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Addition of Enzymes to Improve the Soil Behavior

Carla Pereira Carvalho[1], Arthur Francisco Jorge Ferreira[2]
[1]Department of Civil Engineering, Federal University of Minas Gerais, Brazil
[2]Department of Automation and Control Engineering, Federal University of Minas Gerais, Brazil
([1]carla8cpc@gmail.com, [2]arthurfjferreira@gmail.com)

Abstract -This study intends to prove how advantageous the use of enzymes could be in the construction industry. Thereby, it approaches the chemical and biological functioning of enzymes; it addresses their advantages and applications in the construction field and tests the addition of two different types of enzymes to a soil in different concentrations: Alphasoil and DZ-2X. The comparison between the soil without treatment and with addition of enzymes were based in the flexural and compressive tests. In this way, the results allow to analyze what are the interferences of these enzymes in the resistance of soils and to compare the improvements induced by both substances additions. In conclusion, the study results show that the addition of enzymes to the soil can improve its flexural and compressive behavior significantly.

Keywords-*Enzymes, Soil, Resistance, Flexural Test, Compressive Test*

I. INTRODUCTION

To achieve better material resistance, durability and workability are some of the challenges to be faced by the industries nowadays. To discover a way to improve the procedures to find a more desirable material can mean to withstand corrosion, heavier loads or interference of moisture; it can also mean facilities for design solutions. In this way, new studies arise constantly seeking alternatives and improvements for materials. Some researches with interesting results show that the addition of enzymes in the soil can improve its properties significantly.

The enzymes, as catalysts, behave speeding up chemical reactions by lowering the activation energy which is the energy needed for the beginning of a reaction. Enzymes act by forming an enzyme-substrate complex that reduces the energy required for a particular reaction to occur [6]. These catalysts have specific structures and shapes which restrict their active site for only certain substances binding. If the shape or structure changes, then the binding site also changes avoiding the enzymatic function. To catalyze a reaction, the regions of the binding site must be accurately positioned around the substrate (substance to be reacted).

In this way, in [9], which is one of the studies concerned about the use of enzymes to improve the soil strength, it is explained how the interaction between enzymes and soil particles happens. As a chemical substance, the soil reacts with other chemicals if certain conditions are presented. The reaction results from the attraction of positive and negative charges in the components of the soil and other substances. Most clays have a molecular structure with a negative charge net that attracts cations (positive charges) to its edges and surface in order to neutralize the net. However, if these cations in a clay are weak, the remaining negative net attracts polarized water molecules to fill the spaces in the clay structure. It is that flow of cations through the clay that gives the shrinking and swelling properties of the soils. When the enzymes are added to a soil, they increase the wetting and bonding capacity of the soil particles. These catalysts also allow soil materials to become more easily wet and more densely compacted. In addition, it improves the chemical bonding that helps to fuse the soil particles together, creating a more permanent structure that is more resistant to weathering, wear and water penetration. The process starts with the enzymes being adsorbed by the clay and by the colloids. After, they combine with the large organic molecules to form an intermediary reactant that exchanges ions with the clay structure. In this way, the clay lattice is broken down and it is caused a cover-up effect which prevents further absorption of water and the loss of density. The enzyme is regenerated by the reaction and a new cycle starts [9].

In [8] it is affirmed that the enzymes can react with soil particles generating a cemented bond which stabilizes the soil structure and reduces its affinity for water. It also states that enzymatic emulsions can be applied on a wide variety of soils with a minimum clay content and in small dosages. In surface road layers the enzymes addition provides satisfactory results in dust suppression by bonding dust particles and reducing dust generation. When applied in greater dosages they have stabilization purposes. If the application is adequate and the compaction follows the parameters, the soil forms a dense and waterproofed layer [8].

In [7] it is addressed the necessity of studying the enzymes effects once the manufacturing capacity have been expanded and they show a relatively wide applicability compared to standard stabilizers (hydrated lime, Portland cement and bitumen) which require larger amounts of soil stabilizers than enzymes (higher costs).

Thereby, the constructive industries use these enzymes advantages to eliminate the swelling and shrink behavior of soil and to avoid the interference of water or frost. This addition enables time savings of up to 40% during the construction, saves up to 80% of conventional materials and it reduces the outgoing with transports to move these materials. In conclusion, these benefits can result in up to 50% of financial savings [1].

In this paper, two types of enzymes used in the soil stabilization were added to a clay and then, moulds were filled. After, the soil was compacted according to advices from the enzymes manufacturer and bricks were built. The last step was to subject the bricks to flexural and compressive tests in order to investigate the improvements that these substances can induce in the soil.

II. Materials and Methods

A. Enzymes Description

1) Alphasoil

The first enzyme to be added was the Alphasoil®-06. It is an innovative technology for creating stable grounds for roads, dams, paths, squares, landfills, railway tracks, foundations fundamentals and foundation trench filler as well as producing unfired bricks. A soil stabilisation is based on an electro-physical process that the arrested water film is broken and the soil material is prepared for the ion exchange. It changes the chemical and physical properties of cohesive soils achieving better strength and density than the soil natural characteristics. It also prevents the soil from swelling and shrinking, from water or frost interferences. These changes happen due to the enzymes capacity to reduce the amount of water held in the soil [1]. Every material got a mutual offload behaviour and Alphasoil eliminates this capacity by changing the electrical charge. Then, molecules get closer together, the empty spaces become increasingly narrow.

Alphasoil is suitable for soils with an ultra-fine constituent rate under 0.063mm of at least 1/3 with a minimum of 15% and maximum of 30% of pure clay (<0.002) and its unsuitable for all pure-sand, marsh or humus soils with an ignition loss greater than 4% and saline soils greater than 2%. The optimum moisture of the soil should be nearly to 10% to maximum 14% before the compaction. The concentrated Alphasoil used in this paper was mixed with water in 1:4 ratio. The enzyme concentration was 0.6L/m³ [1].

One of the Alphasoil properties is the capacity of reducing the dipole moment which has a water repelling effect on the individual soil particles, and consequently, it reduces their swelling capacity. It improves the soil shearing strength and its compatibility also is significantly improved. The penetration capacity is strongly increased compared with untreated materials. All these properties can be demonstrated in the Cylinder pressure test and CBR test.

2) DZ-2X

The second enzyme to be added in the soil was the DZ-2X. This enzyme is a unique multi-enzyme product specifically developed as an effective aid to the workability, binding and compaction of soil. It is also used to improve the stability of roads, dams and many other related projects. It is a completely natural and bio-degradable product and it acts altering and improving the soil physical and chemical properties which results in significantly less mechanical effort to achieve greater densities for compaction. Furthermore, it offers a convenient and low-cost method for improving a soils strength and durability, enabling lower construction costs, less maintenance and greater road performance. It is estimated that 1L of enzyme treats approximately 8m³ of soil [7].

Thereby, both enzymes have similar characteristics and work aiming to provide a better compaction for the soil. This paper also intends to seek for the enzymes with better results in the flexural and compressive test.

B. Bricks

For this research the bricks dimensions were chosen according to the British Standards 4729:2005 which states that cuboid bricks must have working dimensions of 190mm x 90mm x 65mm [3]. However, it is important to emphasize that the dimensions of the bricks would not have significant interference on the results of this study.

The bricks were built filling the moulds with soil or soil added of enzymes, compacting it and leaving them dry. To perform the Compressive and Flexural tests it were built eight bricks for each type and concentrations of enzyme and more 8 bricks were filled with natural soil which were added of the same quantity of water as the treated soils received from enzymes. In this way, 80 bricks were built to be tested in the Flexural Test and Compressive Test. For each test there were:

- 8 bricks with 7.2 ml of water added;
- 8 bricks with 3.6 ml of water added;
- 8 bricks with 1.8 ml of DZ-2X added;
- 8 bricks with 0.9 ml of DZ-2X added;
- 8 bricks with 0.9 ml of Alphasoil added.

C. Moulds

The moulds were composed of plywood with 18mm of thickness and screws. In this way, the moulds were enabled to be assembled and dismounted according to the necessities of filling them or demoulding the bricks. To facilitate the handling and to be more practical to transport, the moulds were built to produce 4 bricks as shown in figure 1.

Figure 1. Moulds used in the research

It is important to highlight the necessity of protecting the plywood of the moulds with an appropriate substance that restrain the absorption of water. The number of pieces cut to build the moulds, their labels and their dimensions are shown in the table 1. A plan view and a section D-D are also presented in figure 2 to detail all the pieces that composed the moulds.

TABLE I. NUMBER OF PIECES CUT TO BUILD THE MOULDS, THEIR LABELS AND THEIR DIMENSIONS

Label	Quantity	Length (mm)	Width (mm)	Thickness (mm)
A	1	550	426	18
B	5	190	65	18
C	2	450	65	18

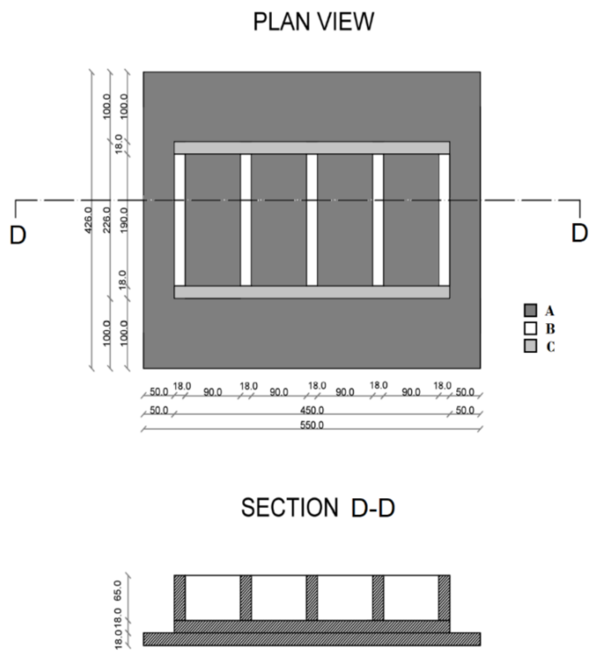

Figure 2. Mould dimensions and Section D-D detail

D. Soil

The figure 3 shows the result from the Laser Particle Size Analysis of the IBSTOCK Testing Services.

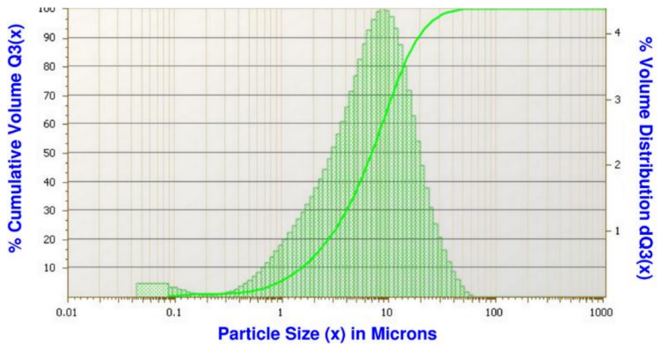

Figure 3. Laser Particle Size Analysis

According to the test it was possible to summarize the data in figure 4.

Classification		%
Coarse Sand	(> 212)	0.0
Fine Sand	(< 212 but > 50)	0.1
Silt	(< 50 but > 2)	86.0
Clay	(< 2)	13.9

Figure 4. Soil Composition

E. Sieving

As shown in figure 4, the soil granulation was composed of coarse grains and big boulders. To reproduce a real pattern of the soil, these fractions were broken into smaller particles and then, for a better brick fabrication, the soil was sieved in a square mesh of 10 mm which is shown in figure 5.

Figure 5. Square mesh of 10 mm

F. Soil Density

To calculate the density of a body, firstly, it is necessary to measure its mass and volume. Therefore, with the known volume (calculated with the mould's dimensions), it was produced 8 bricks without any treatment of enzymes (four from each built mould) which were weighed after. Each brick has 0.0011115 m³, so for 8 bricks produced by time, it was used 0.008892 m³ of soil. Figure 6 was built with the information necessary to obtain the soil density and then, to calculate the quantity of soil necessary to fill the moulds and to produce 8 bricks. The density datum allows to calculate the quantity of soil that would be added of enzymes. In this case, the waste of soil could interfere directly in the enzymes treatment results.

Mould label	Mass of empty mould (kg)	Mass of filled mould (kg)	Mass of soil (kg)	Total mass of soil for 8 bricks (kg)	Volume of 8 bricks (m³)	Density of soil bricks (kg/m³)
M1	2.920	11.167	8.247	16.545	0.008892	1860.66
M2	3.007	11.305	8.298			

Figure 6. Calculus for Density of soil bricks

G. Enzymes added

1) Alphasoil

To dilute the concentrate enzyme, it was necessary to consider the volume of soil that was used to produce the bricks. Each brick has 0.0011115 m³, so for 8 bricks produced by time, it was used 0.008892 m³ of soil. The concentration of diluted enzyme is 0.6 L/m³ and the proportion of dilution should be 1 of enzyme per 4 of water. However, in [2], it was developed a similar study with different concentrations from Alphasoil (0.4 L/m³ and 0.8 L/m³). In this way, in order to compare with the results already known, the concentrations considered for this enzyme were the same.

In this way, with the concentration and the volume of soil known, it is possible to calculate the amount of water and of concentrate enzyme necessary. For the 0.4 L/m³ concentration of enzyme applied in 0.008892 m³ of soil it was necessary 3.6 mL (rounding up) of diluted enzymes. How the proportion is 1:4, it was used 0.9 mL of concentrated Alphasoil in 2.7 mL of water, totalising 3.6mL of diluted enzyme. For the concentration of 0.8 L/m³ applied in the eight bricks, it was necessary 7.2 mL (rounding up) of solution, what means 1.8 ml of Alphasoil in 5.4 ml (totalising 7.2 ml) of water according to the 1:4 proportion.

2) DZ-2X

The enzyme specifications advice that it should be diluted in an appropriate amount of water that will be used to bring optimum content moisture to the soil to be compacted. Also, the enzyme mixture must be allowed to be incubated in the soil for a minimum of 12 hours (24h is optimum) before starting the compaction process. A maximum of 6 inches of treated soil depth should be compacted at one time. The concentration for DZ-2X is 0.125 L/m³. Thus, for 0.008892 m³ of soil it is necessary 1.2 mL (rounding up) of enzyme for an optimum result. To compare the influence of different types of enzymes added to the soil it is important to keep constant the quantity of enzyme added to the bricks in order to avoid any influence of the volume of enzymes in the results. In this way 1.8ml of enzyme and 0.9ml were prepared to be added to 16 bricks (8 bricks from each dose). In this way, it was possible to compare results from the addition of 1.8ml and 0.9ml of DZ-2X.

H. Mixing

The mixing was performed by dividing the soil and the volume of liquid to be added in 6 parts. For each 1/6 of soil it was added 1/6 of liquid (water or water and enzyme) which were measured by a dropper. The soil was mixed in order to maintain it the most homogenous possible.

I. Compaction

The compaction was made in four parts. The first one consisted in adding soil in ½ of the mould's height and then, this first layer was compacted. In the second step the soil was added until complete ¾ of the mould's height and after, it was compacted. Then, some soil was added until filling the mould completely. Later, it was compacted forming a layer in ¾ of the mould. The last step was to add the same quantity of soil (it exceeded the limits of the mould) and then, to compact it until complete the mould.

To compact the soil in each step, it was used a proctor hammer with 2.5kg which fell through a height of 40.5cm. Under the hammer it was positioned a metal plate and under it, there was a timber plate. The objective of having the metal plate was to ensure that the load was equally spread through the brick and the wood was necessary to avoid the metal plate bending.

The proctor hammer drops were performed in different quantities through each layer of soil. For the first and second layer to be compacted, it was performed 10 hits for each one. The third and fourth layer received 20 hits each one. These irregular distributions were chosen because the first brick (which were receiving 15 hits each layer) were presenting a weak superficial layer and a much stronger bottom layer.

III. Results and discussions

A. Flexural Test

The Flexural test regulation is available in BS EN 12372:2006 [4]. It consists of placing a specimen above two rollers where it is applied a progressively load in the middle of the body until its break.

It is important to ensure that the surface of the rollers is clean. Any material that remains in the specimen must be removed to guarantee the correct spread of load. The specimen should be placed centrally on the supporting rollers and the loading roller should be in the middle of the body as shown in figure 7. The load increased uniformly at a rate of 0.25 ± 0.05 MPa/s until the breaking.

Figure 7. Equipment for Flexural Test

1) Bricks filled with soil without Treatment

a) Addition of 7.2 ml of water

Bricks with addition of 7.2ml of water			
Label	Weight	Flexural Load (N)	Maximum Stress (MPa)
1.1	1.908	157.43	0.09
1.2	2.035	99.87	0.06
1.3	1.897	176.40	0.10
1.4	1.789	96.24	0.06
1.5	1.893	126.15	0.07
1.6	1.883	118.57	0.07
1.7	1.971	100.59	0.06
1.8	1.907	62.46	0.04
Mean	1.91	117.21	0.07

Figure 8. Results for Flexural Test in Bricks with addition of 7.2 ml of water

b) Addition of 3.6 ml of water

Bricks with addition of 3.6ml of water			
Label	Weight	Flexural Load (N)	Maximum Stress (MPa)
2.1	1.922	78.33	0.05
2.2	1.981	94.42	0.06
2.3	1.965	94.29	0.06
2.4	1.814	54.25	0.03
2.5	1.915	92.51	0.05
2.6	1.799	141.73	0.08
2.7	1.915	120.66	0.07
2.8	1.848	104.31	0.06
Mean	1.89	97.56	0.06

Figure 9. Results for Flexural Test in Bricks with addition of 3.6 ml of water

The addition of more water implied in a better compaction of the soil since the weight mean is higher for bricks with more water added. In addition, the Flexural Stress has better results in the bricks with addition of more water which the Flexural Load mean are approximately 15% better.

2) Bricks added of Alphasoil

a) Addition of 0.9 ml of Alphasoil

Bricks with addition of 0.9ml of Alphasoil			
Label	Weight	Flexural Load (N)	Maximum Stress (MPa)
3.1	2.131	152.57	0.09
3.2	1.967	170.04	0.10
3.3	1.943	150.69	0.09
3.4	2.055	118.46	0.07
3.5	2.040	155.21	0.09
3.6	1.885	116.35	0.07
3.7	1.970	120.56	0.07
3.8	1.924	103.00	0.06
Mean	1.99	135.86	0.08

Figure 10. Results for Flexural Test in Bricks with addition of 0.9 ml of Alphasoil

Comparing the bricks without treatment (addition of 3.6 ml of water) and with 0.9 ml of Alphasoil, the second type of bricks are approximately 30% stronger when tested in applying a flexural load.

3) Bricks added of DZ-2X

a) Addition of 1.8 ml of DZ-2X

Bricks with addition of 1.8ml of DZ-2X			
Label	Weight	Flexural Load (N)	Maximum Stress (MPa)
4.1	1.983	196.01	0.12
4.2	1.861	162.65	0.10
4.3	1.914	170.15	0.10
4.4	1.868	174.40	0.10
4.5	2.022	171.74	0.10
4.6	1.835	150.16	0.09
4.7	1.971	188.79	0.11
4.8	1.949	159.10	0.09
Mean	1.92	171.63	0.10

Figure 11. Results for Flexural Test in Bricks with addition of 1.8 ml of DZ-2X

b) Addition of 0.9 ml of DZ-2X

Bricks with addition of 0.9ml of DZ-2X			
Label	Weight	Flexural Load (N)	Maximum Stress (MPa)
5.1	1.880	130.42	0.08
5.2	2.005	118.11	0.07
5.3	1.936	146.09	0.09
5.4	1.897	87.94	0.05
5.5	1.874	106.36	0.06
5.6	1.906	40.92	0.02
5.7	1.971	102.16	0.06
5.8	1.792	74.99	0.04
Mean	1.91	100.87	0.06

Figure 12. Results for Flexural Test in Bricks with addition of 0.9 ml of DZ-2X

The results from the Flexural Tests performed in bricks with more and less addition of DZ-2X show that the bricks with 1.8 ml of DZ-2X are approximately 30% stronger than the untreated bricks (171.63 N from 117.21 N). However, the bricks with less quantity of DZ-2X (lower than the optimum volume) shows that the brick is weaker than the untreated bricks added of 7.2 ml of water (100.87 N from 117.21 N) what shows the significance in using the correct amount of enzymes. Comparing the bricks added from 0.9 ml of Alphasoil and DZ-2X, the first one achieved at about 25% better resistance in flexural test (135.86 N from 100.87 N).

B. Compressive Test

The Compressive Test regulation is available in BS EN 772-1:2011 [5]. It consists of placing a specimen in the centre of the plate in the machine where it is applied a uniformly load which increases constantly until the failure. It is important to ensure that the bearing surfaces of the machine are clean. It is necessary to remove any material that remains in the specimen and to align the body carefully in the centre of the machine to guarantee the correct spread of load.

Figure 13. Equipment for Compressive Test

Figures 14-15 show better results for bricks with addition of more water, and consequently, with better compaction. The mean of Compressive Load is approximately 25% better in the bricks with more quantity of water than the ones with only 3.6 ml of water.

1) Bricks filled with soil without Treatment

a) Addition of 7.2 ml of water

Bricks with addition of 7.2 ml of water			
Label	Weight	Compressive Load (N)	Compressive Stress (Pa)
6.1	1.908	5869.83	0.68
6.2	2.035	3618.02	0.42
6.3	1.897	5018.53	0.59
6.4	1.789	3036.43	0.35
6.5	1.893	4694.12	0.55
6.6	1.883	4851.55	0.57
6.7	1.971	4584.99	0.54
6.8	1.907	4572.94	0.53
Mean	1.91	4530.80	0.53

Figure 14. Results for Compressive Test in Bricks with addition of 7.2 ml of water

b) Addition of 3.6 ml of water

Bricks with addition of 3.6 ml of water			
Label	Weight	Compressive Load (N)	Compressive Stress (MPa)
7.1	1.922	3013.505	0.35
7.2	1.981	2181.710	0.25
7.3	1.965	3434.263	0.40
7.4	1.814	3427.775	0.37
7.5	1.915	3156.370	0.42
7.6	1.799	3628.631	0.46
7.7	1.915	3946.805	0.55
7.8	1.848	4696.179	0.44
Mean	1.89	3435.65	0.405

Figure 15. Results for Compressive Test in Bricks with addition of 3.6 ml of water

2) Addition of Alphasoil

a) Addition of 0.9 ml of Alphasoil

Bricks with addition of 0.9 ml of Alphasoil			
Label	Weight	Compressive Load (N)	Compressive Stress (MPa)
8.1	2.131	4636.67	0.54
8.2	1.967	4478.859	0.52
8.3	1.943	3842.348	0.45
8.4	2.055	1891.427	0.22
8.5	2.040	3539.515	0.41
8.6	1.885	3239.923	0.38
8.7	1.970	2197.813	0.26
8.8	1.924	2919.298	0.34
Mean	1.989	3343.232	0.39

Figure 16. Results for Compressive Test in Bricks with addition of 0.9 ml of Alphasoil

Comparing the bricks without treatment and with 0.9 ml of Alphasoil, the bricks with addition of Alphasoil become at about 30% less strong than the bricks without treatment (from 3343.23 N from 3435.65 N) what probably is a result from an inadequate amount of Alphasoil added.

3) Addition of DZ-2X

a) Addition of 1.8 ml of DZ-2X

Bricks with addition of 1.8 ml of DZ-2X			
Label	Weight	Compressive Load (N)	Compressive Stress (MPa)
9.1	1.983	3425.0	0.58
9.2	1.861	2272.0	0.38
9.3	1.914	3377.2	0.58
9.4	1.868	3724.4	0.64
9.5	2.022	2749.9	0.47
9.6	1.835	2216.2	0.38
9.7	1.971	3273.2	0.56
9.8	1.949	4731.6	0.81
Mean	1.925	3221.18	0.55

Figure 17. Results for Compressive Test in Bricks with addition of 1.8 ml of DZ-2X

b) Addition of 0.9 ml of DZ-2X

Bricks with addition of 0.9 ml of DZ-2X			
Label	Weight	Compressive Load (N)	Compressive Stress (MPa)
10.1	1.880	3001.6	0.51
10.2	2.005	4366.7	0.75
10.3	1.936	5271.0	0.90
10.4	1.897	5321.5	0.91
10.5	1.874	5293.2	0.90
10.6	1.906	4809.7	0.82
10.7	1.971	4402.3	0.75
10.8	1.792	5633.1	0.96
Mean	1.925	4762.375	0.81

Figure 18. Results for Compressive Test in Bricks with addition of 0.9 ml of DZ-2X

Comparing the bricks without treatment and the bricks with 1.8 ml of DZ-2X, the addition of the DZ-2X becomes the bricks about 30% less strong than the bricks without treatment (from 4530.80 N to 3221.18 N). However, bricks with addition of 0.9 ml of DZ-2X are 28% stronger than bricks with addition of just 3.6 ml of water (from 3435.65 N to 4762.375 N). Compared with bricks with 7.2 ml of water the bricks with 0.9 ml of DZ-2X are 5% stronger (from 4530.80 N to 4762.375 N).

IV. CONCLUSION

The figure 19 and 20 show how significant the improvements caused by the addition of an enzyme in the soil can be when testing the flexural and compressive resistance. For less quantity of liquid added (results expressed in the charts), the Alphasoil showed better results.

The figure 21 and 22 show that the addition of 1.8 ml of DZ-2X enzyme had the greatest improvement between the different types tested for flexural resistance. In the other hand, for compressive test, the addition of 0.9 ml of DZ-2X presents better results. Thus, the results reveal the importance of considering an optimum amount of enzyme to be added to the soil in order to achieve the better strength.

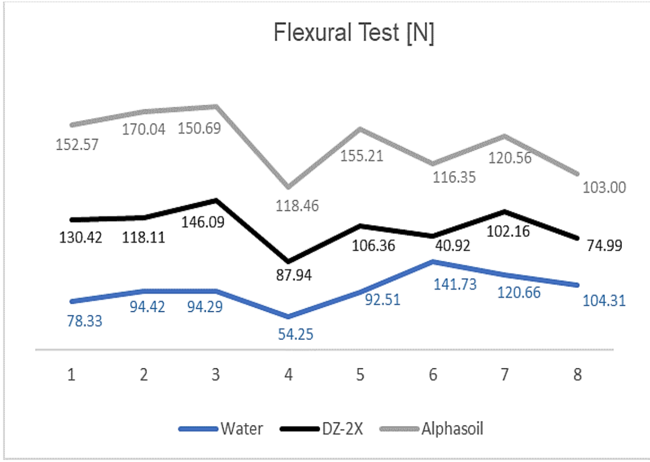

Figure 19. Results for Flexural Test in Bricks with addition of water, DZ-2X and Alphasoil

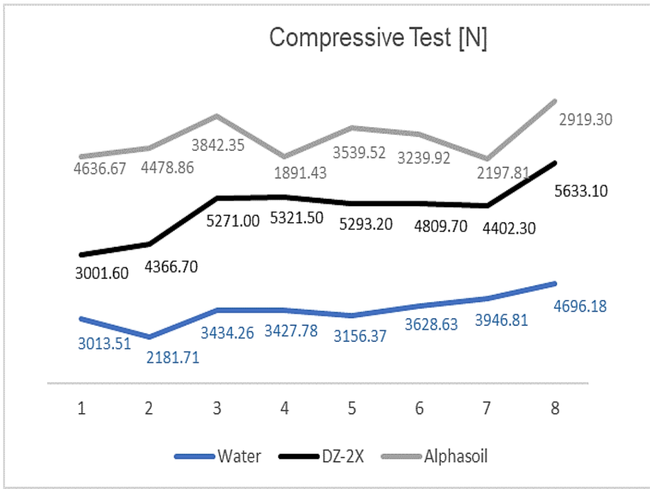

Figure 20. Results for Compressive Test in Bricks with addition of water, DZ-2X and Alphasoil

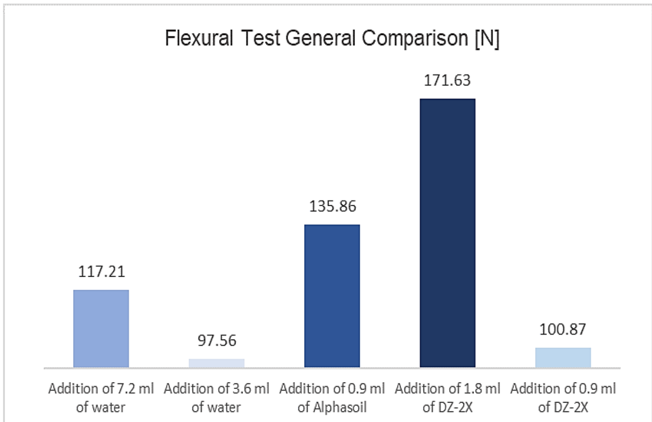

Figure 21. Results comparing the means for all bricks tested in Flexural Strength

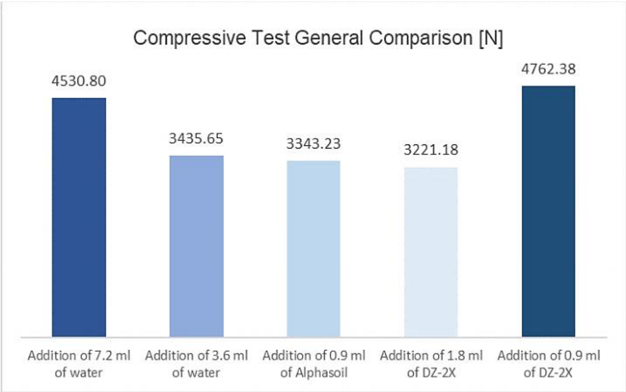

Figure 22. Results comparing the means for all bricks tested in Compressive Strength

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