Why 304H wins: A value-engineering

In the debut column for *Stainless Steel World Americas*, Travis Field, pipe welding specialist and founder of Pipe Welding Institute, walks through a value-engineering materials selection case comparing high-temperature piping alloys for PDH and steam-service piping systems, and explains why 304H emerged as the strongest overall fit.

Travis Field

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He holds Red Seal Journeyman Welder and Alberta B-Pressure certifications and has extensive experience with advanced alloy systems across Canada and the United States.

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Field GTAW welding of 304H stainless piping during fabrication of a high-temperature process system.

A materials selection walkthrough from a Canadian PDH and polypropylene plant

Specifying a metal for a hot service is a balancing act between three things that don't naturally agree: the alloy has to survive what the service throws at it, last as long as the asset is supposed to live, and cost what the project can actually afford. Take, for example, an integrated Propane Dehydrogenation (PDH) and polypropylene plant in Alberta, Canada—two plants on the same site, tied together by piping.

Propane Dehydrogenation takes propane (C_3H_8) and strips two hydrogen atoms off it to ake propylene (C_3H_6). Propylene is the building block for polypropylene, the plastic in everything from yogurt containers to car bumpers to medical syringes. The propylene flows directly from the PDH unit into the polymerization plant next door. Alberta has cheap propane from natural gas processing, so it's an attractive place to build this kind of facility.

Two worlds under one roof

In any chemical plant, you have two broad worlds: the process side and the power side. The process side is everything that touches the actual chemicals—the feed, the intermediates, the product. The power side is the supporting cast: steam, cooling water, instrument air, nitrogen, fuel gas. When an engineer says, "on the process side," they mean the equipment and piping that hold the hydrocarbons themselves. Two services share this site, and each comes with its own materials problem.

case for high-temperature stainless piping

Inside the reactor: A hot hydrocarbon soup

On the process side, the PDH reactor effluent leaves the reactor at around 600°C—a hot soup of propylene, unreacted propane, hydrogen, and small amounts of byproducts like methane, ethane, ethylene, and a bit of coke—before heading downstream for cooling and separation.

It's a reducing hydrocarbon and hydrogen environment with no chlorides and no sulfidation to speak of. The corrosion picture is therefore mild, and what the engineers will be designing against is creep, oxidation, and high-temperature mechanical strength.

On the power side: 540°C and clean steam

On the power side, superheated steam leaves the boilers at around 540° —clean water cooked to vapor and run up to high pressure and temperature—before heading downstream to the process units that need it for heating, stripping, and reboiling.

It's a high-pressure steam environment with no chlorides and no dissolved oxygen to speak of, because the boiler feedwater is treated, demineralized, and continuously monitored. The corrosion picture is again mild, limited to the thin protective oxide scale every stainless steam line grows in service. And once again, what the engineers will be designing against is creep, oxidation, and high-temperature mechanical strength.

Cold weather, hot pipe

There's a fourth design driver hiding in plain sight, and it has nothing to do with what's inside the pipe. It's where the pipe lives.

Alberta is not a temperate climate. Winter lows hit -37°C and summer highs push past +30° —a 70°C swing in the air around the pipe over the year, on top of the much larger swing

Completed external weld profile on 304H stainless process piping fabricated for elevated-temperature hydrocarbon or steam service.

every startup and shutdown. A brittle fracture during a January startup isn't a maintenance problem; it's a hydrocarbon release on the process side and a 540°C steam release on the power side, neither of which any plant is designed to handle.

The practical drivers

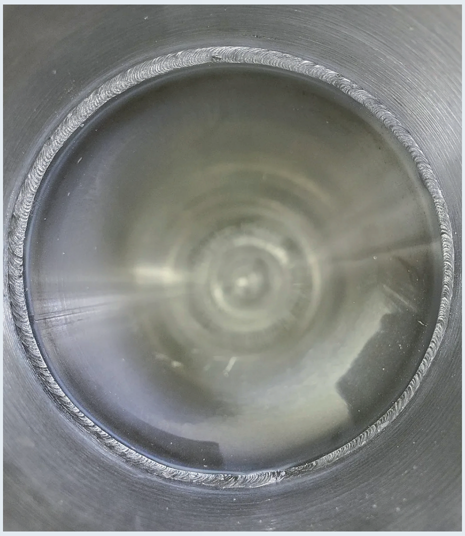
The four design drivers above tell us which metals can do the job, but in real-world materials selection a second list—practical, project-driven, and often the one that makes the decision—drives the answer harder than the first:

1. Economic factors: the full price tag from material through fabrication, installation, and lifecycle replacement.
2. Availability: what's buyable on the project timeline and weldable by the local labor market.
3. Constructability: how cleanly the material welds, forms, inspects, and repairs in the field and the fabrication shop.
4. Long-term degradation: the slow failure modes that show up at year fifteen, not on day one.
5. Code and regulatory: what the codes and the local jurisdiction will accept.
6. Operational and strategic: how the choice fits the plant's existing materials and operating philosophy.
7. Health, safety, and environmental: fabrication exposures, recyclability, and carbon footprint.

Each of these will pull on the candidate list in the next section—sometimes against the technical answer.

Narrowing the field

Two services, the same three high-temperature design drivers, a climate filter, and a list of practical drivers behind them. Eleven material families show up on the candidate list, and most get eliminated quickly—not because there's anything wrong with them, but because they were built for a different service.

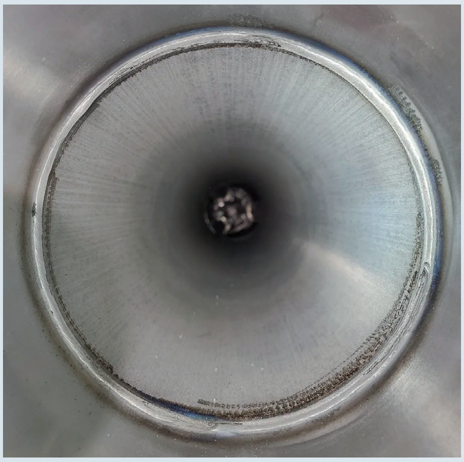


Internal root profile of a GTAW-welded 304H stainless joint.

Carbon steels: low-cost, widely available, weldable everywhere. Topped out around 400°C; useless at 540°C or 600°C. In Alberta, low-temperature grades like A333 Grade 6 are necessary to handle -37°C without brittle fracture. Belongs in the cold ends of the system, not the hot piping.

Chrome steels (Cr-Mo and CSEF Ferritic): P22 takes you to about 580°C; P91 to about 620°C. P91 is the most cost-effective option for 540°C steam and the dominant choice for modern high-pressure steam worldwide, but it demands tight PWHT control, is susceptible to Type IV cracking in welds, and, as a ferritic, has a ductile-to-brittle transition that must be verified for Alberta's -37°C winters. At 600°C it's right at its ceiling, which is why most operators step up to austenitic on the process side.

Stainless steels: the austenitic H-grades (304H, 316H, 321H, 347H, 310H) are purpose-built for elevated-temperature service. 304H is the lowest-cost H-grade and amply qualified for both 540°C steam and 600°C reducing hydrocarbon service with no corrosion drivers requiring an upgrade. Austenitic structure means no ductile-to-brittle transition; full ductility to cryogenic temperatures, no Alberta-winter brittle-fracture risk that the ferritics carry. Trade-offs: higher thermal expansion than ferritic, and welds need 16-8-2 filler instead of 308H to avoid sigma phase formation. An austenitic H-grade is the strongest fit for this service.



Internal appearance of a completed 304H stainless weld after fabrication.

Duplex steels: 2205, 2304, and the lean duplex grades are workhorses for chloride-bearing aqueous service, but the service ceiling is about 315°C. Killed at higher temperatures by 475°C embrittlement and sigma phase formation. Wrong service entirely.

Super duplex: 2507, Zeron 100. Same family, more aggressive chemistry, even more restrictive temperature limit, roughly 250–300°C. Off the table for the same reason as standard duplex.

Nickel alloys: Alloy 800H, Alloy 617, Inconel 625. The premium answer for service the austenitic family can't reach. An H-grade delivers what service needs at roughly a third the cost. Specifying nickel alloy here is paying for capability the design never plans to use.

Copper: softens above 200°C, oxidizes above 250°C. Not a candidate.

Aluminum: loses strength above 150°C, melts at 660°C. Belongs in cryogenic service. Not a candidate.

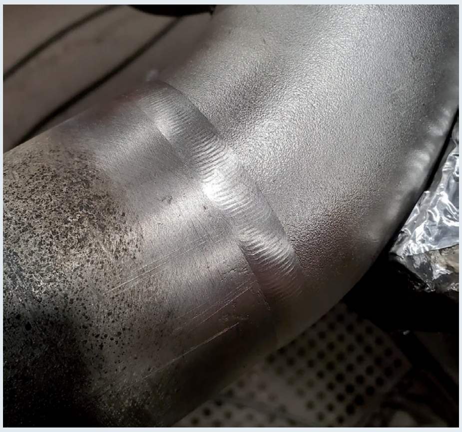
Copper nickel: built for seawater. Service ceiling around 200–250°C. Wrong service.

Titanium: alpha-case formation above 400°C, hydrogen embrittlement in hydrogen-rich service like PDH effluent, not approved under ASME B31.3 for high-temperature hydrocarbon piping. Not viable.

Zirconium: specialty nuclear and concentrated-acid material. Order of magnitude is more expensive than stainless, with hydrogen embrittlement concerns and limited high-temperature capability. Wrong material at any price.

Three realistic answers

Of eleven candidates, three are realistic answers: P91 for the 540°C steam side, an austenitic H-grade for both services, and a nickel alloy (Alloy 800H, Alloy 617) when temperature margin really matters. P91 wins on raw material cost, but an H-grade often wins on total installed cost because standardizing on one spec simplifies welder qualification, filler-metal stocking, and inspection, and removes the Alberta-winter ductile-to-brittle transition temperature concern that the ferritic



Finished weld on stainless process piping prepared for high-temperature service.

option still has to manage. The nickel alloy stays in reserve for service that pushes past the austenitic family.

Choosing the H-grade and filler material

The best austenitic H-grade for our service is 304H. At 540–600°C in clean reducing or steam service, every step up the ladder (316H for chloride resistance we don't need, 321H or 347H for sensitization concerns we don't have, 310H for temperature margin we don't use) is buying capability the service doesn't ask for.

Picking 304H shifts the welding decision to the filler. Matching 308H embrittles in service as its ferrite transforms to sigma phase in the 540–815°C window. 316H accelerates the same failure; nickel fillers like Inconel 82 are sigma-immune but cost five to ten times more; dissimilar fillers solve a ferritic-austenitic problem 304H-to-304H joints don't have. The right answer is 16-8-2 (16Cr-8Ni-2Mo, FN 5–10 ferrite): less chromium, controlled ferrite, and creep strength from molybdenum.

Old pipe, quiet engineering

Good materials engineering rarely looks impressive. The pipe goes in, the welds pass, the plant runs, and twenty-five years later a welder says, "I worked here twenty-five years ago, and it was old then!" That's the work. That's engineering.