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# Galvanized Steel Reinforcement in Concrete

*La galvanisation des armatures*

*Verzinkte Armierungsstähle*

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## Introduction

In recent years a number of reinforced concrete structures have shown signs of deterioration in relatively short periods of time, 2—15 years, and some of this deterioration was apparently caused by corrosion of steel reinforcement in concrete. The existence of such corrosion has been reported in various technical journals [1, 2]. While under normal conditions steel reinforcement in concrete is not subject to any significant corrosion, presence of chemically aggressive elements in the environment combined with inadequate protection of the reinforcement sometimes leads to premature deterioration caused by corrosion of steel reinforcement in concrete.

Numerous methods for protecting reinforcing steel against premature corrosion have been employed. These methods include increase in thickness of concrete cover, use of high quality concrete, and use of miscellaneous coatings on reinforcing steel including zinc coatings. The interest in zinc coatings dates back to 1918 when the concrete ship section of the U. S. Emergency Fleet Corporation investigated the effect on bond resistance of anti-corrosive coatings on reinforcement [3]. Among the various coatings used in this investigation were galvanized, sherardized, and metal spray zinc coatings. Subsequent investigations of bond resistance between zinc coated steel reinforcement and concrete are rather few in number [4, 5, 6, 7]. These studies were limited in scope and the results were contradictory — some indicating superior performance of zinc coated bars, and some indicating inferior performance. Correlation of the various studies is complicated by the fact that plain bars were used in some tests, deformed bars were used in others; in some cases the uncoated bars were polished and in others bars pitted by prior rusting were used. Furthermore, the tests were made on different types and sizes of specimens, and in some cases did not properly reflect the usual bond stress conditions encountered in structural members.

The study reported here represents the first phase in a continuing program of investigation of the effect of zinc coating on bond resistance and corrosion resistance of steel reinforcing bars. The objectives of the limited studies described here were twofold:

1. to determine the effect of galvanizing on bond of steel reinforcement in concrete, and
2. to determine the effect of galvanizing on corrosion of steel reinforcement in concrete.

## Bond Tests

The effect of galvanizing on bond of steel reinforcement was studied in beam specimens generally conforming to the ACI Standard 208-58 of ACI Committee 208 (now 408) on Bond. Two series of tests were conducted: one, on unrusted bars — as received (Series I), with galvanized bars prepared using steel mill procedures and controls; and another on unrusted and lightly rusted[1]) bars (Series II), approximating the more usual field conditions and using shop galvanized bars. In both series ungalvanized (hereafter called black), galvanized, plain and deformed steel bars of intermediate grade (yield stress about 40 ksi) were used. The zinc coating was approximately 3 oz. per sq. ft. of bar surface for both series. The beams were 6½ ft. long, 8 by 18 inches in cross section, reinforced in tension with a single bar, Fig. 1. The concrete in both series was made with type I Portland cement, had a cement factor about 5½ sacks per cu. yard and concrete strength averaging 4.2 ksi. The length of embedment in the first series was 12 in. at each end, and this was reduced to 10 inches in the second series. Beams in the first series were tested at approximately 28 days, and at approximately 20 days in the second series.

In Series I, with unrusted bars, 24 beams were tested, 12 of these were cast "erect" with reinforcing bars in the bottom of the beams and 12 were cast "inverted" with reinforcing bars in the top of the beam. In Series II 16 beams were tested, all cast "inverted" to obtain a more critical bond condition; of these 8 beams were cast with rusted bars and 8 with bars having normal, as received, surface condition. The procedure for rusting the bars was as follows:

a) *Galvanized Bars:* 3 days in aerated water bath at 60—80° F, followed by 59 days in a "fog room" at 70° F and 100% R. H.
b) *Black Bars:* 6 days in aerated water bath at 60—80° F, followed by 56 days in a "fog room".

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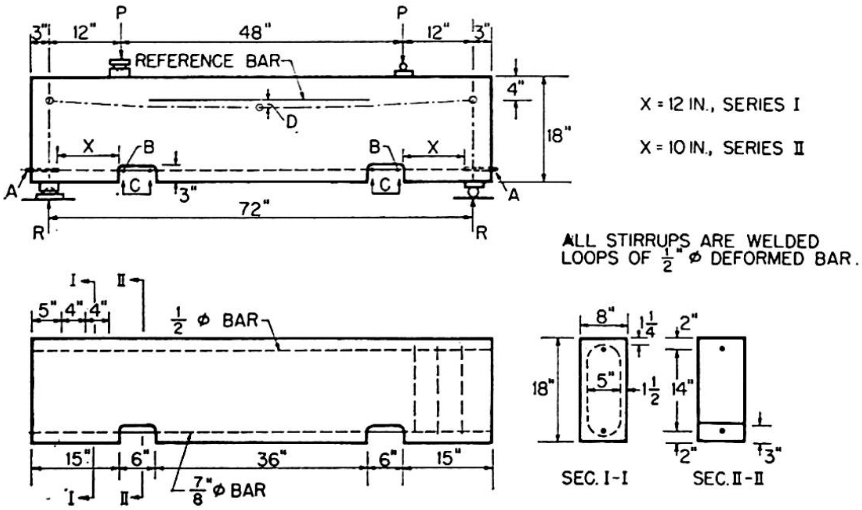
[1]) For galvanized bars rusting refers to "white rust" formed on the surface as a result of exposure to a corrosive environment.

The rusted bars were just wiped clean of loose scale with a soft cloth prior to placing them in the forms.

In Series I for each given condition three similar specimens were tested. The consistency of the results obtained from the three specimens was so good that in Series II only two similar specimens were tested. Averages of the observed or calculated values for the similar specimens are reported here.




Specimens cast erect — main $^7/_8''$ ∅ steel bar in bottom.
Specimens cast inverted — main $^7/_8''$ ∅ steel bar in top.

*A* Dial gage to measure slip at free end of bar.
*B* Dial gage to measure slip at loaded end of bar.
*C* Extensometer with 5 in. gage length to measure strain.
*D* Deflection at midspan measured with respect to reference bar.

Fig. 1. Bond Specimen Details.

Figs. 2 and 3 show the amount of slip at loaded end between the reinforcing bars and the concrete at different levels of bond stress. Average bond stresses were calculated assuming uniform distribution along the embedded length of the bar, and values of slip represent averages taken for both ends of similar beam specimens. Note the change in scale for the slip of plain and deformed bars.

In general the less the slip at a given bond stress, the better is the performance. On the basis of the test data obtained so far and within the limits of these data the following observations can be made:

a) Plain galvanized bars, unrusted, cast erect (i. e. bars in bottom of beam), indicated *significantly better* bond performance than similar black bars.

b) Deformed galvanized bars, unrusted, cast inverted (i. e. bars in top of beam), indicated *somewhat better* bond performance than similar black bars.

c) All other galvanized bars in the two test series had *equal* or *slightly better* bond performance than similar black bars.

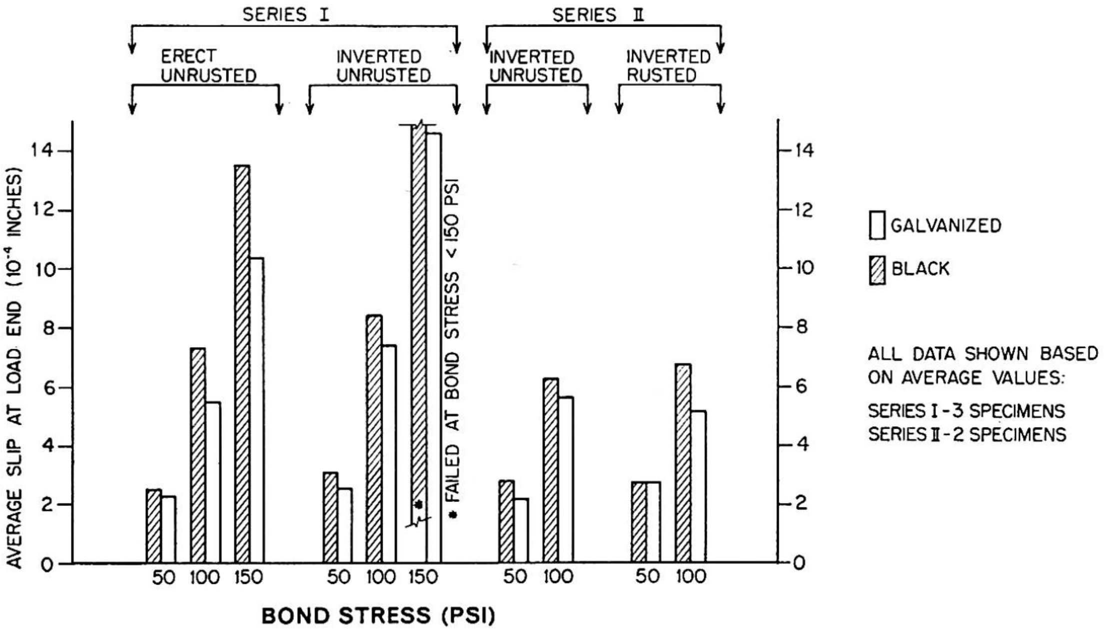



Fig. 2. Bond Performance of Plain Bars.

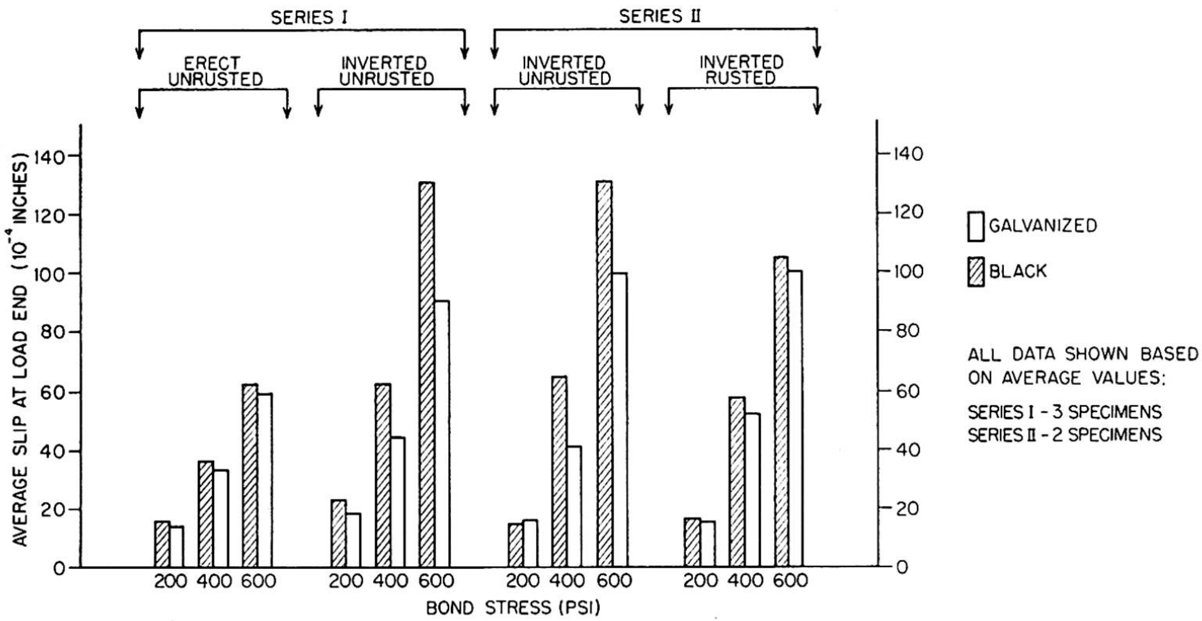



Fig. 3. Bond Performance of Deformed Bars.

**Corrosion Studies of Reinforced Concrete Prisms**

The effect of galvanizing on corrosion of steel reinforcement in concrete was studied on 4 by 4 inches square, 12 inches long, concrete prism specimens, axially reinforced with a $3/4$ inch diameter steel bar, Fig. 4. A $1/2$ inch deep notch was cut at the mid-section of the concrete prism to enforce formation of a crack at the notch when the specimen was loaded. Gauge points insulated from the reinforcement were located above and below this notch on all four faces. The concrete was made with type II (low alkali) Portland cement, had a cement factor of 6.6 scy, and compressive strength of 6.0 ksi.

Each specimen was placed in a loading frame and the steel bar projecting from the prism was stressed to 20 ksi. Companion specimens were exposed to three different environments: 1. in air; 2. immersion in 4% NaCl solution for 3 days, alternating with 4 days drying; and 3. in 4% NaCl solution with sustained impressed direct current of three milliamperes, giving an average density of 20 milliamperes per square foot of steel surface. The impressed current was used to accelerate the corrosion process. A total of 36 specimens were under study.

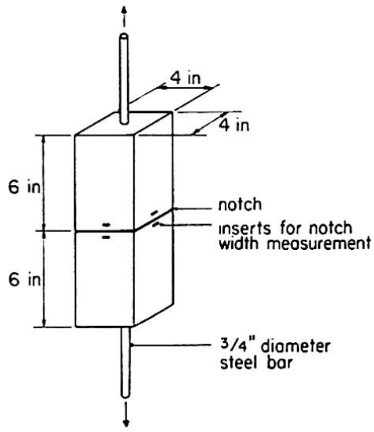



Fig. 4. Corrosion Specimen Details.

Periodically the specimens were removed from the loading frames and subjected to three cycles of loading and unloading during which the width of the notch and the slip between the steel bar and the concrete prism at each end of the specimen were measured. Also, formation of the longitudinal surface cracks in the concrete prism due to corrosion of the reinforcement was observed and recorded periodically. The specimens in air and in salt solution were subjected to cyclic loading at ages of 1, 3, 6, and 12 months. The specimens with impressed current were subjected to cyclic loading at ages of 1, 1½, 2, 3, 4, 5, 6, and 7 months.

Principal observations so far relate to formation of longitudinal cracks in the faces of the prism specimens. These observations can be summarized as follows:

a) Specimens in laboratory air have been observed for a period of about 12 months, without any evidence of corrosion (cracking) in prisms with either black or galvanized reinforcement.

b) Specimens in salt solution (alternating immersion and drying) with black steel reinforcement have shown some cracking at approximately 9 months. Companion specimens in the same environment with galvanized reinforcement show no signs of cracking at the age of 12 months. Cumulative time in salt solution, total length of longitudinal cracks in the prism faces, and maximum crack widths are shown in Fig. 5. The values shown are averages of the observed values for the 3 specimens. For this exposure, based on 12 months observations, corrosion cracks were not observed on specimens with galvanized reinforcement.

c) Specimens with impressed current with black steel reinforcement have shown some cracking at the age of 1 month. Companion specimens in the same environment with galvanized reinforcement have shown similar cracking at the age of 2 months. Cumulative current exposure in ampere-hours, total length of cracks in the prism faces, and maximum crack widths are shown in Fig. 6. The values shown are averages of the observed values for the 3 specimens. For this exposure galvanizing plain bars reduced crack widths but

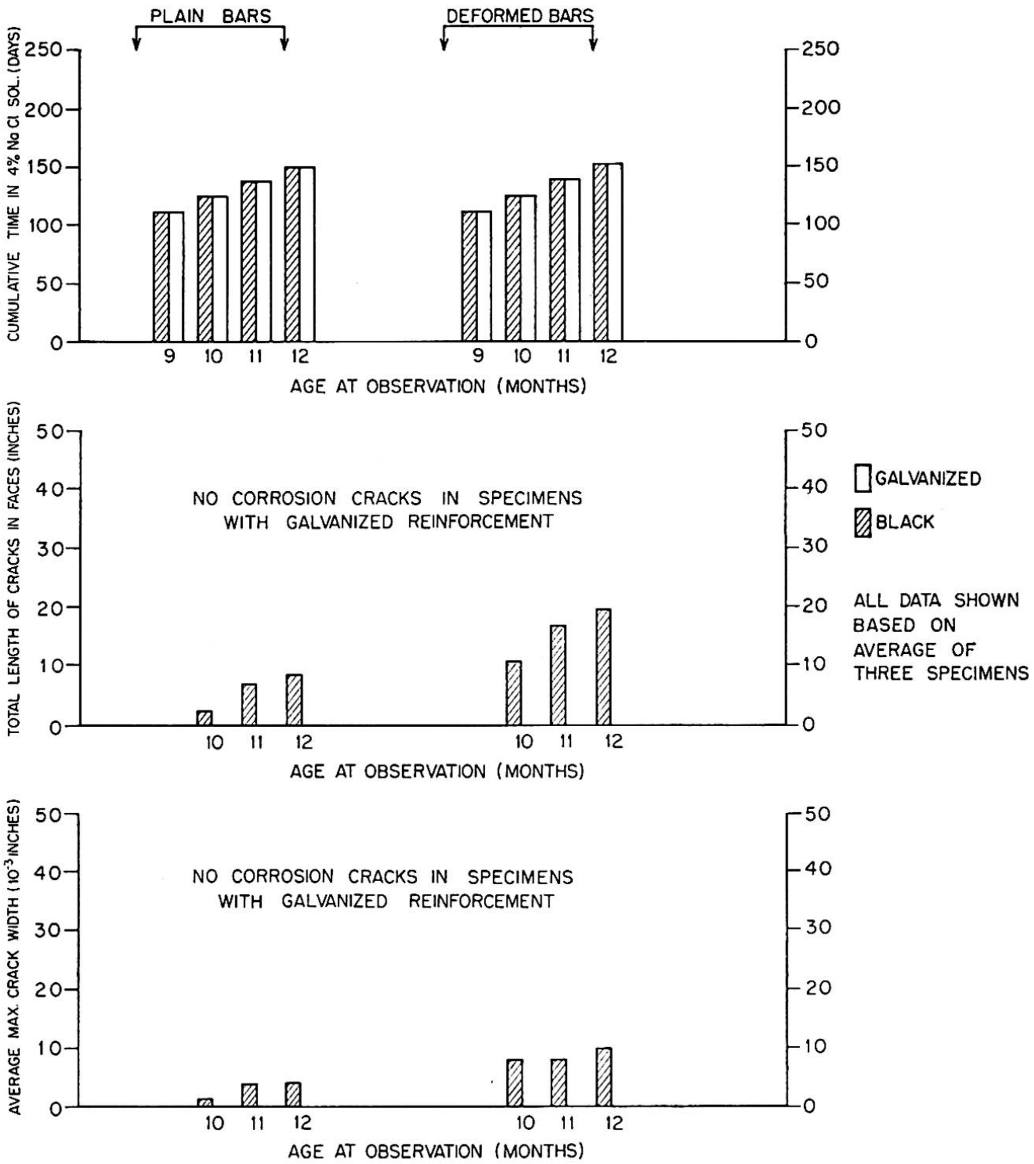



Fig. 5. Corrosion Performance Under Alternating Immersion in Salt Solution.

resulted in about the same or increased crack lengths, and galvanizing deformed bars reduced both crack lengths and crack widths.

It must be emphasized that the salt solution immersion and drying and the sustained impressed current on specimens are somewhat arbitrarily selected as severe corrosive exposures — to obtain some sort of accelerated test. No relationship between these artificial model environments and real prototype exposures can be established at this time.

Nevertheless, under a severe exposure to sustained impressed current, the distress-free "life" of the test prism with galvanized reinforcement was double that for prisms with black reinforcement. For a severe immersion-drying cycles environment, the distress-free life of prisms with galvanized reinforcement appears to be greater than that for prisms with black reinforcement.

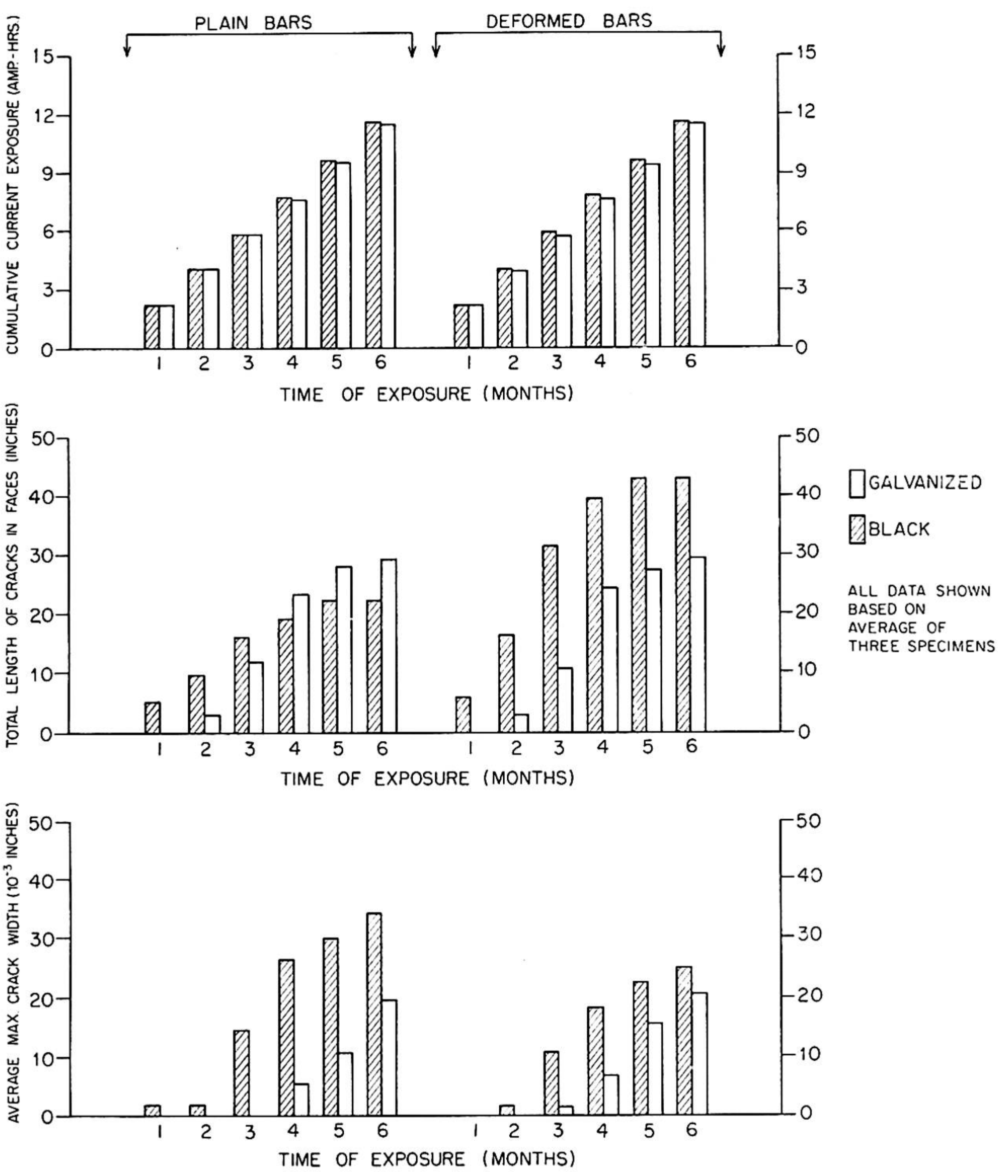



Fig. 6. Corrosion Performance Under Sustained Direct Current.

As the prisms with galvanized reinforcement are still in sound condition, the full extent of the improvement cannot be estimated at this time.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## Summary

A study of the effect of galvanizing on bond and on corrosion of steel reinforcement in concrete is reported here. Test results indicated that galvanized bars had equal or better bond performance than similar black bars and that under accelerated corrosion environment used in these tests galvanized bars showed better performance than black bars.



## Résumé

Les auteurs décrivent des recherches relatives à l'effet de la galvanisation sur l'adhérence et la corrosion des armatures métalliques dans le béton. Les essais ont montré que l'adhérence était égale ou meilleure avec des armatures galvanisées et que, dans le milieu de corrosion accélérée utilisé, le comportement des armatures galvanisées était meilleur que celui des armatures non galvanisées.

## Zusammenfassung

Die Autoren untersuchten den Einfluß der Verzinkung von Armierungsstählen auf Haftung und auf Korrosion im Beton. Dabei zeigten die Versuche, daß die Haftung verzinkter Stähle gleich oder sogar besser ist als bei unverzinkten Armierungen und daß für das angewandte Schnell-Korrosionsverfahren ein besseres Verhalten erreicht wurde.

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