Commercial Metals

it's what's **inside** that counts

GALVABAR®

Continuous Galvanized Rebar

Pure Zinc, Pure Innovation

Supported by studies from:

Tran-SET

THE UNIVERSITY OF KANSAS

The University of Akron

GALVABAR®

Continuous Galvanized Rebar
Pure Zinc, Pure Innovation

it's what's **inside** that counts

Abstract

As the nation's largest corrosion resistant reinforcement provider, Commercial Metals Company firmly believes in the proven corrosion resistance of galvanized reinforcing. Galvanized coatings of rebar extend the service life of bridges and structures in corrosive environments in an economical way. The ASTM A767 "batch" method of galvanizing while effective, creates numerous supply chain challenges for critical infrastructure projects.

In 2016, the GalvaBar® team worked with international experts to develop an updated method of applying a galvanized zinc coating to reinforcing bars, recognized as ASTM A1094, Continuous Hot-Dip Galvanized Steel Bars for Concrete Reinforcement (CGR). This method of applying hot dipped galvanizing meets or exceeds the corrosion resistance of ASTM A767 and improves on scheduling, supply chain and quality problems. This report demonstrates why CGR is a better solution for fabricators and contractors who work with Departments of Transportation and other groups.

The Problem

Galvanized coatings are dominant in areas where corrosion resistance is needed for long-term solutions. Highway guardrails, utility poles, sign structures, automobiles, solar and truck/trailer applications present the largest markets with available vendors. However, when it comes to concrete and steel reinforcement, ASTM A767 Hot-Dip Galvanizing (HDG) has been slow to gain traction and has limited regional vendors. Concerns for consistent quality, availability and a product that meets customer demands present barriers to further market penetration. Both cost and production challenges have also limited the adoption of galvanized rebar. Rebar, specifically fabricated rebar, is not a good fit for the traditional galvanizing process. The number of pieces, shapes, lengths, bundling and tagging requirements, and need for quick a turnaround makes it difficult to provide rebar in a cost-effective, customer-friendly manner.

CGR was developed as a highly-automated method of galvanizing, similar to the continuous galvanized sheet process. The modernization of the galvanizing process allows for operational efficiencies that reduce the facility's carbon footprint with a lower embodied energy output and the on-demand system allows for a more efficient use of zinc and utilizes lead free resources[1].

This galvanizing process provides significant advantages and results in a product that can be fabricated like uncoated "black" rebar. Since CGR can be fabricated after galvanizing without peeling or flaking, it can be staged in customizable inventory, allowing for an effective nationwide supply chain through steel mills, fabricators and distributors. These logistical advantages contribute to CGR's sustainability. The pure zinc coating provides proven protection that dates back hundreds of years. CGR addresses the problematic last mile issues in the current corrosion resistant rebar market, demonstrates excellent corrosion resistance in corrosive environments and is a low-cost corrosion solution for owners.

Mechanistic Performance and Research

Key Differences

The differences between various types of galvanized coating in concrete related to corrosion performance have been widely studied in the last four years by Federal Highway Administration (FHWA)-funded university studies. The focus of the studies is related to the quality and performance of the galvanized coatings in concrete, rather than looking at the thickness of the coatings. The key differences in mechanistic performance in reinforced concrete elements will be discussed in this section.

The current state of the science relating to galvanized rebar performance is outlined in Prof. Yeomans' IABSE 2019 paper, presented in New York City in September, 2019[2]. He writes:

> *While hot-dip coatings do have good corrosion performance, the zinc-iron alloy layers are less corrosion resistant than pure zinc and do not contribute significantly to the corrosion performance. Continuous coatings however, with a greater reserve of pure zinc, are able to provide on-going protection in the event that corrosion commences on coatings with a thin or non-existent pure zinc top layer, such as may be the case with reactive steels.*

This statement about the performance of the zinc-iron layer is backed up by corrosion studies of zinc-iron layers in alkaline environments that simulate both the period of days during which the concrete is fresh[3], and also in the period of years when these compounds may be exposed to chloride concentrations exceeding the threshold where coating corrosion occurs[4].

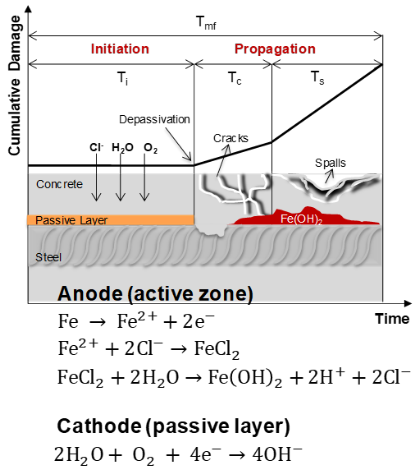
Evidence indicates that it is the thickness of the zinc overlay, rather than the thickness of the iron-zinc layer, that gives the longevity benefits provided by all types of galvanized rebar. In other recent research regarding galvanized batch coatings, it is surmised that the zinc-iron alloy layers will contribute to cracking, once their small reserve of pure zinc is consumed[5]:

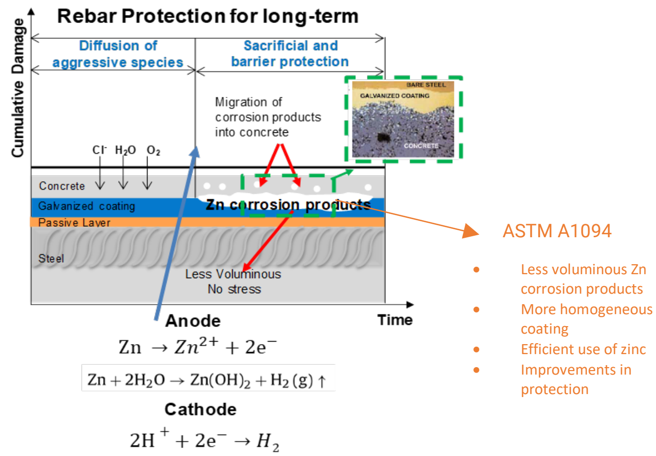
> *Extending the service life of reinforced concrete structures may be achieved by increasing the time to initiation of corrosion or by increasing the time between initiation and spalling of the concrete. While this is often achieved by using a material with a lower corrosion rate after initiation, a material with a less expansive corrosion product would also exhibit an increased service life.*
>
> *Cracking due to corrosion of galvanized reinforcement appears to involve the buildup of corrosion products from the underlying intermetallic layers or from the underlying steel.*

Mechanisms of protection

A767 Hot-Dip Galvanized (HDG) rebar relies on steel chemistry, zinc bath time and temperature to develop a multi-layer zinc-iron coating. This coating structure has an outer zinc “Eta” layer that represents a fraction of the total coating. Because of its steel chemistry reliance, the pure zinc layer is often minimal or, in the case of galvanized rebar with thicker coatings, non-existent.

The Continuous Galvanized Rebar (CGR) process mechanically cleans, pre-heats (via induction) and galvanizes rebar in an inert environment that provides a repeatable, controlled, metallurgically-bonded coating that averages 70 um pure zinc, regardless of steel chemistry. The mechanical cleaning and induction pre-heating processes relieve any potential concerns for strain-age or hydrogen embrittlement of steel. This is important for any potential field adjustments or post-galvanized fabricating of the ASTM A767 HDG product.

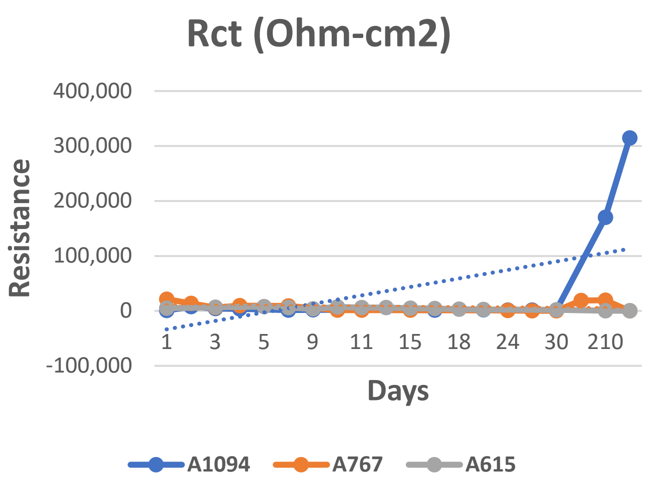


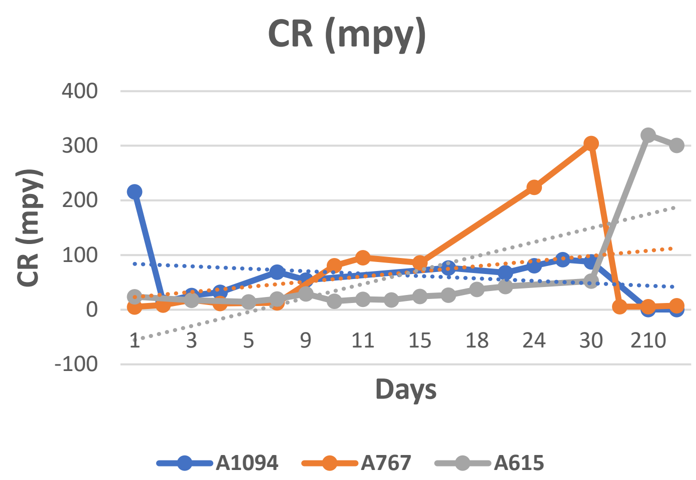


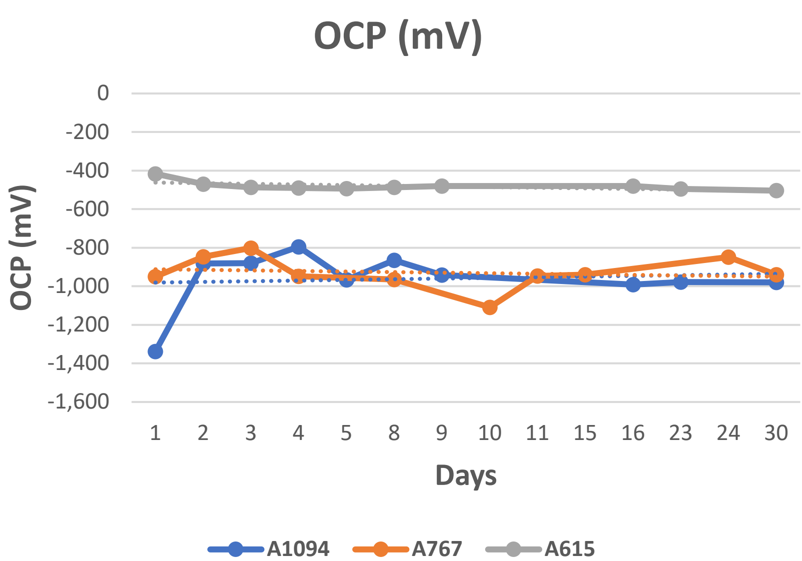
The propagation chart above demonstrates that pure zinc corrosion products are much less voluminous than iron corrosion products on the left. Pure zinc corrosion products from A1094 CGR are also less voluminous than zinc-iron corrosion products that make up the majority of the A767 HDG coating structure. A1094 CGR zinc corrosion products will cause much less stress over the life of your structure and will have reduced cracking due to corrosion[6]. This research is supported by findings in Kansas University research from O'Reilly, Matt & Farshadfar, Omid & Darwin, David & Browning, JoAnn & Locke, Carl. The ASTM A1094 CGR coating structure offers a more efficient use of zinc in a more homogeneous coating that provides improvements in function and protection over ASTM A767 HDG. This work is also confirmed by research from Dr. Anil Patnaik's research from Akron University with several different types of tests[7].

Zinc Passivation and Protection

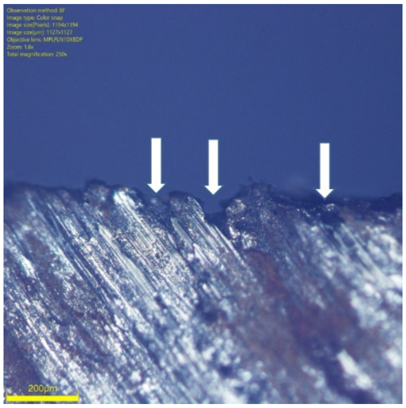
One role of zinc (and <u>not</u> zinc-iron) in concrete is that it passivates quickly by forming a layer of Calcium Hydroxy Zincate (CHZ), and then corrodes at a slower rate. Several studies compared ASTM A767 HDG and ASTM A1094 CGR using aqueous solutions that simulate the concrete environment. Generally speaking, these tests are not good comparisons to other corrosion resistant reinforcement products because they do not allow the proper formation of CHZ that would occur with galvanized coatings in an actual reinforced concrete environment. However, when comparing the two galvanized coatings, it is a fair comparison to see which passivates faster and resists corrosion in a high PH environment that represents the initial reaction in freshly poured concrete.







The charts above from a recent Tran-SET study demonstrates that both galvanized coatings offer much better protection than uncoated conventional rebar. ASTM A1094 CGR also outperformed ASTM A767 HDG in these tests for open circuit potential, corrosion resistance and corrosion rate. A key discovery of this research examined the surface after 17 and 20 months and demonstrated that ASTM A1094 CGR protected the rebar surface from a localized attack or "pitting", as seen in the photos on the next page. Looking at this localized model is a realistic approach for reliability of the protection methods[8].



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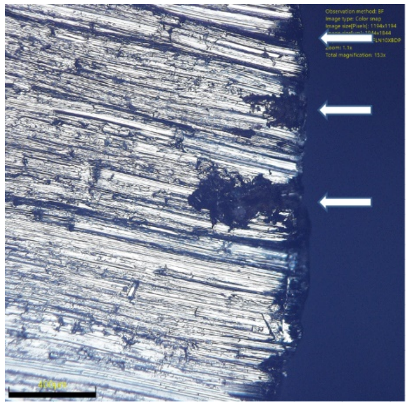

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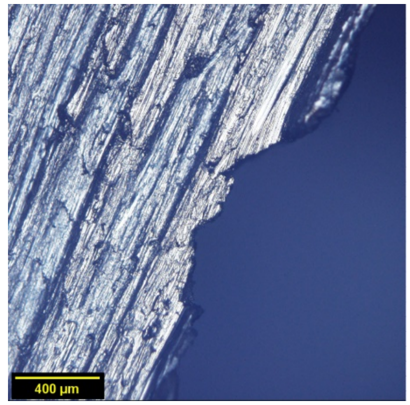

A1094

The University of Kansas report contained several other test models, including Rapid Macrocell, Southern Exposure and Cracked Beam tests. One of the objectives of the 100-year Design Life Analysis was to compare the performance of A767 HDG reinforcement with that of continuous hot-dip galvanized reinforcement A1094 CGR. CGR performed “better or equal” in all test models and the study concluded that “ASTM A767 and A1094 reinforcement exhibited similar corrosion resistance and can be used interchangeably”[9].

Conclusion

CMC's GalvaBar® is Continuous Hot-dip Galvanized Rebar (CGR) that combines the corrosion protection of zinc and exceptional formability without peeling or flaking. Processed prior to fabrication, GalvaBar® allows for seamless procurement of corrosion resistant rebar utilizing existing supply chains — ready for fabrication and delivery straight to the job site. Mechanistic performance in recent federally funded research shows that CGR is a more homogeneous and efficient use of zinc without iron and is equivalent to or better than a thicker zinc-iron alloy layered coating structure. The CGR process yields consistent quality, addressing bars individually throughout its efficient process. CGR eliminates the challenges in the reinforcement supply chain and can expand the market for corrosion resistant reinforcement fabricators and suppliers with a product that meets customer and industry demands.

Expert Commentary and Discussion

University of Kansas –

"ASTM A767 and A1094 reinforcement exhibited similar corrosion resistance and can be used interchangeably."

"The liquid environment can interfere with the formation of the crystalline passive layer (CHZ) that would normally protect zinc in concrete. The behavior in the rapid macrocell test should not, therefore, be taken as representative of the behavior of galvanized reinforcement in concrete, but in comparison A1094 performed significantly better in this aggressive environment. Both the A767 and A1094 bars exhibited losses regardless of damage to the coating; however, A767 reinforcement exhibited significantly higher losses than A1094 reinforcement, a difference that is statistically significant ($p < 0.04$)."

Dr. Anil Patnaik – University of Akron

"CGR will perform better than HDG, and the life-cycle costs for bridges constructed using CGR are expected to be even lower than decks constructed with HDG reinforcement."

Dr. Stephen Yeomans

"While hot-dip coatings do have good corrosion performance, the zinc-iron alloy layers are less corrosion resistant than pure zinc and do not contribute significantly to the corrosion performance. Continuous coatings however, with a greater reserve of pure zinc, are able to provide on-going protection in the event that corrosion commences on coatings with a thin or non-existent pure zinc top layer, such as may be the case with reactive steels"

Dr. Homero Lopez Castaneda

"The continuous hot dip process (ASTM A1094) has resulted in new mechanisms that indicates the controlled dissolution for corrosion allowance. Instead of thinking about damage evolution we can foresee better performance evolution, CGR has shown excellent long-term results in corrosion environments."

International Zinc Association

"The recent research summarized in this paper confirms and extends our knowledge about the performance of both general galvanized and continuous galvanized reinforcing bar for concrete. Its superior performance, compared with other types of reinforcing bar in chloride-containing environments, is manifest through its delayed time until corrosion initiation, lower corrosion rates and the consequences of this improved corrosion performance for reduced formation of cracks in the corroded concrete material. The bond strength of CGR has been shown to be superior to that of other products, and this has been shown to be related to the formation of a dense CHZ layer on the surface of the zinc as the concrete sets and cures. This improved bond strength is likely related to reduced density of surface cracks in concrete after repeated flexing that simulates conditions seen with a typical road deck."

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