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Contribution of local materials and the recycling of slate in the constitution of hydraulic concrete pavements

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Abstract. The main objective of this article is to highlight the progress made in the development of new materials that have been gradually used by humans until today. Of course, this progress must be associated with other parameters in order to guarantee sustainable development. For this, today, it has become urgent to reduce the consumption of cement by resorting to its partial or total replacement by other similar materials in order to reduce CO_2 emissions in our environment. This should certainly help to develop greener building materials. In this study, it was decided to proceed with the partial or total replacement of Portland cement type CEM II/B-L-42.5N by slate and lime that had not undergone any previous transformation. The results obtained revealed that the mortar whose substitution compared to the replacement of cement (100%) cement and sand (0/4) confers better kinetics than those of the series composed of (100%) cement and fraction rubble (0/1).

Keywords: clay; ecological cement; lime; mechanical and physical tests; mortar; slate; substitution

1. Introduction

One way to reduce the consumption of cement in the world is to promote the total or partial use of other materials similar to cement to reduce CO_2 emissions called an ecological cement. Continuous research investigations are present throughout the world to find effective and environment friendly alternative binder materials for Ordinary Portland Cement (OPC) as it is the most used construction material to produce the concrete. The huge demand for concrete using OPC results in high volume of carbon dioxide (CO_2) emission, leads to environmental problems.

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emission, leads to environmental problems continuously and results huge depletion of natural resources have been specified by Performance of eco-friendly mortar mixes against aggressive environments (Saha *et al.* 2020).

This process is part of the replacement of cement by slate as a substitute for the binder associated with limestone, then as aggregate in the mortar to obtain a more economical and environmental mortar. Today according to the researchers we are witnessing that concrete is one of the most frequently used materials in civil engineering exhibited to recycling by Mazloom and Mirzamohammadi (2019).

The first process consists of replacing the cement with slate calcined at 750°C and carrying out mechanical tests with different percentages of slate. Considering the negative effects of the increase in temperature during calcination on the planet, this initiative aimed to try to develop new innovative materials that will constitute products such as mortar or concrete that are sustainable and ecological.

The researchers (Irshidat *et al.* 2021) showed that Cement based materials were considered one of the most broadly used construction materials in the world due to their physical and mechanical properties. However, their low tensile strength usually causes intensive cracks that could end up with major durability problems. One common way to enhance the tensile strength of cement mortar thus control cracking is to add fibers to the mix.

Referring to the literature the economic and environmental problems arise, because of Portland cement production many studies has been carried out to activate natural or artificial materials with an alkaline activator described by Çelikten and Işıkdağ (2020). To begin this investigation, mortar represents the product necessary for research in the construction sector subject to studies carried out previously used for the manufacture of concrete or to improve its characteristics.

According to the literature, concrete is a system subdivided into three phases comprising the coarse aggregate, the mortar matrix containing the cement paste, the fine aggregate and the transition zone at the aggregate-paste interface which is fine, presenting around all large aggregates according to Lionel (2015).

Concrete buildings and construction are dominating the construction industry when we consider the present scenario. This ever increasing demand has increased the need to develop high-performance and high-strength concrete which is developed by increasing the binder content by reducing water/binder (W/B) ratio (Mazloom *et al.* 2004) which will lead to a reduction in no homogeneity, porosity and micro cracks in concrete Gesoğlu and Güneyisi (2007). Experimental study of grapheme oxide on wollastonite induced cement mortar revealed by (Sairama *et al.* 2021).

Some authors note that during the manufacture of new concrete structures, three parameters are essential: the cost of materials and construction, the durability of the structure and the respect of the structure vis-à-vis the environment evoked by Mehta (1999) which will constitute in the end. For this, the consumption of industrial by-products as a substitute for cement or aggregates (silica fume, fly ash, blast-furnace slag, crushed glass or vitrification of non-organic waste) seems to be a good solution if their resistance within concrete over time is not compromised. The study of the durability of such concretes is therefore a key factor in order to be able to reduce costs and the impact on the environment and becomes as important as the mechanical resistance in compression has been described by Lionel (2015).

Over the past ten years, durability has thus become a key property for developing concrete technology and building long-lived structures, with the aim of reducing our impact on the environment while reducing cost reported by Mehta (2002). The latter linked to its ability to resist physical and chemical attacks perpetuated by its environment (Erdogan 2002).

Table 1 The chemical composition of cement

Chemical analyses	Value
Fire Loss (%) (NA5042)	10.0±2
Sulphate content (SO_3) (%)	2.5±0.5
Magnesium oxide content MgO (%)	1.7±0.5
Chlorid content (NA5042) (%)	0.02-0.05

The most frequent attacks are leaching and efflorescence, carbonation, alkali-reaction, freeze-thaw and wetting-drying cycles, abrasion, sulphates and acids. Lionel (2015) whose main factors responsible for physical and chemical attacks are linked to environmental conditions (humidity and temperature for example) and to diffusion mechanisms within the cementitious matrix related by Baradan (2002). Moreover, for lightweight concrete (Mazloom *et al.* 2018) have shown that better compressive strength is obtained with travertine, then with marble rock flours compared to that of limestone powders, by developing tests upstream of the plastic phase were used.

On the other hand they also found that among the research done by the researchers (Mazloom *et al.* 2018) that with the production of such products able to sink under their own weight. These do not require any internal or external vibration.

Knowing that the most frequent attacks are leaching and efflorescence, carbonation, alkali-reaction, freezing-thawing and wetting-drying cycles, abrasion, sulphates and acids.

For this, this work consisted of an experimental contribution to the study of the incorporation of slate in cement mortars and their influences on the rheological and mechanical behavior of these mortars.

2. Experimental procedure

2.1 The materials used

The materials used in this study are:

2.1.1 Cement

The cement used in all the tests is a Portland limestone cement of the CEM II/BL-42.5N type manufactured according to the Algerian standard NA 442-2013 and European standard in 197-1 of the cement works. Its physical properties are: normal consistency: 26, 5±2%; fineness according to Blaine's method 3700±5200 cm^2/g; shrinkage at 28 days<1000 μm/m; dilation≤3 mm. The mineralogical composition determined according to the formulas of the bug is: C_3S=60±3%; C_3A=7.5±1%.4.

This choice was deliberate in order to establish the impact of this product on the dosage, the mixtures to be made in order to avoid a significant hardening of the cementitious matrix.In addition, this binder makes it possible to study cracks or hardening shrinkage, loss of rheology and in particular when dealing with potentially reactive aggregates.It has been demonstrated that the attack of concrete by sulphates results from a chemical reaction which takes place in the presence of water between the sulphate ion and the hydrated calcium aluminate, and/or the constituent elements of the calcium hydrate. Calcium from hardened cement paste.

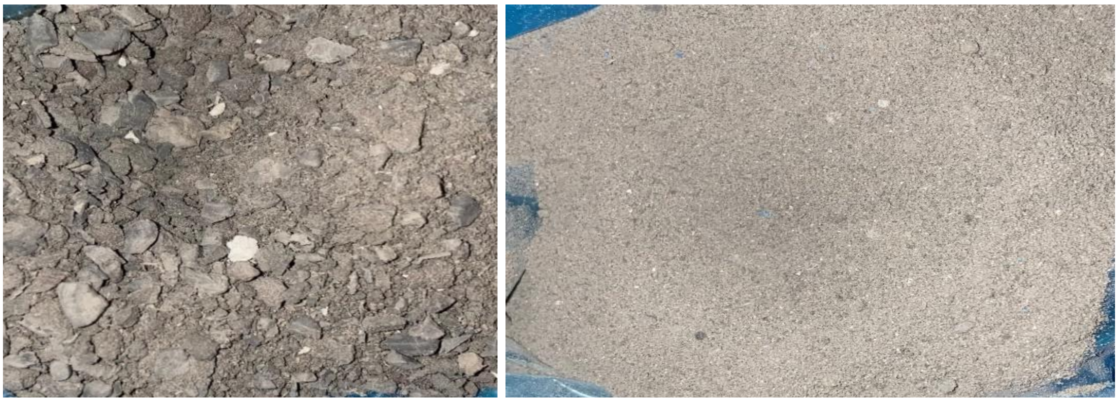

Fig. 1 Local slate

Table 2 Chemical analysis of slate and one mortar

	Symbols	Slate	Sand (mixed sand S2 (0/4)+sand S1 (0/1)
Silica	SiO_2	42.30	36.31
Alumina	Al_2O_3	0.74	0.25
Iron Oxide	Fe_2O_3	Null result	0.78
Sulphates	SO_3 (mg/kg)	1131.90	Null result
Carbontaes	$CaCO_3$	42.06	79.44
Carbon Dioxide	CO_2	18.51	34.95
Chlorides	Cl	0.043	0.057

The products that result from these reactions are calcium sulfoaluminate hydrate called ettringite and calcium sulfate hydrate better known as gypsum.Currently the standards related to the manufacture of concrete for the concrete of the prescriptions of composition which depend on the environment to which the work will be subjected. These prescriptions are supposed to guarantee the durability of the structure against a sulphate reaction of external origin,but the texts do not provide answers in terms of protection against the delayed formation of ettringite. This can be explained by the ignorance of the mechanisms according to Divet (2002).

2.1.2 Slate

Slate is a metamorphic rock derived from clay which belongs to the family of schists, within which it is distinguished by the quality of its flat, very fine and homogeneous grain.Those products with fairly low physical characteristics shown in the micro-Deval and Los Angeles tests used in all the tests are local quarry slate (see Fig. 1).

Slate is a metamorphic rock resulting from a clay which belongs to the family of schists inside which it is distinguished by the quality of its grain of flat shape, very fine and homogeneous having rather weak physical characteristics indicated in the MDE and LA trials used in all trials is local quarry slate (see Fig. 1).

2.1.2.1 Chemical analysis of slate

The results gathered in Table 2 of the analyzes carried out at the laboratory, the slate and the sand have the following composition.

The results of Table 2 of the results of chemical analyzes in the detection of the crystalline presence of iron oxide, silicate and aluminum oxide. On the basis of these results collected, the average sulphate concentration recorded can degrade the concrete by also causing a prior expansion of the material.

However, some components may decrease when the C_3A content dissolved with the C_3A phase of the cement paste gives ettringite accompanied by an increase in volume. They are based on the reduction or elimination of at least one of the four bodies involved in the preceding reactions. The principle according to which, to stop the reaction, it suffices to neutralize only one of the bodies is, in fact, well established. Among other things, the crystalline nature of the slate indicates promising results in terms of hydraulic activity potential. Thus, the cementitious application of crushed slate can therefore be used where the crystalline structure provides information on the stability which is one of the main conditions for its use as aggregates in concrete (Frias Luxàn *et al.* 2000, Rojas 2004, Mahmoud *et al.* 2009, Lionel 2015). The results of Table 2 of the results of chemical analyzes in the detection of the crystalline presence of iron oxide, silicate and aluminum oxide. Based on these results, the average concentration of sulphate recorded can degrade the concrete, also causing the expansion of the material beforehand; nevertheless, certain components can decrease when the content of C_3A dissolved with the C_3A phase of the cement paste sleeps a ettringite accompanied by an increase in volume. Among other things, the crystalline nature of slate indicates promising results in terms of hydraulic activity potential. Thus, the cementitious application of crushed slate is therefore usable where the crystalline structure provides information on the stability which is one of the main conditions for its use as aggregates in concrete characterized by the researchers (Luxàn *et al.* 2000, Rojas 2004, Muhmood 2004, Vitta and Venkateswaran 2009, Lionel 2015).

2.1.2.2 Resistance to abrasion; wear and shock

This fragmentation wear test indicates the impact resistance of rocks and aggregates, used to measure the combined resistance to impact and progressive deterioration by reciprocal friction of the elements of an aggregate. This procedure applies to aggregates used for the construction of pavements and hydraulic concrete. The test protocol was carried out according to the European standard EN 1097-2 describes the Los Angeles test. to the results obtained in the laboratory to determine the friability of the materials; for slate it is (LA)=34.2%, located in the range: 25 and 40% so the sample is medium to low.

The strength of slate is low, the latter cannot be used in the composition of concrete. For the MDE test, the purpose of which is to assess wear resistance. The European standard EN 1097-1 makes it possible to determine the coefficient of micro-Deval.MDE AR=25 and MDE G=0.05 it is therefore noted that the coefficient measures the % of wear, the smaller it is, the greater the resistance to wear is better.

For the MDE test whose purpose is to understand wear resistance. The experimental methods used in this research were necessary to determine the abrasion, wear and impact resistance of coarse aggregate, such as the tests resulting from the Los Angeles and micro-Deval tests that slate has in general low abrasion resistance. The European standard EN 1097-1 has made it possible to determine the coefficient of micro-Deval of slate AR=25. On the other hand, the results obtained respectively on LA and MDE induce that the incorporation of slate in the concrete will not be recommended taking into account its fragility and its friability. In particular that these coefficients are intended to allow us to evaluate the hardness of the aggregates, one of the reasons for this low resistance may come from the density of the natural aggregates.

Their abrasion and wear resistance values are generally less than 20% as reported by Lionel (2015), experimental methods are applied to determine the abrasion, wear and impact resistance of coarse aggregates, such as the Los Angeles and micro-Deval tests. Extensive research has revealed that slate generally has poor abrasion resistance, one of the reasons for this low resistance may be due to the density of natural aggregates.

This fragmentation wear test indicates the impact resistance of rocks and aggregates, used to measure the combined resistance to impact and progressive deterioration by reciprocal friction of the elements of an aggregate. This procedure applies to aggregates used for the construction of pavements and hydraulic concrete. The test protocol was carried out according to the European standard EN 1097-2 describes the Los Angeles test. According to the results obtained in the laboratory to determine the friability of the materials. For the slate it is Los Angeles (LA)=34.2% located in the range: 25 and 40% so the sample is medium to low. The resistance of slate is low, the latter cannot be used in the composition of concrete but such additions can have a beneficial effect on certain characteristics, in particular creep. It seemed interesting to verify this effect on other characteristics of sand concretes, in particular resistance to attrition. For the micro- Deval (MDE) test whose purpose is to assess wear resistance. European standard EN 1097-1 makes it possible to determine MDE coefficient: AR=25.

It will therefore be noted that the coefficient measures the percentage of wear, the smaller it is, the better the wear resistance. According to the results obtained in the laboratory to determine the friability of the materials. The values obtained for the slate is (LA)=34.2% located in the range: 25 and 40% so the sample is medium to low. The strength of slate is low. For the MDE test whose purpose is to understand wear resistance. The experimental methods used in this research were necessary to determine the abrasion, wear and impact resistance of coarse aggregates, such as the tests resulting from the Los Angeles and micro-Deval tests according to requiring the slate has in general low abrasion resistance. The European standard EN 1097-1 has made it possible to determine the coefficient of micro-Deval the MDE of (AR)=25. On the other hand, the results obtained respectively on LA and MDE induce that the incorporation of slate in the concrete will not be recommended taking into account its fragility and its friability. In particular, that these coefficients are intended to allow us to evaluate the hardness of the aggregates, one of the reasons for this low resistance may come from the density of the natural aggregates. Their abrasion and wear resistance values are generally less than 20%. According to Muraz (2015), experimental methods are applied to determine the abrasion, wear and impact resistance of coarse aggregates, such as the Los Angeles and micro-Deval tests. Extensive research has revealed that slate generally has low abrasion resistance, one of the reasons for this low resistance may be due to the density of natural aggregates.

2.1.3 Natural hydraulic lime

With a process similar to that of aerial lime, a natural hydraulic lime is obtained when the starting limestone rock contains, in addition to calcium carbonate, 10 to 20% clay. The presence of clay or other compounds brings in particular silica SIO_2, alumina Al_2O_3 and iron oxides such as Fe_2O_3 to the starting rock. The quicklime CaO which is not associated with the "impurities" will constitute the aerial part of the product obtained. Indeed, a natural hydraulic lime always has an aerial part.

3. Sand

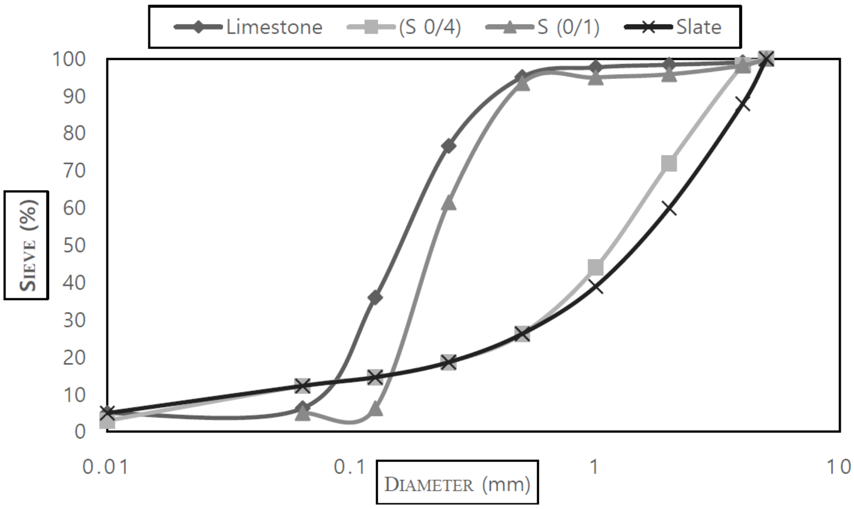

Fig. 1 Particle size analysis of materials

We present the different constituents necessary for the formulation of the mixtures. Chemical analyzes were carried out twice, for the first stage, it consisted in the determination of the mineralogical nature and the specifications to determine the properties which will result in the second phase of this research.

3.1 Particle size analysis of granular slate-limestone-sand materials

The shape of the grains obtained from the sands from the sea sand is more or less round, while that of the slate from has an angular and acute shape. The granulometry makes it possible to determine the staggering of the dimensions of the grains contained in an aggregate. It consists in sieving the latter on a series of sieves, of decreasing opening dimensions, the granulometric curve expresses the cumulative percentages. The shape of the grains obtained from the sands obtained from the sea sand is more or less round, while that of the slate obtained has an angular and acute shape.

The grain size analyzes of the lime and slate sands which were carried out according to standard NF EN 933-1 are shown in Fig. 2. The test consists in classifying the various grains constituting a series of sieves, the materials studied are placed in the upper part of the sieve and the classification of the grains is obtained by vibration of the sieve column. The results are plotted graphically according to their dimensions, with an error of less than 2% of mass loss, making it possible to obtain the granulometric curve of a gravel (*d/b*) or a sand (0/*d*) and of slate (*d/D*).

It can be seen that the curve is continuous for slate. On the other hand, the curves show that for: Sand S 2, Sand S1, and their mixture. The sands must have a grain size such that the fine elements are neither in excess nor in too low proportion. The materials studied following the example of this test, by tracing the granulometric curve which gives the weight percentages, the indicators making it possible to characterize the latter, the granulometric test leads to the calculations of the different fineness modules in order to optimize the water dosage and to have workability and avoid segregation. As well as the more or less fine character of a sand can be quantified by calculating the modulus of fineness (MF), these sandy formations s01 and S04 indicate that these materials contain an iron oxide content value of 0.78, it should be noted however a low glide ratio module that is out of the recommended 2.2 and 2.8 taper. The curves of Fig. 1 reveal that the sand S1 has an (MF1)=1.70, the value is very close to the interval 1.8 and 2.2 while the sand is mainly fine-grained which gives the concrete good maneuverability to the detriment of the resistance found. If one is particularly looking for ease of implementation. If there are too many fine grains, the water dosage of the concrete will have to be increased, while if the sand is too coarse, the plasticity of the mixture will be insufficient and will make placement difficult.

4. Experimental procedures

4.1 Conservation for compressive strength

The tests are carried out on prismatic test specimens in mortar of dimensions (4×4×16) cm^3, the molds covered and stored at room temperature, after 24 hours, the samples were unmolded and stored following the protocol; once removed from the mould, marked and possibly weighed, the specimens are kept completely immersed in distilled water at 20°C±1°C, until the moment of the rupture test. The mechanical resistances of the mortars were determined at the age of 7.28 days according to standard EN196-1 and 60 days. The binders were prepared from different percentages of slate additions to cement or sand.

However, to better elucidate the experimental program, we thought of associating lime in order to possibly understand the behavior of the mortar, including the choice of cement, which was not arbitrary, demonstrated below in the experimental part.

4.2 Composition of mortars

The tests developed on the different series of samples were chosen with the aim of knowing the impact of the binders on the loss of mass that could induce in the future an endogenous cracking of the material, these series were the subject of this test. These series were the subject of this test. Moreover, the process used was developed according to the protocol of the researchers Mazloom and Mohammadi (2019) where the incorporated materials were added in a successive way from the finest to the coarsest.

The Table 3 gives the different percentages of interacting materials entering into the composition of the different mortar mixtures and the quantities are respectively as follows:

Table 3 Nomenclature of samples

Mortar	
MC100S1	100% cement and S1 (0/1)
MC100S41	100% cement and S2 (0/1)
MC50AR50	50% cement, 50% slate in the binder100% S2 (0/4)
MC100S460AR40	100% cement, S2 60% (0/4)+40% substituted slate in the fraction S1 (0/1)
MC100S42	100% cement, S2 60% (0/4)+40% substituted slate in the fraction S2 (0/1)
MC100S1	100% cement+S1 (50% S1(0/1)+S2 (50% (0/4))
MCH100	100% Lime+S1 (0/1)

Table 4 Composition of the different series of mortar

Mortar series	Cement (g)	Sand (S1 (0/1)) (g)	Sand (S2 (0/4)) (g)	Slate (g)	Lime (g)	W/C
M0	450	1350	--------	------	------------	0.55
M1	450	------------	1350	-------	--------	0.5
M2	225	-----------	1350	225	-----	0.5
M3	450	----------		1350 1350		0.5
M4	450	540		810		0.55
M5	225	1350	-----	------	225	1.15
M6	--------	1350	-----	------	450	1.4

These choices illustrated in Table 3, the variation chosen was based on the literature as well as the chemical analyzes which aimed to study the rheological behavior of the material and in this case the shrinkage values of the different samples.

The binder which is the cement and the incorporation of aggregates detected upstream as reagents in Table 3 served to observe the mechanical aspect of the behavior of the mortar under its various substitutions and to carry out the tests which will converge towards shrinkage, hardening and optimal dosage.The composition of the mortars was made according to subsequent research while working with local materials in an environmental and local environment inspired by the research of researchers (Pellegrino *et al.* 2012) that for a high replacement having an impact on the rheology of the concrete. Especially if the replacement of the aggregates also concerns the fine part (<5 mm). It is recommended, in the fine part, to keep at least 50% natural aggregates so as not to have a significant loss of workability so as not to have a significant loss of workability presented by authors (Pellegrino *et al.* 2012, Lionel 2015). Table 5 gives the different percentages of interacting materials entering into the composition of the different mortar mixtures, the quantities are respectively as follows:

5. Interpretation of physical results

5.1 Effect of binder content

Fig. 2 makes it possible to highlight the effect of the different percentages of binder content which will be used upstream of the benchmark to produce the mixtures, this variation in the binder content of the MC100S1 and MCH100 series shows a correlation of the density with the percentage to be considered, which reveals that the two series have a difference that differs within the limit of 23% for the substitution of binder, the trend curve of the two series makes it possible to ultimately predict that the binder content will have an impact on the density beyond this threshold, the convergence of which is shown in the Fig. 2 above.

5.2 Spread test on table Spreading mortar

The table spreading results, described in the European standard NF 12350-5 were carried out, the results of which are presented in the Table 5 is explained by the fact that the reduction in the

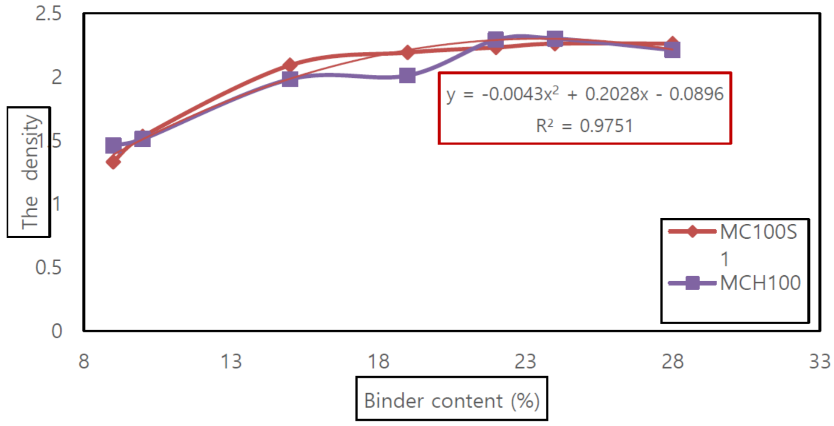

Fig. 2 Effect of binder content on density

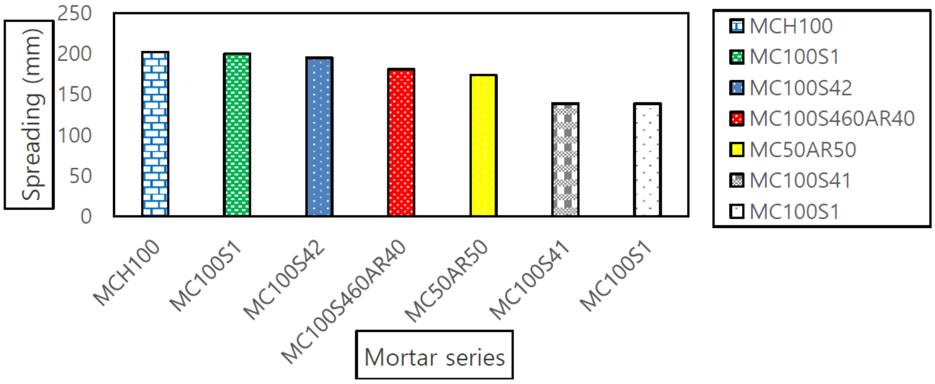

Fig. 3 Results of the different spreads

quantity of water causes a reduction in the distance between the grains and subsequently an increase in the friction between these grains. This test makes it possible to identify the addition of granular fractions at low doses which can greatly improve certain intrinsic characteristics of the mortar and in particular those of the concrete. This phenomenon is explained by the compactness of the sand (0/4 and 0/1) which is greater than that of recycled slate fines according to Fig. 1. This increase in spreading on the impact table of the various tests may be due to the intrinsic characteristics of the slate: its absorption capacity and its surface condition. The aggregates obtained have an angular shape and a significant roughness generated by the grinding of the slate, this can lead to an increase in friction between the grains by replacing the local sand with the fines of the slate and results in greater absorption. of the MC100S460AR40 and MC 50AR50 series compared to conventional mortars. The nature of the sand and the quantity of cement present in the mixture. This leaves less free water which can be used to lubricate mortar components, since unsaturated aggregates can absorb water from the mix during mixing, slag aggregates affect workability as well as the effective W/C ratio of concretes related by researchers (Abu-Eishah *et al.* 2012, Lionel 2015).

The effect of mortar formulation on spreading is shown in the Fig. 3. It should be noted that the increase in the granular concentration leads to a reduction in the spreading of the mortars. For a

W/C ratio=0.5, the increase in granular concentration leads to a 15% reduction in slump for standard sand (SN) and 25% for recycled fines mortar. In order to improve the workability, and therefore the density, of admixtures admixtures are not sufficient to guarantee the resistance to attack on concrete described by Swenson (1974), as shown by the results in Fig. 3.

The spreads of the different mortar confections show us spreads whose result shows a greater increase for the MCH100, MC100S1 series and a drop of 25% for the MC100S41 and MC100S1 samples to which this is due to rapid absorption. Taking into account the quantity of water administered, the value of which is approximately 0.5, the results lead to diameters for which the spread is lower than for the MCH100, MC100S1 and MC100S42 mortars. It should also be noted that for the same w/c ratio, the use of slate is less compared to the mortar of usual composition, this is the result of the significant absorption of water. Which indicates in particular in the Figs. 2, 3 the convergence with the researchers (Sairama *et al.* 2021).

It should also be noted that for the same w/c ratio, the use of slate is less compared to the mortar of usual composition, this is the result of the significant absorption of water.

Also this evolution of the spreading seems to be due to the intrinsic characteristics of the slate: the absorption capacity and their surface state create a greater absorption of the MC100S460AR40 and MC 50AR50 series compared to conventional mortars, the nature of the sand and the amount of cement present in the mix. Since unsaturated aggregates can absorb water from the mix during mixing, slag aggregates affect workability as well as the effective w/c ratio of concrete described by authors (Abu-Eishah *et al.* 2012, Lionel 2015).

5.3 Mass loss

The tests developed on the different series of samples were chosen with the aim of knowing the impact of the binders on the loss of mass that could induce in the future too compromising cracking of the material, these series have been the subject of this essay. No standard method for testing concrete has been developed. However, assessments can be made through outdoor exposure and laboratory testing. According by Swenson (1974), they aim, among other things, to avoid microcracking of thermal origin, but also those related to the delayed formation of ettringite. They aim to avoid microcracks of thermal origin, but also those linked to the delayed formation of

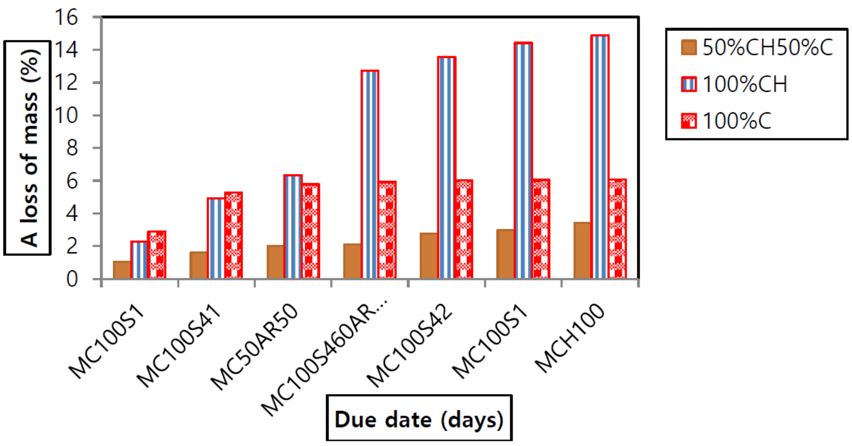

Fig. 4 Ambient air-drying effect of mortars

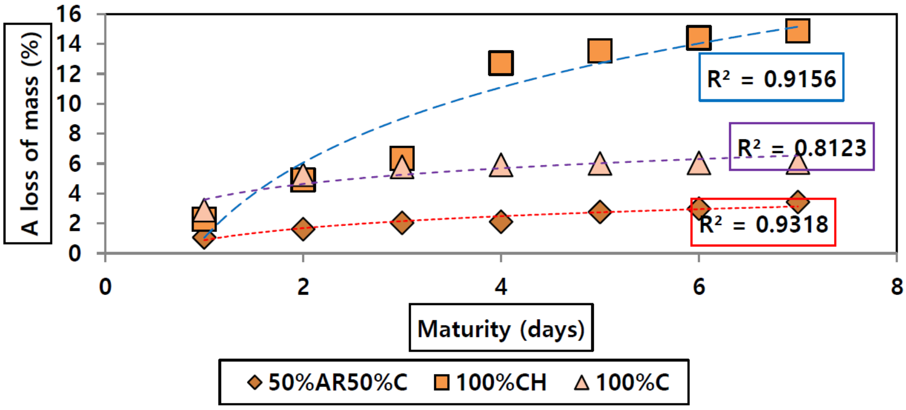

Fig. 5 Correlation values on mortar characteristics

ettringite. Some of these rules are very restrictive for safety reasons and because of ignorance of the influence of each factor on the reaction. The notion of interaction between the different factors is rarely taken into account. Moreover, these rules apply regardless of the type of cement or concrete.

However, standard NF EN 13369, which will be applicable in France in July 2004, takes into account this notion of multiparametric reaction of the delayed formation of ettringite Divet (2002).

Besides, the effective parameters on the flow ability of mortars were analyzed based on the mix design of the mortars (Pedram *et al.* 2019).

In Fig. 4, the different series of composition which were the subject of this chronicle showed, according to the results obtained, that the loss of mass is greater for the samples whose constitution is made of lime. Following the results collected, we opted in this part to choose a batch of the 100% C (50% AR 50% C) and 100% CH series for which new mass loss tests were developed in order to understand the action of the various constituents in the formulated binder.

The mass loss illustrated in Fig. 5 of the different samples in the open air, we can see that the latter is revised upwards for the 100%C series compared to the other series (50%AR50%C) and 100 %CH is a predictable behavior since the hydration is relatively more important for the 100%C series, thus generating a correlation between the composition of the binder and the loss of dry density.

The effect of aggregates on shrinkage makes it possible to quantify by varying the mass ratio and the type of aggregate (natural sand and that of fines (slate+SN (0/4)) and on shrinkage which induces in the Fig. 5 a satisfactory correlation of the various tests, the correlation factor R2 of which is around 0.9, which makes it possible to justify the behavior of the various mortars. The shrinkage results are little influenced by rates below 7%, and the difference in shrinkage becomes greater beyond 20% and all the more so when the concrete is exposed to early drying confirmed by (Mehta 1989).

This regression of the results is attributed to the hydrates formed during the presence of mineral substance which makes the dough more rigid and less deformable. This physical phenomenon whose significant shrinkage caused the appearance of residual tensile stresses and the cracking of the samples, which explains the drops in resistance.

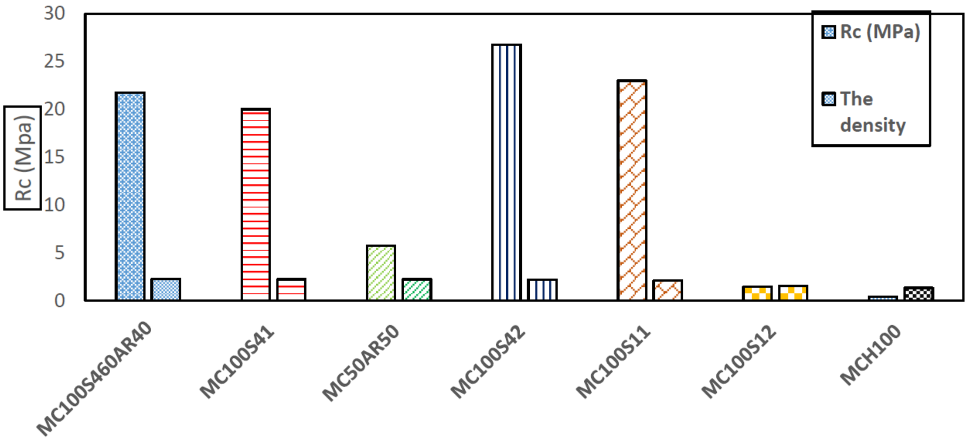

Fig. 6 Influence of density on compressive behavior

6. Results and discussions

6.1 Influence of density on behavior under compression

The compressive strength tests of mortars are shown in the Fig. 6 where it is observed that the total substitution of the slate material by natural sand generates a reduction in the compressive strength. As far as the grain size is concerned, it obeys certain rules: the finest elements are housed in the voids larger elements.

Placement energy is related to addition fines. Sands rich in natural fines generally require much more water, which leads to a drop in resistance knowing that the granulometry of Fig. 1 generally obeys criteria for the arrangement of the rubble, which indicates that relatively the finest grains become lodged in the material to the detriment of the coarser ones, so this energy is normally a predictable result caused by their high natural fines content generally requiring much more water, resulting in a drop in strength.

On the other hand, during the days that follow an increase in mechanical strength of about 30% between 7 days and 28 days, illustrated by graph 6 for mortars based on recycled fines. The results obtained also indicate that the high density made up of cement gradually creates an increasing cohesion within the mixture, which results in obtaining rigid and hard materials with high mechanical performance of a concrete which is an advantageous characteristic for numerous applications associated with the other mechanical parameters necessary for the development of a resistant material and contributes to the durability of the composite.

The grouped mechanical resistances of the series drawn up in Figs. 6-7 reflect an improvement in the two parameters characterizing the mechanical effect on the mortar, which is explained by the substitution of the additions in relation to the quantity of sand incorporated in the mortar. However, these resistances make us understand that the nature of the sand is a major factor in the evolution of these samples. The grouped mechanical resistances of the series drawn up in Figs. 6-7 reflect an improvement in the two parameters characterizing the mechanical effect on the mortar which is explained by the substitution of the additions in relation to the quantity of sand incorporated in the mortar, however these resistances make us understand that the nature of the sand is a major factor in the evolution of these samples. The resistance obtained can be different

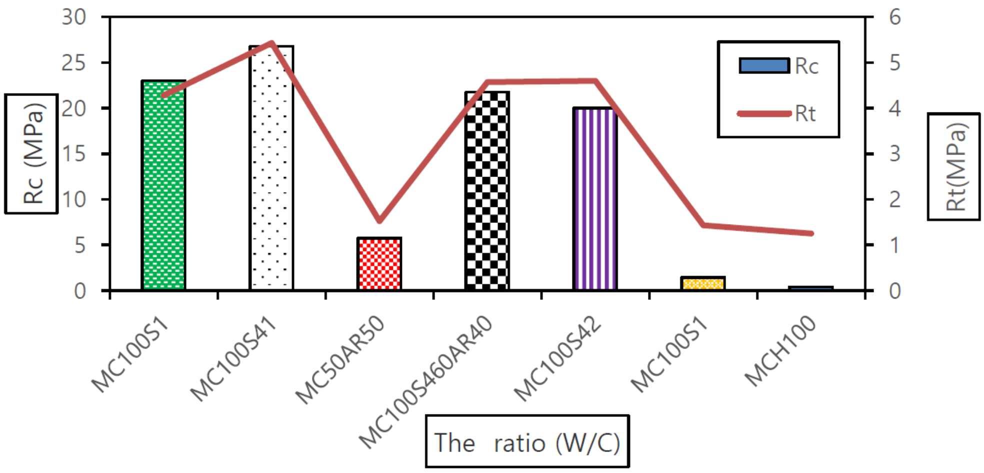

Fig. 7 Influence of density on mechanical behavior

according to a number of parameters and in particular: the fineness of the addition linked to its rate, the nature of the fines and the level of gain in compactness which plays a major acquisition of the mechanical character of the material at a constant cement dosage. However, as mentioned above, the total replacement of the fine part of the aggregates by slag has a negative effect on the compressive strength, which can lead to up to 7% loss compared to a traditional mix (Pellegrino *et al.* 2012). Added, the results conferred on the various specimens thus establishing a relationship between the fraction of aggregates produced in the mortar, which is explained by the increase in density, the fall of which is quite significant in the MC50AR50, MC100S41 and MCH100 series. Like most concretes with usual strengths less than 25 MPa at 28 days, it is the transition zone which limits the strength of the concrete reveal by Mehta and Monterio (1986).

Besides, the results indicate that the different specimens have made it possible to establish a relationship between the fraction of grains produced in the mortar, which is explained by the increase in density, the drop in which is quite significant in the MC50AR50 series, MC100S1 and MCH100. It is the transition zone which limits the strength of the concrete and the loss of mass revealed in Figs. 4 and 5 can cause cracking of the skin as well as residual stresses of the samples, which also confirms the drops in resistance during a strong presence of slate as a substitute element in the binder.

In addition, the results conferred on the different specimens thus establishing a relationship between the fraction of aggregates produced in the mortar, which is explained by the increase in density, the fall of which is quite significant in the MC50AR50, MC100S1 and MCH100 series. Like most concretes with usual strengths (less than 23 MPa at 28 days; it is moreover, the results obtained from Fig. 7 which indicate that the different specimens have made it possible to establish a relationship between the fraction of grains produced in the mortar, which is explained by the increase in density, As most concretes have usual strengths (less than 23 MPa at 28 days, it is the transition zone which limits the strength of the concrete and the loss of mass revealed in Figs. 4-5 will induce pathologies as well as residual stresses of the samples, which also confirms the decreases in resistance during a strong presence of slate as a substitute element in the binder and the sand.

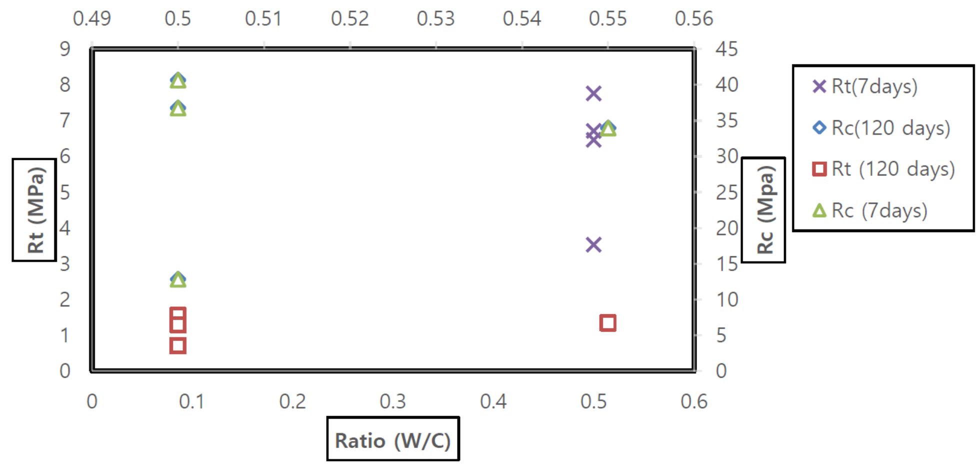

Fig. 8 Impact of density on mechanical behavior

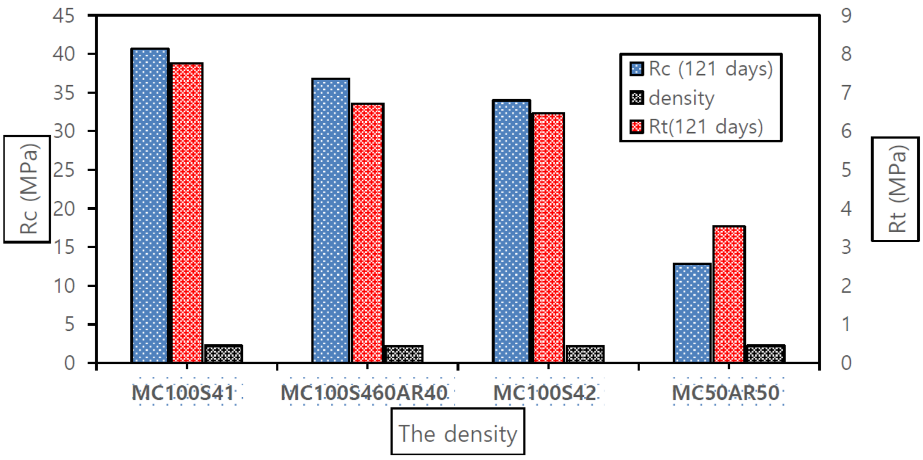

Fig. 9 Influence of density on mechanical behavior

6.2 the impact of the density on the mechanical behavior

The Fig. 8 reveals the improvement in mechanical strength. It shows that the w/c ratio has an effect on the behavior of the mortar for all the series combined. Still, the contribution of this ratio varies according to the composition of the binder and the matrix of the series, but these observations illustrate short- and long-term changes since some binders act on the long-term mechanical characteristics by associating the increase in the effect chemical of these parameters by the retarding effect of regulation. As described in the previous sections, the total replacement of the coarse part of the natural aggregates improves the paste-aggregate transition zone. The roughness of the surface state and the porosity of the slag aggregates are responsible for an interface that is often of very good quality between the aggregates and the cement paste. The roughness of the surface state and the porosity of the slag aggregates are responsible for an interface that is often of very good quality between the aggregates and the cement paste described by (Pellegrino *et al.* 2012).

6.3 Convergence of density on mechanical behavior

Fig. 9 presents the variation of the four representative series of the mechanical characteristics: compression and tension associated with the density at 121 days where one can notice on the one hand that the compressive strengths respectively of the different samples at 7 days have a relatively normal progression compared to their compositions, in particular those with traction.

However, beyond 30 days, there is still a progression in the characteristics of the following samples MC 100 S 41>MC50AR50>MC100460AR40>MC100S42 indicating that the properties of the mortars in Fig. 9 have continued to progress and moreover the use of a w/c ratio in general of 0.5 when an attack by sulphates is to be foreseen. These results show that the addition of slate decreases the mechanical strength of cements in the long term and moreover the use of a w/c ratio in general of 0.5 when a sulphate attack is to be foreseen Swenson (1974).

This indicates a clear improvement compared to the resistance criteria also noted by the chemical analyzes in Table 2 or may be due to the chemical interaction of the various components leading to the improvement of the mechanical characteristics which can also be explained by the The slowing and progressive effect that will emerge in the long term from this improvement shown in Fig. 9. As described above, the density of slag concrete is generally higher than that of conventional concrete even in the hardened state, it has been described by (Abu-Eishah 2012, Lionel 2015).

The highest density of slag aggregates occupying about 75% of the concrete is the cause of this phenomenon. The impact of the replacement of natural aggregate by a crystalline slag on the strength of concrete is, as for the other properties of concrete, a function of the replacement rate was indicated by Lionel (2015).

The higher density of slag aggregates occupying approximately 75% of the concrete is the cause of this phenomenon. The impact of replacing natural aggregate with crystalline slag on the strength of concrete is, as with other concrete properties, a function of the replacement rate which quoted by Lionel (2015). As described above, the density of slag concrete is generally superior to that of conventional concrete, even in the hardened state according by the publications (Abu-Eishah *et al.* 2012, Lionel 2015).

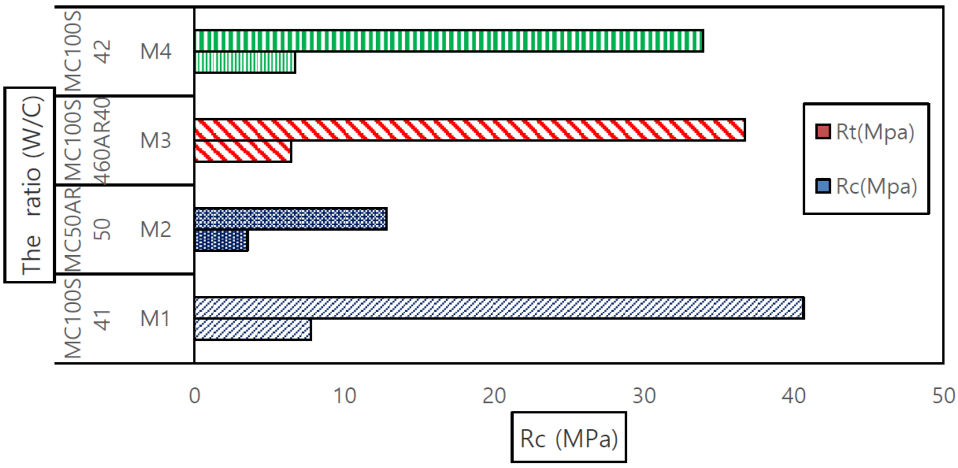

Fig. 10 Influence of W/C ratio on mechanical characteristics

6.4 The optimum W/C ratio sought

Fig. 10 shows that the w/c ratio, which is 0.5, influences the properties of the mortars, also indicating that the effect of the substitution of sand and slate leads to the results determined upstream, thus increasing the desired long-term constitution regarding the manufacture of mortars.

The w/c ratio is one of the most important design factors for concretes in general, justified by the particularities of these concretes and requiring more water than conventional concretes, which translates into a more significant contribution of water. This ratio is generally between 0.6 and 1.5, thus justifying the composition of Table 3. This feature is also due to a larger specific surface of the mixture, the w/c+F ratio (F=fine additions) leads to an increase in the w/c ratio. if this increase can lead to improving this resistance, this gain will automatically vary according to the nature and the dosage of the fines. there is a strong correlation between the w/c ratio and the final strength of concrete described by Lionel (2015) to produce mortars with good resistance while avoiding the phenomenon of desiccation, it is always interesting to set the w/c ratio at 0.5. Nevertheless, according to the intrinsic characteristics of slate and sand, this threshold can hardly be maintained.

7. Young's module

Thus, the modulus of elasticity is normally represented by the slope of the linear section of the stress/strain curve. The most important factors affecting the modulus of elasticity are the w/c ratio, the nature of the coarse aggregates and the entrained air content. the young's modulus is revised downwards, the correlation factor of which is R^2=0.9086 for the series of mortars whose nomenclature is as follows mc50ar50, mc100s1 and mch100. in addition, a clear improvement in this mechanical factor for the mc100s4, mc100s4, ar60ar40 and mc100s42 samples

thus, the modulus of elasticity is normally represented by the slope of the linear section of the stress/strain curve. the most important factors affecting the modulus of elasticity are the w/c ratio, the nature of the coarse aggregates and the entrained air content. the young's modulus is revised downwards whose correlation factor is R^2=0.9086 for the series of mortars whose nomenclature is as follows MC50AR50, MC100S1 and MCH100 these are expected results knowing that the modulus of elasticity being a general data of granular materials (0/D sand) for which the modulus decreases when Dmax decreases.

In addition, a clear improvement in this mechanical factor for the MC100S4, MC100S1, MC100S4, AR60AR40 and MC100S42 samples. We also noticed on the samples a greater porosity than the control mortar which indicates the presence of voids, the size and the number of these voids are distinguished from those of the ordinary mortar so they are materialized by their numbers, their size and their dimensions. This could indicate that their number may lead to a more frequent and easier likelihood of clogging given their small size. This variation is obviously caused by the composition of the mortars suggesting two reasons which seem to be at the origin of the change, the substitution of slate for sand gives better results than those of the binder. Thus, all the authors agree on the fact that concretes made with coarse slag aggregates give compressive strengths at least equal to those of conventional concretes and often even better in the publications (Chunlin *et al.* 2011), Khanzadi and Behnood (2009), Liu and Chen (2011), Pellegrino and Gaddo (2009). Most of the studies carried out on this subject report that the modulus of elasticity seems or better for concretes containing slag aggregates compared to conventional concretes reported by (Pellegrino *et al.* 2012, Abu-Eishah *et al.* 2012).

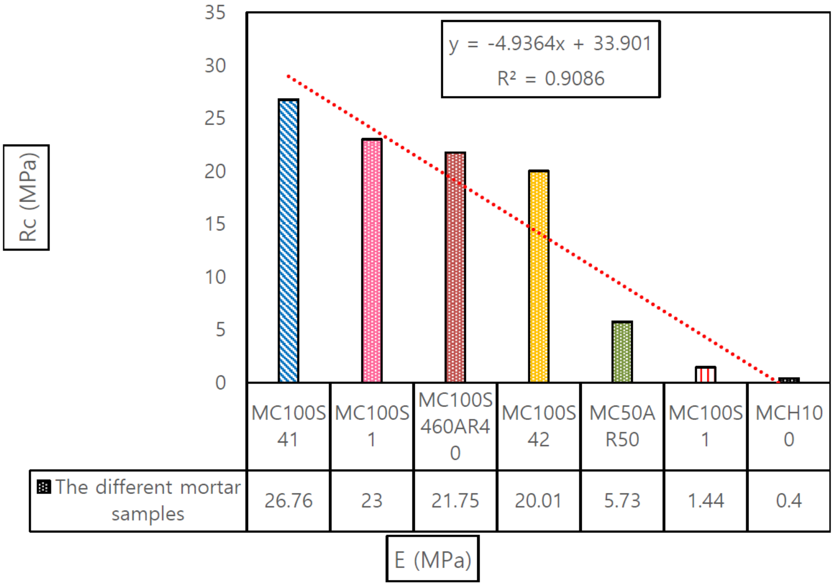

Fig. 11 Evolution of the Young's modulus of the different series of mortar

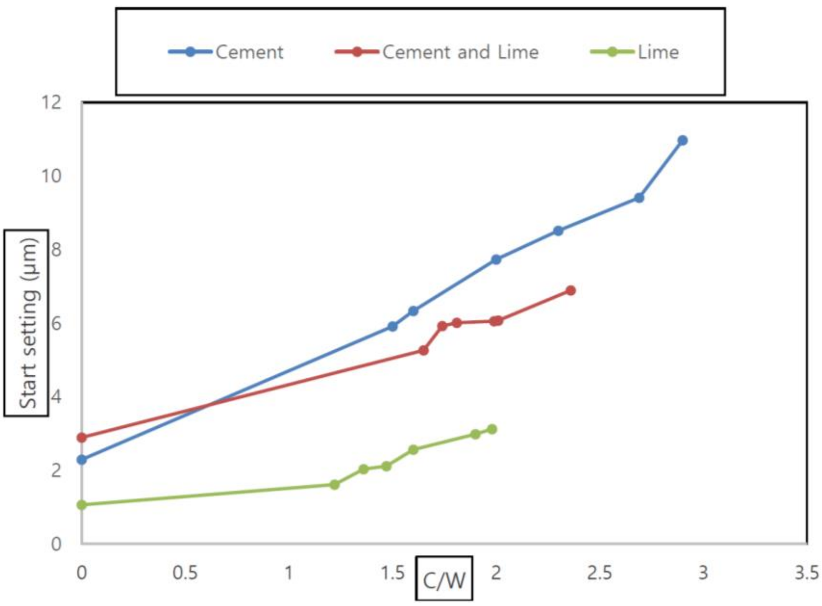

Fig. 12 Effect of binder on setting

8. Influence of different parameters on grout setting:

8.1 Grout setting effect as a function of time

The objective of this section was to study the influence and the stakes of the parameters on the setting of the grout. In order to determine the impact of these parameters on the mixtures chosen

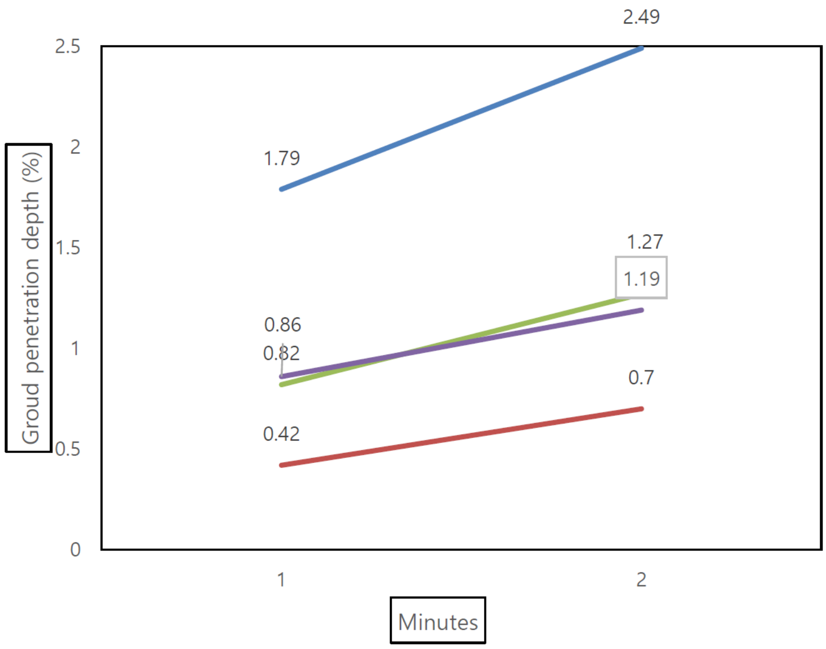

Fig. 13 Depth of penetration into grout

for this purpose Two cases were studied and chosen according to the results obtained above in order to determine the adhesion of the grout, two cases were studied, the MC100S1 and the MC50AR50 for a constant w/c ratio of 0.26.

Fig. 12 shows that for the 1st case the onset of setting occurs after 3h10 min. This cement is therefore classified in the category of slow-setting binders, as well as for the 2nd case the start of setting occurs after 1h20min because the slate absorbs water and dries faster, due to the formation of gypsum ($CaSO_4$. $2H_2O$) then ettringite ($3CaO.AL_2O_3.3CaOSO_3.32H_2O$) which can cause the concrete to swell. Sulfate ions react with cement (portlandite) to form secondary gypsum and alkali hydroxides depending on the reaction (Selecdepol.fr).

This secondary gypsum can then react with the aluminates ($CaO.AL_2O_3.6H_2O$) present in the cement paste to form ettringite (Selecdepol.fr). In general, according to Muraz (2015), it must be assumed that the oxides of silicon (mainly SiO_2) and aluminum (mainly AL_2O_3), free lime (CaO) and percales (MgO). These last two can be responsible for the expansion of the slag and therefore limit its use. Depending on its nature, it willalso contain iron, copper, zinc or titanium oxides as well as a small proportion of alkalis (K_2O and Na $_2$O). The crystalline nature can be a factor as an indicator of low hydraulic activity potential. The cementations application of ground crystalline slag is therefore prohibited by Muraz (2015). Crystalline structure provides information on its stability which is one of the main conditions of use and as concrete aggregates (Muhmood *et al.* 2009, Frías Rojas *et al.* 2004, Luxàn *et al.* 2000, Lionel 2015).

8.2 Grout setting effect as a function of time

For Figs. 12-13, we note that for the 1st case the start of setting which occurs after 3h10 min, the cement used is therefore classified in the category of slow-setting binders, as well as for the

2nd case the start of setting occurs after 1h20 min because the slate absorbs water and dries faster. Some researchers (Mehta and Montreio 1986, Lionel 2015) note that the preferential presence of large capillary pores more or less saturated with water under or near large aggregates promotes the development of portlandite ($Ca(OH)_2$) in the transition zone.

These crystals offer little resistance to the concrete and are easily washable, thus leaving voids in the transition zone, which then weakens and no longer allows the forces undergone by the concrete to be transferred has been decribed by Mehta and Montreio (1986), Lionel (2015). It is therefore relevant to consider the aggregate-paste interface when evaluating the mechanical strength and durability reported by Lionel (2015).

Conventional refractory concretes being compounds made up of tabular alumina aggregates which play the role of a skeleton bound by a cementitious matrix, the latter being made up of clinker and fine alumina AL_2O_3.The transition phase has a lot of influence on the mechanical properties of concrete, which is the link between the mortar matrix and the coarse aggregate, two major components of concrete which is mentioned by Lionel (2015). Even when the strength of these two components is high, it of concrete may be weak due to defects in the transition zone. Desiccation shrinkage is virtually identical at an early age, after 28 days.

9. Conclusions

• The recycling of slates is an asset in the construction sector which will be necessary to reduce the major component that is shale harmful to the environment as well as an improvement in the characteristics of the concretes to which they must undergo calcination before being incorporated and an addition as a charge.

• This work was part of a context of sustainable development and aimed to improve the mechanical performance of the mortar by replacing slate with the quality of sand and the cementitious matrix. In addition, this reduction in density is an important advantage in construction by granting structural lightness. The results showed that in the hardened state, the substitution of slate in one of the constituents, which is sand, affected the mechanical properties of the latter. However, in the state of formation of the grout; a strong decrease in Vicat needle penetration was observed. This stolen allowed; once to demonstrate that calcining slate can reduce the absorptive capacity of grout.

• The partial replacement of the cement by additions of slate can improve the mechanical characteristics of the mortar but we believe that this effect will be greater if this substitute undergoes calcination upstream in order to reduce the absorption of the mortar observed at different times of this research. Nevertheless, according to the results obtained, the addition of slate decreases the mechanical resistance in the short term, but in the long term the contribution is significant, this improvement of all the mechanical parameters.

• One can also retain from this study that the incorporation of slate in the mortar presents interesting results within the framework of the substitution of slate aggregates, thus conferring the possibility of reducing the density of the heavy structures. The use of local materials will therefore be a parameter that will enter into the composition of an ecological cement and will contribute to the development of innovative materials. Further, other cements can be chosen with better characteristics to chemical aggression, thus avoiding aggression and alteration of the concrete. The use of local materials and the reduction of cement consumption could be new parameters to consider in developing ecological materials.

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