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Effect of moisture contents of bentonitic clay on the corrosion behavior of steel pipelines

A.M. El-Shamy [a,*], M.F. Shehata [a], A.I.M. Ismail [b]

[a] Physical Chemistry Department, Electrochemistry and Corrosion Lab, National Research Centre, Dokki 12622, Cairo, Egypt
[b] Geological Sciences Department, National Research Centre, Dokki 12622, Cairo, Egypt

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ABSTRACT

Bentonite is a very important naturally occurring clay and it is used in many great commercial processes. Somehow it is sustained next to the mild steel in many industrial uses. The monitoring of corrosion of mild steel in different moisture contents is very important to avoid deterioration of metal surface of drilling equipment and pipelines. The electrochemical behaviors of mild steel in bentonite were investigated for a series of moisture content. The open circuit potential and potentiodynamic polarization curves proved that the corrosion rate is directly proportional to the moisture content till 40%. The corrosion rate is approximately constant in spite of increase of moisture content more than 40%. The weight loss measurements also proved that there was the same trend of mild steel in bentonite at different moisture contents. The mode of action of bentonite is considered, so the used sample was investigated according to engineering, mineralogical and chemical behaviors by X-ray diffraction, X-ray fluorescence, particle size distribution, natural moisture content, Atterberg limits and swelling shrinkage characteristics.

1. Introduction

1.1. Corrosion overview

The corrosive nature of soils is affected by six parameters like moisture content, pH, resistivity, redox potential, chloride and sulfate contents. The buried pipelines, which are used in supplying drinking water, gas, oil and so on are affected by all of these parameters. The investigation of these soil parameters is considered as very interesting because the corrosive soil can cause failure for buried pipeline. If we make deep research to understand the corrosivity of the soil in particular we can minimize the corrosion of buried pipeline. It is well known that the corrosion control of these buried pipeline structural materials will save the high cost which is required for regular maintenance and replacement (Uhlig and Revie, 1991; Ismail and El-Shamy, 2009). The corrosion behavior of the soil also depends on the presence of anaerobic sulfate-reducing bacteria (Borenstein, 1994; Maslehuddin et al., 2007; El-Shamy et al., 2009; Neelam and Abhinav, 2014). There is an inverse relationship between the corrosion rate and soil resistivity, it has been reported that the sandy and gravel soil have a high corrosion resistance for buried pipelines because of its low conductivity and high resistivity (>6000 Ω·cm). The moisture content is considered as a very important factor on the corrosion behavior of the soil, however with increasing of moisture content the soil resistivity value is decreased and the soil becomes corrosive (Rim-rukehand and Awalefe, 2006). The external corrosion of pipelines chemical, petrochemical and petroleum companies is generally controlled by cathodic protection to avoid the effect of soil corrosivity (Bhattarai, 2013; Javaherdashti et al., 2013).

1.2. Geological overview

Bentonite is now used extensively throughout the world in civil engineering purposes such as lightweight concrete, trenching, bored piling, slurry wall installation, soil sealing and other hydraulic barrier applications. In civil engineering applications bentonite is also used traditionally as a thixotropic, support and lubricant agent in diaphragm walls and foundations, in tunneling, in horizontal directional drilling and pipe jacking. Bentonite, due to its viscosity and plasticity, is also used in Portland cement and mortars. In Egypt, some authors studied natural materials for producing concretes (Ismail and Ghabrial, 2009; Ismail et al., 2013 and Ismail et al., 2013 and Ismail et al., 2014a, 2014b; Ismail et al., 2014a, 2014b). Many authors studied different raw materials for producing lightweight concretes (examples Khokhrin, 1973; Alduaij et al., 1999; de'Gennaro et al., 2005). Bentonite is a naturally occurring clay of great commercial importance in many different industrial processes. It used in producing lightweight aggregate and the high percentage of the voids and pores are characteristic for these aggregates. Expanded clay is produced by firing natural clay, which swells at 900–1200 °C due to the action of the gases

* Corresponding author.
E-mail address: elshamy10@yahoo.com (A.M. El-Shamy).

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generated inside the mass. The lightweight of this product is largely attributed to a relatively high proportion of semi-closed pores which can account for up to 90% of the particle volume which expands into a mass with a high proportion of semi-closed pores. The porous structure of loose expanded clay granulates is composite and formed by the voids between individual grains and by the air-filled opening in the grain base. The conglomerates produced by the use of expanded clays are promising for the concrete prepared from a mixture of the recycled waste glass and expanded clays, with high mechanical properties attributed to the clays coupled with lower thermal conductivity of expanded glass. It is important to recognize that the properties of bentonites from different sources vary, and to take these variations into account when deciding on the suitability of a particular bentonite for a specific purpose. The purpose of this research paper is to provide information that will enable a decision to be made as to whether or not a particular bentonite will produce corrosion behavior at different moisture contents. The properties of bentonites from different sources vary, and it is important to understand that a property which may be required for one application may not be required for another. Differences in the properties of available bentonites should therefore be considered before deciding which bentonite to use for a particular application. Engineers may wish to consider their use, but should always seek the necessary specialist advice on their usage and application.

2. Materials and methods

2.1. Materials

2.1.1. Electrodes

Mild steel rod was subjected for elemental analysis with trace elements of (C = 0.15%, Si = 0.08%, S = 0.025%, P = 0.025% and Mn = 1.02%) encapsulated in a Teflon holder with the exposed area of 0.785 cm^2 used as the working electrode (WE). Platinum wire and Cu/$CuSO_4$ electrodes were used as counter and reference electrodes, respectively.

2.2. Methods

2.2.1. Electrochemical measurements

The electrode surface was abraded successively by emery papers of different grades, i.e. 150, 320, 400 and 600 and finely polished with a 2400 polishing paper to obtain uniform mirror like finish, degreased with acetone and washed with distilled water before experiment. The open circuit potential of mild steel electrode was subjected for 30 min in the electrolyte (bentonite) in free corrosion conditions before recording the polarization curves. Potentiodynamic polarization curves were measured on the mild steel electrode at different moisture contents.

2.2.2. Weight loss measurements

The weight loss measurements are performed with mild steel coupons, each having the dimensions of 10 × 1.5 × 0.2 cm. The steel coupons were polished with different degrees of emery papers from the rough to the finest degrees, and then washed with distilled water and degreased by acetone before immersion in water. At the end of the experiment (about 5 days), the specimens were visually inspected, cleaned and weighed. The cleaning process should remove all corrosion products from the specimens with a minimum removal of sound metal. This has been achieved by washing the coupons with running tap water and scrubbing with bristle brush. Then the coupons were chemically cleaned in inhibited 15% HCl solution. From the average value of the weight loss in the presence of different moisture contents, the metal loss per coupon area is plotted versus the percentage of moisture content. The weight loss is converted to a Corrosion Rate (CR) or a Metal Loss (ML), as the following Eqs. 1, 2 (Nnanna et al., 2013):

$$\mathrm{CR} = \frac{\mathrm{Wt.Loss\,(g)} \quad \times \mathrm{K}}{\mathrm{Density}\left(\frac{\mathrm{g}}{\mathrm{cm}^3}\right) \quad \times \mathrm{Area\,(A)} \quad \times \mathrm{Time\,(hr)}} \tag{1}$$

$$\mathrm{ML} = \frac{\mathrm{Wt.Loss(g)} \times \mathrm{K}}{\mathrm{Density}\left(\frac{\mathrm{g}}{\mathrm{cm}^3}\right) \times \mathrm{Area\,(A)}} \tag{2}$$

where $K = 3.45 \times 10^6$ in case of CR in mpy and K = 10.0 in case of ML in millimeters.

2.3. Location and behavior of the studied bentonite

The location is selected according to its importance because many pipelines of gas and oil passed through this area. The situation is considered as a great depression of about 700 km^2 that lies about 100 km southwest Cairo. It is well known that bentonite deposits are found in many localities such as Komoshim, Qasr El-Sagha, Wadi EL Rayan, Sayala, Gerza, Ellahon and Shaklowaf. The studied bentonite in this paper is located in Komoshim area (35 km Fayoum-Cairo district road) is found in Qasr El-Sagha Formation of Upper Eocen age attaining about 2–4 m in thickness. The bentonites are of sodium type and composed mainly of montmorillonite (34–51%), kaolinite (46–62%) as well as illite (3–4%) (El-Miligy and Rizk, 1999). Qaser El Sagha bentonites are also of Upper Eocenc age (the area is about 40 km Cairo-El-Fayoum district road). The bentonite bed is bound by ferruginous limestone bed on top and ferruginous sandy shale bed at the bottom. It is calcium bentonite of greenish yellow color with grain size ranging between 1.7 μm and 2.6 μm composed mainly of montmorillonite (47.5%), kaolinite (32.4%), gypsum (8.2%), quartz (10.7%) and some impurities. The bentonite in Wadi El-Rayan (near Lake Qarrun) is found in the form of three beds ranging in thickness between 8, 2.8 and 2.9 m, that belongs to Gehanem Formation (Upper Eocene). They are gray in color and of calcium type. Commercial bentonites are hydrated alumino silicates, and comprise predominantly of the mineral montmorillonite. Bentonite occurs as a clay ore containing up to 50% moisture. Commercially viable deposits consist of accessible clay seams, low in accessory minerals, which can be cleanly worked to minimize unwanted inclusions such as sand. The characteristics of the clay vary, and selection is based on factors such as natural sodium bentonite which is characterized by very high swelling ability, high liquid limit and low filter loss. The predominant exchangeable cation in natural sodium bentonite is the sodium cation but there may also be significant amounts of other cations present. Natural calcium bentonite where calcium is the predominant exchangeable cation, is mined world-wide. It has much lower swelling ability and liquid limit, and much higher filter or fluid loss than natural sodium bentonite. Sodium-activated bentonite is produced by the addition of soluble sodium carbonate to calcium bentonite. This affects a base exchange on the surfaces of the clay particles, replacing calcium ions with those of sodium.

3. Results and discussion

3.1. Electrochemical measurement results

3.1.1. Open circuit potential

The corrosion potential or open circuit potential (OCP) variation with time can be measured by determining the voltage difference between an immersed metal surface in bentonite at different moisture contents and an appropriate reference electrode. The suitable reference electrode in this study is Cu/$CuSO_4$. The effect of depolarizers on corrosion reactions could be estimated from the measurement of (OCP) changing with time. Fig. 1a shows the curves of the open circuit potentials versus time for the mild steel electrode in bentonite at different