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Optimization of a Welding Procedure for Making Critical Aluminum Welds on the LBNF Absorber Core Block

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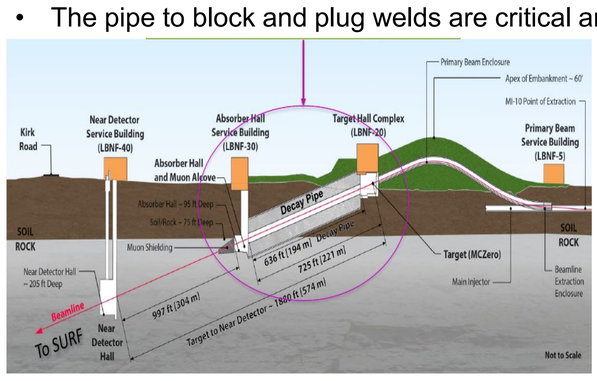
Abstract

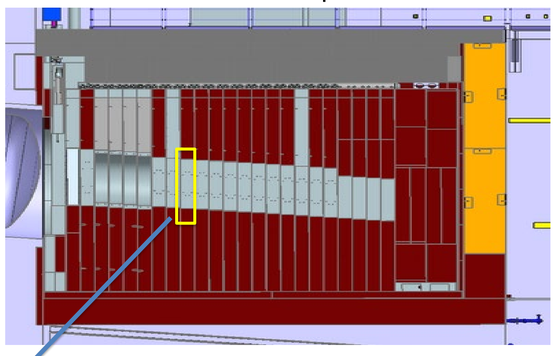
The LBNF Absorber consists of thirteen 6061-T6 aluminum core blocks. The core blocks are water cooled with de-ionized (DI) water which becomes radioactive during beam operations. The cooling water flows through gun-drilled channels in the core blocks. A weld quality optimization was performed to produce National Aeronautical Standard (NAS) 1514 Class I quality welds on the aluminum core blocks. This was not successful in all cases. An existing Gas Tungsten Arc Welding (GTAW) Welding Procedure Specification (WPS) was fine tuned to minimize, in most cases, and eliminate detectable tungsten inclusions in the welds. All the weld coupons however, passed welding inspection as per the piping code: ASME B31.3 Normal Fluid Service. Tungsten electrode diameter, type, and manufacturer were varied. Some of the samples were pre-heated and others were not. It was observed that larger diameter electrodes, 5/32 in., with pre-heated joints resulted in welds with the least number of tungsten inclusions. It is hypothesized that thinner electrodes breakdown easily and get lodged into the weld pool during the welding process. This breakdown is further enhanced by the large temperature differential between the un-preheated sample and the hot electrode.

Overview

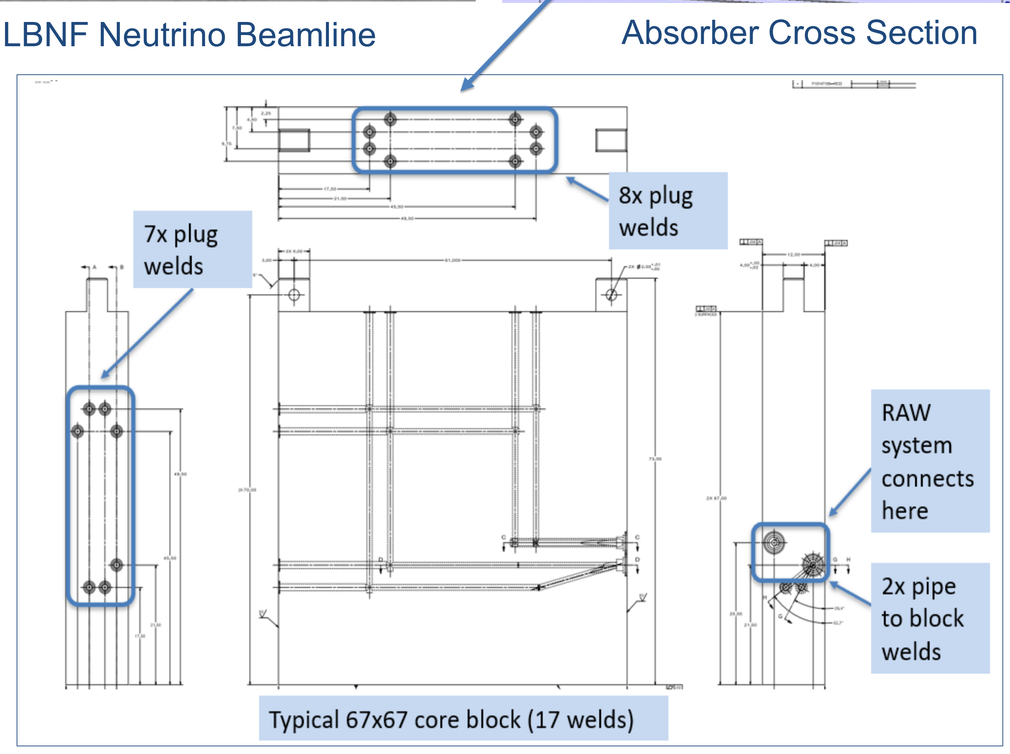
- The absorber consists of two major sections: The core and the surrounding concrete and steel shielding.
- The core consists of an aluminum spoiler block to initiate the particle shower, four aluminum mask blocks with air space in the center, thirteen aluminum core blocks, and four steel blocks.
- Aluminum core blocks have gun-drilled channels through which the cooling water flows.
- Cooling water pipes are welded to the sides of each core block. And to form a closed loop, aluminum rods are inserted through the exit holes of the water channels and are plug welded.
- The pipe to block and plug welds are critical and must last the life of the experiment.



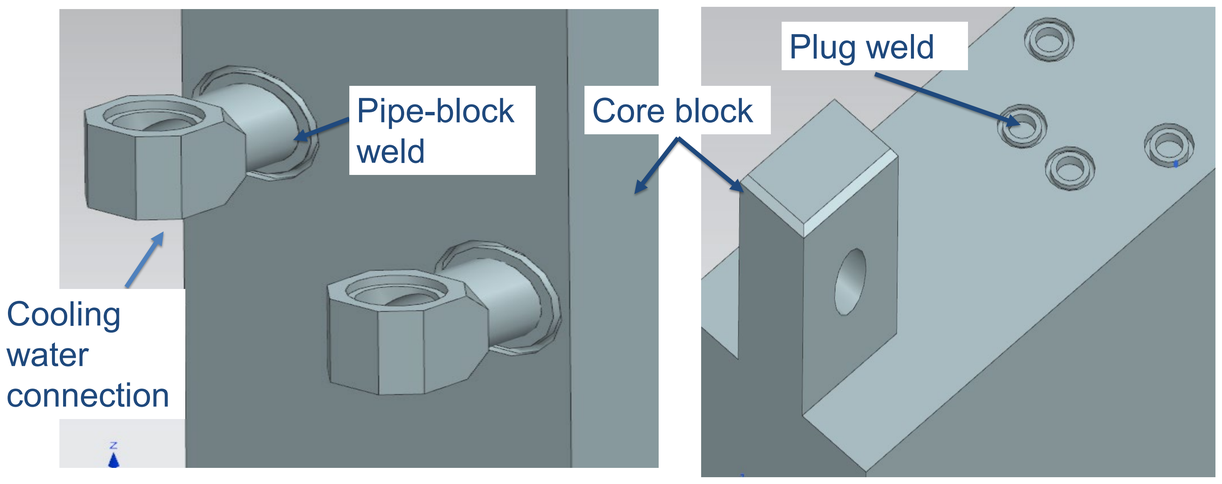
LBNF Neutrino Beamline



Absorber Cross Section



Typical Absorber Core Block



Core Block Connected to Cooling Water Lines

Plug Welds on Core Block

Welding Procedure Specification

- The base procedure involves performing meticulous cleaning and etching and handling operations on the 4043 filler rods. Then they are stored in a vacuum tube until welding begins.
- All the parts to be welded are cleaned with isopropyl alcohol and are scraped to remove the oxide layer with a carbide scraping tool.
- An 80% Alternating Current Electro Negative (ACEN) setting is selected on the welding machine.
- A 99.9995% 75% helium and 25% argon gas mixture is used as the shielding gas.
- A 2% thoriated tungsten electrode between 3/32 in. and 5/32 in. (inclusive) is chosen.
- The purge gas flow is set at 130 SCFH (He.). 1-root pass and 2-filler passes are used.
- Multiple instances of pipe-block and plug weld coupons were created using the weld procedure.
- After fine-tuning the welding procedure, most of the samples passed NAS 1514 Class I criteria.
- All the samples passed ASME B31.3 Normal Fluid Service criteria.

LBNF Absorber 6061-T6 Aluminum Core Block Plug and Pipe Weld Samples Log

Coupon ID:	MC75	MC76	MC77	MC78	MC79	MC80	AF81	AF82	AF83	AF84	MC5	MC6
Drawing numbers:	F10149391 F10149387 F10149388	F10149391 F10149387 F10149388	F10149391 F10149387 F10149388	F10149391 F10149387 F10149388	F10149391 F10149387 F10149388	F10149391 F10149387 F10149388	F10124967 F10124708 F10124959	F10124967 F10124708 F10124959	F10124967 F10124708 F10124959	F10124967 F10124708 F10124959	F10124967 F10124708 F10124959	F10124967 F10124708 F10124959
Component/filler rod prep per ED0000862:	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Electrode size:	5/32"	5/32"	5/32"	5/32"	5/32"	5/32"	5/32"	5/32"	5/32"	5/32"	5/32"	5/32"
Electrode type:	2% Thoriated (CK world wide)	2% Thoriated (CK world wide)	2% Thoriated (Weldmark)	2% Thoriated (Weldmark)	0.8% Zirconiated (CK world wide)	0.8% Zirconiated (CK world wide)	2% Thoriated (Weldmark)	2% Thoriated (Weldmark)	2% Thoriated (Weldmark)	2% Thoriated (Weldmark)	2% Thoriated (Weldmark)	2% Thoriated (Weldmark)
Truncated tip with 35 deg. Angle?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Pre-heat to 230 F?	N	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y
Depth of groove:	0.25"	0.25"	0.325"	0.325"	0.25"	0.25"	--	--	--	--	--	--
Filler rod type:	E4043	E4043	E4043	E4043	E4043	E4043	E4043	E4043	E4043	E4043	E4043	E4043
Filler rod size:	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"	1/16"
Gas type:	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)	75 He./ 25 Ar. (99.9995% HP)
Gas flow rate:	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.	130 SCFH He.
Root pass:	1	1	1	1	1	1	1	1	1	1	1	1
Filler pass:	2	2	2	2	2	2	3	3	3	3	2	2
Current and polarity type:	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN	AC with 80% EN
Max current setting:	250 A	250 A	250 A	250 A	250 A	250 A	250 A	250 A	250 A	250 A	NA	NA
Frequency setting:	130 Hz	130 Hz	130 Hz	130 Hz	130 Hz	130 Hz	130 Hz	130 Hz	130 Hz	130 Hz	NA	NA
Weld start time:	9:04 AM	10:53 AM	9:21 AM	11:08 AM	9:45 AM	10:20 AM	9:06 AM	10:34 AM	1:30 PM	8:31 AM	NA	NA
Weld stop time:	9:20 AM	10:58 AM	9:27 AM	11:13 AM	9:48 AM	10:27 AM	9:30 AM	10:56 AM	1:52 PM	8:47 AM	NA	NA
Measured temperature prior to root pass:	68 F	230 F	70 F	202 F	80 F	230 F	230 F	230 F	230 F	250 F	NA	NA
Avg. voltage measured root pass:	20 V	18 V	20 V	21 V	21.5 V	21.4 V	21 V	21.9 V	22.2 V	22.5 V	NA	NA
Avg. voltage measured filler pass#1:	25 V	20 V	21 V	17 V	--	20 V	22 V	20.4 V	20.9 V	20.4 V	NA	NA
Avg. voltage measured filler pass#2:	21 V	18 V	20 V	19 V	20 V	--	20.4 V	21.4 V	20.5 V	20.1 V	NA	NA
Avg. voltage measured filler pass#3:	NA	NA	NA	NA	NA	NA	21 V	20.7 V	21.4 V	20.4 V	NA	NA
Avg. current measured root pass:	248 A	243 A	248 A	250 A	249 A	250 A	230 A	250 A	250 A	250 A	NA	NA
Avg. current measured filler pass#1:	248 A	235 A	248 A	180 A	--	230 A	215 A	230 A	230 A	235 A	NA	NA
Avg. current measured filler pass#2:	243 A	189 A	248 A	200 A	225 A	230 A	214 A	230 A	211 A	215 A	NA	NA
Avg. current measured filler pass#3:	NA	NA	NA	NA	NA	NA	220 A	200 A	196 A	210 A	NA	NA
Passed ASME B31.3 Normal Fluid Serv.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

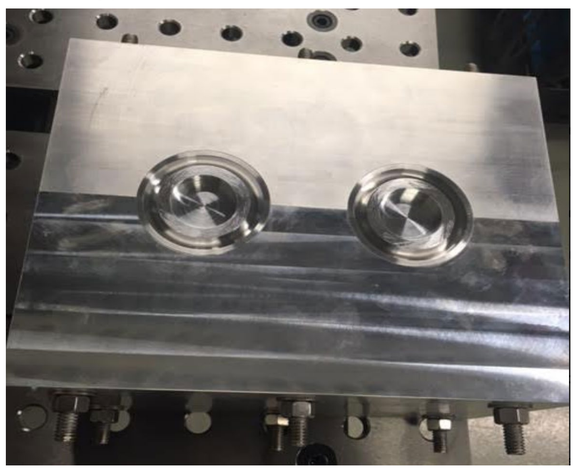
Welding Log for All Coupons

Weld Coupons

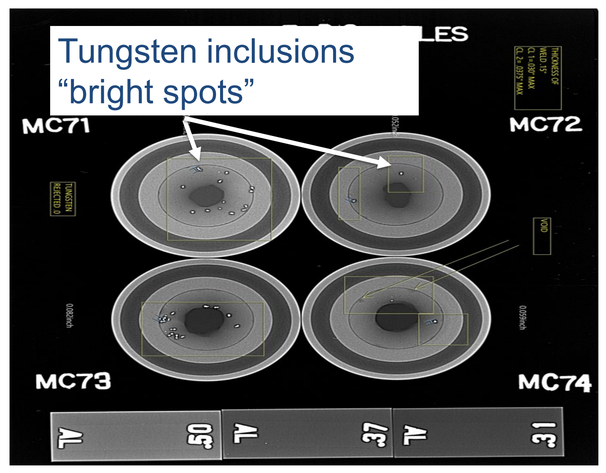
Radiographs of Weld Coupons

Effect of Pre-heating on Tungsten Inclusions

- The quantity and the size of tungsten inclusions is one of the criteria for NAS 1514 Class I.
- Preheating the sample close to 230 °F prior to welding reduced tungsten inclusions.
- This was discovered when plug welds were welded in a special fixture. The fixture was designed to weld multiple samples at a time.
- Four weld assemblies were loaded into the fixture at the same time. While the first one was being welded, the second assembly got pre-heated.
- The weld coupon created from the second assembly showed a smaller number of inclusions.
- The size of the welding electrode influenced weld quality as well. Larger, 5/32 in., tungsten electrodes resulted in better quality welds.
- Thinner electrodes likely break off easily and get lodged into the weld pool.
- Pre-heated and un-preheated coupons passed ASME B31.3 Normal Fluid Service criteria.
- The type, 2% thoriated Vs. 0.8% zirconated electrodes, did not influence weld quality.



Fixture for Plug Welds



Radiographs for Plug Welds

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