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# Biogenic corrosion on ribbed reinforcing steel bars with different bending angles in sewage systems

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## HIGHLIGHTS

- Biogenic corrosion on ribbed rebars with different bending angle was investigated.
- Sulfuric acid was used in three different molarity (0.5 M, 1 M and 1.5 M).
- The cross section of 12 mm straight rebars was decreased between 2.8% and 5.5% in 1.5 M acidic media.
- Rebar diameter and bent angle increased H2 evolution and corrosion rate reduced.
- The steel bar that exposed to 1.5 M acidic media presented a more serious corrosion on the surface.

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## 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 sulfuric acid corrosion on bent steel rebars. In the present paper, investigations were carried out to study the corrosion behavior of unprotected low-carbon ribbed reinforcing steel exposed to different concentrations of $H_2SO_4$ solutions. The ribbed steel bars were of size Ø12, Ø14, Ø16 and bent at angles of angles of 0°, 45°, 90° and 135°. 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. On the other hand, corrosion deterioration was decreased with an increased bending angle.



## 1. Introduction

Reinforcement steel rebar corrosion is one of the worst durability problems facing reinforced concrete (RC) structures. It leads to the deterioration of bond between the concrete and steel bars [1,2]. 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 [3]. 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 [4–7].

A common use of reinforced concrete members is in infrastructure sewage systems. Sewage and other wastewaters contain significant levels of biological and organic materials, including bacteria that remain active in the waste streams. From a corrosion point of view, the most important types of bacteria are those that metabolize sulfur compounds because this microbiological activity can produce acidic chemicals corrosive to concrete and steel or iron. Acids react with the calcium hydroxide of the hydrated portland cement and the reinforcing steel rebars [8,9]. In addition, the products of combustion of many fuels contain sulfurous gases that combine with moisture to form sulfuric acid. Also, certain bacteria convert sewage into sulfuric acid. Sulfuric acid is particularly aggressive on reinforced concrete structures because the calcium sulfate formed from the acid reaction will also deteriorate concrete

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via sulfate attack (Fig. 1) [10–12]. The corrosion of sewage systems is a major problem in the modern world. Millions of dollars are being spent on the repair of reinforcement sewage pipelines notably affected by biogenic sulfuric acid attack, which causes rapid deterioration of concrete and reinforcing steel rebars. As known from the literature, concrete is a porous structure, and acid penetrates to the pipeline's reinforcement steel bar. Hence, acid attacks destroy the reinforced sewage systems [13,14].

Many researchers have investigated the degradation of biogenic corrosion on mild steel. Dadgarinezhad and Baghaei [15] investigated the inhibition effect of a new synthesized organic inhibitor named 1-(3-Nitrobenzylidene) Thiosemicarbazide (A) on the corrosion of mild steel in 0.5 M sulfuric acid at room temperature using weight loss, electrochemical impedance spectroscopy (EIS) and Tafel polarization measurements. They learned that the compound (A) is a very good inhibitor with an efficiency of 98% at 100 ppm additive concentration in acid solution. Omotosho et al. [16] investigated the deterioration of mild steel in 2 M sulfuric acid solution in the presence of Bambusa glauscescens extract using the gasometric technique. Experimental results show that there was a corresponding reduction in corrosion rate as extract concentration increased. Rathi et al. [17] investigated the corrosion rate of mild steel, Tor steel and CRS steel in reinforced concrete. They reported that the corrosion rate is found more in Tor steel than mild steel. Ajeel et al. [18] investigated the corrosion behavior of unprotected and protected low carbon steel using carburizing and hard chrome plating in different concentrations of $H_2SO_4$ and HCl solutions by using the weight loss method. The results show that low carbon steel samples protected by hard chrome plating had better corrosion resistant (less corrosion rate) than unprotected and carburized low carbon steel samples. Osarolube and Oforka [19] studied the corrosion behavior of mild and high carbon steels in various acidic media, and found that the rate of metal dissolution increased with the increase of concentration of the corrosion media and exposure time. Also, the corrosion rates of high carbon steel in all the acidic media were higher than that of mild steel because of carbon contents. Singh et al. [20] investigated the corrosion inhibition properties of ceftazidime (CZD) for mild steel corrosion in $H_2SO_4$ solution by electrochemical impedance spectroscopy (EIS), potentiodynamic polarization and gravimetric methods. They found that CZD was a good inhibitor for mild steel corrosion in acid medium. Bayol et al. [21] investigated the inhibition effect of glycolic acid ethoxylate 4-nonylphenyl ether (GAENE) on the corrosion of mild steel in 1.0 M $H_2SO_4$ solution during both short and long immersion times. Potentiodynamic polarization curves, linear polarization resistance (LPR) and electrochemical impedance spectroscopy (EIS) techniques were used by the authors. They reported that the corrosion rate of mild steel was diminished by GAENE, and that potentiodynamic polarization curves show that GAENE acts as a mixed-type inhibitor with predominant inhibition at anodic state.

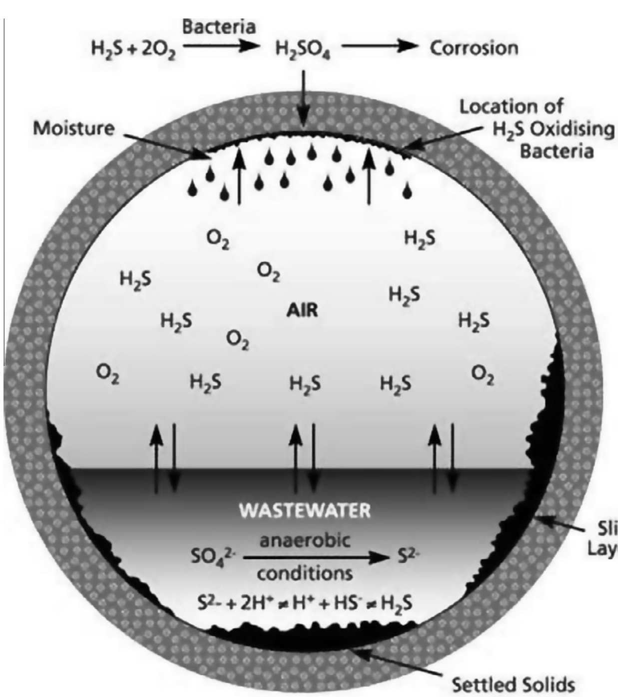


**Fig. 1.** Sulfuric acid corrosion on sewage system [12].

Most of studies on corrosion of mild steel (also known as low carbon steel) were focused on using inhibitors on the surface with different acidic concentrations [22–24]. However, the bending angle of reinforcing ribbed rebars was not considered for exposure to sulfuric acidic media. It also known that different bending angles of rebars are used in the design of structures using such rebar types as stirrups, column tie, bent bar and straight. To provide a better understanding of mechanism of biogenic damage on reinforced infrastructure systems, the present paper investigated the effects of sulfuric acid attack on reinforcing ribbed steel rebars of different bending angles.

## 2. Experiments details

### 2.1. Materials

Reinforcement rebar 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. The experiments of this study were performed on ST-IIIa (S 420) ribber reinforcement steel rebar specimens in size of Ø12, Ø14 and Ø16 (Fig. 2). The characteristic properties and chemical components of ribbed steel rebars are presented in Tables 1 and 2, respectively.


**Fig. 2.** A view of reinforcement steel rebars.

**Table 1**
Characteristic properties of steel rebars.

| Property | Ribbed steel rebar diameter, mm | | |
|---|---|---|---|
| | Ø12 | Ø14 | Ø16 |
| Tensile strength, MPa | 599 | 560.7 | 559 |
| Yield strength, MPa | 442 | 447 | 448 |
| Elongation, % | 25.6 | 22.9 | 23.8 |