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Induction Heat Treating

Taking the Crank Out of Crankshaft Hardening

Gary Doyon, Doug Brown, Dr. Valery Rudnev, Glen Desmier, Jeffrey Elinski – Inductoheat, Inc., Madison Heights, Mich.

Induction heat treatment is traditionally a popular choice for hardening and tempering of quality crankshafts. Continuous process improvement and innovation has resulted in a process that allows crankshaft designers more flexibility to meet tighter requirements.


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Sintering/Powder Metallurgy

Controlling Properties of Sintered-Steel P/M Components Using Atmosphere

Thomas Philips, John J. Dwyer, Zbigniew Zurecki – Air Products, Allentown, Pa.

The composition of the sintering atmosphere is often overlooked as a variable that can optimize the sintered-steel properties of iron-carbon P/M components. The property effects of CO-containing atmospheres versus non-CO atmospheres are examined.


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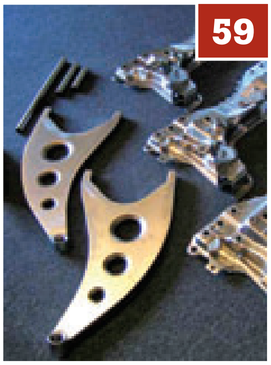
Process Control & Instrumentation

Atmospheric Furnaces – Product Temperature is Critical

Vern Lappe – Ircon Inc., Niles, Ill.

As in most occupations, having the right tools can assure that the job gets done right. In heat treating, having the right temperature-measurement tool can be the difference between success and failure.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Advances in Martensitic Stainless Processing

Daniel Codd, P.E. – KVA Incorporated, Escondido, Calif.

New developments in welding and thermal processing are enabling the cost-effective use of martensitic stainless steels in exciting new applications as an attractive alternative to costly high-alloy materials.

On The Cover:

The induction feature article on page 41 discusses the technology of non-rotational induction hardening of crankshafts such as the one pictured here.

Advances in Martensitic Stainless Processing

Daniel Codd, P.E. – KVA Incorporated, Escondido, Calif.

New developments in welding and thermal processing are enabling the cost-effective use of martensitic stainless steels in exciting new applications. These advancements, coupled with an increased demand for high-strength, lightweight structures, are positioning martensitic stainless as an attractive alternative to costly high-alloy materials.

Stainless, or corrosion-resistant, steels are defined as iron-based alloys with a minimum 10.5% chromium content, which promotes the development of an invisible, adherent and self-healing chromium-rich oxide surface film. Stainless steels are commonly divided into five groups classified by their microstructure at room temperature.

- Austenitic
- Ferritic
- Duplex
- Precipitation hardenable
- Martensitic

Various alloying elements are added to the basic iron-chromium-carbon and iron-chromium-nickel systems to control microstructure and properties. These elements include manganese, silicon, molybdenum, niobium, titanium and nitrogen, among others. There are over 150 grades of stainless steel, of which austenitic stainless steels (type 304, type 316, 18/8, etc.) are the most widely used.

Corrosion resistance, physical and mechanical properties, alloy availability and cost are generally among the properties considered when selecting stainless steel for an application.

Martensitic Stainless Steels

Family Description

Martensitic stainless steels (MSS) – alloys primarily of chromium and carbon – possess a distorted body-centered cubic (bcc), or body-centered tetragonal (bct), martensitic crystal structure in the hardened condition. These alloys are ferromagnetic, hardenable by heat treatments and mildly corrosion resistant.

Wide ranges of strengths and hardness are achievable, ranging from 80HRB, 75 ksi UTS (500 MPa) in an annealed condition to 55HRC, 300 ksi UTS (2,000 MPa) as-quenched.

In general, corrosion resistance of the martensitic grades is not as good as that of the other stainless steels due to the relatively low chromium content and high carbon content. These alloys are generally selected for applications where a combination of high strength and corrosion resistance under ambient atmospheric conditions is required. The low chromium and low alloy content of the martensitic stainless steels also makes them less costly than other stainless types.

Historical applications of MSS include:

- Surgical instruments
- Cutlery
- Gears
- Shafts
- Fasteners
- Steam, gas and jet turbine blades
- Valves

Low-carbon (less than 0.08 wt.%) supermartensitic grades are seeing increasing use in oil and gas pipelines, however, their hardenability and strength is reduced as compared to higher carbon grades.

Welding Difficulties

Due to the formation of untempered martensite during cooling after welding, the martensitic alloys are considered the least weldable of the stainless steels.[1]

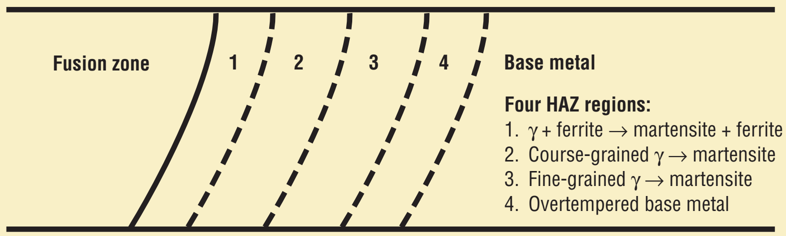

Fig. 1. Four HAZ regions observed in martensitic stainless steel (γ represents austenite)[1]

Table 1. Type 410 stainless steel (UNS S41000) alloying elements nominal wt.% (maximum values)

C	Mn	S	P	Si	Cr
0.15	1.00	0.03	0.04	1.00	11.5-13.5

The compositions of MSS – typically 10.5-18 wt.% chromium – are specifically formulated to render them amenable to a quench-and-temper (Q+T) heat treatment in order to produce high levels of strength and hardness. Although the chromium level is the same as in ferritic stainless steels (e.g. type 409), the higher carbon content of the martensitic grades results in a complete transformation from ferrite to austenite (γ) at high temperature, followed by a subsequent change to the hard martensite phase upon rapid cooling. MSS are considered "air-hardenable," as all but the thickest sections fully harden during an air-quench heat-treatment cycle to room temperature.

The thermal cycle of heating and rapid cooling, which occurs within the fusion and heat-affected zone (HAZ) during welding, is equivalent to a rapid air-cooling quench cycle. As a result, the martensitic weld structure that is produced is extremely brittle in the untempered condition. Regardless of the prior condition of the steel – annealed, hardened, or hardened and tempered – welding produces a hardened martensitic fusion zone and HAZ (Fig. 1).

However, MSS are ideally suited for structural components, tube, pipe and assemblies satisfying the requirements of high strength, toughness and corrosion resistance with ease of forming in the annealed state.

Although most assemblies once fabricated from these alloys would undergo a final homogenizing solution-heat-treatment hardening cycle, great benefits could be realized if the as-welded brittleness could be reduced. Secondary processes on weldments, such as cold working, tube sizing and straightening, bending, flanging or hydroforming (as in the case of seam-welded tubing), could be performed with greater confidence and ease.

The conventional approach to reduce weld hardness is to add filler material, whereby the final metallurgy is modified in such a way that the percentage of hard and brittle components such as martensite is reduced.[2] Another approach is to heat treat the welded part during or after welding. From a production point of view, heat treatment during production is preferred in order to avoid costly pre- or post-treatment.[3]

Typical off-line methods of controlling weld and HAZ hardness include secondary post-weld heat treatments (PWHT) such as process annealing. Preheating methods can be used to slow the rate of cooling, thereby reducing percentage of the martensitic phase present. Unfortunately, these methods are neither cost nor time effective for high production levels associated with modern manufacturing methods. Induction heat treatment has been known for many years to be an efficient way of heat treating steel parts.[4] The simple in-line induction weld cooling control and PWHT method presented here is shown to appreciably increase weld and HAZ ductility without increasing process time.

Processing Developments

Weld Cooling Control

Novel developments in high-speed autogenously welded Type 410 steel (UNS41000/SAE 51410) have been demonstrated to solve many of the historical difficulties associated with welding martensitic stainless steels.[6] Chemical composition for this alloy is shown in Table 1.

Martensitic Stainless Enables Lightweight High-Strength Automotive Bumper Beam

With ever-increasing government regulations on vehicle safety and pressure from consumers concerned with fuel economy and emissions, car and truck manufacturers and their suppliers are turning to new technologies to help them achieve their goals of making components stronger and lighter.

Much promise lies with advanced-materials technologies utilizing exotic engineering alloys or carbon composites, which have seen very limited use in production, however, due to high material costs and lack of compatibility with existing manufacturing processes. On the other hand, low-cost martensitic stainless steels provide excellent mechanical properties – strength, toughness and fatigue performance – in addition to corrosion resistance while remaining easy to form, fabricate and process.

A newly developed fully martensitic stainless steel automotive front bumper beam takes advantage of the high strength of hardened martensitic stainless for increased strength and occupant safety. Novel use of type 410 stainless steel (UNS 41000) exploits the material's ease of formability in the annealed state. Conventional approaches with pre-hardened high-strength steel strip lack the ductility required for forming such complex sections.

A continuous roller-hearth furnace with an inert-gas quench is utilized to harden the beams after forming and welding to obtain uniform hardness (40 HRC) and tensile strengths (1,400 MPa) throughout.

The martensitic bumper beams were validated with frontal-impact crash testing, environmental (corrosion) testing and static strength criteria. Overall performance was improved relative to the baseline designs due in part to the increased strength of the type 410 stainless and to the solution heat treatment's effective elimination of any residual forming stresses or heat affected zone (HAZ) degradation due to welding.

For many applications, switching to high-strength martensitic stainless will result in a product that:

- Costs less than other advanced materials
- Is lighter, yet much stronger than low-alloy steels
- Is compatible with all existing forming, fabricating and thermal processes

This weld cooling-control processing (Fig. 2) promotes transformation of the martensite into ferrite and very fine carbides. This transformation reduces strength but improves ductility and toughness.[5] Additionally, the prolonged time at elevated temperatures increases diffusivity of hydrogen atoms while relieving thermal stresses, thereby reducing the probability of hydrogen-induced cracking or cold cracking.[5]

Guided Bend Weld Ductility Testing

Figure 3 shows typical longitudinal-face bend test samples after testing. Samples tested with weld cooling control exhibit greater overall ductility when compared to as-welded specimens, as measured by ASTM E190: Standard Test Method for Guided Bend Test for Ductility of Welds.

Tensile Testing

Figures 4 and 5 show average results for longitudinal tensile testing of the baseline, weld cooling control (cc) and Q+T weld specimens.

For all thicknesses, the cooling-control methods on the weld seam result in an increase in maximum strain at fracture and a corresponding decrease in ultimate tensile strength (UTS) when compared to the as-welded specimens. The weld cooling-control process does not affect overall performance because Q+T hardening cycles result in strengths near 200 ksi (1,400 MPa), as expected for hardened type-410 stainless steel.

Thermal Processing

After being formed into complex components and assemblies, MSS lends itself to cost-effective thermal processing. Unlike other materials that require a distortion-inducing rapid oil or water quench, thin-wall MSS structural parts are fully quenched in gentle air-cooling cycles.

Continuous furnace lines, such as mesh-belt or roller-hearth furnaces, are ideally suited for processing MSS. Bright hardening of MSS is easily accomplished using lines equipped for bright annealing of austenitic (304, 316, etc.) grades at similar temperatures, speeds and throughputs.

Applications

Seam-Welded Tubing

The weld cooling-control method is easily applied to the production of longitudinally seam-welded MSS tubing.

Typical microhardness-traverse data across the gas tungsten arc welding (GTAW) seam is shown in Figure 6 for comparison. While not softened completely to the level of the base metal, the cooling control significantly reduces the HAZ microhardness relative to the as-welded tube. Furthermore, after a Q+T heat treatment, the microhardness of the tube remains constant across the circumference without any HAZ-weakened areas.

Figure 7 shows typical tube specimens after flange testing. Clearly visible is the HAZ base-metal interface crack in the as-welded sample, whereas the controlled-cooling specimen is free from splits. The

Key advantages of martensitic stainless in structures:

- Forming ease
- Low cost
- Air hardening
- Ultrahigh strength
- Homogenous weld/HAZ/base metal after solution-heat treatment
- Moderate corrosion resistance

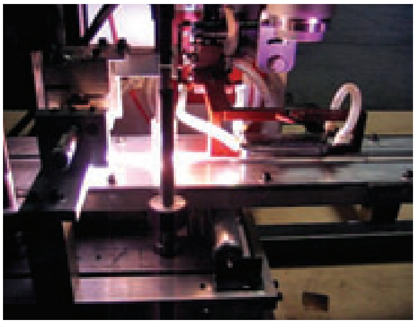

Fig. 2. Seam weld/cooling-control apparatus

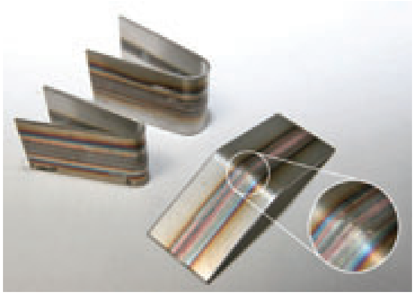

Fig. 3. Typical MSS ASTM E190 guided bend-test weld ductility specimens. From left: cooling-controlled processing 2t bend radius – full bend; cooling-controlled 4t bend radius – full bend; conventional as-welded 4t bend radius – failure

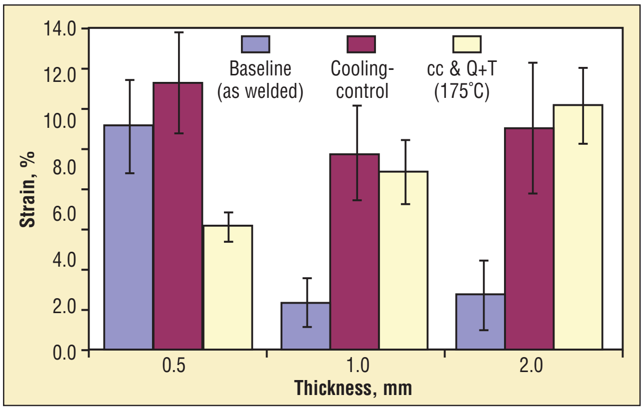

Fig. 4. Comparison of maximum strain at fracture for optimum process conditions – DIN EN 895 longitudinal tensile specimen – average results for 62 trials

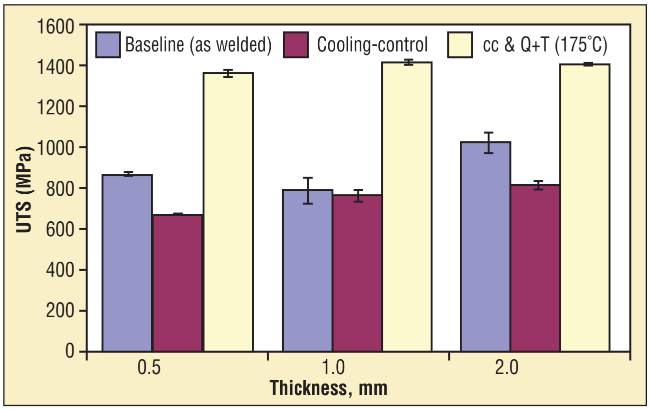

Fig. 5. Comparison of ultimate tensile strength for optimum process conditions – DIN EN 895 longitudinal tensile specimen – average results for 62 trials

Q+T hardened samples exhibit splitting in the base metal, far away from the HAZ and weld zone.

Tubes were also subjected to hydroforming free-expansion burst testing (Fig. 8). As-welded specimens showed premature failure (splitting) in the weld/HAZ, unlike the cooling-controlled tubes that exhibited greater overall expansion and failures in the base metal.

Additionally, the seam-welded MSS tubes were examined microscopically (Fig. 9). The cooling-controlled weld exhibits a more uniform weld-metal macrostructure with less chromium-carbide dispersion and segregation. Additionally, after a Q+T heat treatment, a uniform homogenous microstructure is obtained in the weld, HAZ and base metal, which is functionally equivalent to a seamless joint.

Structural Applications

Several applications utilizing MSS have been successfully developed. In all cases, benefits include:

- Lower cost than other "advanced" materials
- Lighter, yet much stronger than existing designs
- Compatible with all existing forming and fabricating methods
- Low-cost thermal processing

Fig. 7. Typical MSS ASTM A513 ring flare-test tube specimens (from left: as welded, cooling-controlled, cc & Q+T hardened)

Fig. 8. Typical MSS hydroformed free-expansion burst-test specimens (upper: as welded; lower: cooling-controlled)

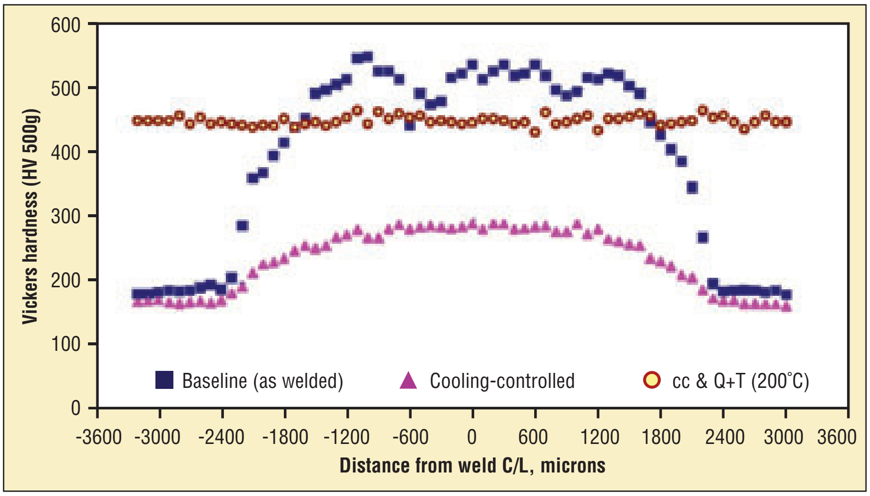

Fig. 6. Typical MSS vickers microhardness profile: (load: 500 g; hardness spacing: 100 µm; seam-welded Ø19.1 x 1.2mm UNS41000 tubing)

Sample MSS part photos are shown in Figure 10.

Conclusions

Novel welding and in-line cooling-control methods now enable the use of existing martensitic stainless alloys in exciting, new applications These simple-to-implement methods have overcome conventional difficulties without resorting to lower-carbon, lower-strength alloys and enable the production of ductile, tough and reliable weldments in low-cost martensitic stainless steels.

Fig. 9. MSS tubing weld photomicrographs (upper: as welded; middle: cooling-controlled; lower: Q+T)

These methods enable the expanded use of martensitic stainless in structural applications. These alloys are suitable for low-cost air-quench hardening cycles ideally using continuous processing lines. **IH**

References

Available online at www.industrialheating.com

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Additional related information may be found by searching for these (and other) key words/terms via BNP Media SEARCH at www.industrialheating.com: martensitic stainless, untempered martensite, fusion zone, heat-affected zone, hydroforming, ferromagnetic

Fig. 10. Martensitic stainless steel wheelchair frame