Application Note

Reinforcing the Service Life of Bridges with Portable XRF Analyzers

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Bridges, concrete, rebar, corrosion, chlorides, inspection, Niton, XRF

Goal

The goal of this note is to document the aging bridge infrastructure in the US, as well as point up the importance of inspection and material verification. In addition, the note illustrates the usefulness of portable XRF for rapid, accurate and on-site material inspection.

Bridges across the United States are feeling their age. The majority were built in the 1950s and 1960s with a design goal of a 50-year service life. The degree to which they are deteriorating is staggering and the statistics revealing.

"Usually built to last 50 years, the average bridge in this country today is 43 years old. While safe to travel, almost one in four bridges is either structurally deficient and in need of repair, or functionally obsolete and too narrow for today's traffic volumes."[1]

"Of the nation's 590,000 bridges, a total of 73,000, about 12 percent, are rated as functionally obsolete… some 80,000 are rated as structurally deficient, about 13 percent."[2]

In concrete bridges, the corrosion of reinforcing steel bars (rebars) is the prevalent cause of the deterioration – often prematurely. The concrete used for bridges is permeable and, over time, will develop cracks. Water and chlorides entering these cracks reach the rebar, induce corrosion, and lead to the weakening of the bridges. Clearly, the problem intensifies in marine areas and in areas subject to de-icing salts. Repair costs are also an important consideration. One study suggests that the repair costs over a period of 32 years can be as high as six times that of the bridge's original construction costs.[3] The combined result of these factors is that the corrosion of conventional carbon steel rebar in reinforced concrete has become a major concern for the country's Departments of Transportation (DOTs).

Sealed in Concrete

Carbon steel reinforcement has performed adequately in non-aggressive environments, but in order to achieve the recommended service life goal of 75-100 years, DOTs are looking into new and more innovative technologies, including the use of improved corrosion-resistant rebar.

Epoxy coated rebar (ECR) is considered one possible solution; however, it offers only modest extension of the service life and is not suitable for more corrosive environments. Another, better, alternative is using clad stainless steel and/or alloyed steels. In fact, one of the recommendations in a report from the Virginia Transportation Research Council is that "the prospect of achieving a design life of at least 100 years, without major repair, is realistic with the use of clad bars and should not be ignored."[4]

NACE also suggests that one way to make bridges more resistant to chloride-induced corrosion is "… making the rebar resistant to corrosion (corrosion resistant alloys, composites, or clad materials)."[5]

Thermo Scientific Niton XL3t Series GOLDD+ Analyzers Benefits at-a-Glance
• **Instant positive alloy grade identification, anytime, anywhere**
• **High throughput for increased productivity**
• **Nondestructive – samples remain intact and undamaged**
• **Real-time traceable results**
• **Lost traceability recovered in seconds**
• **Ease of use – requires little training for use by unskilled operators**

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To meet longer bridge service life, though, the key is using high-performance steels with improved corrosion resistance instead of low alloy steels or ECR. High-performance steel alloys are designed and made by tightly controlling the alloy's chemical composition. In what has evolved as a complex science (and art) over the centuries, even the smallest amounts of certain elements added to an alloy can play a significant role in the alloy's final mechanical and chemical properties. Various ASTM documents list the steel alloy grades that are suitable for this application.[6] See examples of SS grades used in U.S. bridges in Table 1.

Bridge Location (year built)	City, State	SS Grade Used
I-696 (1984)	Detroit, Mich.	304
I-29 (2004)	Sioux Falls, SD	2205
Belt Parkway Bridge (2004)	Brooklyn, NY	2205

Table 1. Some examples of stainless steel grades used in bridges across the United States.[7]

One real-world example concerning a replacement bridge in Oregon was highlighted in an article titled *Stainless Steel Rebar*, John H. Magee and Raymond E. Schnell, *Advanced Materials & Processes Magazine*, October 2002, p. 45. A coastal replacement bridge currently under construction at North Bend, Oregon, graphically demonstrates the benefits of 2205 stainless steel rebar for critical structural elements in a harsh marine environment. The Oregon Department of Transportation (ODOT), which has chosen 2205 duplex stainless steel, expects the new bridge to provide maintenance-free service for an amazing 120 years. That is 2.5 times the service life of the bridge it is replacing."

"When finished, the bridge cost approximately $12.5 million. However, the stainless rebar accounts for only 13% of the total bridge cost. For that small increase, ODOT will save the cost of normal bridge replacement in 50 years. That is an amount likely to be $25 million, or at least twice the cost of bridge construction today."

We can see from the above illustration and recommendations that having better quality materials clearly results in improved performance and longer bridge life, giving a positive return on investment. However, the key to success is ensuring that the alloy grades chosen are indeed the same ones deployed in the bridge construction. Recognizing and mitigating the risks of material mix-ups is, therefore, essential.

Keeping the Chain Strong

Given the complexity of the supply chain – from the steel production site to the bridge construction site – plus the availability of thousands of alloy grades as well as the increased use of scrap in the production of steel magnify the risk of material mix-up. Therefore, it is critical to install check points that can analyze, identify, and verify the proper rebar for the task.

Experience has shown that material certifications alone cannot guarantee the authenticity of the material ordered. Beyond the ultimate responsibility

Corroded rebar on a cement bridge.

of preventing catastrophic failures, using the wrong materials also carries the risk of non-compliance, unnecessary liability, and potential financial consequences.

Making the Grade

With more than 2,700 grades of iron-based ("ferrous") alloys listed – more than 400 grades of stainless steel alone[8] – often, the only difference between two alloys boils down to a small amount of one or two trace elements. (A typical example includes the stainless steel grades 304 and 303 which have overlapping amounts of Cr and Ni; however, the two grades have very small variations in their sulphur content – as small as 0.12% – a difference that can be detected with portable XRF).

Tracing the Lines

Another potential source of material mix-up is the lack of traceability. Every time a product changes hands, the opportunity for error through material mix-up increases and traceability becomes questionable. Typically, movement of material from the production site to the final installation site involves service centers, processing locations, sub-contractors, and several freight companies. Committing to a traceable supply chain is not only good practice, but also helps ensure end-product quality, reduces liability, and increases productivity.

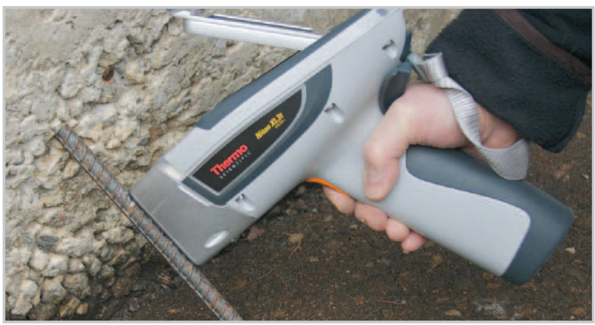
Mixing It Up

The use of scrap in the production of ferrous and non-ferrous metals is on the rise. According to a recent report of the Bureau of International Recycling (BIR)[9], the usage of scrap for crude steel production rose by 10.3% to 41.6m tonnes in the U.S., for the January to September 2011 timeframe (total crude steel production was 64.7m tonnes). More scrap usage means adding new and unknown metal grades into the mixture, which all need to be identified and accounted for.

Non-corroded rebar.

Unmatched Accuracy with Portable XRF

The significance of selecting the correct rebar material and the risks of material mix-ups demands that you have a mechanism in place that will ensure material traceability along the supply chain, and also ensure that you have purchased and installed the correct alloy grade. X-ray fluorescence (XRF) technology provides a reliable, accurate, and sensitive means to achieving these goals. It makes use of the ability to ionize elements by emitting low-power x-rays into the sample and then reading the returning fluorescent x-ray signal to determine the elements present along with their relative concentrations.



Niton XL3t GOLDD+ analyzers provide superior alloy grade ID.

Having this technology built into a robust, portable, field instrument allows for fast on-site measurement, while lowering outside lab analysis costs and minimizing downtime due to sample shipment and lab turnover time.

The handheld Thermo Scientific™ Niton™ XL3t GOLDD™+ XRF Analyzer offers a completely nondestructive method for elemental analysis and positive alloy identification. With a unique library of more than 450 alloy grades, expandable to meet your needs, this remarkable instrument is specifically engineered to bring you low detection limits, uncompromised reliability, and rapid analysis, all combining for superior grade identification. In addition, our Thermo Scientific geometrically optimized large area drift detector (GOLDD) technology brings lab-quality performance to portable XRF analyzers. Delivering up to 10 times faster measurement times than conventional technologies, it also provides the highest sensitivity and measurement accuracy, plus the capability of measuring light elements (magnesium, aluminum, silicon, phosphorus, and sulfur) without helium purge or vacuum. Table 2 shows the detection of low levels of potentially poisonous trace/tramp elements obtained using a Niton XL3t GOLDD+ analyzer.

TIME	2s/filter	3s/filter	5s/filter	10s/filter
ELEMENT	Fe Base	Fe Base	Fe Base	Fe Base
Sn	0.055	0.045	0.030	0.020
Nb	0.0065	0.0055	0.0040	0.0025
Cu	0.045	0.035	0.028	0.018
Ni	0.090	0.070	0.053	0.040
P	0.500	0.200	0.130	0.083
Si	1.250	0.500	0.300	0.190

Table 2. 3-sigma LODs for iron base with various analysis times; all units % wt.

Connecting the DOTs... Additional Applications

The value of portable XRF technology for transportation/engineering-related applications isn't limited to testing rebar for concrete bridges. For example, our instruments can easily detect whether there is lead in the paint used on a bridge's steel structure (see Figure 1). Typically, the steel components are painted with a multi-coat paint system to protect the bridge from corrosion. Prior to 1975, however, that paint contained lead as well as chromium and cadmium, now all considered hazardous substances.

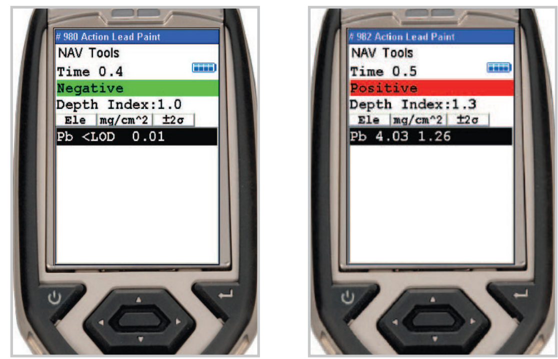


Figure 1. Thermo Scientific portable analyzers perform rapid pass/fail screening for lead in paint as shown on results screen.

Further, our analyzers prove effective for identifying the insert material used in snowplow blades. Because different alloy grades can affect the wear behavior of the blades, by knowing the composition of the inserts, you can better predict the wear behavior, help reduce the costs of snowplowing, and also help ensure proper purchasing practices. Another relevant application is the ability to identify the type of material used for highway sound barriers and verifying a galvanized surface (see Figure 2).

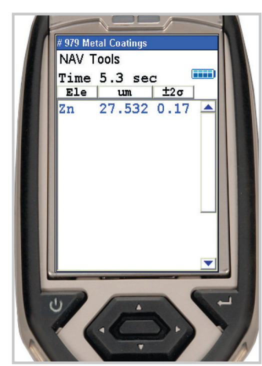


Figure 2. Thermo Scientific portable XRF analyzers can verify galvanized material.

Niton XL3t GOLDD+ Analyzers – Eliminating the Guesswork

The need for material verification of rebar in concrete bridges, as well as other DOT applications, is increasing due to regulations, risk of mixing grades, growing use of scrap in steel production, and the complexity of the supply chain. When you choose Niton XL3t GOLDD+ XRF analyzers, you benefit from fast, accurate elemental analysis and grade identification to aid in quality assurance and quality control. You optimize inspection time, minimize downtime, and conserve lab resources.

To discuss your particular applications and performance requirements, or to schedule an on-site demonstration, please contact your local Thermo Scientific portable XRF analyzer representative or contact us directly by email at niton@thermofisher.com, or visit our website at www.thermoscientific.com/niton.

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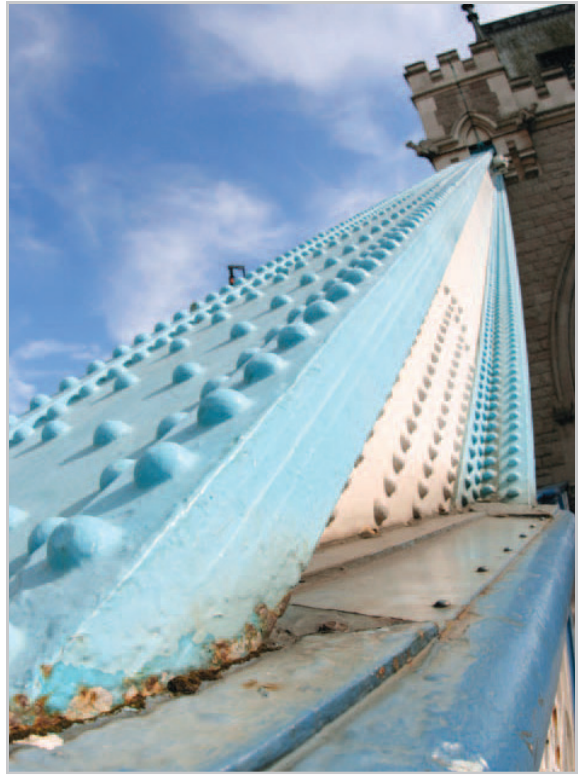

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