International Journal of Natural and Engineering Sciences
E-ISSN: 2146-0086 12(2): 05-09, 2018

Rapid Acidic Corrosion of Ribbed Reinforcing Steel Bars

Tayfun UYGUNOĞLU[1], İbrahim GÜNEŞ[2], Atila Gürhan ÇELİK[3], Emriye ÇINAR[1]

[1]Afyon KocatepeUniversity, Civil Engineering Department, Afyonkarahisar-TURKEY
[2]Afyon KocatepeUniversity, Materials Science Engineering Department, Afyonkarahisar-TURKEY
[3]Giresun University, Civil Engineering Department, Giresun-TURKEY

*Sorumlu Yazar:
E-mail: gunoglu@aku.edu.tr

Abstract
Reinforcement steel rebar corrosion leads to a deterioration of the bond between the concrete and the steel bars. The serviceability and ultimate strength of concrete elements within reinforced structures are accordingly affected. Many studies have been done on the different types of steel bar corrosion. However, very few studies have investigated the effects of restrictions on the degradation of steel when exposed to hydrochloride acid corrosion on ribbed steel rebars. In the present paper, investigations were carried out to study the rapid corrosion behavior of unprotected low-carbon ribbed reinforcing steel exposed to different concentrations of HCl solutions (0.5, 1.0 and 1.5M). The ribbed steel bar was of size Ø14. The weight loss method was used for the estimation of the corrosion. The results show that the corrosion rate and cross-section loss of steel bars increases with increasing acid concentration from 0.5 M to 1.5 M.
Keywords: Corrosion, rebar, reinforcing

INTRODUCTION

One of the worst durability problems facing reinforced concrete (RC) structures is steel rebar corrosion. It leads to the deterioration of bond between the concrete and steel bars [1]. The expansive corrosion will induce hoop tensile stress in the surrounding concrete. In the initial stage of corrosion, the bond strength will increase because of the increased roughness of the steel bar. But after the cracking of the concrete cover, the bond strength will decrease owing to the reduction of confinement [2]. Reinforcement steel rebar corrosion causes damage to structures mainly on account of: (i) loss of cross-sectional area of rebar, (ii) reduction of the mechanical properties of the rebar, and (iii) weakening of the bond between the concrete and the rebars. The deterioration of the bond between steel rebar and concrete can significantly affect the serviceability and ultimate strength of concrete elements [4].

Many researchers have investigated the degradation of acidic corrosion on mild steel. A study has been made on the mechanism of corrosion of mild steel and the effect of nitrilo trimethylene phosphonic (NTMP) acid as a corrosion inhibitor in acidic medium, that is, 10% HC1 using the weight lossmethod and electrochemical techniques, that is, potentiodynamic and galvanostatic polarization measurements by Gpta et al. [5]. They found that the corrosion inhibition efficiency of NTMP is 93% after 24 h. Noor and Al-Moubaraki [6] investigated the corrosion behavior and mechanism for mild steel in hydrochloric acid solutions was studied by chemical, and electrochemical methods. studies for mild steel after immersion in HCl solutions of different concentrations showed general and pitting corrosion and the latter becomes more pronounced at higher level of HCl concentration. Al-Amiery et al. [7] performed a study on corrosion inhibitory effects of new synthesized compound namely on mild steel in 1.0 M HCl at different temperatures using open circuit potential, potentiodynamic polarization and electrochemical impedance spectroscopy. They reported that inhibited mild steel corrosion in acid solution and indicated that the inhibition efficiencies increased with the concentration of inhibitor, but decreased proportionally with temperature.

Acidic media is dangereous for mild steel such as rebar, steel construction member etc [9-11]. Hydrochloric acid is the most difficult of the common acids to handle from the standpoints of corrosion and materials of constructions [12]. Extreme care is required in the selection of materials to handle the acid by itself, even in relatively dilute concentrations or in process solutions containing appreciable amount of hydrochloric acid. This acid is very corrosive to most of the common metals and alloys [13-15].

The aim of this work is to investigate the corrosion behaviour and mechanism for steel rebar in solutions of HCl. The morphology of mild steel surface before and after immersion in HCl solutions was examined at different concentrations of the acid.

EXPERIMENTAL PROGRAM

Reinforcement rebar which was used in the experiments is made of mild steel, a low carbon steel usually used for structural applications. With too little carbon content

(>0.2%) to thoroughly harden, it is weldable, which expands the possible applications in site. The experiments were performed on ST-IIIa (S 420) ribbed reinforcement steel rebar specimens in size of Ø14. It has the composition: 0.02% (P), 0.37% (Mn), 0.03% (S), 0.01% (Mo), 0.039% (Ni), 0.21% (C) and the remainder is Fe. The characteristic properties of ribbed steel rebars are presented in Table 1.

Table 1. Characteristic properties of Ø14 steel rebar

Properties	Ribbed steel rebar diameter, mm
Tensile strength, MPa	560.7
Yield strength, MPa	447
Elongation, %	22.9

The ribbed steel rebar samples were cut out in length of 20 cm. The first preparation process which was used involves an abrasive surface treatment to remove any build up of material by used emery paper to remove the outer surface layer and roughen up the surface. The next portion involves more chemical means, this helps in dissolved contaminants that reach the surface externally from the environment such as oils, dust and grease that usually came from prior processing or handling. The final portion involves washed the samples with running tap water followed by distilled water, dried with clean tissue, immersed in ethanol. They were then allowed to dry. Experiments were carried out to assess the loss of weight. The steel rebar samples were completely immersed in glasses vessel containing 500 ml solution of HCl in different concentrations as 0.5, 1.0, and 1.5M (Table 2). They were exposed for different duration period at room temperature from 7 to 35 days, then the steel rebar samples were cleaned, washed with running tap water followed by distill water, dried, then immersed in ethanol, and dried again. The weight of the steel rebars was measured for each duration. The mass of steel rebar samples before and after immersion was determined using an analytical balance accurate to 0.1 mg. For further data processing, the average of the three replicate values was used. The weight loss (W%) of varying concentration of HCl from the experimental weight measurements were calculated as following Eq. (1):

$$W\% = \left(\frac{W_0 - W_i}{W_0}\right) x100$$

(1)

Where W_0 is the first weight of steel rebars, and W_i is the weight of mild steel after immersing in solutions, respectively.

Table 2. Acidic solution content (for 1000 ml)

Component	Content, ml		
	0.5 M	1.0 M	1.5 M
HCl	42	83	125
Water	958	917	875

The weight loss method was also used to calculate the corrosion rate (CR) by the following Eq. (2) [17]:

$$CR\ (mmPY) = (87.60xW)/(AxTx\ \delta) \qquad (2)$$

Where, W, A, δ and T are weight loss (mg), area of the specimen (cm^2), density of steel rebar (7.86 g/cm^3) and exposure time (h) respectively. The mmPY is millimeters per year.

RESULTS AND DISCUSSIONS

Figure 1 shows the pH variation (acidity) as a function of the acidic molarity of solution which has immersed rebars. After a 21-day exposure, samples were a basic pH close to 5 in the medium. It is because of the reinforcement dissolved in the acidic solution and reduced the acidity of the solution. In addition, the pH value of the increase increases while the conductivity decreased (Fig. 2). Increasing the molarity of the environment resulted in an increase in electrical conductivity.

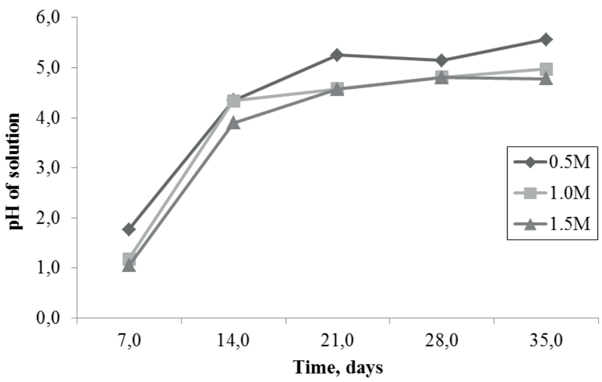

Figure 1. pH of acidic solution depending on corrosion time

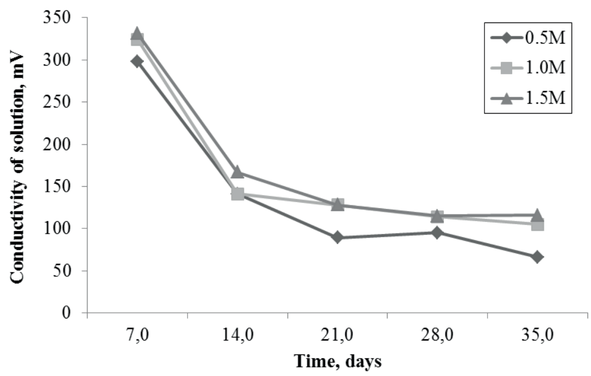

Figure 2. Electrical conductivity of acidic solution

Method of weight loss is suitable to check the various types of steels available in the market under accelerated corrosion in the laboratory. Fig. 3 show the results obtained from weight loss measurements for the different size of steel rebars in 0.5M, 1.0M and 1.5M HCl solutions depending on the acidic treatment duration. On the base of the acidic test results it was found that the weight loss of the steel rebars was initially low and then tendency of increasing was observed depending on time. The lowest weight loss was found at 0.5 M HCl as predictable, and the highest weight loss was obtained at 1.5 M HCl. Also, weight loss was stable after 21 days acidic treatment for each rebar size. For example, the weight loss was 0.5% at the 0.5 M; it was 1.8% at the

1.5 M acidic solution for 21 days acidic environment. This means that increasing of acidic molarity resulted in a relative reduction of weight loss. The reason for corrosion (weight loss) versus treatment time can be the fact that hydrogen is released when metals react with acids.

Corrosion rate data as a function of acid concentration can be used to show the rate dependence of acid concentration. As the acid media concentrations were increased, the corrosion rates also increased, as shown in Fig. 4. This owed primarily to hydrogen ions, the active ions in acids, increasing as acid concentration increased. The corrosion of metals in acidic solution is cathodically controlled by the hydrogen evolution reaction.

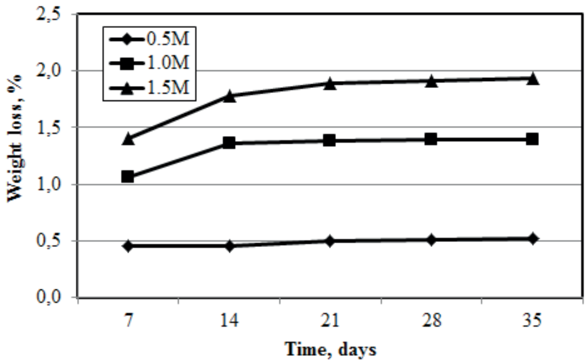

Figure 3. Weight loss of corroded rebars

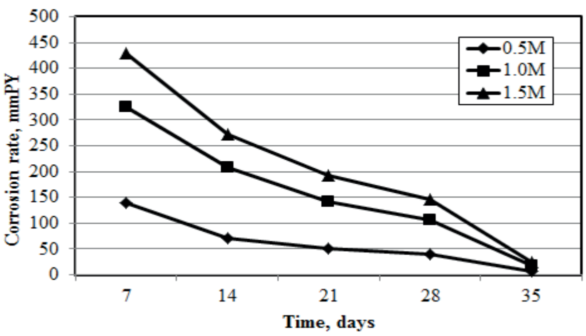

Figure 4. Corrosion rate of rebars versus corrosion time

Fig. 5 shows the section change of rebars depending on acidic media and exposure time. It can be clearly seen that the cross-section loss of rebars increased as acidic molarities increased. The reduction in diameters of the rebar was lower than that of exposed to low acidic molarity rebars. The reduction ratios increases at 0.5 M sulfuric acid solution and the highest were at 1.5 M acidic solution. It was found that the cross-section loss of 14 mm straight rebar was changed between 0.22% and 1% depending on acidic molarities.

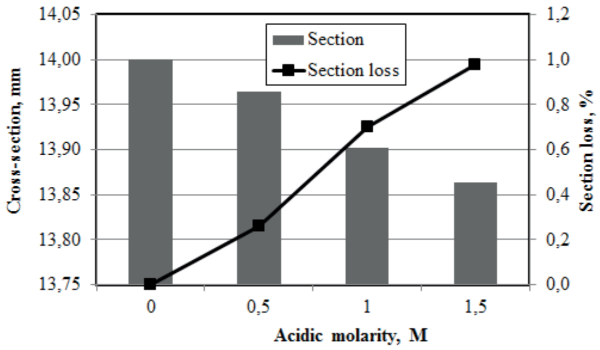

Figure 5. Cross-section change of rebars versus acidic molarity

In Fig. 6, the view of rebar surface after 1.5M acidic treatment for 35-day are seen. The effects of the HCl action on the reinforcing steel rebars were also examined using the 3-D profilometer (Fig. 7-9).

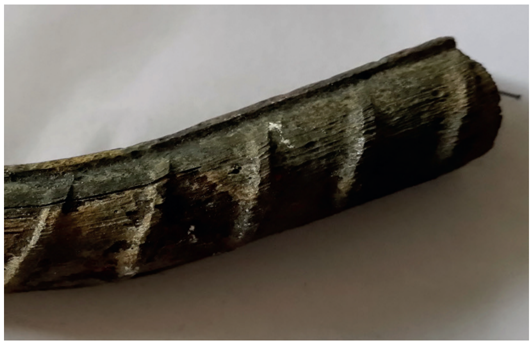

Figure 6. Surface texture of rebar after 0,5M acidic media

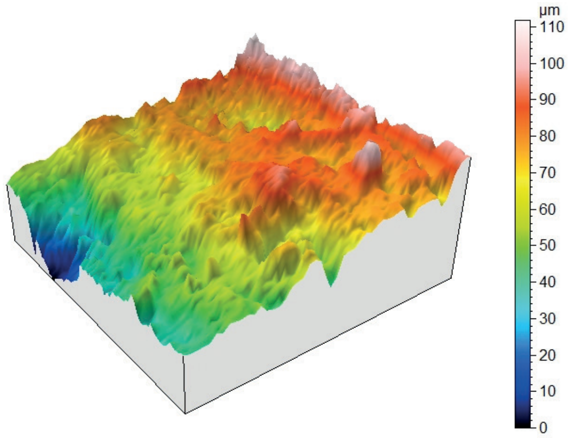

Figure 7. Surface texture of rebar after 0,5M acidic media

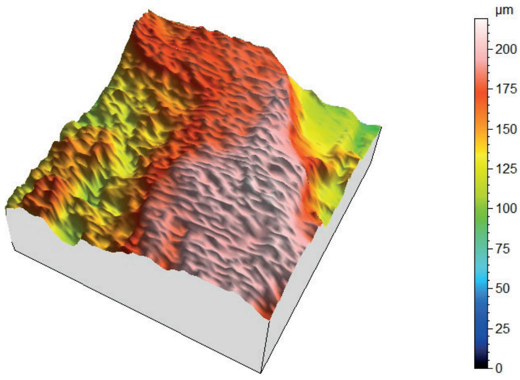

Figure 8. Surface texture of rebar after 1,0M acidic media

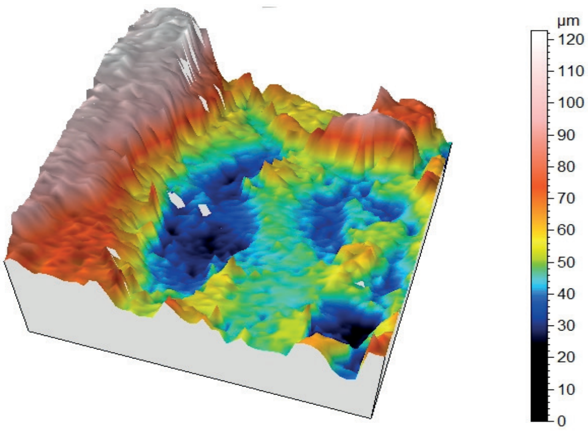

Figure 9. Surface texture of rebar after 1,5M acidic media

The studies were performed on these samples in order to investigate the condition of the steel rebar surface. It is clear that the corrosion of the steel bar not only reduced its cross-section irregularly but also altered the rib shape on a ribbed bar surface. The steel bar exposed to 1.5 M acidic media presented a more serious corrosion on the surface when compared to rebars exposed to lower acidic environment. Decreasing the HCl concentration in practical terms translated to a reduction in steel rebar deterioration and an extension in the useful life of the reinforcement structures.

CONCLUSION

In this study, investigations were carried out on the rapid corrosion behavior of unprotected low-carbon ribbed reinforcing steel exposed to different concentrations of HCl solutions (0.5, 1.0 and 1.5M). As the acid media concentrations were increased, the corrosion rates also increased. After a 21-day acidic media exposure, pH of solution with samples increased from 1 to 5. It was also found that the weight loss of the steel rebars was initially low and then tendency of increasing was observed depending on time. The lowest weight loss was found at 0.5 M HCl as predictable, and the highest weight loss was obtained at 1.5 M HCl. increasing of acidic molarity resulted in a relative reduction of weight loss. The reason for corrosion (weight loss) versus treatment time can be the fact that hydrogen is released when metals react with acids. The cross-section loss of rebars increased as acidic molarities increased. The cross-section loss of 14 mm straight rebar was changed between 0.22% and 1% depending on acidic molarities. Consequently, the rebar diameter reduced from 14 mm to 13.86 mm after 1.5M acidic environment for 35 days. Therefore, the rebar which is exposed to acidic environment must be protected against to cross-section loss.

Acknowledgement

Authors thank to Afyon Kocatepe University for supporting the study with 18.KARIYER.209 Scientific Project.

REFERENCES

[1] J.P. Broomfield,. Corrosion of Steel in Concrete: Understanding, Investigation, and Repair. (1997) London: Spon Press Publications.

[2] D.A.K. Mullick Corrosion of reinforcement in concrete-an interactive durability problem. *The Indian Concrete Journal* 74 (2004), 168-175.

[3] J.Fliz, , S. Akshey, D. Li, Y. Kyo, S. Sabol, H. Pickering, and K. Osseo-Asare. Method for Measuring the Corrosion Rate of Steel in Concrete. *Condition Evaluation of Concrete Bridges Relative to Reinforcement Corrosion*. 2(1992),Washington, D.C., Strategic.

[4] R.D. Brown,. Mechanisms of Corrosion of Steel in Concrete in Relation to Design, Inspection, and Repair of Offshore and Costal Structures. *Special Publication 65-11. Detroit, MI: American Concrete Institute* (1980) 169–204.

[5] M. Gupta, J. Mishra, K.S. Pitre, Corrosion and Inhibition Effects of Mild Steel in Hydrochloric Acid Solutions Containing Organophosphonic Acid, *International Journal of Corrosion*, Article ID 582982 (2013), 1-5.

[6] E.A. Noor, A.H. Al-Moubaraki, Corrosion Behavior of Mild Steel in Hydrochloric Acid Solutions, *Int. J. Electrochem. Sci.,* 3 (2008) 806 - 818.

[4] P. Mohan, R. Usha, G.P. Kalaighan, V.S. Murlidharan, Inhibition effect of benzohydrazide derivativeson corrosion behaviour of mild steel in 1M HCl, *Journal of Chemistry*, Article ID 541691, (2013), 1-7.

[5] S.E. Hussain, A.S. Al-Gahtani, E. Rasheeduzzafar Chloride threshold for corrosion of reinforcement in concrete. *ACI Materials Journal* (1996), 534-538.

[6] K.K. Keneth, E.K. Karl, Corrosion below sewer structure, *Am. Soc. Civil Eng*. 61 (1991) 57–59.

[7] A.A. Al-Amiery, A.A.H. Kadhum, A.H.M. Alobaidy, A.B. Mohamad, P.S. Hoon, Novel Corrosion Inhibitor for Mild Steel in HCl, *Materials* (2014), *7*, 662-672

[8] O.A. Omotosho, O.O. Ajayi, O.S. Fayomi, V.O. Ifepe, Assessing the deterioration behaviour of mild steel in 2 M sulphuric acid using Bambusa glauscescens, *Int. J. Appl. Eng. Res.* 2 (2) (2011) 406–418.

[9] M. Hosseini, S.F.L. Mertens, M. Ghorbani, M.R. Arshadi, Asymmetrical Schiff bases as inhibitors of mild steel corrosion in sulphuric acid media. *Mater. Chem. Phys.* (2003), *78*, 800–808.

[11] A. Singh, E. E. Ebenso, M. A. Quraishi et al., "Corrosion inhibition of carbon steel in HCl solution by some plant extracts," *International Journal of Corrosion*, (2012), Article ID 897430, 1-20.

[12] S.K. Shukla, A. Singh, A.T. Quraishi, Efficient

corrosion inhibitors for mild steel in hydrochloric acid solution. *Int. J. Electrochem. Sci*. *7*(2012), 3371–3389.

[13] X.U. Fengling, H.O.U. Baorong, Triazole derivatives as corrosion inhibitors for mild steel in hydrochloric acid solution. *Acta Metall. Sin.* 22(2009), 247–254.

[14] A.Y. Musa, A.B. Mohamad, , A.A.H. Kadhum, , M.S. Takriff, Corrosion inhibition of mild steel in 1.0 M HCL by amino compound: Electrochemical and DFT studies. *Metall. Mater. Trans., A* 43(2012), 3379–3386.

[15] A.A.H. Kadhum, A.B. Mohamad, L.A. Hammed, A.A. Al-Amiery, N.H. San, A.Y. Musa, Inhibition of Mild Steel Corrosion in Hydrochloric Acid Solution by New Coumarin, *Materials* 7(2014), 4335-4348.