CARBON STEEL BEAMTUBE ? A REVIEW OF OUR LAST 5 YEARS

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OVER 5 YEARS AGO…

A COMPARISON OF OUTGASSING FROM CARBON STEEL VS. STAINLESS[1]

H. F. Dylla , American Institute of Physics (retired)

Park, Ha and Cho[2] published a study in 2015 carefully looking at both total and hydrogen outgassing from three grades of structural mild steels and a typical UHV quality 304 stainless steel

They find that with reasonable care of the vacuum facing surface, total outgassing rates are 3-30 times more than stainless steel

Measured hydrogen outgassing rates was 20 x lower than stainless steels after a modest 150C (48h) pretreatment for both metals

1. Workshop on Large Ultrahigh Vacuum Systems for Frontier Scientific Research Instrumentation, LIGO Livingston Site, LA Jan.29-31, 2019
2. C.Park, T.Ha, and B.Cho, JVST **A34**, (2016) 021601-1

MIT-SPONSORED STUDIES

- MIT Task 1 Report (RPT100013637)

  Review of steel pipe metallurgy, fabricator visits, mfg process quality assurance, initial cost and time estimates

- MIT Task 2 Report

  Ballistic properties of carbon versus stainless pipe

- MIT Task 3 and 4 Report

  Gas diffusion in pipe, carbon v. stainless microstructure, internal/external coatings, specialized alloying, leak testing

- MIT Task 5 and 6 Report

  Beam tube assembly, pipeline welding, bellows and ConFlat portal installation, surface prep prior to evacuation, budget update including assembly

LARGE DIAMETER PIPE MANUFACTURERS

1	Welspun Tubular	Little Rock, AR	India HQ
2	Dura-Bond Industries	Steelton, PA	Pennsylvania-based with coatings facility
3	Europipe (Berg Spiral Pipe)	Panama City, FL	Long length projects are common to them.
4	Stupp Corp.	Baton Rouge, LA	Close to LIGO

CARBON STEELS

AISI 1020	0.2C, 0.5Mn (ferritic steel)
API X60	0.16C, 1.65Mn, 0.45Si, 0.02P, 0.01S, 0.08V, 0.05Nb and 0.04Ti (ferritic, bainitic, or pearlitic steel)
S355J2+AR	0.22C, 1.60Mn, 0.55Si, 0.03P, 0.03S, 0.30Ni (ferritic, bainitic, or pearlitic steel)

S is short for structural steel
355 refers to minimum yield strength (355 MPa)
J2 means impact energy is 27 J minimum at room temp
+AR means as rolled; +N means normalized

CARBON STEELS USED IN OUTGASSING STUDIES

ASTM	Type/Gr	UNS	EN	C	Mn	P max	S max	Si	Cr	Ni	Mo	Cu
					W&M							
A36	Plate	G10200	C22	0.18-0.23	0.30-0.60	0.040	0.050					
					CERN							
A656	50	K12447	S355J2+AR	0.22	1.60	0.035	0.035	0.55		0.30		
A572	50	K12447	S355J2+N	0.22	1.60	0.035	0.035	0.55		0.30		
A516	70+N	K02700	P355N	0.31	0.85-1.20	0.035	0.04	0.15-0.30				
A519	1524	G15240	E355C	0.19-0.25	1.35-1.65	0.040	0.050					
					NIST							
A36	Plate	G10220	S235JR	0.20	0.85	0.009	0.002	0.18	0.09	0.11	0.03	0.27
A36	Plate	G10220	S235JR	0.20	0.86	0.012	0.008	0.15	0.18	0.09	0.03	0.26
A36	Plate	G10220	S235JR	0.20	0.76	0.012	0.006	0.04	0.06	0.03	0.01	0.04
					Welspun							
API X65	PSL2			0.26	1.40	0.04	0.05	0.45				

Hot rolled steel arriving from mill

Spiral welded 80-foot pipe sections

Furnace cleaning to remove scale

Pipes free of scale

Pipe sections after fusion epoxy coating

Pipe sections loaded onto railcars for shipment to construction site

Field welding pipeline

CARBON STEEL BEAMTUBE GUIDANCE

1. Estimated cost of 50 miles of 48-inch-diameter, 1/2-inch-thick, API PSL2 X60 steel line pipe with additional alloying, an external fusion-baked epoxy coating, and helium leak testing including cross country freight, is $69,828,000.

2. The ferritic structure of mild steel has a 23% more open void volume than the austenitic structure of stainless steel, allowing for more rapid diffusion of gases through the lattice. The room temperature hydrogen solubility of ferritic steel at 0.001 ppm should be low enough to eliminate the need for high temperature baking to minimize hydrogen outgassing that was required for stainless steel.

3. It is recommended that the interior surface of the beamtube be either bare carbon steel with a dry, cleaned top surface prior to sealing the vacuum system, or a conversion coating of magnetite, depending on results of the outgassing

studies that are underway.

4. It is recommended that the exterior surface of the beamtube be fusion-baked epoxy, 14 to 16 mils thick, coated to within 6 inches of each end of the pipe segments, to provide abrasion and corrosion resistance for at least 20 years and to provide a leak-tight seal across the spiral welds.

D. Henkel, “Metallurgical Study of 40-km Carbon Steel CE Beamtube Guidance on External and Internal Coatings,” February 13, 2021.

ADDITIONAL GUIDANCE

- Production time for 3,300 (50 miles) 80’ coated and tested pipe segments will be 4 to 6 weeks
- Estimated costs of 50 miles of welded 42”x1/2” and 48”x1/2”, API PSL2 X60 carbon steel line pipe, fully assembled and leak tested with 400 ConFlat portals and 400 expansion joints are $95,590,000 and $108,116,000, respectively.
- The estimated time and temperature for water/gas species desorption from both bare carbon steel and magnetite-coated carbon steel has yet to be determined through ongoing engineering studies. A bakeout process may not be necessary.

D. Henkel, “Metallurgical Study of 40-km Carbon Steel CE Beamtube: Guidance on On-Site Assembly,” October 12, 2021.

METALLURGICAL GUIDANCE

- The room temperature hydrogen solubility of ferritic steel at 0.001 ppm should be low enough to eliminate the need for high temperature hydrogen bakeout
- The interior surface of the beamtube to be either bare carbon steel with a dry, clean surface prior to sealing the vacuum system, or a conversion coating to magnetite
- The exterior surface of the beamtube to be fusion-baked epoxy, 14 to 16 mils thick, coated to within 6 inches of each end of the pipe
- Minimize grain size for high diffusion rate
- Anneal or thermomechanically form for acicular ferritic grain structure (better texture)
- Reduce sulfur to minimize manganese sulfide stringers
- Control surface texture to minimize water binding energy
- Alloy with additional silicon, tungsten, and/or aluminum to reduce solubility of hydrogen, trap existing hydrogen, and increase corrosion resistance

BALLISTIC GUIDANCE

1. A beamtube of 50 miles, constructed of 42-inch-diameter, 1/2-inch-thick, API PSL2 X52 steel line pipe was found to be non-resistant to penetration of lead bullets from high power hunting firearms with terminal velocities of greater than 500 m/s. It is recommended that actual projectile penetration testing on a segment of the proposed steel pipe material be performed during the engineering design phase.

2. Alloying the pipe steel may sufficiently increase the yield strength to resist penetration and internal cracking from conventional hunting projectiles.

3. A secondary shield may be required to protect the sides of the beamtube from stray hunting projectiles. Low-cost designs could include non-metallic

composites or thin, energy-absorbing metal alloys.

4. It is recommended that the new beamtube design incorporate an acoustic or vibration sensor system to detect ballistic impacts.

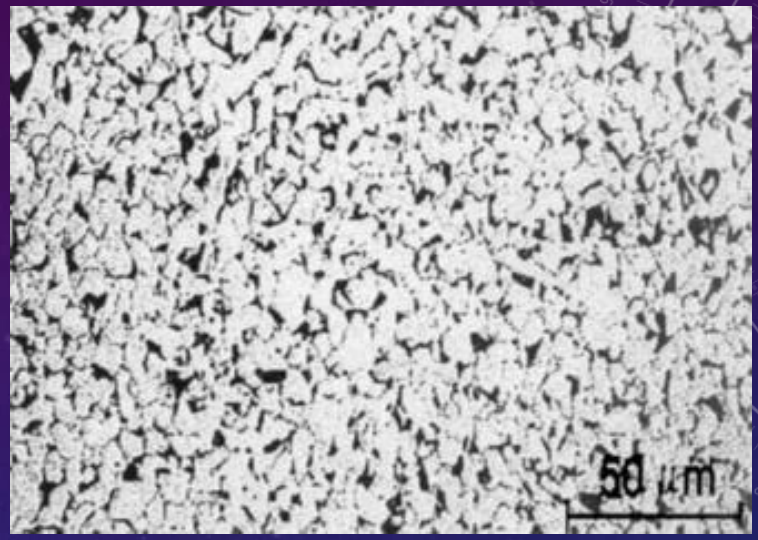
CONSIDERATIONS OF INTERNAL PIPE SURFACES

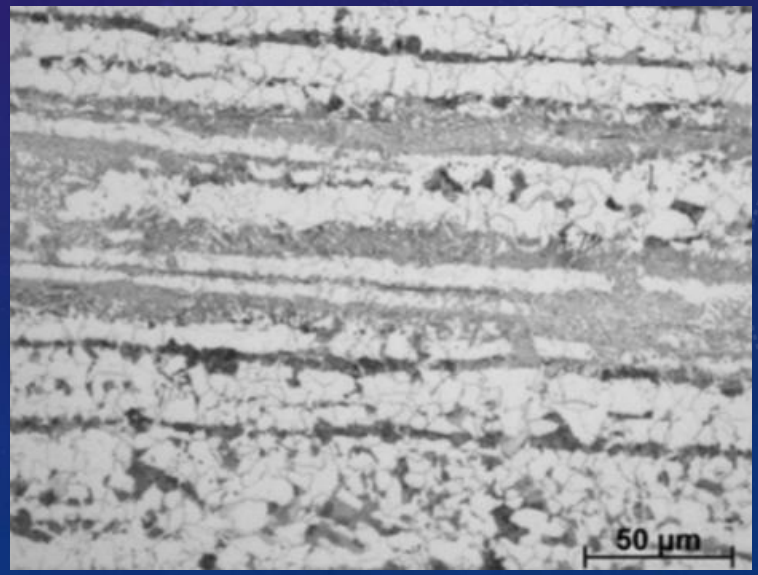
- Conversion coatings – bluing, black oxide, anodizing, aluminizing
- Phosphates
- Galvanizing
- Chemical Vapor Deposition

MICROSTRUCTURAL CONSIDERATIONS

- AISI 1020 0.2C, 0.5Mn
  (ferritic steel)

- API X60 0.16C, 1.65Mn, 0.45Si, 0.02P, 0.01S, 0.08V, 0.05Nb and 0.04Ti
  (ferritic, bainitic, pearlitic steel)





MAGNETITE V. CLEAN STEEL INTERIOR SURFACE

- $6Fe_2O_3 – 4Fe_3O_4 + O_2$
- Magnetite –matte black, nonreflective, non-porous, tightly adhering, may minimize binding energy and bakeout
- Hematite – red rust, porous, easily spalled or removed, leaving clean, low binding energy metal surface

CERN MAGNETS

Magnetil™

Ultra-Low Carbon Electrical Steel

0.0025% C (ferritic steel)

Hot Rolled Steel (800°C)

+ Cold Water Spray

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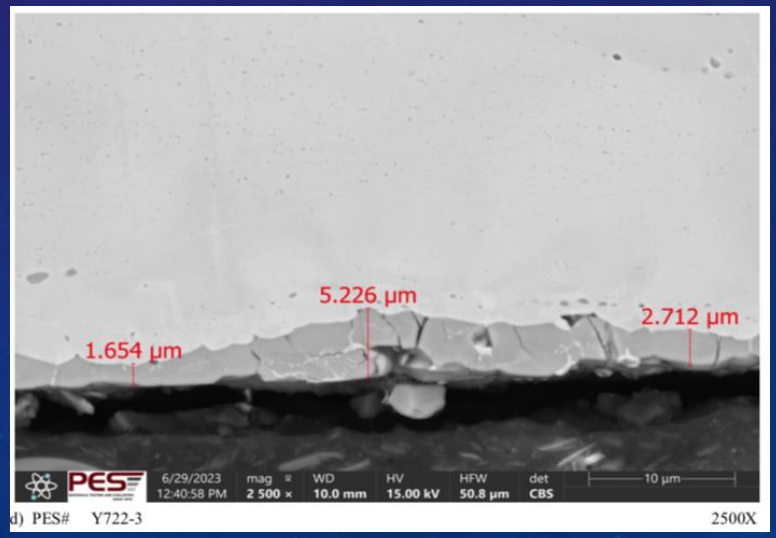
3-5 μm thick magnetite

Photo: Miehu Heat Treating



SUN STEEL METALSTEAM

Low Carbon Steel

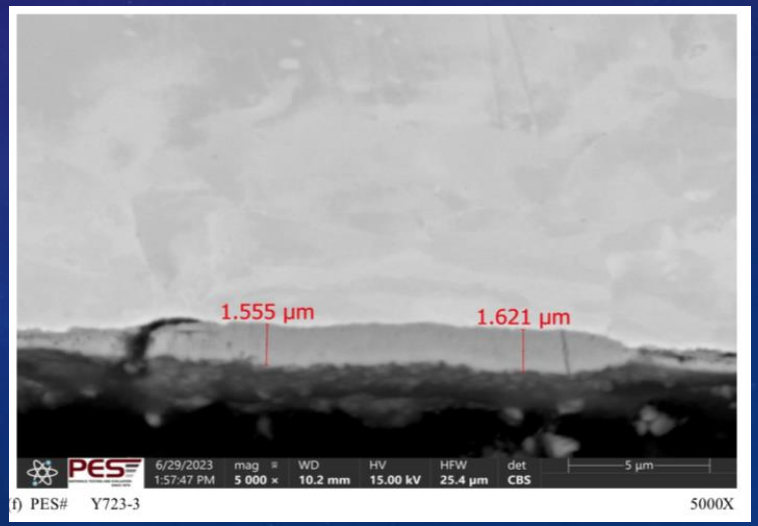
<0.2C, 0.5Mn (ferritic steel)

Hot steel (>530°C)

+ Steam environment

1.5 μm thick magnetite

Photo: Shutterstock



W&M EXPERIMENTAL MAGNETITE

X60 Pipe Steel

0.16C, 1.65Mn, 0.45Si, 0.02P, 0.01S, 0.08V,

0.05Nb and 0.04Ti

(ferritic, bainitic, or pearlitic steel)

Pipe steel (800°C)

+ Cold water quench

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? μm thick magnetite

Photo: Science Photo Library