THE STUDY OF MECHANICAL PROPERTIES IN TERNARY BINDERS SYSTEMS

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Abstract

Cements may be defined as adhesive substances capable of uniting fragments or masses of solid matter to a compact whole. It easily reacts with water (hydrates) to form a solid material, known as hardened cement. By using different techniques, seven systems are studied to determine the influence of ternary binders in the mechanical properties of mortar such as UPV (Ultrasonic Pulse Velocity), flexural and compressive strength at the age of 2, 7 and 28 days. Depending on the age of mortar is noted an increase of dynamic modulus of elasticity values for each system. As a construction material, concrete is employed to resist compressive stresses turning it in one of the most important and useful properties. During the test is noted that the compressive strength value increases with the age of mortars. The results are discussed in the light of the systems composition materials and the hydration reaction that affects the hardening of the systems with increasing age.

Key words: Ternary binders, UPV, flexural strength, compressive strength.

Introduction

Concrete, the most widely used construction material exhibits properties that develop with time. Immediately after mixing, it behaves as a liquid suspension of various particles (cement grains, aggregates, air bubbles) in water while as the hydration reaction proceeds it is transformed into a rigid porous material with considerable load bearing capacity. To achieve the required mechanical properties careful design and mixing of the constituent materials must take place. (Aggelis (2004))

In ternary systems different binders are combined in order to achieve specific technological properties. For about three decades the use of Calcium Aluminate Cement (CAC) is established in order to improve Ordinary Portland Cement (OPC) based Self Leveling Underlayment's (SLU) in specific properties such as rapid set, early strength and rapid drying. Such SLUs usually consist of three reactive materials which are CAC, OPC and CS (Calcium Sulfate). The CS may be used the form of gypsum, anhydrite or hemi hydrate. Typical combinations are depicted in Fig. 1 by their locations in a ternary diagram CAC – OPC – CS. These combinations are either based on mixtures of CAC and CS with eventually an addition of a lime source such as OPC) or on mixtures of OPC and CAC with eventually an addition of CS. (Bier (2013))

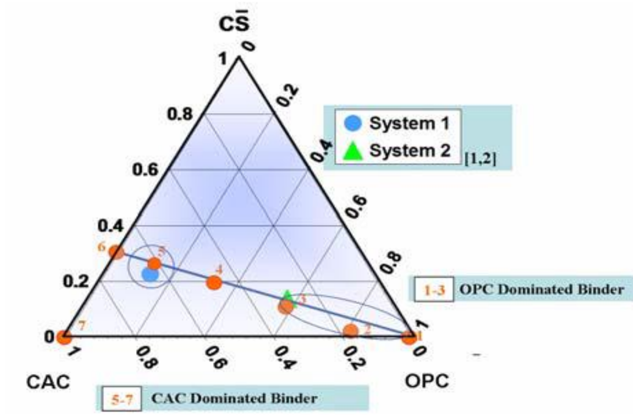

Figure 1. Composition and classification of ternary binders.

The dynamic modulus of elasticity, modulus of rupture (flexural strength) and compressive strength are important properties of concrete. Nondestructive Test (NDT) methods offer the advantage of providing information on the in-place properties of hardened concrete, such as the elastic constants, density, resistivity, moisture content, and hardness characteristics. Unlike coring, a destructive testing (DT) approach introduces weak spots while obtaining the test specimens, with the attendant threats to the integrity and safety of the entire structure. Ultrasonic Pulse Velocity (UPV) is a nondestructive technique that involves measuring the speed of sound waves through materials in order to predict material strength, to calculate low-strain elastic modulus and/or to detect the presence of internal flaws such as cracking, voids, honeycomb, decay and other damages. (Ibrahim Tunde Yusuf (2016)).

Compressive strength of concrete is one of the most important and useful properties. As a construction material, concrete is employed to resist compressive stresses. While, at locations where tensile strength or shear strength is of primary importance, the compressive strength is used to estimate the required property. Common trend in concrete technology is to use compressive strength as a quantitative measure for other properties of hardened concrete.

Early age strength prediction in concrete is very useful in reducing construction cost and ensuring safety. Furthermore, early age strength prediction has several practical applications. It can be used to determine safe stripping time, prestressing application or post – tensioning time, to monitor strength development, particularly when concreting in cold weather, to check serviceability conditions or compliance criteria, to ensure construction safety and, generally to estimate the quality of construction and potential durability. Moreover, prediction of concrete strength at late ages is being significant from both technical and economical points of view. Concrete compressive strength is influenced by many factors including, water/cement ratio, cement content and properties, aggregate type and its properties, etc. (Metwallyabdallah Abd elaty (2014)).

This paper describes the mechanical properties of ternary binders systems. The specific objectives, therefore, are to do the following: i) determine the mechanical properties of ternary binders systems with UPV method such as flexural and compressive strength. ii) determine the relationship between Young modulus of elasticity and compressive strength of seven systems.

2. Materials and methods

2.1 Material and mortar mix design

The basic mix design of the mortars used is given in Table 1. Cement was a CEM I 42.5R (Portland cement with early age strength) (type I OPC). Sand was a local quartzite material. As secondary raw materials lime stone powder (LSP) was used. Calcium sulfate (CS) was an anhydrite for samples 2 and 3 and hemihydrate for samples 4, 5 and 6.

Table 1. Composition of ternary mortars (All ingredients in gram)

System	OPC	CAC	CS	Sand	LSP	Water	SP (super-plasticizer)
1	350	0	0	380	270	192,5	1.85
2	280	45,5	24,5	380	270	192,5	2.50
3	175	108,5	66,5	380	270	192,5	4.20
4	108,5	171,5	70	380	270	192,5	2.3
5	45,5	225,75	78,75	380	270	192,5	1.13
6	0	245	105	380	270	192,5	0.94
7	0	350	0	380	270	192,5	0.85

All mortars were mixed in a Hobart type mixer according to DIN EN 196.1. For compositions with SP the W/C ratio was kept constant with a target flow of 300 mm achieved by a PCE type powdered super-plasticizer (SP) Melflux 4930.

2.2. Characterization and Methods Used

2.2.1 Mortar characterization

The flow behaviour of all ternary mortar systems was characterized using the Hagerman's mini-slump cone (6x7x10 cm^3) spread.

2.2.2 Measurement of UPV

The UPV machine used during the experiment is BB7 Steinkamp with transducer ceramic piezoelectric. The principle of this machine is: Repetitive voltage pulses are generated electronically and transformed into wave bursts of mechanical energy by the transmitting transducer, which must be coupled to the concrete surface through a suitable medium. A similar receiving transducer is also coupled to the concrete at a known distance from the transmitter, and the mechanical energy converted back to electrical pulses of the same frequency. The electronic timing device measures the interval between the onset and reception of the pulse and this is displayed in digital readout.(Bungey (1996)). Measurements are done for different ages of mortar for 2, 7 and 28 days. The set – up is shown in fig. 2.

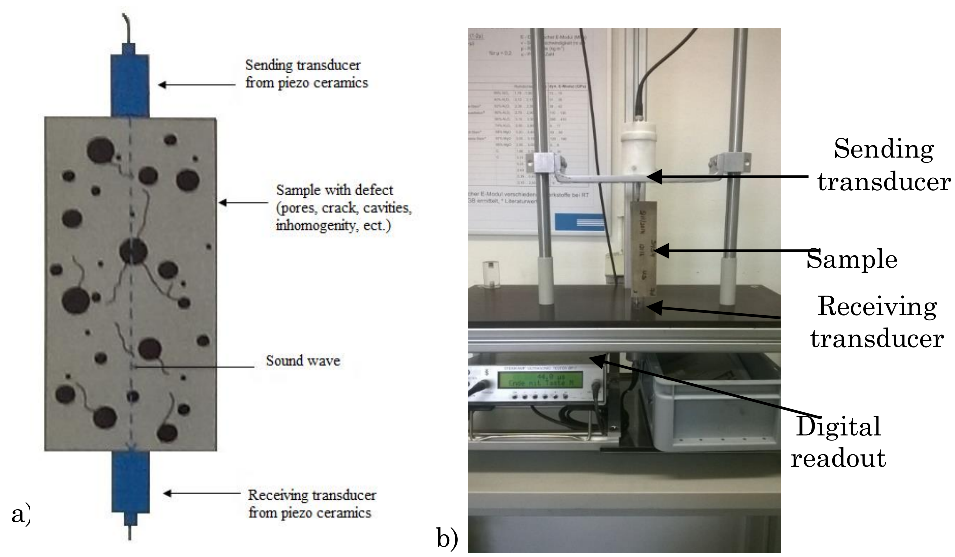

Figure 2 a) Schematic diagram of ultrasonic tester , b) Ultrasonic machine, Steinkamp BP7

2.2.4 Measurement of flexural and compressive strength

The processes of testing the mortar prisms to show off the mechanical properties such as flexural and compressive strength are realized with Toni Technic machinery.

The experiment is realized in two stages:

- In the first stage is conducted a three points flexural strength test.

The testing machine for the determination of flexural strength shall be capable of applying loads up to 10kN, with an accuracy of ± 1,0% of the recorded load in the upper four-fifths of the range being used, at a rate of loading of (50± 10) N/s. The machine shall be provided with a flexure device incorporating two steel supporting rollers of (10,0± 0,5) mm diameter spaced (100,0 ± 0,5) mm apart and a third steel loading roller of the same diameter placed centrally between the other two. After we put the prism in the machinery, we set the geometric data in the soft and start the measurement. When the measurement finished the result are displayed in a digital readout, which are calculated from the bellowed formula, as described in the standard DIN EN 196-1: Chapter 13 (2005)

$$R_f = \frac{1.5 \cdot F_f \cdot l}{b^3} \qquad (1)$$

where:

R_f – flexural strength in MPa

F_f – the applied force in the middle of the prism in N

b – length of the prism in mm

l – the distance between two supporters in mm

- In the second stage we measure the compressive strength of mortar.

The testing machine for the determination of compressive strength use a maximal load of 100kN with an accuracy of ± 1,0%. For each system we have prepared three samples. After flexural test we get six samples in total, which we use for compressive strength measurements. The sample is placed between two steel slabs which have width and length of 40.0 ± 0.1 and the thickness of 10 mm. The geometric data of the sample are recorded in the machine software. After the measurement is finished, the results are displayed in a digital readout that is calculated according to the formula as described in the standard DIN EN 196-1:

$$R_c = \frac{F_c}{1600} \qquad (2)$$

where:

R_c – compressive strength in MPa

F_c – maximal force in N

1600 = 40x40 mm the dimensions of the supporting slabs (the same as the sample dimensions)

The set-up is shown in fig 3.

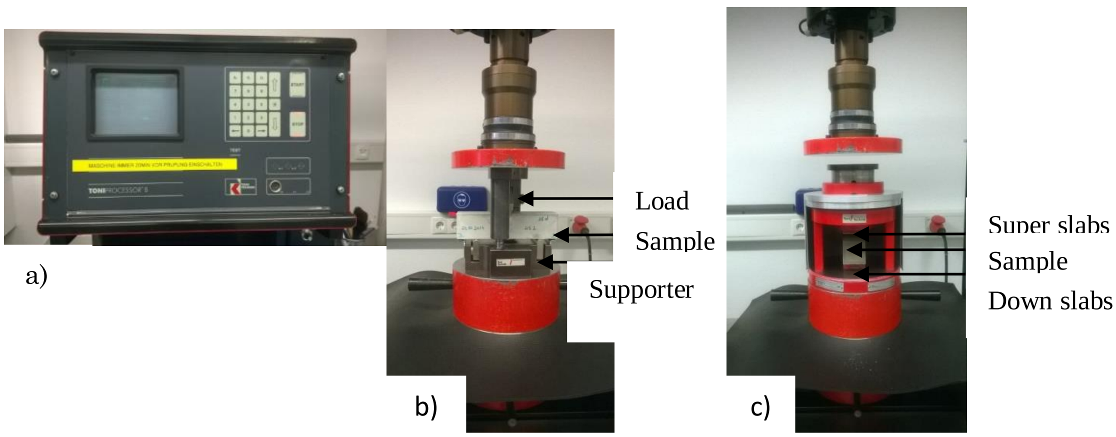

Figure 3. Flexural and compressive strength machinery a) software b) three point flexural equipment c) compressive equipment

3. Results

3.1 Study and analysis of results with UPV method.

The ultrasonic pulse velocity method has been used successfully to evaluate the uniformity of concrete structure, the localization of empty spaces and possible cracks on it. These potential defects can be interpreted through small values of the dynamic modulus of elasticity.

During this study the evaluation of dynamic modulus of elasticity is done through UPV method for seven systems. For each system 3 samples are tested, so in total 21 samples. They are tested for different ages of mortar, for 2, 7 and 28 days. The dynamic modulus of elasticity for each system is computed by the following equation:

$$E = v^2 \cdot \rho \cdot \frac{(1+\mu)(1-2\mu)}{(1-\mu)} \quad (3)$$

where v is the sound velocity, ρ is the density and μ is the Poisson's ratio. The value of Poisson's ratio for mortar is μ=0,2 so the value of expression $\frac{(1+\mu)(1-2\mu)}{(1-\mu)}$ is equal to 0,9:

$$E = v^2 \cdot \rho \cdot 0.9 \quad (4)$$

In each system the average value of the dynamic modulus of elasticity is calculated in this way an average value for each age of mortar is taken into consideration. Based on experimental data and in calculation the graph on figure 4 is plotted.

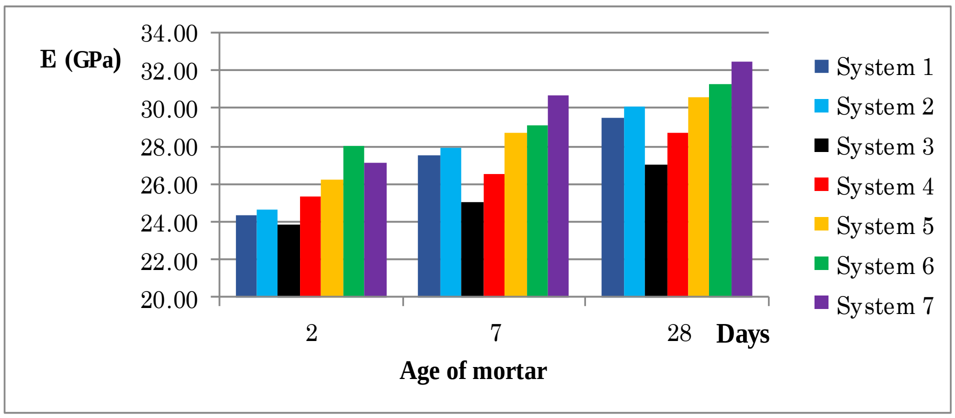

Figure 4. Variation of modulus of elasticity for seven systems with the age of mortar.

Figure 4 illustrates how the value of modulus of elasticity for each system changes with the age of mortar. Each system itself shows an increase in the value of the dynamic modulus of elasticity with age increment. One of the factors which influence the increment of the modulus of elasticity value is the hydration process which continuous with age. Curing of the samples in water also helps in the hydration process and in the improvement of the possible defects, such as cracks, pore, and small holes etc. Filling these small defects which may be present in the sample, it causes the increment of the speed of longitudinal wave that travel in the sample, which leads to a higher value of the modulus of elasticity.

To compare the influence of the cement type (their hydration) on the modulus of elasticity are chosen three systems: system 1 with OPC cement, system 6 with CAC and CS, system 7 with CAC cement. In fig. 5 is shown the relationship between the values of the modulus of elasticity and the age of mortar for the selected systems.

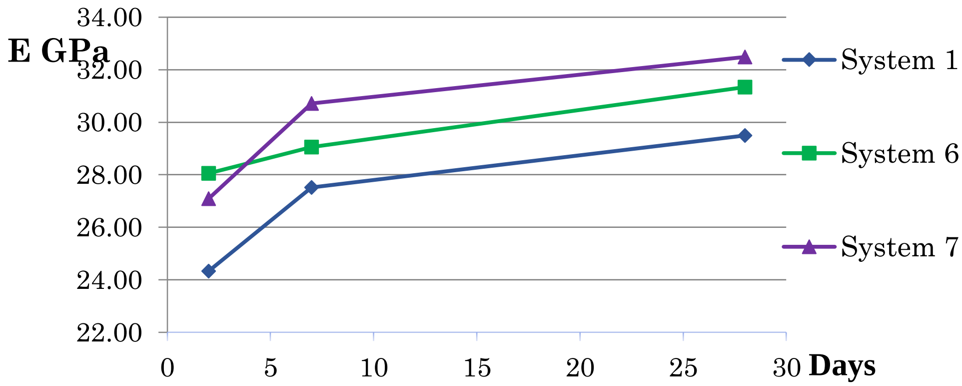

Figure 5. Comparison of modulus of elasticity for systems 1, 6, 7 with the age of mortar.

As soon as the hydration process begins, chemical reaction occurs including water and particles of cement, which form the gel (this mass is called gel because there is no clear definition of crystalline structure and its actual composition is unspecified). As the hydration process continues, the gel extends out of the particles to join the other particles and to form a skeleton structure that hardens the mortar paste. The hydration process of cements influences on the modulus of elasticity. The hydration process of CAC cement was faster than OPC cement (this phenomenon was observed after the mixing process, for 3-4 minutes the first phase of solidification appeared and the mixture was not more fluid), so, we had a faster hardening of system 7 compared to system 1. Also, the presence of CS-hemihydrates in system 6 accelerated the hydration process. This phenomenon also affected the modulus of elasticity.

3.2 Study and analysis of flexural and compresive method results.

In this testing method flexural and compressive strength for seven systems is evaluated. Three samples were tested for each system and after that an average of values were calculated in order to take only one value for each age of mortar 2, 7 and 28 days. In the figure 6 is shown the relationship between flexural strength and the age of mortar. It is noticed that each system shows an increase of the values with the age increment.

Based on the data presented in fig 6, it is observed that each system achieves higher flexural strength at 28 days compared to 2 and 7 days, because the mortar has reached the hardening stage completely. The hardening is mainly due to the formation of calcium silicate hydrate as the hydration process of the cement continues.

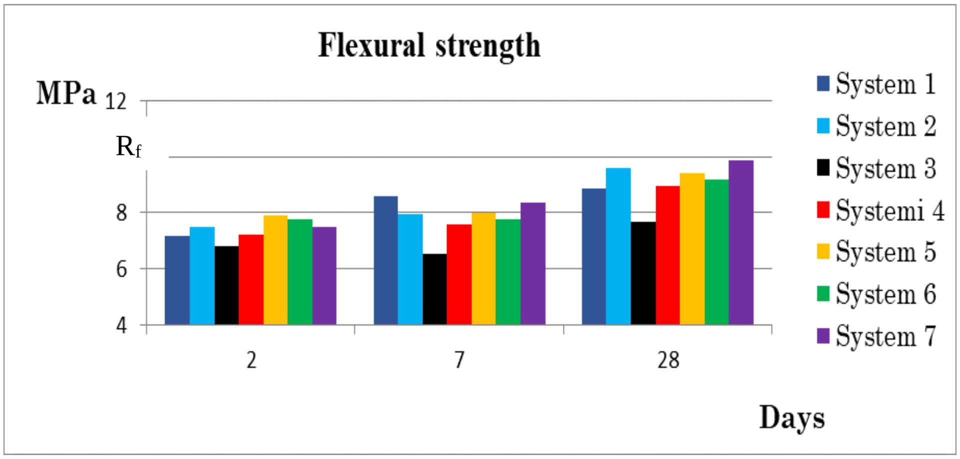

Figure 6. Variation of flexural strength for seven systems with the age of mortar

Through this method, it was also estimated the compressive strength of seven system. The represented values on the graph in figure 7 are the average values of six half samples of each system for 2, 7 and 28 days.

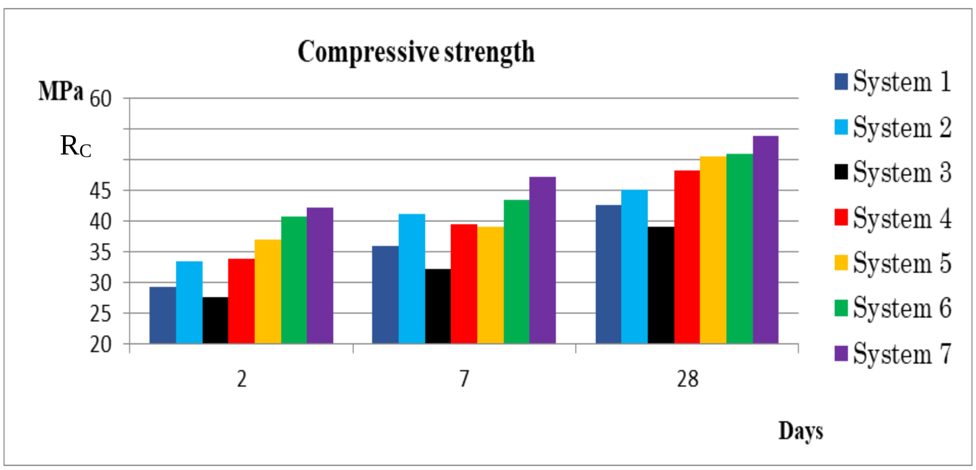

Figure 7. Variation of compressive strength for seven systems with the age of mortar

The values of compressive strength of seven systems increase with the increment of the mortar age. One of the main factors that influence the compressive strength is the porosity of mortar. The more porous the mortar is, the lower the compressive strength values are. For this reason, the water treatment of the samples helps to fill the pores and this was also observed in the increment of the durability at 28 days of the systems, thus, each system has a higher resistance until it reaches fracture compared to 2 and 7 days of mortar.

3.3 The study of relationship between Young's modulus of elasticity and compressive strength of mortar.

The modulus of elasticity is often expressed in terms of compressive strength. The reason is that the mechanical properties of the mortar are highly dependent on the properties and the amount of binders and aggregates.

Based on the data obtain during the experiments a relationship between modulus of elasticity and compressive strength is plotted. (fig 8)

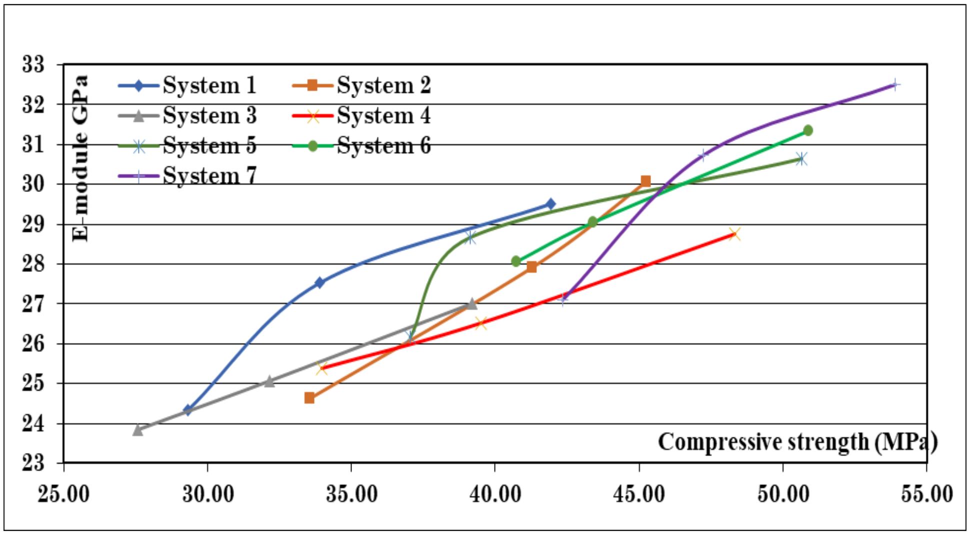

Figure 8. The variation of average value of modulus of elasticity and compressive strength at the age of 2, 7 and 28 days.

Since the modulus of elasticity and compressive strength are two parameters which determine the deformability of mortars, such a plot of their mean values enables us to better understand the relationship that exists between these parameters.

In the figure 8 show that, for each system, the increase of the compressive strength value causes the increment of the modulus of elasticity. By comparing the systems with each other, it is noted that system 7 also presents higher values of modulus of elasticity but also of compressive strength because in the calcium aluminate cements (CAC) CA is the main hydraulic phase which lead to an early strength development and the kinetic of hydration form a higher crystalline structure and take up more space, decreasing the porosity of the overall matrix and consequently increase the values of modulus of elasticity.

Conclusions

Based on experimental data we can conclude that the presence of OPC, CAC, CS cements and their different amount in the mixture affect the mechanical properties of the systems. The composition of ternary binders shown in table1 have different percentage of OPC, CAC and CS that lead to different crystalline structure which affect mechanical properties of systems. This is also shown in represented data in figure 4 and 7.

As mortar age increases, modulus of elasticity increases due to hydration reactions which affect the hardening of systems.

System 7 reach the highest value of Young’s modulus of elasticity that have 100% CAC cements while system 3 has the lowest value (a mixture of CAC, OPC, CS) compared with other systems because the kinetic of hydration that occur in system 7 is faster than in system 3. The presence of CS –anhydrite in system 3 slow down the process of hydration which it affect the speed of longitudinal wave and the Young’s modulus of elasticity.

The flexural and compressive strength values show an age dependence of the systems for 2, 7 and 28 days.

In general the compressive strength results show an increase of values for each system. At the age 28 days, each system presents the heights value of flexural and compressive strength results.

To all seven systems under study, it has been observed that with the increase of the modulus of elasticity value the compressive strength value increase also.

The presence of ternary binders like OPC, CAC and CS experimentally has shown how they affect in mechanical properties of systems. The kinetic of hydration process, the crystalline structure and different phrase that occur during the mixture process and hardening of systems are represented in different values of modulus of elasticity and compressive strength.

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