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Preparation of hydrogel from Carbopol 940 and its use in soil cohesion of gypsum soil

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Abstract
The hydrogel was prepared from Carbopol 940 by dissolving 4 grams in one liter of distilled water with gentle mechanical stirring and leaving it for 72 hours. Diluted concentrations of (0.1%, 0.5%, 1%) were prepared and diluted in 500 mL volumetric flasks and left for 24 hours. After that, the pH was adjusted using ammonium hydroxide and hydrochloric acid, with four pH values being used (2, 4, 6, 8). The hydrogel was then characterized using infrared spectroscopy. Subsequently, it was mixed with soil at different ratios (90/10, 70/30, 60/40).

Keywords: Hydrogel, Carbopol 940, soil cohesion, gypsum soil

1. Introduction
Hydrogel is considered a three-dimensional, cross-linked polymer network that can absorb water from 10 to 100 times its weight. It forms a highly hydrated, water-based gel that is insoluble and responds to several factors, including [1] pH [2] temperature [3] electric fields [4] ion strength [5]. The nature and composition of the swelling medium. The response to these variables is attributed to the presence of polar functional groups such as COOH, OH, ---edt, and others. This makes hydrogel very important in many applications, such as in artificial organs [6] biotechnology [7] ion removal [8] and agricultural applications. One of the polymers addressed in this study is Carbopol, which is widely used in gel-related applications [9-13]. It forms a networked hydrogel that can exist as either interconnected or discrete gel particles at the micron scale. It is considered a polymer with high viscosity, and at dilute concentrations, the viscosity can be controlled by adjusting the pH [14-18]. As for temperature, it has a minimal effect, making it an excellent model for studying viscosity. Carbopol hydrogels are known to exhibit very high shear stress [19, 20]. The aim of this study is to investigate the effect of pH on the polymer's viscosity and to find the optimal viscosity for this polymer in enhancing soil particle cohesion.

2. Experimental Aspect
2.1 Preparation of hydrogel for Carbopol 940
An amount of 4 grams were taken as a weight-to-volume ratio and dissolved in 1 liter of distilled water with slow mechanical stirring to avoid bubble formation. The stirring was intermittent, every six hours, and left for 24 hours. This process was repeated for three days to ensure complete polymer dissolution. After that, diluted solutions were prepared at different concentrations (0.1%, 0.5%, 1%) by dissolving them in 500 mL volumetric flasks and leaving them for 48 hours to ensure that the hydrogel did not form clumps. Base solutions were also prepared using ammonium hydroxide at a 1 molar concentration and hydrochloric acid at a 1 molar concentration. Four acidic solutions (With pH values of 2, 4, 6, and 8) were prepared and left for 48 hours to ensure the stability of the pH values. Afterward, viscosity was measured using a digital device known as the [NDJ] [21-23]. Figure (1) below shows the viscometer device used alongside the precision balance.

2.2 Soil sample preparation
An amount of 1 kilogram of gypsum soil, which suffers from significant cracks, was taken and sieved using a 1-micron sieve. It was then dried in a drying oven at 70 °C for 24 hours.

Fig 1: Below shows the viscometer device used alongside the precision balance

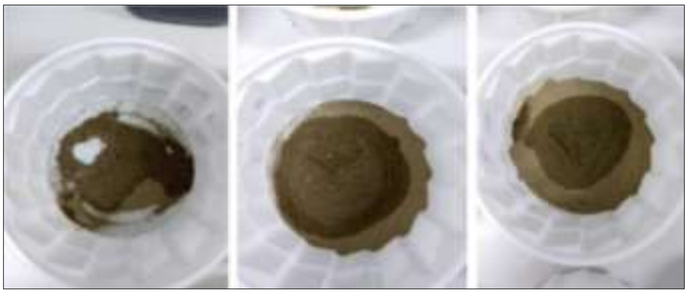

Fig 2: Images of soil samples mixed with hydrogel

2.3 Particle size analysis by dry sieving method

An amount of 30 grams of polymer-treated and untreated soil were weighed and placed in a device containing sieves of different sizes, starting from 500 microns, 300 microns, 300 microns, 212 microns, 212 microns, 150 microns, 125 microns, and 106 microns. The device was left running for 5 minutes with 100 vibrations per minute. Figure (3) below illustrates the device used in the sieving process.

Fig 3: Electric vibrator device for measuring the cohesion of soil particles

3. Results and Discussion

3.1 Infrared spectrum of the prepared hydrogel

From Figure (4) of the acrylic acid polymer before being converted into hydrogel, it can be observed that the hydroxyl group appears within a very wide range, starting from 3059 and ending at 3553 cm^{-1}. A band appears in the range of 2939-2960 cm^{-1}, which corresponds to the CH_2 group, and a strong appearance of the carbonyl group at 1714 cm^{-1}. These are the key bands in this study. However, when preparing the gel by mixing with water, it is noticed that the OH group significantly shifted from 3036 to 3213 cm^{-1}. Additionally, the CH_2 group showed a reduction in the range from 2808 to 2854 cm^{-1}, and the carbonyl group appeared very weak. This indicates the breakdown of the carboxyl group, which transforms it into a polyelectrolyte polymer, where the carboxyl group functions as a fixed anion and the proton ions as mobile cations [25]. When the hydrogel has a higher density of cross-linked bonds, it contains fewer dangling groups on its surface. Therefore, it prevents interference with neighboring particles, leading to its behavior as shown in [26]. The lower the crosslink density, the more flexible the hydrogel becomes, and the groups become more reactive with the surrounding particles [27].

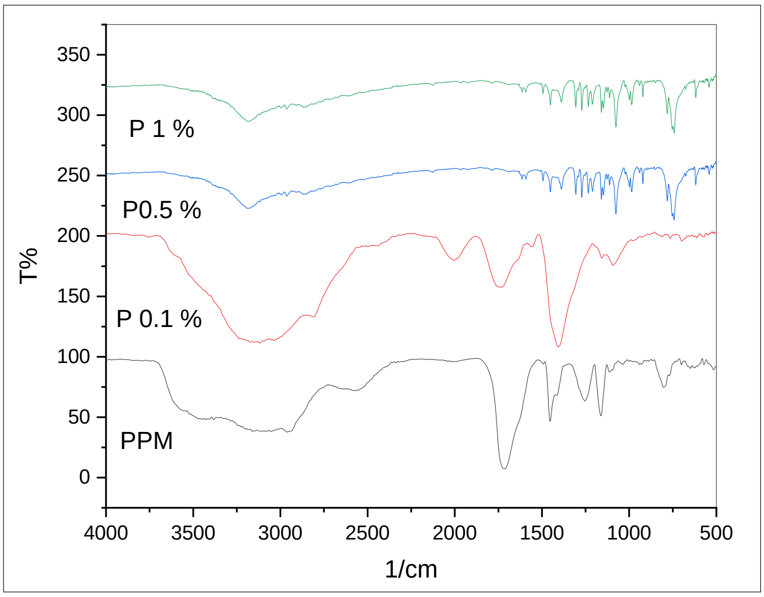

Fig 4: The infrared spectrum of Carbopol (PPM) and the prepared hydrogel polymers at a pH value of 6.

3.2 Viscosity at Different pH Values:

Based on the results obtained and shown in Table (1), there is a significant effect of pH and concentration on the viscosity of the Carbopol hydrogel. This was demonstrated by measuring the viscosity, and these changes are linked to the precise gel ratios. At a pH of 6, very high viscosity with high transparency was observed. However, at a pH of 8, the viscosity slightly decreases, and transparency remains high. At other pH levels, the viscosity significantly decreases, and transparency also reduces. The reason for the difference in transparency at various pH levels is due to a balance between the osmotic pressure inside and outside the molecules [28]. The ions directly enter the negatively charged particles, causing a disruption in osmotic pressure, which leads to the absorption of water into the hydrogel polymer, causing it to swell. At lower polymer concentrations, it was observed that a delayed response to acidic and basic pH due to the hydrogel not swelling enough to fill the voids in the polymer structure. When the pH is moderate or slightly acidic, the viscosity is very high, which enhances the crosslink density in the system [29]. Flory mentioned an inverse relationship between the swelling capacity and crosslink density, and a higher degree of crosslinking leads to an increase in hydrogel viscosity [30-31].

Table 1: The effect of increasing concentration on the viscosity of the polymer at different pH values

Polymer	pH	Concentration %	Viscosity
1	2	0.1	2.22
2	4	0.1	2.23
3	6	0.1	4.45
4	8	0.1	4.40
1	2	0.5	2.24
2	4	0.5	2.23
3	6	0.5	946.3
4	8	0.5	946.2
1	2	1	2.25
2	4	1	2.26
3	6	1	946.5
4	8	1	946.4

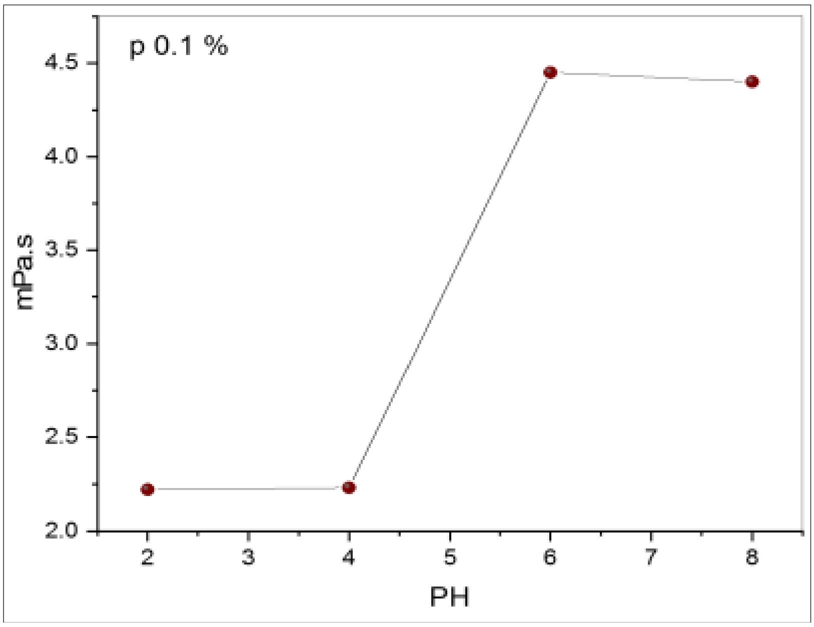

Fig 5: Effect of the acidity function of hydrogel with a concentration of 0.1% on viscosity

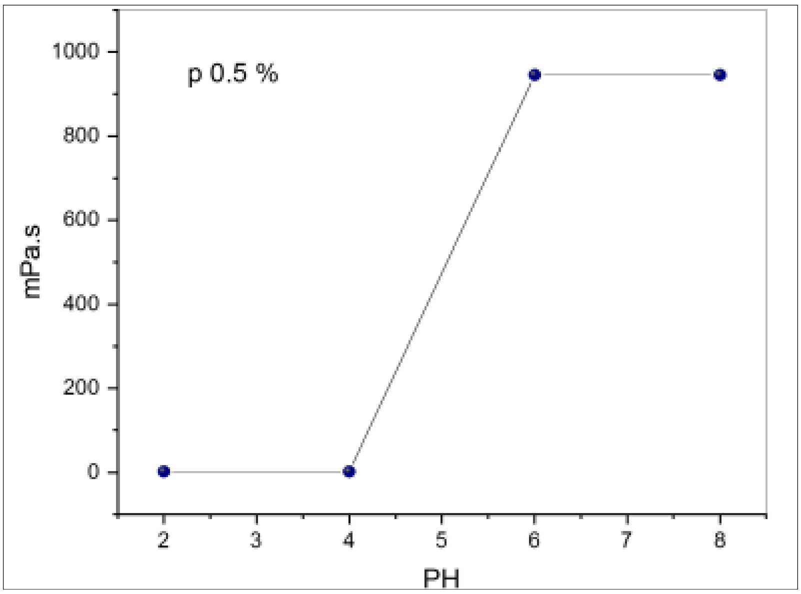

Fig 6: Effect of the acidity function of hydrogel with a concentration of 0.5% on viscosity

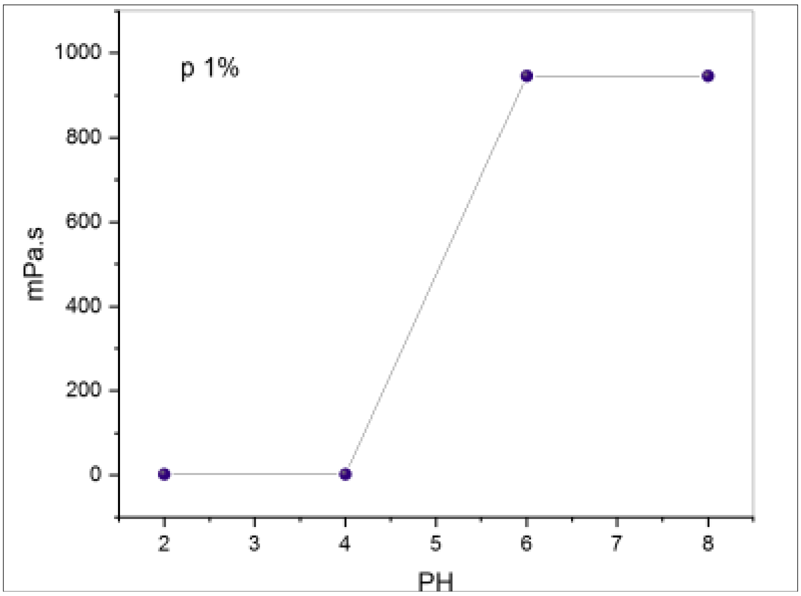

Fig 7: Effect of the acidity function of 1% hydrogel on viscosity

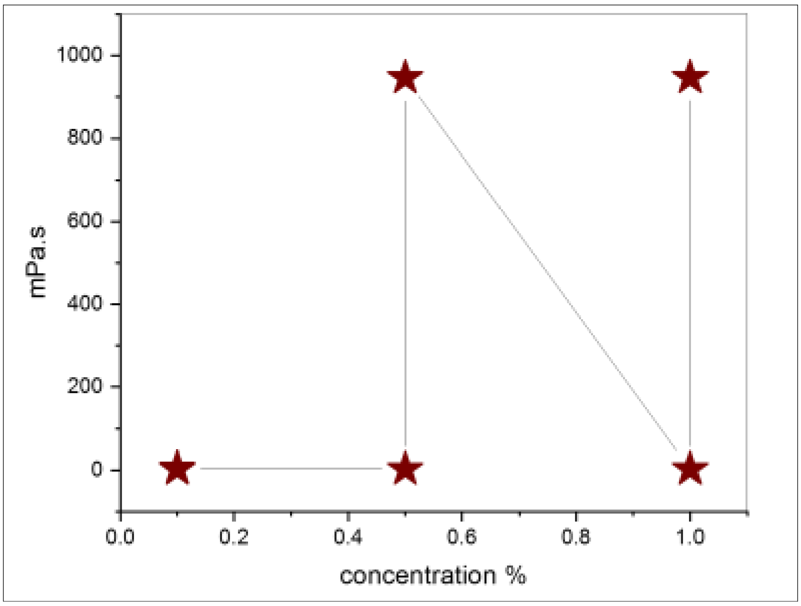

Fig 8: The effect of different concentrations of the prepared hydrogel on the viscosity

3.3 Cohesion of soil particles treated and untreated with polymer

When the hydrogel was added to the soil at mixing ratios of (60/40, 70/30, 90/10) and passed through the available sieves in the laboratory, it is observed from the passing ratio of soil particles through the sieves that the best ratio was for the polymer with a concentration of 1% and a mixing ratio of 70/30. The passing ratio was 29.99% at the 500 µm sieve, while it was 15.33% at the 106-micron sieve. This is due to the fact that the polymer acted to bind the soil strongly and reorganize its structure, i.e. its engineering composition, making it resistant to erosion, as shown in the image (19, 20), which was captured for soil from Tikrit University, College of Science, in the residential area and treated with this polymer. Meanwhile, the results for the polymer with concentrations of 0.5% and 0.1%, and a mixing ratio of 70/30, were 77.66% and 55.96% at the 500 µm sieve, and 25.48% and 40.16% at the 106 µm. This is because the viscosity of the polymer or gel was low, which resulted in the soil not binding strongly and its structure not being reorganized, leading to soil fragility. However, it still produced a good result compared to untreated soil, where the passing ratio was 73.69% at the 500 µm sieve and 25.84% at the 106 µm [32--35]. As shown in the table (2) and the figures that start from(9- 18).

Table 2: Cohesion of soil particles treated and untreated with polymer

106	125	150	212	300	500	Opening size (µm)
25.84	31.99	48.66	60.50	68.36	73.69	N%.soil
20.25	24.27	28.43	36.61	42.35	45.90	N%.p1% 60/40
15.33	15.33	21.27	25.81	28.55	29.99	N%.P1% 70/30
14.77	14.77	26.00	40.03	54.04	70.70	N%.P1% 90/10
40.63	40.63	56.01	71.38	82.49	92.78	N%.p0.5% 60/40
40.16	40.16	54.64	65.87	73.13	77.66	N%.P0.5% 70/30
18.10	18.10	30.06	44.05	59.10	75.84	N%.P0.5% 90/10
46.37	46.37	61.81	76.36	87.5	97.23	N%.p0.1% 60/40
25.48	25.48	37.12	46.51	52.58	55.96	N%.P0.1% 70/30
27.97	27.97	43.61	59.12	71.49	81.70	N%.P0.1% 90/10

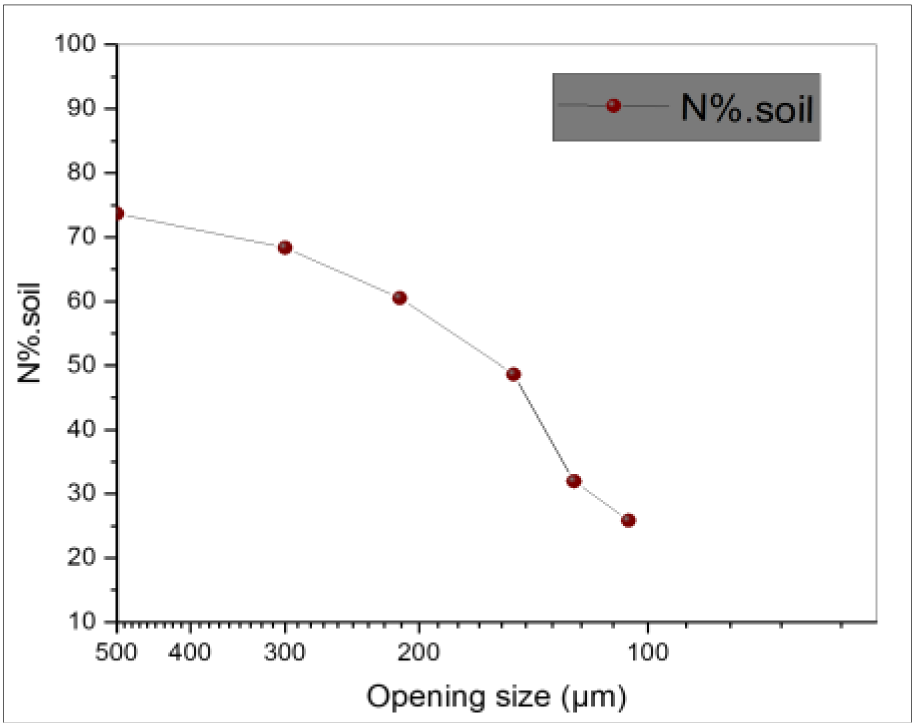

Fig 9: The effect of vibration on the cohesion of soil untreated with hydrogel polymer

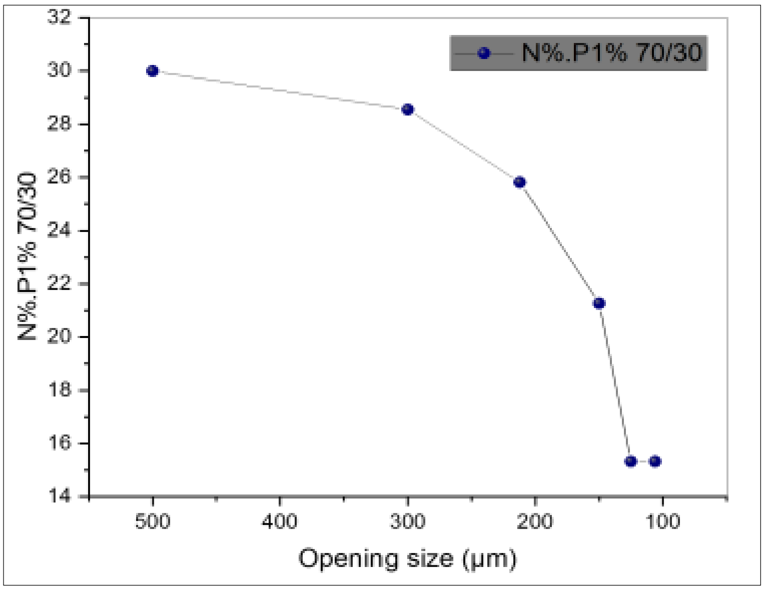

Fig 10: The effect of vibration on the cohesion of soil treated with 1% hydrogel at a mixing ratio of 70/30.

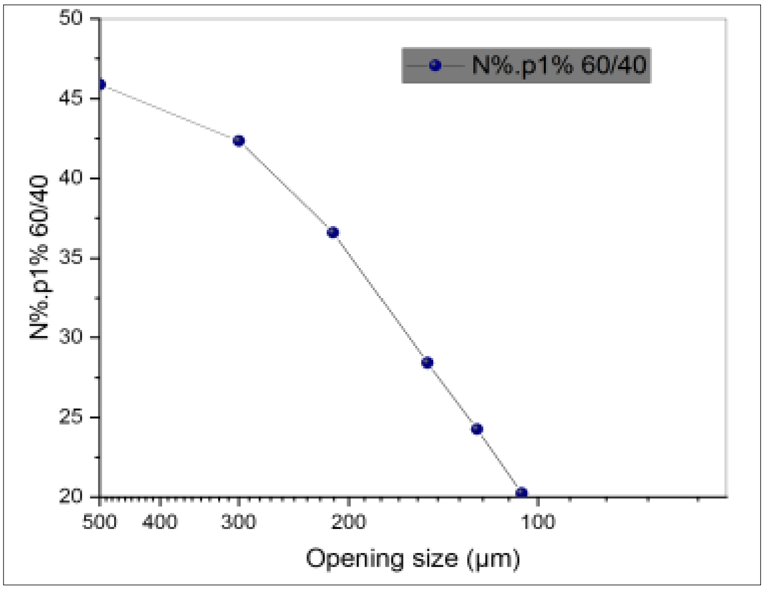

Fig 11: The effect of vibration on the cohesion of soil treated with hydrogel at a concentration of 1% and a mixing ratio of 60/40

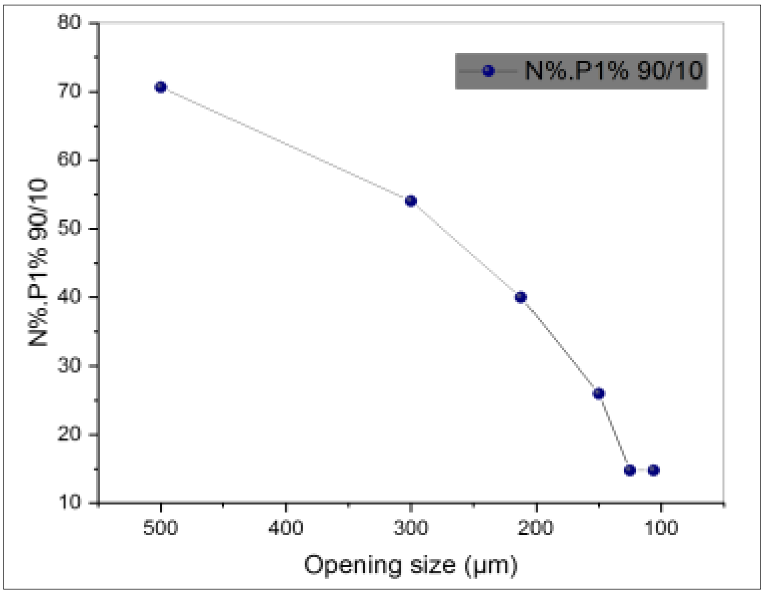

Fig 12: The effect of vibration on the cohesion of soil treated with hydrogel at a concentration of 1% and a mixing ratio of 90/10

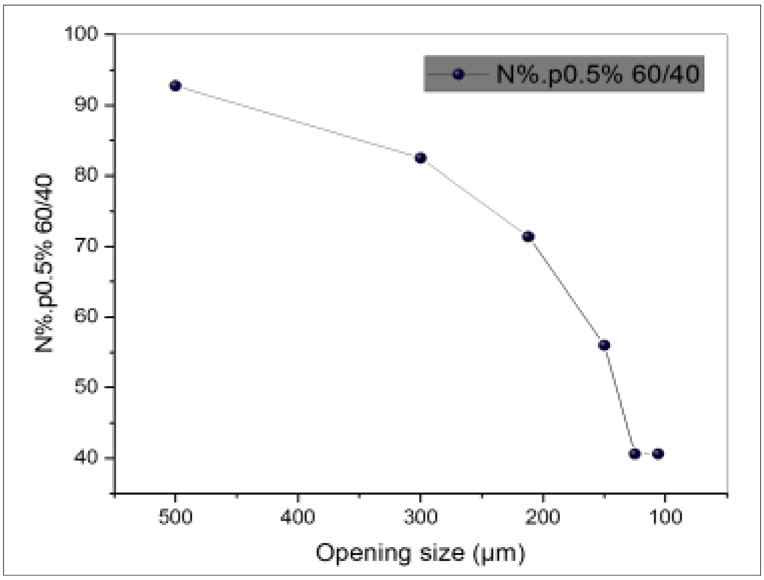

Fig 13: The effect of vibration on the cohesion of soil treated with hydrogel at a concentration of 0.5% and a mixing ratio of 60/40

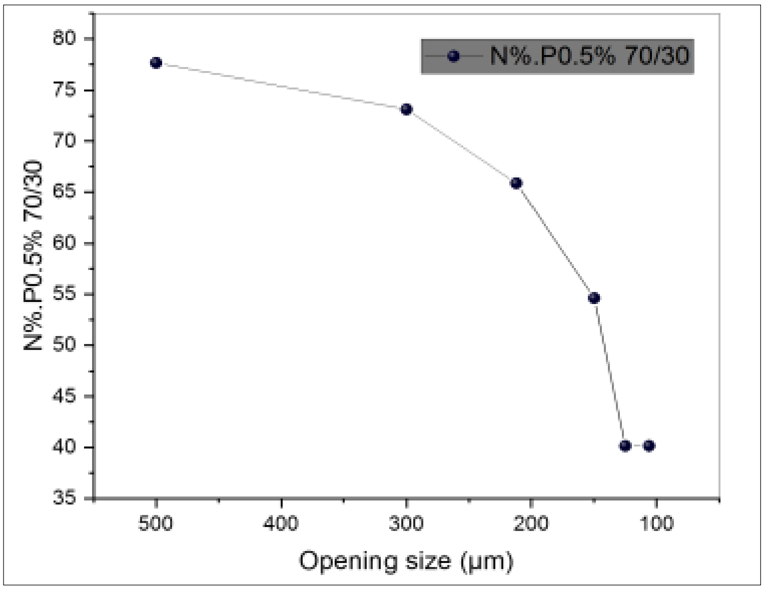

Fig 14: The effect of vibration on the cohesion of soil treated with hydrogel at a concentration of 0.5% and a mixing ratio of 70/30

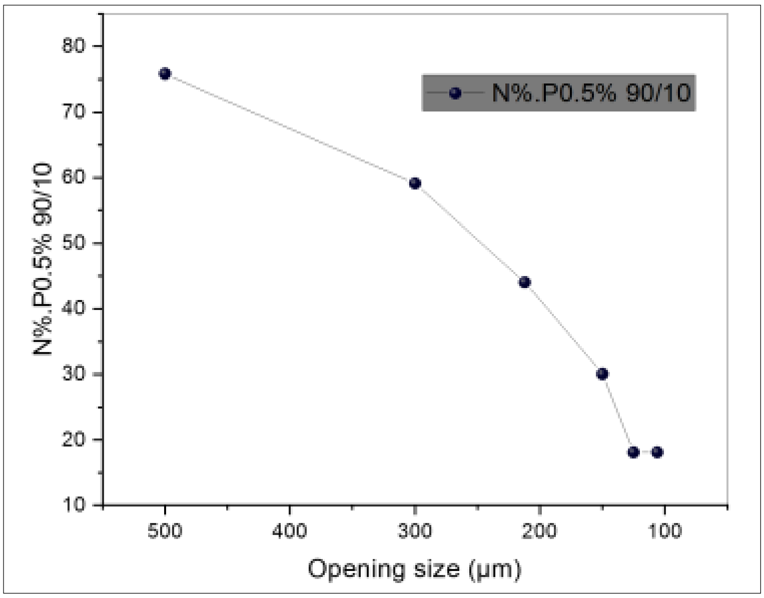

Fig 15: The effect of vibration on the cohesion of soil treated with hydrogel at a concentration of 0.5% and a mixing ratio of 90/10

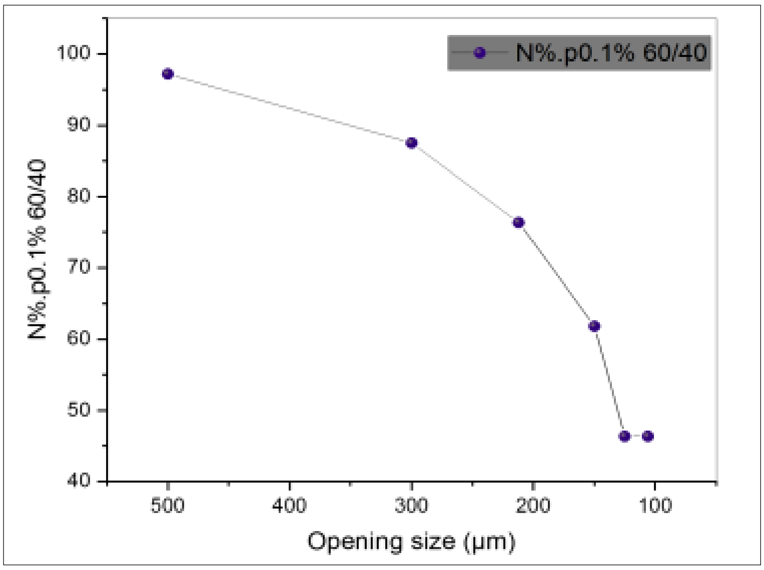

Fig 16: The effect of vibration on the cohesion of soil treated with hydrogel at a concentration of 0.1% and a mixing ratio of 60/40.

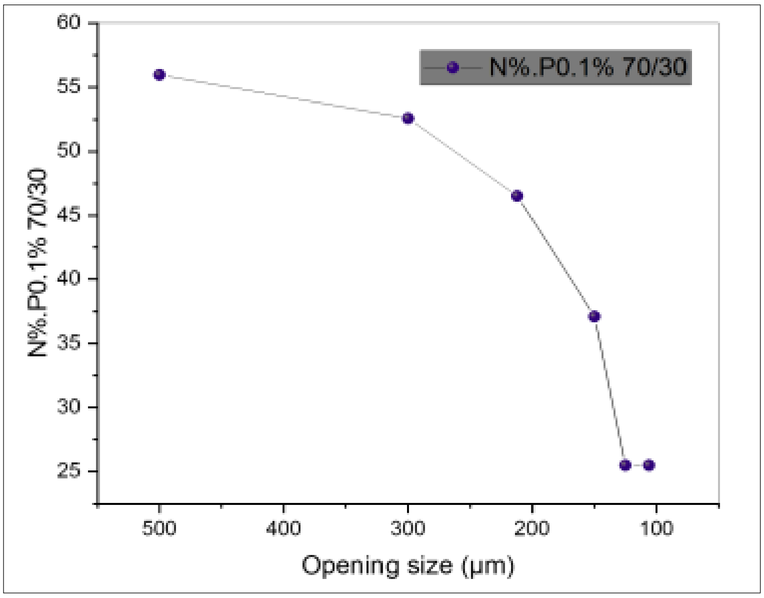

Fig 17: The effect of vibration on the cohesion of soil treated with hydrogel at a concentration of 0.1% and a mixing ratio of 70/30.

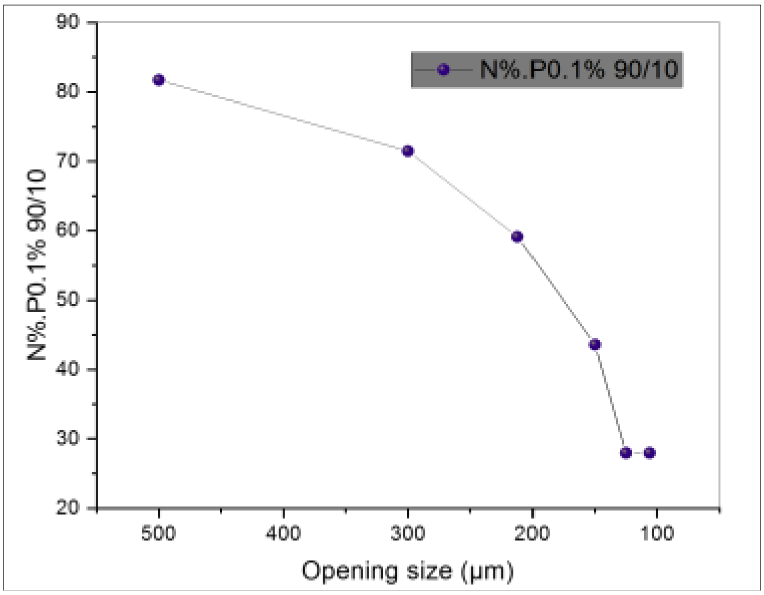

Fig 18: The effect of vibration on the cohesion of soil treated with hydrogel at a concentration of 0.1% and a mixing ratio of 90/10

Fig 19: An image of the soil that experienced erosion before being treated with hydrogel

Fig 20: An image of the soil after being mixed with hydrogel

4. Conclusions

The results obtained show that the viscosity of the hydrogel is strongly related to the pH value. At a certain pH level, the viscosity becomes high, along with increased clarity and transparency in the hydrogel. However, when the pH value is either increased or decreased, the opposite occurs, with a decrease in both viscosity and transparency. When high-viscosity hydrogel is mixed with soil, strong cohesion occurs between the soil particles, making it resistant to erosion. Additionally, it prevents the easy leaching of nutrients and fertilizers from the soil into the water. This was observed through the visible light spectrum.

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