Redefining Steel Through Development and Application of NanoScale Materials As An Enabling Surface Technology


SYNOPSIS

Steel is one of the oldest materials known to mankind and has been in use for at least 3,000 years. While modern society utilizes many types of advanced materials, steel can be considered the backbone of industry and is often the material of choice due to its combination of superior properties including its ease of manufacturing, availability, ability to be recycled, and relatively low price. However, in very severe corrosive or abrasive environments, conventional steel is seldom utilized since the performance characteristics can be insufficient especially when compared to much higher costing materials such as nickel-based superalloys for corrosion or tungsten carbide hardmetals for abrasion. This paper will focus on how structural refinement from conventional length scales down to the nanoscale can produce revolutionary combinations of properties such as very high hardness and wear resistance and high surface passivity and corrosion resistance. Specific application examples highlighting the enabling structure will show NanoSteel as a advanced surface technology in challenging industrial environments.

BACKGROUND / VISION

A. Industrial markets are globalized and performance limits are stretched, materials are expected to do more with improved performance but at a lower cost. It has been known for decades that if nanoscale materials can be developed they will offer improved combinations of properties. However, the ability to bridge the gap and achieve this on an industrial scale has been known for only a short time. Through a Bulk Materials Nanotechnology (BMN) approach, NanoSteel has successfully bridged this gap and developed nanostructured steel materials which exhibit properties and combinations of properties well outside known steel material boundaries. Application of BMN as an advanced surface technology has been utilized to solve compelling needs in mainstream industries such as mining, oil & gas, power generation, cement, and ready mix concrete. Through continuous material development, BMN has been enabled through various application methods, including thin thermal spray coatings applied by plasma, HVOF, and TWAS processes, and thick weld overlays applied by GMAW, FCAW, OAW, SAW and SMAW (shielded metal arc welding for stick electrode processes).

MATERIALS NANOTECHNOLOGY

B. Bulk Materials Nanotechnology has been achieved in NanoSteel commercial products by utilizing solid-solid state approaches which involve forming iron based glass forming chemistries that have critical cooling rates in the targeted range for various surface applications. The metallic glass structure is a very high strength structure since entire classes of defects, including 1-d dislocations and 2-d grain and phase boundaries, are eliminated. Upon subsequent heating, which may be done through a post-heattreatment or during elevated temperature exposure, the metallic glass precursor transforms into multiple solid phases through devitrification which further increases hardness and wear resistance. Glass devitrification occurs at lower fractions of the melting temperature (typically 0.4 to 0.7), whereas diffusion is limited and the driving force, due to the metastable nature of the glass state, is extremely high. During devitrification a very high nucleation frequency occurs with limited time for grain growth before impingement between neighboring grains. This platform approach represents a simple yet elegant solution to the complex technical problem of forming nanoscale structures on industrial surfaces.

NanoSteel Thermal Spray Coating on Boiler Tubes Provides Erosion Resistance

Inside a circulating fluidized bed boiler at a coal fired power plant in Pennsylvania, a thermal spray coating field trial comparison was conducted on a section of boiler tubes where severe erosion damage occurred and caused tube failures.

A NanoSteel SHS 7170 twin wire arc spray (TWAS) thermal spray coating was applied to a 7 ft (2.1 m) section of boiler tubes and placed in service between two competing steel thermal spray coatings of equal size. When the boiler tubes were inspected during a scheduled outage after 9 months of service, the NanoSteel SHS 7170 TWAS coating did not show any signs of erosion damage while both competing steel coatings showed significant erosion damage requiring repair.

NanoSteel Thermal Spray Coating Provides Corrosion Resistance on Dry Scrubber Chamber ID Wall

Spray drying absorption (dry scrubber) systems remove sulfur dioxide from flue gas at fossil fuel power plants. This process occurs inside a chamber vessel fabricated from cast steel. As flue gas enters the chamber at 300°F (149°C), a mixture of fly ash, lime milk and cooling tower blowdown water is sprayed to absorb sulfur dioxide.

Where spraying occurs, a combination of corrosion scale, fly ash and lime milk containing high concentrations of calcium sulfate, calcium sulfate and chlorine can build up on the surface of the chamber ID wall and cause severe corrosion and chloride pitting damage. This damage can result in significant wall material loss and cause the chamber to buckle and fail.

At a coal fired plant in Arizona, a NanoSteel SHS 7750 twin wire arc spray (TWAS) thermal spray coating was applied to a 30 mil (0.76 mm) thickness on an 18 inch (457 mm) height around the circumference of the chamber ID wall for resisting corrosion and chloride pitting damage.

A visual inspection after 12 months showed no corrosion or chloride pitting damage.

NanoSteel Coating on Aluminum Chutes Provides Performance of Steel Without the Weight

Steel extension chutes widely used on ready mix concrete trucks are four feet in length and weigh approximately 50 lbs. Driven risk injury on the job from lifting the heavy steel chutes, resulting in a risk of profit loss and additional insurance costs for truck owners.

A mixer truck in Ohio was equipped with aluminum chutes to evaluate abrasive wear caused by sliding concrete. A NanoSteel SHS 7170 twin wire arc spray (TWAS) thermal spray coating was applied to an average phase size ≈ 80 nm. It is clear that NanoSteel coated chutes are an alternative that can reduce driver injury risks. However, in very severe corrosive or abrasive environments, conventional steel is seldom utilized since the performance characteristics can be insufficient especially when compared to much higher costing materials such as nickel-based superalloys for corrosion or tungsten carbide hardmetals for abrasion.

NanoSteel Coating on Overlay Wear Plate Extends Blower Fan Blade Service Life by 3x

Industrial centrifugal blowers in cement plants provide ventilation of hot gases ≤ 932° F (≤ 500° C) rich in dust. Blower Fan Blade Service Life by 3x

NanoSteel, a metallic glass nanocomposite was developed that contains a nanocrystalline core surrounded by near-nanoscale (≤ 400 nm) grains which yield levels of high hardness and high toughness properties.

Concrete

NanoSteel microstructure contains grains that vary in size from hundreds of microns to several millimeters. After scale is removed, the NanoSteel SHS 9192 OAW coating shows no erosion or corrosion damage.

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A NanoSteel SHS 7170 twin wire arc spray (TWAS) thermal spray coating was applied to a 7 ft x 5 ft (2.1 m x 1.5 m) section of boiler tubes and placed in service between two competing steel thermal spray coatings of equal size. When the boiler tubes were inspected during a scheduled outage after 9 months of service, the NanoSteel SHS 7170 TWAS coating did not show any signs of erosion damage while both competing steel coatings showed significant erosion damage requiring repair.

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NanoSteel Hardband Combines Industry Best Casing Wear Protection with Best-in-Class Tool Joint Protection

NanoSteel developed a tool joint hardband for drill pipe that provides minimum casing wear while maintaining excellent tool joint protection.

All previous tool joint hardband materials were conventional alloys and steels with microstructures containing grains that vary in size from hundreds of microns to several millimeters.

In conventional alloy development, there is a performance trade off. As hardness properties increase, toughness properties decrease. Similarly, as toughness increases, hardness decreases.

The NanoSteel tool joint hardband is a near nanocrystalline material applied as a gas metal arc weld (GMAW) overlay that eliminates the trade off between hardness and toughness while also providing very high resistance to cracking and spalling.

The NanoSteel hardband is applied as a weld overlay hardfacing and features a microstructure containing near nanoscale (≤ 400 nm) grain sizes which yield levels of high hardness and high toughness properties.

Mining

NanoSteel Overlay Wear Plate Outperforms Q&T Monolithic and Chrome Carbide Overlay Plates

Skip cars are used in underground mining for transporting ore in process from one station to the next. During loading and unloading, wear plate inside the cars are exposed to sliding abrasion and impact.

In an underground gold mine in Canada, 20 ton capacity skip cars transport ore between two levels. During loading, one drops 30 ft (9 m) onto a deflector plate and slides into the car. During unloading, the car is tilted at a 30° angle and the ore slides over the deflector plate onto a conveyor.

To reduce surface material loss and increase service, the mine installed a NanoSteel SHS 9800 submerged arc weld (SAW) overlay wear plate for resisting sliding abrasion and impact.

The NanoSteel SHS 9800 overlay wear plate was removed from service for inspection after deflecting more than 1 million tons of ore. The existing thickness represents a service life increase of 2.3x over 500 B well quench & temper (Q&T) monolithic wear plate and up to 2x over chrome carbide (CC) overlay wear plate. Upon being placed back in service, mine engineers predicted that the NanoSteel SHS 9800 plate will exceed Q&T plate life by 4.3x before requiring replacement.