# Cement composite design using natural zeolites from the coast of Ecuador


## Abstract

The world needs civil works; since the beginning of time, people have had the need to build, from a simple rain cover to the pyramids of Egypt; from a cave, to the great Chinese wall.

Today is not the exception, because technology has grown enormously and has allowed the development of construction methodologies, creation of new materials, among others; This has allowed ports, airports, space stations, roads, islands, lakes and even artificial beaches to be built.

Most of the constructions around the world are built using concrete which is constituted by fine aggregate, coarse aggregate, water, and cement, being the sand the fine aggregate. In this study the possibility of replacing the sand for a novel material called zeolite was analysed, due that zeolites compose 10-60% of the rock in the Coastal Ecuador in the Cretaceous Cayo formation. The mechanical properties like compressive, tension and tensile strength were analysed using experimental design which were tested in laboratory.


Keywords: zeolites, concrete, construction, tests

## Introduction

The main material for buildings worldwide is the cement, this material is the key ingredient to get concrete as we known, the 8% of emissions of CO2 is coming of the cement´s production (Lucy Rodgers 2018); becoming the cement industry the mainly CO2 emitter due two reasons: the combustion of fuels and the calcinations of raw materials, alternative raw materials is the most efficient way for reduce CO2 emissions some measures have been considered (Zhang et al. 2014).

For many years, cement has been used in civil constructions of large massive concentrations such as stadiums, churches and buildings; and also is mostly used in small constructions such as single-family houses, swimming pools, walls; However, to obtain the best performance of the cement it is necessary to mix it with water and aggregates, with this mixture the paste obtained that is known as concrete, and if the coarse aggregates are removed, it is obtained a paste called mortar; In most countries of the world, the possibility of designing concretes with different fibers and raw materials is being analyzed, in order to reduce the use of ordinary Portland cement, to reduce the pollution emitted by the process of obtaining the cement. The drawback to date is that there are not many studies that incorporate zeolite in the process of obtaining concrete to analyze the ductility of this material, it must be taken into account that if CO2 pollution from cement manufacturing is reduced, less impact and the ozone layer will suffer deterioration, which implies that subsequent generations will not yet be affected by ultraviolet rays, so it is extremely important to look for alternatives of different materials that may be partially replaced the use of cement.

For the other side, the context of performance design, the mechanical characteristics must be supplied to a structure in such a way that, within acceptable technical and economic limits, they are able to control and accommodate its dynamic response within thresholds consistent with the acceptable level of damage; the concept of design by performance will help us determine to what extent it becomes feasible and applicable to add more or less amount (percent) of component, i.e.: zeolites, fiber, and so on to determine the efficient application.

The zeolites compose 10-60% of the rock in the Coastal Ecuador in the Cretaceous Cayo formation and the two main zeolites are Ca-heulandite and Ca-clinoptilolite (Machiels et al. 2008). One of the parameters that zeolite contributes the development is the resistance showing its activity over the 28 days (Raggiotti, Positieri, and Oshiro 2018). Quantifying the ductility of concrete using zeolite will determine the ability of ordinary Portland cement to decrease. The cement paste specimens designed by type I Portland cement, 25% zeolite 2 and water reached a maximum compressive strength value of

 

80.59 MPa at 28 days of curing (Ochoa, 2008). The addition of 15% zeolite in a cement paste did not cause a significant difference in the maximum resistance to compression on day seven of curing with the cubes of days fourteen, twenty-one, and twenty-eight, being at 7 days an average compressive strength of three tested specimens of 53.57MPa, and at 28 days an average compressive strength of three tested specimens of 53.9 MPa (Mazacón, 2009). With the addition of 15% to 25% of zeolite, the compressive strength of the concrete decreases, obtaining a compressive strength at 28 days of curing of 116 MPa (Aguirre, 2008).

The properties that improve in mortars that partially replace zeolite in Portland cement are the workability of fresh mixes and the compressive strength obtained after 28 days of age (Robalino, 2004). The addition of 15% zeolite existing in Ecuador to the mortar produces a progressive increase in compressive strength until reaching a maximum value of 116.29MPa after 28 days of curing (Leon, 2008). Incorporating 10% of zeolite to the concrete paste increased the value of the resistance to simple compression, diametral compression traction after 28 days, in the same way in the air content test a reduction of air was presented as that increased the percentage of zeolite reaching its maximum value of ultrasound speed when 10% of zeolite was added to the concrete (Saltos, 2005).

Studies based on the incorporation of zeolite in the concrete paste differ in the calculated value of the compressive strength at 28 days, additionally in most of the studies only the compressive strength is analyzed, setting aside important properties of the zeolite such as ductility, however for the present study, a mortar will be designed adding zeolite and PVA fibers with five different dosages in order to analyze the dosage which shows the best performance such as resistance to compression and ductility. Until now, no studies have been carried out in the Ecuadorian Sierra region, so the existence of zeolite in this sector of Ecuador is unknown, which would cause the zeolite to be transported from the Coast to the Sierra, implying an increase in cost. of this material.

As part of this contribution, the compressive strength, uniaxial tension, ductility, flexural strength and technical characterization of the compounds will be analyzed using X-ray diffraction, scanning electron microscopy, thermogravimetric analysis and calorimeter, spectrometry Infrared by Fourier transform. In this study, concrete mortars designed using natural zeolites from the coast of Ecuador will be developed, optimizing mechanical properties such as tensile strength and ductility of the mortars.

## Materials and Methods

The main materials that were used for this study were ordinary Portland Cement type I, water, sand, synthetic polyvinyl alcohol (PVA) fibers and saturated zeolite, although to reduce the moisture, hyper-plasticizer liquid additive, water reducer formulated based on polycarboxylics, density (g/cm3) 1.076 ± 0.01were used.

Technical properties of Ordinary Portland cement (Type I, OPC, Holcim Rocafuerte), silica sand and PVA fibers used in this study are shown in Table 1.

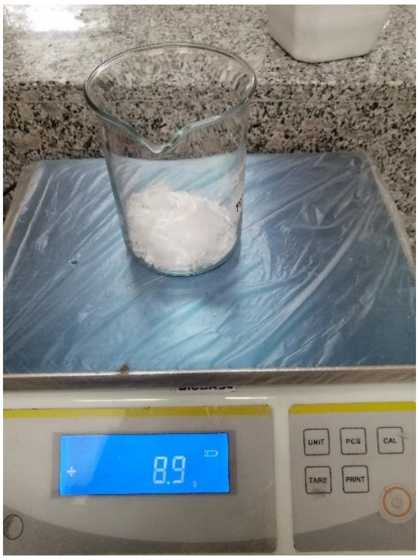


Fig.1. Fiber dosage

**Table 1**

Technical properties of main materials used in this study

| Materials | Grade | Standard | Specific Gravity | Particle size, um | |
|---|---|---|---|---|---|
| | | | | $D_{v50}$ | Range |
| OPC | Type I | ASTM C150 | 3.15 | 15 | - |
| Silica Sand | F-75 quartz | - | 2.65 | 115 | 53-210 |
| PVA | - | - | 1.3 | - | - |

The water employed was from the water supply network which fulfills the requirements for prepare concrete or mortar.

PVA fibers are chemically bonded to cement, allowing concrete to acquire the characteristic of ductility (malleability

/ flexibility) which is part of the main reason of this study. Typical properties of the PVA fibers are shown in Table 2.

**Table 2**

Typical properties of the PVA fibers

| Diam. (um) | L (mm) | Tensile (MPa) | Density (kg/m³) | Elastic modulus (GPa) | Max. elongation (%) |
|---|---|---|---|---|---|
| | | | | $D_{v50}$ | Range |
| 39 | 12 | 1600 | 1300 | 42.8 | 6 |

The zeolite used is a porous aluminosilicate corresponding to class F pozzolan as per previously compared in Table 1 Chemical Requirements of ASTM C618 Standard (2015).

**Method.**

Dosage:

The experiment design is shown in Table 3, M1 were designed as conventional concrete or 0% Zeolite; then three different dosages were prepared to M2, M3 and M4, where the amounts of water, OPC, PVA fibers and hyper-plasticizer liquid additive were kept constant, for the other side the amounts of sand and zeolite were modified.

**Table 3**
Experiment Desing

| Sample | Sand | Zeolite | OPC/Sand | Water/OPC | PVA | Hyp |
|---|---|---|---|---|---|---|
| M1 | 1 | 0 | "1:1" | 0,44 | 0,02 | 0,007 |
| M2 | 0,75 | 0,25 | "1:1" | 0,44 | 0,02 | 0,007 |
| M3 | 0,5 | 0,5 | "1:1" | 0,44 | 0,02 | 0,007 |
| M4 | 0,25 | 0,75 | "1:1" | 0,44 | 0,02 | 0,007 |

The zeolite needs to be saturated, therefore it was placed in a container with water for three days. Once determinated the requiered volumen to get the specimens, the amount of each element is shown in Table 4, then specimens M1 to M4 were obtained.

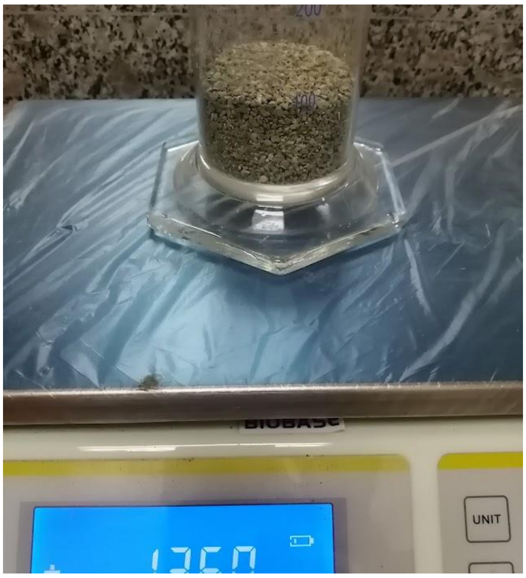


Fig.2 Referential Zeolite Dosage

The procedure used to obtain the specimens of M1, M2, M3 and M4 was to place and mix the solid elements in one container and the liquid elements in another; and then place them in a single container and with the use of a mixer prepare the mixture as shown in Fig. 3.

**Table 4**

Dosage

| Sample | Sand (g) | Zeolite (g) | OPC (g) | Water (ml) | PVA Fibers (g) | hyper-plasticizer (ml) |
|---|---|---|---|---|---|---|
| M1 | 1475 | 0 | 1475 | 649 | 29,5 | 10,325 |
| M2 | 1106,25 | 368,75 | 1475 | 649 | 29,5 | 10,325 |
| M3 | 737,5 | 737,5 | 1475 | 649 | 29,5 | 10,325 |
| M4 | 368,75 | 1106,25 | 1475 | 649 | 29,5 | 10,325 |

Fig. 3. Preparation of Specimens with the use of a mixer

**Preparation of Samples:**

Each mix is poured into the molds previously sprayed with oil to avoid damage when stripping, the molds are cube-shaped (5x5x5 cm), rectangular prisms (4x4x16cm), and dog-bone (see dimensions in Fig. 4);

Afterwards, the samples are stripped for analysis with the different tests.

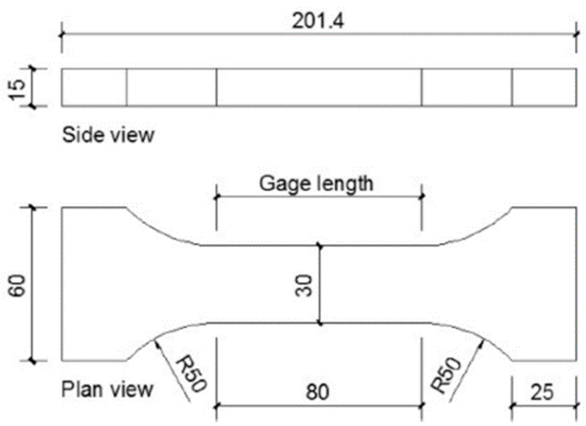


Fig. 4. Dimensions of the dog-bone samples for the uniaxial tensile test (Note: all dimensions in mm).

The present study is based in the Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (ASTM C109), for preparate the specimen molds apply a thin coating of release agent in the interior faces of the molds, shall be oils or greases. Wipe the mold with a cloth to remove any excess release agent, if the release agent is an aerosol lubricant spray directly on to the mold froma a distance of 6 to 8 in. [ 150 to 200 mm] in the same way wipe the surface with a cloth as necessary to remove any excess of aerosol lubricant.

The proportion of materials is detailed in table 3 for the five different mixes. Use a water-cement ratio of 0.44.

The quantities of materials to be mixed are described in table 3 for making three test specimens for each mold: cubes, rectangular prisms and dog-bone.

Starting casting the specimens within a total of no more than 2 minutes and 30 seconds after completing the initial mixing of the kneaded from the mortar. A layer of mortar about 1 inch (25 mm) (about half the depth of the mold) is placed in all compartments of the cube. The mortar is rammed in each cubib compartment 32 times in aproximately 10 s in 4 rounds, each round must be at right angles to the others and must consist of eight adjoining blows on the surface of the specimen. The tamping pressure should be just enough to ensure uniform filling of the molds. The 4 rounds of tamping (32 strokes) of the mortar must be completed in one bucket before moving on to the next.

Inmediately after completing the model, the test specimens are placed in a wet room. All test specimens, inmediately after casting, should be kept in their molds on base plates in a damp wet room for 20 to 72 h with ther surfaces exposed to humid air but protected from dripping water.

To determinate the compressive strength specimens are tested inmediately after removal form the wet room for 24 hour specimens, and from storage water for all other specimens. All test specimens for a given test age must be broken within the following allowable tolerance

| Test Age | Permissible tolerance |
|---|---|
| 24 h | ±½ h |
| 3 days | ± 1h |
| 7 days | ± 3h |
| 28 days | ±12 h |

The load must be applied to the specimen faces that were in contact with the truly flat surfaces of the mold. The specimen is carefully placed in the testing machine under the center of the upper support block. Before each cube is tested, the spherically seated block shall be checked to see that it is free to tilt. No cushioning or seating materials should be used. Place the spherical seat block in uniform contact with the surfce of the specimen. The load speed is applied with a relative speed of movement between the upper and lower plates correspondig to a load on the specimen in the range of 900 to 1800 N/s (200 to lb/s).

**Results and discussion**

The compressive strength was measured on cubes (5x5x5 cm), for determinate the concrete quality, fig.5 shows the results of the compressive strength of the each sample of the 4 mixes at 28 days. In the mix 1, it was obtained 12.9, 14.5 and 14.3 MPa, in the mix 2, the results were 13.3, 12.9 and 12.5 MPa, in the mix 3 the values of compressive strength were 13.5, 13.1 and 9.94 MPa, and in the last mix the compressive strength were 10.5, 10.6 and 10.7 MPa, the sequence of results show that exist proportional relationship between the sand and compressive strength, while the concentration of sand decreases the compressive strength decreases too.

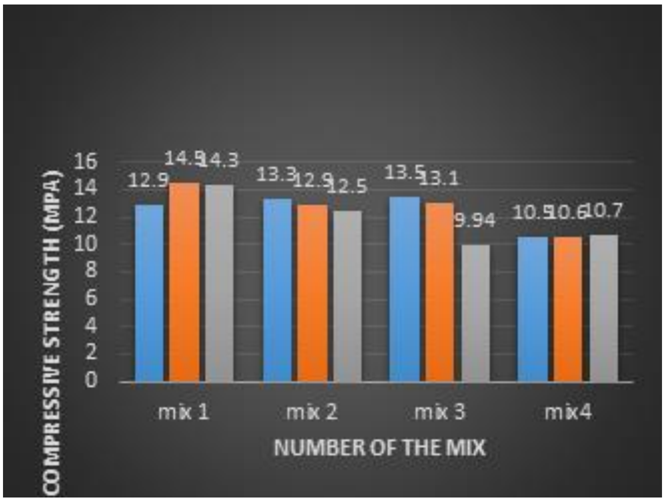


Fig.5 Compressive strength

The average for each mix is, 13.9, 12.9, 12.18 and 10.6 MPa respectively

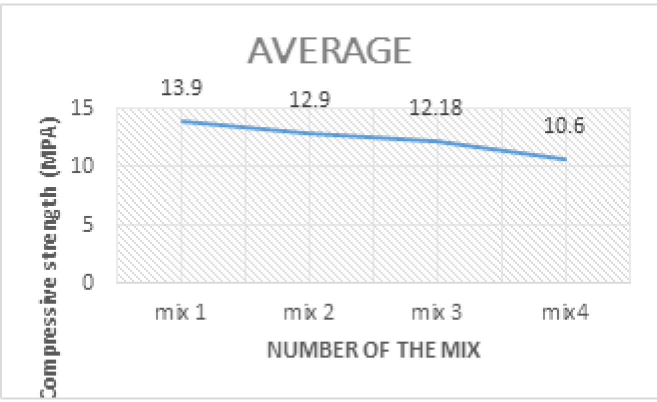


Fig.6 Average of compressive strength

In the analysis of the flexion strength, were made rectangular prisms, fig shows the results of the flexion strength of each sample of the 4 mixes at 28 days. In the mix 1, it was obtained 3.93, 5.51 and 5 MPa, in the mix 2, the results were 3.26, 3.37 and 3.97 MPa, in the mix 3 the values of flexion strength were 2.51, 3.03 and 1.9 MPa, and in the four mix the flexion strength were 10.5, 10.6 and 10.7 MPa, in the same way the proportional relationship between the sand and flexion strength keeps, while the concentration of sand decreases the flexion strength decreases too.

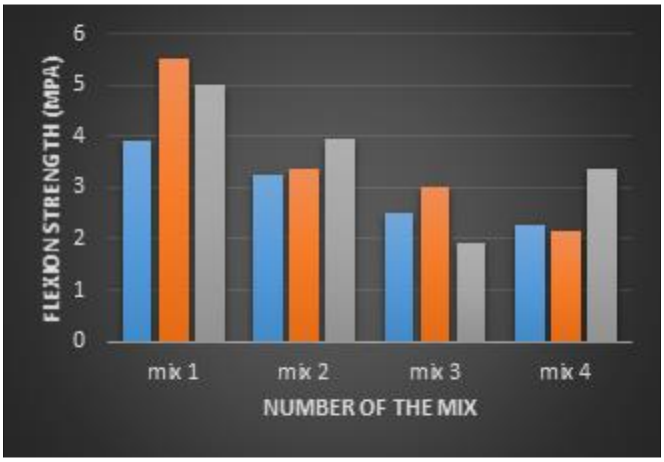


Fig.7 Flexion strength

The average for each mix is 4.81, 3.53, 2.48 and 2.59 MPa respectively.

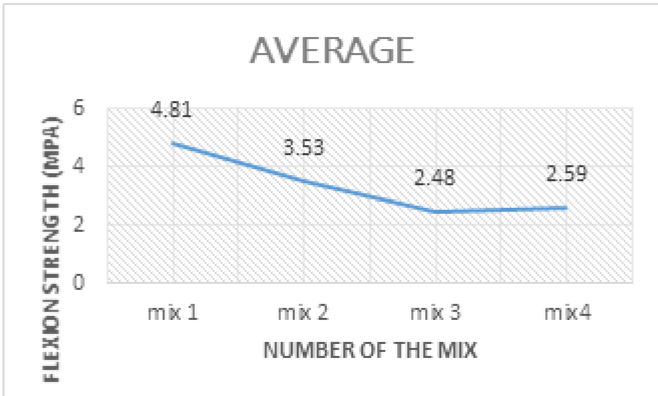


Fig.8 Average of Flexion strength

The properties on tensile of the material was examined through uniaxial tension of the dog bone-shaped specimens, fig presents the stress-strain relation. A similar situation happens in tensile results show that exist proportional fig relationship between the sand and tensile strength, in the mix 1: the results are 1.92, 2.44, 2.51 MPa in mix 2: 2.01,1.06 1.45 MPa, in mix 3: 1.81, 1.57, 0.98 MPa and in mix 4: 0.66, 0.45, 1Mpa.

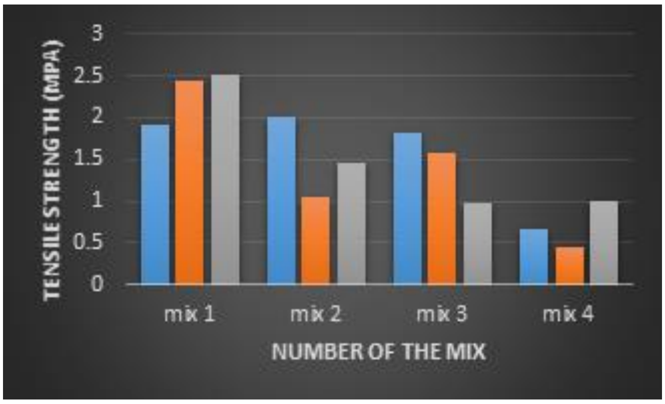


Fig.9 Tensile strength

the average for each mix is 2.29, 1.51, 1.45 and 0.7 MPa respectively

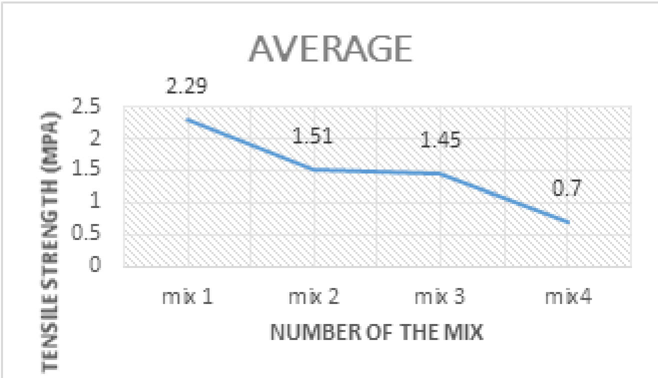


Fig.10 Average of Tensile strength

In the compression test, the second sample it was needed a load of 36.9 (N), for obtained the maximum compressive strength 14.5 (MPa) with an elongation 1.31 (mm)

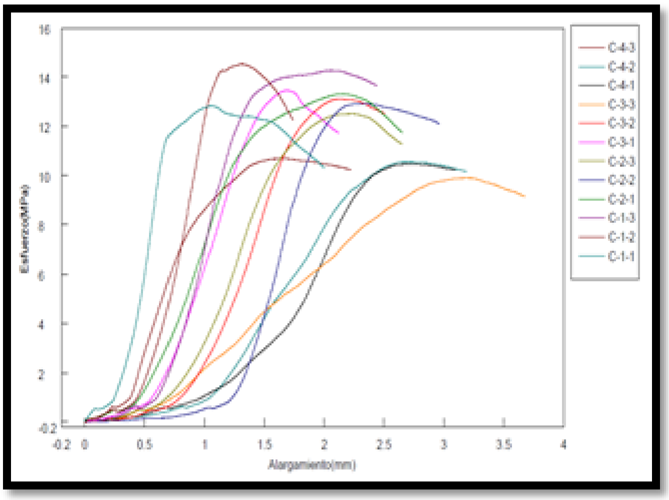


Fig.11 Compression test

In the graphic deformation vs load shown in the fig. the maximum value of the load applied was 2370.94 N, with a flexion strength of 5 MPa.

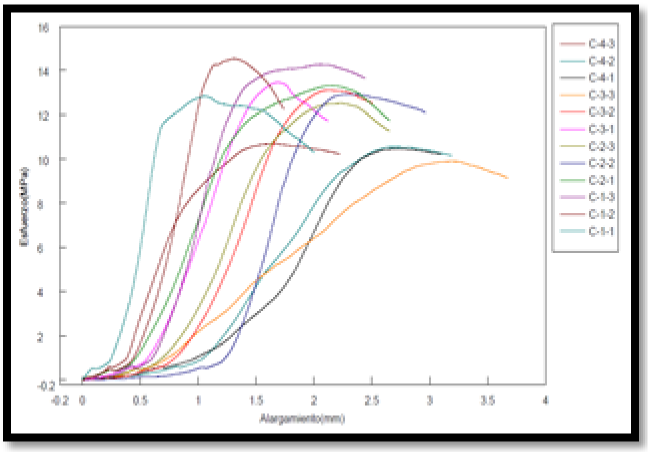


Fig.12 Flexion test

The maximum value of the tensile stress was 2.51MPa with a deformation of 2.48 percent.

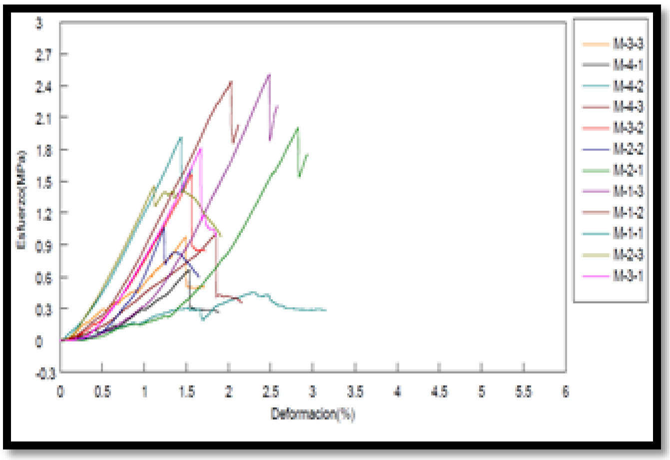


Fig.13 Tensile test

The three maximum values of compressive, flexion and tensile strength were obtained in the first mix, when the dosage of aggregate was 100% of sand and 0% of zeolite.

## Conclusions

The study has shown that by increasing the amount of zeolite up to 75% of the sand/zeolite composition, percentages of maximum deformation similar to those of conventional concrete mix are obtained; then, the amount of reinforcing steel for a given design and whose application could be non-structural might be reduced.

With the results obtained, the use of Zeolite could be proposed for non-structural applications such as: wall patching, replanting, curbs and sidewalks.

The expected values of resistance to compression and tension of the mixtures with Zeolite are relatively close to those obtained without Zeolite, which would imply to carry out more studies; could be alternated with the increase of the amount of fiber.

Part of a following study would be to make a mixture, M5, with 0% sand and 100% Zeolite, in order to determine its mechanical properties at 28 days and verify if the trend of the percentage of maximum deformation is maintained.

There are very few studies on the behavior of Zeolite in construction, however if these studies continue and the application of this compound for non-structural elements is confirmed, the next step would be to regulate its use and, in this way,, it will be possible to contribute to the environment.

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