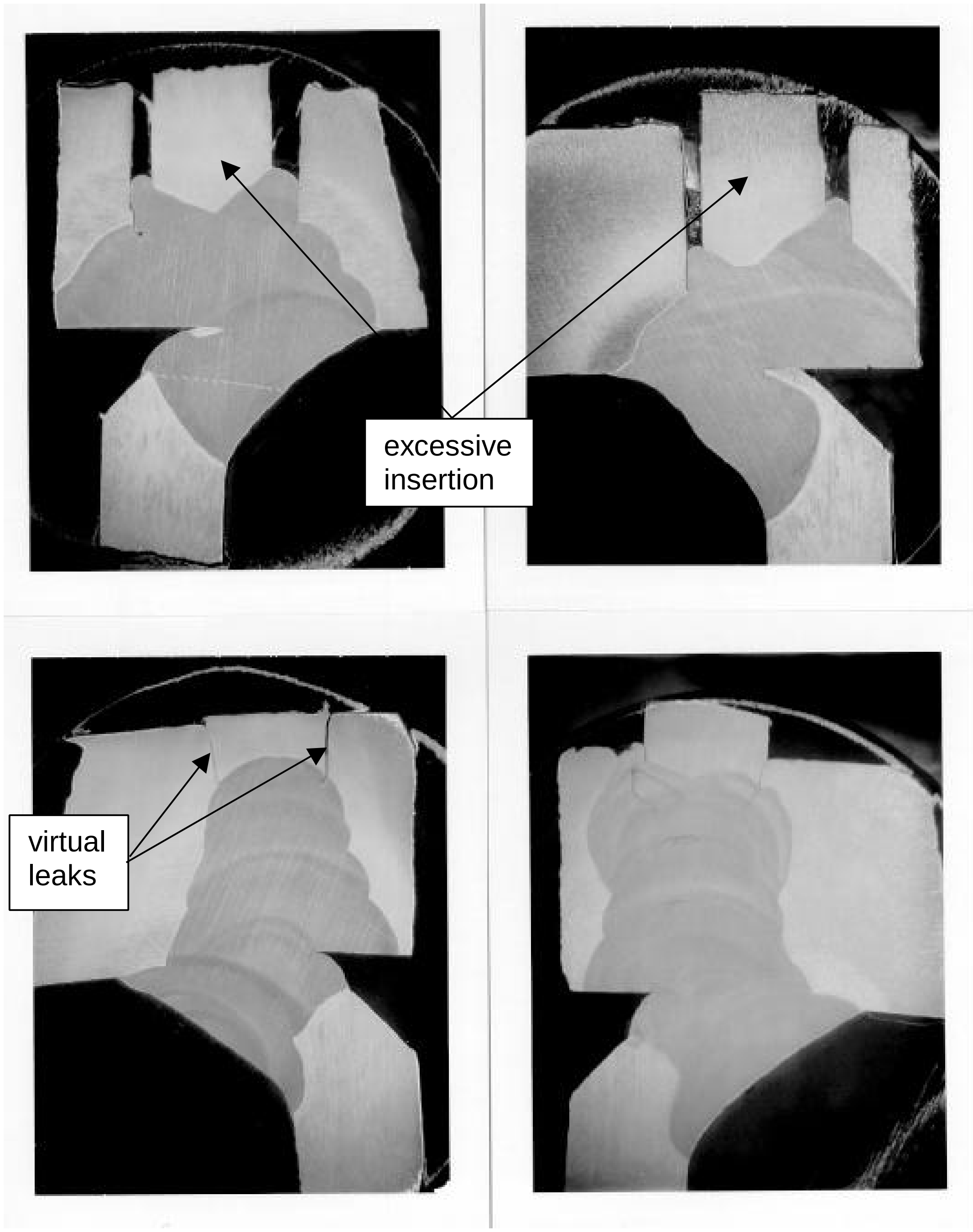

Figure 11. Micrographs of plug welds. (magnification 5x)

The upper two specimens were done by Nosmas, and the lower two, by PSI. The lower leg, in all 4 photos, represents the downtube, as it is welded to the top part of the BSC optics table. The leg in the top center of all 4 pictures represents the 1/4" core element of the optics table. The remainder is the 1/2" plate that forms the top part of the optics table. All photos show large virtual leaks.

Nosmas made another weld sample with their own modified weld prep. They machined large 60^o chamfers on the 1/2" plate. See Figure 12.

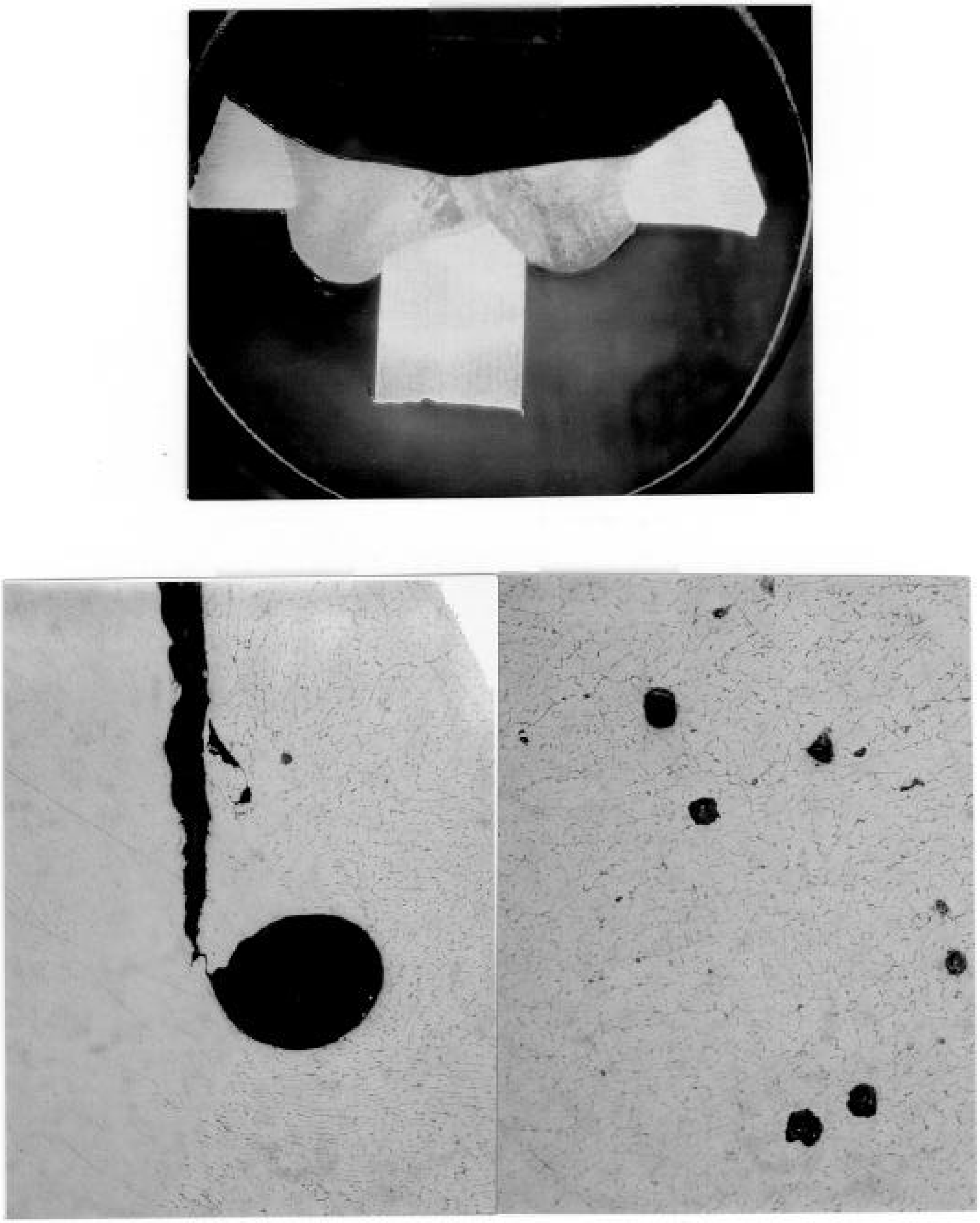

Figure 12. Nosmas 2nd plug weld. (magnification: top 5x, bottom 100x)

Significant weld penetration has been made on either side of the central plate. The welds are sound in general, but the penetration appears rather excessive. A large pore was found at the root of the weld with a small amount of oxide enfoldment, as shown at the lower left of Figure 12. The welds also contained a number of very small voids and shrinkage cavities, as shown in the lower right photo.

Dr. Eagar had some suggestions for this weld, also. See Figure 13. Dr. Eagar suggested that the first pass or two be autogenous with argon gas. The remaining passes should use 4043 filler and AC voltage.

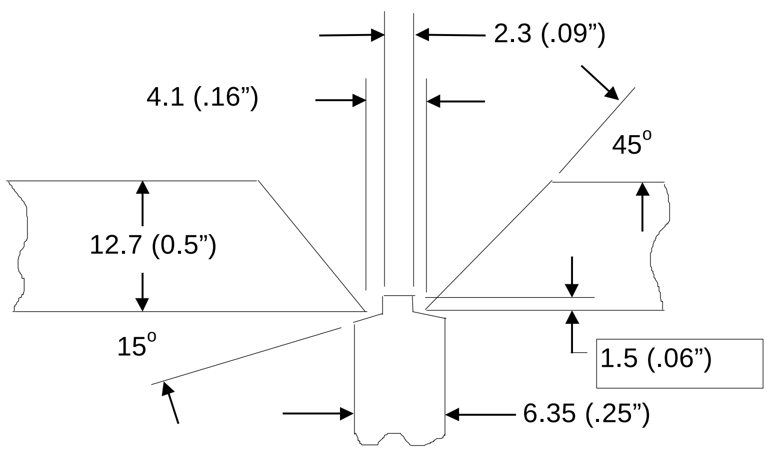

Figure 13. Recommended design of the plug weld.

2.3 Residual stress

As was mentioned in paragraph 1, both weld prototypes were measured prior to cutting out the 25.4 mm slice. The results are shown in Table 1.

	PSI	Nosmas
L1 = length as built (mm/inches)	610.36/24.030”	608.16/23.943”
L2 = length after cutting (mm/inches)	610.64/24.041”	609.85/24.010”
Strain = (L2 - L1) / L1	.000458	.002798
Residual stress = Strain x Modulus (Pascals/psi)	31.6E6/4,577	192.9E6/27,980

Table 1. Residual Stresses in Weld Prototype

Both prototypes were given identical stress reliving cycles. After welding, they were held at 204^{o} C (400^{o} F) for 2 hours and air-cooled. Following machining, they were stress relieved at 177^{o} C (350^{o} F) for 6 hours and air-cooled. The surface representing the optics table was measured for flatness before and after the machining cycle.

2.4 Optics table distortion

One of the main purposes of building the weld prototypes was to determine the achievable flatness of the surface of the optics tables. Both vendors were required to make flatness measurements of the optics table surface at several stages of the fabrication. The measurements scheme used is shown in Figure 14.

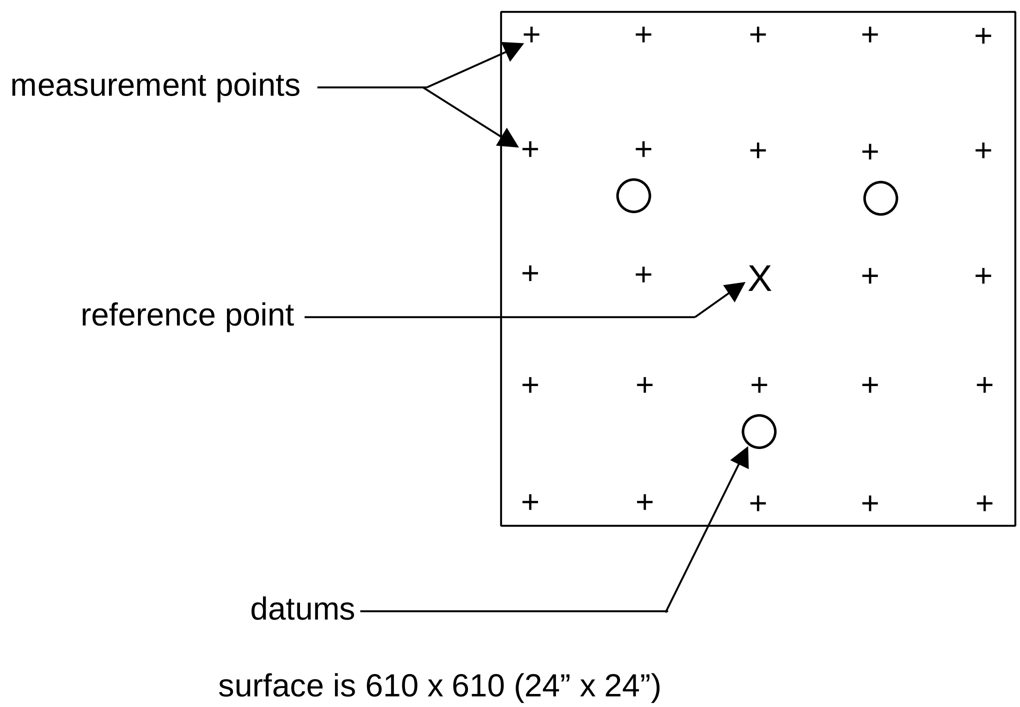

Figure 14. Relative locations of the significant points on the weld prototype

The results for the two weld coupons are shown in the following tables.

RESULTS OF THE **NOSMAS** WELD PROTOTYPE

AFTER WELDING				
-0.032	-0.034	-0.04	-0.042	-0.064
-0.021	-0.008	-0.0065	-0.009	-0.03
-0.0195	-0.003	0	0.01	-0.013
-0.0195	0.0035	0.008	0.012	0.001
-0.021	-0.002	0.002	0.01	0.005

AFTER STRESS RELIEF 1				
-0.0350	-0.0330	-0.0400	-0.0440	-0.0650
-0.0215	-0.0080	-0.0090	-0.0090	-0.0330
-0.0210	-0.0030	0.0000	0.0075	-0.0145
-0.0175	0.0020	0.0080	0.0185	0.0030
-0.0181	0.0020	0.0025	0.0130	0.0085

DIFFERENCE				
0.0030	-0.0010	0.0000	0.0020	0.0010
0.0005	0.0000	0.0025	0.0000	0.0030
0.0015	0.0000	0.0000	0.0025	0.0015
-0.0020	0.0015	0.0000	-0.0065	-0.0020
-0.0029	-0.0040	-0.0005	-0.0030	-0.0035

AVERAGE=	-0.0003
RMS =	0.00236
STD_DEV	0.00240
MAXIMUM DELTA =	0.0030
MINIMUM DELTA =	-0.0065

AFTER MACHINING				
0.0034	0.0027	0.0019	0.0014	0.0010
0.0021	0.0009	0.0002	0.0008	0.0010
0.0016	0.0000	0.0000	-0.0001	-0.0001
0.0016	0.0004	0.0000	-0.0001	-0.0001
0.0020	0.0010	0.0002	0.0002	-0.0003

AFTER STRESS RELIEF 2				
0.0010	0.0009	0.0005	0.0006	0.0008
0.0010	0.0007	0.0002	0.0010	0.0000
0.0030	0.0014	0.0000	-0.0004	-0.0008
0.0025	0.0010	-0.0003	-0.0005	-0.0010
0.0020	0.0012	-0.0007	-0.0007	-0.0014

DIFFERENCE				
0.0024	0.0018	0.0014	0.0008	0.0002
0.0011	0.0002	0.0000	-0.0002	0.0010
-0.0014	-0.0014	0.0000	0.0003	0.0007
-0.0009	-0.0006	0.0003	0.0004	0.0009
0.0000	-0.0002	0.0009	0.0009	0.0011

AVERAGE=	0.0004
RMS =	0.0010
STD_DEV	0.0009
MAXIMUM DELTA =	0.0024
MINIMUM DELTA =	-0.0014

LENGTH BEFORE CUTTING = 23.943"

LENGTH AFTER CUTTING = 24.010"

RESIDUAL STRESS =
[(24.010-23.943)/23.943] X 1E7 = 27,983 PSI

RESULTS OF THE **PSI** WELD PROTOTYPE

AFTER WELDING				
-0.0080	0.0350	0.0255	0.0180	-0.0280
-0.0100	0.0375	0.0375	0.0375	0.0040
-0.0140	0.0370	0.0000	0.0390	0.0100
-0.0300	0.0375	0.0370	0.0430	0.0100
-0.0340	0.0370	0.0150	0.0330	0.0020

AFTER STRESS RELIEF 1				
-0.0550	0.0240	0.0750	0.0650	-0.0690
-0.0640	-0.0020	0.0020	0.0090	-0.0350
-0.0710	-0.0020	0.0000	0.0150	-0.0295
-0.0730	0.0000	0.0075	0.0190	-0.0250
-0.0770	-0.0195	-0.0070	-0.0030	-0.0300

DIFFERENCE				
0.0470	0.0110	-0.0495	-0.0470	0.0410
0.0540	0.0395	0.0355	0.0285	0.0390
0.0570	0.0390	0.0000	0.0240	0.0395
0.0430	0.0375	0.0295	0.0240	0.0350
0.0430	0.0565	0.0220	0.0360	0.0320

AVERAGE= 0.0287

RMS = 0.0387

STD_DEV 0.0265

MAXIMUM DELTA = 0.0570

MINIMUM DELTA = -0.0495

AFTER MACHINING				
0.0007	0.0005	0.0003	0.0000	-0.0002
0.0006	0.0003	0.0000	-0.0001	-0.0003
0.0005	0.0002	0.0000	-0.0002	-0.0004
0.0003	0.0002	-0.0002	-0.0004	-0.0005
0.0002	-0.0001	-0.0006	-0.0005	-0.0006

AFTER STRESS RELIEF 2				
0.0006	0.0005	0.0003	0.0000	-0.0003
0.0006	0.0004	0.0002	-0.0001	-0.0003
0.0006	0.0002	0.0000	-0.0002	-0.0004
0.0004	0.0002	-0.0001	-0.0004	-0.0006
0.0002	0.0000	-0.0003	-0.0005	-0.0007

DIFFERENCE				
0.0001	0.0000	0.0000	0.0000	0.0001
0.0000	-0.0001	-0.0002	0.0000	0.0000
-0.0001	0.0000	0.0000	0.0000	-0.0001
-0.0001	0.0000	-0.0001	-0.0001	0.0001
0.0000	-0.0001	-0.0003	0.0000	0.0001

AVERAGE= 0.0000

RMS = 0.0001

STD_DEV 0.0001

MAXIMUM DELTA = 0.0001

MINIMUM DELTA = -0.0003

LENGTH BEFORE CUTTING = 24.030"

LENGTH AFTER CUTTING = 24.041"

RESIDUAL STRESS =
[(24.041-24.030)/24.030] X 1E7 = 4,577 PSI

3. Conclusion

Both the fillet weld and the plug weld reside in a low stress environment. From a structural standpoint, almost all the welds were adequate. The larger concern is the presence of virtual leaks in nearly all of the welds. It is recommended that additional weld coupons are made and the investigation continued prior to fabricating the actual parts.

In order to minimize microcreep, it is necessary to have components with low residual stress. The large variations in vendor results warrant the final hardware being monitored closely to assure that the welding and subsequent stress relief processes are followed.

With regard to residual stresses, and flatness of the parts, there is no explanation regarding why they varied so greatly between the two vendors. Both vendors supplied certifications for their respective identical stress relieving cycles.

The resulting flatness of the part of the prototype representing the optics table varied dramatically between the two vendors. This leads one to believe that the two parts were not processed the same. The PSI stress relief showed substantial motion after the first cycle, 0.0387” RMS motion, while the NOSMAS moved only 0.0023”. The second stress relief showed only 0.0001” motion on PSI’s part and 0.001” on the NOSMAS part.

Another observation is that after final machining, the PSI part moved much less in the stress relieving cycle (0.00035” total) than the Nosmas (0.0038”). This is consistent with PSI’s prototype having less residual stress than the other.

Note 1, Linda Turner, 09/03/99 02:25:04 PM
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