ISSN: 2716-9227 Algerian Journal of Engineering and Technology 06 (2022) 085–097 e-ISSN: 2716-9278

Algerian Journal of Engineering and Technology

Journal homepage: https://jetjournal.org/index.php/ajet

Original Article

Investigation of soundness and erosion rate of rocks used for strengths the bank river in southern Iraq

Haider Hadi Jasim

Chemical Engineering Department, College of Engineering, Basrah University, Iraq

ARTICLE INFO

Article history:
Received 13 March 2022
Revised 23 May 2022
Accepted 27 May 2022

Keywords:
soundness;
rock;
porosity;
absorption;
erosion rate;

ABSTRACT

Rocks are the basic materials that are used to strengthen the banks of rivers. Their properties and characteristics play an important role in controlling erosion problems. This paper compares and studies the soundness and erosion rates of several types of rocks collected from four locations in Muthanna Province, southern Iraq. Soundness testing is performed using two experimental approaches (ASTM C88 method and EN 1367-2 (Annex B) approaches). To perform the erosion test, a rotating erosion testing apparatus (RETA) was built in the laboratory. Soundness tests indicated that the rock of South Muthanna sites (SRM2) had a lower resistance to degradation, whereas the rock of West Muthanna sites (WMA1) had a higher resistance. Both ASTM C88 and EN 1367-2 techniques yield similar results, but the EN 1367-2 method yields greater mass loss than ASTM C88. As well, it was discovered that the porosity of the rock and its capacity to absorb water directly affect the soundness test results. Tests conducted with the erosion function apparatus (EFA) indicated that the erosion rate value is higher than those obtained from the rotating erosion testing apparatus (RETA). High water salinity decreases erosion rates; whereas higher water velocity leads to increase it.

1. Introduction

All riverbanks erode naturally; it is a continuous process that occurs over time and leads to the accumulation of sediments and suspended matter [1]. The factors influencing riverbank and dims erosion in southern Iraq are complex and interrelated. Among these factors are rains, strong winds, human impact, water salinity, and the rate, amount, and velocity of water into river streams which play a large role, especially during a short winter season. River bank erosion is a very important problem due to chemicals, construction materials and sediment, which end up being carried into waterways along with a variety of pollutants. Moreover, it has a negative impact on the quality of water and it can drastically change the shape of a landscape. Additionally, it causes huge economic losses. In order to reduce riverbanks erosion problems, several methods have been employed. Some methods utilized natural materials (rocks and stones) to reinforce and cover riverbanks and dams that can actually improve the appearance of the river stream and provides benefit to wildlife [2]. All rocks and stones used are of natural origin, and usually the most common type spread in southern Iraq is limestone, whose chemical composition contains calcium carbonate ($CaCO_3$). Most of the rock and stone quarries in southern Iraq are located in Al-Muthanna province. Additionally, this rock is readily available, it is inexpensive, easy to cut, and easy to transport. The presence of $CaCO_3$ in rocks reduces the rock solubility in acidic and alkaline water, as well as neutralizing acids in the soil, reducing porosity, and improving rock resistance [3].

Before using rocks to strengthen river banks, it is necessary to study their properties, evaluate their quality and the effect of water on them before use. The quality of rock can

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* *Corresponding author.* Tel.: 07840043748
E-mail address: raidhani73@yahoo.com

Peer review under responsibility of University Basrah.

be assessed by conducting specific engineering tests, including tests for soundness and erosion. Other properties such as water absorption and density are also used to characterize rock durability and strength. Soundness tests of rocks are used to measure a rock's resistance to degradation caused by weathering under service conditions. In the soundness test, the rock samples undergo alternate cycles of immersion in magnesium or sodium sulphate solutions and then dried. For assessing a rock's soundness, there are two approaches: ASTM C88 method and EN 1367-2 (Annex B) approaches [4, 5]. The ASTM method uses sodium or magnesium sulphate (hydrated or anhydrous), while the EN 1367-2 method uses heptahydrate magnesium sulphate. With both tests, there is a requirement of a specific density range for salt solutions and based on the computation of a weighted average [6]. Additionally, rocks are porous materials that can absorb and release water, which affects their strength to a large extent [7]. A rock erosion process is either rock substance erosion or rock mass erosion. Rock substance erosion refers to the erosion of the materials themselves, whereas rock mass erosion refers to the removal of the rock blocks from the joined rock masses [8].

Few studies have been conducted on strengthening the banks of rivers with rocks and assessing the effects of various factors on them in Iraq. Also the studies of soundness of rock used ASTM C88 and the EN 1367-2 methods are very limited. Osama et al. [9] examined the effect of rainfall on erosion in several parts of Iraq's rivers and cities. They showed that the rain is contributing greatly to erosion problems and that there is a strong positive relationship between rainfall and erosion. Albadran et al. [10] researched the erosion and sedimentation problems of the Shatt Al-Arab river in the southern Iraqi region. The researchers demonstrated that the bank river erosion process is restricted to areas of the site where strong water flow occurs and is largely concentrated in meander. Samadi et al. [11] Researched the main factors contribute to riverbank failure. They illustrated that a significant portion of the erosion rate and stability of riverbank can be traced to soil properties, particularly density and grain size. Janet et al. [12] studied the parameters support severe erosion of riverbanks and deviation of rivers. They found through research that riparian slope and flow variation affect riverbank erosion and river deviation. Harrison et al. [13] studied carbonate rock characteristics and deformation influenced by water impact and rock porosity. They demonstrated that rock porosity affects rock deformation and, therefore, rock strength. Balazs et al. [14] conducted an experimental study by using the European standard (EN 1367-2) to assess aggregate durability under salt weathering. It was discovered that a linearly rising tendency in the values of magnesium sulfate during the test for a long time experiments of salt crystallization. Toan et al. [15] studied the riverbank cantilever failures and indicate that the failure shapes depend on the properties of soil, and water levels fluctuate along the river sides.

In this study, the rotating erosion testing apparatus (RETA) is constructed in a laboratory and used to evaluate the effects of pH, velocity, and salinity of water on erosion rates of rocks used to reinforce river banks and earth dams in southern Iraq. The rock samples were collected from four different positions in Muthanna Provence, southern Iraq. Rocks were tested for soundness using two experimental methods: ASTM C88 and EN 1367–2 method.

2. **Materials and Methods**

2.1. Rocks Samples

In general, the most important stones and rocks quarries are located primarily in the Muthanna province in southern Iraq. As shown in Figure 1, there are four main quarries for extracting rocks in this province. These main quarries are the following:

- West Muthanna area (WMA), there is three quarries in this region refer as (WMA1, WMA2, and WMA3).
- Muthanna - Salman area (MSA), there are three main quarries refer as (MSA1, MSA2 and MSA3).
- The south region of Muthanna (SRM), it is located south of Muthanna and there are 5 main rock quarries refer as (SRM1, SRM2, SRM3, SRM4, and SRM5).
- The east regions of Muthanna (ERM), there are two main quarries refer as (ERM1 and ERM2).

2.2. Simples Preparation and Tests According To the ASTM C88 Method

This test technique is outlining an initial test procedure for assessing a rock's soundness in a preliminary manner. To perform this test, a square sample has a dimension of 12.5 mm length, 4.75 mm thick, and has a weight of 300 g been used, according to the procedures outlined in ASTM D75-13 [16], and ASTM C88-13 [17]. The instruments utilized are as follows:

- Baker 500 ml for immersing the samples.
- Water baths for regulating the temperature of the test rock samples.
- The magnesium sulfate solution will prepared by melting 500g of magnesium sulphate (anhydrous) in 1L water at (21°C) for the immersion of test rock samples.

- The drying oven must be able to maintain a constant temperature of 110°C.

The bakers are filled with the prepared test solution, then the test samples are immersed in the solution for a period 16h to 18h, ensuring that the test samples are completely immersed by the solution. A cover is placed over each baker to minimize evaporation and accidental accumulation of extraneous substances. During the immersion test period, the samples are kept at 21°C. Extract the rock samples from the test solution and allow them to drain for 15 min before placing them in a 110°C oven to dry. Following that, remove each experiment sample from the dry oven and weigh it at intervals 2h to 4h to calculate the weight losses of each test samples. The percent mass loss is calculated as follows:

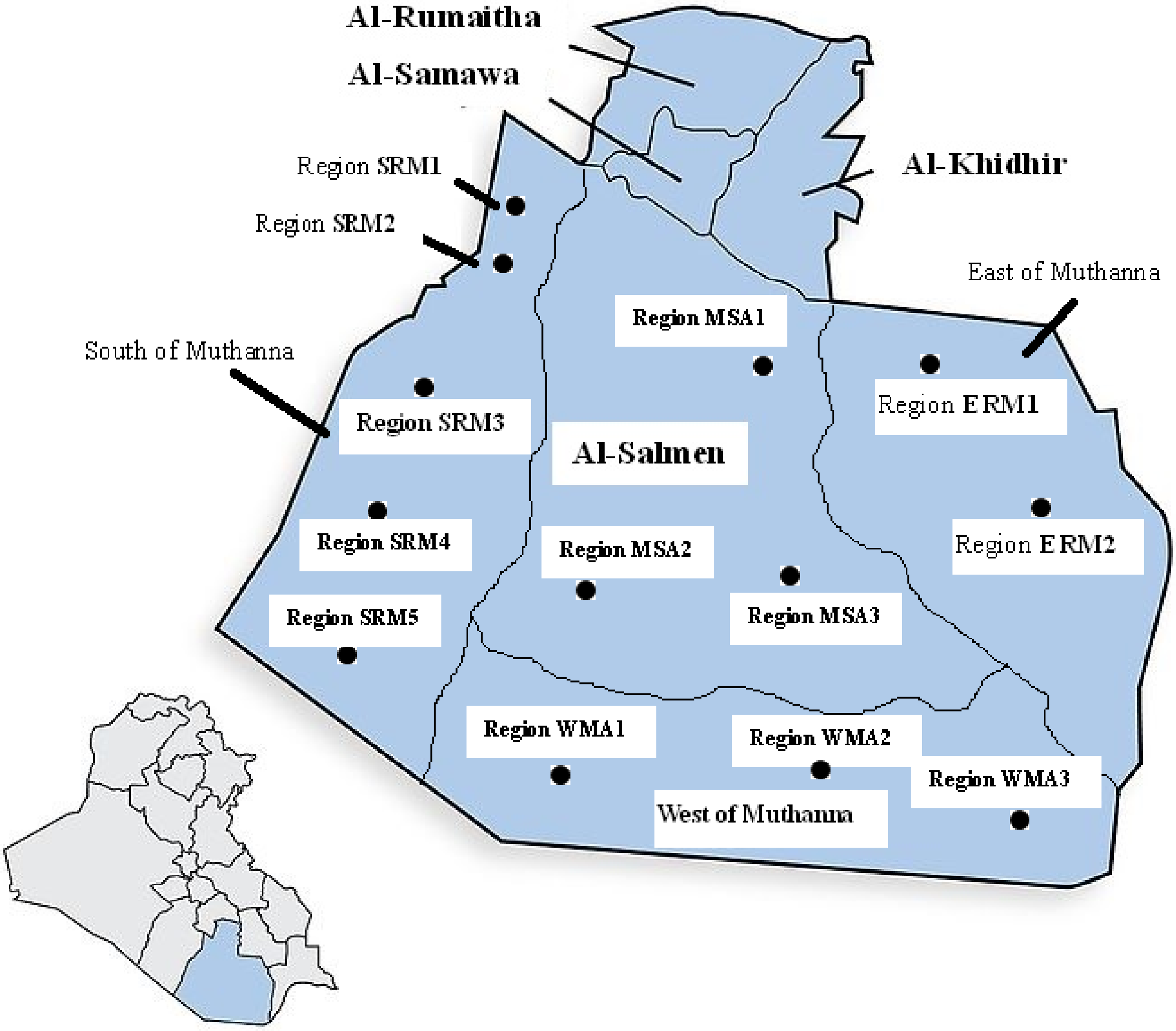


Fig 1. Distribution of rock sites in Muthanna province south Iraq.

$$\% \, mass\ loss = \frac{M_1 - M_2}{M_1} \times 100 \qquad (1)$$

Where,

M_1: initial mass of test specimen in g.

M_2: final mass of test specimen in g.

2.3. Simple Preparation and Experimental Test by EN 1367-2 (Annex B) approaches

The EN 1367-2 approach uses magnesium sulphate heptahydrate. The following is a summary of the approaches: Each sample will be suspended in a beaker containing saturated magnesium sulfate solution at (20+2)°C, so that the tops of the rocks are completely submerged to a depth of 2 cm for (17+0.5) h. Maintain a minimum distance of 2 cm between each sample, the side of the beaker and the accumulated salt cakes. After each sample has been immersed in the test solution, remove it and drain for (2+0.25) h, then covering the beakers immediately. Each sample is dried and cooled to 25^{o}C for 15 min., and then start the next immersion cycle, a total of five cycles and each cycle required (48+2) h [18, 19]. Finally, weighting the test rocks and the mass loss for each specimen is calculated as percent using Eq.1.

2.4. Water Absorption and Porosity of Rock

The amount of water absorbed by rock specimen's is a key parameters affected on the rock strengths which can also be linked to other properties, such as porosity, shrinkage, and soundness. The water absorption test is conducted using the techniques BS 812-121 [20] and ASTM128-01 [21]. Water absorption is measured by comparing the weight of rock specimens in a water-saturated state with those after drying, then measuring the increase in weight due to pore water, and expressing it as a percentage of their dry weight. The test samples were cut into cubes with a 6 cm length on each side. A total of three rocks samples were taken from each site for testing. The water absorption value of each rock sample was calculated using the following equation [21]:

$$W_A = \frac{B}{A} * 100\ \% \qquad (2)$$

Where,
A: dry weight in g.
B: saturated surface dry weight in g.

Porosity of rocks is often measured using the saturation (imbibition) technique. In this method, a clean, dry sample of rock has dimensions of (2*2*2) cm^3 is taken and weighed. Then it is immersed in a beaker contains Toluene solution until saturated. The time of rock sample saturated is taken as 48 h [22]. The saturated sample weight is determined after excess brine is removed from its surface. The bulk volume of a rock sample that is in the form of a cube can be found by a geometric method using the calliper. From knowing the saturating fluid density (ρ_{fluid}), the porosity ∅ is determined using the relation [22]:

$$\emptyset = \frac{(W_{sat.} - W_{dry}) / \rho_{fluid}}{V_{bulk}} \qquad (3)$$

Where,
W_{dry}: weight of dry rock.
W_{sat}: weight of saturated rock.
V_{bulk}: bulk volume of the sample.

2.5 Erosion Test Methods

Two types of experimental erosion tests were used to estimate and comparison the erosion rate values of rocks.

2.5.1. The Rotating Erosion Testing Apparatus (RETA)

The erosion test apparatus is constructed in a laboratory and is identical to that described by David et al. [23]. A collection of erosion testing equipment is illustrated in Figure 2. It is composed mainly of an outer rotating cylinder, an electric motor and a control system. A belt and pulley system connects the outer cylinder to an electric motor, which rotates the cylinder to exert shear stress on the test sample surface. The torque exerted during the test is controlled by an adjustable slip clutch. The rock specimens were cut into vertical cylindrical with a diameter of 4.45 cm and a height of 10.16 cm. The specimens also had a vertical hole in the center with a diameter of 0.48 cm. The rock sample is placed within the cylinder and linked to the control system, which allows for the application of the required torque (shear stress). The annular space between the outer cylinder and the rock sample is filled with water. Torques of 2, 3, 4, 5, 6, 7, 8, and 9 N.mm were applied throughout the test. When the test is being conducted, torque is applied and the cylinder is rotated at a consistent rotational speed. The shear stress (τ) is computed as follows in terms of torque (T) and sample dimensions:

$$\tau = \frac{T}{2\pi R^2 L} \qquad (4)$$

Where, R and L are the radius and length of the sample tested respectively.

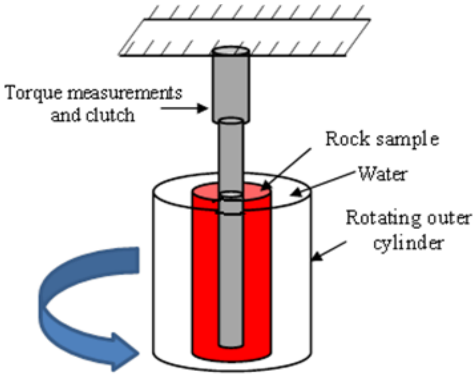


Fig 2. Apparatus used for erosion testing

Prior to performing the test, a rock sample's primary weight is determined. After that, each sample is tested for 72 h with a rotating speed of 1500 RPM. In the end, the sample is removed from the apparatus; it is placed in an oven for 16 h, and then weighed. To estimate erosion rate, subtract primary rock weight from weight of rock after test, and then apply the following equation [23]:

$$\text{erosion rate} = \frac{mass\ lost\ (g) * duration\ taime}{density\ of\ rock * sample\ surface\ area} \qquad (5)$$

Different techniques can be used to measure the density of the collected rock samples [24]. The easiest conventional procedure to measure the density of rock is to weight it in air, and refer to it as (W_a) and then weight it when immersed in pure water at 25°C and refer to it as (W_w), and then using the following equation to calculate the density [24]:

$$\rho = \frac{W_a}{W_a - W_w} \qquad (6)$$

2.5.2. Erosion Function Apparatus (EFA)

Briaud et al. [25] established a direct relationship between erosion rates and interface shear stress for rock sample in early 1990, and developed the EFA model. The erosion function unit used in this study was manufactured by Humboldt, Inc. in the USA. (ASTM D1587 [26] was followed in the preparation of the rock specimen. An illustration of the test specimen arrangement is shown in Figure 3. Samples are collected from the rock locations and deposited into an ASTM-standard Shelby tube, which is then placed into the bottom of a rectangular cross-section pipe through a circular hole. A piston on the bottom of the Shelby tubing works just like a water jet to force dirt up as easily as water erodes dirt. To calculate the erosion rate for each water velocity, divide the length of the sample eroded by the time required, while the hydraulic shear stress is computed using the following formula:

$$\tau = \frac{1}{8} f \rho v^2 \qquad (7)$$

Where,

f: fraction factor obtained from Moody chart.

ρ: mass density of water.

v: mean flow velocity in pipe (m/s).

By repeating the measurements for varying water flow rates, the rate of erosion against shear stress is generated.

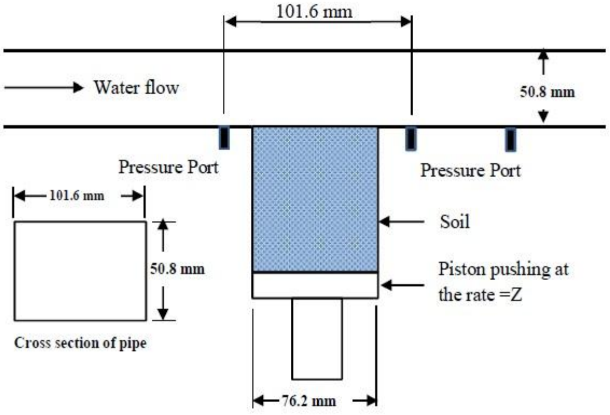


Fig 3. Arrangement of tested specimen used for erosion testing.

3. Results and Discussion

3.1. *Testing of Soundness, Absorption and Porosity of Rock*

Soundness tests were performed using the ASTM C88 and the EN 1367-2 (Annex B) approaches separately. Table 1 summarizes the measured soundness values from tests. Based on Table 1, Muthanna's southern region, SRM2, has a lower soundness value, while Position ERM1 in Muthanna's western region has a higher soundness value. Comparison of EN 1367-1 and ASTM C88 test results indicates EN1367-2 (Annex B) shows greater values of soundness testing results. The mass losses were lower for the samples tested with magnesium sulfate (anhydrous) when compared to the samples tested with magnesium sulphate heptahydrate.

Test results can be affected by various factors. Some are related to the test solutions, such as concentrations, viscosity, density, coefficient of thermal expansion, and phase changes of the two solutions, and the other is related to the rock sample composition.

Due to the higher concentration of magnesium sulfate heptahydrate in the water than magnesium sulfate anhydrous, more salt is likely to crystallize inside the pores of the rocks. Magnesium sulphate anhydrous has a lower dissociation rate than magnesium sulphate heptahydrate [27]. Typical, a solution of magnesium sulphate (anhydrous) has a viscosity ranges between 2 and 4.8 cps at 25°C and atmospheric pressure [28], while magnesium sulphate heptahydrate has a viscosity not restricted and it is dependent upon pressure and temperature. In comparison to magnesium sulphate heptahydrate, magnesium sulfate anhydrous is highly water soluble. The results reported for $MgSO_4$ hydrates agree well with localized water molecules [29]. General decomposition reactions of magnesium sulphate heptahydrate ($MgSO_4.7H_2O$) and magnesium sulphate anhydrous ($MgSO_4$) are heterogeneous reactions, as shown by their reaction equations [30, 31]:

$$\mathrm{MgSO_4.7H_2O(s)} \xrightarrow{H_2O} \mathrm{MgSO_4.7H_2O(s)} \longrightarrow \mathrm{MgSO_4.6H_2O(s)} + \mathrm{MgSO_4(aq)} \qquad (8)$$

$$\mathrm{MgSO_4}\ (s) \xrightarrow{H_2O} \mathrm{Mg^{+2}} + SO_4^{-2} \qquad (9)$$

$MgSO_4.7H_2O$ (s) dehydration in water passes through stages, as stated by reaction Eq.8, and this affects the rocks throughout the test when compared to $MgSO_4$(s) dehydration in water. The interaction of magnesium ions Mg^{+2} with water ions produces magnesium oxide (MgO), which lowers the expansion of rock and, as a result, its reduces soundness.

When the phase of magnesium sulfate salts change in the pores of rocks, it can greatly damage them. The reason for this is that the space occupied by confined salts has increased. This differing behavior can be explained by the differences in the properties of the two solutions, particularly the viscosity of the magnesium sulfate solution.

Table 1. The test results of soundness at 22^{o}C for rocks samples.

Rock Samples		**Soundness %**	
		ASTM C88	**EN1367-2 (Annex B)**
West Muthanna Area	WMA1	1.30	1.52
	WMA2	2.36	2.96
	WMA3	1.66	2.47
Muthanna Salman Area	MSA1	7.33	9.22
	MSA2	4.56	5.88
	MSA3	1.70	3.44
South Region of Muthanna	SRM1	1.20	1.89
	SRM2	0.91	1.44
	SRM3	5.11	6.67
	SRM4	1.71	2.99
	SRM5	1.89	4.33
East region of Muthanna	ERM1	10.87	13.63
	ERM2	9.33	12.44

A rock's ability to absorb water can be determined from the amount of water a rock can absorb when submerged in it. Based on experiments with the rock, Table 2 shows the measured porosity and the measured water absorption values. According to Table 2, the water absorption values of west Muthanna and south of Muthanna rocks are less than 1%. Muthanna's east region and the Muthanna-Salman area have higher absorption values and exceed 1%. In Muthanna's east region and Muthanna-Salman area that have higher water absorption values and porosity of rocks lead to rocks being less weathering resistant than in Muthanna's west and south regions. As rocks are exposed to water, the water begins to infiltrate the pores, cavities, and cracks, causing them to soften and weaken. This causes the rocks to lose their strength and stability. Alternatively, Muthanna's east region has absorption values exceeding the limitations given ASTM C88 method and EN 1367-2 (Annex B) approach, as can be seen in Table 2. According to experiments conducted by [32], Magnesium sulfate heptahydrate is less easily absorbed by rocks than Magnesium sulfate anhydrous.

Table 2 shows significant changes in value of rock porosity from one set of rocks to another. There is an inverse relationship between porosity and strength of rocks, i.e., an increase in porosity will increase water permeability and, consequently, will decrease rock strength. Based on Table 2, the west Muthanna rock has the lowest porosity, which tends to give it the best soundness. There is a high degree of porosity in the rock from Muthanna's east area, which makes it less soundness values.

Table 2. Water absorption values of rocks samples

Rock Samples		**Absorption %**	**Porosity %**
West Muthanna Area	WMA1	0.49	3.65
	WMA2	0.78	3.89
	WMA3	0.55	3.72
Muthanna - Salman Area	MSA1	1.65	5.18
	MSA2	1.37	4.83
	MSA3	1.11	4.66
South Region of Muthanna	SRM1	0.43	3.54
	SRM2	0.35	3.12
	SRM3	0.48	3.63
	SRM4	0.64	4.11
	SRM5	0.41	3.37
East region of Muthanna	ERM1	2.33	7.64
	ERM2	2.22	7.21

A rock's soundness is significantly influenced by its other rock characteristics, including the rock's absorption and saturation levels. Table 2 illustrates the significant difference in the water absorption values of four types of rock samples. A higher water absorption value leads to negatively impact the various properties of rocks [33]. When rock is exposed to water, it will soften and crystallize, which will result in a loss of strength [34]. On the other hand, in soundness test, the cycles of immersion and drying processes are affected and it’s taken into consideration effects. During the drying process, salt is precipitated in the porous empty region inside the rock. If rock sample is re-immersed, slat rehydrates and exerts internal expansion pressures that affect soundness test values [35].

In order to clarify the effect of test samples by the two different types of salts (magnesium sulfate (anhydrous) and magnesium sulphate heptahydrate), as well as the methods of tests and to clarify which of them are more destroyed, a visual photographs of the samples has been taken after the end of the test. Figures 4, 5, 6 and 7 illustrated the samples after completing testing based on the two approaches. Visual inspection of all Figures shows that the magnesium sulphate heptahydrate is more destructive to test specimens than magnesium sulphate anhydrous. When Magnesium Sulphate solution is infiltrated into rock specimens, it dissolves the salts inside the rock, and subsequent the water reacts chemically with the rock minerals. Over time, this caused changes in the rock's internal composition and microstructure, affecting its physical and chemical properties. In all Figures 4 to 7, it can be seen that there is a lot of damage as well as black spots on the specimens. As a general, the variations between the two test salt solutions are almost caused by differences in concentration, but they can also be related to other characteristics, such as viscosity. The magnesium sulphate heptahydrate salt solution has a significantly higher viscosity, and in most cases is slowly soluble, causing deep crystallization inside the rock samples. On the other hand, the lower viscosity of magnesium sulphate anhydrous retards the crystallization of solution, which produces the destructive reaction closer to the sample surface.

MSA1 (ASTM C88) MSA2 (ASTM C88)

MSA3 (ASTM C88)

MSA1 (EN 1367-2) MSA2 (EN 1367-2)

MSA3 (EN 1367-2)

Fig4. Specimens from the Muthanna-Salman Area region after testing.

ERM1 (ASTM C88) ERM1 (EN 1367-2)

ERM2 (ASTM C88) ERM2 (EN 1367-2)

Fig 5. Specimens from the east region of Muthanna after testing.

WMA1 (ASTM C88) WMA2 (ASTM C88)

WMA3 (ASTM C88)

WMA1 (EN 1367-2) WMA2 (EN 1367-2)

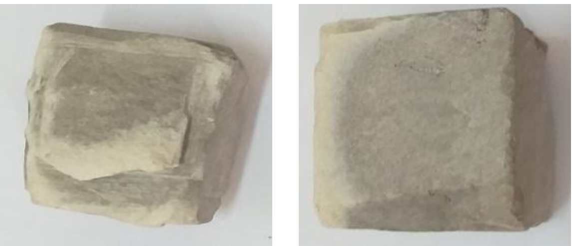
WMA3 (EN 1367-2)

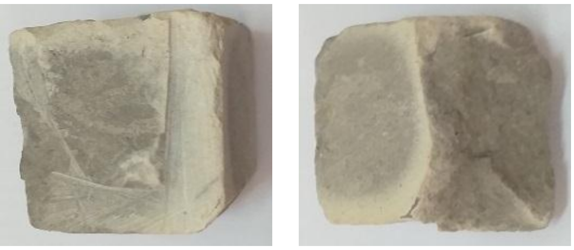
Fig 6. Specimens from the west Muthanna - area after testing.


SRM1 (ASTM C88) SRM2 (ASTM C88)


SRM3 (ASTM C88) SRM4 (ASTM C88)


SRM4 (ASTM C88)


SRM1 (EN 1367-2) SRM2 (EN 1367-2)


SRM3 (EN 1367-2) SRM4 (EN 1367-2)


SRM5 (EN 1367-2)

Fig 7. Specimens from the south of Muthanna region after testing.

3.2. Erosion Test Results

The first step in determining erosion rates from rock samples was to calculate densities of those samples using the saturation (imbibition) technique in pure water and by utilize Eq.6; the values of densities results from calculations are listed in Table 3. In the second step, estimate the erosion mass losses by conducting an EFA test and a RETA experiment test. Based on the density values stated in Table 3 and mass losses obtained from EFA and RETA tests, erosion rates are calculated using Eq.5. Figures 8 to 11 show erosion rates in (mm/y) versus shear stress (Pa) obtained from both EFA and RETA experimental tests. The scales of drawing of erosion rate are different for each figures according to data obtained from each test.

Based on table 3, the rock sample from region SRM2 of south Muthanna had the lowest density value of 2.12 g/cm^3, while the rock sample from region ERM1 from east Muthanna has the maximum density value of 2.73 g/cm^3.

According to Figures 8 to 11, all samples showed a similar erosive response, i.e. erosion rates were lower at low shear stresses and increased with increasing shear stresses. Moreover, curves have varying slopes. At the beginning of the test, there is a low erosion rate difference between the curves, but it grows as shear stress increases. Comparatively to rotational erosion test apparatus (RETA), erosion function apparatus (EFA) yields higher erosion rates. Muthanna's east region experienced higher erosion rates than other sites, while SRM2 areas in Muthanna's south region had lower erosion rates. Testing results generally show a linear relationship between erosion rate and shear stress.

Table 3. Densities of rock obtained from experimental test

Samples		**Density (g/cm^3)**
West Muthanna Area	WMA1	2.36
	WMA2	2.48
	WMA3	2.41
Muthanna - Salman Area	MSA1	2.64
	MSA2	2.52
	MSA3	2.45
South regions of Muthanna	SRM1	2.23
	SRM2	2.12
	SRM3	2.61
	SRM4	2.70
	SRM5	2.33
The east region of Muthanna	ERM1	2.73
	ERM2	2.69

As shown in Figures 8 to 11, the erosion resistance of rocks varies among the rocks regions. The reason for this depends on a variety of factors that affected both the composition of the rock and the test conditions. Due to the high porosity of rocks, water easily soaks in rock and causes cracks to form, and this effects in rock strength which resulting in rock fracture.

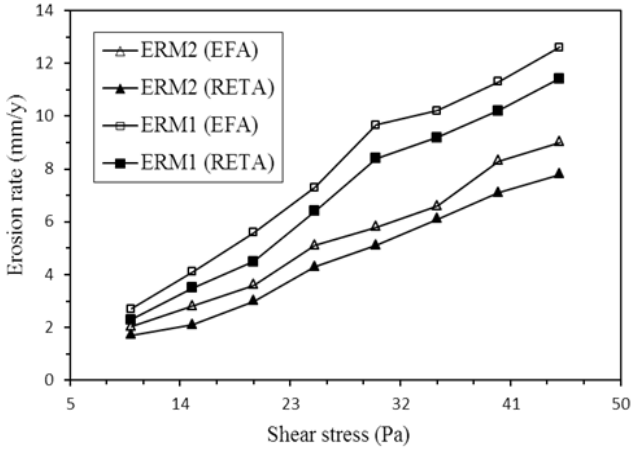


Fig 8. Erosion rate vs. shear stress for east region of Muthanna.

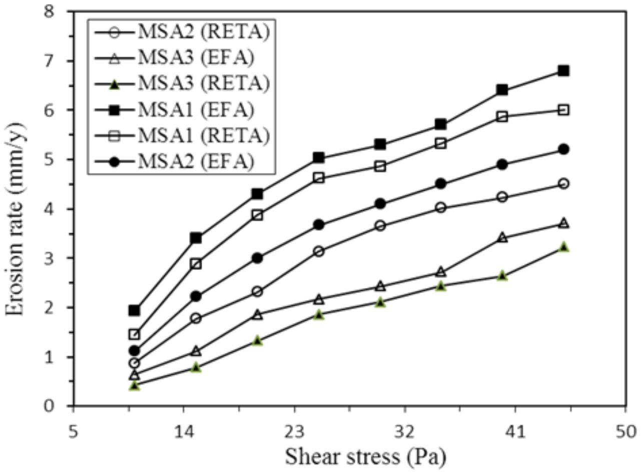


Fig 9. Erosion rate vs. shear stress for Muthanna - Salman Area.

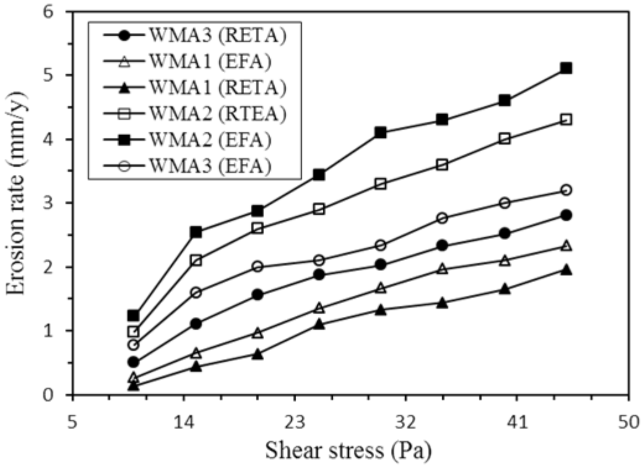


Fig10. Erosion rate vs. shear stress for west Muthanna area.

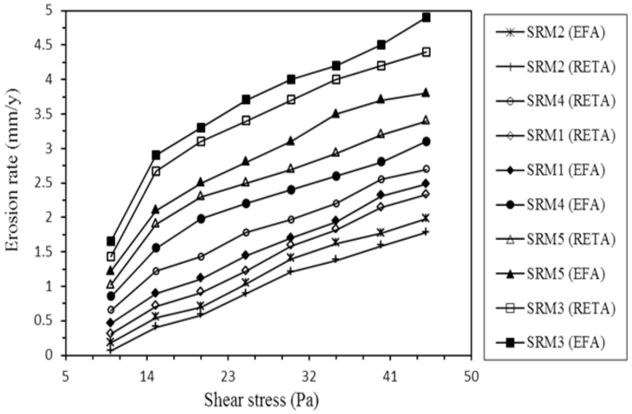


Fig 11. Erosion rate vs. shear stress obtained from erosion tests for south of Muthanna.

3.3. Evolutions the Effect of pH of Water

Test water was prepared by adding the appropriate amount of HCl solutions to the pure water. Figures 12 to 15 illustrate the erosion rate vs. shear stress of different rocks samples when exposed to acidic water with varying pH values. It has been shown that the erosion rates is inversely related to pH values, which means that lowering pH (increased acidity) leads to an increase in degradation of rock samples. The acid in the water reacts with some of the minerals in the rock, resulting in an accelerated process of rock erosion.

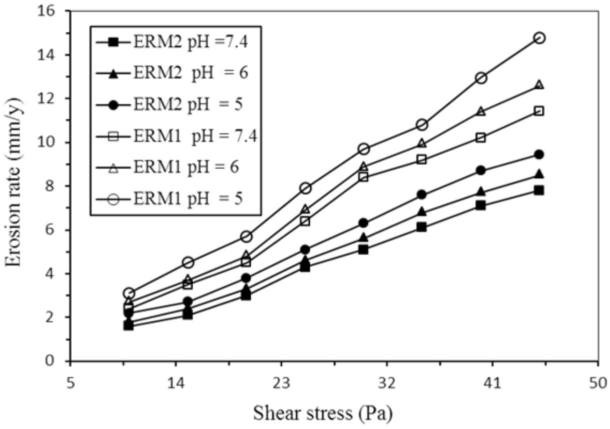


Fig 12. Erosion rate vs. shear stress at various pH values for east region of Muthanna.

The dissolution of rock occurs more rapidly in high acidic water than in low acidic water because the acidic water dissolved rocks more rapidly than lower acidic water. This results in faster fragmentation of rocks over time. However, rising pH levels have a significant effect on the physical characteristics of rock, particularly its strength, leading to higher erosion rates [36]. On the other hand, a rise in pH value) can affect the texture of the constituent minerals of rocks, which can lead to more changes in the rock texture, resulting in more rock erosion. [37].

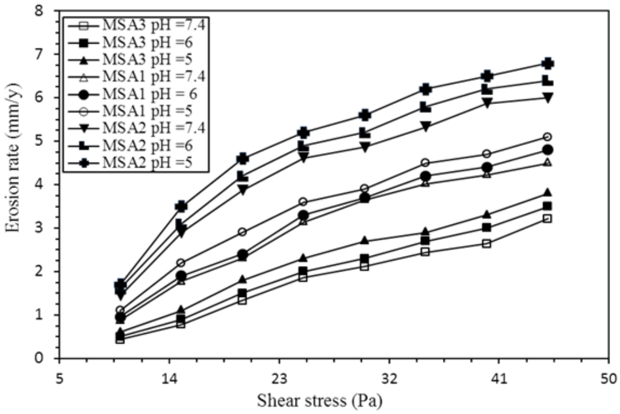


Fig13. Erosion rates vs. shear stress at various pH values for Muthanna-Salman Area.

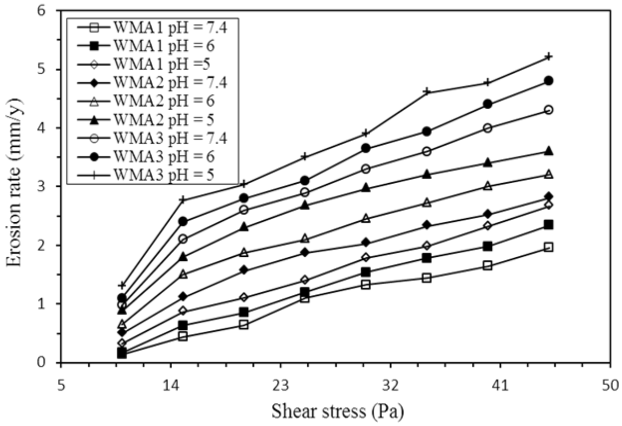


Fig 14. Erosion rate vs. shear stress at various pH values for west Muthanna area.

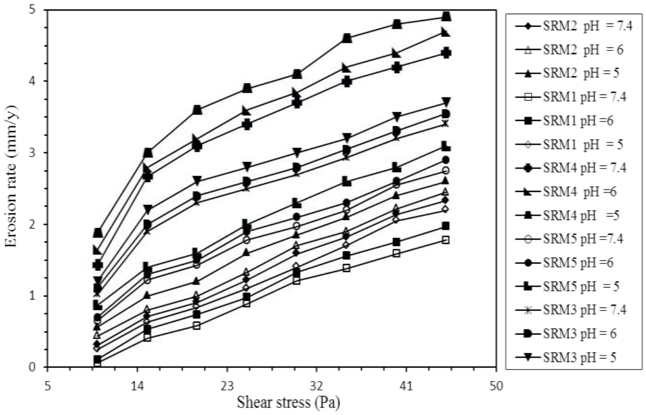


Fig 15. Erosion rate vs. shear stress at various values of pH for south Muthanna area.

3.4. Evaluations the Effect of Velocity and Salinity of Water in Erosion Rate

The rotational speeds are taken to be 1000, 1250, 1500, 1750 and 2000 RPM which are equivalent to 4.6, 5.8, 7, 8.15 and 9.32 m/s respectively. During the test, a torque of 9 N.mm was applied. The sea water is obtained from the Arab Gulf in southern Iraq. The total dissolved solid (TDS) of sea water was measured experimentally and found that it has an average value of 41,500 ppm, while TDS for Shut Arab river water has an average value of 500 ppm.

Figures 16-19 plot erosion rate versus velocity obtained from the RETA test. As shown in the figures, increasing water velocity increases erosion rate, while increasing water salinity decreases erosion rate. The rate of rock deterioration is accelerated with an increase in water velocity. Furthermore, rock sediments are carried in greater amounts when the water speed is increased. The erosion rates in river water were higher than those in sea water. This was linked to a number of factors, including the influence of water salinity. The high salinity of sea water (high salt concentrations) has an impact on erosion rates because salinity and acidification cause the pH of seawater to drop [38]. Also, the entry of various salts into the rocks and their gathering inside cracks and holes will reduce water absorption and thus reduce and slow down the effect of rock disintegration and erosion. The deposition of salts on the outer surface of rocks increases their resistance to shock from sea water currents. The rise in rock shear stress with salinity was ascribed to a higher number of interparticle bonds per area with salinity, resulting in higher the activation energy required for surface erosion [39].

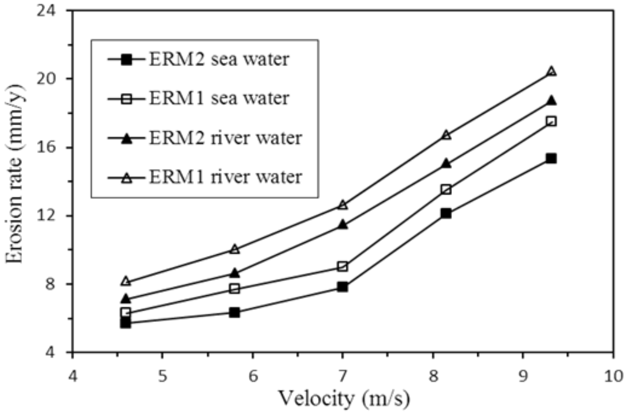


Fig 16. Erosion rate vs. velocity for east region of Muthanna.

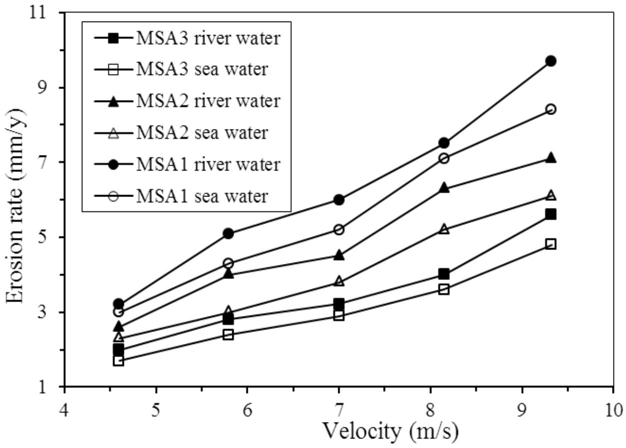


Fig 17. Erosion rate vs. velocity for Muthanna-Salman Area.

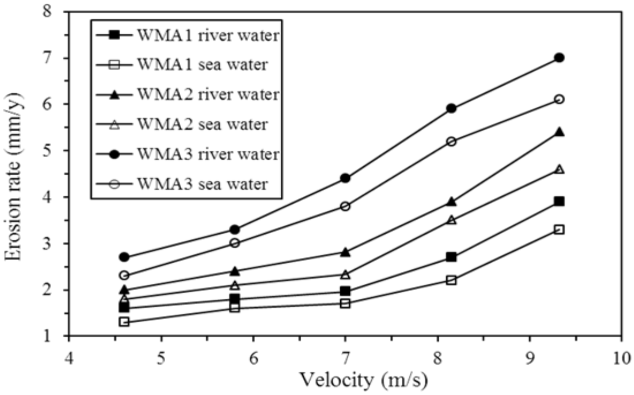


Fig 18. Erosion rate vs. velocity tested at sea and river water for west Muthanna area.

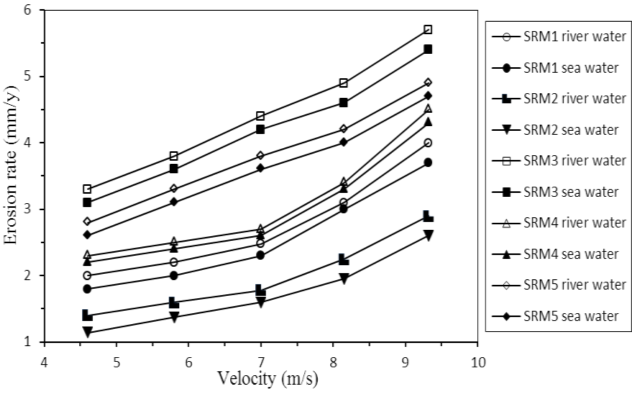


Fig 19. Erosion rate vs. velocity tested at sea and river water for south Muthanna area.

4. Conclusion

Experimental methods were used to examine the erosion rate and soundness of rock samples collected from four different locations in Muthanna province southern Iraq. As far as soundness testing goes, the ASTM 88 method and the EN 1367-2 (Annex B) approach provide similar results, except that the EN 1367-2 (Annex B) approach produces higher results than the ASTM C88 method. A higher amount of damage in test samples is caused by the magnesium sulphate heptahydrate compared to the magnesium sulphate (anhydrous). A lower soundness value and erosion rate were recorded at Muthanna's southern site SRM2 while a higher soundness rate and greater erosion rates were recorded at Muthanna's western site WRS1. Moreover, it’s found that rocks with lower water absorption are more resistant to erosion and have a high soundness.

When compared to the rotational erosion testing apparatus (RETA), the erosion function apparatus (EFA) produces higher erosion rate results. The porosity of rocks is essential in determining the rate of erosion; as porosity raises, the rate of erosion increases. The rate of erosion increases as the velocity of the water increases, whereas the rate of erosion decreases as the salinity increases. The rate of erosion is inversely proportional to the pH value; decreasing the pH enhanced the rate of rock deterioration.

Acknowledgements

The authors communicate their thoughts to the chemical engineering laboratory's staff engineer for assistance in conducting soundness testing. The author also expresses gratitude to the staff at Basrah civil engineering department for performing the ERA test.

Conflict of Interest

The author declare that they have no conflict of interest

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Recommended Citation
Jasim HH. Investigation of soundness and erosion rate of rocks used for strengths the bank river in southern Iraq. *Alger. J. Eng. Technol. 2022*, 6:85-97.