

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

D.J. Branagan, B.D. Merkle, W.D. Kiilunen, W.G. Nixon, and B.E. Meacham

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 poster 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 an advanced surface technology in challenging industrial environments.

BACKGROUND / VISION

As 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, PTAW, OAW, SAW and SMAW (shielded metal arc welding for stick electrode) processes.

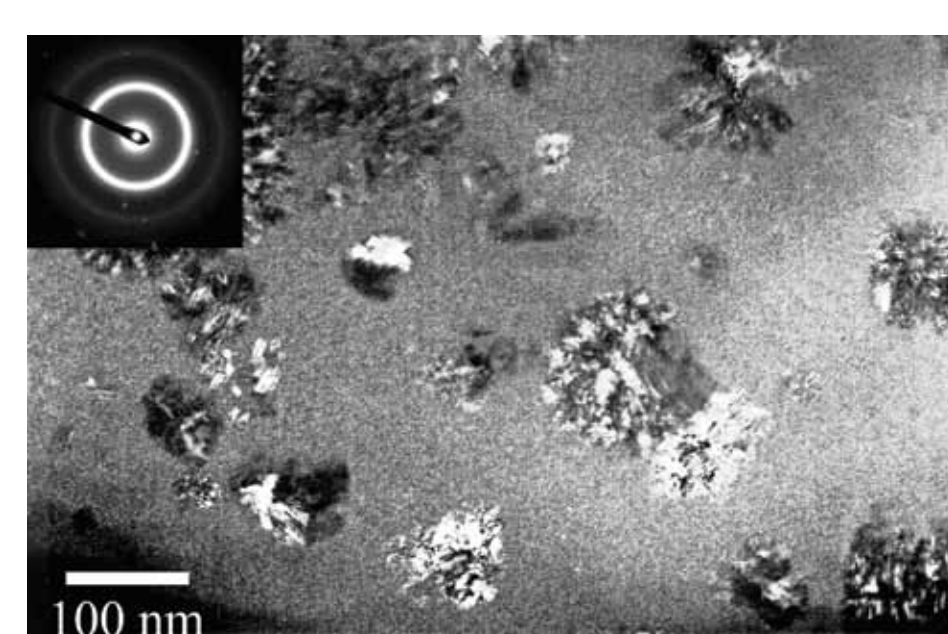
MATERIALS NANOTECHNOLOGY

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-heat treatment 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 low fractions of the melting temperature (typically 0.4 to 0.7 T_m) where 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.

Power Generation

NanoSteel Thermal Spray Coating on Boiler Tubes Provides Erosion Resistance

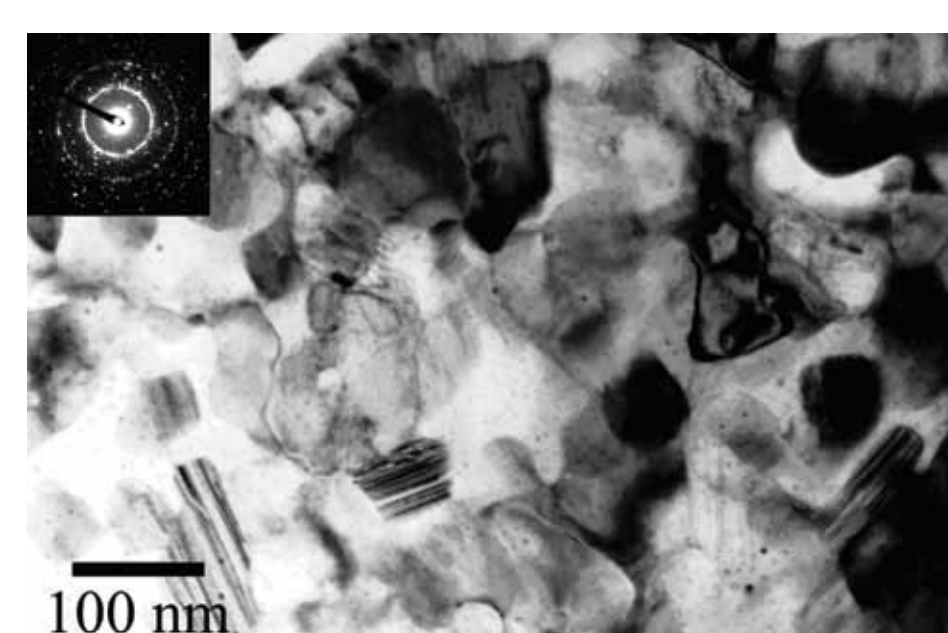
Inside a circulating fluidized bed boiler at a coal fired power plant in Pennsylvania, a thermal spray coating field trial comparison was conducted on a section of boiler tubes where severe erosion damage occurred and caused tube failures.



TEM micrograph of as-sprayed SHS 7170 TWAS coating. The matrix as identified in the upper left selected area diffraction pattern is amorphous and contains nanoscale borocarbide phases.

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.



TEM micrograph of SHS 7170 TWAS coating devitrified by heat treating at 700° C for 10 minutes. It is clear that a nanoscale composite microstructure formed with an average phase size = 80 nm.

Competing Coating After 9 Months



Competing steel coating shows damage from erosion requiring repair.

NanoSteel Coating After 9 Months



NanoSteel SHS 7170 TWAS coating shows no erosion or corrosion damage.

Power Generation

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

Spray drying absorption (dry scrubber) systems remove sulphur dioxide from flue gas at fossil fuel power plants. This process occurs inside a chamber vessel fabricated from A36 carbon 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 sulphur dioxide.

Where spraying occurs, a combination of corrosion scale, fly ash and lime milk containing high concentrations of calcium sulfite, 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.



Corrosion scale, fly ash and lime milk build up on chamber ID wall.

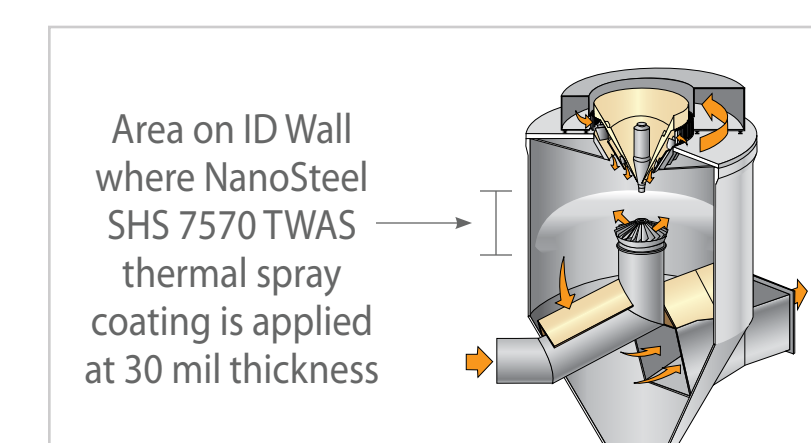
After scale is removed, example of chloride pitting damage.

At a coal fired plant in Arizona, a NanoSteel SHS 7570 twin wire arc spray (TWAS) thermal spray coating was applied to a 30 mil thickness on an area 15 ft (4.6m) in height around the circumference of the chamber ID wall for resisting corrosion and chloride pitting.

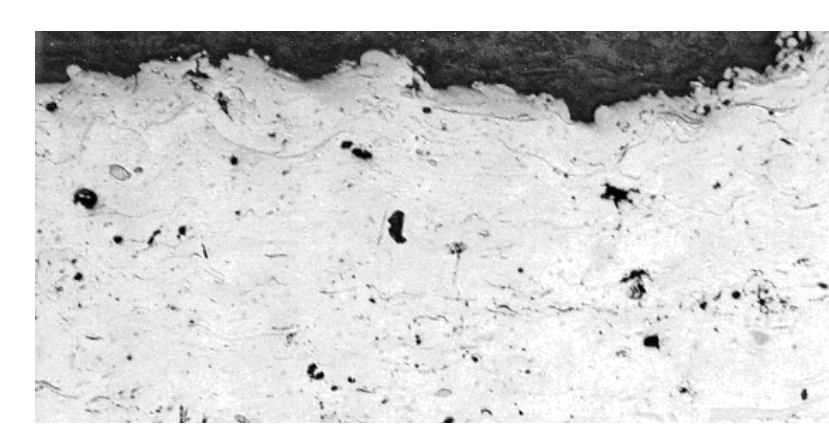
A visual inspection after 12 months showed no corrosion or chloride pitting damage.



Significant material loss can cause the chamber to fail.



NanoSteel coating as applied to ID wall.



Optical micrograph (100x) shows as-sprayed coating with density greater than 96% and no connected pathway to substrate.

Oil & Gas

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.

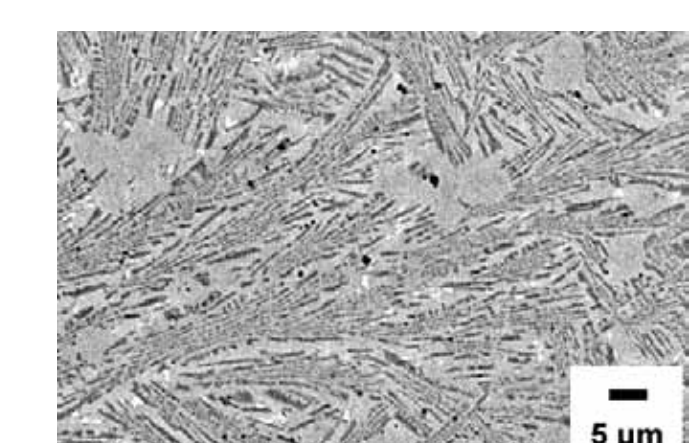
All previous tool joint hardband materials were conventional alloys and steels with microstructures containing grains that vary in size from hundreds of microns to several millimeters.

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.



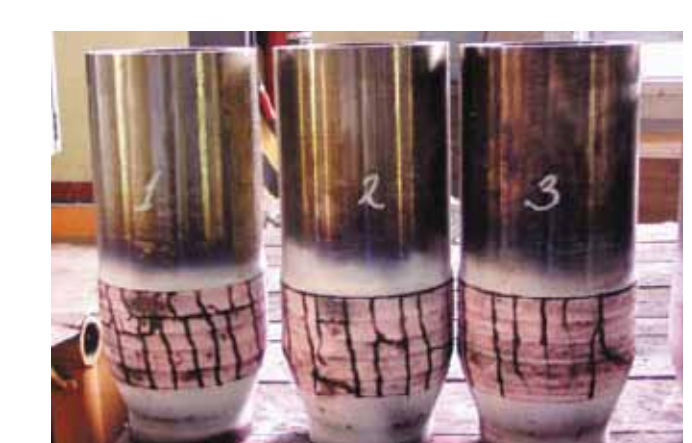
The NanoSteel hardband is applied as a weld overlay hardfacing and features a microstructure containing near nanoscale (≤ 400 nm) grain sizes which yield levels of high hardness and high toughness properties.



Platinum microstructure with grains several hundreds of microns in size.



NanoSteel microstructure contains near-nanoscale (≤ 400 nm) grains.



Dye penetrant testing reveals cracking in conventional hardbands.



Dye penetrant testing proves the crack resistance of NanoSteel.

Concrete

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. Drivers 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.



On a mixer truck in Ohio equipped with aluminum chutes, one chute is coated with NanoSteel SHS 7170 TWAS.

Aluminum extension chutes weighing approximately 30 lbs (13.6 kg) are an alternative that can reduce driver injury risks. However, aluminum chutes wear faster than heavier steel chutes and require frequent replacement.

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 a thickness of 0.33 - 0.39 in (8.5 - 10.0 mm) on one chute, which added approximately 2 lbs (0.9 kg) to the total weight.

Since the aluminum chute will still be at its original thickness when the NanoSteel SHS 7170 TWAS coating wears off, the chute can be recoated and placed back in service without any loss to its original thickness. An aluminum chute has the ability to last almost indefinitely with repeat NanoSteel thermal spray coatings.



After 13 months in service, the NanoSteel chute has 75% of coating thickness present and the aluminum base is 100% intact.



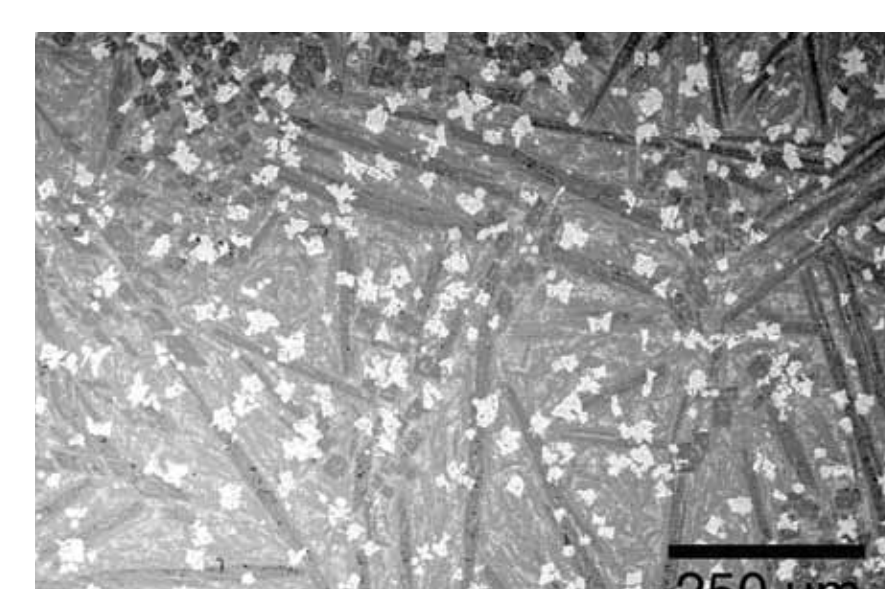
The unprotected chute shows severe wear from abrasion, leaks at the seams and must be removed from service.

Cement

NanoSteel Coating and Overlay Wear Plate Extend Blower Fan Blade Service Life by 3x

Industrial centrifugal blowers in cement plants provide ventilation of hot gases ≤ 932° F (≤ 500° C) rich with fine particle dust expelled from high temperature environments.

At a cement plant in Peru, blower fan blades mounted inside a pair of discs are fabricated from unprotected quench & temper (Q&T) steel and not sufficiently resistant to the combination of abrasion, fine particle erosion and corrosion that they are exposed to during service. Material loss from wear and corrosion is severe, requiring replacement after only 2-4 months of service.



SEM backscattered micrograph shows overlay microstructure of NanoSteel SHS 9192 OAW.

A NanoSteel SHS 9192 open arc weld (OAW) overlay wear plate, 0.24 in (6.1 mm) thickness, for resisting severe abrasion was installed on fan blade and disc ID surface exposed to greatest amount of wear. A NanoSteel SHS 7170 twin wire arc spray (TWAS) coating, 0.04 (1.0 mm) thickness, for resisting fine particle erosion and corrosion was applied to the wear plate and all other fan blade and disc ID and OD surfaces.



Unprotected steel fan blades are worn and must be replaced after 2-4 months of service.



Fan blades with NanoSteel wear plate and thermal spray coating after 12 months of service.

After only 2-4 months of service, unprotected steel fan blades are worn through and must be replaced. However, fan blade and disc surfaces protected by a NanoSteel SHS 9192 overlay wear plate and a SHS 7170 TWAS thermal spray coating showed minimal wear after 12 months.

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, ore 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 2.9x over 500 Brinell quench & temper (Q&T) monolithic wear plate and up to 2x over chrome carbide (CrC) 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.

| | Wear Plate Thickness | | | Substrate Material |
|-----------------------------|----------------------|------------------|------------------|--------------------|
| | Monolithic Plate | Weld Overlay | Weld Overlay | |
| 500 Brinell Quench & Temper | 0.62 in (15.7 mm) | 0.31 in (7.9 mm) | 0.31 in (7.9 mm) | |
| Chrome Carbide Overlay | 0.31 in (7.9 mm) | 0.31 in (7.9 mm) | 0.31 in (7.9 mm) | |
| NanoSteel Overlay SHS 9800 | 0.19 in (4.8 mm) | 0.19 in (4.8 mm) | 0.19 in (4.8 mm) | |



After deflecting 410,000 tons, NanoSteel overlay wear plate has exceeded Q&T plate life by 1.2x.



After deflecting 625,000 tons, NanoSteel overlay wear plate has exceeded Q&T plate life by 1.8x.



After deflecting 1,050,000 tons, NanoSteel overlay wear plate has exceeded Q&T plate life by 2.9x.