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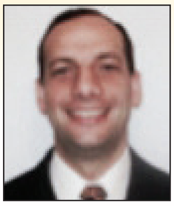
Adherence comparison of concrete with unprotected steel and hot galvanized steel

Comparativo da aderência do concreto com aço sem proteção e o aço galvanizado a quente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Abstract

Increasing the service life of structures is of great importance for civil construction, either because of economic aspects or security ones to the users. Corrosion of reinforcement is one of the most recurring problems, especially in environments with high chloride content. One of the most effective alternatives to protect reinforcement against corrosion is the hot-dip galvanizing of steel bars, with the addition of a zinc coating that is consumed before steel entering in reaction, extending the service life of the structure. Nevertheless, this layer of zinc should not affect the adherence of rebars with concrete. In this paper, it was investigated this connection, establishing comparisons to unprotected reinforcement, with the analysis of three bar diameters, 8, 12.5 and 16mm through the bending test of beams, the procedure of Rilem, 1978 [1]. After statistical analysis, it was observed that there was no significant loss of adherence in any of the diameters, showing that the adherence between the concrete and the hot-dip galvanized steel is not lower than the steel without protection for these materials.

Keywords: corrosion of reinforcement; hot-dip galvanization; adherence; bending test.

Resumo

O aumento da vida útil de estruturas é de grande importância para a construção civil, seja por aspectos econômicos quanto de segurança aos usuários. A corrosão de armaduras é um dos problemas mais recorrentes, principalmente em ambientes com alto teor de cloretos. Uma das alternativas mais eficientes para proteger as armaduras contra a corrosão é a galvanização a quente das barras de aço, com a incorporação de uma camada de zinco que será consumida antes do aço entrar em reação, prolongando a vida útil da estrutura. Porém, esta camada de zinco não deve prejudicar a aderência das barras de aço com o concreto. Neste trabalho, foi investigada esta relação, comparativamente com a armadura sem proteção, com a análise de três diâmetros de barras, 8, 12,5 e 16mm, através de ensaio de flexão em viga, com o procedimento da Rilem, de 1978 [1]. Observou-se que não houve perda de aderência significativa em nenhum dos diâmetros, após análise estatística, mostrando que a aderência entre o concreto e o aço galvanizado a quente não é inferior do que com os aços sem proteção, para estes materiais.

Palavras-chave: corrosão de armaduras; galvanização a quente; aderência; ensaio de flexão.

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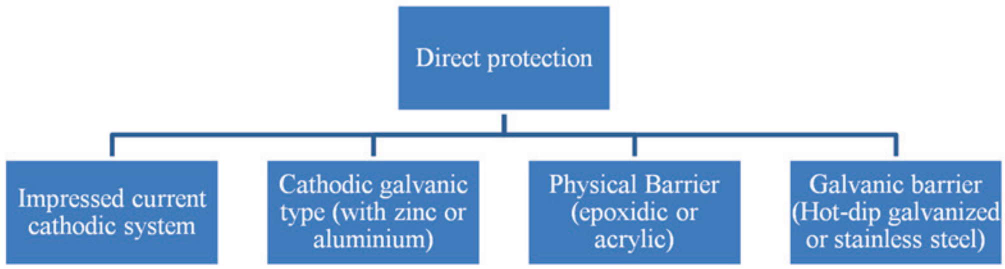
1. Introduction

According to ABNT NBR 15575:2013 [2], the service life of reinforced concrete in Brazil, for residential purposes, must be at least 50 years on the minimum level, or 75 years on upper levels. On the other hand, BS 7543:2003 [3] stipulates 120 years of service life for works of art, such as bridges and viaducts and 60 years for new buildings and reformation of public buildings. Achieving these values is no easy task, especially if the maintenance process is not efficient.
The corrosion of rebars is one of the most recurrent pathological signs in steel-reinforced concrete structures, especially those exposed to aggressive agents throughout its service life, such as chlorides and carbon dioxide, found in abundance in large cities and on the coast.
According to Gonçalves, Andrade and Castellote (2003) [4], to protect the reinforced concrete structures it is possible to use the direct protection (on steel) and the indirect protection (on the concrete). The direct protection is more efficient because it protects the rebars directly. Among the types of direct protection exists the impressed current cathodic system, the cathodic galvanic type, the physical barrier and the galvanic barrier. The first two have the disadvantage of requiring constant maintenance and the operation may be complex depending on the aggressiveness of the exposure environment. On the other hand, the physical barrier demands skilled labor force and it is preferably used in specific situations, due to the labor force required. For broader and more effective response, there is the galvanic barrier produced by hot-dip galvanizing of steel bars. Figure 1 shows the options for the direct protection.
The hot-dip galvanized steel has great durability and that is the reason why its application in the market grows increasingly. Widely used in metal structures, it can also be an option for reinforced concrete structures (Baltazar-Zamora et al., 2012 [5]). The galvanization brings many advantages that go beyond the increasing of service life, such as reducing the risks of cracks caused by the steel expansion during the corrosion process, the rust stains and degradation of the concrete, due to a lower frequency and magnitude of the concrete repairs. Therefore, the initial cost to deploy such a system in reinforced concrete structures can be counterbalanced by the several advantages mentioned before.
The galvanization is a process that creates a protective zinc film base to the steel, isolating the surface of the bar from the exposure environment. This protective film acts as the anode, with the steel acting as the cathode. Thus, being zinc more electronegative, it sacrifices itself, protecting steel from deterioration. The alloys formed between iron and zinc on the contact surface drive the coating to its integration to the metal base, so that, besides protecting the steel, zinc coating also allows the handling, transportation and installation of galvanized parts without causing damage to the surface (YEOMANS, 2004 [6]).
According to Yoo et al. (2011) [7], in general the average thickness of zinc is sufficient to achieve the useful life of the structure without maintenance for long periods. Thus, according to Pannoni (2011) [8], it is also possible to estimate the service life of the structure with the support of ISO 9223:2012 [9] from the thickness of galvanizing, as shown in Table 1.
The adherence between the steel and concrete ensures the proper performance of reinforced concrete structures, thereby ensuring that the materials work mutually. The galvanization of rebars cannot affect the adherence of the set, and this is a point to be validated.
The adherence can be obtained in three ways: by superficial adherence, friction and mechanically. According to Caetano (2008) [10], adherence friction occurs after the breaking of the bonding adherence, that is, when the sliding of the bar begins to happen. This portion refers to the action of the frictional force between the steel and the concrete, which varies according to the surface coefficient bar. This factor can be harmed by the hot-dip galvanization, once the bar gets a zinc coating, making the rebar smoother. There is no proof of the dimension of this loss, and if it is tolerable or not, within the parameters established by ABNT NBR 7480:2007 [11], which specifies the steel for the reinforcement shall have a coefficient (η) of 1.5 minimum.
Regarding the influence of the friction adherence part of the ribbed bars, there is still some disagreement among authors, whether it influences or not. According to Lutz and Gergely (1967) [12] and Cairins Du and Law (2007) [13] this part only exists in smooth bars, however for most of the latest research, the adherence provoked by friction also affects the ribbed bars.
There is also the mechanical resistance, which in its turn is the most aggravating for a good adherence, being directly allied to the hardness of the material. Thus, it is worth mentioning that the me-

Figure 1 – Types of direct protection of steel bars



Source: Gonçalves et al. (2003)

Table 1 – Indicatives rates of corrosion for different environmental

Corrosivity category	Loss in mass per unit of surface/loss of thickness (after one year of exposition)			
	Low-carbon steel		Zinc	
	Loss in mass (g/m²)	Loss of thickness (µm)	Loss in mass (g/m²)	Loss of thickness (µm)
C1 – very low	≤10	≤1,3	≤0,7	≤0,1
C2 – low	>10 a 200	>1,3 a 25	>0,7 a 5	>0,1 a 0,7
C3 – medium	>200 a 400	>25 a 50	>5 a 15	>0,7 a 2,1
C4 – high	>400 a 650	>50 a 80	>15 a 30	>2,1 a 4,2
C5 – very high	>650 a 1500	>80 a 200	>30 a 60	>2,1 a 4,2

Source: ISO 9223:2012

chanical resistance of carbon steel varies from 32 to 66kg/mm². According to Fusco (1995) [14] and ACI (2003) [15], the rebars still suffer, in addition to these, three other efforts, which would be compressive and frictional forces on the ribs in addition to the friction on the body of the bar. These forces act in many ways, preventing the sliding of the bar.

To simulate all these conditions and verify adherence between the concrete and steel without external protection and hot-dip galvanization, the method that most closely matches the real situation is the Beam Test proposed by Rilem (1978) [1] . In this experiment, the beam is subjected to bending with the contribution of other important factors on the steel-concrete adherence.

Thus, the aim of this paper is to compare the adherence of steel bars of 8.0, 12.5 and 16.0mm hot-dip galvanized and without galvanization, traditionally used in civil construction. The test for adherence between steel and concrete is achieved through the Rilem (1978) [1] procedure that is the bending test on the concrete beams to identify adherence. Concrete mix was used for the beams, 1:6 of mass to ensure the compressive strength of 25MPa, with a tolerance of 2.5 MPa, according to the procedure. After the results, a statistical analysis to identify significant properties for this parameter was performed.

2. Materials and method

2.1 Materials

To scale the beams to be tested, it was followed the procedure of Rilem (1978) [1] according to the specifications of Table 2. In the concrete, it was used the trace 1:6, by mass, the proportion between the binder and the aggregates, with water/cement ratio of 0.6 and abatement of the Abrams cone in the fresh state of 100mm. This trait was set to achieve what was proposed by the Rilem (1978) [1] method, which provides the compressive strength of concrete at 28 days, at 25 MPa, with a tolerance of 2.5 MPa. For a better understanding of the growth curve of the concrete, the tests were performed in 7 and 28 days. The dosage method of the concrete was Ibracon (Brazilian Institute of Concrete, 2011) [16].

2.2 Method

After defined the parameters of the beams and materials, three sets were molded for each studied diameter (8mm, 12.5mm and 16mm) and for each condition (reference and hot-dip

Table 2 – Parameters for verifying adherence between the concrete and steel bars

Properties and dimensions	Type A	Type B
Diameters of the bars (mm)	<16	≥16
Grip length (ld)	10 ø	10 ø
Thickness of concrete blocks (cm)	18	24
Height of concrete blocks (cm)	37,5	60
Distance between the concrete blocks (cm)	5	6
Overall width of beam (cm)	80	126
Width of the bars (cm)	100	150
Distance between the axis of the bar and the axis of the kneecap (cm)	10	15
Distance between the axis of the bar and the axis of the bottom face of the beam (cm)	5	5
Distance between loads (cm)	15	20
Distance between suports (cm)	65	110

Source: Adapted of Rilem, 1978

Figure 2 – concrete placement set beams for testing adherence between the bars and the concrete

galvanized), totalizing 18 sets, consisting of 36 parts. Figure 2 illustrates one of the concretes and six molded sets.

After this, the sets were cured in a moist chamber for 28 days. The beams were instrumented at its ends, with digital dial indicators to measure the deformations of the bars that tend to slip during the test. Points 1 mm, 0.1 mm and 0.01 mm, specified in the procedure, were measured. The principle used was the arithmetic mean of the results obtained at both ends, moments before the breaking of the beam. For the last reading (1mm) it was considered the first load that reached this limit. The rate of the load application to the rods of 8.00 mm, 12.5 mm and 16.0 mm diameter was obtained according to equation 1:

$$v_b = \frac{5 \text{ x } d^2}{10_0} \quad (1)$$

Where:

v_b = speed of load application

d = diameter of the test bar in cm

After that, the beams were placed and subjected to the bending test being double supported and receiving the load application

Figure 3 – Execution of the beam test

Table 3 – Results of compressive strength at 7 and 28 days

Diameter of the bars (mm)	Trace of concrete, in mass	w/c ratio	fc 7 days (MPa)	fc 28 days (MPa)
8	1:6	0,6	16,7	26,4
12,5	1:6	0,6	15,5	23,2
16	1:6	0,6	14,5	22,5

distributed on two points, as it can be seen in Figure 3.

2.3 Method of the analysis of the results

To analyze the test results of the beams, it was adopted the method of analysis of variance (ANOVA), which seeks to verify the existence of significant differences, based on a statistical analysis between the obtained mean values. In addition, the method checks whether the applied values influence the dependent variable. This investigation was performed using the software STATISTICA, version 10, produced by the company StarSoft.

3. Results and considerations

3.1 Compressive strength

The results of the 7 and 28 days of compressive strength of the concrete are shown in Table 3.

It is observed that the concrete had compressive strength within the range recommended by Rilem (1978) [1], allowing the tests within the specified time.

Figure 4 – Behavior of load versus for each bar diameter for each condition, with 3 beams tested for each case

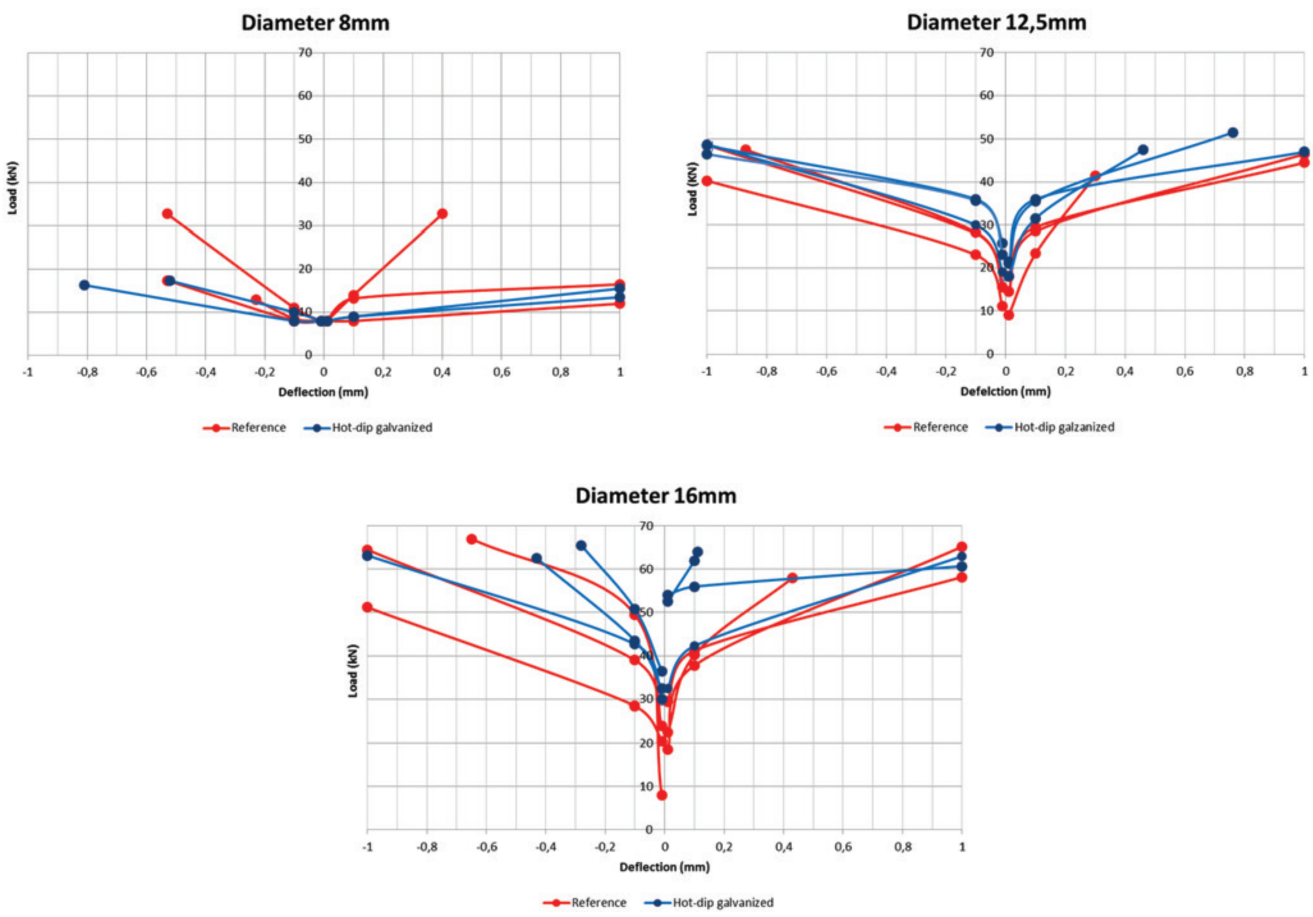


Table 4 – Values obtained from adherence tests

Type and diameter of the bars	Left measure		Wright measure		Adherence strength (τ – bu – MPa)	Average adherence strength (τ – bu – MPa)
	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)		
8mm reference	0,01 0,10 0,53*	8 11 32	0,01 0,10 0,40*	8 14 32	7,77	–
8mm reference	0,01 0,10 0,23*	8 8,5 –	0,01 0,10 1,00	8 8 12	7,46	8,50
8mm reference	0,01 0,10 0,53*	8 8 –	0,01 0,10 1,00	8 13,2 16,5	10,26	–
8mm hot-dip galvanized	0,01 0,10 0,52*	8 10 –	0,01 0,10 1,00	8 9 15,5	9,64	–
8mm hot-dip galvanized	0,01 0,10 1,00	8 8,5 8,5	0,01 0,07** –	8 – –	5,28 (resultado desprezado)	9,01
8mm hot-dip galvanized	0,01 0,10 0,81*	8 8 16,3	0,01 0,10 1,00	8 9 13,5	8,39	–
12,5mm reference	0,01 0,10 1,00	11 23 40,3	0,01 0,10 0,30*	9 23,3 –	10,26	–
12,5mm reference	0,01 0,10 0,98*	17 28 –	0,01 0,10 1,00	14,5 28,5 46,5	11,84	11,14
12,5mm reference	0,01 0,10 0,87*	15,5 28,3 –	0,01 0,10 1,00	18 29,5 44,5	11,33	–
12,5mm hot-dip galvanized	0,01 0,10 1,00	19 30 48,8	0,01 0,10 0,76*	21 35,5 –	12,43	–
12,5mm hot-dip galvanized	0,01 0,10 1,00	25,8 36 47	0,01 0,10 1,00	21,5 36 47	11,97	12,08
12,5mm hot-dip galvanized	0,01 0,10 1,00	23 35,7 46,5	0,01 0,10 0,46*	18 31,5 –	11,84	–
16mm reference	0,01 0,10 1,00	24 39 64,5	0,01 0,10 1,00	29,5 41,2 58,2	11,44	–
16mm reference	0,01 0,10 0,65*	8,0 49,5 67,0	0,01 0,10 1,00	18,5 37,8 65,2	12,16	11,05
16mm reference	0,01 0,10 1,00	20,5 28,5 51,2	0,01 0,10 0,43*	22,5 40,2 58,0	9,55	–
16mm hot-dip galvanized	0,01 0,10 0,28*	36,5 50,8 –	0,01 0,10 1,00	32,5 42,3 63,0	11,75	–
16mm hot-dip galvanized	0,01 0,10 1,00	30,0 42,7 63,2	0,01 0,10 0,11*	52,5 62,0 64,0	11,79	11,62
16mm hot-dip galvanized	0,01 0,10 0,43*	32,5 43,5 62,5	0,01 0,10 1,00	54 56 60,7	11,32	–

* Beam breakup occurred before completing 1,00 mm deflection
** Beam breakup occurred before completing 0,10mm deflection
*** Beam with problems during the tests – despised result

Table 5 – Tests results of adherence

Parameters	SQ	GL	MQ	Fcal	P
Interception	1855,494	1	1855,494	1900,878	0,000000
Diameter of bar (mm)	25,557	2	12,779	13,091	0,001233
Type of bar	1,884	1	1,884	1,931	0,192179
Diameter of bar (mm) and type of bar	0,146	2	0,073	0,075	0,928198

SQ – sum of squares; GL – degree of freedom ; MQ – mean square; Fcal – Fisher parameter for the test of significance of effects

3.2 Adherence between the concrete and hot-dip galvanized and unprotected rebars

For each type of bar diameter (8mm, 12.5mm and 16mm), and each condition (reference and hot-dip galvanized) was examined by the proposed method of Rilem (1978) [1], measuring the load required in kN for deformed bars of 0.01 mm, 0.1 mm and 1 mm, both the left and the right of the application of the load, when the test is considered ended. Figure 4 shows the load versus deflection curves for each diameter and provided with three measurements for each condition.
It is noticeable that for beams with diameter of 8.0 mm the limit of 1.0 mm has always occurred to the right side of the beam, getting a smaller load for most of them, with a beam having a different performance of others. In beams with bars of 12.5mm diameters, achieved loads were higher than in the previous beams, as it was to be expected. For both bars, from 8mm to 12mm, the adherence between the concrete and steel was higher in beams with hot-dip galvanized reinforcements. The same performance was observed on the beams with 16mm bars, showing that for larger diameters, the adherence between the concrete and hot-dip galvanized steel was also higher. It is important to highlight that the parameters of the beams with 16mm bars is different from the earlier ones, according to the Rilem procedure (1978).
Based on the collected data, it was calculated the values of adherence strength, expressed in Table 4.
Based on the bond tension, statistical analysis (ANOVA) was used, in the software STATISTICA to verify the relationship between adherence and the type and diameter of the bars. The results are shown in Table 5.
If Fcal is higher than the tabulated value of F, the null hypothesis will be rejected. So that means there is significant difference between the group means and, consequently, the study variable influences the dependent variable. In this way, it is noticeable that the kind of bar (galvanized or not) does not have a significant level, because P is greater than 0.5, commonly used in civil engineering, unlike the diameter of the bar, which has a significant level. Therefore, it is observed that the diameter of the bar influences the bond strength between the concrete and the steel, but whether the bar is hot-dip galvanized or not, it does not affect the final adherence to the results obtained in this paper.
Finally, Figure 5 shows the values of the arithmetic mean among the three results of bond strength for each type and diameter of the bar.
It is observed that the adherence strength increases considerably at 31% for the unprotected steel and 34% for the hot-dip galvanized steel to diameters between 8.0 and 12.5 mm. As for the 16mm diameter was reduced from 1% for the regular steel to 4% for the hot-dip galvanized one, showing some stabilization in larger diameters.

But when comparing the adherence strength between the different types of steel, it is observed that the galvanized bars and rods have always obtained higher values in comparison to the unprotected ones, 6% for the 8mm diameter, 8.4% for the 12, 5mm diameter and 5.2% for the 16mm. Therefore, the zinc layer which protects the reinforcement against corrosion did not damage the adherence between the steel and the concrete, and there may even be a small gain in certain situations.

4. Conclusions

After the experimental work, it is possible to conclude that:
- the diameter of the bars has a significant influence on the adherence strength between the concrete and the steel;
- the type of steel, hot-dip galvanized or without protection, does not have significant influence on the adherence strength between the concrete and the steel;
- the hot-dip galvanized bars and rods were resistant to adherence between the concrete and the upper unprotected steel bars, in 6, 8.4 and 5.2% for diameters of 8, 12.5 and 16mm respectively.

Therefore, for these materials under these conditions, it is possible to specify the hot-dip galvanized steel without concerning for adherence strength between the concrete and the steel.

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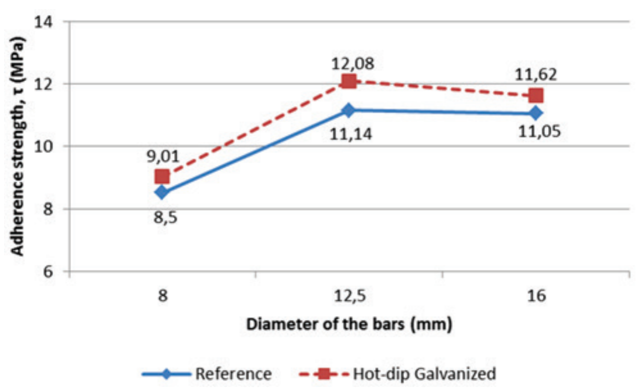
Figure 5 – Adherence strength versus diameter of the bars



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