Escola de Camins
Escola Tècnica Superior d'Enginyeria de Camins, Canals i Ports
UPC BARCELONATECH

"CONTROL LOW STRENGTH MATERIALS"

A SUSTAINABLE PRODUCT FOR OUR URBAN ENVIROMENT

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TREBALL FINAL DE GRAU

DEDICATION

.

This is for you, Mom and Sister.

Thanks for have never left my side.

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ABSTRACT

The Controlled Low Strength Material (CLSM) is a cementitious material of fluid consistency that allows for self-compacting, and is used as a filling alternative to compacted fill. In this research work analyses the applicability of the recycled aggregate, steel slag sand and fly ash from construction waste and demolition, as a constituent of CLSM for use as fill material excavated.

The fabrication process of the CLSM was conducted in three stages that are explained in Chapter IV.
In phase 1 defines the optimal control of dosing CLSM with natural aggregate. Since it, in phase 2, defines the starting dosages CLSM with the recycled aggregate substitutions 20, 50 and 100 %, and starts an improved process for optimum dosage for a material made from recycled aggregate CLSM. It was also analysed the influence of the steel slag in a mixture made with the 20 % of replacement percentage. The criteria for acceptance of CLSM fabricated are based on the study of plastic properties, flowability, density and air content, as well as the compressive strength of hardened property. In phase 3, were examined the sway of fly ash as part of the cement paste and also the influence of the fly ash and steel slag mixed in a CLSM dosage.

In Chapter V discusses other plastic properties of CLSM as bleeding and penetration resistance to determine the setting time, both in fresh state, and in addition to the hardened state properties was analysed tensile strength, modulus and density, porosity and absorption.

Finally, was conducted a study of the large scale (from 8 to 37 litres) behaviour of CLSM.

With this research it was observed that the CLSM made with Portland cement, water, natural aggregate, recycled aggregate (in proportions of 20 and 50 %) and foaming agent for lightweight, obtain suitable properties in both state plastic and in service, and this is easily excavated for future. It was also observed that the use mixed of fly ash and steel slag has suitable properties in both states.

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CHAPTERS

CHAPTER I. INTRODUCTION

1.1. General aspects

This document is the result of an experimental process that was carried out with the aim of achieved a material made of aggregates, cementitious material, water and sometimes chemical admixtures that constitute a self-compacting, flowable and low-strength material that allows being excavate in the future. This material is known as Control Low Strength Material (CLSM). However, the necessity of this research emerge from the initiative to create a replaced material that implement as aggregate recycled sand or steel slag that came from the construction and demolition waste or the steel making process, respectively.

Construction and demolition waste are composed of concrete, asphalt, brick and ceramic and after being treated it is usually used as recycled coarse aggregates for the production of construction materials as several research works shows. However, it is known that 50 % of the weight of the crushed construction and demolition waste is fine aggregate. The recycled fine aggregates modify the fresh and hardened concrete properties due to their high absorption capacity and few researchers have checked their applicability for new materials. Consequently its use is still limited and there is a need for further research on the matter. Controlled Low Strength Materials could be a good option in order to reduce the accumulations of high volume of recycled fine aggregates [1].

The great advantage to incorporate recycled sand or industrial by-products at the manufacturing process of CLSM is to find solutions to the excess generated at recycling plants or at the factories. In fact, these types of aggregates are no really used in construction materials due to the high requirements, this aggregates hold low density, high absorption percentage, ceramic waste, asphalt, brick and ceramic. For this is important to find applicability of these aggregates in the production of CLSM.

With the development of this research project the use of CLSM are going to be use with recycled aggregate and steel slag sand because achieves the specific requirements and as compaction is not required, the trench width or excavation size required can be minimized, and this is key in Barcelona city, where the space is limited.

The research work described was conducted in three stages in order to analyse the applicability of recycled fine aggregates in the production of CLSM using air-entraining and a superplasticizer admixture. Stage 1 consisted in defining the optimum mix proportion of conventional CLSM made with Portland cement, water, air entrained admixture and natural fine aggregates, achieving the specific requirements defined by ASTM in fresh and hardened state. Stage 2 measured the influence of the use of recycled fine aggregate and steel slag on fresh (flowability, consistency, unit weight and air content) and hardened (compressive strength) properties in the analysis of the CLSM material. Recycled aggregates were used in 20%, 50% and 100% substitution of natural fine aggregates volume defined in conventional CLSM mixture in stage 1 and the obtained results were compared to those of conventional

CLSM. The optimum mix proportions, according to specific requirements defined by ASTM, of CLSM made with different percentages of recycled aggregates were determined. In stage 3, first of all a control dosage made with fly ash was search that has suitable properties in both states. The second part in stage 3 was to see the influence in a CLSM mixture made with fly ash and a substitution of 20 and 50 % of natural aggregate by steel slag. When suitable mixture were found bleeding and penetration resistance for fresh state and tensile strength, modules, density, porosity and absorption in hardened strength were tested in optimum mix proportion of CLSM made with natural sand, 20%, 50% and 100% of recycled aggregates, fly ash and fly ash with steel slag were determined in order to guarantee the quality of CLSM materials.

1.2. Targets

1.2.1. General targets

The purpose of this project is the analysis of the different aggregates applicability, as recycled aggregate, steel slag and fly ash, like main constituents for the produce of CLSM.

1.2.2. Specific targets

1. Define a control dosage that gives suitable fresh and hardened state properties with just the use of natural aggregate.
2. Study of the behaviour in both states of CLSM made with different proportions (20, 50 and 100 %) of recycled aggregate to find the optimum percentage to substitute for natural aggregate.
   In addition, the use of steel slag is also study with a replacement proportion of 20 and 50 %, to discover if its use is possible.
3. Observe the use of another type of cementitious material as fly ash, and lastly the use of this cementitious material (fly ash) mixed with steel slag to find a suitable dosage that achieves the required properties.
4. Verify all the optimum dosages achieved.

1.3. Structure of the end-of-degree project

This end-of-degree project is basically structured in six chapters to provide the understanding of this research project that have been performance.

The experimental process was divided in three different stages, containing many photos for the purpose of increase the comprehension quality because when talking about different types of materials is challenging to imagine it just by reading.

CHAPTER I. Introduction

In this chapter is introduced abbreviatedly the main motivation for the development of this experimental project. It is detail the different objectives and gives a brief description of the project structure.

CHAPTER II. State of the art

In this chapter is explained all the information know it until nowadays about Control Low Strength Materials (CLSM). It is also referenced previous researches that are the guideline of this experimental process and the examination of the obtained results.

CHAPTER III. Materials and Experimental process

In this chapter is described all the components that had been used, with their main characteristics, to produce CLSM. It is also explained the experimental process, manufacturing process and the testing procedure in both fresh and hardened state.

CHAPTER IV. Mix proportion determination

In this chapter are indicating the dosages in a small quantity that have been used for produce CLSM and the attributes of the manufactured material in the different states.

CHAPTER V. Optimum dosages

In this chapter, having had a good mixture from the previous chapter, the same dosage was made increasing the quantity of material in order to analyse more plastic properties that were not exclusionary.

CHAPTER VI. Conclusions

In this chapter are exposed the obtained conclusions and it is suggest future research lines.

CHAPTER II. STATE OF THE ART

2.1. Introduction

Control Low Strength Material is a cementitious material, with fluid consistency, self-compacting and is used mainly as alternative backfill to the conventional compacted fill. Control Low Strength Materials (CLSM) is described for the ACI 116R as a mixture that hardens into a material with a higher strength than the soil, but less than 8.3 MPa. However, in order to make possible a future excavation, is required a compressive strength under 2.1 MPa.

The material has won a special recognition in the EE.UU and Canada as backfill material due to these inherent advantages. These advantages are self-compacting, flowable, controlled density, low-strength material to be excavatable in the future and economy.

Control Low Strength Materials (CLSM), named for the ACI Committee 229, can be described as a mixture of soil or aggregates, cementitious material, fly ash, water and sometimes chemical admixtures. Used as a replacement for compacted backfill, CLSM can be placed as slurry, a mortar, or a compacted material and typically has strengths of 350 to 700 KPa for most applications [2].

Another terminology can be used as fluid filling, filling without shrinkage, controlled density filling, soil-cement grout, plastic soil-cement, K-Krete, fluid mortar or poor filling mixture [3] [4] [5]

Table 1 describes briefly the more notable features of the use of CLSM [6].

Table 1. CLSM Advantages

Advantages	Description
Availability	With the use of local materials, the concrete producers can produce CLSM accomplishing with all the specific requirements.
Delivery ease	Mixer trucks can deliver the necessary quantities of CLSM at work when its necessary.
Placement ease	CLSM can be placed directly from the gutter or can be pumped. CLSM adjust to the type and localization of the space that needs to be fulfilled. Because of CLSM is self-compacting it increase the construction speed and reduce labour.
Versatility	CLSM mixtures can be adjusted to meet specific requirements of fulfilling, for example they can be adjusted to improve flowability, if more strength is required is need just a more amount of cement or fly ash, if setting time need to increase or reduce just a different type of admixtures can be used. Just adding foaming agent to the mixture the samples are light and insulated.
Strength and durability	CLSM load capacity is greater than compacted or granular soil. CLSM is also less permeable and this means it has more abrasion resistance. When using as permanent backfill CLSM can be designed to reach 8.3 MPa, but is usually that the upper limit resistance design is lower to 2.1 MPa in order to be excavate in the future.
Quick traffic reopening	Because of CLSM can be placed quickly and can withstand traffic loads in a few hours, the time used to repair the pavement is minimal.
No sedimentation	When placement the CLSM mixture, the mixture can avoid the hole formation and does not cause sedimentation. This advantage is very important if the backfill is covert by pavement.
Costs reduction	CLSM allows that the trench width or excavation size required be minimal because the space for compaction machine are no required.
More safety	Workers can place the CLSM without going into the trench that need to be fulfil, these condition reduce potentially their exposure to landslides.
Application in any type of weather	CLSM is capable of moving stagnant rain water (or snow) that is in the trench reducing the need for pump. When using CLSM in a cold weather, the materials can be heated using the same methods for heating concrete aggregates.
Excavability	CLSM with compressive strength lower than 1.4 MPa are easily excavate with conventional equipment but is also strong enough to cover most of the needs of a backfill.
No inspection requirement	During placement backfill, the soil need to be tested after each load in order verifies that there is enough compaction. CLSM is self-levelling and self-compacting that not need to be tested.
Equipment reduction	When using CLSM is not necessary the use of any bulldozer, rollers or tampers.
By-products use	CLSM that contains by-products as can be slag or fly ash, benefits the environment.

2.2.Application

Due to the low compressive strength that CLSM has, is not a material suitable for structural functions, but it has another applications thanks to the adherent properties such as flowability, workability and self-compacting powers that is required in another construction activities. Depending on the scope, CLSM required different values of compressive strength.

In Boston, USA, in earliest 1992 began the construction of a central tunnel with a great importance due to the need to alleviate the high congestion of cars produced toward Logan Airport. The use of CLSM was key to this work. It was used for underground corridors because of its versatility. It was also perfect when the need of filling cavities between the outside of the tunnel walls and holes in the ground that reached up twenty four metres deep with only sixty centimetres wide. The engineers responsible considered CLSM as the best option because of the need for a material to behave like a fluid that could flow in difficult and accessible locations [7].

2.2.1. Backfill

The CLSM is used primarily as backfill, void fill, and utility bedding instead of conventional compacted fill. Since compaction is not required, the trench width or excavation size required can be minimized. When the backfill is made against retaining walls the lateral pressures exerted by the backfill fluid should be considered. When the hydrostatic pressure fluid is considerable, CLSM must be placed in layers allowing each to harden before applying the next. According to ACI 229 [3] [8], compressive strength of a well compacted soil ranges from 0.3 to 0.7 MPa, so its suggest that the compressive strength minimum requirement higher than 0.7 MPa.

2.2.2. Structural backfill

Depending on the resistance requirements, CLSM can be used as a support for foundations. When used as structural backfill, the compressive strength, according to the ACI 229 [3] and depending on the design requirements the ranges could be from 0.7 MPa to 8.3 MPa [9].

In the case of weak soils, CLSM can distribute the structure load over a larger area. For layers that are not level or not uniform under foundations, CLSM can provide a surface that is level and uniform, and can also reduce significantly the required thickness because of their strength. If it is due to keep the dimensions of such elements, it may use a lower strength CLSM.

Some experiences [3] like one near Boone, Iowa (EEUU), where 2141 m^3 of CLSM were used to provide a support for a lift footing, reveal the good performance of this material as structural fill.

2.2.3. Thermal insulation

CLSM is also applied where thermal insulation conditions are required. Examples include placing this material in soils adjacent to geothermal wells. Foundation soil adjacent to power plants with combustion engines, various industries production plants among others. For all of these applications CLSM with low density is of special interest.

2.2.4. Pavement base

CLSM can be used for bases, sub-bases and leveled subgrades. The mixtures can be directly emplaced from the mixer truck to existing curbs that would act like confiners. When it is necessary restoring a service road in a 24 hours period time, its suggest using CLSM with compressive strength higher than 1.5 MPa [9].

2.2.5. Bedding pipeline

CLSM behaves excellently as backfill material for pipelines, electrical services telephony and other types of conduits. Material characteristics allow even fill cavities in the pipe providing an uniform support.

The filling fluid may be designed to provide resistance to erosion under the pipe, acting as a support bedding which also prevents water appearance between the pipe and the bracket.

Coating the entire CLSM duct also serves as future protection for the conduit. If excavate in the pipe vicinity, the apparent change material between CLSM and the field alert the existence of a pipeline. Moreover, the use of colour pigments in the mixture helps to identify the presence of CLSM.

2.2.6. Erosion control

CLSM resists erosion better than other types of backfill. The test results set forth in ACI 229 [3] that was comparative tests with sandy and clay soils, showed that exposing the water at a speed of $0.52\frac{m}{s}$, has better behaviour both in the amount of losses material and suspended material.

The material of this study is used for protecting embankments and dissipation energy works to prevent the displacement of rocks and prevent erosion. This material is also used to backfill voids under the pavement, sidewalks and other structures where the natural soil or granular cohesive and non-cohesive fillers are eroded.

2.2.7. Other applications

CLSM was used to fill tanks and abandoned underground sewers, avoiding the formation of voids that can settle the land, or gas that can cause explosions. CLSM is also been used for closed and stabilization dumps, tunnels, landfills construction, abandoned mines, wells, etc.

2.3. Materials y Mixture dosages

The components of the CLSM are the cementitious-binder material, aggregates, water and additions and/or additives are also used [1]. Other mixtures are formed only by Portland cement, water and fly ash, or other option would be a constitution formed of water, Portland cement, aggregates and additives.

Selection of materials for its production should be based on availability, cost and specific application. The most important properties are the flowability, unit weight, bleeding and setting time in its fresh state and compressive strength, density, tensile strength and modulus in its hardened state.

2.3.1. Cement

Cement is used in a limited quantity and provides the cohesion and strength for CLSM. Portland cement types I and II are commonly used according to ASTM C 150. Other types of cement can also be used if the preliminary tests on the mixtures provide acceptable results. Cement content generally ranges from 30 to 120 $\frac{kg}{m^3}$ [3], depending on the requirements of strength and setting time. The increase in the amount of cement, while maintaining all other factors, usually increases resistance and reduces the hardening time [1]. Another aspect to consider is the cost increase per cubic meter if the quantity of cement also increases.

In some references they have been used different types of cement in varying amount for produce CLSM, yield different resistance values. For example, CEM II/A-V [10] from 54 to 100 $\frac{kg}{m^3}$, CEM II/A-M [1] from 110 to 135 $\frac{kg}{m^3}$, CEM I [4] from 30 to 120 $\frac{kg}{m^3}$ and Portland cement [5] from 30 to 276 $\frac{kg}{m^3}$, obtaining strengths from 0.5 to 7 MPa, 0.6 to 1.6 MPa, 0.07 to 3.7 MPa and 0.05 to 0.9 MPa, respectively.

In one research [8] where different types of cement were used, including Portland cement I/II and common calcium aluminate cement, it was observed that the use of calcium aluminate cement develops a high strength in a short period of time respect to the Portland cement I/II.

2.3.2. Fly ash

The main function of the fly ash is to improve flowability, increases strength and reduces bleeding, shrinkage and permeability [3] [4] [10]. However, the use of fly ash reduces the compressive strength in early age [9] [11]. Some research has shown [4] that the use of fly ash increased water demand, despite the variations in the content of fly ash does not significantly affect water demand.

There are two types of fly ash that are able to provide different compressive strength to the mixture, mainly due to the discrepancy in the chemical composition and the reactivity of the same. The fly ashes quality not only depends on the type and source of coal, but also the type of boiler and combustion process employed. Fly ash class F is generally derived from hard coal and minerals, while fly ash class C are typically derived from sub-bituminous coals [12].

The content of fly ash class F are used for making CLSM reaches up to 1200 $\frac{kg}{m^3}$ [3], and are mainly used as backfill fine material. Fly ash class C are used to produce CLSM in amounts up to 210$\frac{kg}{m^3}$, although there are references that have been used until 360 $\frac{kg}{m^3}$ [4]. The amount of fly ash to be used is determined by the availability and the flowability requirements of the project.

2.3.3. Water

Water accepted to develop concrete and mortars is suitable for produce CLSM. Any free water, acids, alkalis or organic material can be used for manufacturing CLSM. High water content in CLSM causes that the material can to flow easily, self-consolidating and self-levelling, but reduces the compressive strength.

Usually more water is used in CLSM than in concrete. Water contents typically range from 193 to 344 $\frac{kg}{m^3}$ [3] [4] [10] for most CLSM mixtures containing aggregate. Water content for Class F fly ash and cement-only mixtures can be as high as 590 $\frac{kg}{m^3}$ to achieve good flowability.

Some research shows that there is not significant variation in water demand when fly ash class C or F are used, but more water is needed when fly ash with high content of coal [4] are used. The water content will be high if the amount of fine aggregate in the mixture increase.

The water cement ratio $(\frac{w}{c})$ used in some researches ranges from 1.00 to 1.75 for mixtures made with Portland cement [5] [8] [13]. This wide range is due primarily to the characteristics of the materials used in CLSM and the flowability degree desired.

2.3.4. Aggregate

Coarse aggregate is not generally used in CLSM mixtures as often as fine aggregates. The amount of recycled fine aggregates used, ranges from 1500 to 1800$\frac{kg}{m^3}$, is estimated once the volume of cement, fly ash, air and water is defined in order to produce 1 m^3 of CLSM. However, some references [14] have been found where amounts of aggregates are used from 550 to 1.550 $\frac{kg}{m^3}$ for the CLSM production.

Although not as really common, there are also references [15] where some coarse aggregate are used in an amount of $\frac{1}{3}$ of the amount of fine aggregate.

Natural aggregate

Aggregates are the main component in a CLSM mixture. The type, classification and the form of the aggregates determine physical properties of the CLSM mixture, such as flowability and compressive strength.

Aggregates that have been used successfully are those that have the requirements of ASTM C33 (sand gravel, maximum particle size of 19 mm or less, sandy soils with more than 10 % of material passing through the sieve No. 200, waste product from a quarry usually of 10 mm or less).

Excavated granular materials with lower properties than the concrete aggregates are a potential source to produce CLSM, and should be considered. In a research about obtaining CLSM mixtures from rejection crushing processes [8], the results showed that is possible to use fractions of aggregate surpluses, usually with high fines content in order to obtain CLSM.

Recycled aggregate

In general, recycled aggregate is defined as the aggregate that came from the processing of inorganic materials previously used as building materials. The raw materials for their production are stone materials generated as waste during construction and demolition processes.

With the aim of developing a construction material respectful with the environment, there is a study [1] that experiment the production of CLSM with recycled aggregate that has a lot of ceramic waste. The study concludes that the use of recycled fine aggregate substituting in various proportions to the natural aggregate, and by applying different variations of some properties in the dosage, as can be the water cement ratio $(\frac{w}{c})$ or the amount of cement allows to obtain the characteristic of a suitable CLSM mixture .

An experimental study [11] investigated the feasibility of using recycled aggregate with coarse and fine slag and fly ash to produce CLSM without the need of Portland cement. The results showed a suitable CLSM for a wide range of applications, especially those that require a structural support and rapid hardening.

Steel slag

Foundry sand can be used as a substitute for ash [16] (the increase of bleeding is produced) or natural sand [4] [5] which produces a decrease of compressive strength.

2.3.5. Air-entraining admixture

The inclusion of air in CLSM can help to improve workability, reduced shrinkage, little or no bleeding, minimal segregation and control of ultimate strength development [17]. Lower unit weights CLSM mixtures are obtained from the use of air entraining admixture as part of the dosage. This admixture consists of air cells generated from foam concentrates or chemicals that produce gas. Its use in CLSM produced lower unit weight than the obtained in a standard mixture and controls the compressive strength development. As added, is an admixture that reduces the risk of segregation [17] and its use is highly recommended in CLSM when not using fly ash since the amounts of water and aggregate to be used are very high [1].

The foam concentrate should have a chemical composition capable of produce stable air molecules that resist chemical and physical force during mixing, placement and settlement of flowable fill. If the molecular structure is not stable it will result in a no-uniform density increase. The procedures for evaluating foam concentrates are specified in ASTM C796 and ASTM C869.

Some of the air-entraining agents found in the international market are: MasterCell 10 and Rheocell Rheofill. The usual dosage of MasterCell 10 (see Appendix I) recommended by the manufacturer are from 0.5 to 3.0 $\frac{l}{m^3}$ of concrete, although it could vary depending on the desired effect. Its density is 1.030 ± 0.02$\frac{g}{cm^3}$. The product is manufactured by BASF.

High doses of air entraining admixture can be used in the CLSM to decrease the density or unit weight. To prevent extended setting times, extra cement or the used of an accelerating admixture may be required [18] [19] [20]. By using these products it is important to consider the manufacturer recommendations. Some research work [4] [21] suggest that the incorporation of air-entraining agents in the CLSM should keep the amounts of entrained air in the mixture in a range between 15% and 30%.

The use of this admixture is advantageous when the weight of the stuffing should be minimized by weak soil conditions. Water content can be reduced as much as 50 % when using air-entraining admixtures. It is also effective as a thermal insulator.

The air entraining admixture may be added during mixing after adding water, aggregates and cement (and obtained a uniform consistency) either in the ready-mix plant, in a concrete truck or directly into the mixer.

Most air-entrained CLSM mixtures are pumpable but can require higher pump pressures when piston pump are used.

2.3.6. Superplasticizer admixture

Superplasticizer, also known as high range water reduce, are used to reduce the amount of water while maintaining a certain level of consistency and workability and to increase workability for reduction in $\frac{w}{c}$ ratio.

One of the superplasticizers found in the international market is Viscocrete 20 HE. The usual dosage of Viscocrete 20 HE (see Appendix II) recommended for the producer is 0.5 – 1.5 % of the cement weight.

2.3.7. Other admixtures

Other admixtures, such as zeolites, heavy minerals and clays can be added to the mixture. Typical proportions are in the range of 2 to 10% of the total mixture. Fly ash and cement can be adjusted accordingly, keeping all other factors.

2.3.8. Colour pigments

The producer recommends not using more than 8 % of cement the weight.

2.4. Properties

CLSM is produced with a materials and a manufacturing process similar to concrete productions. Far from having similar characteristics, in hardened state CLSM has more properties similar to the soil than the concrete properties. CLSM qualities are influenced by components and proportions thereof.

CLSM characteristics in fresh and hardened state are determining and decisive for the material utility, which implies a need of control over them.

The most important properties are described below:

2.4.1. Properties in fresh state

Some bibliographies [8] [22] expose that the fresh state properties of CLSM are similar to concrete or grout in fresh state and, therefore, their placement is best seen in terms of concrete technology.

Here are some of the most important properties of CLSM in fresh state.

Flowability

Flowability is the property that makes Controlled Low Strength Material (CLSM) suitable material for use as backfill. Without the need for conventional placement and compaction equipment flowability allows that the material is self-levelling, flow within a hollow space, fill, and self-compacting. The placement of the material, when the hydrostatic pressure is important, should follow a process of successive layers, allowing the layer harden before applying the next one.

ASTM D6103 [2], has developed its own approach to determine CLSM flow consistency, which will be described later (Chapter III).

The flowability criterion for CLSM ranges are from 20 to 30 cm according to ASTM D6103 [2](ACI [3]). These values are established by some research works whose results obtained from flow tests are, for example, from 175 to 275 mm [5], 211 to 255 mm [12], 158 to 325 mm ($\frac{w}{c}$ from 1.25 to 1.75) [23], 140 to 432 mm ($\frac{w}{c}$ from 0.4 to 4.6) [24], 280 to 540 mm [25]and 168 to 600 mm ($\frac{w}{c}$ from 1.5 to 4) [26].

Flowability depends on the $\frac{w}{c}$ ratio, when this ratio increases higher values are obtained [11] [5] [26]. Air entrained admixtures can also increase flowability up to 40 % [26], as well as the use of fly ash [11] [9]. In the same way that when a concrete in order to improve the flowability of the material a fluidizer admixture or a superplasticizer is added.

Density

The resulting material density depends on the materials used in the mixture. According to ACI 229R [3], the wet density of normal CLSM is determined by ASTM D6023 [27], from a range of 1840-2320$\frac{kg}{m^3}$. However, by using light weight aggregates, such as silty sand or mixes with light weight aggregate, lower unit weights can be achieved between 1360 and 1760$\frac{kg}{m^3}$. If all the mixture aggregates has been replaced by fly ash, CLSM density should be determined between 1440 and 1600$\frac{kg}{m^3}$. CLSM density in fresh state should be measured according to ASTM D6023 [27].

Some of those mixtures show CLSM density values as 1382 to 2291 $\frac{kg}{m^3}$ [4], 1100 to 1400 $\frac{kg}{m^3}$ [8], 1350 to 1720 $\frac{kg}{m^3}$ [23], 1430-1760 $\frac{kg}{m^3}$ [1], 1730 to 1840 $\frac{kg}{m^3}$ [28], to 2009 to 2198 $\frac{kg}{m^3}$ [24].

The inclusion of air reduces the density, then the density of the CLSM mixture is inversely proportional to the amount of air present [8] [23] [22], but depend of the type of aggregate used [10] [22], being proportional the increase thereof. In cement-rich mixtures, increasing amounts of sand the density remains similar [8] because of in the mixture sand is not as remarkable as cement, in terms of density is concerned.

Segregation

If the CLSM dosage is not correct, there may be loss of homogeneity in the mixture with high levels of flowability, when the dosage is characterized by high water/cement ratios ($\frac{w}{c}$) [11] [3]. In mixtures with low amounts of cement, its variation has little effect on segregation, although the use of fly ash reduces the segregation phenomenon [22] [26]. In CLSM mixtures contents of coarse and heavy materials are minimal, therefore segregation probabilities are low [5]. It also helps that CLSM does not need to be compacted, this means be vibrated [5].Otherwise, with the use of denser materials, the mixture tends to sink producing the loss of homogeneity [29].

Settlement

The shrinkage is related with volume reduction of the CLSM mixtures as the water contained and trapped air through the consolidation of the mixture is removed. High ratios of water/cement ($\frac{w}{c}$) are given to allow the flowability of the mixture, but that provides an excess of water apart from that amount required to consolidate and moisturize, this excess is generally absorbed by the adjacent soil or removed through the surface as bleeding [12]. The shrinkage typical value is between 3 and 6 mm for every 30 cm deep, this value is generally found in mixtures with high water content [3]. Mixtures containing appropriate water quantities have little or no shrinkage. The material settlement may be experienced during the first 2 to 4 hours after placement [21].

In an experimental study that investigate the feasibility of using recycled aggregates of fine and coarse concrete with slag and fly ash to produce CLSM, without the need to add portland cement [11] settlements between 0.3 and 4% were reported.

Setting time

According to ACI 229R [3], is the period of time that CLSM takes to acquires a state of hardening enough to support the weight of a person. Setting time is variable, and depends on the bleeding. When water excess come out of the mixture the contact and adhesion increases between the particles and the hardening process starts. It can be as short as an hour, but under normal conditions can take between 3 and 5 hours.

According to Dockter [30], the setting time has special interest to predict the feasibility and portability. The setting time can be defined in two different stages. The first stage which takes approximately 3 to 4 hours is when CLSM mixture can support a person standing. The second stage, usually occurs in 1 or 2 days, and is when CLSM mixture acquired stability to place products on it, such as cargo transport. Setting times are very important when the backfill is placed in layers.

There is a research [31] to determine if using stainless steel slag is feasible and its observed that increasing the water/matrix ratio ($\frac{w}{m}$) from 3.4 to 3.8 the setting time increase in 30 %. The study also shows that the replacement of part of the conventional Portland cement for steel slag may increase setting time up to 62 % according to the percentage replaced.

ASTM C403 [32] determines the setting time of CLSM from its resistance to penetration. These test method is described in Chapter III at experimental process (testing procedure).

Normal factors that have influence on the setting time are [3]:

- Cement: type and quantity
- Permeability and saturation degree of the soil around CLSM
- Relative humidity
- Mixture dosage
- Room temperature
- Moisture
- Backfill depth

Bleeding

CLSM could present bleeding, if the dosage has water excess, with the addition of fly ash bleeding would be decrease and at the same time, flow properties improve the mixture. It could also be incorporated into the mixture high density aggregates or larger quantities of cement in order to reduce exudation [4].

In a research based on the constituent materials effects, the quantities in water demand and compressive strength of CLSM [4], bleeding values between 0 and 7.2 % were reported.

The standard test method to measure bleeding is determined by ASTM C232 [33] described in the section about experimental process (Chapter III).

Pump

CLSM can be pumped, for this reason the dosage is critical. In the same way as for concrete pumping it is important to maintain a continuous flow through the pump line. If an interruption occurs the mixture could be segregate and this may cause plugging. The CLSM mixtures with high levels of air entrained can be pumped, but the bomber should be at low pumping pressures in order to not suffer considerable losses in air content and to not reduce the pumping capacity.

Fly ash can help to the pumping acting as a micro aggregate to fill the gaps, cement can also be added for this purpose, although it should be careful to limit the strength thereof for not hinder the future excavation.

2.4.2. Properties in hardened state

The properties exhibited by the Controlled Low Strength Material (CLSM) in hardened state resemble those obtained by soils.

Here are described some of the most important properties of CLSM in service.

Compressive strength

The unconfined compressive strength is a measure of the CLSM ability to distribute loads. The compressive strength of CLSM at 28 days must be higher than 0.7 MPa [3] [27] [32] [34] [8] while that of a well compacted soil varies from 0.3 to 0.7 MPa. CLSM can also be used as structural filler, in which case the recommended compressive strength should be higher than 2 MPa, depending on specific requirements [9]; and for pavement bases, sub-bases, and subgrades it should be of 1.5 [1].

For projects where future excavation is expected with mechanical equipment is important to keep the resistance low, less than 1.4 MPa, although the limit for CLSM excavable is defined by the value of 2.1 MPa. Some mixtures that are acceptable at early ages continue gaining strength over time, so that makes future excavations difficult. The compressive strength test method for CLSM is described in ASTM D4832 [34] (Chapter III).

Some research [1] [4]show how compressive strength varies significantly with the materials and amounts thereof, especially when the materials increase water demand. In the research [4] it was reflected that replacing foundry sand for natural sand in similar dosages, the compressive strength decrease from 3.49 MPa to 0.25 MPa in 91 days, and the decline was caused by the increased water demand.

The water/cement ratio ($\frac{w}{c}$) is the most significant factor when determining CLSM compressive strength. Compressive strength decreases depending on the increase of the ratio $\frac{w}{c}$ [26]. Some bibliographical references show values of $\frac{w}{c}$ from 0.6 to 1.9 [14] and from 1.48 to 4.59 [35].

Compressive strength is also influenced by the adhesion strength between the aggregate and the cement matrix. When the mixture has been properly cured, a material based on cement is expected that became more resistance over time due to the increase of compressive strength is mainly a function of the cement and fly ash hydration degree [26].

Density

According to ACI 229R [3], there is a considerable reduction in volume weight when hardened state is achieved, which must be considered in the mix design, depending on the use of the material. It is possible to achieve lower volumetric weight using lightweight aggregates or air entraining admixtures for example.

In one research [5] about the performance of industrial by-products in CLSM, were obtained dry density values between 899 and 1832 $\frac{kg}{m^3}$ while the saturated dry surface density was within 1365 and 2088$\frac{kg}{m^3}$.

Excavability

The possibility to excavate the soil constitute by CLSM mixture in the future is an important consideration. Generally, a compressive strength of 0.3 MPa or less can be manually dug. Compressive strength between 0.7 and 1.4 MPa, mechanical equipment such as backhoes can be used. The mixtures that only consist of fine sand or fly ash as aggregate can be dig also with backhoes even if the compressive strength is 2.1 MPa [3].

When there is a possibility of a future excavation, the type and amount of cement is important. It has obtained a long-term acceptable behaviour with cement contents from 30 to 276 $\frac{kg}{m^3}$ [5].

In order to maintain low resistance, and limit the amount of cementitious material in the mixture, a foaming agent can be incorporated.

Given that CLSM typically continue gaining strength beyond the period of conventional test methods, it is suggested, especially for CLSM with high cementitious material that long-term tests can be conducted in order to estimate the potential of a subsequent excavation over the years.

Differential settlement

Traditional compacted fillings may suffer settlements even when compaction requirements have been made. By contrast, the CLSM mixtures do not undergo settlements after hardened [3].

According to ACI 229R [3], measurements taken in various works demonstrated the absence of contractions and settlements after hardened state. Moreover, in a project in Seattle Washington, in which 601 m^3 were used to fill a hole of 37 m depth, placement took 4 hours and differential settlement in the hardened state was 3 mm [36].

Thermal insulation and conductivity

When insulation is required the mixture must be provided to obtain low density and high porosity. Conventional air-entrained admixtures have low density and have a high insulation value. Lightweight aggregates can be used to reduce the density. Cell foams have low densities and show good insulation properties.

When high heat conductivity is required, as in the case of fillers for power cables, it try to have a high density and very low porosity, this means maximum contact area between the solid particles. As the moisture content and the dry density increases, so does the conductivity.

Other parameters to consider, but are minor, are mineral composition, shape and particle size, particle size distribution curves, organic content and specific gravity.

Permeability

The permeability of most CLSM mixtures is similar to the compacted granular fillers. Typical values [18] are in the range 10^{-4} to$10^{-5}\frac{cm}{s}$. Flowable fill mixes with higher strengths and fines content achieved permeability as low as $10^{-7}\frac{cm}{s}$ [22] .

The permeability increases as the cementitious material content decreases and the aggregate increases. The materials used to reduce permeability, such as bentonite clay, previously shall be tested because they may affect other properties in CLSM mixtures.

Shrinkage

Shrinkage does not affect the performance of the MBRC. Several reports have indicated that there is very little shrinkage in this material, the typical linear shrinkage is in the range of 0.02 to 0.05 % [37] [38] [39]

Polyethylene compatibility

The MBRC are compatible with polyethylene of high, medium and low density, commonly used for protecting underground works or installation of such works. The CLSM fine gradation minimizes the chances of breaking the polyethylene surface [3].

2.5. Costs

Some researchers [22] say that CLSM costs about two thirds to three quarters of the ready-mixed concrete price. CLSM is generally more expensive per cubic meter than most conventional fillers. However, these costs depend on the materials used, manufacturing process, transport and placement method. The mixing flexibility design has allowed some producers to develop CLSM with local materials, which are more economical. Moreover what makes it really economically attractive is the low cost of labour, short run times and minors inspection during placement.

In Boston, USA (1992) started the construction of a central artery tunnel, note that for 1983, the initial budget with conventional materials was 2.3 billion dollars. For 1993, the budget became 6.4 billion dollars considering the use of CLSM, although, if conventional materials have been considered would have amounted to 15 billion dollars [7].

2.6. Quality control

Quality control implemented to CLSM changes according to previous experience, application, materials used in the mixture and the desired level of quality. When the application is important and has not prior documents about the mixture used or when the mixture uniformity is doubtful, it would be appropriate carry out flowability and compressive strength tests. However, when preliminary tests have been carried to the mixture, control can be limited to a visual inspection of the entire work.

It is suggested that, in the relevant projects, a mixture design and preliminary tests of flowability, unit weight, strength, long load application, durability, permeability, etc. Once the preliminary test program had been conducted, it should be necessary to define the test method that need to be performed in construction place.

The responsibility is to that person who does the technical specifications and to the CLSM producer, to determine and implement an appropriate quality control for the mixture that need to me placed. Table 2 show some of the ASTM standards used to determine properties in fresh and hardened state of CLSM.

Table 2. ASTM Regulations

Regulation	Name	Property
ASTM C232	Standard Test Methods for Bleeding of Concrete	Bleeding
ASTM C403	Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance	Setting time
ASTM D559	Standard Test Method for Wetting and Drying Compacted Soil-Cement Mixtures	Durability
ASTM C939	Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)	Fluency
ASTM D1883	Standard Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils	Strength
ASTM D4832	Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders	Strength
ASTM D5084	Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter	Permeability
ASTM D6023	Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter	Permeability
ASTM D6024	Standard Test Method for Ball Drop on Controlled Low Strength Material (CLSM) to determine Suitability for Load Application	Setting time
ASTM D6103	Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM)	Flowability

CHAPTER III. MATERIALS AND EXPERIMENTAL PROCESS

In this chapter is described the properties of the materials that had been used to the development of the experimental process. In addition it is also described the manufacturing process to produce Control Low Strength Material (CLSM), and detailed the testing procedure to analyses the behavior of CLSM in fresh and hardened state.

3.1. Materials

3.1.1. Cement

CEM II / A-L 42.5 R [40] was used for the experimental process in the production of different CLSM mixtures. It was proportionated by PROMSA Company (Ciments Molins S.A). The cement with limestone aggregate has a high initial resistance of 42.5 MPa.

Table 3 and 4 shows the chemical and physics characteristics (cement components).

Table 3. Cement chemical and physic characteristics

Composition (%)	**CEM II A-L 42.5 R**
SiO_2	19,0
Fe_2O_3	3,7
Al_2O_3	5,6
CaO	64,5
MgO	2,0
K_2O	0,9
Na_2O	0,1
SO_3	3,2
Physic properties	
Specific surface (Blaine, $\frac{cm^2}{g}$)	3,98

Table 4. Cement characteristics of CEM II/A-L 42.5 R according to [34] and usual values

	Characteristics	**Specifications** [40]	**Usual values**
Components	Clinker	80 - 94 %	88 %
	Calcaria	6 - 20 %	10 %
	Minority component	0 - 5 %	2 %
Chemical	Chloride	< 0.1 %	0.01 %
	Sulphates	< 0.4 %	3.3 %
Physics	Initial setting	> 60 min	120 min
	Final setting	< 720 min	180 min
	Expansion	< 10 mm	0.5 mm
Mechanical	Compressive strength (2 days)	> 20 MPa	25 MPa
	Compressive strength (28 days)	42.5 < R < 62.5 MPa	52 MPa

3.1.2. Fly Ash

The Fly Ash used was equivalent to ASTM class F (fly ash is generally derived from hard coal and minerals). Table 5 shows the chemical compositions of the fly ash used.

Table 5. Fly Ash chemical composition

Composition (%)	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	TiO2	P2O5	Na2O	LOI
Fly Ash	55.46	26.94	5.86	5.70	1.50	1.51	1.41	0.83	0.62	3.70

$$Specific\ surface = 3360\ \frac{cm^2}{g} \qquad Density = 2.32\ \frac{g}{cm^3}$$

3.1.3. Water

The water used was ordinary tap water collected from the laboratory because comply with the Spanish requirements of the UNE regulations (Table 6) [41] [42] [43] [44] [45].

Table 6. Water specifications [40]

pH	≤ 5
Dissolves substances	$\leq 5\ \frac{g}{l}$
Sulphates	$\leq 200\ \frac{mg}{l}$
Chloride	$\leq 6\ \frac{g}{l}$
Carbohydrate	0
Organic substances	$\leq 15\ \frac{g}{l}$

3.1.4. Natural aggregate

Figure 1. Natural aggregate

Figure 2. Natural aggregate ready for use

Natural aggregates were used in the CLSM mixtures. Locally available and provided by PROMSA Company, limestone sand was used as the natural aggregate.

$$Natural\ aggregate\ density = 2.58\ \frac{kg}{dm^3} \qquad Natural\ aggregate\ absorption = 1.7\ \%$$

Natural aggregate granulometric curve is show in Figure 7.

3.1.5. Recycled aggregate

Figure 3. Recycled aggregate

Figure 4. Recycled aggregate

One type of recycled aggregate of construction and demolition waste sourced from a treatment plant located in Montoliu (Lleida) was used. The usual composition of recycled aggregates (determined according to EN 933-11 standard) [46] is given in Table 7.

Table 7. Recycled aggregates composition following UNE-EN 933-11:2009

Composition (%)	Concrete products	Unbound aggregates	Masonry products	Bituminous products	Glass products	Others (Wood, plastics and gypsum)
CMA	22.2	9.8	67.3	0	0.1	0.7

CMA composition did not fulfil the requirements of the RILEM [21] and DIN standards [22] to be classified as ceramic aggregate (>90% or >80% of ceramic content, respectively). The mixed aggregate category was adopted to define the CMA composition in spite of showing a high proportion of ceramic components.).

The properties of the natural and recycled aggregates were tested according to British Standard methods [47] [48] as shown in Figure 7.

$$Recycled\ aggregate\ density = 1.9\ \frac{kg}{dm^3}$$

$$Recycled\ aggregate\ absorption = 17\ \%$$

3.1.6. Steel slag

Figure 5. Steel slag aggregate

Figure 6. Steel slag aggregate

Slag has been provided for PROMSA Company, the same as the natural aggregate.

$$Steel\ slag\ aggregate\ density = 3.04\ \frac{kg}{dm^3}$$

$$Steel\ slag\ aggregate\ absorption = 5.88\ \%$$

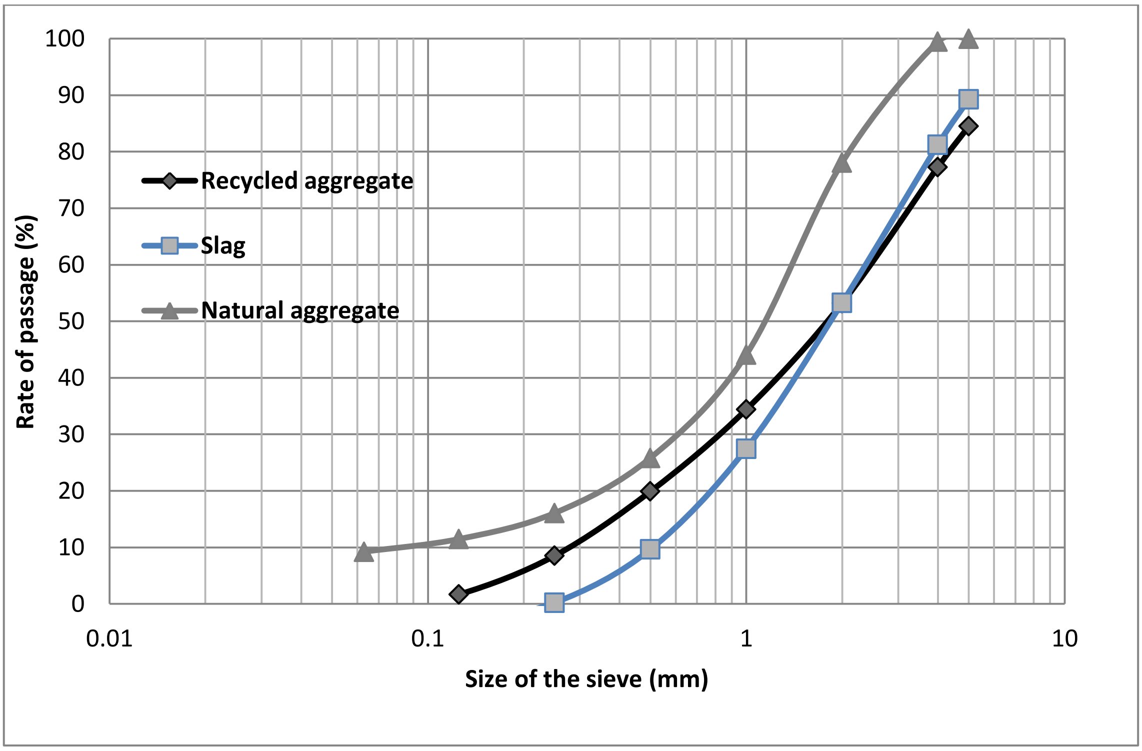

Figure 7. Granulometric curves

3.1.7. Air-entraining admixture

RHEOCELL Rheofill was used to entrain air in CLSM mixtures. It is ready-to-use concentrated self-contained product for use in various Controlled Low Strength Materials (CLSM) applications where air contents up to 30 % are desired.

It is a foaming agent that gives lows densities because of the air entrained and increase the workability.

Figure 8. Air entraining admixture

3.1.8. Superplasticizer admixture

Sika Viscocrete 20 HE is a superplasticizer that is also known as high range water reduces.

It is used for his chemical admixtures where well-dispersed particle suspension is required. This is when a dosages is done when part of the components are steel slag and fly ash for example.

Figure 9. Superplasticizer admixture

3.1.9. Colour pigment

Figure 10. Blue mixture

Figure 11.Test specimens difference

Figure 12. Blue specimens

As already mentioned in previous paragraphs, CLSM is used elementally as backfill, void fill or just to sustain, so his used is extensively extend for example, to cover the line coating in order to be undamaged.

The importance of this experiment is to see if using CLSM in trenches is possible to make them with colors depending on the type of pipe they are covering. In other words, if an excavation is carrying out and the colour of the soil is red or orange, the construction workers can notice and be aware because they already know that they are near a pipe gas.

Two different types of mixture were used with blue colour pigment (MC-5 and MC-AR-20-6) in order to analyse the influence of the colour in each type of dosages. As it can be seen the influence of the blue pigment is not significant, so in a future proceeding will be very interesting to try to analyse different types of colour pigments, or mixtures using white cement.

3.2. Manufacturing process

The manufacturing process of all CLSM were made in the “Laboratori de Materials de Construcció” of the “Departament d’Enginyeria de la Construcció” at the UPC.

3.2.1. Mixing receptacle

The receptacle shall be a suitable cylindrical container with sufficient capacity to allow easy sampling and remixing of the CLSM. The container shall conform to the requirements that shall be free of corrosion, coatings or lubricants.

In the manufacturing process of CLSM have been used three different types of receptacles. The type of container used was chosen depending on the part of the production that it was.

For stage 1 and stage 2 was used the mixers show in Figure 13 and Figure 14 with the object of produce a limited quantity of each mixture, 2 and 8 litres, respectively.
For stage 3 the regular mixer used for produce concrete (Figure 15), was used for produce CLSM more material quantities.

Figure 13. Mixer of 2 l

Figure 14. Mixer of 8 l

Figure 15. Mixer of 37 l

3.2.2. Natural aggregate

In stage 1 was used just natural aggregate in order to find a control dosage that could be used as a pattern. In all the mixtures made with just natural aggregate was used the same sequence. First of all, the natural aggregates and cement were introduced in the mixer and then water was added.

After one minute of mixing with the mixer working, the air-entraining admixture dissolved in water (the amount which would be absorbed by aggregates) was also added to the mixture and after 1 minute the mixer was stopped for 30 s in order to clean the mixer walls because its highly probable that the natural aggregate still remained untouched by the mixer blades, and finally started again for a further 3 minutes of mixing.

3.2.3. Recycled aggregate

On the other hand, in stage 2 was used recycled aggregate (natural aggregate have been displaced). Therefore manufacturing process was a little bit different because recycled aggregate has higher absorption.

Once the natural and recycled aggregate was on the mixer, a small amount of water was added and the mixer comes into operation, with the idea that the recycled aggregate was to absorb part of the water. When this operation is already done it, the manufacturing process was the same developed in stage 1.

3.2.4. Slag

When making the mixture using natural aggregate with a proportion of steel slag instead of recycled aggregate (stage 2), although the slag absorption is lower than the recycled aggregate the same process used with recycled aggregate were made, just adding a low quantity of water absorbed.

3.2.5. Fly ash

In stage 3 the dosages were made with fly ash that works as additional cementitious material. That is to say that the fly ash was added with the cement in the same manufacturing process performed in stage 1 with just natural aggregate.

3.2.6. Slag and Fly ash

In stage 3 where mixtures were made with slag and fly ash there was a combination between the two proceeds performed with just steel slag and with just fly ash.

At first the natural aggregate with slag was added with a proportion of water with the aim that the water would be absorbed by the aggregates, after a minute of mixing the cement, fly ash and water was added. Then the manufacturing process was completely the same as the previous said.

3.3. Experimental process

In this section is described the three experimental stages carried out that are part of the manufacturing process of Control Low Strength Material (CLSM).

3.3.1. Stage 1

Having analyzed different types of dosages of CLSM that had been used in the bibliography with cement, water, natural aggregate and admixture (a foaming agent), a dosage has been set as a starting point to produce CLSM. Then the manufacturing process starts on the laboratory with natural aggregate with the target of provide an optimum mixture of CLSM that achieves the specific requirements defined by ASTM in fresh and hardened state.

The analysis criteria used to find the correct proportions were, in fresh state, the flowability, the density and the air entrained following by the compressive strength in hardened state at 7 and 28 days.

The processes to improve the material when the previous properties mentioned had been already analyzed were based on the modification of the quantities of one of the constituents of the mixture in order to find the adequate interval of flowability and compressive strength.

After having stipulated a dosage that has suitable properties the amount of mixture was increased from 8 to 37 litres in order to determine more properties as tensile strength, modules, density, porosity, absorption and the losses of the CLSM material.

In this stage all the dosages were made with just natural aggregate.

3.3.2. Stage 2

Mix proportions of CLSM employing recycled aggregate

Once the correct proportion mixtures have defined in stage 1, the manufacturing process of CLSM with recycled aggregate started. The percentage substitution of the natural aggregate by recycled aggregate was starting for a quantity of 20 %, continuously with 50 % and finally with the 100%.

In order to find the optimum mix proportions mixing natural aggregate with recycled aggregate the criteria was the same used in stage 1 (flow test and compressive strength) making 8 litres of each mixture and when the mixture gives suitable properties increase the amount produce to 37 litres.

The target in state 2 was to substitute the maximum natural aggregate by recycled aggregate.

Mix proportions of CLSM employing steel slag

Once the correct dosage was made for natural aggregate and recycled aggregate, the utilization of the slag can be used in the different types of mixtures starting in the same way as the recycled aggregate was made, this means making a substitution of the natural aggregate for a percentage of slag.

What is proposed in the production of CLSM using a by-product as steel slag is to try to use as much as is possible. However, due to their properties it is known that the use of slag has more difficulties than the use of recycled aggregate. For that reason, the first step in the manufacturing process is to reduce a low percentage (20 %) of natural aggregate for steel slag and analyse the behavior.

Having seen the type of mixture obtained employing steel slag, is probably that another type of paste or admixtures could be used in order to obtain appropriated mixtures.

3.3.3. Stage 3

Mix proportions of CLSM employing fly ash

Fly ash is used as a supplementary cementitious material. That is why the way of the use of fly ash is completely different, because this addition is not making a replacement of a percentage of an aggregate, fly ash works as "cement", so when making the dosages using fly ash is possible to reduce the use of cement.

If the dosages made with fly ash should happen to work, could be a good way to avoid the segregation when making the mixtures with steel slag.

The production of CLSM with fly ash was conducted in the same method as the previous stages, this means first of all identify a control dosage making a volume of 8 litres, and once the control mixture is made reproduce it in a big volume (37 litres).

Mix proportions of CLSM employing steel slag with fly ash

It is well known that the production making a combination of steel slag and fly ash with portland cement is used to create economical concrete mixes. The use of both aggregates in CLSM may be a wise decision.

The combination of the slag and fly ash is a mixture very fair because of the low proportion of cement used and the slag as an aggregate that carry economic and environmental benefits.

3.4. Testing procedure

Fresh and hardened properties were determined in all mixes. The properties of fresh mix were tested immediately after mixing. Flow test [2], Unit weight [27], Air content [27], Bleeding [33] and setting time [32] were tested in fresh state.

The inverted slump test was also used in order to determine the flowability. In this case and Abrams cone is raised quickly and the CLSM flow into a patty, where the average diameter of the patty is determined. But this test method was only used at mixtures made of 22 litres, because at the other dosages there is not enough mixture.

According to their hardened properties, the test elements were transported to a humidity room after 24 h and were demold 7 days after their production. They were kept in a curing room until the test date was 28 days.

Cubic test specimens 100x100x100 were tested to determine the density, absorption and porosity tests after 28 days of curing according to [49] and cylinder test specimens of 104 x 200 mm for compressive strength at 7 and 28 according to [34], and also at 28 days the cylinders were tested for modulus, tensile strength and wetting and drying.

3.4.1. Test pieces

Due to the low strength that our dosages are, the mixtures need to be molded for at least seven days. It has been done a large amount of cylinders samples in order to maintain the manufacturing process in continuous movement.

Figure 16. Test pieces

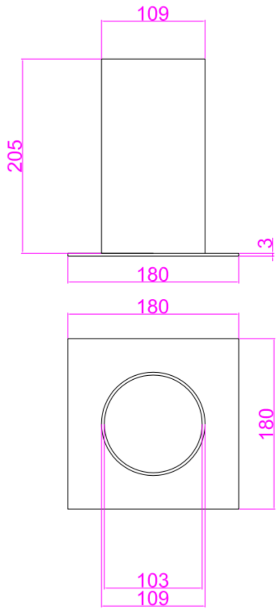

Figure 17. Test pieces measures

3.4.2. Test method of CLSM in fresh state

This test method provides a procedure to determine the status of a freshly mixed CLSM. They are also intended to assist the quality control purposes and when specified to determine compliance for some specific characteristics.

Every single method is one of a series of quality control tests that can be performed on CLSM during construction to monitor compliance with specification requirements.

Test method for Flow Consistency

Figure 18. Flow Test cylinder

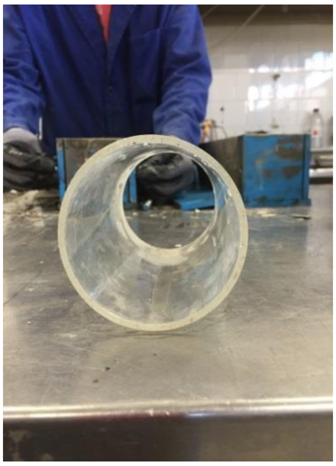

Figure 19. Flow test open ended cylinder

According to ASTM D6103-04 [2] the standard test method for flow consistency of Controlled Low Strength Material (CLSM) covers the procedure for determination the flow consistency of fresh CLSM.

Flow consistency is a measurement of the spread of a predetermined volume of CLSM achieved by removal of the flow cylinder within a specified time.

An open-ended cylinder is placed on a flat, level surface and filled with fresh CLSM. The cylinder is raised quickly so the CLSM will flow into a patty. The average diameter of the patty is determined and compared to established criteria.

This test method is intended to determine the fluidity of CLSM mixtures for use as backfill or structural fill.

The flow cylinder shall be a 150 mm length of 76 mm inside diameter, straight tubing of plastic (non-absorbent material and non-reactive with CLSM containing Portland cement). The flow cylinder shall have a smooth interior, open at both ends and a rigid shape that is able to hold its dimensions and under conditions of severe use.

Procedure

1. Place the nonporous surface on a flat, level area that is free of vibration or other disturbances.
2. Dampen the flow cylinder with water and place it on end, on a smooth nonporous level surface. Hold firmly in place during filling.
3. Thoroughly remix the CLSM, the minimum amount necessary to ensure uniformity, in the sampling and mixing receptacle.
4. With the filling apparatus, scoop through the center portion of the receptacle and pour the CLSM into the flow cylinder. Fill the flow cylinder until it is just level full or slightly overfilled.
5. Strike off the surface with a suitable straight edge, until the surface is flush with the top of the flow cylinder, while holding the flow cylinder in place. Remove any spillage away from the cylinder after strike off.
6. Within 5 seconds of filling and striking off, raise the flow cylinder quickly and carefully in a vertical direction. Raise the flow cylinder at least 15 cm by a steady upward lift with no lateral or torsional motion in a time period between 2 and 4 seconds. Complete the entire test from the start of filling through removal of the flow cylinder without interruption within an elapsed time of 1.5 min.

Test method for Air Content

Figure 20. Air entrained gauge

According to ASTM C 231/C231 M-14 [50] the standard test method for determined the air content in CLSM mixtures. The procedure are intended to be used solely with Portland cement concrete but it seems that the ease and speed of the procedures along with a comparable level of accuracy has led to the more general application as can be determining air entrained in CLSM materials.

This test method employs a pressure based method for finding the air content. The test is based on Boyle's law which states that the pressure and volume of a closed system are inversely proportional.

Procedure

1. The mixture was filled in the deposit. The excess of mixture was struck off with a piece of paper.
2. The edge was cleaned and the lid attached.
3. The petcocks were filled with water, until it flowed out of the opposing side and then sealed.
4. The meter was pressurized to the appropriate level and then the pressure was released into the main chamber while simultaneously being struck by a rubber mallet.
5. The resulting reading was recorded as the air content of the CLSM mixture.

Test method for Density

Figure 21. Density container

According to ASTM D6023-07 [27] the standard test method for density (unit weight) of Control Low Strength Material (CLSM) explains the determination of the density of freshly mixed CLSM.
The density of the CLSM is determined by filling a measure with CLSM, determining the mass, and calculating the volume of the measure. The density is then calculated by dividing the mass by the volume.
A cylindrical container made of steel is used to determine the density. It shall be watertight and sufficiently rigid to retain its form and calibrated volume under rough usage.

Procedure

1. Place the measure on a level, rigid, horizontal surface free from vibration and other disturbances.
2. Thoroughly mix the sample of CLSM in the sampling and mixing receptacle to ensure uniformity.
3. With the filling apparatus, scoop through the center portion of the sample and pour the CLSM into the measure. Repeat until the measure is full.
4. On completion of filling, the measure shall not contain a substantial excess or deficiency of CLSM.
5. After filling, strike-off the top surface of the CLSM and finish it smoothly with the flat strike-off plate using great care to leave the measure just level full.
6. After strike-off, clean all excess CLSM from the exterior of the measure and determine the gross mass of the CLSM.

Test method for Bleeding

According to ASTM C232/C232 M-14 [33] the standard test method for bleeding of concrete covers the determination of the relative quantity of mixing water that will bleed from a sample of freshly mixed concrete.

This test method provides procedures to be used for determining the effect of variables of composition, treatment, environment, or other factors in the bleeding of concrete.

Figure 22. Test method for bleeding

Figure 23. Procedure to determine bleeding

Procedure

1. During the test, maintain the ambient temperature between 18 and 24 ^{o}C.
2. Immediately after troweling the surface of the specimen, record the time.
3. Place the specimen and container on a level platform or floor free of noticeable vibration and cover the container to prevent evaporation of the bleed water.
4. Keep the cover in place throughout the test, except when drawing off the water.
5. Draw off, using a pipet, the water that has accumulated on the surface at 10 minutes intervals during the first 40 min and at 30 minutes intervals thereafter until cessation of bleeding, recording the time of last observation.
6. After the water is removed, return the container to a level position without jarring.
7. After each withdrawal, transfer the water to a graduated cylinder.
8. Record the accumulated quantity of water after each transfer.

9. Determine the mass and record the mass of the beaker and its contents.
10. Dry the beaker and its contents to constant mass and record the final mass.
11. The difference between the two masses, D, is equal to the mass of the bleed water. The mass of the sludge shall also be obtained, if desired, by initially determining the tare mass of the beaker.

Calculation

1. The volume of bleed water per unit area of surface is:

$$V = \frac{V_1}{A} \quad \begin{cases} \text{V1: Volume of bleed water measured during the selected time interval} \\ \text{A: Area of exposed concrete in } cm^2 \end{cases}$$

.

2. The accumulated bleed water, expressed as a percentage of the net mixing water contained within the test specimen is:

$$C = \frac{\omega}{W} \cdot S$$

$$Bleeding\ (\%) = \frac{D}{C} \cdot 100 \quad \begin{cases} \text{C: mass of net mixing water in the specimen, g} \\ \text{W: total mass of the batch, kg} \\ \omega\text{: mass of net mixing water in the batch, kg} \\ \text{S: mass of the specimen, g} \\ \text{D: accumulated mass of the bleed water, g} \end{cases}$$

Test method for Setting Time

Figure 24. Penetration needles and loading apparatus

Figure 25. Container with specimen

According to ASTM C403/C403 M-08 [32] the standard test method for time of setting of concrete mixtures by penetration resistance covers the determination of the time of setting of concrete, with slump greater than zero, by means of penetration resistance measurements on mortar sieved from the concrete mixture.

The CLSM mixture is placed in a container and stored at a specified ambient temperature. At regular time intervals, the resistance of the mixture to penetration by standard needles is measured. From a plot of penetration resistance versus elapsed time, the times of initial and final setting are determined.

In this test method, the times required for the mortar to reach specified values of resistance to penetration are used to define times of setting.

Procedure

1. Insert a needle of appropriate size, depending upon the degree of setting on the mortar, in the penetration resistance apparatus and bring the bearing surface of the needle into contact with the mortar surface.
2. Gradually and uniformly apply a vertical force downward on the apparatus until the needle penetrates the mortar to a depth of 25 $\pm$2 mm.
   The time required to penetrate 25 mm of depth shall be 10 $\pm$2 seconds.
   Record the force required to produce the 25 mm penetration and the time of application, measured as elapsed time after initial contact of cement and water.
3. Calculate the penetration resistance by dividing the recorded force by the bearing area of the needle, and record the penetration resistance.
4. In subsequent penetration tests take care to avoid areas where the mortar has been disturbed by previous tests. The clear distance between needle impressions shall be at least two diameters of the needle being used. The clear distance between any needle impression and the side of the container shall be at least 25 mm.
5. For CLSM mixtures at laboratory temperatures of 20-25 ^oC, make the initial test after an elapsed time of 3 to 4 hours after initial contact between cement and water. For concrete mixtures at temperatures higher it is advisable to make the initial test after an elapsed time of 1 to 2 hours.
   Subsequent tests should be made at half to one hour intervals. However, time intervals between subsequent tests may be adjusted as necessary, depending upon the rate of setting, to obtain the required number of penetrations.
6. Make at least six penetrations for each time of setting test, with time intervals of such duration as to provide a satisfactory curve of penetration resistance versus elapsed time.

3.4.3. Test method of CLSM in hardened state

The detailed testing procedures to analyses the behaviour of CLSM I n hardened state are described below.

Test method of Compressive Strength

Figure 26. Testing machine

Figure 27. Test sample of compressive breaking load

According to ASTM D4832 - 10 [34] the standard test method for preparation and testing of controlled low strength material (CLSM) test cylinders covers the procedure for the determination of compressive strength.

CLSM is typically used as a backfill material around structures, particularly in confined or limited spaces. Compressive strength testing is performed to assist in the design of the mix and to serve as a quality control technique during construction. Mix design is typically based on 28-day strengths and construction control test performed 7 days after placement. The cylinders are prepared by pouring a representative CLSM sample into molds, then depending on the strength development, either curing the cylinders then removing them from the molds, and preparing the cylinders for compression testing.

Procedure

1. Place the lower bearing block, with its hardened face up, on the table of testing machine directly under the spherically seated (upper) bearing block. Wipe clean the bearing faces of the upper and lower bearing blocks and of the test cylinder, and place the test cylinder on the lower bearing block. As the spherically seated block is brought to bear on the top of the cylinder, rotate its movable portion gently by hand so that uniform seating is obtained.
2. Apply the load continuously and without shock. Apply the load at a constant rate such that the cylinder will fail in not less than 2 minutes. Make no adjustment in the controls of testing machine while a specimen is yielding rapidly immediately before failure.
3. Apply the load until the cylinder fails, and record the maximum load, to either two or three significant digits, carried by the cylinder during the test. For about one out of every ten cylinders, continue the loading until the cylinder breaks enough to examine the appearance of the interior of the specimen.

Test method of Splitting Tensile Strength

Figure 28. Testing machine

Figure 29. Tensile strength fissure

Figure 30. Tensile break

According to ASTM C496-C496 M-11 [51] the Standard Test Method for Splitting Tensile Strength of cylindrical concrete specimens is used for the determination of splitting tensile strength of CLSM using a lower load than the generally used for the concrete specimens.

Splitting tensile strength is generally greater than the direct tensile strength and lower than the flexural strength (modulus of rupture). It is used in the design of light weight dosages as can be CLSM to evaluate the shear resistance provided by cement and to determine the development length of the reinforcement.

Procedure

1. Apply a diametrical force along the length of a cylindrical test piece at a rate that is within a prescribed range until failure.
2. This loading induces tensile stresses on the plane containing the applied load and relatively low compressive stresses in the area immediately around the applied load.
   Although it is being applying a compressive load, due to Poisson's effect, tension is produced and the specimen fails in tension.
   Tensile failure occurs rather than compressive failure because the areas of load application are in a state of triaxial compression, thereby allowing them to withstand much higher compressive stresses than would be indicated by a uniaxial compressive strength test results.
3. Thin, plywood bearing strips are used to distribute the load applied along the length of the cylinder.
4. The maximum load sustained by the specimen is divided by appropriate geometrical factors to obtain the splitting tensile strength.

Test method of Elastic Modulus


Figure 31. Modulus test procedure

According to ASTM C469 [52] the standard test method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression describes modulus of elasticity as a stress to strain ratio value for hardened concrete at whatever age and curing condition that may be designated. This standard also states that the modulus of elasticity is applicable with the customary working stress range of 0 to 40 % of the ultimate concrete strength. The modulus of elasticity is often used in sizing reinforcement and non-reinforced structural members, establishing the quantity of reinforcement, computing stress for observed strain, and is especially important in the design of pre-stressed concrete members.

Procedure

1. Demolded CLSM samples are subjected to a slowly increasing longitudinal compressive stress.
2. Longitudinal strains are determined using either a bonded or unbonded sensing device that measures the average deformation of two diametrically opposite locations to the nearest 5 millionths of strain.
3. The applied load and longitudinal strain are recorded when the longitudinal strain is 50 millionths and when the applied load is equal to 40 % of the cylinder compressive strength.
4. It is necessary to determine the compressive strength on companion specimens prior to testing for modulus of elasticity. The modulus of elasticity is calculated as the slope of the straight line between the 40 % compressive stress-strain curve by taking more frequent readings either manually or automatically.
5. The modulus of elasticity values will usually be less than the modulus derived under rapid load application and usually greater than values obtained under slow load application, when all other conditions remain the same.

Test method of Density, Porosity and Absorption

According to ASTM C 642-06 [53] the standard test method covers the determinations of density, percent absorption, and percent voids in hardened concrete. The samples shall consist of several individual portions of CLSM mixture, each to be tested separately and shall be free from observable cracks, fissures, or shattered edges.

Procedure

1. Determine the mass of the portions, and dry in an oven at a temperature of 100 to 110^{o}C for not less than 24 hours. After removing each specimen from the oven, allow it to cool in dry air to a temperature of 20 to 25 ^{o}C and determine the mass. If the specimen was comparatively dry when its mass was first determined, and the second mass closely agrees with the first, consider it dry. If the specimen was wet when its mass was first determined, place it in the oven for a second drying treatment of 24

hours and again determine the mass. If the third value checks the second, consider the specimen dry. In case of any doubt, redry the specimen for 24 hours periods until check values of mass are obtained. If the difference between values obtained from two successive values of mass exceeds 0.5 % of the lesser value, return the specimens to the oven for an additional 24 h drying period, and repeat the procedure until the difference between any two successive values is less than 0.5% of the lowest value obtained.

2. Immerse the specimen, after final drying, cooling, and determination of mass, in water at approximately 21 °C for not less than 48 h and until two successive values of mass of the surface-dried sample at intervals of 24 h show an increase in mass of less than 0.5 % of the larger value. Surface-dry the specimen by removing surface moisture with a towel, and determine the mass.
3. Suspend the specimen, after immersion, by a wire and determine the apparent mass in water.

Test methods for Wetting and Drying

According to ASTM D 559-96 [54] the standard test method covers the procedure for determining the soil-cement losses, water content changes, and volume changes (swell and shrinkage) produced by repeated wetting and drying of hardened soil-cement specimens. These test methods are used to determine the resistance of compacted soil-cement specimens to repeated wetting and drying.

Procedure

1. At the end of the storage in the moist room, submerge all the specimens in potable water at room temperature for a period of 5 hours and remove. Weigh and measure the number 1 specimen (volume and moisture change specimen).
2. Place the specimens at 71 °C for 42 hours and remove. Weigh and measure the number 1 specimen.
3. Give specimen number 2 two firm strokes on all areas with the wire scratch brush. Apply these strokes to the full height and width of the specimen with a firm stroke corresponding to approximately 13.3 N forces. Eighteen to twenty vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end.
4. The first 3 steps mentioned before constitute one cycle (48 hours) of wetting and drying. Again submerge the specimens in water and continue the procedure for 12 cycles.

   Weight determinations of specimen number 2 before and after brushing are usually made at the end of each cycle.
5. The number 1 specimen may be discontinued prior to 12 cycles should the measurements become inaccurate due to soil-cement loss of the specimen.
6. After 12 cycles of test, dry the specimens to constant weight at 110 °C and weigh to determine the oven-dry weight of the specimens.
7. The data collected will permit calculations of volume and water content changes of specimen number 1 and the CLSM losses of specimen number 2 after the prescribed 12 cycles of test.

CHAPTER IV. MIX PROPORTION DETERMINATION

In this chapter the dosages did to make CLSM are described and is given the obtained results in fresh and hardened state in each of the three experimental stages that had been done.

4.1.Stage 1

Various mixing proportions with cement, water, a foaming agent and natural aggregate were produced in order to define the optimum dosage which met the specific requirements of CLSM in both fresh and hardened state. These requirements were flowability (flow test > 20 cm), air content (20-25 %), unit weight and compressive strength (0.7 - 1.4 - 2.1 MPa).

The process used to determine the mix proportion was the following: first the water/cement ratio and the amount of cement to be used for production of 1 m^3 of CLSM were defined and the amount of water was calculated. Second, assuming that there was 20-25 % of air content, the volume of aggregates was determined. In each mixture, the air volume and the density in fresh state were measured in order to verify the production of the estimated volume material. Dried natural sand was used and during mixing the water absorbed by the aggregates was added. It was estimated that the effective absorption capacity of the natural sand was 65 % of the total absorption capacity.

The productions of CLSM a cement/aggregate ratio of $\frac{1}{12}$ approximately, 110 kg of cement and water/cement ratio value of 1.79 were used in all mixtures. Different amounts of admixtures were applied and after several trials it was fixed between 1000 and 1100 g (see Table 8).

Table 8 shows all the dosages that have been used in the laboratory in order to obtain a control mixture.

The designation of the mixtures is MC-X where X makes reference to the type of the proportions that were studied.

Table 8. CLSM dosages for MC (m3)

Description	Cement (kg)	Natural aggregate (kg)	Water (kg)	Air (g)	w/c	Vol (l)	Natural Aggregate Absorption (%)
MC-1	110	1332.4	196.9	909	1.79	22	30
MC-2	110	1332.4	196.9	909	1.79	22	55
MC-3	110	1332.4	196.9	950	1.79	8	65
MC-5 (c. pig.)	110	1332.4	198.9	1100	1.79	8	65

As it can be seen the different dosages were made in different volumes, the first two dosages of 22 litres and finally all others were of 8 litres.

This was because every single mixture first of all has to reach the optimum properties in fresh state (experimenting with 8 l, or 22 l) and if the mixture reaches that, the same mixture was made with a high volume (37 l) that is explained in Chapter V: Optimum Dosages.

Table 9. Fresh state properties of MC

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)
MC-1	1.82	21.25	17.5
MC-2	1.84	21	20.25
MC-3	1.83	20.5	22.75
MC-5 (colour pigment)	1.87	18	22.75

When making the first dosages (MC-1) it was supposed that the natural aggregate absorbed 30 % of his own capacity according with the capacity that has at the first 10 minutes, that was a low percentage due to the low flowability (17.5 cm) that the mixture has, so it was decided to increase the percentage absorbed first at 55 % (MC-2). The mixture MC-2 was at the limit (20.25 cm), so the air entraining admixture was increased from 909 g to 950 g in order to obtain a high length in the flow test, the growth was not sufficient so the admixture was increased until 1100 g (MC-5) with a percentage of natural aggregate absorption finally set at 65 % (MC-3 and MC-5), that is the capacity absorption of the natural aggregate when half an hour were past (Table 9).

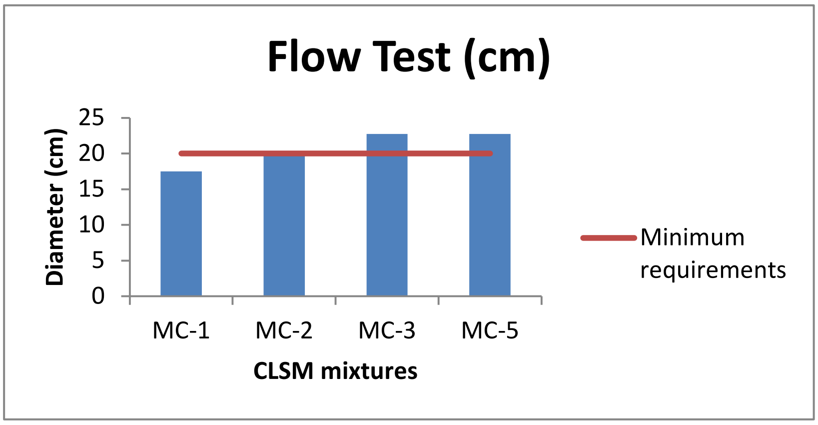

Figure 32. Flow test of MC (8 l)

Figure 32 show that the mixtures MC-2, MC-3 and MC-5 achieved suitable flowability.

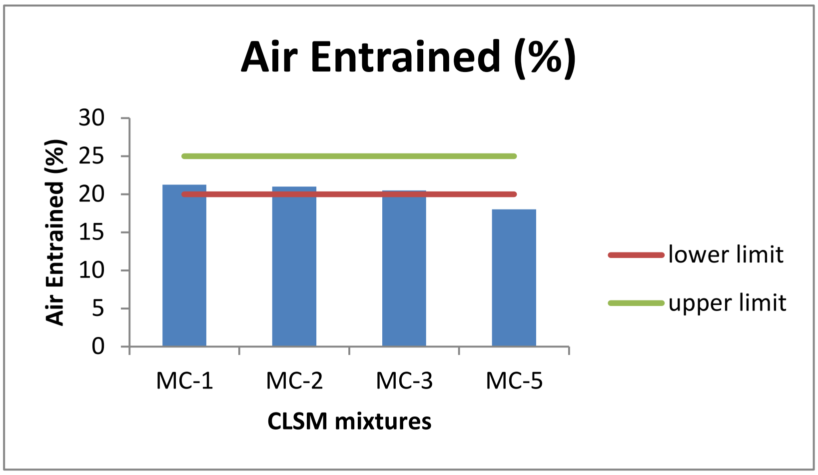

Figure 33. Air content of MC (8 l)

Figure 33 shows that the mixes made with higher air content achieved less compressive strength (Table 10).

Table 10. Compressive strength for MC

	Compressive Strength (Mpa)	
Description	7 days	28 days
MC-1	1.20	1.55
MC-2	1.16	-
MC-3	-	1.75
MC-5 (c. pig.)	1.57	-

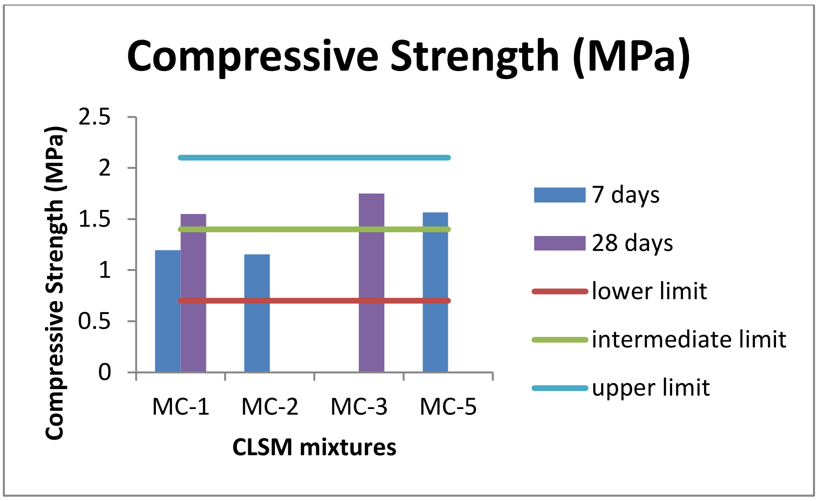

Figure 34. Compressive strength for MC (8 l)

The mixtures MC-3 and MC-5 achieves all the fresh and hardened property requirements (Figure 34) [3], and they were defined as adequate mix proportions to carry out the stage 2, where the CLSM was produced using recycled aggregate.

4.2. Stage 2

4.2.1. Mix proportions of CLSM employing recycled aggregate

Different mix proportions of CLSM made using different percentages of recycled aggregates were produced (22, 2 and finally 8 litres) and tested.

The mixtures of CLSM, made with 20 %, 50 % and 100 % of recycled aggregate on substitution (by volume) of natural aggregates were produced. The analysis of mix proportions was carried out according to the minimum requirements defined in the previous stage.

The designation of the mixtures is MC-AR-X-Y (AR: recycled aggregate) where X makes reference to the percentage of recycled aggregate that were substitute and Y the type of proportions that were studied.

Both dry, recycled and natural sand were used in CLSM production and the water absorbed by the aggregates was added during mixing. It was estimated that the effective absorption capacity of the natural and recycled sand was 65 % and 90 %, respectively, of the total absorption capacity.

Table 11, Table 12 and Table 13 shows the mix proportions of the CLSM produced with recycled aggregate. There the optimum CLSM mix proportion defined in stage 1 (MC-4 and MC-6) was maintained to analyse the influence of recycled aggregate on the material properties.

Table 11. CLSM dosages for MC-AR-20 (m3) (8 l)

Description	Cement (kg)	Natural aggregate (kg)	Recycled aggregate (kg)	Water (kg)	Air (gr)	w/c	Vol (l)
MC-AR-20-1	110	1065.92	114.07	196.9	1136.3	1.79	22
MC-AR-20-2	110	1065.92	114.07	196.9	1136.3	1.79	2
MC-AR-20-3	110	1065.92	114.07	196.9	1136.3	1.79	8
MC-AR-20-5 (c.pig)	110	1065.92	114.07	198.9	1136.3	1.79	8

The cement quantity of CLSM made with 50 % of recycled aggregate was increased to 125 (13.6 % more than the standard mixture) and the water/cement ratio was decreased to 1.74 (Table 12).

Table 12. CLSM dosages for MC-AR-50 (m3) (8 l)

Description	Cement (kg)	Natural aggregate (kg)	Recycled aggregate (kg)	Water (kg)	Air (gr)	w/c	Vol (l)
MC-AR-50-1	125	625.11	442.74	217.5	1200	1.74	5
MC-AR-50-2	125	625.11	442.74	217.5	1000	1.74	8

The CLSM made with 100 % of recycled aggregate was produced with 135 kg of cement and a water/cement ratio of 1.72 (Table 13).

Table 13. CLSM dosages for MC-AR-100 (m3) (8 l)

Description	Cement (kg)	Natural aggregate (kg)	Recycled aggregate (kg)	Water (kg)	Air (gr)	w/c	Vol (l)
MC-AR-100-1	135	0	880.36	232.2	1000	1.72	8

Fresh state properties

Two hypothesis were raised according to the absorption of the recycled aggregate, the first one was that the aggregate has the absorption capacity at the first 10 minutes (70-80 %) and the second one was that has the absorption capacity at half an hour (90 %).

The basic properties results obtained in fresh state of the CLSM produced in stage 2 are described in Table 14, Table 15 and Table 16.

A. Mixtures with 20 % of recycled aggregate

The mixtures MC-AR-20-1, MC-AR-20-2, MC-AR-20-3 and MC-AR-20-5, achieved the minimum requirements for flowability (>20 cm) and the quantity of air entrained are in the adequate interval (Figure 36). In order to increase the air content the hypothesis of the recycled aggregate absorption capacity was introduced.

Table 14. Fresh state properties of MC-AR-20 (8 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)
MC-AR-20-1	1.86	18	22.25
MC-AR-20-2	1.78	23	21.75
MC-AR-20-3	1.79	19.5	21.75
MC-AR-20-5 (pig.)	1.86	18.5	30.25

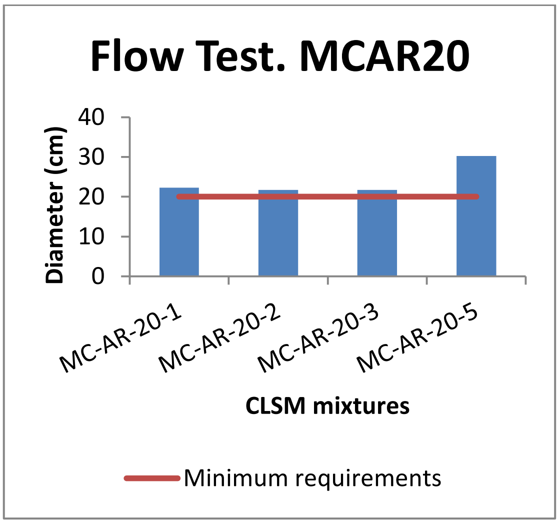

Figure 35. Flow test of MC-AR-20

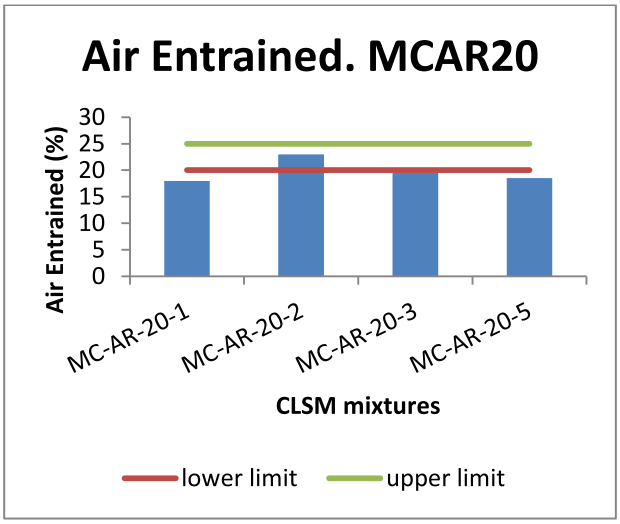

Figure 36. Air entrained of MC-AR-20

Comparing the different mixtures made with 20 % of recycled aggregate with the optimum requirements (Figure 35 and Figure 36) it is possible to say that the flowability are in a good ranges, and although air entrained are not in the lower limit, are really near, so is feasible to say that both properties are adequate and has the properties needed.

B. Mixtures with 50 % of recycled aggregate

Mixtures MC-AR-50-1 and MC-AR-50-2 achieved both flowability and air entrained properties in fresh state (Table 15).

Table 15. Fresh state properties of MC-AR-50 (8 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)
MC-AR-50-1	1.54	28.5	22.5
MC-AR-50-2	1.67	21	24.25

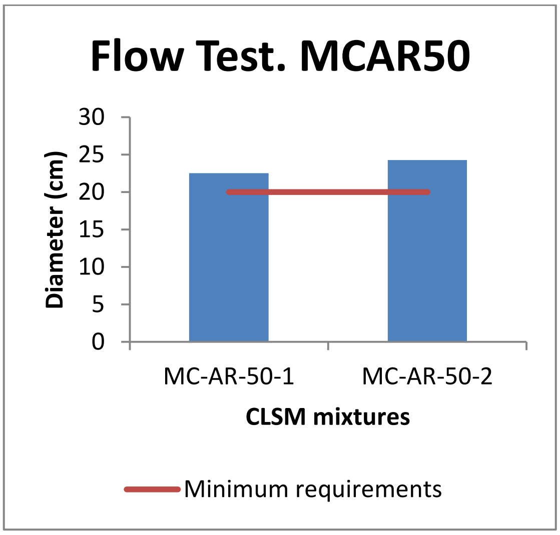

Figure 37. Flow test of MC-AR-50

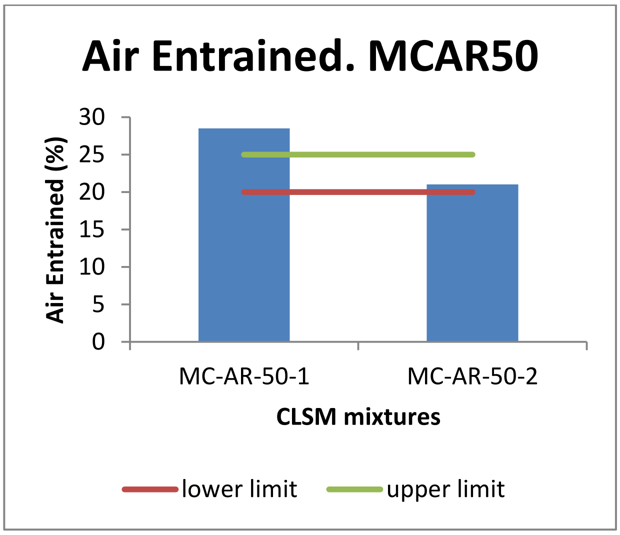

Figure 38. Air entrained of MC-AR-50

The mixtures MC-AR-50-1 and MC-AR-50-2 made with 50 % of recycled aggregate acquire the minimum requirement for flowability and air content (Figure 37 and Figure 38). For flowability both mixtures has more than the minimum requirements and for air content both mixtures are in the adequate interval.

C. Mixtures with 100 % of recycled aggregate

The mixture MC-AR-100-1 acquired the minimum range of flowability, but the range of air entrained is less than the minimum requirement (Table 16).

Table 16. Fresh state properties of MC-AR-100 (8 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)
MC-AR-100-1	1.52	18.5	21

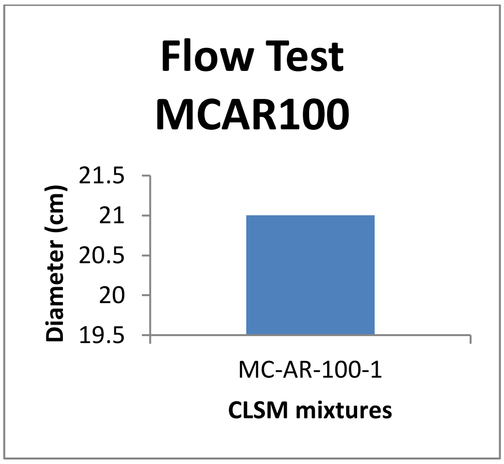

Figure 39. Flow test of MC-AR-100

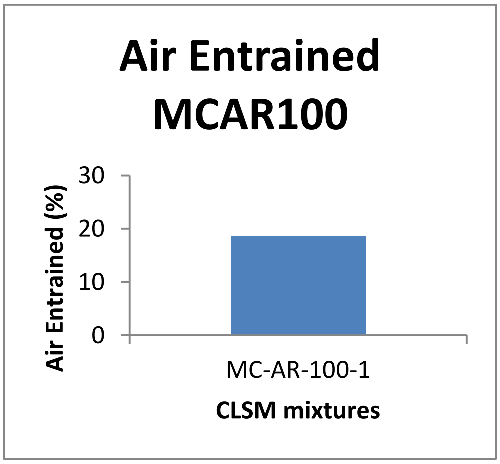

Figure 40. Air entrained of MC-AR-100

Discussion

It can be appreciated that mixtures made with 50 % and 100 % of recycled aggregate obtained with difficulties the required properties of a self-levelling and excavatable CLSM, with a higher amount of cement and lower water/cement ratio than that required for a CLSM made of just natural aggregate (conventional mixture).

Providing the amount of air content remained similar, it could be appreciated that the density of CLSM decreased when the percentage of recycled aggregate increased. However the density is strongly related to the amount of air content in the mixture. It can also be seen that increasing the quantity of recycled aggregate, for quantities higher than 50 % of the material, the CLSM material lost its flowability and the influence of air content was higher.

Hardened state properties

The compressive strength of mixtures made with 20, 50 and 100 % of recycled aggregate are going to be tested. It is highly probable that the range of compressive strength values decrease when the percentage of recycled aggregate increase, because of the high absorption capacity of the recycled aggregates. The hardened properties of the CLSM produced in stage 2 are also shown in Table 17, Table 18 and Table 19

A. Mixtures with 20 % of recycled aggregate

The mixtures that were tested achieved the minimum values to be suitable as a type of dosage to produce CLSM because all the dosages are in the ranges of the requirements to be named as CLSM (Figure 41).

Table 17. Hardened state properties of MC-AR-20 (8 l)

	Compressive Strength (Mpa)	
Description	**7 days**	**28 days**
MC-AR-20-1	1.08	1.62
MC-AR-20-2	-	-
MC-AR-20-3	-	1.44
MC-AR-20-5 (pig.)	0.99	-

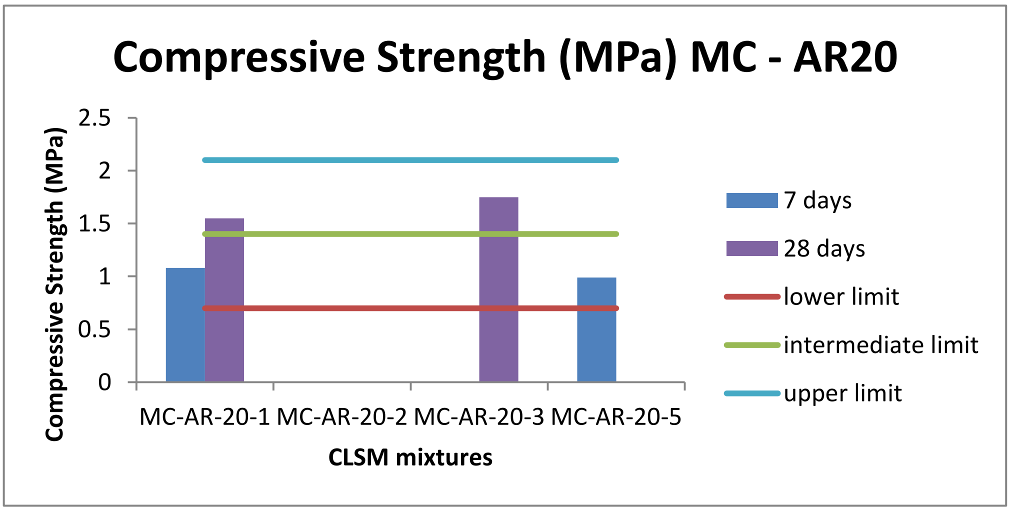

Figure 41. Compressive strength of MC-AR 20

B. Mixtures with 50 % of recycled aggregate

Mixtures made with 50 % of recycled aggregate does not achieved the minimum requirements for compressive strength (Table 18), this means another dosages need to be done in order to try to acquire the minimum values.

Table 18. Hardened state properties of MC-AR-50 (8 l)

	Compressive Strength (Mpa)	
Description	7 days	28 days
MC-AR-50-1	0.18	-
MC-AR-50-2	0.43	0.96

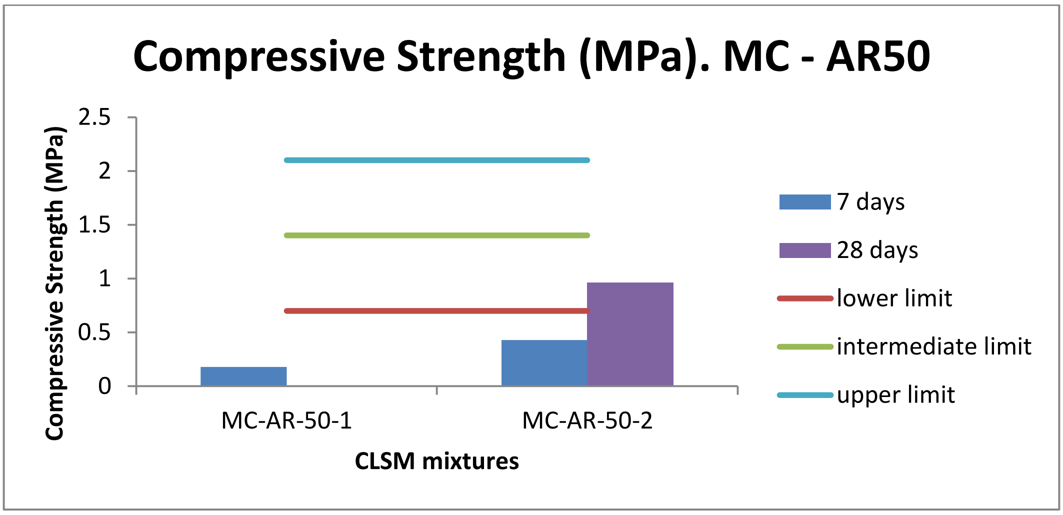

Figure 42. Compressive strength of MC-AR 50

C. Mixtures with 100 % of recycled aggregate

Dosages made with 100 % of recycled aggregate did not achieved the minimum compressive strength requirement (Table 19 and Figure 43) with the first given characteristics. In order to try to achieve the minimum requirements it is necessary to change water/cement ratio, or the amount of cement.

Table 19. Hardened state properties of MC-AR-100 (8 l)

	Compressive Strength (Mpa)	
Description	7 days	28 days
MC-AR-100-1	0.29	0.53

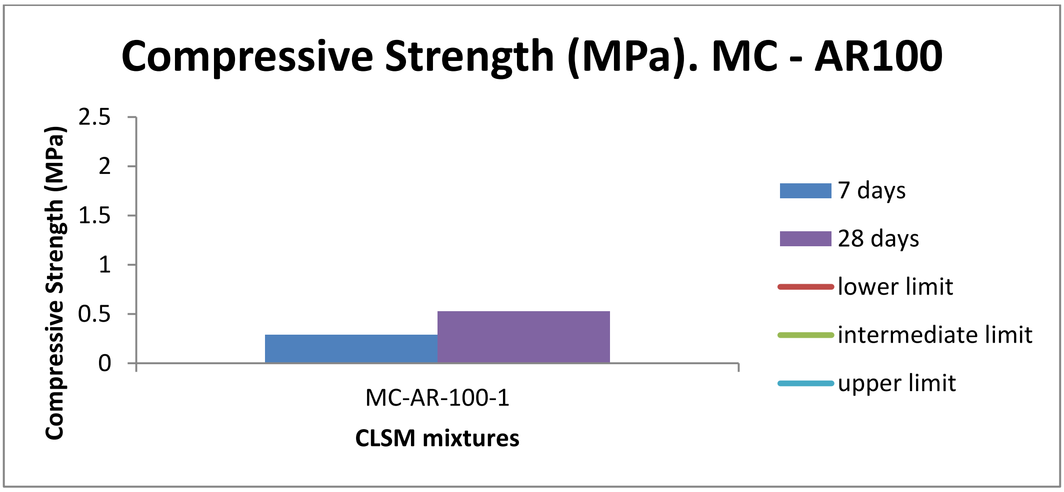

Figure 43. Compressive strength of MC-AR 100

Discussion

As Figure 35, Figure 36 and Figure 41 shows the mixture properties barely change when compared to those of the standard mixture in which up to 20 % of recycled fine aggregates were used. However, when the percentage of recycled aggregate was more than 50 % (Figure 37, Figure 38 and Figure 42), the required properties (according to ASTM) for CLSM in fresh and hardened state were not achieved. The compressive strength of MC-AR-100-1 was reached to 0.5 MPa at 28 days (Figure 43).

It can be noted that MC-AR-20-1 obtained suitable properties in both the fresh and hardened state. However, the air content obtained was 18 % (Figure 36), which is below the designed percentage; therefore, the volume of the material produced was lower than designed and consequently the amount of cement used exceeds 110 kg/m^3 of CLSM.

According to obtained results of flow test and compressive strengths, MC-AR-20-3, MC-AR-20-5, MC-AR-50-2 and MC-AR-100-1 were defined as the most adequate mix proportions in each type of concretes.

These different mixtures were going to be the based for stage 3 where the volume is higher (37 litres) in order to obtain more plastic properties in both states.

4.2.2. Mix proportions of CLSM employing steel slag

First of all and having the aim of try to use steel slag as a substitute of natural aggregate as much as is possible, the dosages were defined to look into the right proportions that could achieves all the fresh and hardened properties requirements.

The designation of the mixtures is MC-AS-X-Y (AS: slag aggregate) where X makes reference to the percentage of steel slag aggregate that were substitute and Y the type of proportions that were studied.

Starting the manufacturing process of CLSM made with a percentage of steel slag, the initial replacement was 20 % of natural aggregate by steel slag.

The dosages used are showed in Table 20.

Analysing the percentage of replacement of the quantity of material (slag) is higher than the quantity used for recycled aggregate that is because of the difference between both densities.

Table 20. CLSM dosages for MC-AS (m3) (8 l)

Description	Cement (kg)	Natural aggregate (kg)	Slag (kg)	Water (kg)	Air (gr)	w/c	Vol (l)
MC-AS-20-1	110	1065.92	182.51	196.9	1136.3	1.79	8
MC-AS-20-2	110	1065.92	182.51	196.9	1350	1.79	8

Once in the manufacturing process and when the mixing receptacle was working the mixture presented the texture showed in Figure 44 and Figure 45.

Figure 44. Segregate mixture

Figure 45. Segregate mixture

As it can be seen the mixtures made with cement and steel slag presents segregation. The segregation is due to the high density of steel slag aggregates. This condition of segregation makes the mixtures completely unusable.

The fresh and hardened state properties are show in Even that Table 21 and Table 22 shows that the fresh and hardened state properties achieved good ranges, if the mixture have been segregate the values obtained are not reliable because of the loss of homogeneity.

Table 21 and Table 22. However, these properties are no reliable because of the problem of segregation that it has. Even that Table 21 and Table 22 shows that the fresh and hardened state properties achieved good ranges, if the mixture have been segregate the values obtained are not reliable because of the loss of homogeneity.

Table 21. Fresh state properties of MC-AS (8 l)

Description	ρ (kg/dm³)	Air (%)	Flow test
MC-AS-20-1	1.84	18	23.75
MC-AS-20-2	1.69	19	28.5

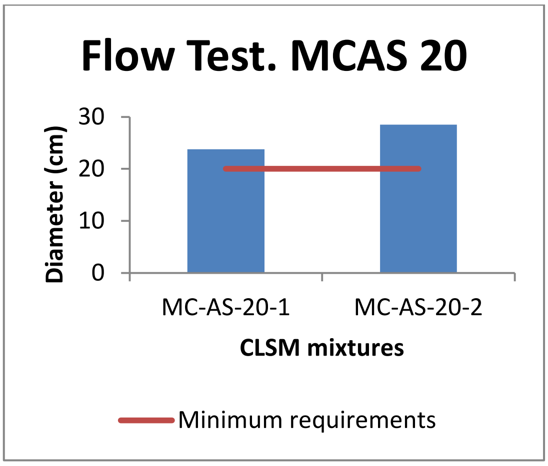

Figure 46. Flow Test of MC-AS 20

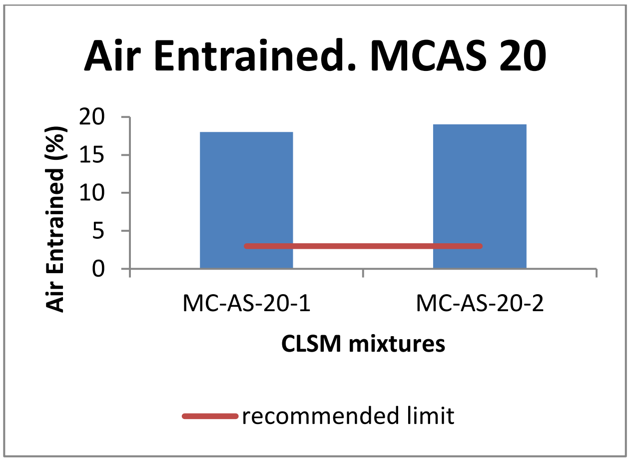

Figure 47. Air entrained of MC-AS 20

Table 22. Hardened state properties of MC-AS 20 (8 l)

	Compressive Strength (Mpa)	
Description	7 days	28 days
MC-AS-20-1	1.23	-
MC-AS-20-2	1.03	-

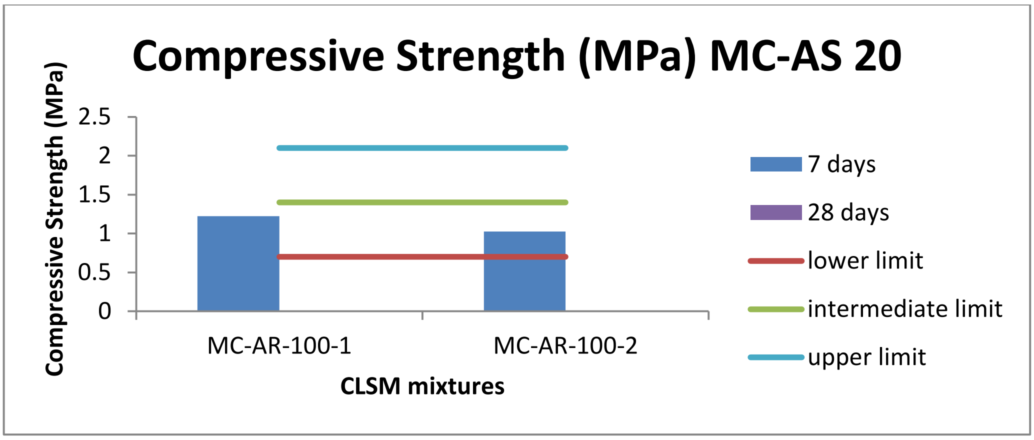

Figure 48. Compressive strength of MC-AS 20

4.3. Stage 3

4.3.1. Mix proportions of CLSM employing fly ash

Different types of dosages were made with fly ash. The aim was to find a control dosage that had suitable fresh and hardened state properties in order to be possible a dosage with low percentage of cement. The dosages made with fly ash far from being part of the aggregates, work forming a paste, this means that are part of the cementitious paste. This is very important because the amount of cement used in the different dosages could be decrease in a high percentage reducing the cost of the total mixture.

The designation of the mixtures is MC-FA-X (FA: fly ash) where X makes reference to the type of proportions that were studied. Another designation was used as MC-FA-mezcla Y because that was the same type of mixture with some variations where Y makes references to the type of variation in the different dosages.

The different mixtures made with fly ash are described in Table 23.

Table 23. CLSM dosages for MC-FA (m3) (8 l)

Description	Cement (kg)	Natural aggregate (kg)	Fly Ash (kg)	Water (kg)	Air (gr)	w/c	Vol (l)
MC-FA-1	50	1788.47	125	236.25	500	1.35	8
MC-"Ash"-2	50	1788.47	125	236.25	500	1.35	8
MC-FA-mezcla 1	60	1603.6	240	255	500	0.85	8
MC-FA-mezcla 2	30	1602.98	280	248	500	0.8	8
MC-FA-mezcla 3	70	1424.35	285	301.75	500	0.85	8

Table 24. Fresh state properties of MC-FA (8 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)
MC-FA-1	2.2	-	24.75
MC-"Ash"-2	1.92	-	22.25
MC-FA-mezcla 1	2.06	7	31.75
MC-FA-mezcla 2	2.13	5.8	26.75
MC-FA-mezcla 3	2.03	11.5	47.75

As it can be seen in Table 23 and Table 24 all the mixtures achieved suitable fresh state properties, in terms of flowability and they have a good percentage value of air entrained (Figure 49 and Figure 50).

The recommended limit for air entrained are low compared to the limit for natural or recycled aggregate. This is because when using fly ash, the quantity of 20-25 % of air entrained is not useful because the compressive strength can decrease. The value need to be in the range of 3 % because of the low quantity of cement that the mixture has

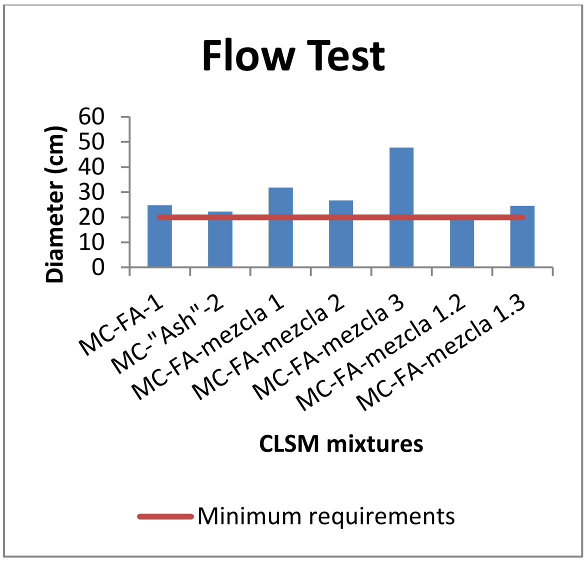

Figure 49. Flow Test of MC-FA

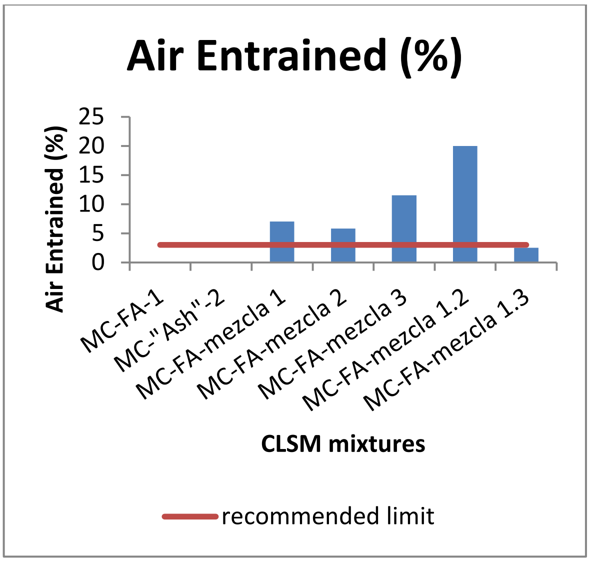

Figure 50. Air entrained of MC-FA

Table 25. Hardened state properties of MC-FA (8 l)

	Compressive Strength (Mpa)	
Description	**7 days**	**28 days**
MC-FA-1	0.74	-
MC-"Ash"-2	1.17	-
MC-FA-mezcla 1	0.52	-
MC-FA-mezcla 2	0.3	-
MC-FA-mezcla 3	0.37	-

Having removed the test pieces from the moist room, could be appreciate that the samples had got a lot of bleeding, for that reason the dimensions of the test cylinders had been smaller than the standard dimensions, and the values obtained of the compressive strength are no reliable (Table 25 and Figure 51).

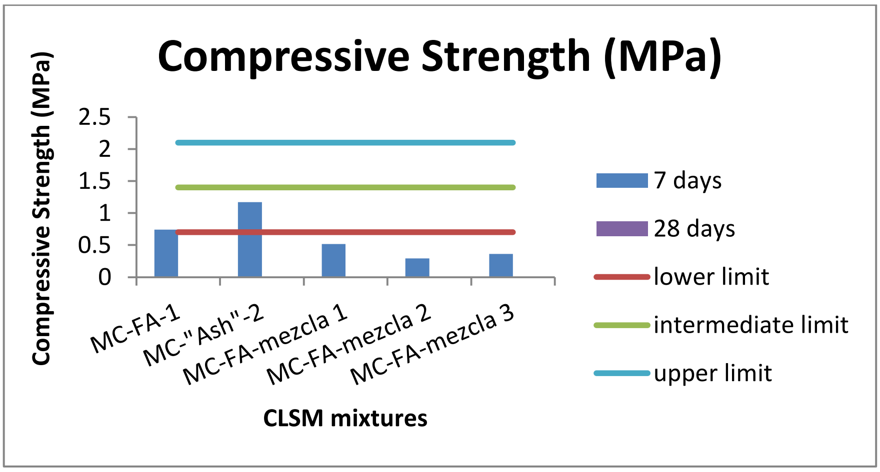

Figure 51. Compressive Strength of MC-FA

In the next section the analysis came from this results, it is studied if with this dosages another type of component, as fly ash, could work avoiding an excess of bleeding.

4.3.2. Mix proportions of CLSM employing steel slag with fly ash

In order to avoid the segregation of the mixture when using steel slag aggregate, and also prevent the overabundance of bleeding in the dosages made with fly ash, it is studied the behavior of both components (fly ash and steel slag) in a mixture.

Using a cementitious material as can be fly ash with a low proportion of steel aggregate instead of natural aggregate segregation should be evade because of the increase of paste in the mixture.

The designation of the mixtures is MC-FA-X-AS (FA: fly ash and AS: slag aggregate) where X makes reference to the quantity of steel slag that was substitute.

The dosages are show in Table 26.

Table 26. CLSM dosages for MC-FA-AS (m3) (8 l)

Description	Cement (kg)	Natural aggregate (kg)	Fly Ash (kg)	Slag (kg)	Water (kg)	Viscocrete (gr)	w/c	Vol (l)
MC-FA-20-AS	45	1253.01	360	369.1	222.75	2025	0.55	8
MC-FA-50-AS	45	809.25	360	953.54	202.5	1237.5	0.5	8

Table 27. Fresh state propeties of MC-FA-AS (8 l)

Description	ρ (kg/dm³)	Air (%)	Flow test
MC-FA-20-AS	2.33	1.5	22.75
MC-FA-50-AS	2.4	2.1	23

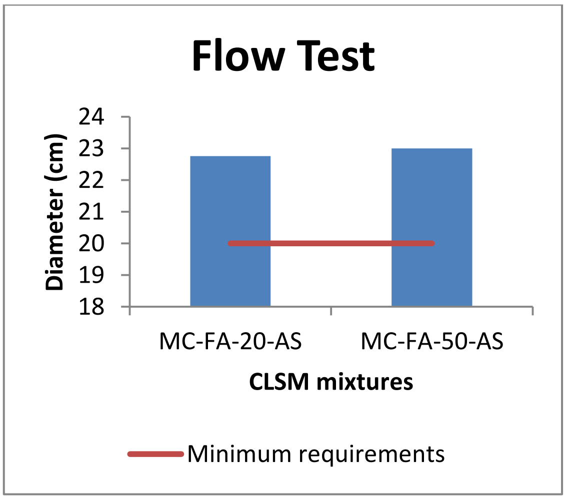

Figure 52. Flow test of MC-FA-AS

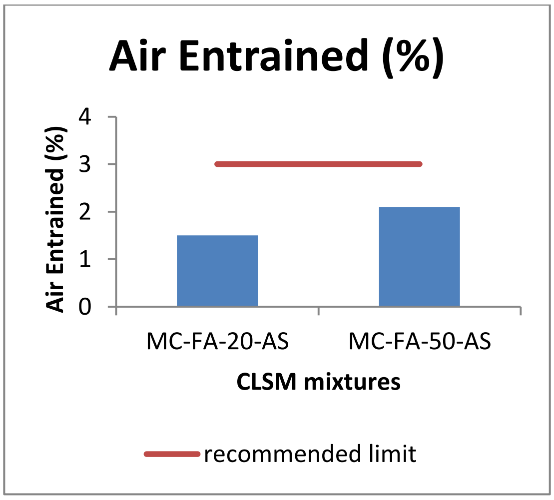

Figure 53. Air entrained of MC-FA-AS

Table 28. Hardened state properties of MC-FA-AS (8 l)

	Compressive Strength (Mpa)	
Description	**7 days**	**28 days**
MC-FA-20-AS	1.41	-
MC-FA-50-AS	1.62	-

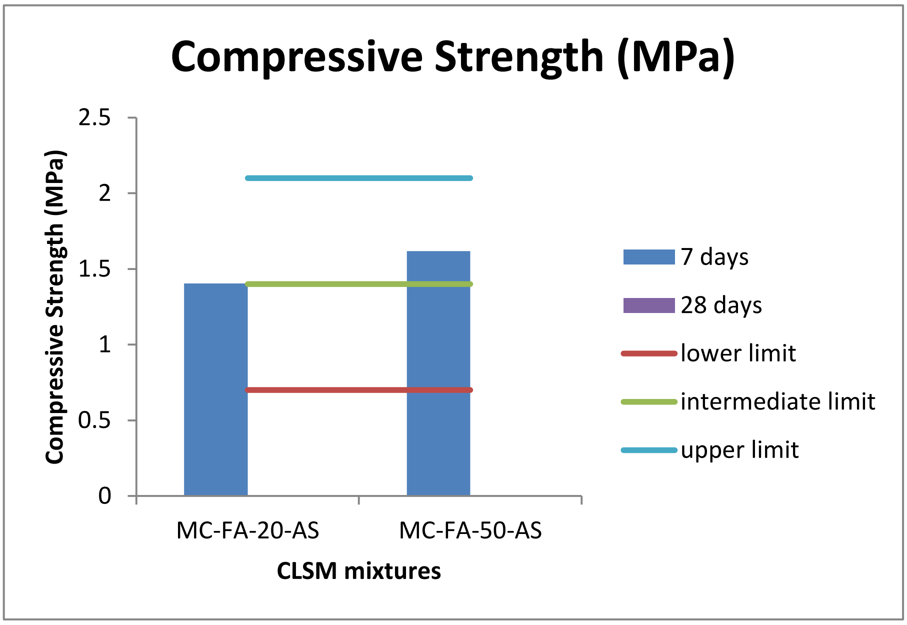

Figure 54. Compressive strength of MC-FA-AS

Discussion

Substituting 20 % and 50 % of natural aggregate for steel slag aggregate, in both cases the results fulfil the basic fresh and hardened state properties, both mixtures has a suitable flow test, the amount of air content is lower than the maximum recommended and compressive strength analyse at 7 days is highly good.

Next step is to proceed to increase the quantity that is have been made, in order to analyse more deeply the fresh and hardened state properties (Chapter V).

CHAPTER V. OPTIMUM DOSAGES

5.1. Introduction

The optimum mix proportions determined in stage 1, stage 2 and stage 3 (Chapter IV) of CLSM (MC-3, MC-5, MC-AR-20-3, MC-AR-20-5, MC-AR-50-2, MC-AR-100-1, MC-FA-mezcla1, MC-FA-20-AS an MC-FA-50-AS) were produced in a high level volume in order to analyse more properties in fresh and hardened state

The physical properties of density, porosity and absorption, compressive strength and its development, tensile strength and modulus were analysed in hardened state. Bleeding and setting time were determined in fresh state. All this properties are going to be examined in the mixtures MC-4, MC-6, MC-AR20-4, MC-AR20-6, MC-AR50-3, MC-AR50-4, MC-AR50-5, MC-AR50-6, MC-AR100-2, MC-AR100-3, MC-FA-mezcla1.2, MC-FA-mezcla1.3, MC-FA-20-AS-2 and MC-FA-50-AS-2.

5.1.1. Stage 1

As well as MC-3 and MC-5 were defined as adequate dosages, the mixtures named MC-4 and MC-6 are the same respectively (Table 29) just change the quantity produce, this means that the proportions of each component are the same the only thing that change is the volume produce.

The dosage named MC-6 is the same as MC-4 just 100 g (for m^3) more of air entraining admixture was added with the objective of improve the flowability.

Table 29. CLSM dosages for MC (m3) (37 l)

Description	Cement (kg)	Natural aggregate (kg)	Water (kg)	Air (g)	w/c	Vol (l)
MC-4	110	1332.4	196.9	1000	1.79	37
MC-6	110	1332.4	196.9	1100	1.79	37

Fresh state properties

Table 30 shows the results obtained with the conventional mixtures, using natural aggregate, in fresh state properties.

The MC-4 obtained adequate flowability (it is near the minimum requirement); however it shows that a higher amount of air content produced higher density than MC-6 (Table 30).

Table 30. Fresh state properties of MC (37 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)	Bleeding (%)
MC-4	1.75	25	18.75	1.7
MC-6	1.65	22	24.5	2.04

As it can be seen in Figure 55 and Figure 56, high amount of air content makes decrease flowability because of the air content avoid segregation and the mixture form a paste that are more compacted. The mixture MC-6 acquired appropriate flowability and the quantity of air entrained are in the adequate interval.

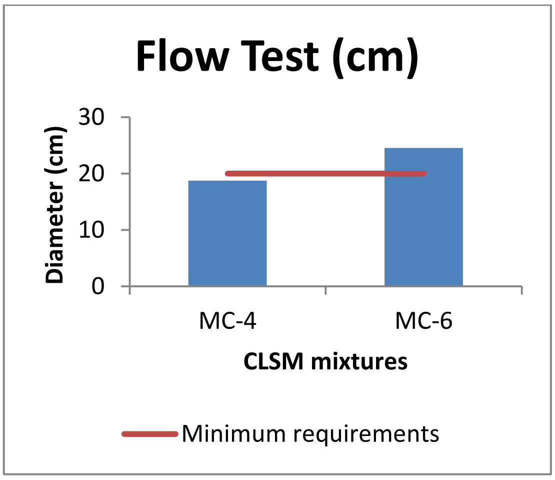

Figure 55. Flow test of MC (37 l)

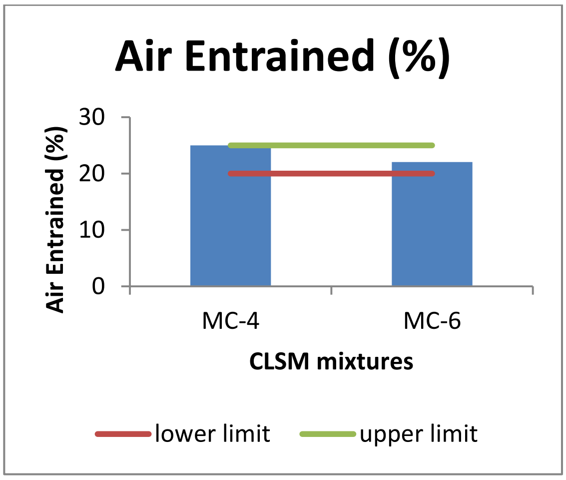

Figure 56. Air entrained of MC (37 l)

Hardened state properties

Table 31 shows hardened state properties of the mixture made with just natural aggregate. As it was expected the CLSM mixture made with natural aggregate achieved suitable ranges for compressive strength (Figure 57). These obtained values accomplish the requirements that define the CLSM mixtures.

CLSM tensile strength, following the rules of concrete, is approximately the 11.5 % of the compressive strength (Table 31).

Table 31. Hardened state properties of MC (37 l)

	Compressive Strength (Mpa)		Tensile Strength (Mpa)	
Description	7 days	28 days	28 days	Modulus (Mpa)
MC-4	0.98	1.11	0.13	5614.35
MC-6	0.97	1.2	-	-

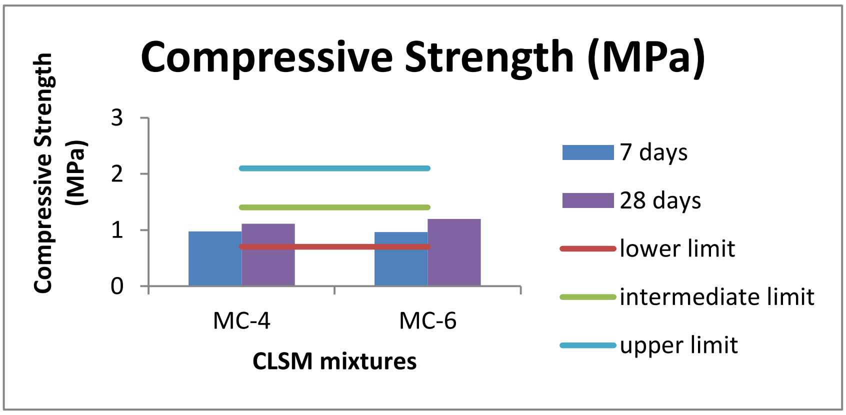

Figure 57. Compressive strength of MC (37 l)

5.1.2. Stage 2

The mix proportions, made with natural aggregate, with most adequate fresh and hardened properties were chosen in order to evaluate more deeply the influence of recycled aggregate on conventional mixture on his fresh and hardened state properties.

The optimum mixtures chosen to make this analysis was the defined as MR-AR-20-3, MC-AR-20-5, MC-AR-50-2, MC-AR-100-1 that were tested in Chapter IV.

Mix proportions of CLSM employing recycled aggregate

The mixtures that were defined as MC-AR-20-3, MC-AR-20-5, MC-AR-50-2 and MC-AR-100-1 in the previous chapter were chosen as a control dosage to begin with the new mixtures based on them in an extended quantity, 37 litres.

Table 32, Table 33 and Table 34 show the new dosages that are based on the previous made, with the 20, 50 and 100 % of the recycled aggregate, in Chapter IV.

Table 32. CLSM dosages of MC-AR-20 (37l)

Description	Cement (kg)	Natural aggregate (kg)	Recycled aggregate (kg)	Water (kg)	Air (gr)	w/c	Vol (l)
MC-AR-20-4	110	1065.92	114.07	196.9	1136.3	1.79	37
MC-AR-20-6	110	1065.92	196.24	196.9	1136.3	1.79	37

Table 33. CLSM dosages of MC-AR-50 (37l)

Description	Cement (kg)	Natural aggregate (kg)	Recycled aggregate (kg)	Water (kg)	Air (gr)	w/c	Vol (l)
MC-AR-50-3	125	625.11	442.74	217.5	1000	1.74	37
MC-AR-50-4	125	642.85	473.42	210	1000	1.68	37
MC-AR-50-5	125	655.75	482.92	200	900	1.6	37
MC-AR-50-6	132	646.81	476.33	204.6	900	1.55	37

Table 34. CLSM dosages of MC-AR-100 (37l)

Description	Cement (kg)	Natural aggregate (kg)	Recycled aggregate (kg)	Water (kg)	Air (gr)	w/c	Vol (l)
MC-AR-100-2	135	0	880.36	232.2	1000	1.72	37
MC-AR-100-3	135	0	908.58	226.8	1000	1.68	37

Fresh state properties

A. Mixtures with 20 % of recycled aggregate

The mixtures made with 20 % of recycled aggregate seem to be adequate because it has all the basic properties in fresh state (Table 35).

Table 35. Fresh state properties of MC-AR-20 (37 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)	Bleeding (%)
MC-AR-20-4	1.72	23	26.75	3.4
MC-AR-20-6	1.765	23	21.25	3.1

Both mixtures made with 20 % of recycled aggregate has a suitable flowability because obey the minimum requirement (Figure 58 and Figure 59) that is to have a diameter in flow test method more than 20 cm and to have between 20 and 25 % of air entrained.

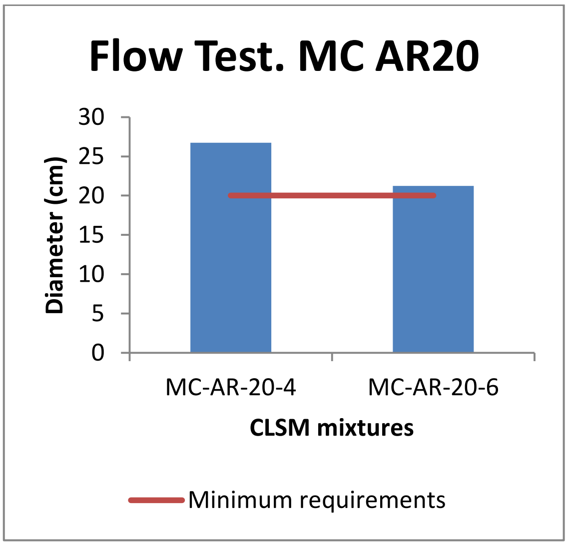

Figure 58. Flow test of MC-AR-20 (37l)

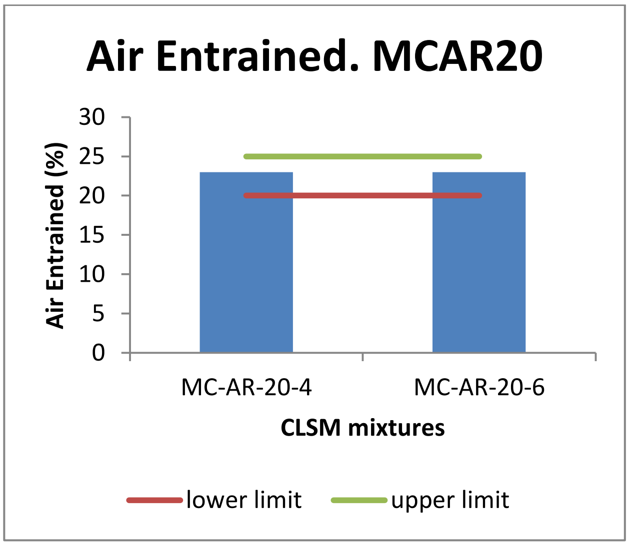

Figure 59. Air entrained of MC-AR-20 (37l)

The only difference is the assumption of the percentage that the aggregate absorbed. First of all it was supposed that the aggregates of the mixture MC-AR-20-4 absorb his own capacity at the first 10 minutes (55 % and 70 % for natural aggregate and recycled aggregate, respectively), and at the mixture MC-AR-20-6 it was supposed that the aggregates absorbed his own capacity at 30 minutes (65 % and 90 % for natural aggregate and recycled aggregate, respectively).

B. Mixtures with 50 % of recycled aggregate

When making the dosages for the mixtures with 50 % of recycled aggregate, the water/cement ratio was decrease for the requirements in hardened state as it can be seen later.

If the water/cement ratio decreases, that has influence in the fresh state properties (Table 36).

It is supposed that if the water/cement ratio decrease it also has to decrease the flowability of the mixture, but this is not convenient in CLSM mixtures because is one of the properties that make really interest this material, so in order to avoid the decrease of the flowability it is supposed that the recycled aggregate absorbed more water (instead of 80 % at the first 10 minutes, 90% at 20-30 minutes). With that condition the water/cement decrease but the flowability accomplishes the requirements of flow test and air entrained (Figure 60 and Figure 61).

Table 36. Fresh state properties of MC-AR-50 (37 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)	Bleeding (%)
MC-AR-50-3	1.67	26	23	2.8
MC-AR-50-4	1.63	26	27	1.4
MC-AR-50-5	1.64	24	20.75	0
MC-AR-50-6	x	24	22.25	1

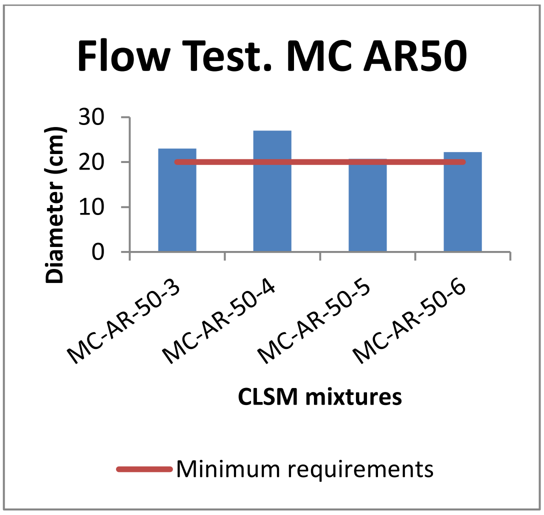

Figure 60. Flow test of MC-AR-50 (37l)

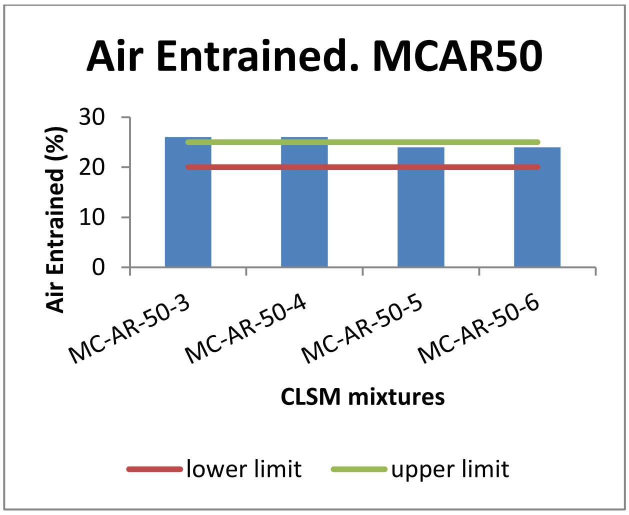

Figure 61. Air entrained of MC-AR-50 (37l)

C. Mixtures with 100 % of recycled aggregate

The dosages with 100 % of recycled aggregate before any test method, it is known that the amount of cement has to increase because of the high percentage of absorption of the recycled aggregates compared to the natural aggregates. The CLSM made with 100 % of recycled aggregate was produced with 135 kg of cement and a lower water/cement ratio was needed (1.68) in order to achieve the compressive strength lower limit as we can see in hardened state properties. This growth in the quantity of cement has influence in the fresh state properties.

Both mixtures, MC-AR-100-2 and MC-AR-100-3 achieved suitable ranges for flowability and air entrained (Figure 62 and Figure 63).

Table 37. Fresh state properties of MC-AR-100 (37 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)	Bleeding (%)
MC-AR-100-2	1.36	26	27.25	0
MC-AR-100-3	1.54	22.5	25	0

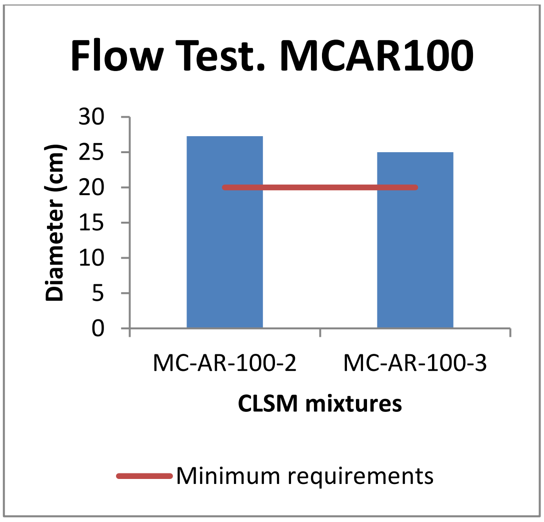

Figure 62. Flow test of MC-AR-100 (37l)

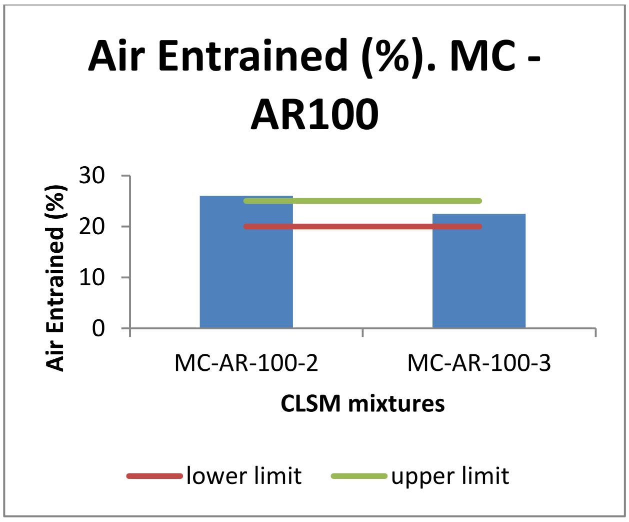

Figure 63. Air entrained of MC-AR-100 (37l)

Hardened state properties

Once fresh state properties have been acquired, compressive strength, splitting tensile strength and modulus has been tested at 28 days in hardened state.

A. Mixtures with 20 % of recycled aggregate

As it can be seen in Table 38 and Figure 64 compressive strength mixture with 20 % of natural aggregate is near the upper limit. It acquires the minimum requirements, so is possible to say that the mixture with 20 % is available to use it in work provided that previously the mixture had been tested.

When it was supposed, in the mixture MC-AR-20-4, that the aggregates absorbed 55 and 70 % (natural and recycled aggregate, respectively) the compressive strength values were higher than when it was supposed, in the mixture MC-AR-20-6, that the absorption was 65 and 90 %. This is because the mixture MC-AR-20-4 has less water content.

Table 38. Hardened state properties of MC-AR-20 (37 l)

	Compressive Strength (Mpa)		Tensile Strength (Mpa)	
Description	**7 days**	**28 days**	**28 d**	**Modules (Mpa)**
MC-AR-20-4	0.85	1.08	0.15	7262.9
MC-AR-20-6	0.6	0.9	-	-

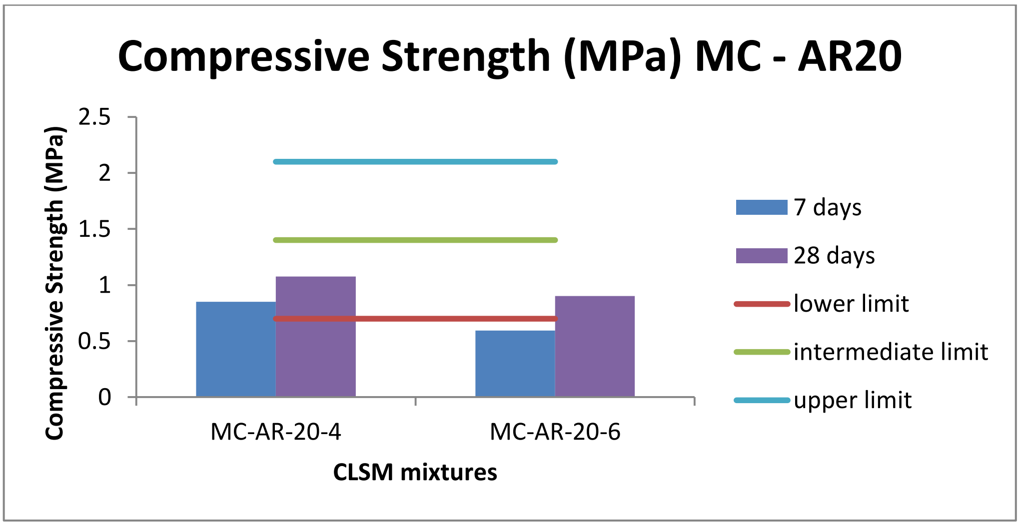

Figure 64. Compressive strength of MC-AR 20 (37 l)

CLSM tensile strength, following the rules of concrete, is approximately the 14% of the compressive strength (Table 38).

B. Mixtures with 50 % of recycled aggregate

As it was mentioned before, in order to achieve the minimum levels of compressive strength, the water/cement ratio was decrease several times. It was also increase the amount of cement in the mixture (Table 33).

In the mixtures made with 50 % of recycled aggregate is needed a high compressive strength and for that the water/cement ratio was decrease first from 1.74 to 1.68 and viewing that the target was not achieved was decrease for second time from 1.68 to 1.6 and it was also carried out a decrease of the air entraining admixture (from 1000 g to 900 g), finally the water/cement ratio was stablished at 1.55 and an increment of the cement quantity was required.

Table 39 shows the different values of compressive strength depending on the dosage.

Table 39. Hardened state properties of MC-AR-50 (37 l)

	Compressive Strength (Mpa)		Tensile Strength (Mpa)	
Description	**7 days**	**28 days**	**28 d**	**Modules (Mpa)**
MC-AR-50-3	0.49	0.83	0.05	5037.8
MC-AR-50-4	0.23	0.56	0.12	3031.35
MC-AR-50-5	0.41	-	-	-
MC-AR-50-6	0.49	-	-	-

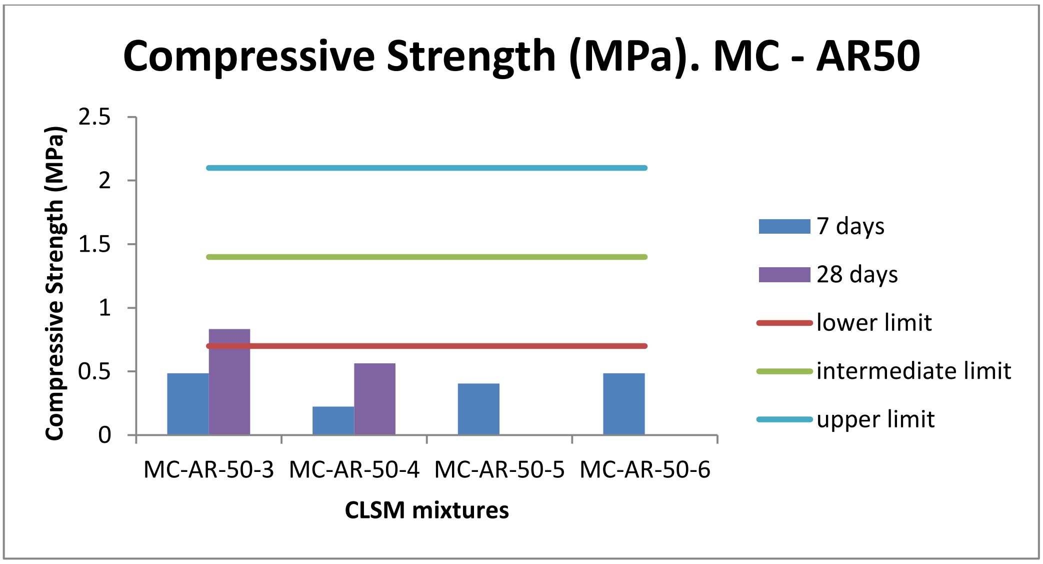

Figure 65. Compressive strength of MC-AR 50 (37 l)

The upper limit was hardly achieved (Figure 65) when the water/cement ratio was 1.55 and the cement quantity was 132 kg (m^3).

Mixtures MC-AR-50-5 and MC-AR-50-6 are expected to achieve a good range of compressive strength because they have suitable dosages, and then the material will be qualifies positively.

CLSM tensile strength, following the rules of concrete, is approximately the 6 % of the compressive strength (Table 39).

C. Mixtures with 100 % of recycled aggregate

The CLSM made with 100 % of recycled aggregate was produced with 135 kg of cement and a lower water/cement ratio was needed (1.68) in order to achieve the requirements for compressive strength (Table 34).

Despite of being raised the amount of cement and reduce the water cement ratio, the aim was not achieved (Figure 66). These are probable due to the high percentage of absorption of the recycled aggregate.

With the obtained values in Table 40 the CLMS mixture made with 100 % of recycled aggregate are not feasible to use it as an optimum dosage.

Table 40. Hardened state properties of MC-AR-100 (37 l)

	Compressive Strength (Mpa)		Tensile Strength (Mpa)	
Description	**7 days**	**28 days**	**28 d**	**Modules (Mpa)**
MC-AR-100-2	0.18	0.41	0.02	2380.05
MC-AR-100-3	0.3	-	-	-

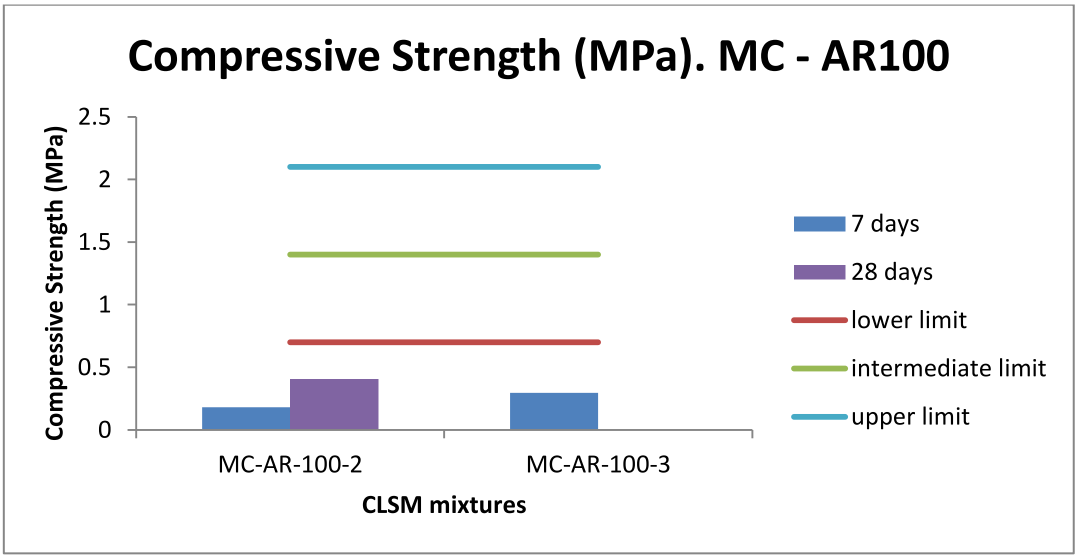

Figure 66. Compressive strength of MC-AR 100 (37 l)

CLSM tensile strength, following the rules of concrete, is approximately the 5 % of the compressive strength (Table 40).

Mix proportions of CLSM employing steel slag

Having seen the influence of steel slag in the CLSM mixtures is not necessary to produce the mixtures in high volume because of the segregation phenomenon.

Steel slag could have had a good result if could avoid the separation of the different parts.

5.1.3. Stage 3

Mix proportions of CLSM employing fly ash

Having defined a control dosage as MC-FA-mezcla1 in Chapter IV, is possible to increase the amount produced until 37 litres, in order to study more plastic properties in both states.

In this section when making the mixture MC-FA-mezcla1.2 in a high volume the water/cement ratio was decrease from 0.85 until 0.82 (Table 41). Another dosage was made, MC-FA-mezcla1.3, that was completely the same as MC-FA-mezcla1.2, but instead of putting a foaming agent, it was used superplasticizer as admixture (0.5 %) (Table 41).

Table 41. CLSM dosages for MC-FA (37 l)

Description	Cement (kg)	Natural aggregate (kg)	Fly Ash (kg)	Water (kg)	Admixture (gr)	w/c	Vol (l)
MC-FA-mezcla 1.2	60	1626.82	240	246	500 (air)	0.82	37
MC-FA-mezcla 1.3	60	1626.82	240	246	1500 (visc)	0.82	37

Fresh state properties

In the mixture MC-FA-mezcla1.2 low percentage of air entrained admixture was added, although the test method for air content said that the mixture has 20 % of air entrained (Table 42). With this, it was possible to predict that the mixture are not going to be suitable for compressive strength values because of the low quantity of cement with the high level of air content that it has.

The obtained results for MC-FA-mezcla1.3 were favorable in fresh state either for flowability and air content (Figure 67 and Figure 68).

Table 42. Fresh state properties of MC-FA (37 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)	Bleeding (%)
MC-FA-mezcla 1.2	1.84	20	19.5	1.89
MC-FA-mezcla 1.3	2.22	2.5	24.5	3.28

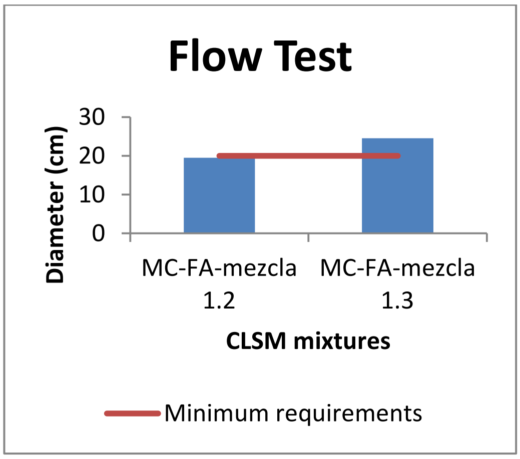

Figure 67. Flow test of MC-FA

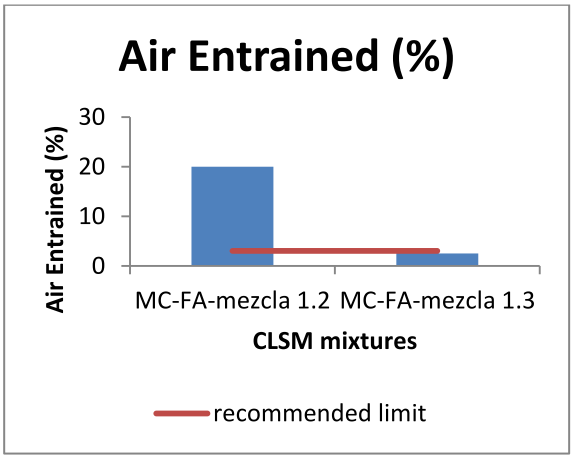

Figure 68. Air entrained of MC-FA

Hardened state properties

Given that the mixture MC-FA-mezcla1.2 has a lot of air entrained (Table 42) and there is not cement enough, the low percentage of compressive strength was predictably (Figure 69).

Mixture MC-FA-mezcla1.3 achieved a good result of compressive strength that means the decision of use another type of admixture as a superplasticizer make the dosage achieved suitable hardened state properties.

Table 43. Hardened state properties of MC-FA (37 l)

	Compressive Strength (Mpa)		Tensile Strength (Mpa)	
Description	7 days	28 days	28 d	Modules (Mpa)
MC-FA-mezcla 1.2	0.16	0.17	0.01	-
MC-FA-mezcla 1.3	0.86	-	-	-

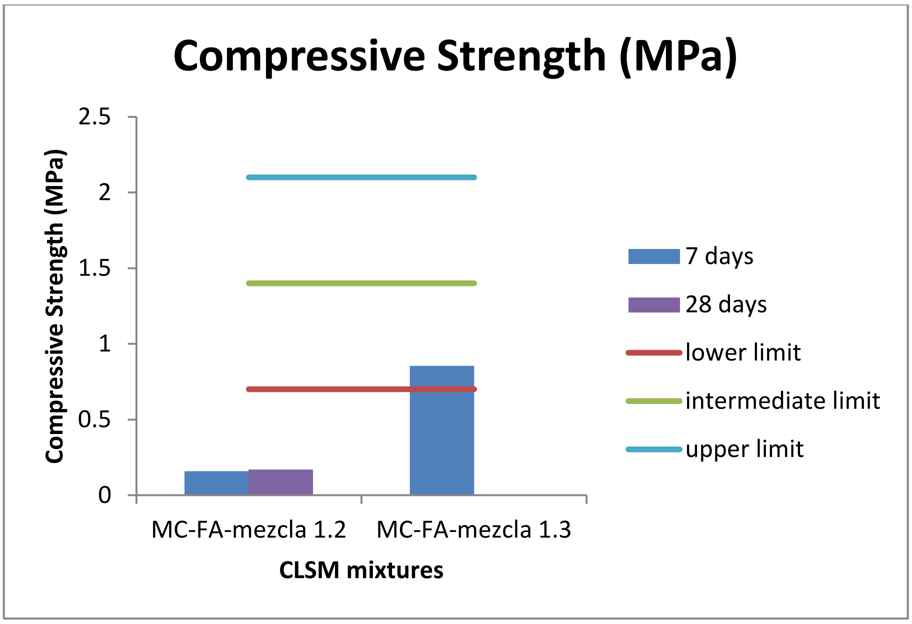

Figure 69. Compressive strength of MC-FA

With the compressive strength value of the mixture MC-FA-mezcla1.2 we can rule out the foaming agent as admixture in the dosages that employ fly ash.

The obtained results for MC-FA-mezcla1.3 were favorable in hardened state properties. As it can be seen the compressive strength at seven days are in the adequate interval, for this is expected to obtain a good compressive strength value at 28 days.

Mix proportions of CLSM employing steel slag with fly ash

Having obtained good results in Chapter IV from MC-FA-20-AS and MC-FA-50-AS mixtures, the same type of mixtures were made in a large volume. Table 44 shows the dosages that were produced.

In this type of mixture where the possibility of segregation is high due to the high density of the steel slag, its decided to use superplasticizer as admixture, as in Chapter IV, because can maintain the flowability of the mixture even if the water/cement ratio has been decreases.

Table 44. CLSM dosages for MC-FA-AS

Description	Cement (kg)	Natural aggregate (kg)	Fly Ash (kg)	Slag (kg)	Water (kg)	Viscocrete (gr)	w/c	Vol (l)
MC-FA-20-AS-2	45	1253.01	360	369.1	222.75	2025	0.55	37
MC-FA-50-AS-2	45	783.13	360	922.76	222.75	1338.75	0.55	37

Fresh state properties

Both types of mixture acquired adequate properties in terms of flowability and air entrained (Figure 70 and Figure 71).

Consequently is important to still evaluating this type of mixture that employs steel slag as aggregate and fly ash as a cementitious paste.

Table 45. Fresh state properties of MC-FA-AS (37 l)

Description	ρ (kg/dm³)	Air (%)	Flow test (cm)	Bleeding (%)
MC-FA-20-AS-2	2.25	5.5	29.5	0.47
MC-FA-50-AS-2	2.38	7	28	0

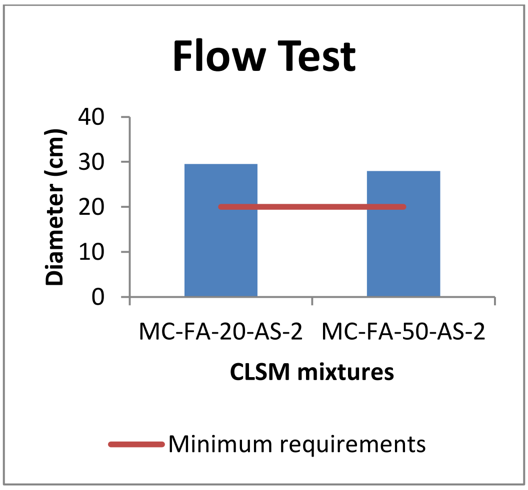

Figure 70. Flow test of MC-FA-AS

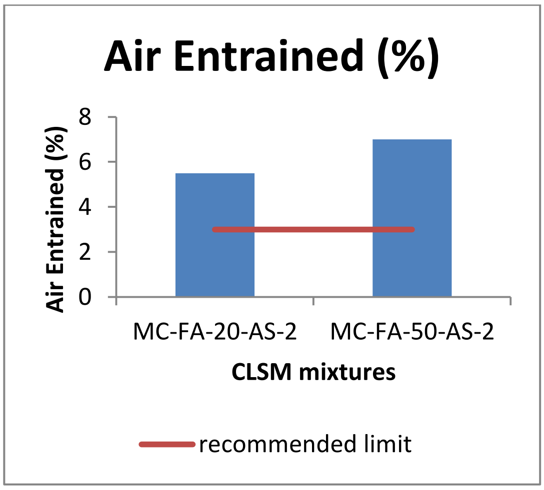

Figure 71. Air entrained of MC-FA-AS

Hardened state properties

Compressive strength should not be decreases because of the use of steel slag, because a huge amount of fly ash is used in order to create a paste that does not permitted the descent of the compressive strength.

Table 46. Hardened state property of MC-FA-AS (37 l)

	Compressive Strength (Mpa)		Tensile Strength (Mpa)	
Description	7 days	28 days	28 d	Modules (Mpa)
MC-FA-20-AS-2	1.38	-	-	-
MC-FA-50-AS-2	1.36	-	-	-

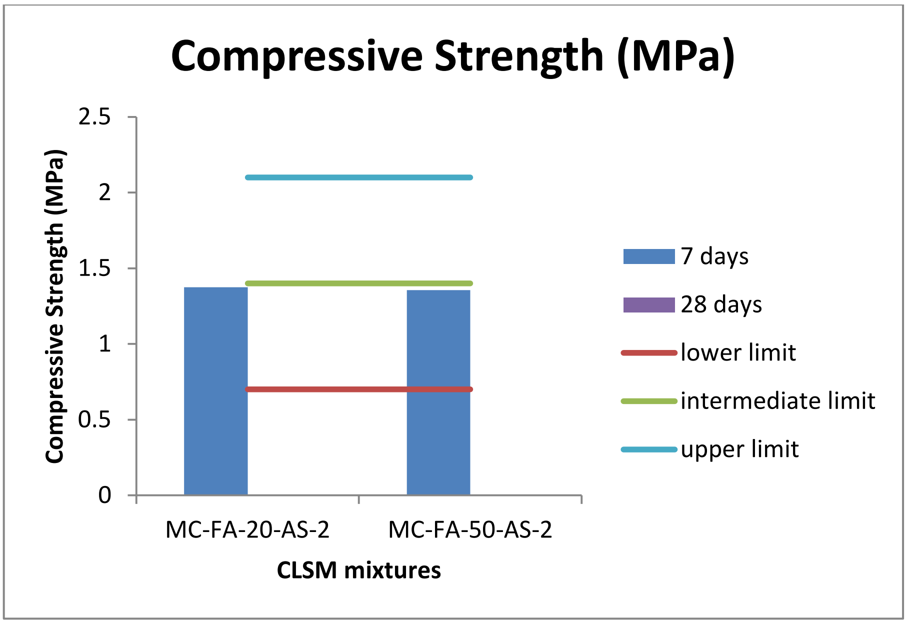

Figure 72. Compressive strength of MC-FA-AS

MC-FA-20-AS-2 and MC-FA-50-AS-2 has really good properties in both states, for this are going to be a possible mixture to still producing and investigating due to the low quantity of cement and the use of waste material as a good type of aggregate.

Both mixtures, MC-FA-20-AS-2 and MC-FA-50-AS-2, achieved a good value for compressive strength at 7 days, for this due to the continued expansion of compressive strength over the days, it is foreseeable to achieve a good compressive strength at 28 days.

5.2. Stage 1 and Stage 2: Natural and Recycled Aggregate

Having seen the results of each part is considerably interesting to analyse the behaviour of each type of mixture, made with recycled aggregate (MC-AR-20/50/100), with the control dosage made with natural aggregate (MC).

It is known, as it was said before, that the attitude of recycled aggregate are not the same of the natural aggregate, recycled aggregate present a bit more dispersion in the results than natural aggregate, this is probable due to the percentage of absorption.

As long as the analysis give positive results, meaning that each type of mixture acquires the specific requirements, the dosages would be classified as proper.

From each group of mixture it was selected a dosage that best result had obtained, this specifics dosages are for the 20 % of recycled aggregate: MC-AR-20-4, for the 50 % of recycled aggregate: MC-AR-50-3 and for 100 % of recycled aggregate: MC-AR-100-2.

5.2.1. Fresh state

In this type of material the conditions in fresh state are determining factors that can exclude a dosage on the spot. The results are thought to be appropriate, for all the analysis that has been done in the previous chapters, until a percentage of recycled aggregate substitution up to 50 %.

Flow test

The mixtures not only are adequate in terms of flowability but also are better than the mixture made with 100 % of natural aggregate (optimum and control dosage) (Figure 73).

The three different types of mixture (MC-AR-20-4, MC-AR-50-3 and MC-AR-100-3) achieved suitable flowability concerning to the control dosage.

If the mixture MC was the reference with 100 % of flowability, the mixtures MC-AR-20-4, MC-AR-50-3 and MC-AR-100-3 obtain 143, 123 and 145 % respectively.

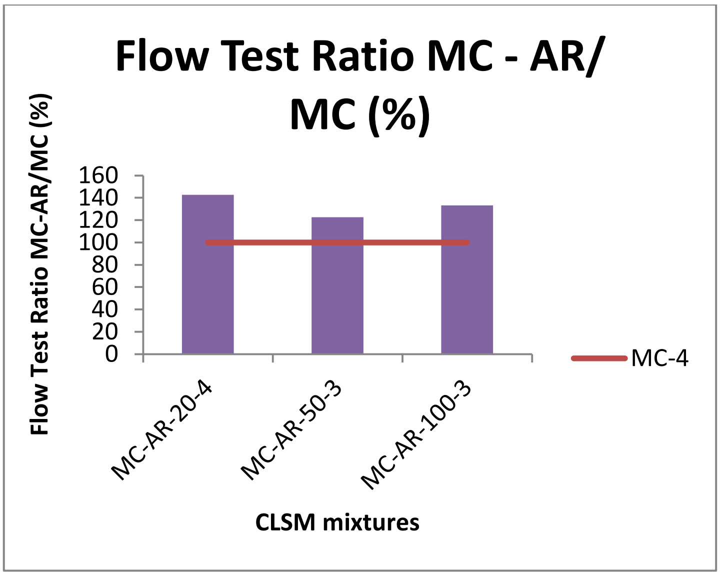

Figure 73. Flow Test Ratio MC-AR/MC

Air entrained

What is analysed is the influence of the amount of air entrained admixture in each type of mixture with the flowability.

It would probably be deduce that with more quantity of foaming agent more flowability, but is not just like that, because the aim of add air in the mixture was to avoid the segregation, and this happen because the air are capable to form air cells that make the mixture more compacted.

Figure 74 is an analysis criteria that gave the influence of the air entraining admixture in both cases, flowability and segregation.

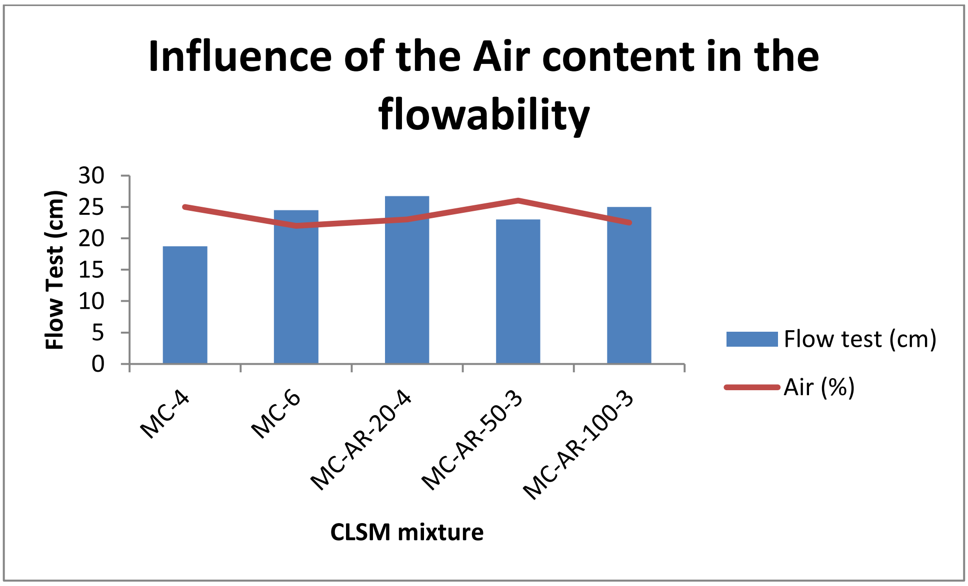

Figure 74. Air content vs Flowability

Having seen that from any of the mixtures MC-4, MC-6, MC-AR-20-4, MC-AR-50-3 and MC-AR-100-3 was experimented segregation, is possible say that the amount of air content avoid segregation and also improves the flowability (Figure 74) of the mixture with a range values of air content between 22 and 26 % (in the adequate interval), and for flowability from 18.75 until 27.25 cm.

Bleeding

In the experimental process with big quantities of each mixture was determined the amount of water that bleeds in fresh state.

Figure 75 shows that the CLSM produced with recycled aggregate have low bleeding, probably due to the high and quick absorption capacity of recycled aggregates and their surface roughness compared to that of natural aggregates. On the contrary, the material produced with just natural aggregate (CLSM standard) showed a high percentage of bleeding.

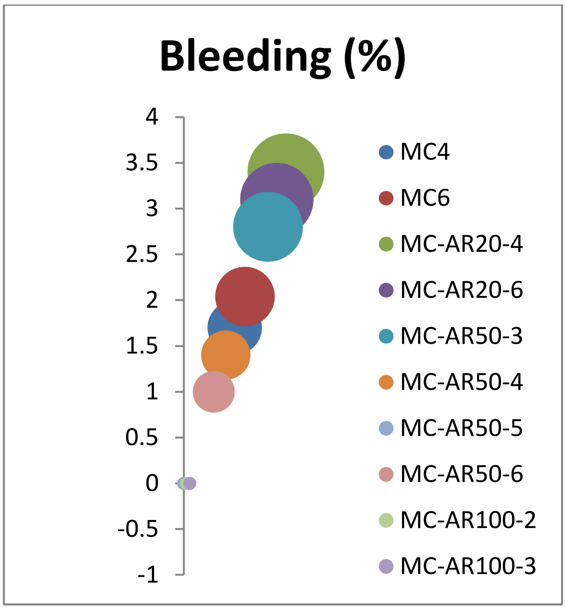

Figure 75. Bleeding for MC and MC-AR

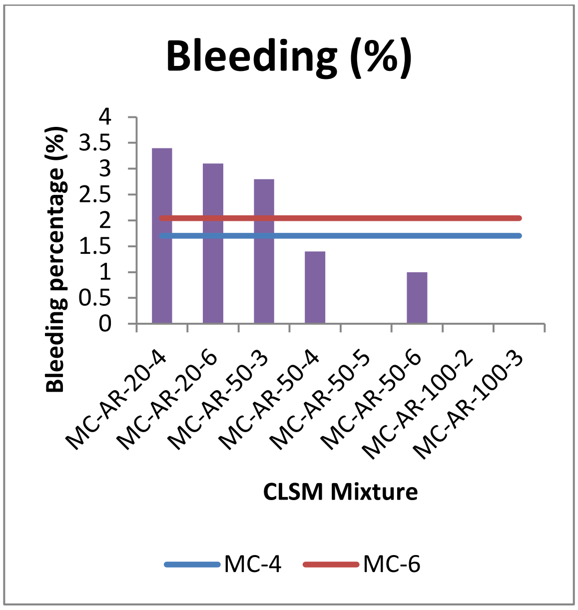

Figure 76. Mixtures bleeding compared to MC

Figure 76 shows the bleeding percentage of mixtures MC-AR20-4, MC-AR20-6, MC-AR50-3, MC-AR50-4, MC-AR50-5, MC-AR50-6, MC-AR100-2, MC-AR100-3 regarding to MC-4 and MC-6 mixtures. It shows that while the quantity of recycled aggregate increases, the bleeding percentage of each mixture decrease, until arrived at 0 % with a dosage made with 100 % of recycled aggregate, due to the high absorption capacity and surface roughness of this.

There was no evidence of a tendency to the decanting of heavy aggregates and no segregation was observed in any of CLSM's produced.

Setting time

If the factor that could have influence on the setting time are analysed [3] is easy to see that if different values are obtained it would be due to the different mixture dosages, because the other factors that have influence in all the mixtures were the same, for example the cement, permeability and saturation degree of the soil around, relative humidity, room temperature, moisture and backfill depth.

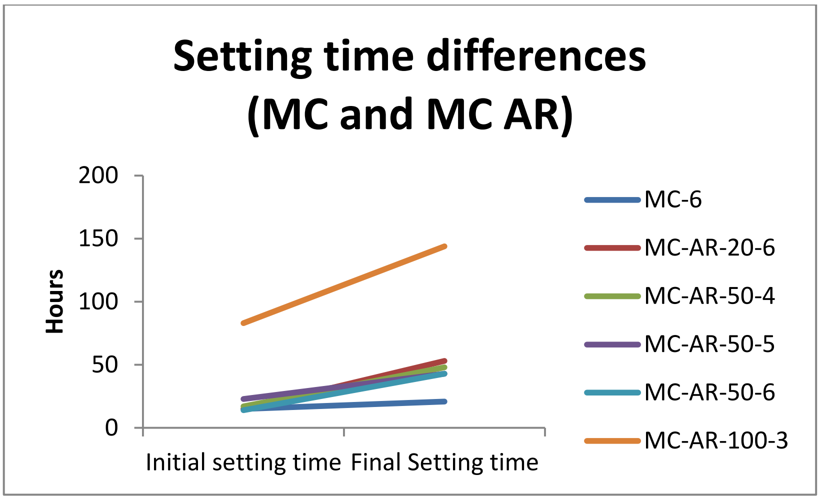

Figure 77. Setting Time difference between MC and MC-AR

As it can be seen in Figure 77 the different types of mixture presents approximately the same ranges for initial and final setting time. Despite of, the mixture MC-AR-100-3 which has been made with 100 % of recycled aggregate that has a long setting time. It would be interesting the addition of setting accelerator.

Another aspect to take into consideration is the total water amount, this can influence significantly on setting time. Table 47 shows the total water quantity added to the mixture showing the water of the dosage and the water absorbed by the aggregates.

Table 47. Total water amount

Description	Water (kg/m^3)	Agua absorbed (kg/ m^3)	TOTAL water (kg/ m^3)
MC-6	196.9	14.7	211.6
MC-AR-20-6	196.9	41.8	238.7
MC-AR-50-4	210	79.5	289.6
MC-AR-50-5	200	81.1	281.2
MC-AR-50-6	204.6	80	284.7
MC-AR-100-3	226.8	139	365.9

As it can be seen the total water amount used in recycled aggregate mixture is higher than that of MC conventional. The total water amount increase progressively and directly proportional to the percentage of recycled aggregates that the mixture has, this is because as more quantity of recycled aggregate more water quantity the mixture absorbed.

For this, the mixtures with more percentage of recycled aggregate spent more setting time, because the mixtures have to absorbed more water.

Figure 78 show in next page initial setting times of MC-6, MC-AR-20-6, MC-AR-50-4, MC-AR-50-5, MC-AR-50-6 and MC-AR-100-3 were 15, 15, 17, 23, 14 and 83 hours respectively. According to Dockter [30] the approximate time to initiate setting takes from 3 to 4 hour, this means the mixture shown in the next page has an extended setting time.

On the other hand, also according to Dockter, the final setting time can be produced in the first or second day, this means between 24 and 48 hours. According to the Figure 78 finals setting time values are for MC-6, MC-AR-20-6, MC-AR-50-4, MC-AR-50-5, MC-AR-50-6 and MC-AR-100-3 were 21, 53, 48, 43, 43 and 144 hours respectively. That reveals a final setting time according to the specifications, although that is no applicable for the mixture MC-AR-100-3 which take approximately 6 days.

In general, to prevent a long setting time, more cement can be incorporated into the mixture. In the case of MC-AR100-3, which had an extended setting time and whose amount of cement per cubic meter was at a higher level, an accelerating admixture could be necessary in order to reduce setting time.

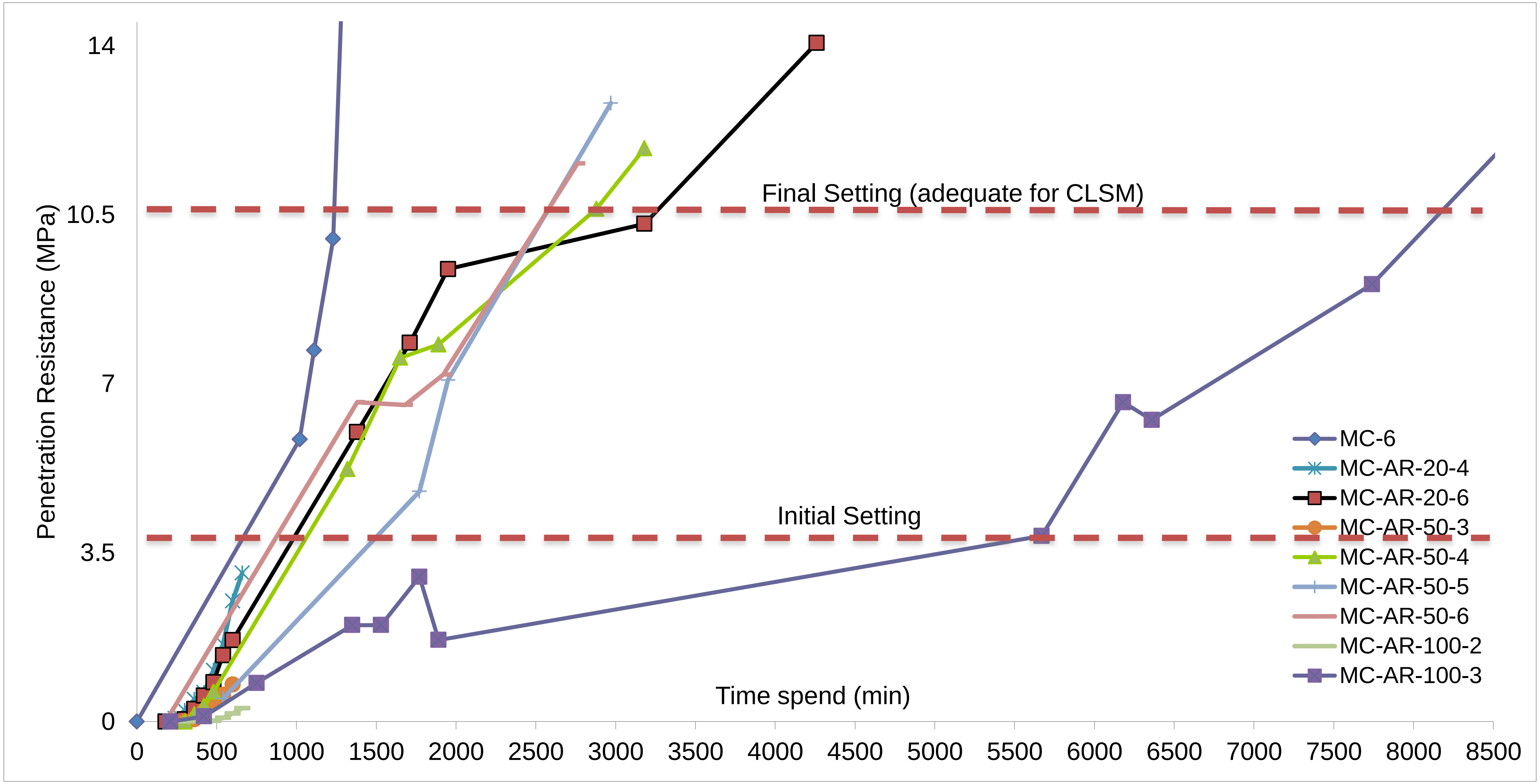

Figure 78. Setting time for MC and MC-AR

5.2.2. Hardened state properties

Different properties in hardened state were analysed as compressive strength, splitting tensile strength, modules and density, porosity and absorption in order to make research about more plastic properties of this material. However, distinct from another plastic properties compressive strength are decisive to rule out or not the mixture.

Said that, compressive strength had being analysed accurately and is the most important property in hardened state.

Compressive strength

Compressive strength is a measure of the CLSM ability to distribute loads. The compressive strength requirements of CLSM at 28 days are that must be higher than 0.7 MPa. For projects where future excavation is expected with mechanical equipment is important to keep the resistance low, less than 1.4 MPa. CLSM can also be used as structural filler, in which case the recommended compressive strength limit for CLSM excavable is defined by the value of 2.1 MPa.

Mixtures that are acceptable at early ages continue gaining strength over time (Table 48)

Figure 79 shows the compressive strength development from 7 days to 28 days of the CLSM materials produced in stage 1 and stage 2. The CLSM made with a higher volume of recycled aggregates developed more strength, probably due to the presence of cement and fine ceramic material in the recycled aggregates which may have a pozzolanic effect, improving the long-term strength [55], the CLSM made with 100 % of recycled aggregates rose by 80 % from 7 to 28 days.

Table 48. Compressive strength development

Description	Compressive Strength (MPa)		
	7 days	28 days	Development (%)
MC-4	0.98	1.11	14.19
MC AR20-4	0.85	1.08	26.67
MC AR50-3	0.49	0.83	71.82
MCAR100-3	0.3	0.53	79.6

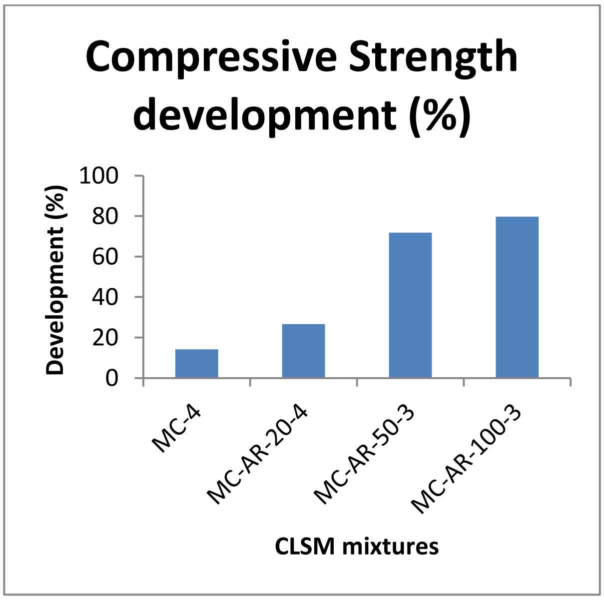

Figure 79. Compressive strength development

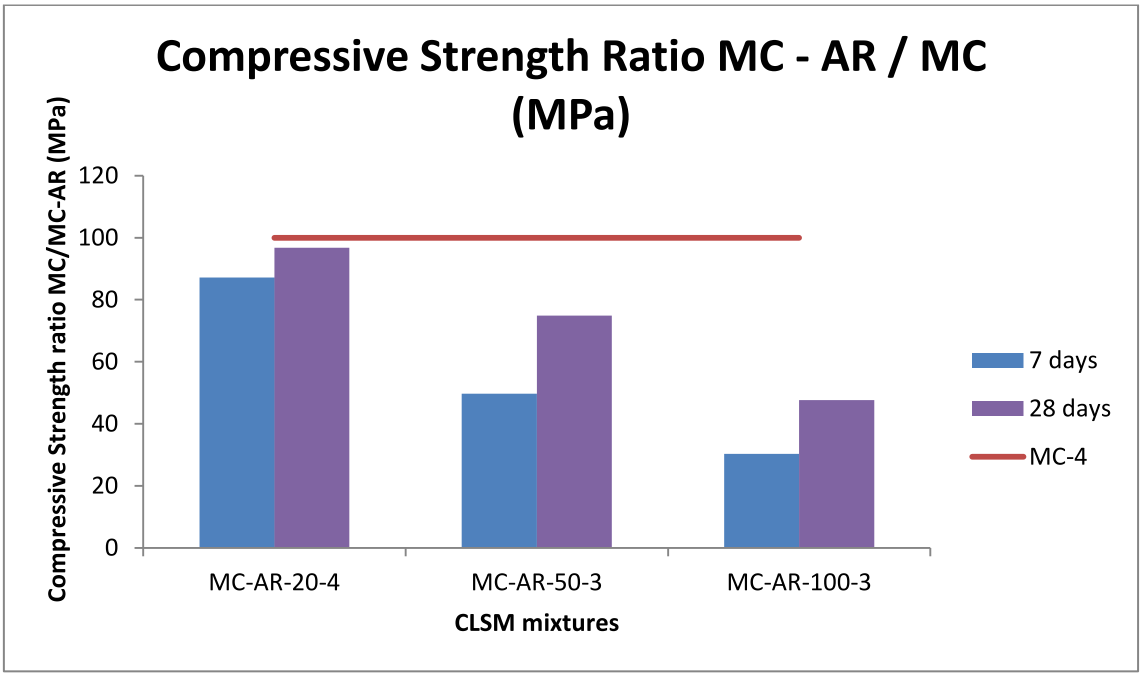

Figure 80. Compressive strength ratio MC-AR /MC

Figure 80 shows the compressive strength acquired in 7 and 28 days for the mixtures MC-AR-20-4, MC-AR-50-3 and MC-AR-100-3 compared to the compressive strength achieved for the mixture MC-4.

The compressive strength of the mixtures made with recycled aggregate hardly achieved the values of the mixtures made with natural aggregate. And the difficulty to achieve the compressive strength of MC-4 is increasing more when the percentage of recycled aggregate also increases in the mixture.

Seen this graphic is possible to conclude that the mixtures made with 20 and 50 % of recycled aggregate can be a good substitution of the mixture made with just natural aggregate due to achieves values that are in an adequate interval.

Splitting tensile strength

Splitting tensile strength according concrete rules is approximately 10 % of the compressive strength of the mixture (Figure 81).

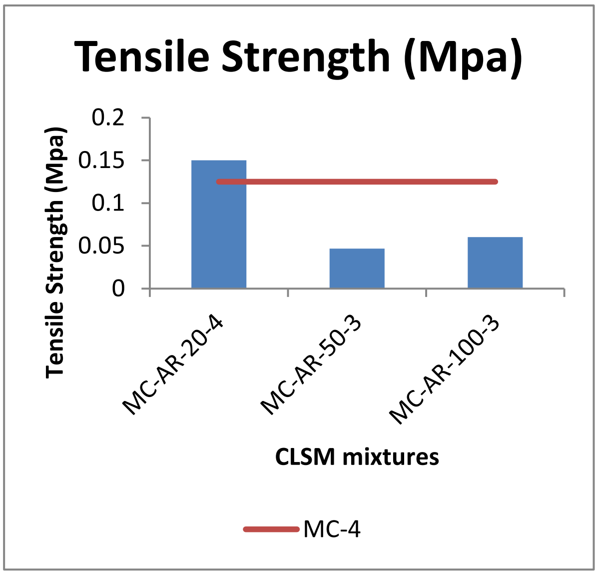

Figure 81. Tensile strength of MC and MC-AR

An analysis was due in order to corroborated if this rule comply also with CLSM mixture. Conventional mixture (MC-4) was the comparative between this one and the mixture made with recycled aggregate, and the results were:

The percentage of compressive strength that is the value of tensile strength in the different type of mixtures is:

MC	→	11.5 %
MC-AR-20	→	14 %
MC-AR-50	→	6 %
MC-AR-100	→	5 %

This shows that the tensile strength value using a value of compressive strength percentage decrease if the amount of recycled aggregate increase.

Elastic Modulus

The modulus of elasticity of CLSM is described through the modulus of elastic of concrete, and is the stress to strain ratio.

Predictably, the modulus of mixtures as MC, MC-AR-20 and MC-AR-50 has similar values. However, the modulus of mixtures made with 100 % of natural aggregate has a low value.

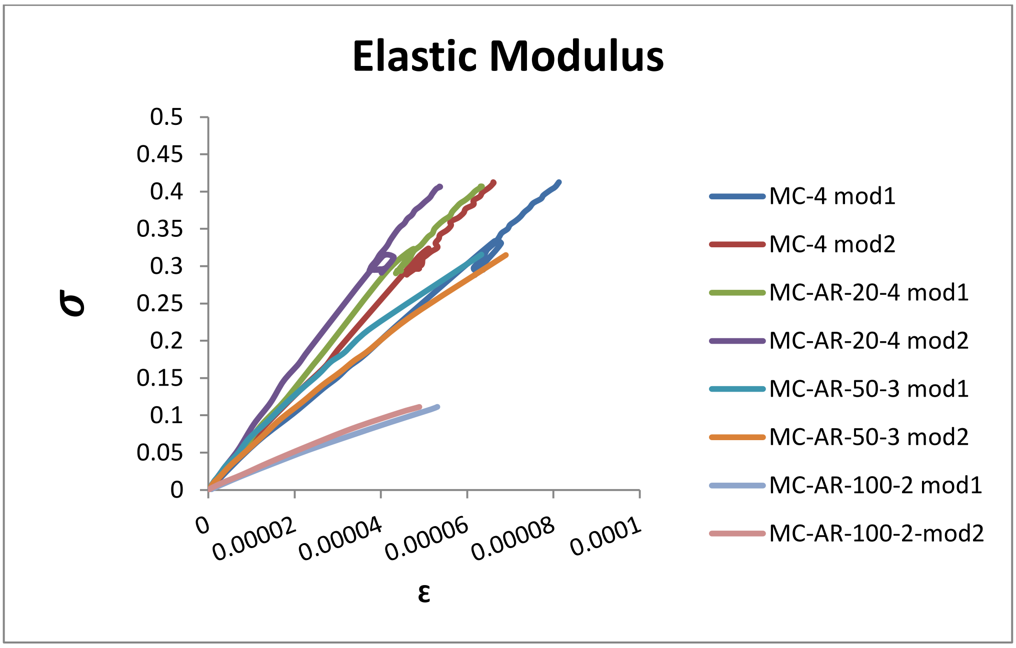

Figure 82. Modules of MC and MC-AR

Density, porosity and absorption

The dry density of CLSM material made with recycled aggregate up to 50 % approximately was of 1.4 $\frac{kg}{dm^3}$. The air content had a higher influence than the percentage of used recycled aggregate. When 100 % of recycled aggregate was used the density was to 1.2 $\frac{kg}{dm^3}$ too. The saturated density of CLSM made with raw and with 20 % of recycled aggregates increased around 11.5 % with respect to dry density values. The CLSM made with 50 % was increased by 20 %, while the CLSM made with 100 % increased its density by 32.5 %, tending to increase as the percentage of recycled aggregate in the mix rose according to the total absorption capacity of the CLSM. Dry density and saturated surface dry density were generally in the range of the values found in the bibliography [5] [13] [12]. Moreover, the porosity ranged from 21.37 % to 58.84 %, also tending to increase as the percentage of recycled increase (Table 49).

Although there was a clear tendency in the increase of absorption and porosity, and a decrease of density while the % of recycled aggregate increased. The absorption, porosity and density vary significantly because of the intervention of the air-entraining admixture in the CLSM mixtures.

The compressive strength for all the mixtures was in the appropriate range of CLSM and met all the specific requirements according to ASTM, making an exception with the mixtures made with 100 % of recycled aggregate.

Table 49. Physical properties

Description	Absorption (%)	Porosity (%)	Bulk density (Kg/dm^3)	Satured surface dry density (Kg/dm^3)	Dry density (Kg/dm^3)	Compressive Strength (Mpa) 7 days	Compressive Strength (Mpa) 28 days
MC-2	9.47	21.37	2.26	1.86	1.68	1.16	-
MC-4	9.46	20.27	2.14	1.78	1.61	0.98	1.11
MC-AR-20-1	11.60	27.41	2.36	1.85	1.64	1.08	1.62
MC-AR-20-4	12.08	26.39	2.19	1.73	1.52	0.85	1.08
MC-AR-50-2	16.77	42.76	2.55	1.79	1.49	0.43	0.96
MC-AR-50-3	16.86	40.20	2.38	1.70	1.41	0.49	0.83
MC-AR-50-4	17.34	39.27	2.26	1.63	1.34	0.23	0.56
MC-AR-100-1	24.98	67.33	2.70	1.61	1.21	0.29	0.53
MC-AR-100-2	25.23	58.84	2.33	1.47	1.10	0.18	0.41
MC-AR-100-3	23.87	58.68	2.46	1.55	1.18	0.30	0.53

Wetting and drying

This test method was made in order to determine the CLSM mixture losses produced by repeated wetting and drying processes of hardened specimens. With this test the aim was to determine the resistance of CLSM dosages that were produced.

After all the data were available the changes in the materials were calculated and the results are expressed in a percentage of the original quantity material (Table 50).

Table 50. Percentage of material lost

Description	CLSM mixtures losses (%)
MC-4	6.59
MC-AR-20-4	13.18
MC-AR-50-3	15.45
MC-AR-100-2	34.42

As it can be seen in Figure 83, the percentage of material lost increase proportionally with the amount of recycled aggregate that the mixture has.

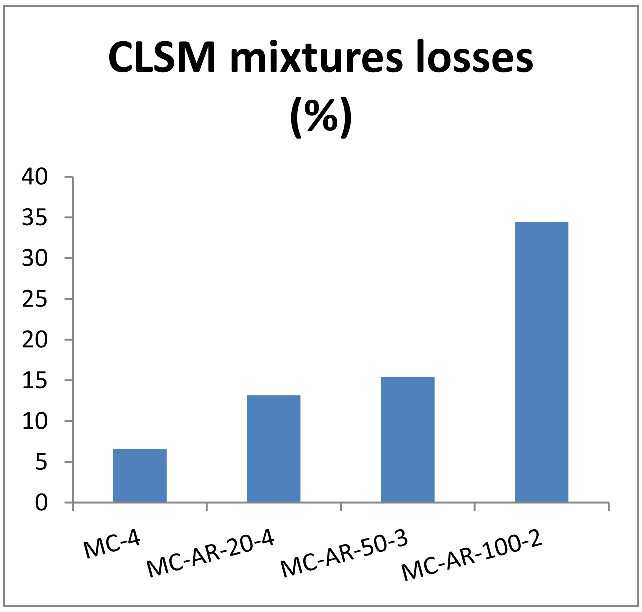

Figure 83. CLSM mixtures losses

The reasons are because the recycled aggregate are not uniform and this is because they depend on their treatment plant, depend on the method used and other factors.

The mixtures made with high percentage of recycled aggregate achieve low compressive strength value and this is connected with the resistance the mixture has when making the brushing operation use in the test method.

Even if the mixture with 100 % of recycled aggregate has more cement quantity, this is not determining when analysing the material losses, because as it have been said previously the mixture made with a substitution percentage more than 50 % the dosages hardly achieved the specific requirements.

A criteria to determine the maximum amount of loss material in CLSM mixtures that may could have, this means the degree of variation, since there is no accepted reference material suitable for determining the bias for the procedure for measuring weight loss, no statement on bias is being made.

5.3.Stage 3: Fly ash and Steel Slag with fly ash

Having done and tested the mixtures with fly ash (MC-FA-mezcla1.2 and MC-FA-mezcla1.3) and the mixtures with fly ash and steel slag (MC-FA-20-AS-2 and MC-FA-50-AS-2) in big volume, it is possible to rule out the mixture MC-FA-mezcla1.2 because of his low compressive strength value.

According to that, the mixtures MC-FA-mezcla1.3, MC-FA-20-AS-2 and MC-FA-50-AS-2 can be compared with the optimum mixture made with 100 % of natural aggregate, in order to analyse if the dosages are adequate.

5.3.1. Fresh state

In this material (CLSM) the most important properties are in fresh state, for this reason this analysis has a transcendental effect on the future possible dosages.

Flow test

Flowability is the property that makes CLSM interesting, because can flow easily without the need of any extra machinery.

Having decided that the mixture MC-4 has suitable flowability it can be consider as a control value to compare the flowability of the mixtures MC-FA-mezcla1.3, MC-FA-20-AS-2 and MC-FA-50-AS-2.

Figure 84 show that the mixtures made with fly ash and fly ash mixed with steel slag achieved suitable flowability, even more than the control dosage MC-4.

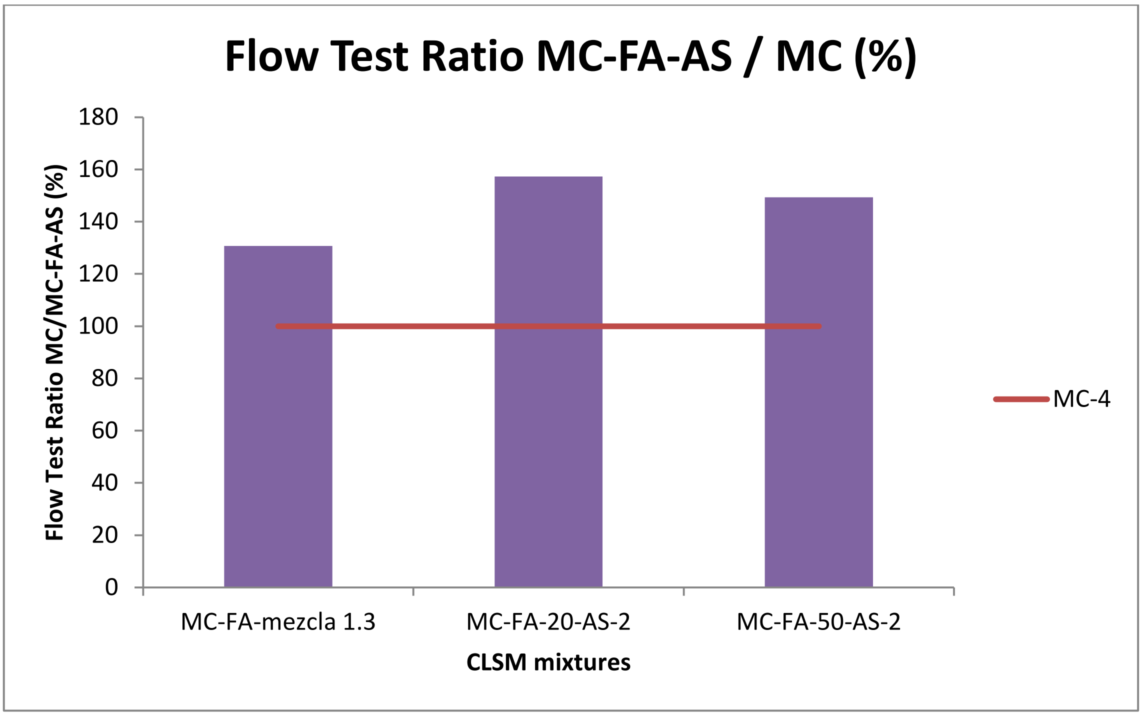

Figure 84. Flow test ratio MC-FA-AS/MC

According with Figure 84 the mixtures MC-FA-mezcla1.3, MC-FA-20-AS-2 and MC-FA-50-AS-2 increase his flowability according to MC-4 in 130, 157 and 149 %, respectively.

Bleeding

In the experimental process with big quantities of each mixture was determined the amount of water that bleeds in fresh state.

Figure 85 and Figure 86 shows that the CLSM produced with fly ash have more bleeding than the mixture made with steel slag and fly ash. As it is well-known with the addition of fly ash bleeding would be decrease.

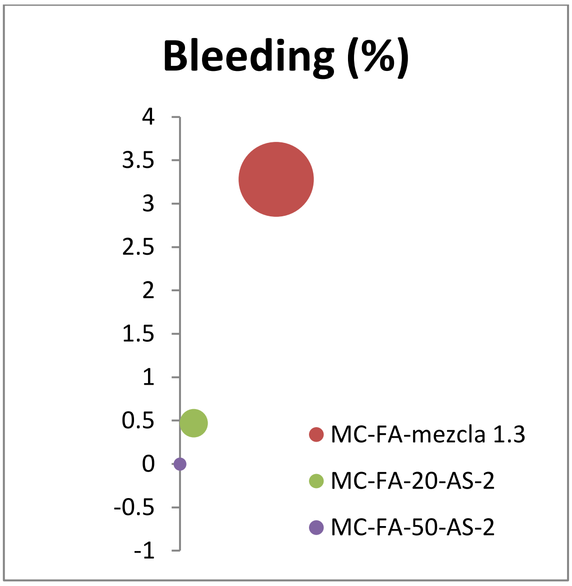

Figure 85. Bleeding of MC-FA and MC-FA-AS

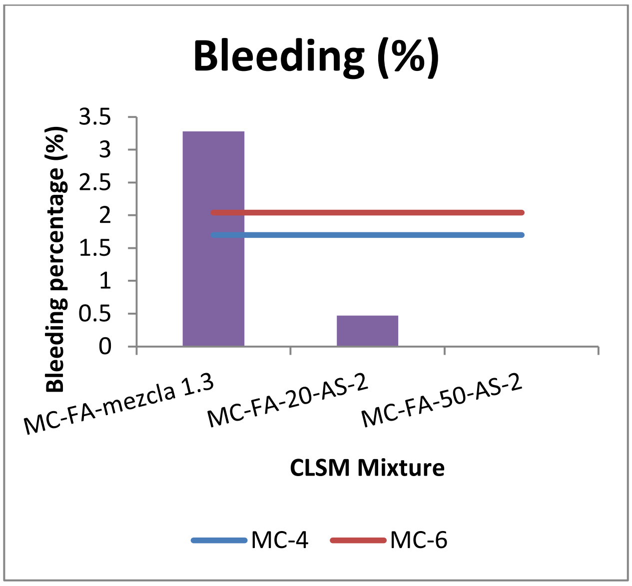

Figure 86. Bleeding of MC-FA and MC-FA-AS

There was no evidence of a tendency to the decanting of heavy aggregates and no segregation was observed in any of CLSM's produced.

Setting time

As we have said in Chapter II, the replacement of part of the conventional Portland cement for steel slag may increase setting time up to 62 %.

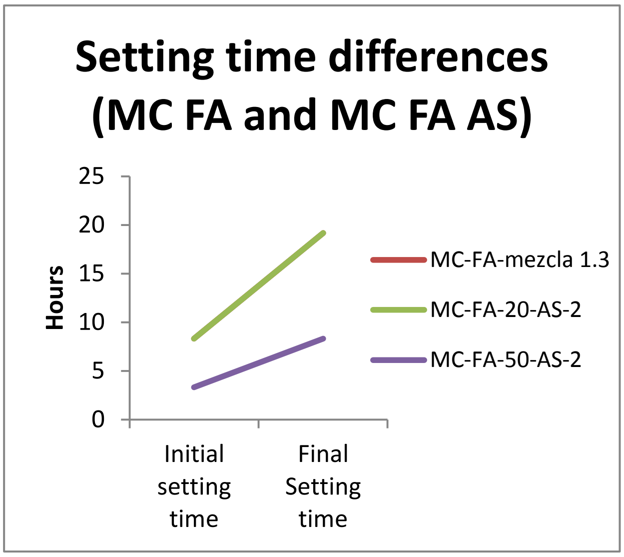

Figure 87. Setting Time difference (MC FA –MC FA AS)

Figure 87 shows the setting time difference between the mixtures that just employ fly ash and the mixture that were made of fly ash and steel slag. The difference is no too relevant because both initial and final setting time in the ranges of regular setting times. Setting time for MC-FA-AS-2 and MC-FA-mezcla1.3 are the same. Some specifications said that the initial setting time need to be produced in the first 3-4 hours and the final setting time are in the next 24-48 hours.

Figure 88 show initial setting times of MC-FA-mezcla1.3, MC-FA-20-AS-2 and MC-FA-50-AS-2 that were 8, 8 and 3 hours respectively. According to the Figure 88 finals setting time values are for MC-FA-mezcla1.3, MC-FA-20-AS-2 and MC-FA-50-AS-2 were 19, 19 and 8 hours respectively. That reveals a final setting time according to the specifications when talking about mixtures MC-FA-mezcla1.3 and MC-FA-20-AS-2, although that is no applicable for the mixture MC-FA-50-AS-2 which take less than one day.

In the case of MC-FA-50-AS-2, which had a short setting time a retardant admixture could be necessary in order to increase setting time.

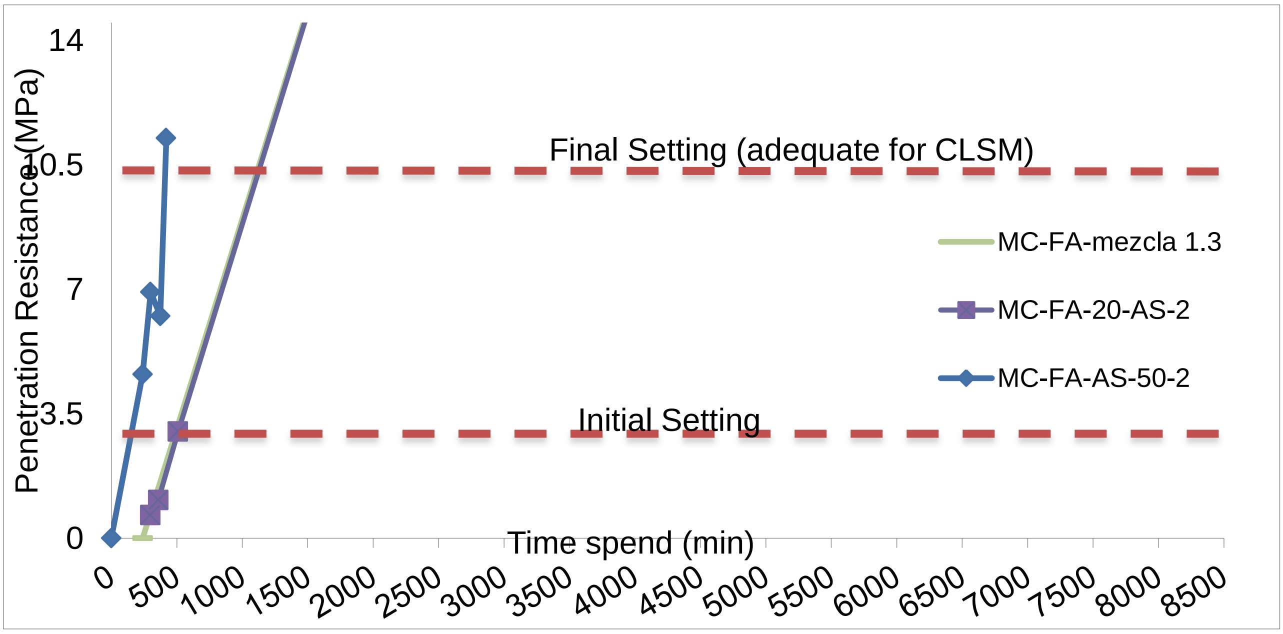

Figure 88. Setting time for MC-FA and MC-FA-AS

5.3.2. Hardened state

Compressive strength

Figure 89 show the relation between the mixtures made with fly ash and steel slag and the mixtures with natural aggregate.

The mixtures MC-4 was chosen as an optimum control dosage to were able to select if one dosage are in the correct range or not.

The compressive strength of CLSM made with natural fine aggregates (MC-4) represented 100 % of the compressive strength ratio, while the MC-FA-mezcla1.3, MC-FA-20-AS-2 and MC-FA-50-AS-2 increased 88, 141 and 139 %, respectively.

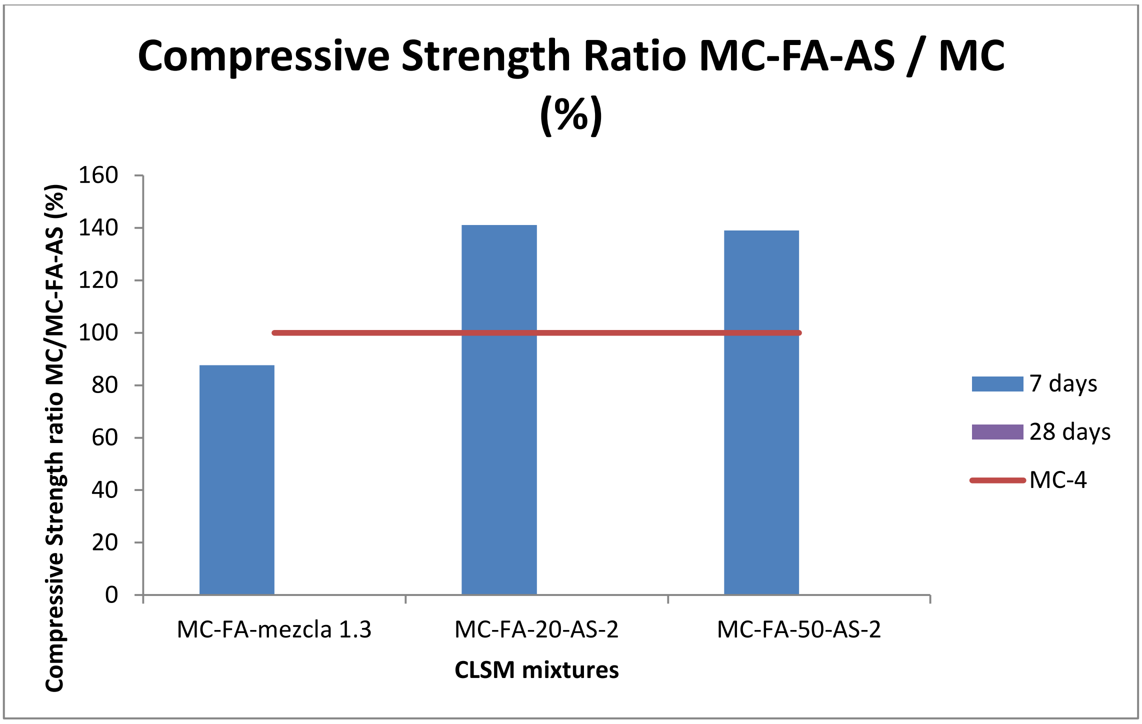

Figure 89. Compressive strength ratio MC-FA-AS/MC

All the dosages analyzed (MC-FA-mezcla1.3, MC-FA-20-AS-2 and MC-FA-50-AS-2) are able to substitute the CLSM made with 100 % of recycled aggregate. Even if MC-FA-mezcla1.3 did not arrived at the 100 %, it has a compressive strength that are in the adequate intervals.

CHAPTER VI. CONCLUSIONS

6.1. Conclusions

In accordance with the experimental phase carried out in this study, there are some conclusions to expose according with each state.

6.1.1. CLSM with recycled aggregates

- CLSM made with recycled aggregate replacing natural aggregate obtains suitable properties in both its fresh and hardened state, being self-compacted and easily to excavate in its hardened state.
- The CLSM produced with recycled aggregates, replacing the natural aggregate up to 50%, obtained the same acceptable properties as the control CLSM when it was produced with 20-25% of air content, 110 kg of cement per cubic meter and w/c ratio of 1.79.
- It was necessary to increase the amount of cement paste and reduce the w/c ratio in the CLSM produced with 50 % or higher percentages of recycled fine aggregates, in order to maintain the same flowability and compressive strength as a CLSM made with natural aggregate.
- The CLSM made with 50 % of recycled fine aggregate, with 24-26 % of air content in fresh state, needed 125 kg of cement (13 % more than conventional CLSM) and w/c ratio of 1.6 to achieve similar properties to those of standard CLSM.
- In CLSM material manufactured with 100 % of recycled aggregate a 135 kg of cement per cubic meter of mix, and w/c ratio of 1.62 was required. However, this was no sufficient to acquire the necessary properties.
- The rise of compressive strength from 7 days to 28 days was higher in CLSM produced with high percentages of recycled aggregates when the recycled aggregates had a high amount of ceramics as their component (pozzolanic effect).
- While more percentage of recycled aggregate the mixture has less bleeding phenomenon occurs, because of the huge absorption capacity and the roughness surface of the recycled aggregates.
- With a high percentage of recycled aggregate it is necessary mixtures that containing accelerators to reduce setting time.
- The splitting tensile strength value decrease when the percentage of recycled aggregate increase. In order to calculate using a value of compressive strength percentage, this decrease if the amount of recycled aggregate increase.
- The modulus of elasticity is similar when comparing conventional mixtures with mixtures made of recycled aggregate if the percentage is until 50 %. If the mixture is made with 100 % of recycled aggregate has a lower modulus elastic value.
- The materials are less resistance diverse types of cycles if the percentage of recycled aggregate is higher.

6.1.2. CLSM with steel slag

- CLSM produced with just steel slag is not possible due to segregation that suffers because of the high density of the steel slag, it would be necessary the use of a cementitious material as could be fly ash.

6.1.3. CLSM with fly ash

- CLSM mixtures made with fly ash in substitution of cement, the quantity of cementitious paste in each m^3 of CLSM need to be 60 kg.
- CLSM dosages need to have a water/cement ratio in the range of 0.8 to comply with the requirements.
- CLSM made with fly ash need a superplasticizer in order to avoid the segregation. This type of admixture can maintain the flowability when reducing the water/cement ratio.
- CLSM mixtures made with fly ash and conventional aggregate, bleeds more water than the mixtures made with 100 % of natural aggregate.

6.1.4. CLSM with fly ash and steel slag

- CLSM mixtures made with fly ash and a substitution of a percentage of natural aggregate for steel slag in magnitude of 20 % until 50 % has suitable properties to still investigating and producing.
- CLSM made with 50 % of steel slag achieved suitable properties, but is necessary to control the manufacturing process in order to avoid the segregation phenomenon, this means the water and the admixtures need to be controlled when adding.
- When making dosage with fly ash and slag if the temperatures at the laboratory are higher than 25 ^oC it is advisable mixtures that contained retarder admixture.
- CLSM mixtures made with fly ash and steel slag achieved suitable flowability, even more than the mixtures made with conventional aggregates.
- Less bleeding occurs, arriving almost until 0 % when making the CLSM dosages with fly ash as part of the cementitious material and steel slag as part of the aggregates.
- The initial and final setting times of the dosages made with fly ash and steel slag comply with the time values required.
- CLSM dosages made with fly ash and steel slag achieves more compressive strength in the first days than the dosages made with natural aggregate.
- CLSM that contains by-products as can be steel slag are beneficial to the environment.

6.2. Futures research lines

- Study of the large scale behavior of CLSM.
    - Influence of the different quantities made with the dosages in the different plastic properties of the mixtures because of the volume manufactured.

- Influence of the colour pigments in the different types of dosages.
    - Possibility of the white cement.

- CLSM and other types of materials using steel slag aggregate and fly ash as cementitious material.

- CLSM produced with more quantities of steel slag as part of the aggregate (more than 50 %) mixed with fly ash as cementitious material.

- Use of the types of admixtures and aggregates such as heavy minerals, avoiding the segregation phenomenon.

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APPENDIX I: TECHNICAL INFORMATION OF AIR-ENTRAINING ADMIXTURE

BASF
The Chemical Company

MasterCell 10

Antes: RHEOCELL ESPUMANTE

Aditivo espumante para hormigón celular.

CAMPO DE APLICACIÓN

MasterCell 10 es un aditivo generador de espuma que se utiliza para la preparación de morteros de bajas densidades ya que actúa ocluyendo una gran cantidad de aire estabilizado. Con MasterCell 10 se consiguen hormigones tan ligeros que pueden flotar por encima del agua.
Ideal para la fabricación de placas o bloques ligeros, recrecidos de cubiertas, etc.

Consultar con el Departamento Técnico cualquier aplicación no prevista con esta relación.

PROPIEDADES

- MasterCell 10 posee un elevado poder aireante que, sin la necesidad de emplear dosis altas, proporciona un elevado efecto espumante.
- Debido a la inclusión de aire en la masa de hormigón, MasterCell 10 mejora la trabajabilidad.

MODO DE UTILIZACIÓN

Para obtener hormigón celular deberán seguirse los siguientes consejos:
Cuando el amasado se efectúa en amasadora, se mezclan previamente cemento, arena y agua. A continuación se añade MasterCell 10 y se mezcla hasta alcanzar la densidad deseada. Mezclas sucesivas deberán realizarse de la misma forma, respetando la intensidad y el tiempo de mezclado.

DOSIFICACIÓN

La dosificación habitual es de 0,5 hasta 3,0 litros por metro cúbico de hormigón, aunque es totalmente variable en función del efecto deseado. Si la mezcla se lleva a cabo en un camión hormigonera, se deberá prever una cantidad de hormigón suficiente (mínimo 3 m^3) para obtener un mezclado suficientemente homogéneo.

En cualquier caso deberán realizarse ensayos previos para ajustar la mezcla ideal y la dosificación de aditivo que permita obtener la densidad deseada con los materiales que se disponga.

LIMPIEZA DE HERRAMIENTAS

La limpieza de herramientas y equipos sucios de MasterCell 10 puede realizarse con agua preferiblemente caliente.

PRESENTACIÓN

MasterCell 10 se suministra en garrafas de 25 Kg.

CONDICIONES DE ALMACENAMIENTO/ TIEMPO DE CONSERVACIÓN

MasterCell 10 se conserva hasta 12 meses en sus envases originales cerrados, protegido de temperaturas extremas.

MANIPULACIÓN Y TRANSPORTE

Irritante. Irrita los ojos y la piel. En caso de contacto con los ojos, lávense inmediatamente con agua y acúdase a un médico. En caso de contacto con la piel, lávese inmediatamente con agua y jabón. Úsense guantes adecuados y protección para los ojos y la cara.

La eliminación del producto y su envase debe realizarse de acuerdo con la legislación vigente y es responsabilidad del poseedor final.

No es un producto de mercancía peligrosa por carretera

MASTER® BUILDERS SOLUTIONS

BASF
The Chemical Company

MasterCell 10

Antes: RHEOCELL ESPUMANTE

Aditivo espumante para hormigón celular.

HAY QUE TENER EN CUENTA

Se recomienda siempre la realización de ensayos previos a la utilización del aditivo.
No emplear dosificaciones superiores ni inferiores a las recomendadas sin previa consulta a nuestro Departamento Técnico.

Propiedades	
Función principal:	Espumante.
Función secundaria:	Plastificante.
Efecto secundario:	Reducción de resistencias por efecto del aire ocluido.
Aspecto físico:	Líquido amarillento.
Densidad (20° C.):	1,030 ± 0,02 gr/cm^3
Valor pH (20° C.):	7 ± 1
Cloruros:	< 0,1%
Viscosidad 20° C Brookfield Sp00/100rpm:	< 30 cps.
Los datos técnicos reflejados son fruto de resultados estadísticos y no representan mínimos garantizados. Si se desean los datos de control, pueden solicitarse las "Especificaciones de Venta" a nuestro Departamento Técnico.	

MASTER® BUILDERS SOLUTIONS

BASF
The Chemical Company

MasterCell 10

Antes: RHEOCELL ESPUMANTE

Aditivo espumante para hormigón celular.

NOTA:
La presente ficha técnica sirve, al igual que todas las demás recomendaciones e información técnica, únicamente para la descripción de las características del producto, forma de empleo y sus aplicaciones. Los datos e informaciones reproducidos, se basan en nuestros conocimientos técnicos obtenidos en la bibliografía, en ensayos de laboratorio y en la práctica.
Los datos sobre consumo y dosificación que figuran en esta ficha técnica, se basan en nuestra propia experiencia, por lo que estos son susceptibles de variaciones debido a las diferentes condiciones de las obras. Los consumos y dosificaciones reales, deberán determinarse en la obra, mediante ensayos previos y son responsabilidad del cliente.
Para un asesoramiento adicional, nuestro Servicio Técnico, está a su disposición.
BASF Construction Chemicals España, S.L. se reserva el derecho de modificar la composición de los productos, siempre y cuando éstos continúen cumpliendo las características descritas en la ficha técnica.
Otras aplicaciones del producto que no se ajusten a las indicadas, no serán de nuestra responsabilidad.
Otorgamos garantía en caso de defectos en la calidad de fabricación de nuestros productos, quedando excluidas las reclamaciones adicionales, siendo de nuestra responsabilidad tan solo la de reingresar el valor de la mercancía suministrada.
Debe tenerse en cuenta las eventuales reservas correspondientes a patentes o derechos de terceros.

Edición: 01/02/2014

La presente ficha técnica pierde su validez con la aparición de una nueva edición

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MASTER® BUILDERS SOLUTIONS

APPENDIX II: TECHNICAL INFORMATION OF SUPERPLASTICIZER ADMIXTURE

Instrucción de Uso
25 de Septiembre de 2003
Sika Viscocrete 20 HE

Construction

Sika Viscocrete 20 HE

Superplastificante de alto rendimiento para hormigones

Descripción

El SIKA VISCOCRETE 20 HE es un superplastificante de altas prestaciones para hormigones.

Ventajas

El SIKA VISCOCRETE 20 HE combina diferentes mecanismos de acción. La adsorción en la superficie de los finos así como su mejor dispersión durante el proceso de hidratación producen los siguientes efectos:

- Pronunciada aptitud de autocompactación. Se utiliza en hormigones autocompactables.
- Reducción muy importante de agua de amasado dando hormigones de altas resistencias y gran impermeabilidad.
- Altas resistencias iniciales.
- Disminución de la fluencia y retracción.
- Retarda los efectos de carbonatación del hormigón.

El SIKA VISCOCRETE 20 HE no contiene cloruros ni sustancias que puedan provocar o favorecer la corrosión del acero y por lo tanto puede utilizarse sin restricciones en hormigones armados o pretensados.

Datos Técnicos

Tipo:	Policarboxilato modificado en base acuosa.
Aspecto:	Líquido poco viscoso color miel.
Densidad:	Aprox. 1,085 gr/ cm3
Contenido en sólidos:	Aprox. 40 %
pH:	Aprox. 4,5

Usos

El SIKA VISCOCRETE 20 HE se utiliza en la confección de hormigones de altas prestaciones en prefabricación, obras y en centrales de hormigón elaborado.
Los hormigones tratados con SIKA VISCOCRETE 20 HE se caracterizan por su baja relación a/c, una fluidez elevada, así como una cohesión óptima y una gran facilidad de autocompactación.
La importante reducción de agua unida a la elevada fluidez dan lugar a hormigones de muy alta calidad.
El SIKA VISCOCRETE 20 HE se utiliza en:

- Prefabricación.
- Pavimentos fast- track.
- Muros con encofrados deslizantes.
- Hormigones con una gran reducción de agua.
- Hormigones de altas prestaciones.
- Hormigones de altas resistencias iniciales

Aplicación y Consumo

Modo de empleo
El SIKA VISCOCRETE 20 HE se añade en el agua de amasado o en la mezcladora al mismo tiempo que el agua. Para aprovechar de manera óptima la gran capacidad de reducción de agua recomendamos un preamasado cuidadoso durante 60 segundos como mínimo.
Dosificación
Entre 0,5 y el 1,5% del peso de conglomerante , dependiendo de que se emplee como superplastificante o gran reductor de agua. En caso necesario puede aumentarse dicha dosificación.

Forma de Entrega	Tambores de 230 Kg.
Almacenaje	Al resguardo de las heladas, entre +5 °C y + 30 °C. Conservación: 12 meses, desde su fecha de fabricación, en sus envases de origen bien cerrados y no deteriorados.
Indicaciones Importantes	Las normas y reglas de orden general para la preparación de un hormigón de calidad deben seguirse cuando se usa SIKA VISCOCRETE 20- HE. El hormigón realizado con SIKA VISCOCRETE 20 -HE debe ser curado convenientemente. Si el SIKA VISCOCRETE 20- HE se helase, puede utilizarse sin que se vea disminuida ninguna de sus cualidades después de deshelarse lentamente y agitarlo cuidadosamente. Ante cualquier duda consulte con nuestro Departamento Técnico. NOTA: Si bien la mayoría de los aditivos de SIKA ARGENTINA S.A.I.C. son compatibles entre sí, siempre deberán realizarse ensayos previos con los materiales y las mismas condiciones de la obra.
Indicaciones de Protección Personal y del Medio Ambiente	El SIKA VISCOCRETE 20 HE no es tóxico ni inflamable; en caso de contacto con la piel lavar con agua y jabón. Si el SIKA VISCOCRETE-20 HE entrara en contacto con los ojos o con mucosas, enjuague inmediatamente. No arrojar el producto a la tierra o a cursos de agua o desagües. Una vez endurecido el hormigón que contiene SIKA VISCOCRETE 20 HE no es contaminante del medio ambiente.
Advertencias al Comprador	Las indicaciones de esta Instrucción de Uso, basadas en pruebas que consideramos seguras, son correctas de acuerdo con nuestra experiencia. No pudiendo controlar las condiciones de aplicación, no nos responsabilizamos por ningún daño, perjuicio o pérdidas ocasionadas por el uso inadecuado del producto. Aconsejamos al usuario que previamente determine si el mismo es apropiado para el uso particular propuesto.

Construction

Empresa adherida al "Programa Cuidado Responsable del Medio Ambiente"

SIKA ARGENTINA S.A.I.C.
Certificado de "Sistema de Aseguramiento de la Calidad" ISO 9001.

Certificado de "Sistema de Gestión Ambiental" ISO 14001.

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