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# Thermal Spray Applications in the Steel Industry

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PRODUCT QUALITY, maintenance costs, and production requirements are paramount drivers for engineering improvements where key surfacing technologies play an important role in the production of steel. Product quality begins during raw material production and continues with shape forming and product sizing in a continuous flow. This continuous production flow requires tooling to withstand high metal melting temperatures and pressures and to have excellent corrosion and erosion resistance. If these criteria are met, steel can be formed into shapes, including flat rolled product, pipe, and bars. Products then can be shipped to secondary markets such as the automobile industry. To enhance product quality, the steel industry has used various types of surface-modification technologies. Thermal spray is one important surface-modification process implemented by the steel industry. This article reviews thermal spray materials and equipment used—and gives examples of where typical coated components result in improved performance—in the steel industry.

## Steel Manufacturing

The making, shaping, and treating of steel is shown in Fig. 1. This "wheel," published by the Association for Iron and Steel Technology, is a representation of the processes required to convert raw materials into finished steel products. The process starts in the center with the three main ingredients of iron in the form of iron ore, coke, and lime, which are fed into a blast furnace to produce molten iron. The molten iron is mixed with recycled steel scrap and further processed in a basic oxygen furnace to make steel. The electric arc furnace melts recycled steel scrap. The molten steel is formulated to precise chemical compositions during the secondary refining process. The refined steel then is cast into a variety of solid shapes, usually by a continuous casting method. The solidified shapes are processed into finished goods by various processes, including hot rolling, cold rolling, annealing, and coating. The making, shaping, and treating of steel "wheel" can be downloaded at www.aist.org.

## Thermal Spray Growth Opportunities in the Steel Industry

The steel industry is an important market for the thermal spray industry. Since the 1970s,

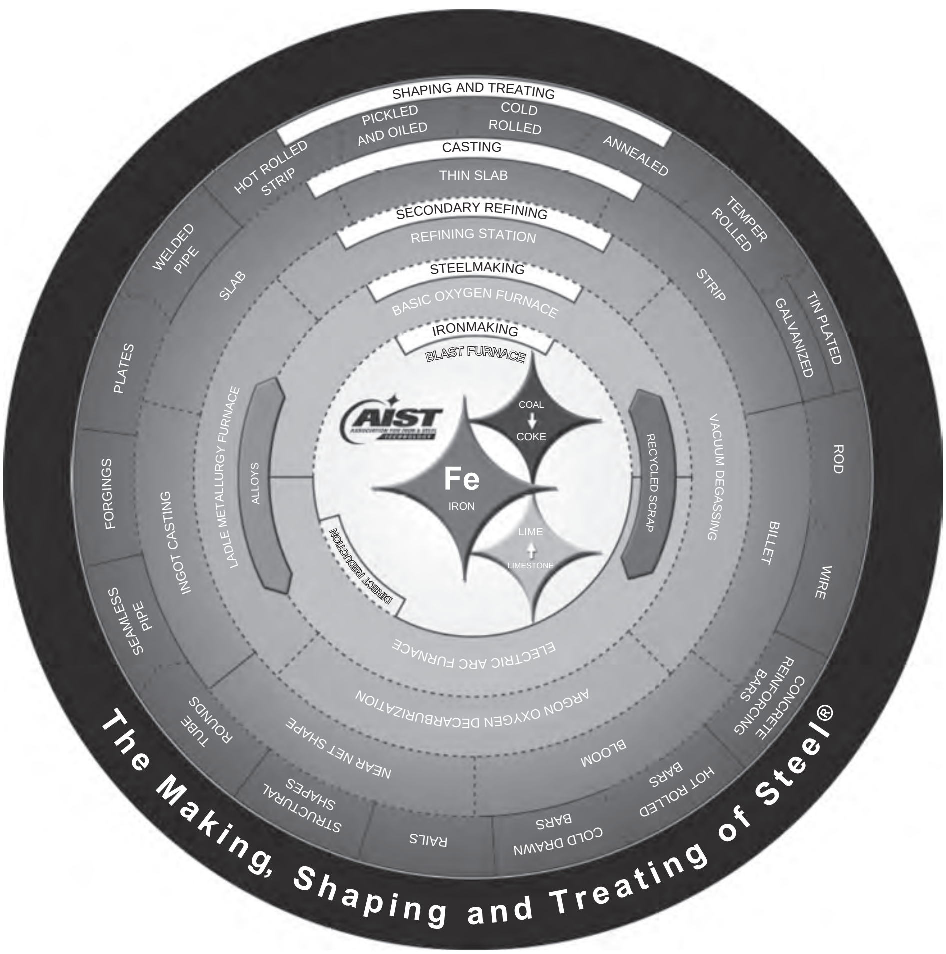


**Fig. 1** The making, shaping, and treating of steel

thermal spray has been accepted and used by steel manufacturers. As thermal spray technology has grown, along with more reliable materials and equipment, manufacturers have been able to increase the number of applications in which thermal spray technology is used. Today (2013), high-velocity oxyfuel (HVOF) and detonation gun technology is more mainstream in steel manufacturing plants worldwide. Applications from the melting and transfer of steel from furnace to end product use all types of coatings, with WC-Co and $Cr_3C_2$-NiCr cermets playing large roles. Coatings withstand all types of wear and corrosion and have resulted in longer production life and better final product quality of the steel strip, bar, pipe, or billet—enormous benefits that make thermal spray a welcome technology for many applications in the steel industry.

## The Need for Coatings in the Steel Industry

Throughout the steel production process, components are exposed to a combination of high temperature, corrosive environments, and various wear mechanisms. This results in a wide range of degradation mechanisms, leading to a reduction in product quality, reduced operation efficiencies, and greater maintenance costs and downtime. Although thermal spray technology has been used since the 1970s, recent advances in materials, equipment, and processes are furthering applications in these markets. These improvements in thermal spray technology, along with growth in the automotive sector in traditional and developing countries, should expand the use of thermal spray products for this market. One area that has seen dramatic growth is in the implementation of HVOF technology along with key cermets such as WC-Co(Cr) and NiCr-$Cr_3C_2$ for many types of roll applications.

Figure 2 is a good view of the harsh conditions found in the manufacturing of steel. Key areas of concern are heat, corrosion, and wear. To help enhance the life of equipment used in the production of steel, a number of thermal spray coatings are being used today (2013). Figure 2 shows a hot coil being wound from strip steel. Wrapper rolls, which force the strip to turn into a coil, use a nickel-base self-fluxing alloy that is combustion sprayed and fused. This is one of only a very few coatings that has worked in this extremely harsh environment. Other surface-modification processes, such as submerged arc or welded coatings, also can be used for this application. The temperature of the steel strip shown in Fig. 2 is estimated at over 1400 °C (2500 °F); note the high-pressure cooling water flowing onto the coil as it is being wrapped. This is one of the harshest environments in strip steel manufacturing.

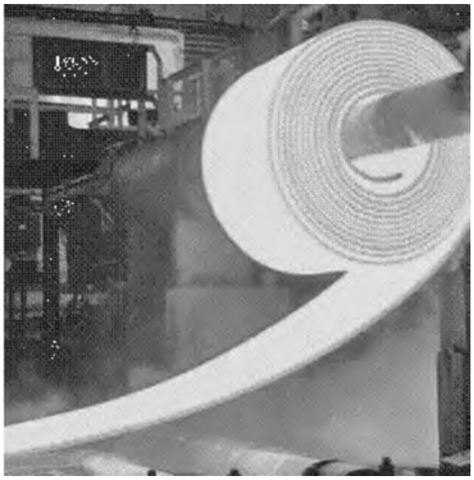

**Fig. 2** Hot steel coil being wound, showing the harsh conditions of steel manufacturing

## Thermal Spray Applications in Steel Manufacturing

Many surface-modification processes are proprietary to the steel manufacturer or the coating applicator, but the basic thermal spray coating applications—along with the environment, process, and materials used in steel manufacturing—are listed in Table 1. As can be seen in Table 1, there is a significant amount of materials science and engineering involved in the understanding of which surface-modification process and material chemistry work best for a specific application. The quality of the final product and the surface finish is critical to the selection of the process and material.

Wires, rods, sheets, and billets are just a few of the forms that steel can take before its release to second-tier industries. Specific areas of steel production where coatings are used include:

- Gas ducting system from molten metal refining
- Gas injection tuyeres, lances, and nozzles
- Continuous casting molds
- Various types of processing rolls, for example, bridle, deflector, and annealing furnace rolls

It is important to review the many technical references that give a much more detailed description and overview of these applications.

**Continuous Casting Molds.** Figure 3 shows casting molds. The base material is copper, and the mold is water cooled. The main purpose of a casting mold is to control the rate of solidification and the shape of the resulting billet. Mold life (gaged by the number of pours and tonnage) is limited by the ability of the coating to withstand wear that could transfer marks unto the slab or billet. The coating materials used for this type of application are carbides, cermets, and ceramics.

**Coiling Mandrels.** Figure 4 shows a continuous coiling mandrel. Typically in steel applications, hot mill strip products require further processing. The transfer of coils to other continuous process lines requires the coil to be unwound then rewound, holding the core of the coil tightly wrapped. Friction, grip, and long-wearing surfaces allow proper strip tension from the initial weld joining to final trimming and wrapping. Rolls with detonation gun and HVOF-applied carbide coatings have surfaces harder than the strip materials. In addition, optimized surface profiles and high friction coefficients support the gripping of strip to rolls without causing harm to the surface finish properties of the steel strip.

**Annealing Line Rolls.** Figure 5 illustrates the various rolls used in an annealing line. The type of coatings used are shown in Table 1 and discussed in reference articles (Ref 1, 2). Rolls in production today (2013) use either HVOF or detonation gun coatings. Proprietary coatings using oxidation-resistant MCrAlY cermets are used for extremely high furnace temperatures. For lower-temperature heat treatment of low-manganese steels, NiCr-$Cr_3C_2$ coatings are used. For high-temperature annealing of low-manganese steels, oxides and/or borides or cermets of MCrAlYs and alumina have been used in production. High-manganese steels result in more severe problems for rolls. Corrosion/oxidation products, typically in the form of oxides of chromium and aluminum on MCrAlY coatings, react with manganese from the steel, reducing the service life of the coatings and the quality of the steel sheets. Today (2013), there are many proprietary coating solutions that optimize MCrAlY chemistries, along with additions of alternative oxides and/or carbides.

**Continuous Galvanizing Line.** Degradation of sink rolls and other rolls associated with continuous galvanizing lines (Fig. 6) is due to zinc and/or aluminum reactions with iron from the steel rolls. These reaction products degrade the rolls and affect the surface of the steel products. Some of these reaction products are called dross particles. Today (2013), the most commonly used zinc baths are galvanized zinc with minor concentrations of aluminum, zinc with 0.5 wt% Al, and zinc with 55 wt% Al and minor amounts of silicon (Ref 3). Currently, coatings use tungsten carbide/cobalt powders applied via HVOF or detonation gun technology (Table 1). The success of these coatings depends on the spray parameters, powder manufacturing method, and sealant system. The key to increased life is to reduce the amount of free cobalt in the coating.

## Conclusions and Future Growth

As thermal spray technology continues to evolve, coating systems are becoming more

**Table 1 Thermal spray applications in iron-steel manufacturing**

| Application | Comments | Environment | Process | Materials |
|---|---|---|---|---|
| Molten steel processing—gas duct system | Dust system from electric arc furnace | Gas temperatures between 1000 and 1500 °C (1800 and 2700 °F), particle erosion, corrosive gases | Mainly plasma for melting of oxide ceramics. HVOF alternative for bond coats | Thermal barrier materials: insulating YSZ topcoats with oxidation bond coats (NiCr alloys and MCrAlYs) |
| Molten steel processing—gas injection tuyeres, lances, and nozzles | Thermal insulation/corrosion protection for copper substrates. Thermal stresses due to expansion issues | Molten slag/iron attack | Mainly plasma for melting of oxide ceramics. HVOF alternative for bond coats | Thermal barrier materials: insulating YSZ topcoats with oxidation bond coats (NiCr alloys and MCrAlYs). Ceramic-NiCrAl cermets as possible intermediate layers. Self-fluxing alloys for improved bonding |
| Molten steel processing—ceramic nozzles | Parts change direction of molten metal | Thermal shock, erosion, and corrosion from slag | Mainly plasma for melting of ceramics | Zirconium silicate/stabilized zirconium oxide (YSZ), alumina, chromia with oxidation-resistant bond coat |
| Continuous casting—molds | Function of mold lining is to control rate of solidification and the shape of the resulting billet. Typically copper lined | Technical issues of copper pickup on steel and diffusion. Past industrial standard has been electroplated Ni and Cr, which offers wear resistance without sacrificing thermal conductivity of the mold. Thermal spray alternative solution—wear resistance, thermal conductivity, thermal fatigue | HVOF and, in some cases, plasma/combustion processes | WC-Co wear coatings using chromium oxide/silica/alumina-base slurries and/or chromium oxide sealers. Also blends and cermets using self-fluxing alloys |
| Processing rolls—general | Roll surface critical for performance. Many types of rolls used in processing steel | ... | ... | ... |
| Processing rolls—bridle | Control tension in steel strip—continuous pickling, annealing, and galvanizing lines | Optimized surface roughness from gripping and wear resistance | Alternatives to hard chrome plating, HVOF technology | WC-Co materials as an alternative to hard chrome plating |
| Processing rolls—furnace | Cold-rolled steel is heat treated (annealed or normalized) in continuous annealing lines to improve ductility. | Majority of steel is heated to 730–830 °C (1350–1530 °F). Special grades good up to 1200 °C (2200 °F). Rolls must be corrosion resistant under high temperatures, reducing conditions, and must withstand multiple heat-up and cool-down cycles. Rolls must withstand abrasion from foreign particles (oxides) and must resist dents and scratches. Major problem with high-strength steels due to manganese and silicon, which results in oxides/spinels being formed and transferring from rolls to sheet at elevated temperatures. Other challenges are creep and thermal expansion mismatch. | HVOF process for many applications. Detonation gun process for some high-temperature applications | **For low-manganese steels:** temperatures up to 850 °C (1560 °F), chromium carbide cermets. Powder type plays a role in overall performance. Temperatures up to 1100 °C (2000 °F), oxides or boride-based cermets. Typically, an MCrAlY binder with oxides of alumina or other ceramic phases. Above 1100 °C (2000 °F), oxide coatings are used in place of a metallic bond coat. Types of ceramics include $Cr_2O_3$-$Al_2O_3$, $ZrO_2$-$SiO_2$, $TiO_2$-$Al_2O_3$, $Zr_2SiO_4$, and YSZ. **For high-manganese steels:** Alumina scale formation is not good from a design standpoint. For MCrAlYs, the correct Al:Cr ratio is important. Some applications use cermets and oxides of spinel ($MgAl_2O_4$), while others use chromium carbide and an MCrAlY binder or carbides and borides. |
| Processing rolls—acid pickling conveyance | Acid pickling | Wear, corrosion | HVOF | WC-Ni/Co |
| Processing rolls—guide | Cold mill | Wear, corrosion | HVOF/plasma | $Cr_3C_2$-NiCr, CoCrW alloys, S/F Ni alloys |
| Continuous galvanizing line—sink rolls, correcting rolls, stabilizer rolls | Severe corrosion due to zinc bath, reactions with steel. Addition of aluminum into bath adds to corrosion problems | Different bath chemistry: 1) low concentration of aluminum in bath (0.3 wt%), 2) 0.5 wt% Al, and 3) 55 wt% Al. Corrosion of rolls degrades surface of strip. Zinc and aluminum react with steel/iron. Formation of oxide and intermetallic compounds (dross) can affect bath and quality of sheet and roll. | Mainly HVOF technology for carbide cermets. Oxide coatings use plasma. | WC-Co/WC-CoCr alloys—Optimization of coating microstructure and material is critical for performance, along with proprietary sealers. New systems are MoB-CoCr. For high-aluminum baths, oxide-based systems, multilayered cermet-ceramic, or continuous graded coatings |

HVOF, high-velocity oxyfuel; YSZ, yttria-stabilized zirconia; APS, air plasma sprayed

robust and reliable, allowing steel manufacturers to better predict the life of critical equipment used in the manufacture of steel products. This also results in improved and more consistent high-quality steel products. Continuous galvanizing lines, continuous annealing furnace rolls, continuous cold mill processing lines, and duct mold plates are just a few areas in various mills that use thermal spray coatings. Today (2013), carbide cermets of tungsten carbide/cobalt (chromium) or nickel chromium/chromium carbide, oxidation-resistant MCrAlYs with ceramics such as alumina, self-fusing/fluxing alloys with or without blends of carbides, and thermal insulation materials of zirconium oxide/zirconium silicate with proprietary sealants are used many types of steel processing applications.

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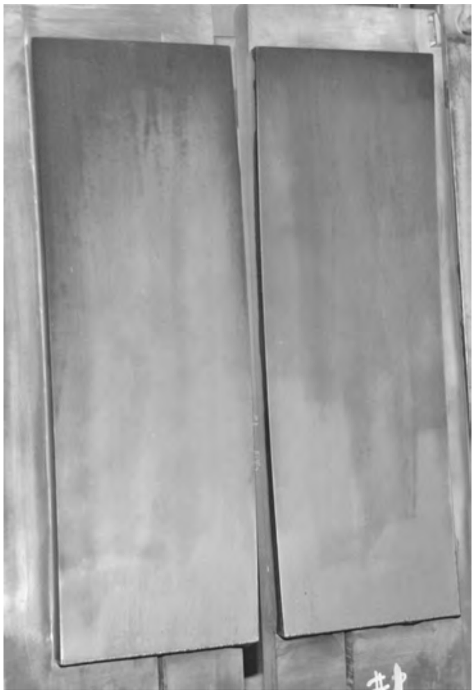

**Fig. 3** Continuous caster mold plates. Courtasy of ASB Industries, Inc.

**Fig. 4** Segments for coiling mandrel. Courtesy of ASB Industries, Inc.

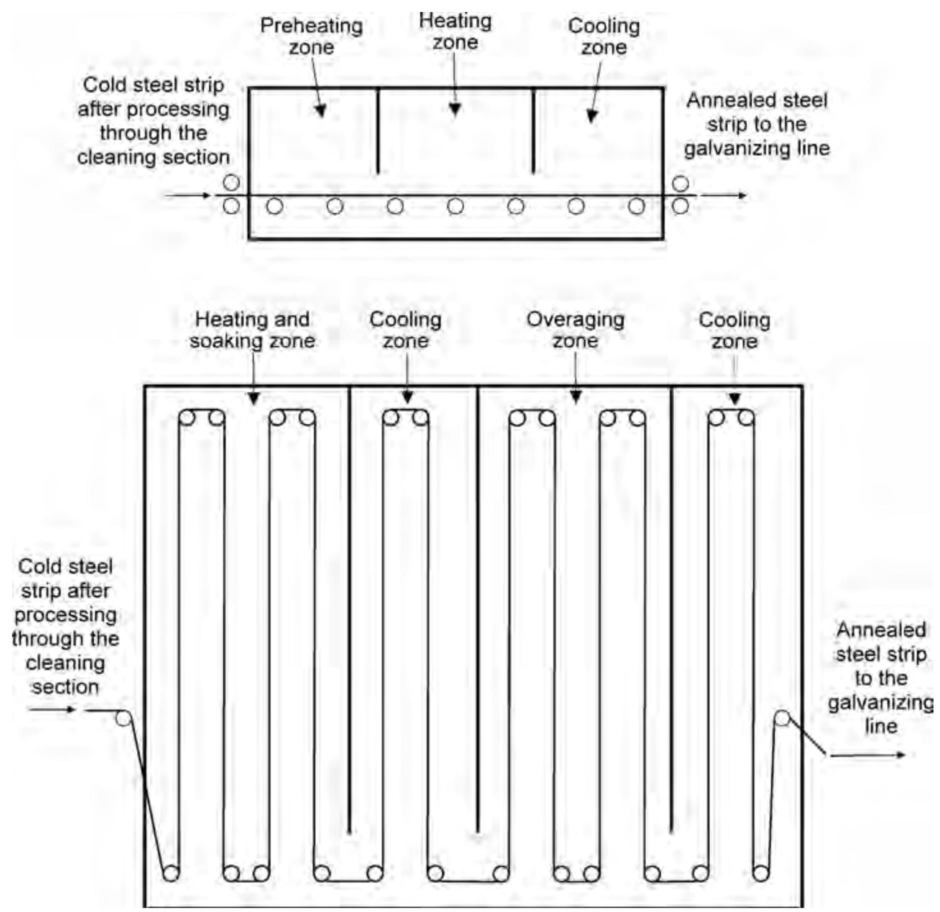


**Fig. 5** Schematics illustrating the sheet steel path in a horizontal continuous annealing line (top) and a vertical continuous annealing line (bottom). Schematics redrawn based on Ref 1

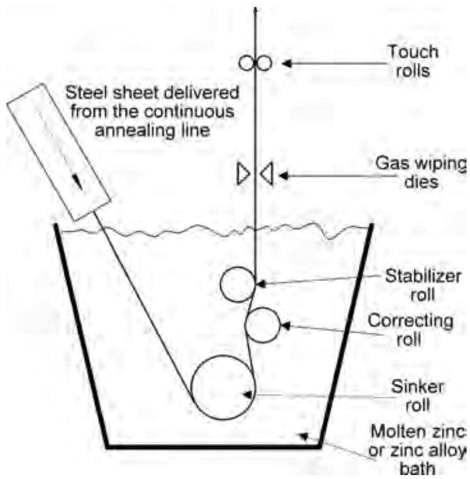


**Fig. 6** Schematic diagram of the pot region of a continuous hot dip metal coating line. Schematic redrawn based on Ref 2 and 3