

# Passivation Behavior of Steel Rod and Wires of Nepal in Acidic and Alkaline Solutions

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## Abstract

The passivation behavior of steel rods and wires those are produced in Nepal was studied in 1 M HCl and 1 M NaOH solutions at 25°C, open to air using immersion tests and electrochemical measurements. The corrosion resistance of all the examined steel rods and wires in this work is found significantly higher in alkaline 1 M NaOH than in acidic 1 M HCl, mostly due to an ennoblement of the open circuit corrosion potentials of the steels at passive potential regions in 1 M NaOH solution at 25°C. The corrosion rate of all the examined steel rods and wires is about in the range of  $1-5 \times 10^1$  mm/y in acidic 1 M HCl solution which is nearly three orders of magnitude lower corrosion resistance than in alkaline 1 M NaOH solution at 25°C. Therefore, these steel rods and wires seem to be very corrosion resistance materials in very alkaline environments like a reinforcing concrete.

**Key words:** steels, corrosion rate, open circuit potential, immersion test, electrochemical measurements.

## Introduction

Corrosion causes damage to several steel-structures around the world. Environmental corrosion damage of steels is becoming a big problem since the beginning of 20<sup>th</sup> century because, steels have been successfully used as structural materials and now it is one of the major construction materials (Uhlig & Revie 1991). We have a large number of commercial buildings, domestic dwellings, marine structures, bridges, etc, some of which are beginning to show signs of corrosion damages and over the years a large quantity of steels have been used. If the on-going corrosion activity on steel is not addressed, section loss of the structures will occur and significant repair or replacement may eventually be required. Therefore, as time goes on we will have to face new corrosion problems of the steel-structures in different environments.

In this context, corrosionists are recently focused to find out better quality models for the progression of steel corrosion with time. Good control of corrosion of structural materials like steels requires the awareness and co-operation of the entire design team, including engineers and corrosionists. Adequate means for collecting, reporting and recording corrosion information from operational situations must be planned. Furthermore, in order to ensure more durability of the new steel-structures, we need to understand what can be

done to ensure that the corrosion risk of the steel should be reduced to a minimum in different environments. In general, the degree of corrosion resistance of steels by atmospheric exposure depends on the environments; the most harmful factors are oxidizing acids and chloride ions, and the most beneficial medium is alkaline. Steels passivate generally at a pH higher than 10, even though the passivity decreases in very strong alkaline solutions at high temperature in which iron has a tendency to dissolve as ferrous ions ( $\text{HFeO}_2^-$ ) (Uhlig & Revie 1991). Therefore, alkaline solutions employed in many chemical processing industries have been handled in steel equipment.

In the 1970s when instruments for surface analysis became available, many corrosion studies of steels were performed by using surface analysis techniques (Asami *et al.* 1976, Kamimura & Stratmann 2001, Shibata 2007, Fujimoto & Tsuchiya 2007, Yang & Macdonald 2007). The corrosion behavior of steels has been mainly investigated in inorganic acids (Kivisakk 2003), a strongly oxidizing peracetic acid (Qu *et al.* 2008), salts (Nagies & Heusler 1998), alkaline solutions (Newman 1981; Gonzalez *et al.* 2007) and marine media (Nishikata *et al.* 1995; Melchers 2003; Reffass *et al.* 2006; Isaacs *et al.* 2007). It has been reported that many heterocyclic compounds containing heteroatoms like N, O, S, have been proved

to be effective inhibitors for the corrosion of steels in acid media (Saliyan *et al.* 2008). But little has been studied about the corrosion of steels produced and used in Nepal (Bhattarai *et al.* 2007).

In this context, the main aim of the present work is to study the passivation behavior of steel wires and rods of Nepal, those are used as construction materials for a reinforcing concrete, in acidic 1 M HCl and alkaline 1 M NaOH solutions at 25°C, open to air using corrosion tests and electrochemical measurements.

**Table 1.** Chemical composition of steel rods produced in Nepal

Elements	Carbon(C)	Manganese (Mn)	Silicon(Si)	Phosphorus(P)	Sulfur(S)	Iron(Fe)
Average weight (%)	0.17-0.25	0.90	0.40	0.05	0.05	balance

Prior to the immersion tests and electrochemical measurements, the steel specimens were mechanically polished with a silicon carbide paper No. 600 to 1500 in cyclohexane, degreased by acetone and dried in air. The corrosion rate of the steel wire and rod specimens was estimated from the weight loss after immersion for 240 h in 100 ml of 1 M HCl and 1 M NaOH solutions at 25°C, open to air. The weight loss measurement was done two times or more for each specimen and the average corrosion rate of individual steel specimens were estimated. The time dependence of the corrosion loss of the steel wire was also estimated at various time intervals.

The open circuit corrosion potentials (OCCP) of the steel wire and rod specimens were measured after immersion for 72 and 2 h, respectively, in acidic 1 M HCl and alkaline 1 M NaOH solutions at 25°C, open to air. The cathodic and anodic potentiostatic polarization measurements were also carried on the steel wires of Nepal in 1 M NaOH solution at 25°C. A platinum mesh and saturated calomel electrode were used as counter and reference electrodes respectively. The steel wire and rod specimens were used as working electrodes. All the potentials given

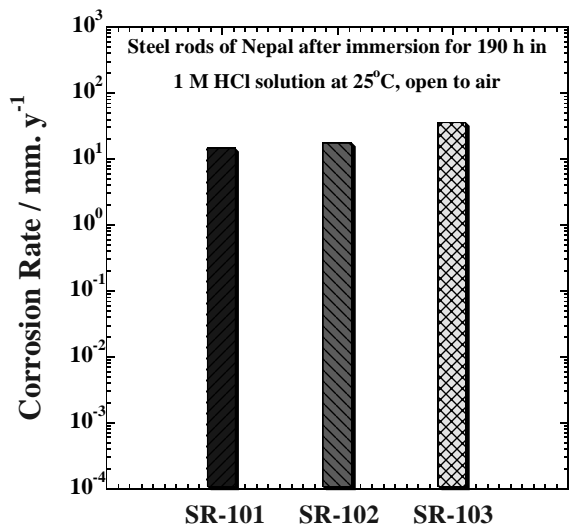
## Materials and Methods

Three different branded steel rods (named as SR-101, SR-102 and SR-103) and wires (named as SW-1, SW-2 and SW-3) produced by various steel and iron companies of Nepal were used in this study. These steels are used mainly for construction purposes and are the most commonly available in the local market. The chemical composition of a steel rod provided by the local steel and iron companies of Nepal has been presented in Table 1.

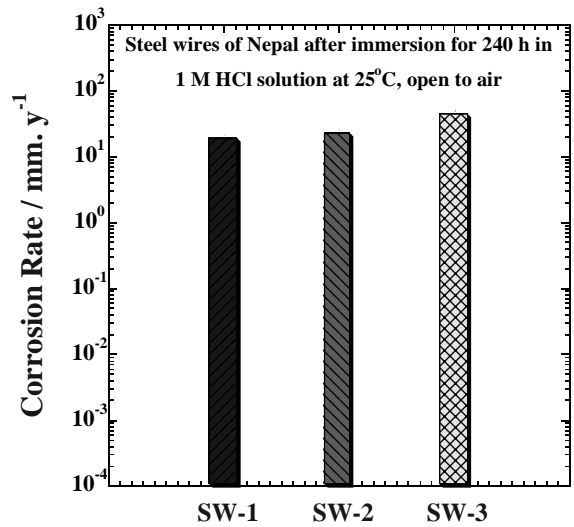
in this paper are relative to saturated calomel electrode (SCE).

## Results and Discussion

Figures 1 and 2 showed the corrosion rates of three steel rods and wires after immersion for 190 and 240 hours in acidic 1 M HCl solution at 25°C respectively. The corrosion rates of all the examined steel rods and wires were in the ranges of about  $1.3-3.4 \times 10^1$  mm/y and  $2-5 \times 10^1$  respectively. Steel rod samples SR-101 and SR-102 showed the corrosion rates in the range of about  $1.3-1.7 \times 10^1$  mm/y which were nearly half of the corrosion rate of the SR-103 sample (that is about  $3.4 \times 10^1$  mm/y) in 1 M HCl solution. Similar trend of the corrosion-resistant behavior of the steel wires of various steel and iron companies of Nepal was clearly observed in 1 M HCl solution also. Among three different steel wires of Nepal, samples SW-1 and SW-2 showed the corrosion rates in the range of about  $2.0-2.5 \times 10^1$  mm/y which were nearly half of the corrosion rate of the SW-3 sample. The corrosion rate of the SW-3 was about  $5 \times 10^1$  mm/y in 1 M HCl solution. Consequently, both steel rods and wires produced by companies 1 and 2 showed slightly higher corrosion resistance than that of the steels produced by company 3 in acidic solutions.



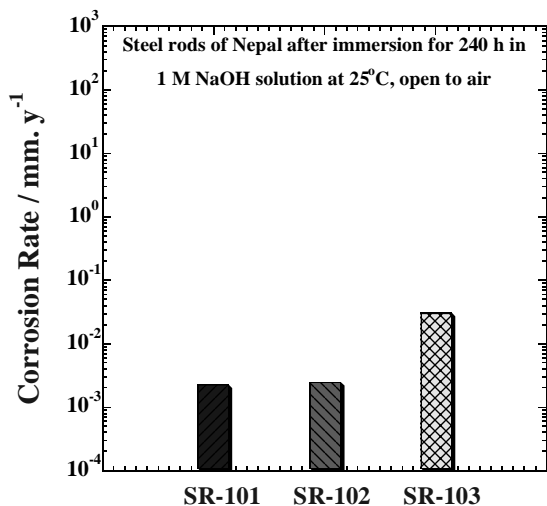
**Fig. 1.** Corrosion rates of steel rods of Nepal after immersion for 190 h in 1 M HCl solution at 25°C



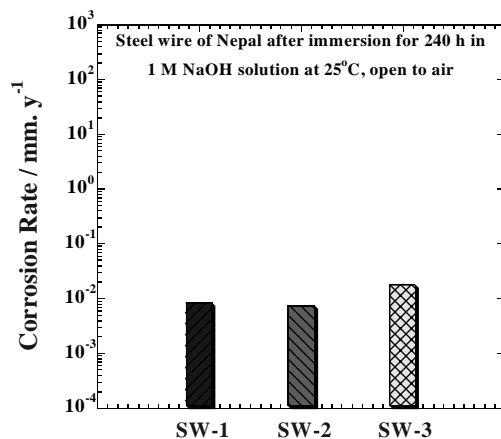
**Fig. 2.** Corrosion rates of steel wires of Nepal after immersion for 240 h in 1 M HCl solution at 25°C

Figures 3 and 4 showed the corrosion rates of the steel wires and rods respectively, after immersion for 10 days in alkaline 1 M NaOH solution at 25°C, open to air. The corrosion rate of the steel rod samples SR-101 and SR-102 was about  $2 \times 10^{-3}$  mm/y which was more than one order of magnitude lower than that of the corrosion rate of the steel rod sample SR-103 (that is, about  $3 \times 10^{-2}$  mm/y). On the other hand, the steel wire samples

SW-1 and SW-2 showed almost the same corrosion rates of about  $8.0 \times 10^{-3}$  mm/y. However, the corrosion rate of the sample SW-3 was about two times (that is,  $18.4 \times 10^{-3}$  mm/y) than those of SW-1 and SW-2 samples. Consequently, all the examined steel wires and rods of different companies of Nepal showed very high corrosion resistance in 1 M NaOH solution at 25°C, open to air.



**Fig. 3.** Corrosion rates of steel rods of Nepal after immersion for 240 hours in 1 M NaOH solution at 25°C



**Fig. 4.** Corrosion rates of steel wires of Nepal after immersion for 240 h in 1 M NaOH solution at 25°C

In order to clarify the time dependence of the corrosion rate of the steels, the corrosion rate of the steel wire samples were estimated after immersion for various time intervals. Figure 5 showed the changes in corrosion rates of the steel wires in acidic 1 M HCl and alkaline 1 M NaOH solutions at 25°C, as a function of immersion time. The corrosion rates of the steel wires were generally high at initial period of immersion (that is, 2 hours) in both acidic and alkaline solutions. However, the corrosion rates of the steel wires become almost steady after immersion for about 35 h in 1 M NaOH while the corrosion rates of the wires in 1 M HCl become almost steady after immersion for about 120 hours. These results revealed that initially faster dissolution of the steel wires of Nepal resulted in faster passivation by forming a more protective passive film on the surface of the steel wire in alkaline 1 M NaOH solution. Consequently, all the examined steel wires showed very high corrosion resistance in 1 M NaOH solution at 25°C, open to air.

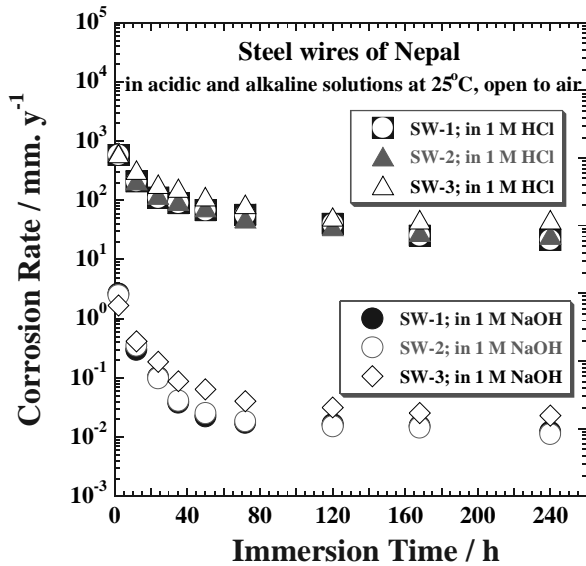


Fig. 5. Changes in corrosion rates of steel wires of Nepal in acidic 1 M HCl and alkaline 1 M NaOH solutions at 25°C, as a function of immersion time

Electrochemical measurements were carried out for a better understanding of the passivation behavior of the steel wire and rod of Nepal after immersion for 72 and 2 h respectively, in both acidic 1 M HCl and alkaline 1 M NaOH solutions at 25°C, open to air. Figure 6 shows the changes in open circuit corrosion potentials of the steel rod and steel wire samples in 1 M HCl solution, as a function of immersion time. The changes in the open circuit potentials for the examined steel wires and rods are not significant with immersion time. The open circuit potentials of all the examined steel wires are more negative value (that is, in the range of about -500 to -535 mV, SCE) than those of steel rods (that is in the range of -425 to -435 mV, SCE) after 2 h immersion in 1 M HCl, and hence steel rods showed more passivity and corrosion-resistant than those of steel wires. However, the open circuit potentials of the steel wires shifted to more positive potential range (i.e., about -512 to -464 mV, SCE) after 72 hours immersion. These facts coincide with the changes in the corrosion rates of the steel rod and wire samples in 1 M HCl solution as shown in Figures 1 and 2.

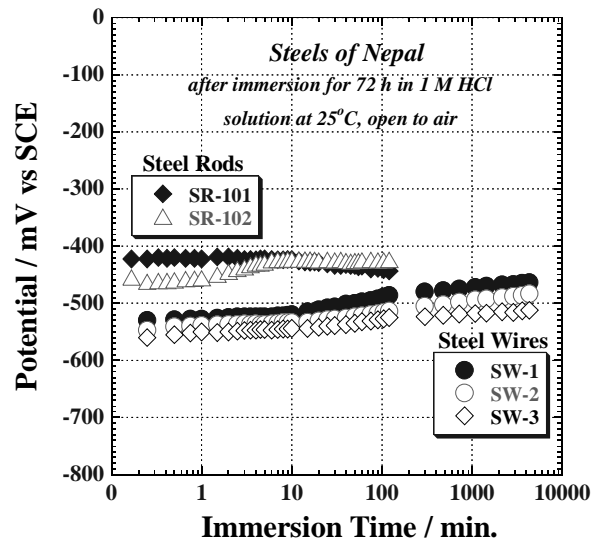


Fig. 6. Changes in open circuit corrosion potentials of steel rods and wires of Nepal in acidic 1 M HCl solution at 25°C, as a function of immersion time

On the other hand, the nature of change of the open circuit corrosion potentials of the steel wire and rod samples with immersion time in alkaline 1 M NaOH solution was not same as in acidic 1 M HCl solution. The changes in the open circuit potentials for all the examined steel rod and wire samples are shown in Figure 7 in 1 M NaOH solution at 25°C, as a function of immersion time. The changes in the open circuit potentials for all the examined steel rods and wires were clearly observed with immersion time and shifted to more positive (or more noble) direction in alkaline 1 M NaOH solution. The open circuit potentials of all the examined steel rods are more positive value (that is, in the range of about -140 to -160 mV, SCE) than those of steel wires (that is, in the range of -280 to -300 mV, SCE) after immersion for 2 h in 1 M NaOH, and hence steel rods showed more passivity and corrosion-resistant than those of steel wires as shown in Figures 3 and 4. However, the open circuit potentials of the steel wires shifted to more positive potential range (i.e., about -204 to -160 mV, SCE) after immersion for 72 h in alkaline 1 M NaOH solution. Consequently, steel rods and wires were more passive in alkaline 1 M NaOH than that in acidic 1 M HCl. These facts coincide with

the changes in the corrosion rates of the steel wires in both HCl and NaOH solutions as shown in Figures 1, 2, 3 and 4.

Figure 8 showed the potentiostatic anodic and cathodic polarization curves for the steel wires after polarization for 1 h in alkaline 1 M NaOH solution at 25°C, open to air. All the examined steel wires show clearly the active-passive transition and transpassivation. The steel wire is active at the potential range between -500 to -250 mV (SCE) while it is passive at the potential range between -200 to 250 mV (SCE) in 1 M NaOH solution. The passive current density of the steel wires was in the range of  $2-4 \times 10^{-2}$  A/m<sup>2</sup> in 1 M NaOH solution. Transpassivity was clearly seen after polarization at about 200 mV (SCE) or more anodic potentials probably due to the formation of soluble ferrate ( $\text{FeO}_4^{2-}$ ) in 1 M NaOH solution (Uhlig & Revie 1991). Consequently, the corrosion rates of the steel wires and rods are significantly higher in 1 M HCl than those in 1 M NaOH as shown in Figures 1, 2, 3, 4 and 5. This is mostly due to an ennoblement of the open circuit potentials of steel wires at passive potential regions in 1 M NaOH solution at 25°C.

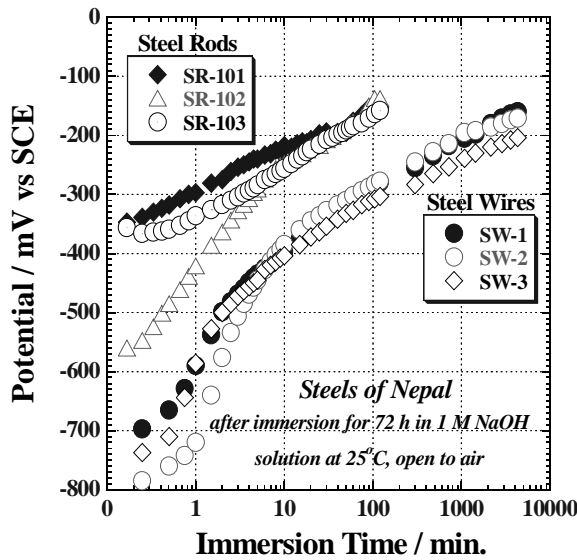


Fig. 7. Changes in open circuit corrosion potentials of steel rods and wires of Nepal in alkaline 1 M NaOH solution at 25°C, as a function of immersion time

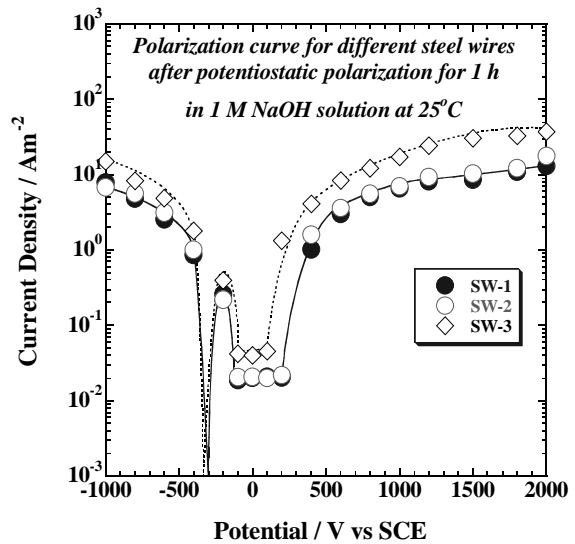


Fig. 8. Potentiostatic polarization curves of the steel wires of Nepal in 1 M NaOH solution at 25°C, open to air

The steel rods and wires produced by companies 1 (samples SR-101 & SW-1) and 2 (samples SR-102 & SW-2) showed higher corrosion resistance than that of the steels produced by company 3 (samples SR-103 & SW-3) in both acidic and alkaline solutions.

The corrosion resistance of all examined steel rods and wires of Nepal is significantly higher in alkaline solutions than in strong acidic solutions, mostly due to an ennoblement of the open circuit potentials of steels at passive potential regions of steel in 1 M NaOH, while OCPs of the steels were located in the active potential regions in acidic 1 M HCl solution at 25°C.

The faster dissolution of the steels of Nepal results in faster passivation by forming a more protective passive film on the surface of the steels in alkaline 1 M NaOH solution. Therefore, these steel rods and wires seem to be very corrosion resistance in very alkaline environments like of the reinforced concrete.

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