



People's Democratic Republic of Algeria
Ministry of Higher Education And Scientific Research
Amar Thelidji University-Laghouat



FACULTY: Civil Engineering and Architecture

DEPARTMENT: Civil Engineering

MASTER MEMORY

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FIELD: SCIENCE AND TECHNOLOGY

SECTOR: Civil Engineering.

OPTION: Materials of Civil Engineering

Title

Contribution to the study of the compatibility of self-compacting repair mortar based on local materials reinforced with sisal fibers

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Acknowledgements

In the Name of Allah, the Most Merciful, the Most Compassionate all praise be to Allah, the Lord of the worlds; and prayers and peace be upon Mohamed His servant and messenger.

First and foremost, I must acknowledge my limitless thanks to Allah, the Ever-Magnificent; the Ever-Thankful, for His help and bless.

I express my gratitude to my supervisor **Dr. Krobba Benharzallah** for his mentoring and supervision throughout the project, for the detailed reviews and constructive comments on the manuscript. I am fortunate to work under his supervision **Dr.kouidri Zohra** for her suggestions, and being part of my committee.I would like to thank them for the trust and sympathy they testified to me during these six months.

I also thank the committee members **Dr. Djoudi Amina** and **Dr. Lakhdari Mohamed Fatah** for the consideration given to the work submitted and for having agreed to examine me today, wishing to benefit from their experience through their remarks.

I wish to express my sincere thanks to all the teachers of the Faculty of Civil Engineering, and the laboratory technicians.

In special I would like to thank my parents and my family for their love and encouragement. Without them I would have never become the person I am today. There is no suitable word that can fully describe their everlasting love for me.

Finally, It is my proud privilege to release the feelings of my gratitude to several persons who helped me directly or indirectly to conduct this research project work.

Dedications

I dedicate this work to:

*My dearest **mother**, the symbol of love and giving, who leads me through the valley of darkness with light of hope and support,*

*My great **father**, who stands by me when things look bleak,*

*To my **aunt** and my **uncle Salah** for been always there when I need,*

*My beloved brothers and sisters: **Imed, Rania, Maroua, Abdou**, whom I can't force myself to stop loving,*

*My special friend **Fatima Zohra**, who has never left my side,*

To all my family, My friends, all the promotion 2019 - 2020 who encourage and support me near or far this work,

To all the people in my life who touch my heart.

ملخص

الخرسانة المسلحة هي المادة الأكثر استخدامًا في العالم، ولكنها مصممة مع مراعاة عمر خدمة محدد وتتدهور بمرور الوقت بسبب تعرضها للظروف البيئية. من أجل زيادة العمر الافتراضي للهياكل الخرسانية، يمكن أحيانًا إعادة تأهيلها وإصلاحها باستخدام مواد الإصلاح. ومع ذلك، قد تحدث مشاكل بين مادة الإصلاح والخرسانة القديمة بسبب التشوه التفاضلي بينهما. نظرًا لتوفر مجموعة واسعة من مواد الإصلاح في ميدان البناء ذات خصائص فيزيائية وميكانيكية متنوعة، فمن المهم تحديد توافق مادة الإصلاح مع الخرسانة القديمة. تعتبر قوة الترابط الجيدة بين المونة والركيزة عاملاً رئيسيًا في أداء إصلاح الخرسانة. الهدف من هذا العمل هو دراسة مدى توافق ملاط الإصلاح ذاتي القولية على أساس رمل الكثبان ورمل الحجر الجيري وألياف السيزال. تم قياس قوة الانضغاط وقوة الانحناء والانكماش ومعامل المرونة والمسامية وامتصاص الماء الشعري لمواد الإصلاح بشكل فردي في المرحلة الأولى. في المرحلة الثانية، تم التحقق من التوافق باستخدام اختبارات السحب، القص المائل، واختبار الشد. تشير النتائج إلى أن مونة الإصلاح المنتجة تتميز بالالتصاق ممتاز بالركيزة مقارنةً بملاط الإصلاح الجاهز للإستخدام.

الكلمات المفتاحية: إصلاح الخرسانة، التوافق، قوة الالتصاق، السحب، القص المائل، الشد.

Abstract

Reinforced concrete is the most widely used material in the world, but is designed with a specific service life and deteriorate over time due to their exposure to environmental conditions. In order to increase the service life of concrete structures, they can sometimes be rehabilitated and repaired using repair materials. However, problems may develop between the repair material and old concrete due to differential deformation between them. Due to the availability of a wide variety of repair materials in the construction field with a wide range of physical and mechanical properties, it is important to determine the compatibility of a repair material with the old concrete. Good bond strength between overlay and substrate is a key factor in performance of concrete repair. The aim of this work is to study the compatibility of self-compacting repair mortars based on dune sand, limestone sand and sisal fibers. Compressive strength, flexural strength, shrinkage, elastic modulus, porosity and capillary water absorption of the repair materials were individually measured in the first part. In the second part, the compatibility was investigated using a pull-off, slant shear, and splitting tensile tests. Results indicate that elaborated repair mortars present excellent adhesion to the substrate compared to the Ready-Mixed Mortar (RMM).

Key words: Concrete repair, Compatibility, Bond strength, Pull-off, Slant shear, splitting tensile.

Résumé

Le béton armé est le matériau le plus utilisé dans le monde, mais il est conçu pour une durée de vie spécifique et se détériore avec le temps à cause de son exposition aux conditions environnementales. Afin d'augmenter la durée de vie des structures en béton, il est parfois possible de les réhabiliter et de les réparer à l'aide des matériaux de réparation. Cependant, des problèmes peuvent se développer entre le matériau de réparation et le vieux béton à cause de la déformation différentielle entre eux. Vu la disponibilité d'une grande variété de matériaux de réparation dans le domaine de la construction avec une large gamme de propriétés physiques et mécaniques, il est important de déterminer la compatibilité d'un matériau de réparation avec le vieux béton. Une bonne force d'adhérence entre le revêtement et le substrat est un facteur clé dans la performance de la réparation du béton. L'objectif de ce travail est l'étude de la compatibilité des mortiers de réparation auto-plaçant à base de sable de dunes, de sable calcaire et de fibres de sisal. La résistance à la compression, la résistance à la flexion, le retrait, le module d'élasticité, la porosité et l'absorption d'eau capillaire des matériaux de réparation ont été mesurés individuellement dans la première étape. Dans la deuxième étape, la compatibilité a été étudiée à l'aide des essais d'arrachement, de cisaillement oblique et de traction par fendage. Les résultats indiquent que les mortiers de réparation élaborés présentent une excellente adhérence au substrat par rapport au mortier prêt à l'emploi (RMM).

Mots clés : Réparation du béton, Compatibilité, Force d'adhérence, Arrachement, Cisaillement oblique, Traction par fendage.

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List of Abbreviations	
ACI	American Concrete Institute.
ASTM.	American Society for Testing and Materials.
W/B	Water to binder ratio
MP	Marble powder
C_c	Capillary absorption coefficient ($g.cm^{-2}.min^{-1/2}$).
Ab	Absorption coefficient (%).
E_d	Dynamic modulus of elasticity (GPa)
ρ_s	Specific gravity (kg/m^3).
C_p	Compactness (%).
RH	Relative humidity (%)
σ_l	The slant shear bond strength (MPa)
ρ	Bulk density (kg/m^3).
FM	Fineness modulus.
σ_f	Flexural strength (MPa).
σ_c	Compressive strength (MPa).
σ_p	The pull-off bond strength (MPa).
σ_T	Splitting tensile strength (MPa).
Vs	Volume of sand .
Vm	Volume of mortar.
P	Total porosity (%).
Sp	Superplasticizer .
SCM	Self-compacting mortar.

General introduction

All reinforced concrete structures have a limited service life; many of them require maintenance, repair interventions or rehabilitation. In recent years, great interest has been oriented towards the use of local materials in the building and public works. This is to satisfy the enormous need for these materials and to contribute to sustainable development. So, the idea was born to formulate repair mortars based on local materials (dune sand, crushing limestone sand and natural fibers), which are available in very large quantities, especially in the south of Algeria.

Repair systems are usually divided according to three different material phases: the repaired substrate, the repair material and the interface phase between the concrete substrate and repair material. Each phase plays a role in the durable repair of a system. The suitability of a material for repair relies upon several factors: foremost, bond strength and compatibility[1].

The association of a repair mortar with substrate concrete produces a composite with two materials having different properties. In addition, the dimensional changes cause internal stresses within the repair material and inside the substrate. Consequently, there is a problem of compatibility that is never completely guaranteed. Then, the question asked is about the durability of the repair system.

Compatibility is defined as an association between the properties of the two materials in contact. It is required to make a suitable choice of the repair material in order to have a durable repair. Currently, a great deal of research is devoted to the production of good quality repair materials [2]. High adhesion causes higher tolerance on the non-compatibility of properties of both materials [3]. Increasing the efficiency of the interfacial transition zone between the repair mortar and substrate concrete in terms of bond strength and durability remains a challenge in concrete repair technology and is thus given considerable attention by researchers[4].

The use of vegetable fibers as reinforcement of cement-based composite materials is an ancient practice that has seen its interest renewed worldwide. In addition, the energy and cost for production of these fibers are low when compared to those of glass and polymer fibers. This type of composite is particularly interesting for countries where a great availability of vegetable fibers exists. These composites have considerable advantages in the building and civil engineering field where they are used to protect, repair or strengthen

General introduction

structures. The literature review concluded that, in general, the incorporation of cellulose fibers significantly improves the material characteristics (ductility, mechanical strength), and can control the drying shrinkage cracks and plastic shrinkage[5].

In this experimental work, we use local aggregates for preparing repair mortar using two types of sand (dune sand and limestone sand) and vegetable fiber. The dune sand used is coming from the northern region of Laghouat city (Oasis Nord). Limestone sand is obtained from the Ouezzane station situated in the north of Laghouat city (near of the Oued M'zi Bridge). The vegetable fibers used as reinforcement of repair mortar are sisal fibers with different length (5, 10, 20) mm, obtained from the market. Limestone coarse aggregates (3/8mm) and river sand (0/5mm) are used for preparing substrate concrete. The approach of using local materials (dune and limestone sand) and the vegetable sisal fiber for the elaboration of a repair mortar could be a solution for environmental, economic and technical problems of concrete constructions.

The main objective of this work is to study the dimensional compatibility of the different elaborated repair mortars, as well as the ready-mixed repair mortar with the concrete substrate. This work is a continuation of a previous work carried out as part of a master study project under the supervision of Mr. KROBBA during the 2018-2019 academic year.

As a first part, the main objective is to study the physical-mechanical properties of the different elaborated repair mortars, as well as the ready-mixed repair mortar such as the mechanical strengths, the modulus of elasticity, the total , the autogenous and the drying shrinkage.

The second work part is focused on evaluation of the bond strength between the different repair mortars and substrate concrete. In order to determine its bond strength and the type of failure that may occur after loading, an investigation is carried through the slant shear test, the splitting tensile test, and the direct tension pull off test.

The third part is focus on the study of the durability indicators of the different repair mortars such as water absorption by capillarity and porosity.

The work in this dissertation is divided into three chapters. General introduction provides background information on the research objectives and scope of this work. Chapter

General introduction

one covers topics in which significant work has already been done, and for which findings are already available in the literature. The first section of this chapter outlines the compatibility between the repair mortar and concrete. The second section discusses the bond strength. The third section outlines the constituents (sands, fibers) of repair mortars. Chapter two provides the materials used in this research and the experimental methods. Chapter three discusses the results obtained from the experimental programs.

Finally, the memory closes with the conclusions and recommendations for the further research.

Chapter I

Literature review

I.1 Introduction

Repairing concrete structures is quite common and usual in many countries. Concrete remains a high-performance and durable material, but the explosion in the use of concrete for construction works and buildings after the Second World War has led to an increase in the number of maintenance and repair operations on such structures[3]. Concrete repair is generally an action taken to reinstate, to an acceptable level, the necessary function and performance of a structure or its components that have been damaged in some way[6].

This chapter contains a literature review that provides a concise summary of the existing state of knowledge on the bond strength and compatibility between repair and substrate concrete.

I.2 Compatibility

Compatibility in repair systems was defined as the balance of physical, chemical, and electrochemical properties and deformations between the repair and the existing substrate that ensures that the composite repair system withstands all stresses induced by all loads, chemical and electrochemical effects, and restrained volume changes without distress and deterioration over a designed period of time. The compatibility is defined by the ability of the material to maintain a given strain and, hence, carry the correct stress. In protective repairs, the definition concentrates on what happens at the interface, and compatibility becomes maintaining the geometry of the interface. Compatibility for a structural repair may be defined as that combination of properties and dimensions that ensures that the repair carries its design load, allowing for any changes that may take place with time and the environment. Compatibility for a protective repair may be defined as that arrangement of dimensions and properties of the materials that ensures that interface bond strength is not exceeded[6].

Clearly, these definitions involve knowledge of the repair dimensions, in conjunction with a variety of material properties of both the repair and the substrate. The substrate properties include failure stress and failure strain, and the repair properties are principally elastic modulus and creep[6].

I.3 Compatibility between repair material and substrate concrete

Most of the failure in repairs is due to incompatibility between the new and old concretes or high shrinkage levels that lead debonding and cracking. The composite system has to bear up the different stresses caused by variations in the overlay material volume and chemical and electrochemical effects without delamination or cracking over the specific service life of the rehabilitation[7].

The compatibility of materials and sections is a complex subject with many different facets. The factors by which the repair materials should be selected are shown in the Figure.I.1.

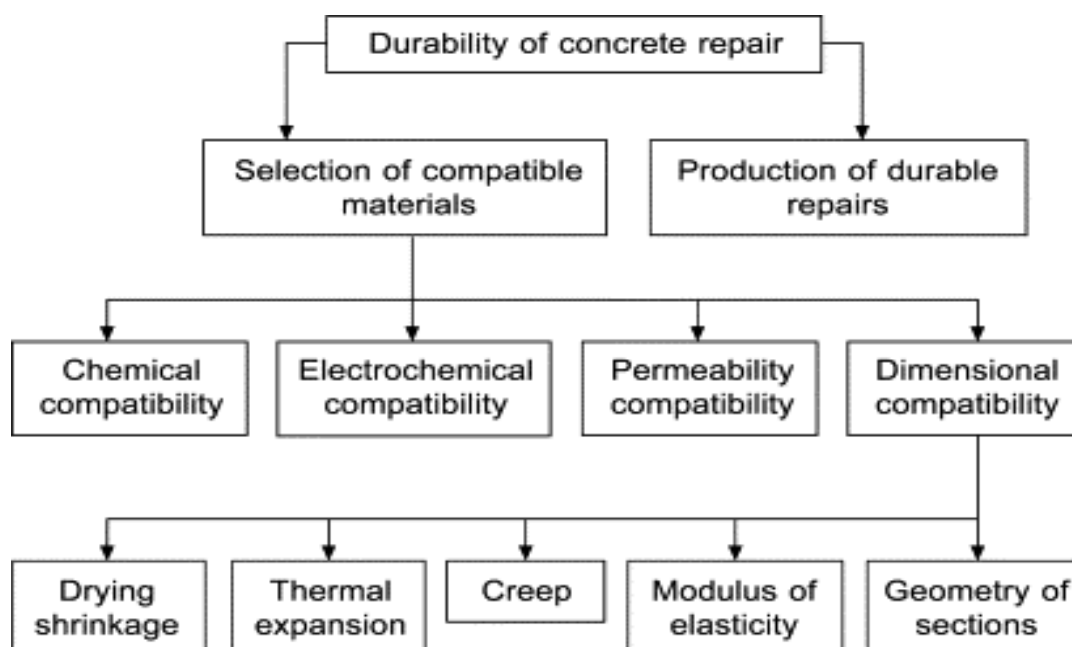


Figure I.1. Factors affecting durability of concrete repair [8].

Good compatibility between the repair material and the substrate ensures a repair with a limited and predictable degree of change over time, where the repair material can withstand stresses resulting from volume changes and load for a specified environment over a designated period of time without experiencing distress and deterioration throughout its intended life and purpose .However, since it is unlikely that a repair material will be found that behaves in exactly the same fashion as the substrate when subjected to loads, temperature and moisture changes, choosing an optimum repair material is a job of compromise[8].

The main parameters of the repair material to take into consideration to decide which one to use for the rehabilitation of a concrete structure are discussed in the following points:

- **Bond strength at interface.** The bond strength between the new and old materials is crucial for the success of the repair.
- **Curing requirement.** It is desirable that the repair material harden as soon as possible in order to reduce the down time of the structure. In today's economic climate, rapid setting materials are highly advantageous for accelerated construction and repair scenarios.
- **Dimensional stability.** Significant variations in the overlay material volume might cause cracking in the new material and increase of shear stresses in the interface, increasing the risk of delamination and cracking.
- **Mechanical properties.** The repair material has to exhibit adequate mechanical properties to bear and transfer the loads.
- **Durability properties.** The overlay materials have to offer protection against all the different process that can deteriorate the structure such as chemical or water penetration, abrasion and freeze-thaw deterioration. The success of the repair and its final service life depends largely on the performance of the repair material as a barrier
- **Constructability.** It is recommendable to use repair materials with similar construction methods to that of normal concrete in order to reduce the potential failures due to mistakes in the phase of construction. Properties such as self-consolidating behavior allow material to be placed without the need for vibration and often have good adhesion to the substrate without using any bonding agents have proven advantageous.
- **Cost.** The cost of the repair material has a significant impact on the final choice of the material used for the rehabilitation, but it should not be put before the performance characteristics. A poor choice of repair material would cause the earlier failure of the rehabilitation[7].

I.4 Dimensional compatibility (Dimensional stability)

One of the most important compatibility requirements is dimensional (deformational) compatibility of repair materials with the existing substrate. According to Morgan, the dimensional compatibility is the capacity of the rehabilitated region to withstand volume

variations without loss of bond and delimitation and to transfer the applied loads without distress[7]. The essence of dimensional compatibility can be stated as follows:

- Shrinkage of the repair material relative to the substrate;
- Differences in the rate of thermal expansion or contraction of the repair and substrate materials;
- Differences in modulus of elasticity, which may cause unequal load distribution and strains, resulting in interface stresses;
- Differences in creep;
- Relative fatigue performance of the phases in the composite system.

The listed differences may result in initial tensile stresses that either crack the repair material or cause debonding at the repair substrate interface (the transition zone). Both of these will negatively affect durability and load carrying capacity of the repaired structure. Hewlett defined the phenomenon of dimensional compatibility as “stable interfacial coexistence[6]”.

I.5 Factors influencing the dimensional compatibility

To achieve durable repairs, it is necessary to consider the factors affecting the design and selection of repair systems as parts of a composite system. The factors influencing the dimensional compatibility include shrinkage, thermal expansion, modulus of elasticity, and creep. Many materials change volume with moisture and temperature changes. Tensile stresses are induced in one material, compressive stresses are induced in the other; as a result, shear will occur at the interface. Similar stresses will result from the differential thermal movement and moduli of elasticity figure I.2.

I.5.1 Modulus of elasticity

The modulus of elasticity is a measure of the stiffness of a material. It is the ratio of stress to strain for tension or compression below the elastic limit of the material. Elastic refers to the reversible character of the dimensional change. A material with a higher modulus of elasticity is more rigid than a lower modulus material, which is more flexible. One way of visualizing this is to determine the slope of the straight line portion of a graph of stress (force

per unit area, MPa) versus strain (deformation per unit length; that is, inch per inch, mm/m)[6].


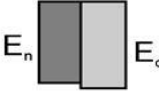
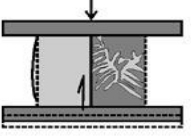

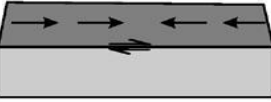
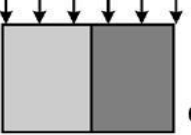
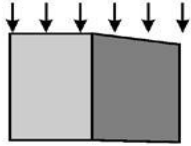
<table border="1" style="margin-bottom: 5px;"> <tr><td style="background-color: #cccccc;">New (n)</td><td>α_n</td></tr> <tr><td style="background-color: #cccccc;">Old (o)</td><td>α_o</td></tr> </table> <p>Thermal Coefficient of Expansion (α)</p> <p>Given a temperature change evenly distributed through the materials the following stresses will occur according to the relationship of the Thermal Coefficients of the new and old materials.</p>	New (n)	α_n	Old (o)	α_o	<p>$\alpha_n = \alpha_o$</p> <p>If $\alpha_n > \alpha_o$ or $\alpha_n < \alpha_o$</p>  <p>Shear Bond Is Stressed</p>
New (n)	α_n				
Old (o)	α_o				
 <p>Modulus of Elasticity (E)</p> <p>Given an evenly distributed load, the following stresses will occur according to the relationship of the Modulus of Elasticity of the new and old materials.</p>	<p>If $E_n = E_o$ No Stress Occurs</p> <p>If $E_n > E_o$ or $E_n < E_o$</p>  <p>Shear Bond Is Stressed</p>				
 <p>Drying Shrinkage (S_n)</p> <p>Assuming the old material has already developed a stable drying shrinkage volume, then the following stresses will occur according to the amount of drying shrinkage of the new material.</p>	<p>If $S_n = 0$ No Stress Occurs</p> <p>If $S_n > 0$</p>  <p>Shear Bond Is Stressed, Loads carried by repair are reduced, tension in repair material.</p>				
 <p>Creep (C_n)</p> <p>Assuming the old material has already developed a stable creep volume, then the following stresses will occur according to the amount of creep occurring in the new material.</p>	<p>If $C_n = 0$ No Stress Occurs</p> <p>If $C_n > 0$</p>  <p>Shear Bond Is Stressed, Loads carried by repair are reduced.</p>				

Figure I.2. Volume change effects on repair[6].

Low modulus materials deform more than those of high modulus under a given load. When the external load (compressive or tensile) is applied parallel to the bond line (see Fig I.3.a), materials with different elastic moduli will transfer stresses from the low modulus material to the high modulus material, leading to stress concentration and failure of the high modulus material. When the external load is applied perpendicular the bond line (see Fig I.3.b), the difference in stiffness between both materials is less problematic if the external load is compressive[8]. A repair material with higher modulus of elasticity than that of the substrate attracts more loads causing an irregular stress distribution. For this reason, many researchers, such as Rangaraju and Morgan, usually recommend that the new material has a similar modulus of elasticity to that of the concrete substrate to ensure a uniform distribution of stress and minimize the potential failure of the new material[8].

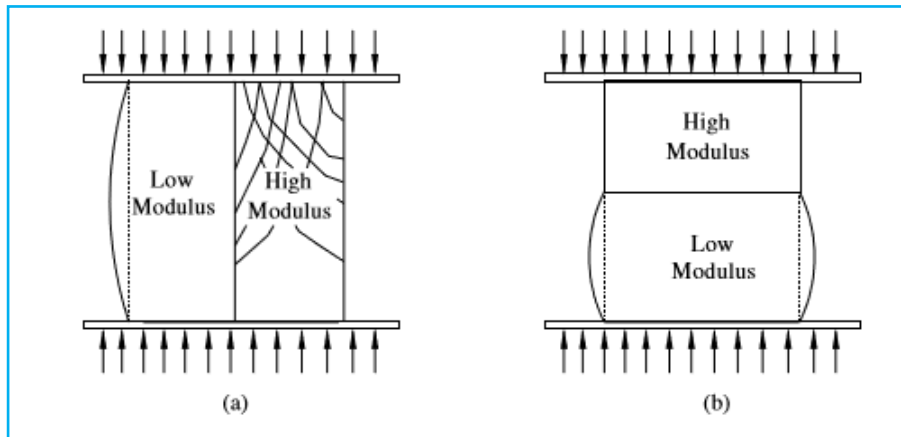


Figure I.3. Effects of Mismatching Elastic Moduli (a) Load parallel to interface (b) Load perpendicular to interface[8].

I.5.2 Shrinkage

Shrinkage is the volumetric changes of concrete structures due to the loss of moisture by evaporation[9]. In repairs, differential volume changes occur, with the largest shrinkage found at and near the surface. Figure I.4 shows the stress distribution around a new repair material that does not carry its part of the load [6].

Since most repair materials are applied to an older substrate concrete that has negligible shrinkage, repair materials with very low shrinkage potential should be chosen to minimize the compatibility problems between repair material and substrate concrete[8].

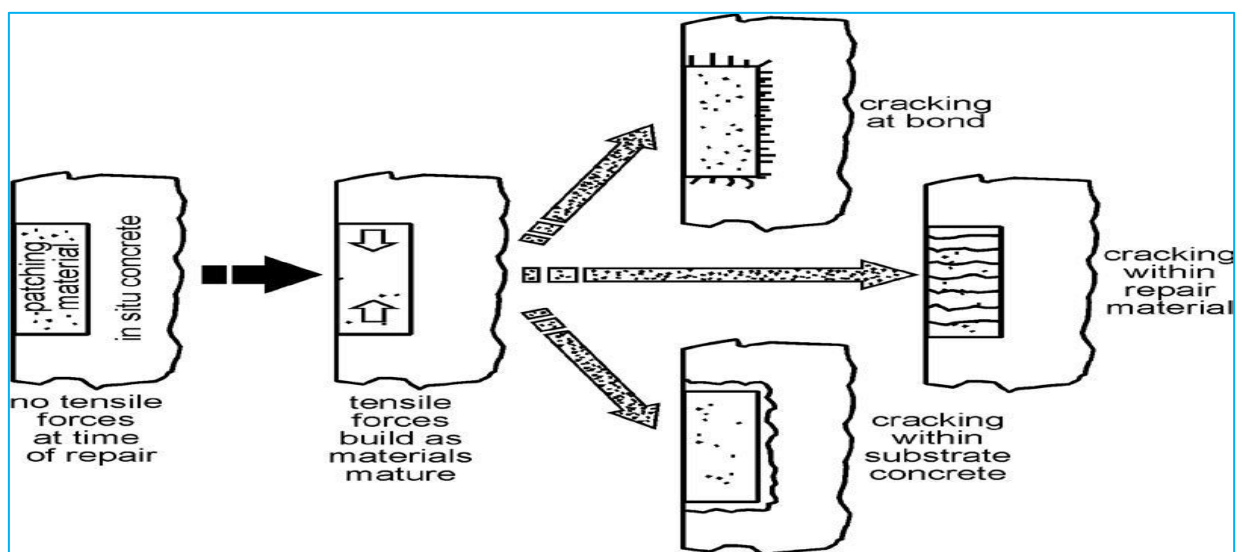


Figure I.4. The effects of shrinkage[6].

I.5.2.1 Types of shrinkage

Shrinkage of concrete can occur in two different stages: early and later ages. The first stage (within the first 24 h) is defined as a duration in which concrete is setting and starting to harden. Second stage, on the other hand, refers to the age beyond 24 h. Shrinkage at both stages mainly include autogenous shrinkage, drying shrinkage and thermal shrinkage which have overlapping results but with different mechanisms. In long term, the carbonation shrinkage is also added which has an accumulated effect[10].

I.5.2.1.a Plastic shrinkage

The first form of shrinkage a concrete mixture can experience is plastic shrinkage. Plastic shrinkage occurs while the concrete is still in a plastic state, and water evaporates from the surface faster than it is replaced by bleed water. The overall loss of moisture at the surface causes shrinkage and can lead to cracking[11].

I.5.2.1.b Drying shrinkage

The drying shrinkage of cementitious material is caused principally by the contraction of the calcium silicate hydrate (C-S-H) gel in the hardened cement water paste, when the moisture of the gel is decreased[11]. Drying shrinkage is best known because of its negative effects on durability as a result of the numerous cracks it can produce. Commonly, water is lost by evaporation to the atmosphere, but the loss can also occur by suction of underlying dry concrete or soil. For many concrete mixtures, and typically for those with a w/c over 0.42, it is the largest source of shrinkage[6].

I.5.2.1.c Autogenous shrinkage

Autogenous shrinkage is defined as a concrete volume change occurring without moisture transfer to the environment. It is merely a result of the internal chemical and structural reactions of the concrete components. The contribution of autogenous shrinkage has previously been viewed as “insignificant” in typical concrete mixtures due to the dominant role of drying shrinkage[10]. Autogenous shrinkage, which occurs when a concrete can self-desiccate during hydration, and which becomes more significant as the strength of concrete is increased, is analogous to drying shrinkage[12].

I.5.2.1.d Chemical shrinkage

Chemical shrinkage refers to the volume change during the early ages of hydration resulted by formation of hydration products with lower volume in comparison with the volume of the initial reactants (water and cement) during the hardening process. Chemical shrinkage, as a measurement of the absolute internal volume reduction, is considered as the driving force of autogenous shrinkage which represents the external, bulk volume change of concrete.

Figure I.5 depicts a general relationship between the definition of chemical and autogenous shrinkage in concrete. After the formation of initial structure of slurry (roughly referred to as the early coagulation), further hydration causes voids within the matrix. At this stage, the autogenous shrinkage value is less than the chemical shrinkage as the former measures the apparent volume of reduction; the accumulated volume of voids is considered in measurement of chemical shrinkage value[10]

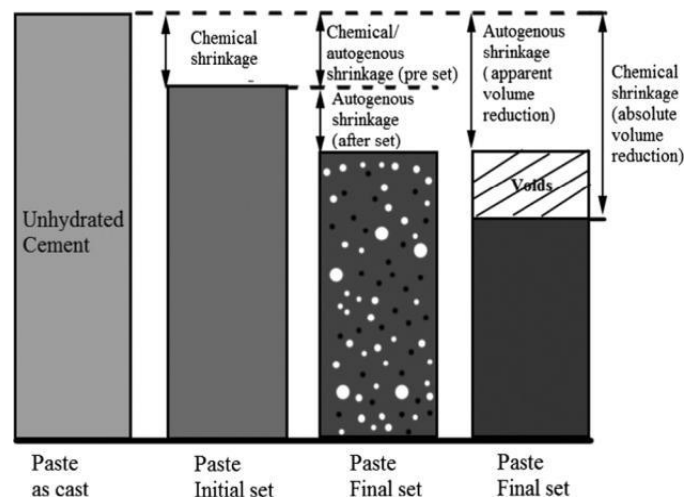


Figure I.5. The relationship between chemical shrinkage and autogenous shrinkage[10].

I.5.2.1.e Thermal shrinkage

Thermal shrinkage indicates reduction of volume triggered by excessive temperature gradient between the inner and outer layers or temperature descending in the early stage of concrete hardening.

I.5.2.1.f Total shrinkage

When all or some of these types of shrinkage occur, their sum is referred to as “**total shrinkage**”. From a practical standpoint, it is not the presence of shrinkage that matters; it is

the occurrence of cracking caused by shrinkage. It is possible for all forms of shrinkage to induce cracking[6].

I.5.3 Creep

Creep is defined as the deformation over time caused by a sustained load. Rangaraju stated that the repair material must usually exhibit low creep except if the material is going to be loaded in tension, since in that situation, creep can compensate the negative effect of shrinkage[7].

I.5.4 Coefficient of thermal expansion

If thermal expansion coefficient of the repair material differs significantly from that of the substrate, it might result in the failure of the rehabilitation due to stresses transferred to the bond interface in areas exposed to significant temperature variations. ACI 546R-04 stated that this factor is most important in those repairs which are going to be frequently subject to large temperature changes[7].

I.6 Bond in concrete

I.6.1 Definition of the bond strength

One of the most important parameters ensuring the durability of concrete repair is the bond between the substrate and the repair mortar[13]. Good bond strength is a key factor to have a monolithic system[14]. The term ‘adhesion’ describes the connection in the boundary layer between two materials with a common interface.[15]. The bonding tests are classified in three categories. The first category includes the direct tension pull-off test, the direct tension test, the flexural test (indirect tension) and the splitting tension test[2] .

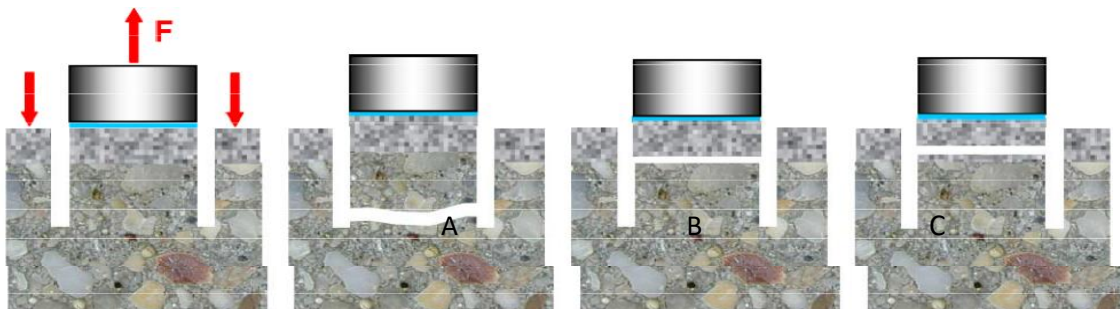


Figure I.6. A) Failure in substrate, B) Bond failure, C) Failure in overlay[14].

I.6.1.1 The concept of adhesion

The concept of adhesion has firstly to be clearly defined because of the “duality” of the term (Derjaguin, 1978)[16]: “on one hand, adhesion is understood as a process through which two bodies are brought together and attached – bonded – to each other, in such a way that external force or thermal motion is required to break the bond. On the other hand, we can examine the process of breaking a bond between bodies that are already in contact. In this case, as a quantitative measure of the intensity of adhesion, we can take the force or the energy necessary to separate the two bodies”.

Adhesion has therefore two different aspects, according to whether our interest is mainly in the conditions and the kinetics of contact or in the separation process. The intensity of adhesion will depend not only on the energy that is used to create the contact, but also on the interaction existing in the interface zone. Generally speaking, mechanism of adhesion has to be considered from two origins: specific adhesion and mechanical interlocking (Figure I.7)[16].

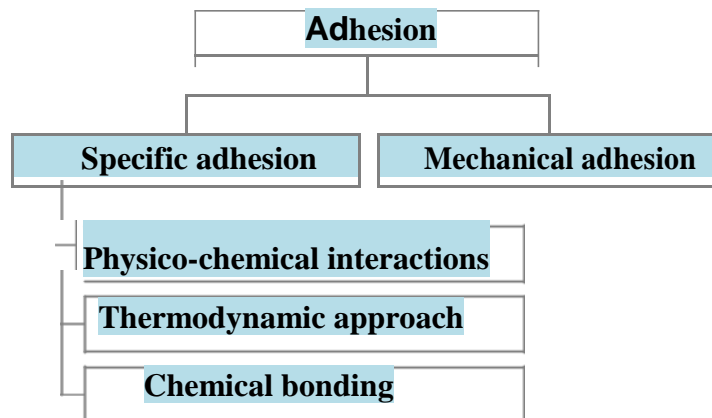


Figure I.7. Principles of the theory of adhesion.

I.6.2 Bond between two concrete materials

Espeche and Leon[17] described that there are two different mechanisms that provide the bond strength between two cementitious materials: bond-adhesive (micro-scale) and bond-cohesion (macro-scale). The bond-adhesive concept results from chemical forces acting at the micro-scale. Some researchers have described the existence of three different layers to explain the adhesion between the old and new concretes, as shown in Figure I.8.

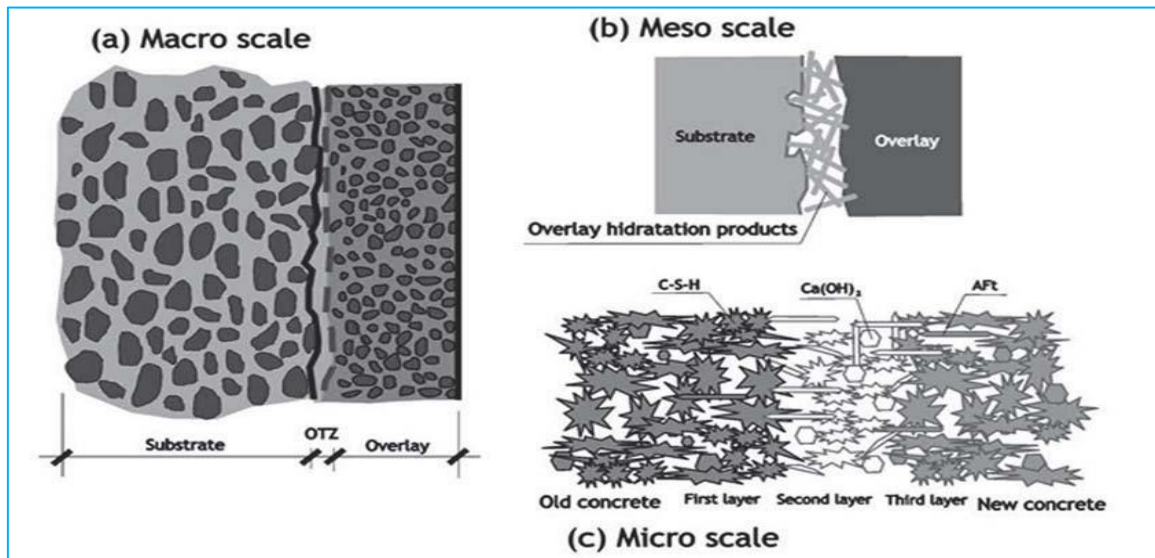


Figure I.8.Representation of the interface between old and new concretes[7].

The first layer, also called penetration layer, is made inside the old cementitious material and it composed of new constituents (calcium silica hydrate with lesser amounts of Aft or calcium hydroxide) that respond chemically with active constituents in the old substrate. The second layer has high porosity and it is composed of calcium hydroxide and Aft crystals highly oriented. The third layer approximately has a very similar micro-structure as the bulk new cementitious material. At the macro-scale, the bond-cohesive concept is a material property connected to the overlay transition zone of the new cementitious material.

A good bond can be achieved by casting new concrete (rapid-hardening Portland) against old concrete with no bonding agents[7].

I.6.3 Factors affecting bond strength

As we all know, the effectiveness of a repair is related to the bond properties between the repair material and the old substrate .Many factors including interface the roughness, the adhesive agents, the mechanical properties of the two cementitious materials and the evaluation method of the bond strength can influence the bond strength. Among these factors, the interface roughness is an important factor affecting the mechanical behavior of the interface, which affects the bond strength by affecting the cohesion of the interface.[18]

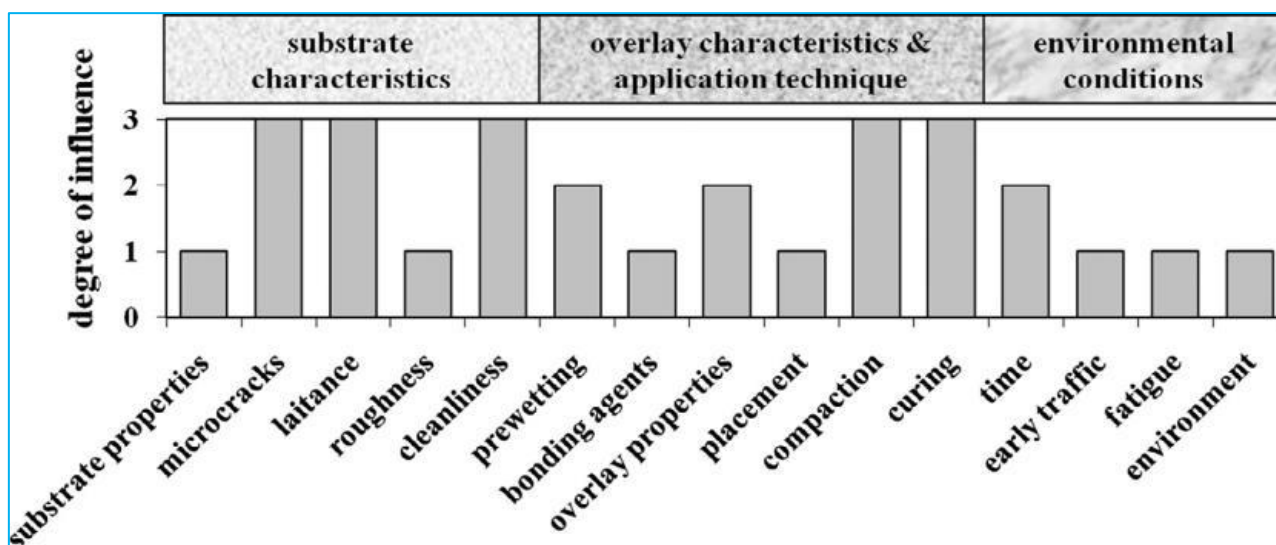


Figure I.9. Factors affecting bond between concrete substrate and repair material[19].

I.6.3.1 Cleanliness

A bond surface must be free of dust, oil, grease and other contaminants. These have significant influence on the bond strength if remain. They decrease the friction and make the preventive layer for interlock between substrate and top layer. Dusts can be blown off easily but there are some difficulties to clean the oil or grease from the surface[14].

I.6.3.2 Surface Roughness

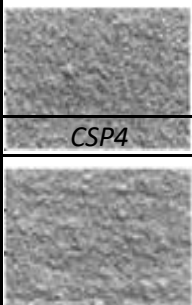
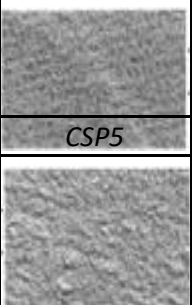
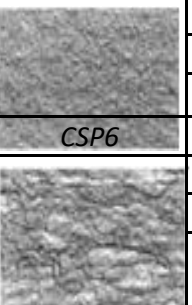
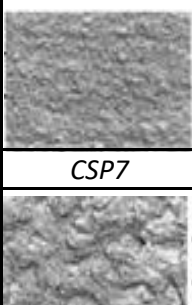
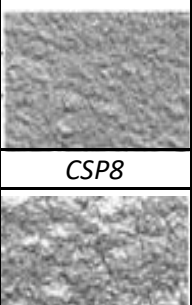
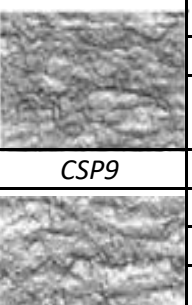



As it has been proved by Courard or Bissonnette, texturing of the surface of the concrete substrate is a promising method, and could be especially effective when carried out on the surface of the fresh and liquid material of the substrate. According to the authors, there have been no attempts to investigate the effect of texturing of the surface of concrete substrate on its adhesion to cement mortar overlay[20].

Besides, a number of previous studies confirmed that the bond strength between two concrete layers is considerably influenced by the roughness of a surface substrate. Surface roughness, when accurately measured, can lead to easy prediction of the bond behavior of externally applied composite[4]. Some of the most frequent methods for surface preparation have been summarized in Table I.1. Figure I.10 shows the surface prepared with some of the methods.



Figure I.10. A) Substrate surface partially chipped, B) Substrate surface prepared with steel brush[14].

Table I.1. Commonly used concrete surface preparation methods and corresponding Concrete Surface Profile (CSP)[16].

<i>Profile image</i>			<i>Surface preparation methods</i>	<i>CSP</i>
<i>CSP1</i>	<i>CSP2</i>	<i>CSP3</i>	<i>Detergent scrubbing</i>	1
			<i>Low-pressure water cleaning</i>	1
			<i>Acid etching</i>	1-3
			<i>Grinding</i>	1-3
<i>CSP4</i>	<i>CSP5</i>	<i>CSP6</i>	<i>Abrasive (Sand) blasting</i>	2-5
			<i>Steel shotblasting</i>	3-8
			<i>Scarifying</i>	4-9
			<i>Needle scaling</i>	5-8
<i>CSP7</i>	<i>CSP8</i>	<i>CSP9</i>	<i>Hydrodemolition</i>	6-9
			<i>Scabbling</i>	7-9
			<i>Flame blasting</i>	8-9
			<i>Milling/rotmilling</i>	9

I.6.3.3 Compaction and placement of the overlay

Compaction is an important factor for obtaining a dense and homogeneous overlay as well as a good and even bond. Compaction helps the overlay fill and cover cavities and voids at the surface which means to have more efficient contact area and fewer caves. The other advantage is to have better and less permeable overlay which is also helpful for durability of the bond. On rough and uneven surface, there is a risk for air pockets in the depressions of the surface[14].

I.6.3.4 Overlay curing and temperature effect

Curing plays an important role in durability of the overlay by reducing the risk of cracks. Curing helps the concrete to gain more and faster tensile strength and this protects the concrete against cracks caused by early age shrinkage. Fewer cracks mean to have less permeable overlay. Therefore curing can reduce the risk for debonding. Curing has a strong influence on the wear resistance. Surface strength development can be reduced significantly when curing is defective, because the water loss is always larger in the top layer.

It is important to know that temperature mostly has an influence on the speed and rate of the hydration. Effect of curing duration on compressive strength development is presented in Figure I.11 [14].

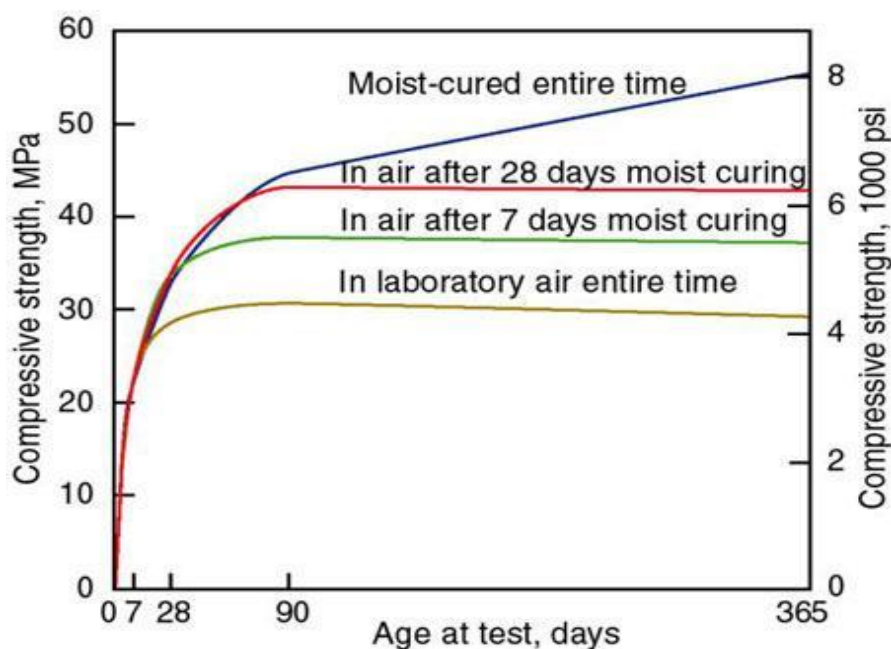


Figure I.11. Effect of curing duration on compressive strength development[14] .

I.6.4 Bond test methods

Common bond test methods include interface shear, torsion and tension tests. A wide range of possible test set-ups have been developed for laboratory testing[15].

The first group includes all those tests that evaluate the bond strength under tension stress, being the pull-off test (a), splitting tensile test (m, n) and direct tension test (l) the most accepted methods of this first group. The second category covers all those tests that measure the pure shear stress. Torsion bond test (b), the direct shear test (c), the modified vertical shear bond test (f), the push-out test (j), the bisurface shear test (k), and the guillotine test (g, h, i) fall in this group. The main challenge with the pure shear tests is properly subjecting the interface between both materials to only shear stress without transmitting any bending stress.

The third category of bond strength tests includes all those tests in which the bond is under a combined state of shear and compression stresses. The shear-compression test (d) and the slant shear test (e) belong to this category[7]. In figure I.12 schematics of various test methods to determine interface bond strength.

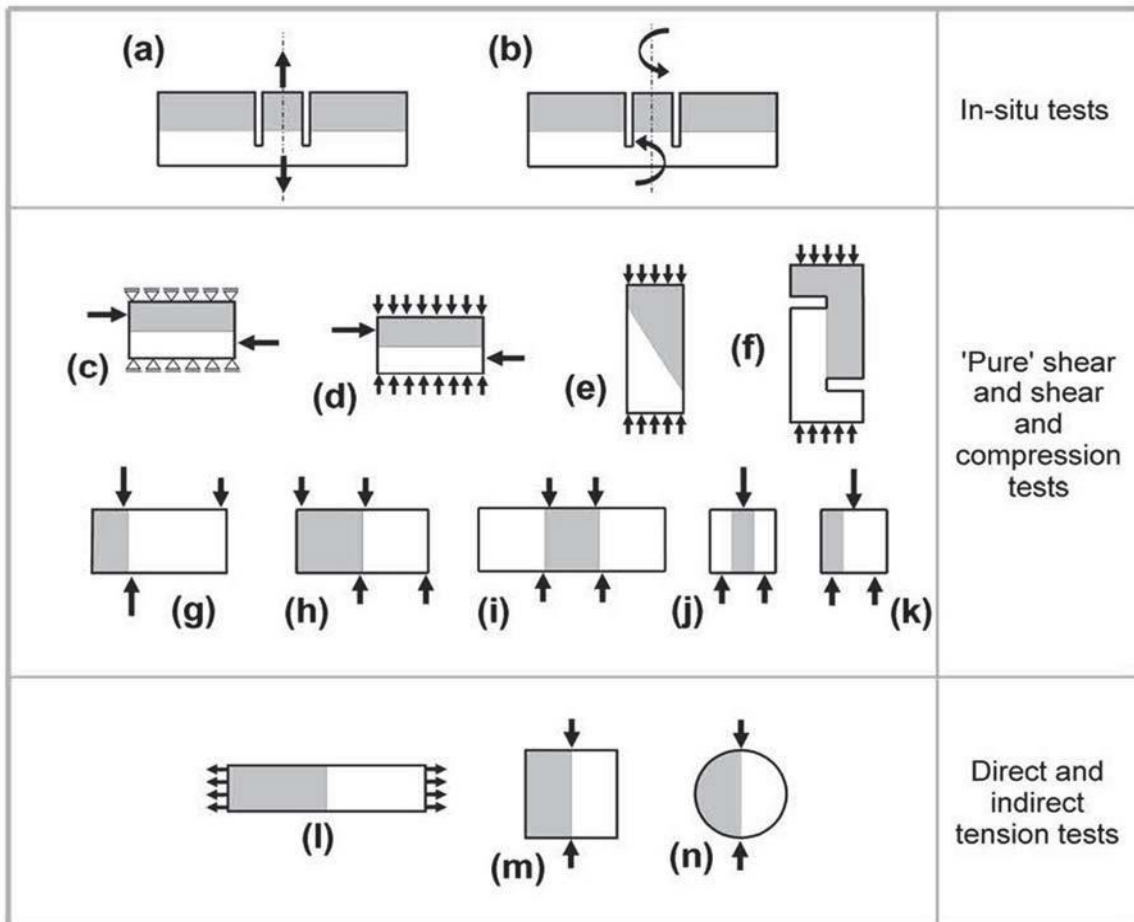


Figure I.12. Most common bond strength tests[7].

Mohr's Circle can be used to find stresses in different elements and angles. Figure I.13 represents the typical failure envelope of the concrete as a brittle material in the plane states of stresses. According to the failure types the different test methods can be classified; the aim of each test method is to apply certain stresses in the certain directions to approach the failure and measure the failure stresses. It is important to place the bond surface in the correct angle in which the failure might happen.

In tensile tests the tension stress or force is applied to the specimen. As it can be found in the figure I.12, the failure in tension occurs in the plane perpendicular to the specimen's cross section, so in the tensile bond test pull-off test the interface is placed perpendicularly to the tension force direction (Figure I.12.a). Unlike the tensile failure, the failure under compression occurs in the plane which has an angle around 30° with the compression force direction. To be able to find out the bond strength in the compression-shear type test such as slant shear test, the interface is placed with the angle close to the probable angle in which failure might happen (Figure I.12.e). This means that if a compressive force applies to the concrete which has integrity, the failure cracks will be in the plane with similar angle as the angle chosen in the test[14].

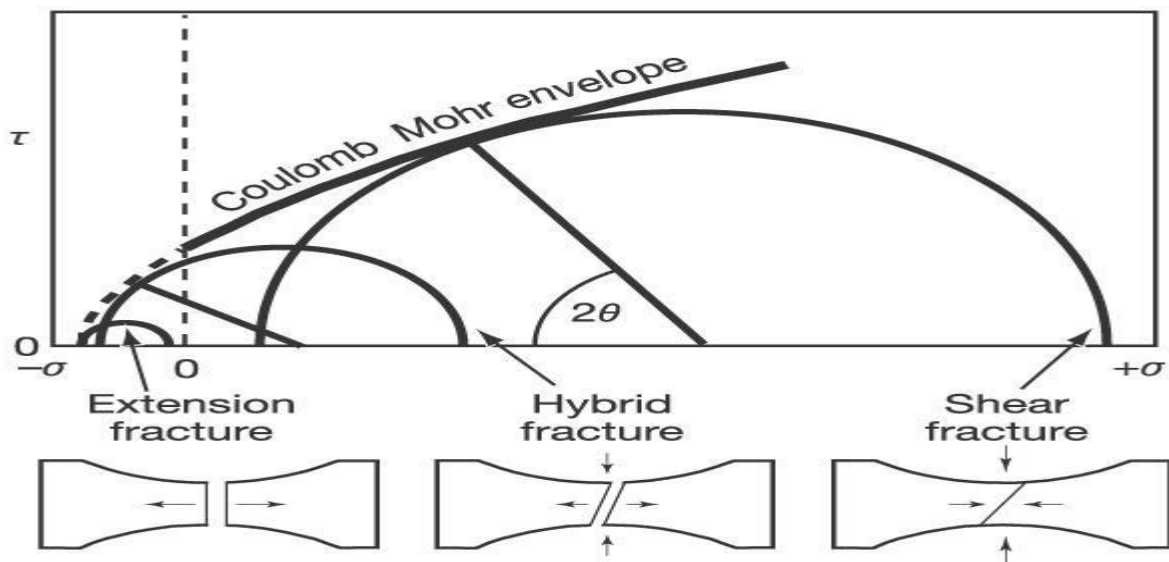


Figure I.13. Failure envelope of the concrete[14].

I.7 Relationship between compatibility and bond in composite repair systems

When compatibility issues are properly addressed in repair systems, durability of the bond is achieved, as it ensures a lasting coexistence of the repair material and substrate concrete. Incompatibility issues cause premature debonding and repair failures. Unfortunately, at the present time, there is much confusion, many misconceptions, and misleading guidance concerning compatibility of repair and the substrate concrete. These issues negatively affect the design, specification, implementation, and, as a result, service life of concrete repairs and overlays. Development of reliable guidelines that address compatibility, with special emphasis on the factors related to dimensional compatibility issues, is needed for the repair industry to evolve as an engineering discipline[6].

I.8 Rehabilitation of concrete structures

Currently, there is a wide range of solutions that have been used for the rehabilitation of concrete structures that are yielding excellent results for some specific applications, but still there is a need to develop a material capable of extending the service life longer than 20 years in harsh environmental with a minimum of maintenance.

I.8.1 Causes of concrete deterioration

It is convenient to recall the primary causes whereby a concrete structure might need to be repaired. These causes can be classified as:

- **Errors in the phases of design or construction.** The addition of excessive amount of water in concrete mixtures, insufficient concrete, inadequate joints, or construction defects are typical examples that fall into this group.
- **Excessive deterioration due to chemical attack or aggressive environment.** The most common causes of deterioration that form part of this group are alkali-aggregate reaction, sulfate attack, carbonation and freezing-thawing cycles.
- **Corrosion of reinforcing steel.** Corrosion usually takes place when the concrete exhibits cracks that allow the entrance of water or the passivity around steel bars created by the alkalinity of the Portland cement is damaged through carbonation or

bar damage. The corrosion of the steel creates additional cracking and/or delimitation that accelerates the corrosion process.

- **Structural loads.** Fatigue caused by continuous high loads or overload by heavy vehicles.
- **Extraordinary actions:** Damage caused by impacts, earthquakes or fire.
- **Abrasion and erosion:** Erosion is the progressive disintegration of the concrete by the abrasive or cavitation action of gases, fluids, or solids in motion, while abrasion is the wearing away of the concrete surface by rubbing and friction[7].

I.8.2 Concrete repair process

Many concrete repair projects are complex and include condition evaluation of existing structures, durability planning, engineering project objectives, detailed design, specifications, material selection, construction, and quality control. In addition, to help ensure success despite this complexity, repair projects should include an integrated systemic approach to properly address compatibility issues.

- Assessing the condition of existing structure (degree of deterioration or distress);
- Assessing the cause(s) of deterioration/distress;
- Establishing the nature and severity of the internal environment in the existing structure;
- Ascertaining the probable service life of the repaired structure;
- Establishing realistic design objectives;
- Selecting an appropriate repair system;
- Developing repair details and specifications;
- Implementing the repairs as specified[6].

I.8.3 Types of repair materials

A wide variety of patch repair materials are now available to the industries, which can be classified into three primary groups: cementitious mortars, polymer-modified cementitious mortars, and resinous mortars. Table **I.2** illustrates how these groups can be further subdivided

Table I.2. Types of repair materials[8].

Cementitious materials	Cementitious materials Polymer-Modified	Resinous materials
Ordinary Portland Cement (OPC)	Styrene Butadiene Rubber modified	Epoxy mortar Polyester mortar
High Alumina Cement (HAC)	Vinyl Acetate modified	Acrylic mortar

It is essential that the engineer should have a thorough knowledge of the mechanical and physical characteristics of the available products and the existing substrate before a suitable repair material is chosen[8]. Table.I.3 shows the performance requirements for structural and no-structural repairs.

Table I.3. Performance requirements for structural and no-structural repairs. [21]

Performance characteristic	Requirement			
	Structural		No structural	
	Class R4	Class R3	Class R2	ClassR1
Compressive strength	$\geq 45 \text{ Mpa}$	$\geq 25 \text{ Mpa}$	$\geq 15 \text{ Mpa}$	$\geq 10 \text{ Mpa}$
Restrained shrinkage	Adhesion stress after test			No requirements
	$\geq 2.0 \text{ Mpa}$	$\geq 1.5 \text{ Mpa}$	$\geq 0.8 \text{ Mpa}$	
Modulus of elasticity	$\geq 20 \text{ Gpa}$	$\geq 15 \text{ Gpa}$	No requirements	
Capillary absorption	$\leq 0.5 \text{ kg.m}^{-2}.\text{h}^{-0.5}$		$\leq 0.5 \text{ kg.m}^{-2}.\text{h}^{-0.5}$	No requirements
Bond strength	2.00 Mpa	1.50 Mpa	0.8 Mpa	0.8 Mpa

I.9 Primary constituents of cement mortar-composites reinforced with fiber

The main constituents of repair mortar are cement, water, sand, mineral additions (marble powder, silica fume, pozzolanas, fly ash..etc.) , superplasticizer and fiber (synthetic, metallic, .etc). The following points explain briefly these main ingredients.

I.9.1 Sand

The sand needs to have excellent qualities, both in strength and low absorption. The particle sizes have to be small, frequently lesser than 1 mm, to achieve an adequate homogeneity in the mix [7].

1.9.1.1 Dune sand

The introduction of dune sand as a new element in the construction can be more relieve the domain of building, and contribute to the development of the southern regions of Algeria.

1.9.1.2 River sand

The river sand made from rocks are composed of natural quartz grains, which is one of the hardest and most durable materials. The major constituent of quartz is silica (silicon dioxide).

1.9.1.3 Crushing limestone sand

Crushed sand is very abundant in limestone quarries and its use could significantly decrease the materials cost of concrete, eliminate the dust disposal cost, reduces environmental pollutions and dilapidation of natural resources. The effect of inclusion of limestone fines in crushed sand on fresh and hardened mortar and concrete has been a major research topic for many years. It was found that up to 15% of limestone fines do not affect strength performance of limestone concrete manufacture [22].

I.9.2 Cement

Cement will remain the key material to satisfy global housing and modern infrastructure needs[23]. Cement, in general, is the binding materials used in building and civil engineering construction.

I.9.3 Marble powder

The marble has been commonly used as a building material since ancient times. Disposal of the marble powder material of the marble industry, consisting of very fine powder[24].

I.9.4 Water

The amount of water used is strictly necessary to hydrate the cement; the formation of pores is quite reduced, avoiding interconnection between them. The absence of capillary structure improves the strength and impermeability of this material.

I.9.5 Superplasticizer

Due to the low water-cement ratio, the introduction of superplasticizers is necessary to achieve an adequate workability by helping the fine particles to fill the empty spaces and to decrease the amount of water in the mix. In most cases, polycarboxylate superplasticizers are used.

I.9.6 Fibers

Fibers are added to the concrete to increase the ductility and mechanical properties. The amount of fibers influences on the workability of the final product. [7]. The main factors that control the performance of the composite material are:

- Physical properties of fibers and matrix
- Strength of bond between fibers and matrix.

Fibers are typically added to concrete in low volume dosages (often less than 1%), and have been shown to be effective in reducing plastic shrinkage cracking. The fibers typically do not significantly alter free shrinkage of concrete, however, at high enough dosages they can increase the resistance to cracking and decrease crack width.

I.9.6.1 Advantages and disadvantages of using fibers

Fibers are typically distributed throughout the concrete cross section. Therefore, many fibers are inefficiently located for resisting tensile stresses resulting from applied loads. From a conceptual point of view, reinforcing with fibers is not a highly efficient method of obtaining composite strength. Fiber concretes are best suited for thin section shapes where correct placement of conventional reinforcement would be extremely difficult. In addition, spraying of fiber concrete accommodates the fabrication of irregularly shaped products. A substantial weight savings can be realized using relatively thin fiber concrete sections having the equivalent strength of thicker conventionally reinforced concrete sections[25].

I.9.6.2 Types of fibers

There are several types of fibers that differ in nature, diameter, length (macro or micro fibers), shape and surface condition. Fibers can be natural or artificial.

A. Steel fibers

Steel fibers are short, discrete lengths of steel with an aspect ratio (ratio of length to diameter) from about 20 to 100, and with any of several cross sections. Some steel fibers have hooked ends to improve resistance to pullout from a cement-based matrix. Steel fibers have a relatively high modulus of elasticity. Their bond to the cement matrix can be enhanced by mechanical anchorage or surface roughness and they are protected from corrosion by the alkaline environment in the cement matrix[25]. Steel fibers do not affect free shrinkage. Steel fibers delay the fracture of restrained concrete during shrinkage and they improve stress relaxation by creep mechanisms[26].

B. Glass fibers

The first research on glass fibers in the early 1960s used conventional borosilicate glass (E-glass) and soda-lime-silica glass fibers (A-glass). Alkali attack on glass-fiber surfaces reduces fiber tensile strength and, subsequently, lowers compressive strength. The single largest application of glass-fiber concrete has been the manufacture of exterior building façade panels[25].

C. Synthetic fibers

Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries. Fiber types that are used in Portland cement concrete are: acrylic, aramid, carbon, nylon, polyester, polyethylene, and polypropylene[25].

D. Natural fibers

Natural fibers were used as a form of reinforcement long before the advent of conventional reinforced concrete. Mud bricks reinforced with straw and mortars reinforced with horsehair are just a few examples of how natural fibers were used long ago as a form of reinforcement. Many natural reinforcing materials can be obtained at low levels of cost and energy using locally available manpower and technical know-how. Such fibers are used in the

manufacture of low-fiber-content concrete and occasionally have been used in thin-sheet concrete with high-fiber content. The properties and composition of natural fibers are presented in table I.4, I.5, respectively.

Table I.4. Properties of natural fiber types[25].

Natural Fiber type	Specific gravity	Diameter, μm (0.001 in.)	Tensile strength, MPa (ksi)	Modulus of elasticity, MPa (ksi)	Strain at failure, %
Wood cellulose	1.50	25-125 (1-5)	350-2000 (51-290)	10,000-40,000 (1,500-5,800)	
Sisal			280-600 (40-85)	13,000-25,000 (1,900-3,800)	3.5
Coconut	1.12-1.15	100-400 (4-16)	120-200 (17-29)	19,000-25,000 (2,800-3,800)	10-25
Bamboo	1.50	50-400 (2-16)	350-500 (51-73)	33,000-40,000 (4,800-5,800)	
jute	1.02-1.04	100-200 (4-8)	250-350 (36-51)	25,000-32,000 (3,800-4,600)	1.5-1.9
Elephant grass		425 (17)	180 (26)	4,900 (710)	3.6

Table I.5.Composition of vegetable fibers[27].

Fiber	Lignin (%)	Cellulose (%)	Hemicellulose (%)	Extractives (%)	Ash (%)
Bagasse	21.8	41.7	28.00	4.00	3.50
Banana leaf	24.84	25.65	17.04	9.84	7.02
Banana trunk	15.07	31.48	14.98	4.46	8.65
Coconut coir	46.48	21.46	12.36	8.77	1.05
Coconut tissue	29.7	31.05	19.22	1.74	8.39
Eucalypts	25.4	41.57	32.56	8.20	0.22
Sisal	11.00	73.11	13.33	1.33	0.33

D.1 Advantages and disadvantages of natural fibers.

Natural fiber cement composites have some negative issues regarding long-term durability because of the varying nature of the fiber, the balling effect in fresh composites, moisture sensitivity, and degrading effects in a cement medium (i.e., alkaline conditions). The degradation of a natural fiber composite mainly results from the alkaline pore water that is present in the composite, which attacks the fiber's components and reduces the reinforcing capacity of the fibers[28].

One of the disadvantages of using natural fiber is that they have a high variation on their properties which could lead to unpredictable concrete properties[27]. Vegetable (sisal) fiber has a negative influence on the stress-strain behavior under compression loads of the cement matrix [29]. On the other hand, natural fibers are a renewable resource and are available almost all over the world. Therefore, they are stronger as synthetic fibers, cost-effective and above all environmental friendly. The use of vegetable fibers such as sisal, jute and coconut in concrete poses an exciting challenge to the construction industry since they are a cheap and readily available form of reinforcement and require only a low degree of industrialization for their processing[30].

D.2 Treatment of fiber with chemical agents

The mechanical performance and durability of the composite reinforced with plant fibers is conditioned by the adhesion between the fibers and the matrix, because good adhesion interfacial means better mechanical performance, low porosity and long life.

Why is an alkaline treatment used? .Alkalization or alkaline treatment is a process of chemical modification of the fiber which increases the fibers stability against humidity and decreases its hydrophilicity due to the elimination of hemicellulose and leads to an increase in the crystallization index of the fiber, which increases their resistance[31] .

D.3 Sisal fibers

Sisal fiber (*Agave sisalana*) is one of the most widely used natural fibers and it is very easily cultivated[32]. Sisal fibers are extracted from the leaves of the plants, which vary in size, between 6-10 cm in width and 50-250 cm in length depending on the species, climate and soil in the plantation. Table **I.6** shows properties of sisal fibers.

Table I.6. Properties of sisal fibers.[33]

Diameter	0,10-0,13 mm
Tensile strength	371±28 MPa
Modulus of elasticity	12.43±2.23 GPa
Shape	straight
Color	cream to white
density	0.113 g/cm ³

Sisal is one of the cheapest natural fibers, and is second only to cotton in amount produced and variety of uses[34]. It should be noted that the production of sisal in Brazil has reduced since 1985 and is creating serious local economic problems. It should be mentioned that the plantation of sisal has an ecological advantage as it has been proven to prevent desertification of the land[35].

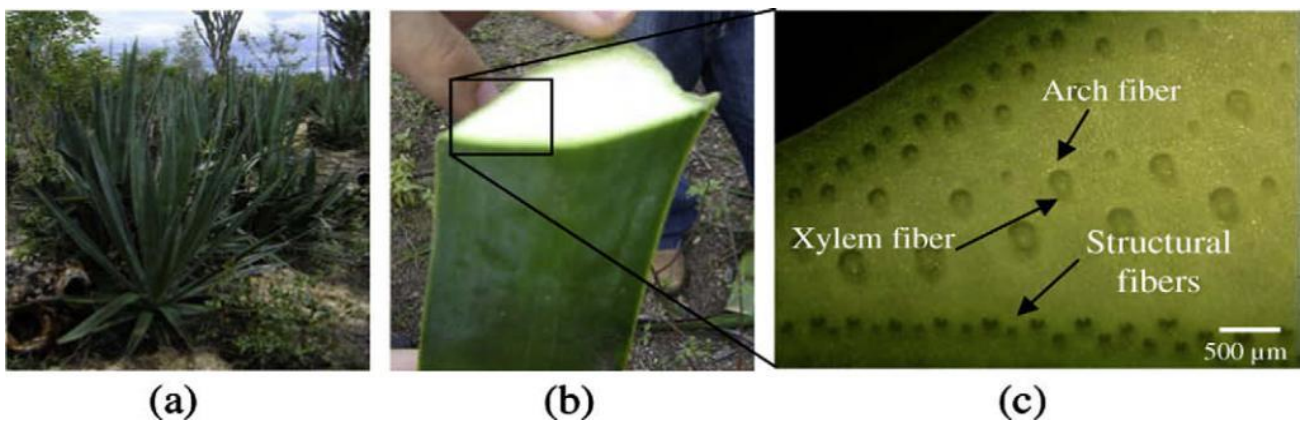


Figure I.14. The sisal plant (a), leaf (b) and leaf cross-section showing different fiber types (c)[36].

The sisal plant leaf (fig I.14) is a functionally graded composite structure which is reinforced by three types of fibers: structural, arch, and xylem fibers. The first occurs in the periphery of the leaf providing resistance to tensile loads. The others present secondary reinforcement, occurring in the middle of the leaf, as well as, a path for nutrients. The microstructure of the fiber-cell is shown in figure I.15.[36].

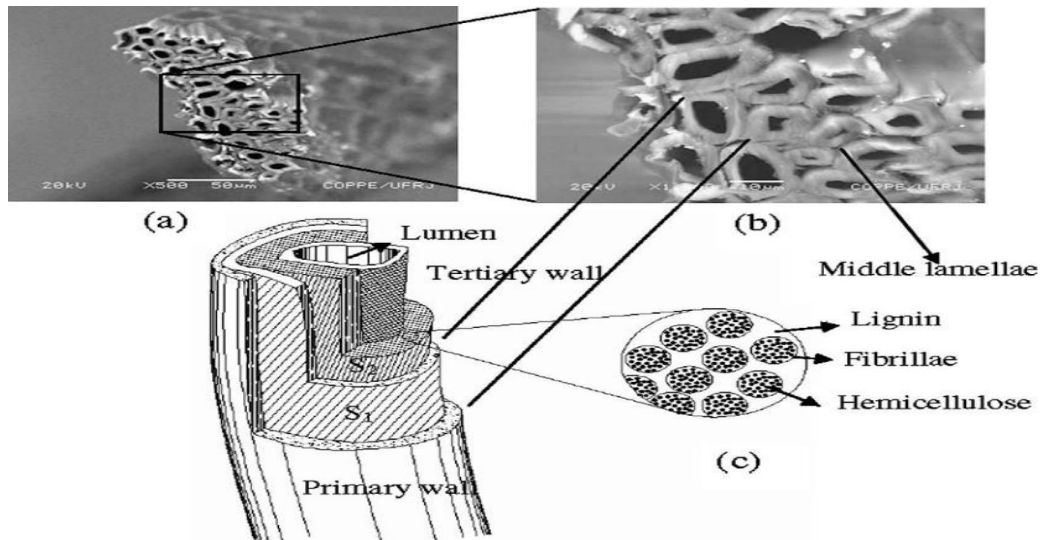


Figure I.15. Fiber-cell microstructure: (a) cross-section view showing the fiber-cells, lumens and middle lamellae, (b) magnification of the cross-section and (c) schematic drawing showing the different layers of an individual fiber-cell[36].



Figure I.16. production processes of sisal fibers[37].

A sisal plant produces about 200–250 leaves and each leaf contains 1000 ± 1200 fiber bundles which are composed of 4% fiber, 0.75% cuticle, 8% dry matter and 87.25% water [14], so a leaf weighing about 600 g will yield about 3% by weight of fiber, with each leaf containing about 1000 fibers[32].

I.10 The effect of mortar constituents on these performances

Vegetable fiber mortar is a non-homogeneous composite material which makes it very sensitive to the characteristics of these constituents. However, several researchers have taken this point into account; they have shown the effects of each constituent to sweat the performance of the mortar, in particular the mechanical performance.

I.10.1 Effect of type of sand

The work done by **Lakhdari et al.**[38] presents an experimental study on the formulation and characterization of a repair mortar based of dune -alluvial sand . The results show that the compressive strength of mortars is about 15.3 MPa, 18.3 MPa, and 37.40 MPa for dune sand mortar, dune-alluvial sand mortar, and alluvial sand mortar, respectively. In addition, it was found that the dune-alluvial sand mortar exhibits an enhancement of 20 % in the compressive strength compared to the dune sand mortar.

The work done by **Benabed et al.** [39] tries to provide solutions for the use of dune sand in the manufacture of mortars. They result that mixed sand mortars (river-dune) present the best mechanical performances, than those of dune sand mortars with superplasticizer and without superplasticizer. They note a compressive strength at 28 days of the order of 37 MPa for mixed sand mortar.

However, the study carried out by **Bouziati et al.**[40] which consists in using dune sand of different mass proportions (0, 10, 20 and 30) % and river sand and see their effects on the properties of a sand concrete. They concluded that the concentration of dune sand (10%) allows the sand concrete to have good fluidity, thus good performance in compressive strength (58Mpa) at 28 days.

Another research was carried out by **Benabed et al.**[41] in 2012 on the properties of self-compacting mortar made with various types of sand (crushed sand (CS), river sand (RS), dune sand (DS) and a mixture of different sands). The results indicate that the rheological properties and strength improve with mixtures of crushed and river sands but decrease with mixtures of crushed and dune sands especially for higher dune sand content. Crushed sand with (10–15%) of limestone fines can be used successfully in the production of SCM with good rheological and strength properties.

Another research was carried out by Maza.[42] on the analysis of the physico-mechanical properties of mixed sand mortar (dune sand and crushed sand), he concluded that: The addition of crushed sand improves the physical properties of mixed sand (low porosity, high compactness, improved cement-aggregate adhesion, etc.). The use of mixed sand also improves the mechanical resistance (Figure I.17).

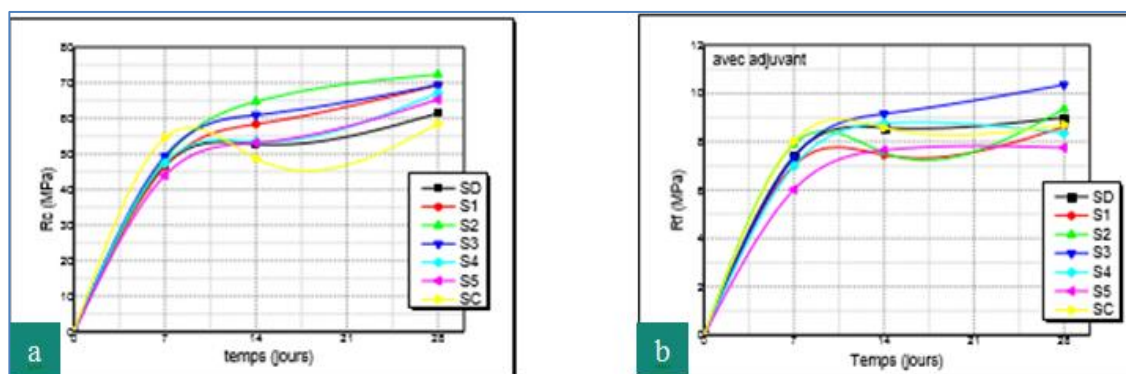


Figure I.17. Compressive strength (a) and flexural strength (b) of mixed sand mortars with superplasticizer[42].

I.10.2 Effect of sisal fibers

I.10.2.1 Effect of sisal fiber addition on water absorption

The study carried out by Okeola et al .[43] in 2018 on experimental investigation of the physical and mechanical properties of sisal fiber-reinforced concrete. This corresponds to the addition of 0.5%, 1.0%, 1.5% and 2.0% of sisal fiber by weight of cement, which means that the increase in fiber content is followed by an increase in water absorption (Figure I.18).

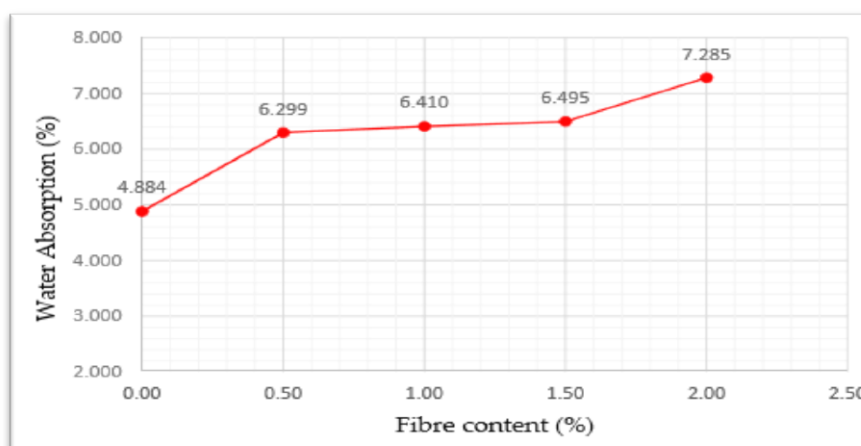


Figure I.18. Effect of sisal fibers on the water absorption of concrete[43].

I.10.2.2 Effect of sisal fiber addition on shrinkage

Filho et al.[44] which examined the effect of low modulus sisal polypropylene fiber on the free and restrained shrinkage of mortars at early age. A comparison was made between the addition performances of (0.1% and 0.2%) for each type of fiber in controlling these phenomena. The results showed that the addition of 0.2% of sisal fibers decreases the free plastic shrinkage more than the addition of 0.2% of polypropylene fibers.

Kawashima and Shah.[45] studied the effect of cellulose fibers on autogenous shrinkage of mortar with water-to-binder ratio of 0.28 was investigated. They reported that the addition of 1% cellulose fiber significantly inhibited the cracks caused by autogenous shrinkage due to the internal solidification of the matrix (**figure I.19**).

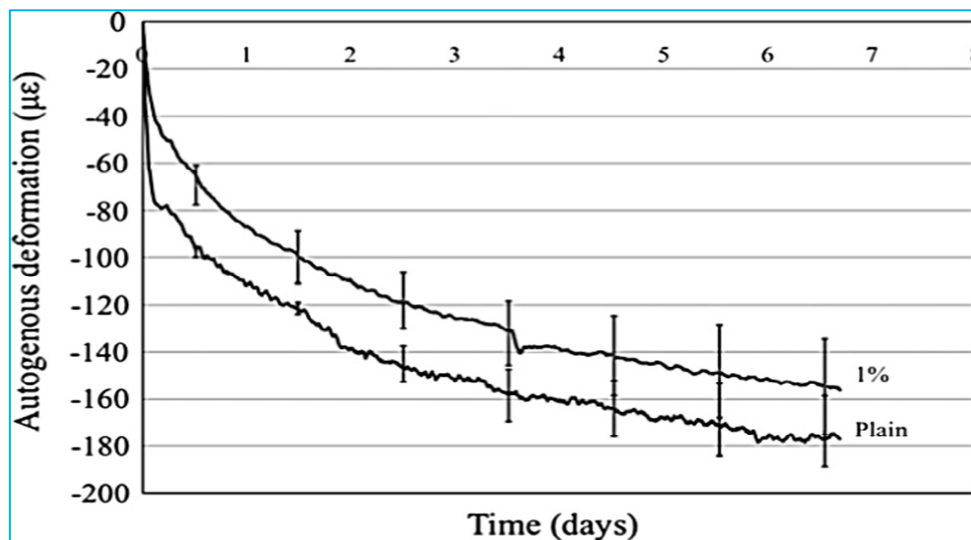


Figure I.19. Linear autogenous deformation of mortar specimens with and without cellulose fiber addition[45].

I.10.2.3 Effect of sisal fiber addition on mechanical properties

Maurya et al [46] studied the mechanical properties of epoxy composite using short sisal fiber with various length (5, 10, 15 and 20 mm) but constant 30 weight percent of sisal fiber content. The result offered that impact properties have enhanced by the reinforcement of sisal

into epoxy matrix. However, the result of flexural test shows the positive effect of sisal fiber reinforcement into the epoxy matrix.

Toledo Filho et al.[47] has studied the mechanical behavior of sisal fiber reinforced mortar composites as a function of fiber length, fiber content and humidity conditions of fibers (dry and saturated). A significant improvement in impact properties was noticed in all cases.

I.10.3 The effect of fiber reinforcement on bonding

Nunes et al.[48] have studied the mechanical compatibility and adhesion between alkali-activated repair mortars and Portland cement concrete substrate. Mortars with equivalent compressive strength and modulus of elasticity (with and without polypropylene fiber reinforcement) were applied onto the substrate and subjected to bond tests (pull-off and bending tests). Results indicate that the presence of fiber slightly helped the adhesion of the repair mortar increasing the average bond strength in most of the cases figure I.20.

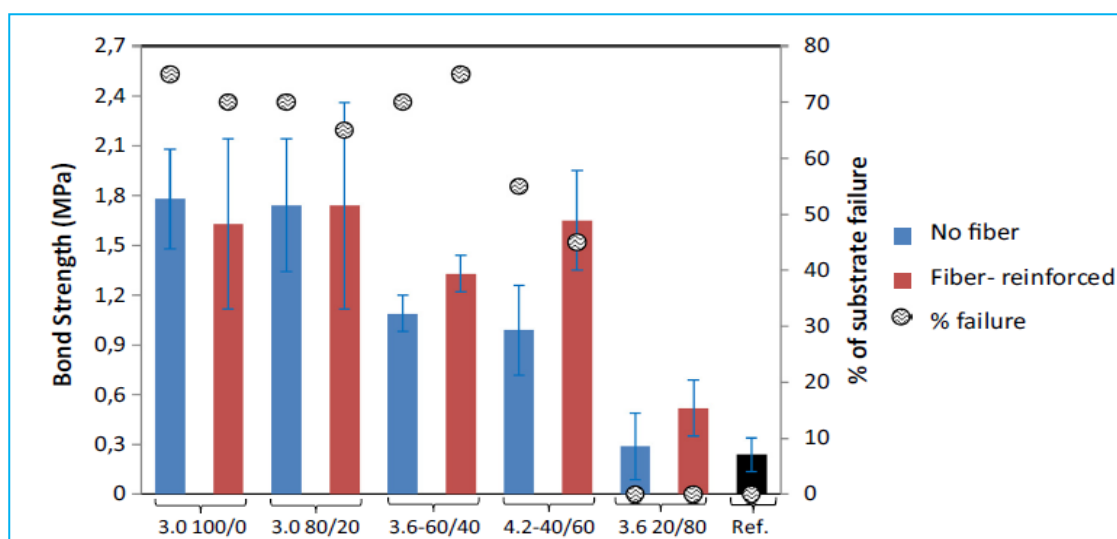


Figure I.20. Bond strength results obtained by pull-off test[48].

Krobba et al[49] studied the effect of Alfa natural microfiber on compressive strength, flexural strength, shrinkage, sorptivity, gas permeability and bond strength of repair mortar. The results obtained show an enhancement of the mechanical and physical properties of mortars with natural microfibers compared to those of mortars without natural fibers. It was

observed that whatever the type of mortar, the bond strength is greater than the minimum value (1.5 MPa) for structural repair required. Table I.7 shows the bond strengths and failure modes of mortars tested.

Table I.7. Bond strengths and failure modes of mortars tested[49].

Simple	Bond strength (MPa)			Failure mode		
				Mortar		
	MS	MA	MV6	MS	MA	MV6
1	2.18	2.52	2.57	Interface	Substrate	Substrate
2	2.22	2.50	2.52	Substrate	Substrate	Substrate
3	2.15	2.39	2.49	Interface	Interface	Interface
4	2.13	2.41	2.50	Mortar	Interface	Substrate
5	2.23	2.47	2.49	Substrate	Substrate	Substrate
Average value	2.18	2.46	2.52			

Kenai et al[50].studied the performances of repair mortar with natural fibers. They noted that the result of slant shear show that the bond of fiber mortars and substrate have a comparable slant shear strength to that of without fibers .Moreover, they concluded that the fibers improve the bond interface mortar concrete.

I.11 Conclusion

From the literature review, it is noticed that the concrete repair is a complex process. This chapter covers topics in which significant work has already been done, and for which findings are already available in the literature .This knowledge is considered very important for a better analysis of our research study, especially concerning the experimental part of our study.

Chapter II

*Materials and
experimental program*

II.1 Introduction

The purpose of this chapter is to identify and characterize the materials used in our study (cement, marble powder, dune sand, limestone sand, river sand, limestone coarse aggregates (3/8) and sisal fibers) ,in the first part.

In the second part, all the methods and the procedures that were followed to investigate the research topic were presented in detail. In the fresh state the characterization is carried out by tests of spreading with the mini cone, and in the hardened state on the physic-mechanical tests (shrinkage, compressive and flexural strength, capillary water absorption, sonic auscultation and total porosity).Three methods, were used to study the adhesion of repair mortars-concrete; a series of slant shear, pull off and split tensile tests.

II.2 Materials

II.2.1 Cement

The cement used is an Ordinary Portland cement CEM I 42.5 R (fig II.1) .It is produced by Biskra cement factory (Algerian company). Marble powder rated by (MP) is added to the cement. Their chemical and physical properties are classified in Table II.1.



Figure II.1.used cement

Table II.1. Chemical analysis and physical properties of cement and MP[51].

Chemical analysis (%)	Cement	MP
CaO	65.9	55.6
SiO ₂	21.9	0.6
Al ₂ O ₃	4.8	0.4
Fe ₂ O ₃	3.5	0.2
MgO	1.6	0.1
K ₂ O	0.5	-
SO ₃	0.48	-
CaCO ₃	-	90
Na ₂ O	-	-
Cl	0.1	0.1
Ignition loss	1.2	43
physical properties		
Specific gravity	3.1	2.7
Activity index at 28 days	-	0.79
Compressive strength at 28 days (MPa)	44	-
Fineness Blaine (m ² /kg)	279.2	212.6

a) Physical properties of used cement

The physical properties of used cement are classified in Table II.2.

Table II.2. Physical properties of used cement

Properties	Bulk density (kg/m ³)	Absolute density (kg/m ³)	fineness (cm ² /g)	Consistency (%)	Beginning of setting (min)	End of setting (min)
standards	NF P18 -555	NF P18 -555	EN 196-6	EN 196-3	EN 196-3	
Results	1,40	3,04	4100	25,8 ÷ 26,4	170 ÷ 190	230 ÷ 280

b) Mechanical properties of used cement

In table II.3 are expressed the mean values of the compressive and flexural strength of the cement used according to the EN 197-1 [52] standards test.

Table II.3. Mechanical properties of used cement.

Propreties	28 days
Compressive strength	45,03±2,35 (MPA)
Flexural strength	8,08±0,4 (MPA)

II.2.2 Aggregates

In this experimental work, it was decided to use local aggregates. The aggregates used then are the following:

- For the substrate concrete, class of crushed gravel 3/8 was used from Laghouat (Algerian), with river sands (0/5 mm) noted by (RS)
- For the self-compacting repair mortar, two types of sand are used: dune sand noted by (DS) and crushing limestone sand noted by (CS). The dune sand used is coming from the northern region of Laghouat city (Oasis Nord). It is a fine sand of wind origin. Crushing limestone sand is obtained from the Ouezzane station where situated in north of Laghouat city (near of the Oued M'zi Bridge).

For use in the manufacture of mortars and concretes, the aggregates must be subjected to laboratory tests such as particle size analysis, sand equivalent testing and chemical analysis ...etc.



Dune sand (DS)



Crushing limestone sand (CS)

Figure II.2. The different types of sand used in repair mortar.

a) Physical characteristics

i. Sieve analysis

The particle size analysis (Fig II.3) was carried out in accordance with EN 933-1 [53], which makes it possible to determine the size and percentages of the grains constituting the sample. It applies to all aggregates with a dimension of 80 mm or more, the material studied is placed in the upper part of the sieves and the grading of the grains is obtained by vibration of the sieve column. The results of the particle size analysis, carried out on dune sand, crushed lime sand, alluvial sand and 3/8 gravel are grouped in table II.4 and presented in figure II.4.



Figure II.3. Sieve analysis of gravel (3/8).

Table II.4. Sieve analysis results.

RS		DS		CS		G3/8	
Sieve size (mm)	Percent passing(%)	Sieve size (mm)	Percent passing(%)	Sieve size (mm)	Percent passing(%)	Sieve size (mm)	Percent passing(%)
4	96.97	1	99.92	4	99.98	10	99.76
2	88.07	0.8	99.65	2	89.87	8	97.79
1	78.2	0.5	92.75	1	67.68	6.3	57.57
0.5	49.7	0.315	63.71	0.5	48.68	5	21.21
0.25	5.34	0.25	42.37	0.25	32.25	4	6.29
0.125	0.87	0.2	30.41	0.125	21.34	3.15	2.16
Pan	0.39	0.16	18.54	pan	0.46	2.5	0.79
		0.125	12.06			pan	0.7
		pan	2.5				

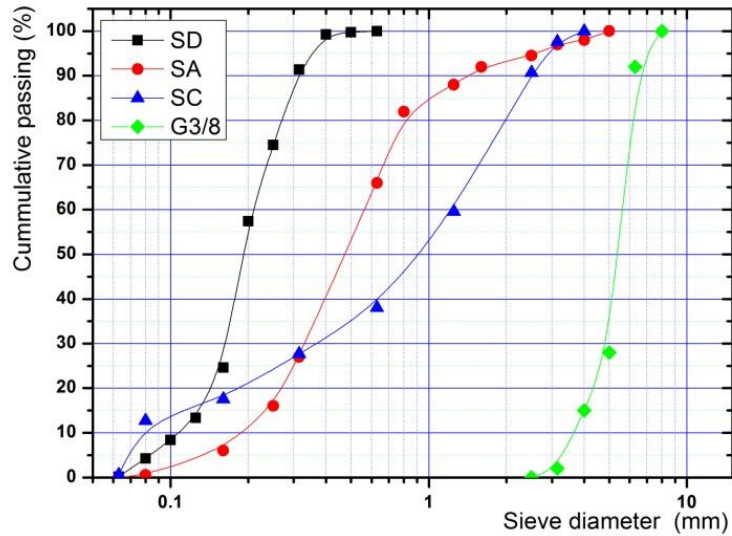


Figure II.4. Particle size distribution of aggregates.

The fineness modulus **FM** according to the **EN 12620** [54] is defined as one hundredth of the sum of the refusals, expressed in percentages on the different sieves of the following series : (0.125;0.25;0.5;1;2;4) mm.

According to the following relation:

$$FM = \frac{\sum \text{cumulative percent retained \% (0.125; 0.25; 0.5; 1; 2; 4)}}{100}$$

Where:

FM: fineness modulus.

Table II.5. Fineness modulus

Type of Sand	CS	DS	RS
Fineness modulus	2.4	1.53	2.81
FM			

Fine aggregate having a fineness modulus more than 3.2 or less than 1.8 should not be considered as fine aggregate. Various values of fineness modulus for different sands are detailed below Table II.6.

Table II.6 . Coarseness or fineness based on the fineness modulus.[54]

Type of sand	Fineness modulus
Coarse sand	2.8 < FM < 4
Medium sand	2.1 < FM < 2.8
Fine sand	0.6 < FM < 2.1

According to the figure II.4, and the table II.5:

- ✓ Crushing limestone sand gives a continuous particle size distribution with a lower percentage of 12% of fine elements less than 80µm.
- ✓ The fineness modulus value confirms that dune sand is very fine sand. And for the river sand is medium sand.

ii. Bulk density

The bulk density (ρ) or unit weight of sand according to the EN 1097-3[55] is determined by the following relation:

$$\rho = \frac{w_1 - w_2}{V}$$

Where:

w_1 : Total mass (container + material) (kg).

w_2 : Empty container mass (kg).

V : Container volume of 1 litre (1000g).

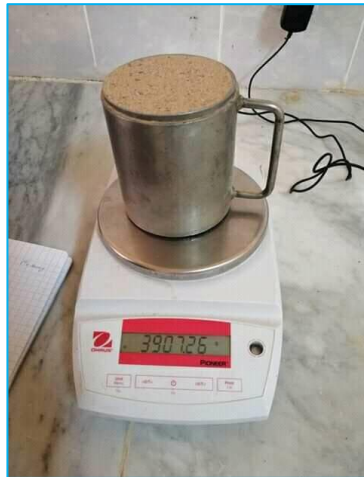


Figure II.5. Bulk density test.

Table II.7. Bulk density.

Type of aggregates	CS	DS	RS	Gravel (3/8)
ρ (kg/m ³)	1538	1521	1648	1319

iii. Specific gravity

According to the EN 1097-6 [56], the specific gravity ρ_s (relative gravity) is determined with pycnometer as:

$$\rho_s = \frac{w_3}{w_0 + w_3 - w_4}$$

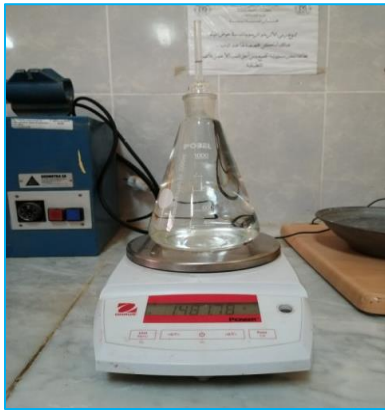
Where:

ρ_s : Specific gravity (kg/m³).

w_0 : Weight of the pycnometer filled with water (kg).

w_3 : Dry weight (kg).

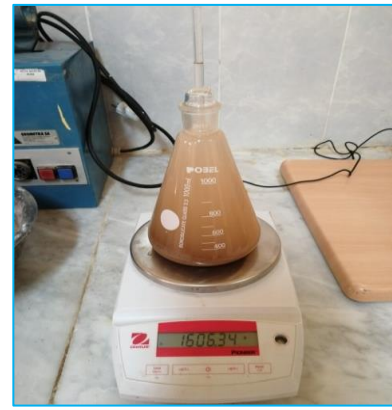
w_4 : Weight of the pycnometer filled with sand and water (kg).



Water volume.



Pycnometer filled .



Weight measuring.

Figure II.6. Specific gravity test.

Table II.8. Specific gravity.

Type of aggregates	CS	DS	RS	Gravel (3/8)
ρ_s (kg/m ³)	2627.3	2614.8	2607.4	2671.6

iv. Compactness

Compactness (C_p) is the ratio of the volume of full material to the total volume. Compactness is defined by:

$$C_p = \frac{\rho}{\rho_s} * 100$$

C_p : Compactness (%).

ρ : Bulk density (kg/m³).

ρ_s : Specific gravity (kg/m³).

Table II.9. Compactness results.

Type of aggregates	CS	DS	RS	Gravel (3/8)
C_p (%)	58.54	58.17	63.20	49.37

v. Water absorption

The absorption coefficient **Ab** of fine aggregate is determined according to the **EN 1097-6** [56]. Figure **II.7** shows the absorption test of the aggregates.

$$Ab(\%) = \frac{W_a - W_s}{W_s} * 100$$

Where:

Ab: absorption coefficient (%).

W_a: saturated weight with dry surface (g).

W_s: dry weight after passing to the oven at 105 c⁰ (g).



Saturated sand



stream of air

Figure II.7. Absorption test

Table II.10. Absorption results.

Type of aggregates	CS	DS	RS	Gravel (3/8)
Absorption (%)	4.00	1,00	0.49	2.16

vi. Sand equivalent

The sand equivalent test (figure II.8) provides a measure of the relative proportions of detrimental fine dust or clay-like material in fine aggregates. The sand equivalent (E_s) is defined according to the EN 933-8 [57] by:

$$ES_v = \frac{H_2}{H_1} * 100\%$$

$$ES_p = \frac{H'_2}{H_1} * 100\%$$

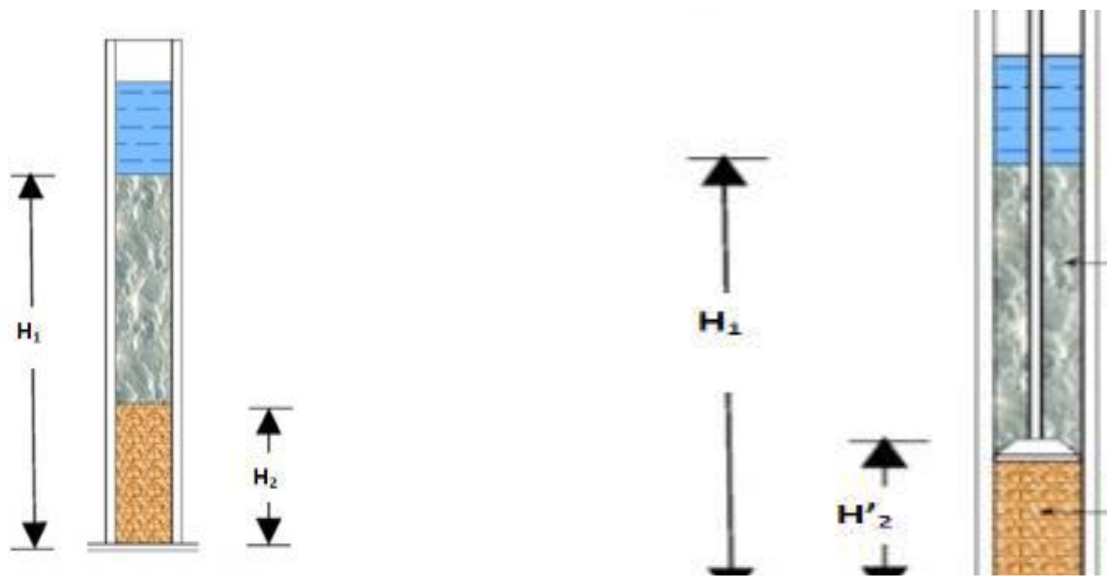


Figure II.8. Sand equivalent test

Where:

ES_v : Visually sand equivalent (%).

ES_p : Piston sand equivalent (%).

H_2 or H'_2 :height of sand measured visually or with piston (cm).

H_1 : Height of sand +clay (cm).



Mechanical Sand Equivalent Shaker



piston sand equivalent

Figure II.9. Sand equivalent test.

Table II.11. Sand equivalent results.

Type of sand	CS	DS	RS
ES_v	73	72	97
ES_p	64	62	82

Table II.12. Class of sand equivalent.

ES_v (visually)	ES_p (with piston)	Quality of sand
$ES_v < 65$	$ES_p < 60$	"Clayey sand" risk of shrinkage or swelling to be rejected for quality concrete.
$65 \leq ES_v \leq 75$	$60 \leq ES_p \leq 70$	"Slightly clayey sand" of acceptable cleanliness for standard quality concrete
$75 \leq ES_v \leq 85$	$70 \leq ES_p \leq 80$	«Clean sand» with a low percentage of fine clay which is ideal for high-quality concrete
$ES_v \geq 85$	$ES_p \geq 80$	"Very clean sand" the almost total absence of fine clayey materials

From the table II.11 and table II.12:

- The river sand is very clean sand.
- The limestone sand and dune sand are clean sands.

b) Chemical characteristics

The various minerals constituting the sands used are given by the X-ray spectroscopy following (Fig II.10, II.11).

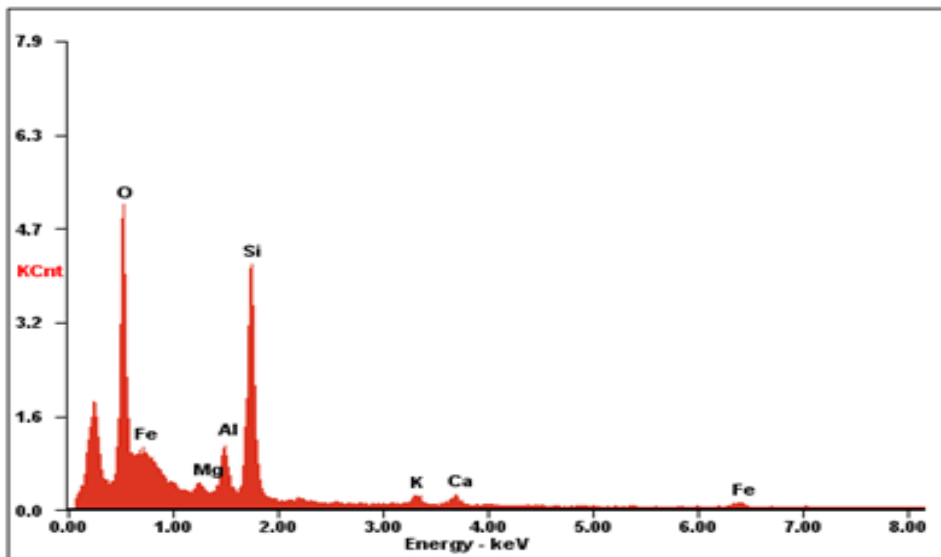


Figure II.10. X-ray spectroscopy of dune sand.[37]

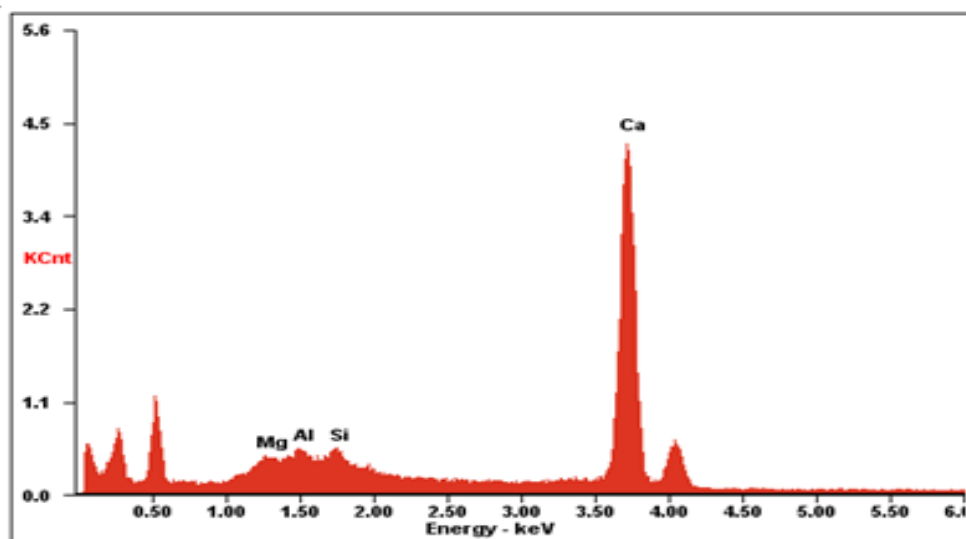


Figure II.11. X-ray spectroscopy of limestone sand. [37]

From the X-ray spectroscopy of dune sand (**figureII.10**) and limestone sand (**figureII.11**), it can be seen that:

- Dune sand is composed of quartz SiO_2 .
- The limestone sand is composed of dolomite $\text{CaMg}(\text{CO}_3)_2$ and some traces of other elements.

II.2.3 Water

The mixing water used is potable water from the tap of the Civil Engineering laboratory in Laghouat.

II.2.4 Superplasticizer

MEDAFLOW30 used is an Algerian superplasticizer in accordance with **EN 934-2** [58].It is a third generation high water-reducing superplasticizer. It is based on polycarboxylate which considerably improve the properties of concrete. According to the GRANITEX technical notice :

- Appearance: liquid.
- Color: light brown.
- Ph: 6-6.6.
- Density: 1.07 ± 0.01 .
- Chlorine content: $< 0.1 \text{g/l}$.
- Dry extract: 30%.
- Dosage: $0.90 \pm 0.98\%$.

II.2.5 Fibers

The fibers used in this study are vegetable sisal fibers available on the market. The fibers are cut into pieces of different lengths 5, 10 and 20 mm (Figure **II.12** and Figure **II.13**).

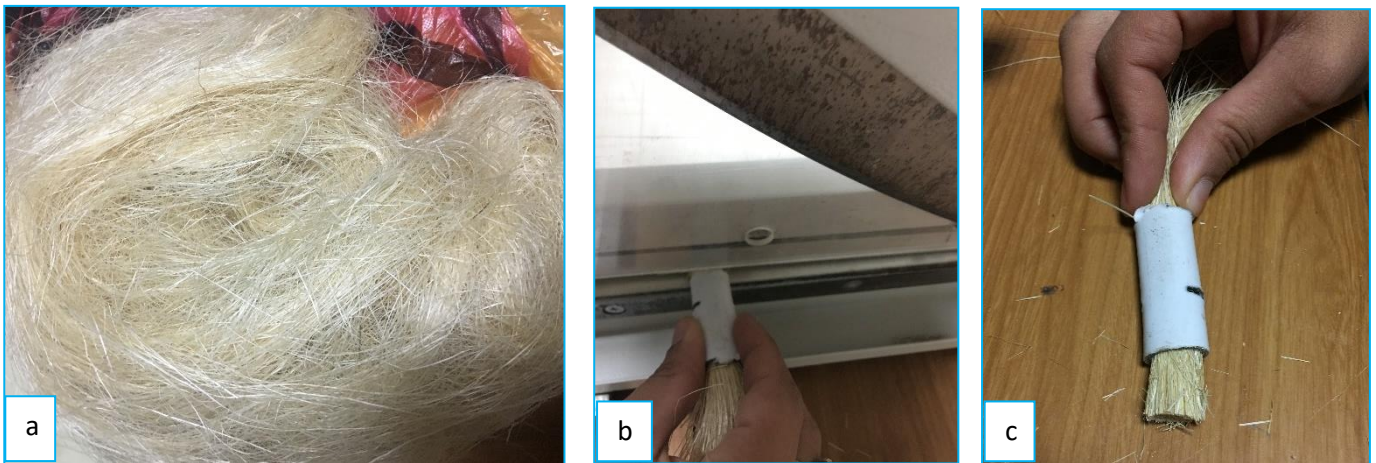


Figure II.12. Cutting the sisal fibers into different lengths.



Figure II.13. The different lengths of sisal fiber.

a) Characteristic of the sisal fibers

The tensile test is carried out in the mechanical laboratory at Laghouat University using a 5KN capacity tensile press as shown in Figure II.14. The characteristics results of fiber are given in table II.13. Figure II.15 shows the diagram force-elongation of sisal fiber.



Figure II.14. Fiber tensile test.

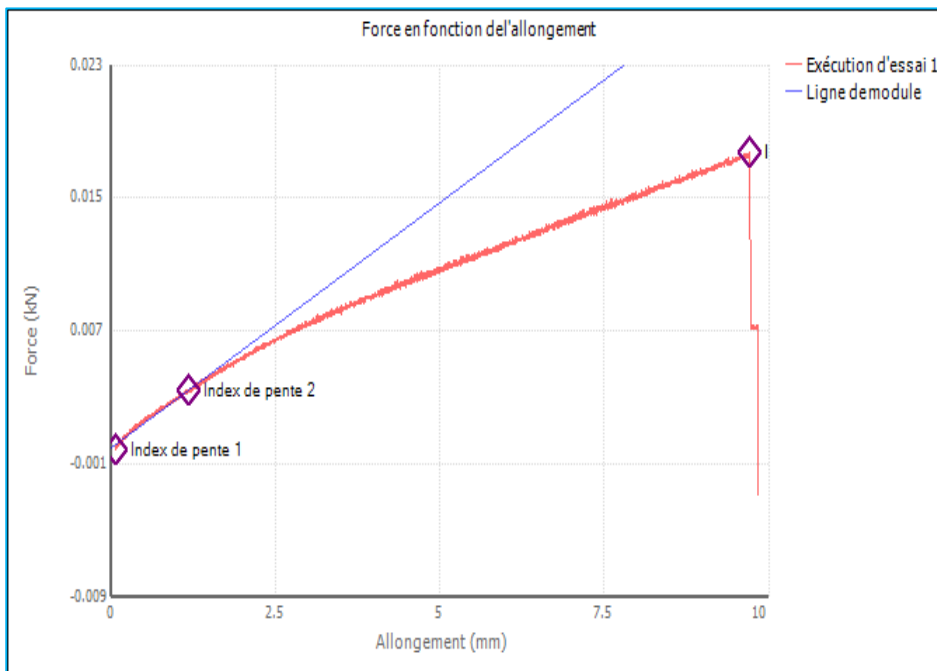


Figure II.15. Diagram force-elongation of sisal fibers.

Table II.13.Characteristic of fiber.

Properties	Values	references
Density	1,3	[37]
water absorption (%)	143,78%	
Tensile strength (MPa)	572,95	
Elasticity modulus	4,77	
Deformation at rupture (mm/mm)	0,191	
Hémicellulose (%)	9,9	
Cellulose (%)	65,8	
Lignin (%)	9,91	

II.2.6 Commercial repair product (ready-mixed mortar)

Experimental investigations were performed on commercially available repair mortars supplied by **Sika Monotrop 650**.A details of the ready-mixed mortar used are given in annex.

II.3 Experimental method

II.3.1 Mixing method of substrate concrete and repair mortars

After determining the quantities of each material in the composition of the self-compacting mortar and substrate concrete, mixing process is carried out with a mortar mixer and concrete mixer (figure **II.16**) as below:

- **Self-compacting mortar without fiber:** The beginning of the mixing is done by mixing the dry constituents (cement + marble powder + sand) for 60 seconds at slow speed, and then 70% of the mixing water is added for 30 seconds. After one minute and 30 seconds, the rest of water 30% is added with superplasticizer. The mixing continues for another 2 minutes at high speed, which ensures better dispersion of the particles, the mixture must stand for 90 seconds and then another 90 seconds at high speed. This makes a total of 7 minutes of mixing.
- **Self-compacting mortar with fiber:** For the mixing procedure of the SPM with fiber, it is the same procedure as the SCM without fiber except that the mixing time of the dry constituents (cement + marble powder + sand + fibers) 30 seconds are added, which gives 90 seconds of dry mixing. And another 30 seconds is added to the last step, which gives 120 seconds of high speed mixing. In total 8 minutes of mixing.

- **Substrate concrete:** For the mixing procedure of the substrate concrete is done by mixing the dry constituents (cement + coarse aggregate of 3/8 + sand) for 30 seconds, and then 70% of the mixing water is added for 60 seconds. The rest of water 30% is added with superplasticizer, the wet mixing is kept for 30 seconds.

After the mixture is relaxed for 90 seconds and then remixed for 90 seconds. This makes a total of 5 minutes mixing.



Mortar mixer with a 5 litres of capacity.



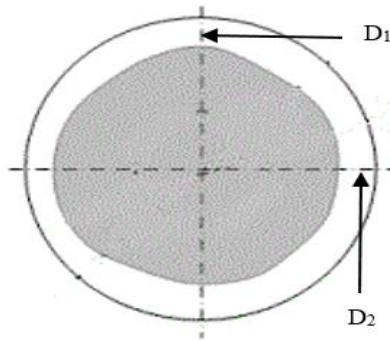
Concrete mixer with a 60 litres of capacity.

Figure II.16.used material of mixing.

II.3.2 Tests in a fresh state

a) Measure of workability

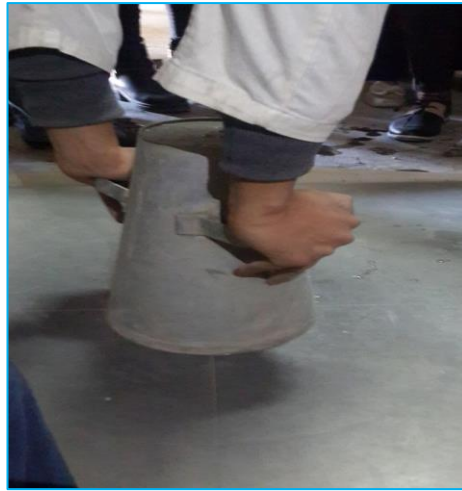
After mixing, the fresh properties of mortars were evaluated by the workability test, using the mini cone ($D= 100$ mm, $d= 70$ mm, $h=50$ mm). The diameter of the mortar slab must be between 260 and 300 mm to have a self-compacting mortar. (figII.17.a.b). Control of the workability of concrete is carried out using the Abrams cone slump test according to **EN 12350-2** [59] with an slump upper than 20 cm to obtain a fluid concrete.



a. Measure of workability



b. Mini cone mould.



c. Abrams cone slump test

Figure II.17. Workability test.

II.3.3 Tests in the hardened state

a) Preparing and curing of specimens

▪ Repair mortars :

The mortars were cast in prismatic moulds ($4 \times 4 \times 16 \text{cm}^3$). The moulds containing the specimens were covered with plastic film and stored in the laboratory environment (figII.18.a). After 24 hours of preparation, the specimens were carefully removed from the moulds, cleaned of dust and loose particles, and cured in the following environment until the age of the test:

- At a temperature of $(21 \pm 2) ^\circ\text{C}$ and $(60 \pm 10) \% \text{RH}$ for the free shrinkage test (Figure II.18.b).
- At a temperature of $(21 \pm 2) ^\circ\text{C}$ and $(60 \pm 10) \% \text{RH}$ for the endogenous shrinkage test, (the specimens used are covered with aluminum).
- In controlled chamber of $(21 \pm 2) ^\circ\text{C}$ and $(90 \pm 2) \% \text{RH}$ for the other tests (mechanical tests, modulus of elasticity, total porosity, capillary absorption, adhesion tests.) (Fig II.18.c).

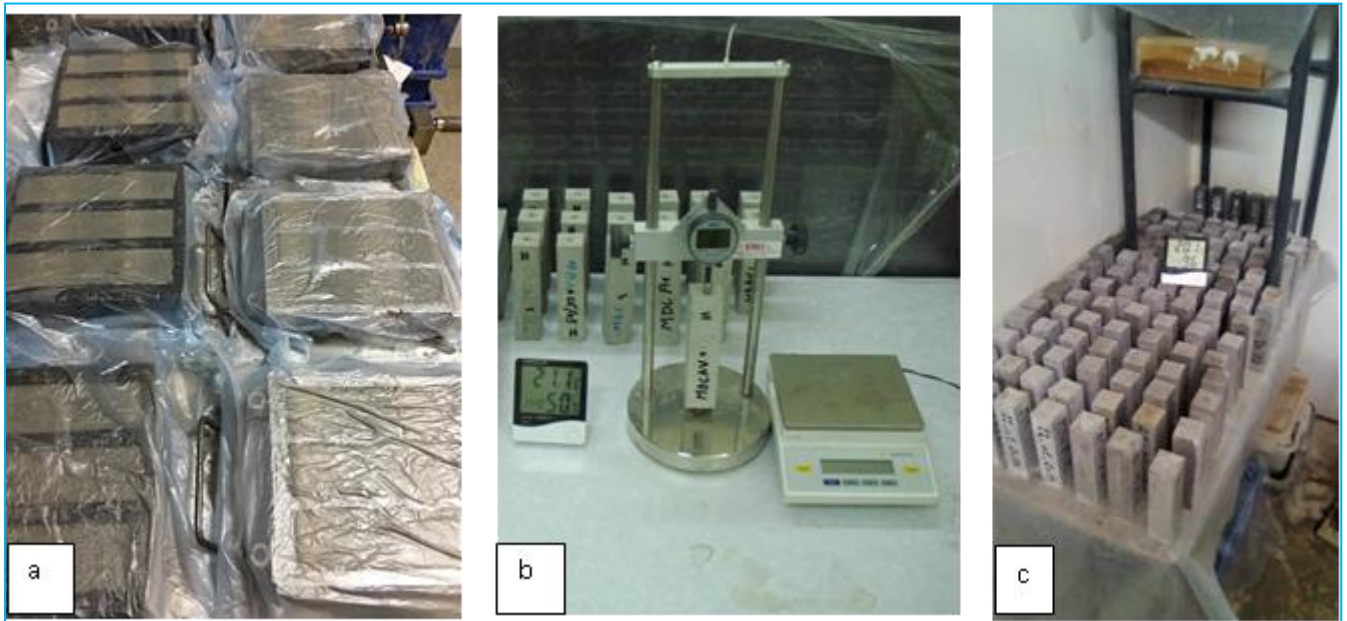


Figure II.18.Method of preservation




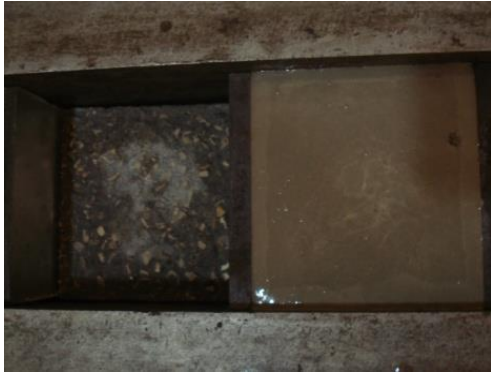
▪ Substrate concrete :

After casting, the fresh samples were sealed and left to set in the different types of moulds for 1 day. On the next day, the specimens were removed from their moulds, cleaned of dust and loose particles, and cured in the controlled chamber of $(21 \pm 2) ^\circ\text{C}$ and $(90 \pm 2) \% \text{RH}$ up to the age of the repair mortar application(28 days).

After 24 hours of the application of repair mortar, the composite specimens (concrete substrate – repair mortar) were demolded and were cured in the controlled chamber until the day of testing the adhesion test (pull-off, slant shear, splitting tensile), and at a temperature of $(21 \pm 2) ^\circ\text{C}$ and $(60 \pm 10) \% \text{RH}$ for the restrained shrinkage test.

Each of the composite specimens comprised concrete as substrate and fiber mortar as repair material. Table II.14 shows (mortar -concrete substrate) specimens.

Table II.14. Mortar –concrete specimens.

Tests	Number	Dimension of samples	(Mortar –concrete) specimens
Pull off	6	(30*30*10cm³)	
Restrained shrinkage	6	(30*30*10cm³)	
Slant shear	18	(10*20cm²)	
Split tensile	18	(10*10*10cm³)	

b) Physical-mechanical characterization of mortars

i. Mechanical properties

According to EN 196-1[60] , Mechanical tests are carried out to characterize the mortars at different ages,7,14and 28 days of age on prismatic specimens (4x4x16 cm³)using testing machine (fig II.19),with a maximum charge load of 100 KN. The acquisition and piloting are managed by a computer equipped with control software that processes the results.



Figure II.19.Testing machine.

1. Flexural strength

Third point flexural test (figII.20) is determined with a charging speed of 50 N/s by the following relation:

$$\sigma_f = \frac{1.5 * F_f * L}{b^3}$$

Where;

σ_f : flexural strength (MPa).

F_f : maximum load (N).

L: Distance between the two supports on the tension surface of the beam (L=100mm).

b: width of the beam (b=40mm).

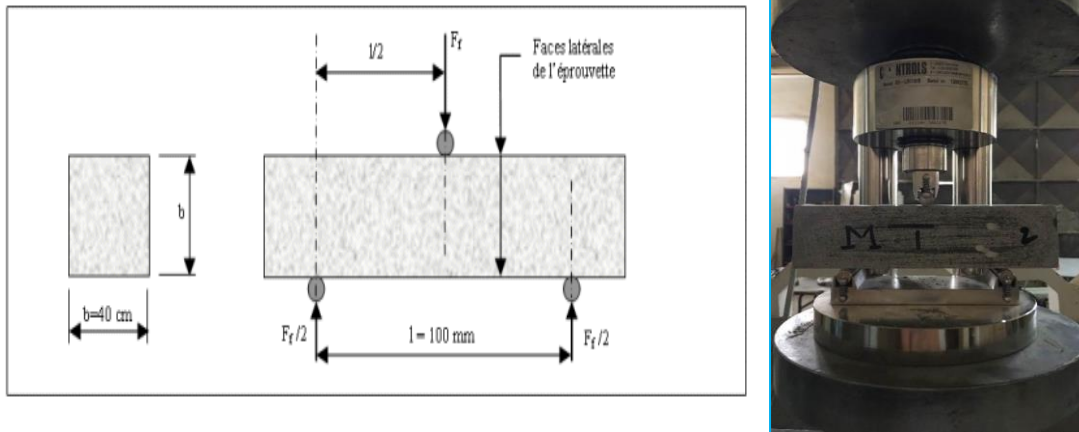


Figure II.20. Third point flexural test.

2. Compressive strength

The compressive strength test is carried out on the half prisms resulting from the bending test (fig II.21), with a charging speed of 2400 N/s. It σ_c is calculated as follows:

$$\sigma_c = \frac{F_c}{b^2}$$

Where;

σ_c : compressive strength (Mpa).

F_c : maximum compressive strength (N).

S : cross section of the beam ($b*b$ mm²).

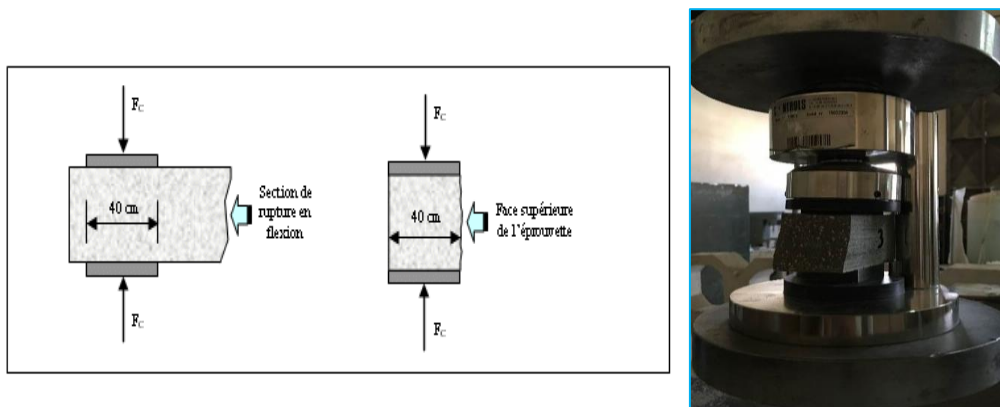


Figure II.21. Compressive strength test

ii. Total and autogenous shrinkage

According to EN 12617-4[61], total and endogenous shrinkage are measured on prismatic specimens 4x4x16 cm³ (fig II.22). The length change measurements were conducted in the 1st, 2nd, 3rd, 5th and the 7th day of the first week subsequent length change measurements were conducted every 7 days up to 28 days.



Figure II.22. Shrinkage test.

iii. Total porosity

According to ASTM C642[62], the porosity test is carried on cubic specimens (40x40mm²); the cubic specimens were immersed in water for 24 hours (fig II.23.a), after which they were dried in an oven at 80°C (fig II.23.b). The porosity is determined by the following:

$$P = \frac{M_{sat} - M_s}{V_t}$$

Where;

P: total porosity.

M_{sat}: the saturated mass (g).

M_s: dry mass (g).

V_t: total volume (cm³).



Figure II.23. Total porosity test.

iv. Ultrasonic

Ultrasonic non-destructive testing (figII.24) is technique frequently used to estimate the quality and to determine the dynamic modulus of elasticity of concrete or mortar according to EN 12504-4[63]. This method is based on the measurement of the wave propagation speed which allows us to determine the dynamic modulus of elasticity E_d by the following equation:

$$E_d = V^2 \rho \frac{(1 + \nu)(1 - 2\nu)}{(1 - \nu)}$$

With;

E_d : dynamic modulus of elasticity (GPa).

ρ : density (kg/m^3).

ν : poisson coefficient.

V : the speed of wave propagation (m/s).

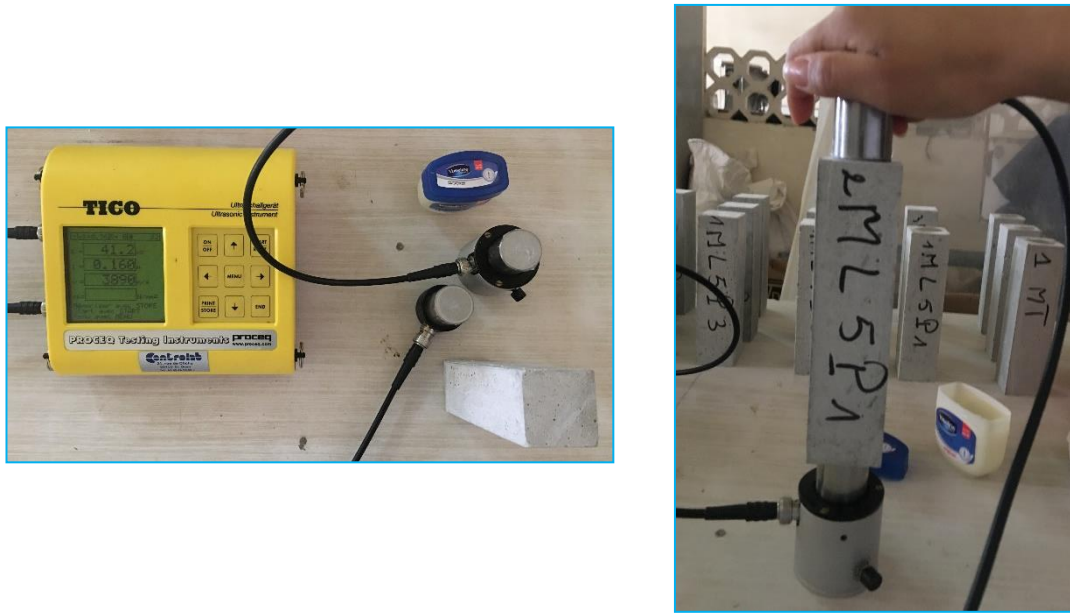


Figure II.24. Ultra Sonic equipment.

vii. Capillary water absorption

The capillary water absorption test (figII.25) is used to characterize the capacity of a mortar to absorb and transmit water. The test is carried out on prismatic samples (4x4x16 cm³) according to **EN 1015-18**[64] previously dried in the oven at about 80°C to constant weight. The lateral side of the specimens was sealed with adhesive aluminium to obtain a unidirectional flow. The water level during the test was kept constant and 5 mm above the surface of the specimen in contact with water. The weight of the samples is measured at different times: 0,15,30,60,120,240,360,480 and 1440 min, after 28 days of curing.

The capillary absorption coefficient (sorptivity) is obtained using the following relation:

$$C_c = \frac{M}{S * \sqrt{t}}$$

Where,

C_c : Capillary absorption coefficient (g.cm⁻².min^{-1/2}).

M: the volume of water absorbed by the specimen (g).

S: the cross-sectional area of each specimen (cm²).

t: the time of exposure (min).

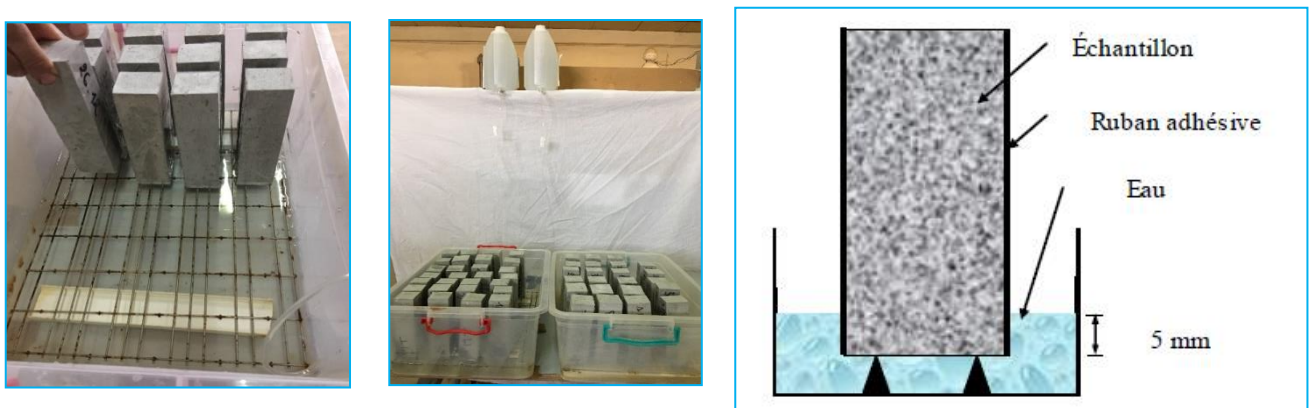


Figure II.25. Capillary absorption test set-up.

viii. Adhesion tests

There are a various test methods that can be used to the evaluation of the adhesion of concrete-repair mortar .On our project, of pull-off, splitting and slant shear tests were used for evaluate de adhesion strength.

1. Slant shear test

The Slant shear test is one of the most common methods used to assess the bond strength between repair mortars and old concrete (substrate). According to **ASTM C882**[65], the test (figII.26) uses a cylindrical sample (100 mm diameter, 200 mm high) made of two similar half –specimen .Each part has a diagonal surface of 30^0 to the vertical. The bond strength is evaluated under combined compressive and shear stresses.

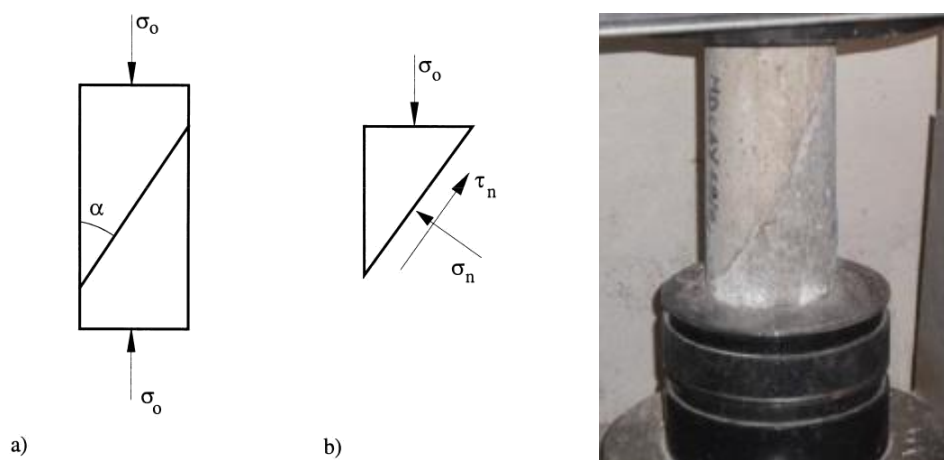


Figure II.26. Slant-shear configuration.

The bond strength for the slant shear was calculated by dividing the maximum measured load by the bonded area, which can be expressed as:

$$\sigma_l = \frac{2F_l}{\pi A}$$

Where σ_l is the bond strength (in MPa); F_l is the maximum recorded force (in N); and A is the area of the slant surface (in mm²).

2. Pull-off test

The pull-off test (fig II.27) is a common tensile test method used to assess the bond strength between the repair overlay and the existing concrete substrate. According to the standard BS EN1542[66], the pull-off test was chosen for reasons to evaluate the bond strength at the tension of the interface. Five pull-off tests were performed for each substrate-repair slab, by drilling 50 mm cores of diameter. Steel disc were glued over the drill spots using an epoxy bonding agent. The pull-off tests were carried out using a Pull-off equipment. The load was manually applied at a rate of 0.05 MPa/s.

The pull-off bond strength (σ_p) was calculated by dividing the tensile (pull-off) force at failure (F_p) by the area of the fracture surface (A), as shown in Equation

$$\sigma_p = \frac{F_p}{A}$$

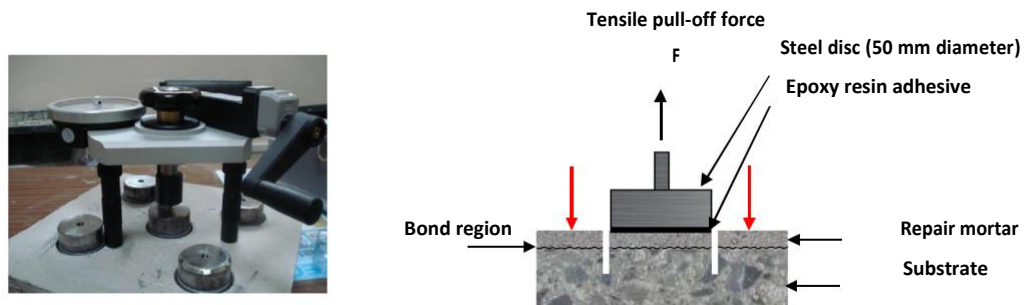


Figure II.27. Pull-off test schematic representation.

3. Splitting tensile strength

The splitting tensile test was carried out on cubic specimens (10x10x10) cm³ according to EN 12390-6 [67] in order to determine the bond strength (concrete substrate/repair mortar). It is an indirect tensile test using the same machine as the three point bending test. The loading is applied steadily at rate of 0.05 Mpa/s. The cubic specimens, shown in fig II.28, were obtained after cutting the composite half-prisms resulting from the bending. The splitting tensile strength σ_T is calculated using the equation:

$$\sigma_T = \frac{2F_T}{A\pi}$$

Where; σ_T is splitting tensile strength (MPa), F_T is the applied force (N); A is the area of the bonding surface (bxb) mm².

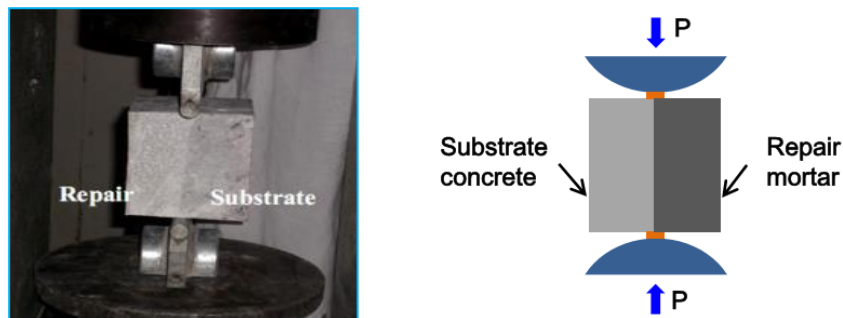


Figure II.28. Splitting tensile specimen.

4. Restrained shrinkage test

In order to verify the effect of restrained shrinkage on the adhesion between the repair mortar and the concrete substrate, pull-off tests were carried out according to the standard EN 1542[66]. The pull-off bond tests were conducted after 28 days of cured at a temperature of (21 ± 2) °C and (60 ± 10) % RH.

II.4 Conclusion

In this second chapter, we have presented the materials and experimental methods used in this study. The characterization of the materials allows us to obtain a material of good quality, it shows that:

Chapter II Materials and experimental program

-The aggregates used have a good properties; it can be used for concretes and mortars with a good physical behavior;

- Dune sand is siliceous and very clean sand.
- Limestone and river sand are clean sands.
- The gravel of granular class 3/8 is fine coarse aggregates.

-Sisal fibers have an absorption rate of 143.72%.

- The cement used meets the specifications of current cements.

-The potable water is acceptable for mixing concrete or mortars.

-The used superplasticizer improves the workability of mortar.

Approximately, 150 prismatic specimens, 12 slabs, 27 cylindrical sample, 25 cubic specimens were made for this work.

Chapter III

Results and discussions

III.1 Introduction

This chapter presents the experimental results obtained from different tests, and a discussion of them. All the test methods for evaluating the dimensional compatibility of different mortars have been analyzed concerning the total, drying and autogenous shrinkage, modulus of elasticity. The properties of the repair mortars at hardened state are also analyzed for compressive, flexural strengths, capillary water absorption, and total porosity.

A presentation of test results of the bond strength between the repair mortars and substrate concrete determined by the pull-off testing, slant shear and splitting tensile tests are given.

A detailed discussion and analysis of the repair mortars and its composition are presented in chapter three with regard the literature results.

III.2 Composition of self -compacting repair mortars (SCRM)

The formulation of the self-compacting mortars is that developed at the University of Kochi. It uses it to obtain fluid mortars and at the same time stable compositions against the phenomenon of segregation. Fluidity of mortars can be obtained by introducing high water-reducing superplasticizers. The principle of this approach is based on the following conditions:

- Volume limitation of the aggregates;
- Decrease of W/B ratio;
- Use of superplasticizers.

15 mixes are prepared by varying the percentage of superplasticizer (Sp) with the same water to bind ratio (W/B). A fiber dosage of 0.2 % by volume, which is previously fixed (**Mhissat and Mahçar,2019**)[37] is used in this work ,due to the good results have been found either in shrinkage or in flexural strength. Mixtures are prepared as follows:

- The volume of sand (V_s) is about 50% of the volume of mortar (V_m), so $V_s/V_m=0.5$.

- In our work we replaced 15% of the cement by marble powder.

-The chosen W/B ratio is equal to 0.4, which gives the desirable workability of self-compacting mortars with a spreading of about (28±2 cm).

- Find out the percentage of superplasticizer (Sp) which gives the desirable workability of fiber mortar, with a same W/B and a percentage of fibers of 0.2% (with 5, 10, and 20 mm in length or cocktail). Table (III.1) gives the designation of the different mortars.

Table III.1 .Designation of the different mortars.

NOTATION	DESIGNATION
CM	Control mortar
M 50 25 25	0.2 % fiber-reinforced mortar with 50 % of short fibers (5mm) and 25 % of (10mm) in length and 25 % of macro fibers (20mm).
M 100 0 0	0.2 % fiber-reinforced mortar with a length of 5mm.
M 0 100 0	0.2 % fiber-reinforced mortar with a length of 10mm.
M 0 0 100	0.2 % fiber-reinforced mortar with a length of 20mm.
RMM	Ready -mixed mortar.

III.2.1 Composition of control mortar (without fibers)

The mixture **CM** is control mortar. It needs an acceptable water dosage and a superplasticizer percentage lower than those fibers mortars. The table (III.2) gives the composition of control mortar.

Table III.2. Composition of control mortar.

	C	MP	DS	CS	SP	W	Fibers
	(g)	(g)	(g)	(g)	(%)	(g)	(g)
CM	575.58	102.68	776.66	520.34	0.84	293.56	0.00

III.2.2.Composition of fibers mortars

With the same composition of control mortar, fiber mortars are prepared with a new optimization of superplasticizer to obtain the desirable workability. All the constituents of different types of mortars are presented in the annex .We illustrate only the composition of 0.2 % fiber-reinforced mortar. Table.III.3 presented the composition of fibers mortar

Table III.3. Composition of fibers mortars/L.

N°	Mixes	CS (g)	DS (g)	C (g)	MP (g)	SP (%)	W70 (g)	W30 (g)	L5 %	L10 %	L20 %
1	M 50 25 25	518.24	773.52	575.58	102.68	0.86	206.81	88.63	50	25	25
2	M 100 0 0	518.24	773.52	575.58	102.68	÷	206.88	88.66	100	0	0
3	M0 100 0	518.24	773.52	575.58	102.68	0.9	206.78	88.62	0	100	0
4	M0 0 100	518.24	773.52	575.58	102.68		206.75	88.61	0	0	100
5	RMM	2000.00					320.00		0.00		

III.3 Composition of substrate concrete

The substrates are made of fluid concrete; their composition is determined by the Dreux Gorisse formulation method (Dreux, 1995). The mixed proportions are given in the following table.

Table III.4. Substrate concrete proportions.

Cement (kg/m ³)	380
Sand (kg/m ³)	847
Gravel (kg/m ³)	1011
Water (l/m ³)	186.5
Superplasticizer %	3.4
Slump (cm)	> 20
Flexural strength (MPa)	7.5 ± 0.4
Compressive strength (MPa)	33±2

III.4. Mechanical properties of self –compacting repair (SCRM) mortars

III.4.1.Compressive strength

The values of the compressive strength at 7 and 28 days are presented in the figure.III.1 and III.2, respectively. It should be noted that the maximum values of compressive strength are obtained in control mortar, at any age, which means that the effect of fibers is negligible on the compressive strength at 7and 28 days, while the minimum values are obtained in ready mixed repair mortar.

At 7 days, a decrease was observed in the compressive strength of composites with the increase of fiber length. These decreases are 5, 14 and 21% for M10000, M01000, and M00100, respectively, compared to the control mortar (without fiber). This could be due to the presence of voids at the cement–fiber interface, as reported by some authors **John and Naidu** [68].

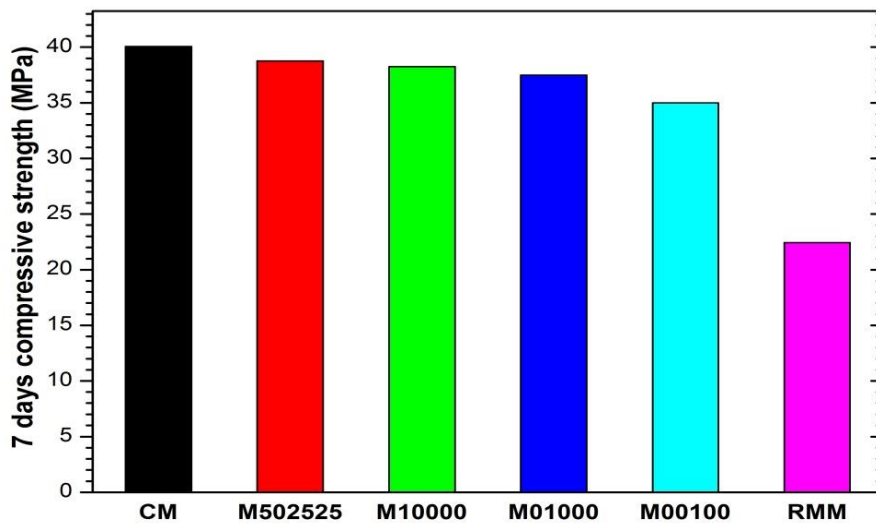


Figure III.1.Effect of sisal fibers on compressive strength at 7days.

Observing to figure.III.2 ,it can remarked that the compressive strength values are similar in fibers mortars at 28 days .Moreover ,it can mention that the compressive strength values of all mortars, except the RMM, are greater than 45MPa which is the strength value recommended by the **1504-3** standard.

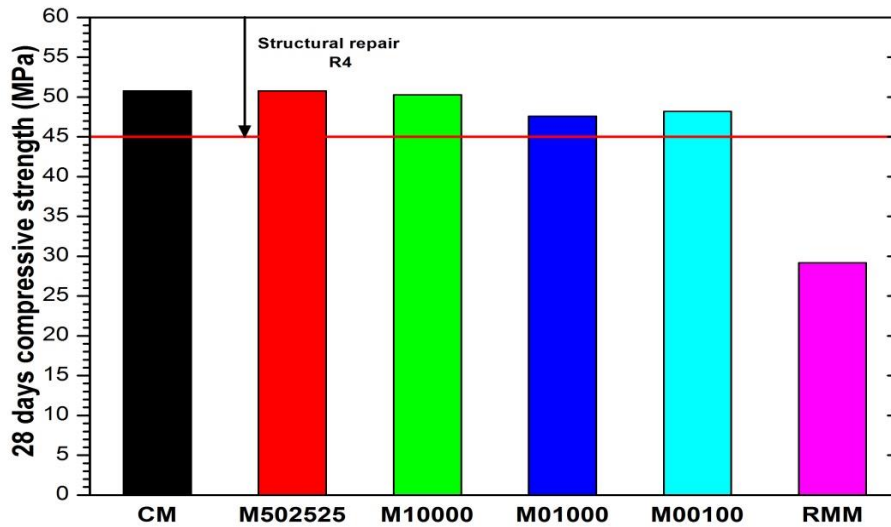


Figure III.2. Effect of sisal fibers on compressive strength at 28days.

III.4.2 Flexural strength

Figure.III.3and III.4 show the effect of adding sisal fibers on the flexural strength of mortars at 7 and 28th days of age, respectively. Generally, the result shows the positive effect of sisal fiber reinforcement in the matrix.

The value of flexural strength was found maximum in the mortar M 00100 (6.4MPa), while the minimum was found with the mortar CM (6MPa) at 7 days. Observing to figure III.4, it seems that the composite M00100 gives the best flexural behavior about (8 MPa) at 28 days, compared to the control mortar (7.2Mpa) which means that the fibers of sisal have significantly changed this behavior by improving the toughness of repair mortar.

However, by increasing the length of the fiber from 5 to 20 mm, the tensile and flexural strength of the epoxy resin composite are increased, as reported by **Joseph et al**[69], the result is in accordance with **Maurya et al**[46] and **Filho et al**[44].

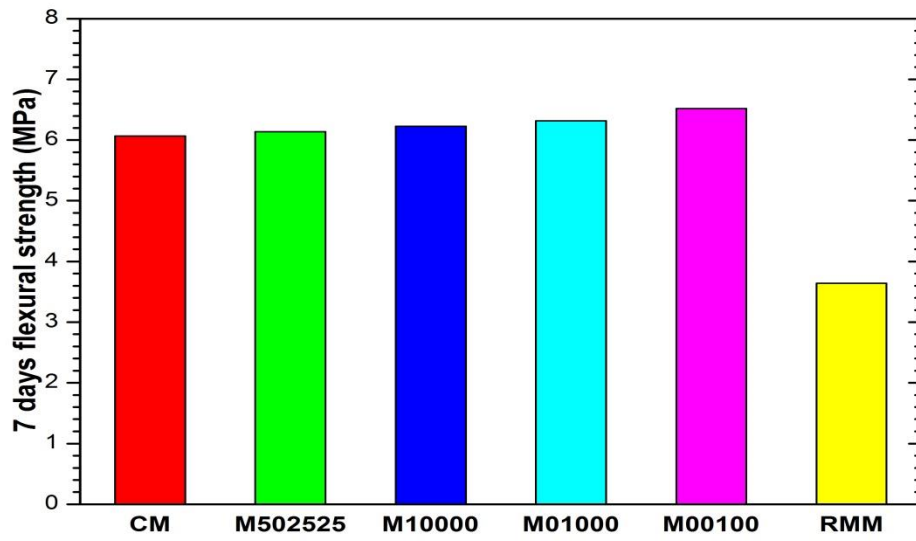


Figure III.3. Effect of sisal fibers on the flexural strength at 7days.

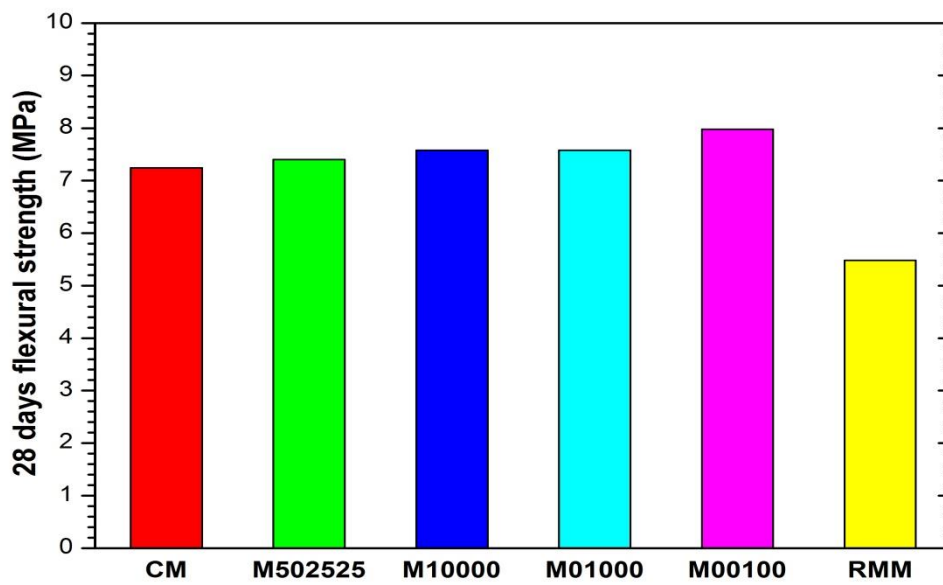


Figure.III.4. Effect of sisal fibers on the flexural strength at 28days.

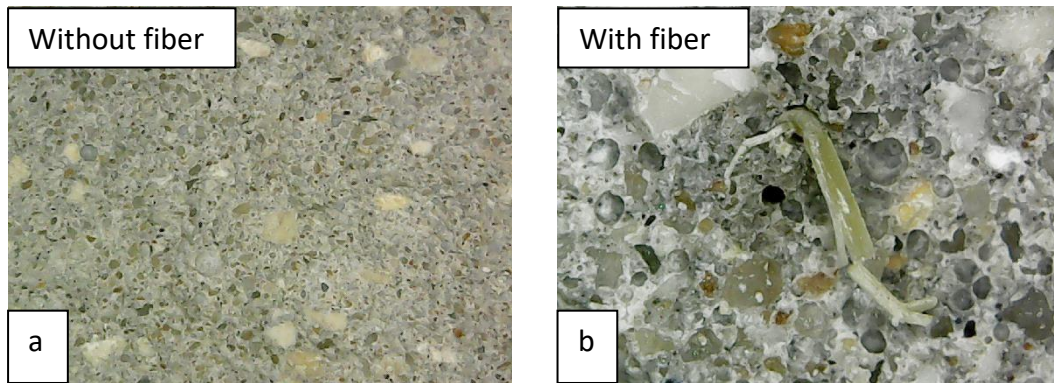


Figure III.5. A microscopic view of the samples.

Figure III.5 shows a microscopic view of the samples obtained from the flexural strength test. It is noted that the control mortar (Figure III.5.a) is less porous than the fiber mortar (Figure III.5.b). Therefore, No pullout problem is observed during the flexural test in all mortars. This may be due to the better adhesion between the fibers and the matrix and to the sufficient fiber length used in this work.

III.5 Dimensional compatibility

III.5.A Shrinkage

III.5.A.1 Total shrinkage

Total shrinkage evolution as a function of the time for the different types of mortars is given in figure III.6. It can be seen that a large amount ($\cong 70\%$) of total shrinkage deformation is developed after one week. Then it has hardly evolved until the stabilization nearly to 1200 $\mu\text{m}/\text{m}$. It's clear that the ready mixed mortar (RMM) and the mortar M00100 exhibit greater shrinkage compared to the other mortars. The mortar M10000 gives the lowest shrinkage compared to other mixes, with a decrease of 4.40% , 2.1% and 3.1% compared to that of control mortar (without fiber) at 3, 7 and 28 days respectively, which means that the addition of short fibers (5mm of length) leads to evolve the positive effect of fibers on shrinkage. For the M502525, M00100 and RMM mortars, an increase of 3%, 9.1% and 9.7% respectively was observed in the total shrinkage at 28 days compared to the control mortar.

Similar results were found by **R.D. Tolêdo Filho et al**[44] concluded that all fibers used today for the purpose of controlling the shrinkage cracks. **Shekarji et al** [12] reported that there is a direct relationship between stability of the mortar and control of the shrinkage by fiber addition.

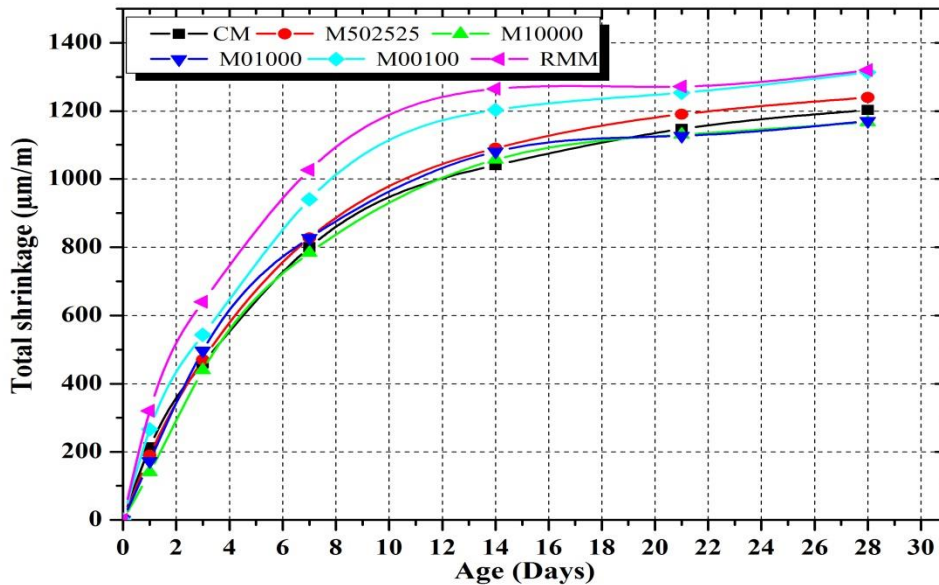


Figure III.6. Variation of total shrinkage with age.

III.5.A.2. Autogenous shrinkage

The results of the autogenous shrinkage obtained up to 28 days are presented as it can be seen in the figure.III.7. The evolution of the autogenous shrinkage ratio with time was generally high during the first three days and then continued afterward to approach a stable value. It can observe that generally fibers mortars reduce the autogenous shrinkage.

The autogenous shrinkage was found maximum with the mortar M00100, an increase by 18% compared to control mortar .A significantly lower autogenous shrinkage value is found for mix RMM during the first fourteen days, then at long term the M10000 gives the lower autogenous shrinkage value of 175 µm/m. It must be noted that the introduction of the fiber into the mortar allowed significantly more efficient crack control.

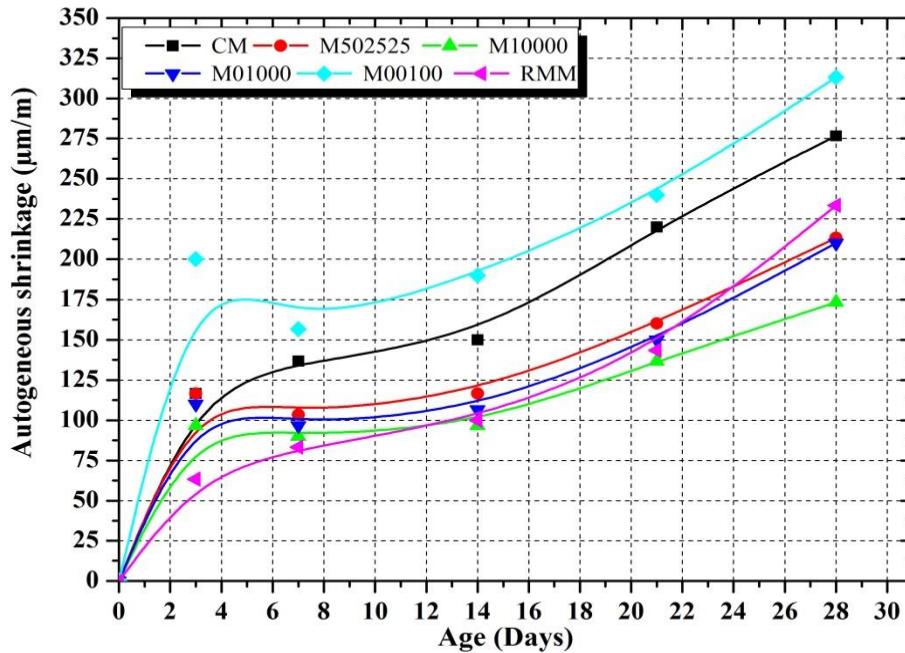


Figure III.7. Variation of autogenous shrinkage with age.

It was shown that at high addition, the sisal fibers had a mitigating effect on autogenous shrinkage, due to their low absorption capacity. In this sense, it is reported that **Kawashima & Shah**[45] cellulose fibers have the capacity of internal curing to prevent the endogenous shrinkage in cementitious matrix. It is in agreement with the results of the endogenous shrinkage.

III.5.A.3. Drying shrinkage

Drying shrinkage is analogous to endogenous shrinkage. Figure III.8 presents the variation of drying shrinkage with time. It remarked that the drying shrinkage develops rapidly with age, especially during the first week ($\cong 70\%$); then it continues to evolve slowly until the stabilization 1000 $\mu\text{m}/\text{m}$.

The results indicate that the higher drying shrinkage was achieved in ready-mixed mortar RMM, an increase by 17.3 % compared to control mortar at 28 days. While the results of fibers mortar and control mortar are similar which means that the fiber addition have not an effect on drying shrinkage.

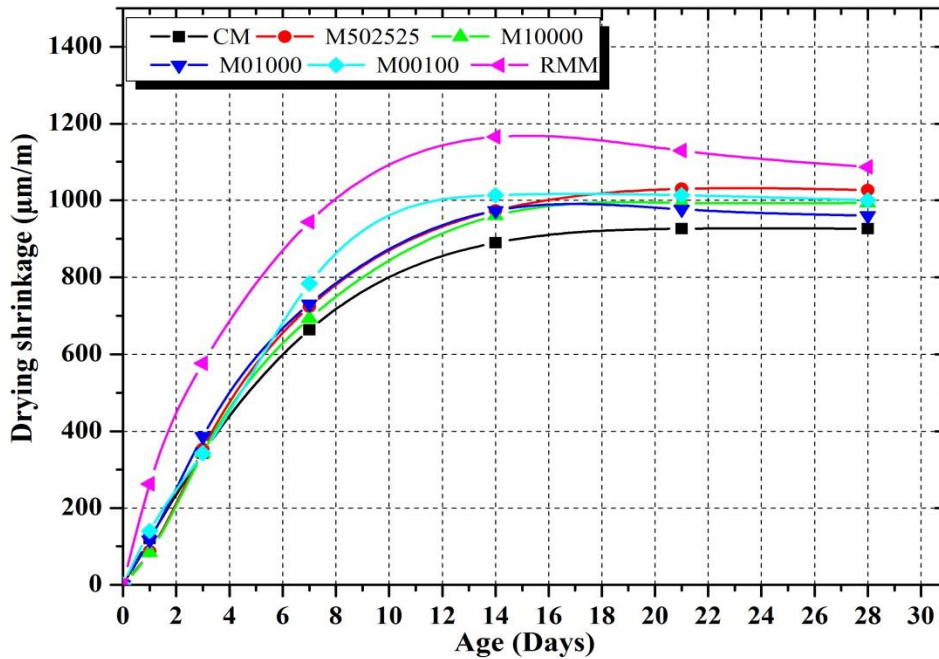


Figure III.8. Variation of drying shrinkage with age.

The cellulose fibers were not found to affect drying shrinkage, but they are effective in mitigating drying shrinkage-induced cracking when adequate dispersion is achieved, as indicated by other authors **Kawashima & Shah**[45]. This is in agreement with the results of the autogenous shrinkage test.

III.5.B. Dynamic modulus of elasticity

Modulus of elasticity is an important parameter to describe the relative rigidity or stiffness of the material. Figure.III.9 and III.10 presented the dynamic modulus of elasticity results at 7, 28 days, respectively. It can be seen that, the dynamic modulus of elasticity of ready mixed mortar is lower than the modulus of elasticity of other mortars while the control mortar gives the higher modulus, at any time.

The values of dynamic modulus increased with the decrease of fiber lengths as can be observed from the fig.III.10. A percentage decrease in E_d of 6.45 % and 10% could be seen for M00100 and M00100, compared to control mortar (CM). It can be explained that increase in voids in mortars due to the addition of fibers results in a decrease of the modulus of dynamic elasticity.

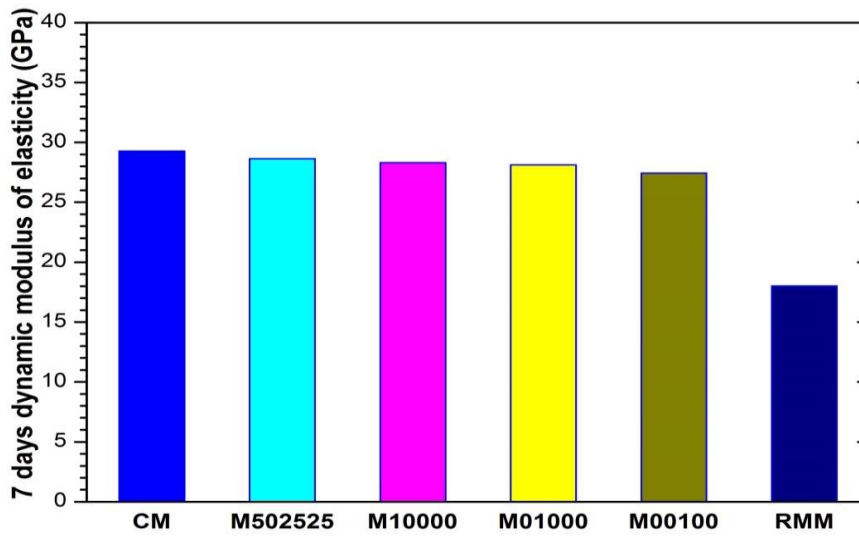


Figure III.9. Dynamic modulus of elasticity results of different mortars at 7 days.

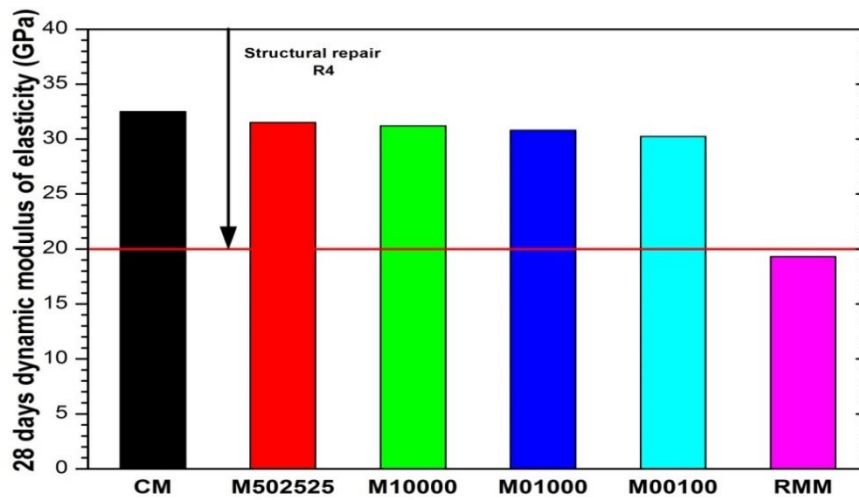


Figure III.10. Dynamic modulus of elasticity results of different mortars at 28 days

These results are in correlation with **Ali et al** [70] observed that the modulus of dynamic elasticity decreases with increasing the fiber content or the length of the fibers. In general, the modulus of elasticity remains higher than the value of 20 GPa required by the standard **EN 1504-3**.

III.6 Adhesion

In order to achieve more reliable results of adhesion, for each specific repair material there were five specimens in pull-off test, three specimens in splitting prism test and three specimens in slant shear test. The results were reported for each test method and each repair material.

III.6.1 Pull-off

The adhesion strength of repair mortar and concrete is one (if not the first) of the most important technical characteristics of repair materials. The pull-off bond stresses and the failure modes obtained for the different mortars tested at 28 days are presented in table III.4. Figure.III.11 shows the bond strength results obtained by pull-off test of different mortars.

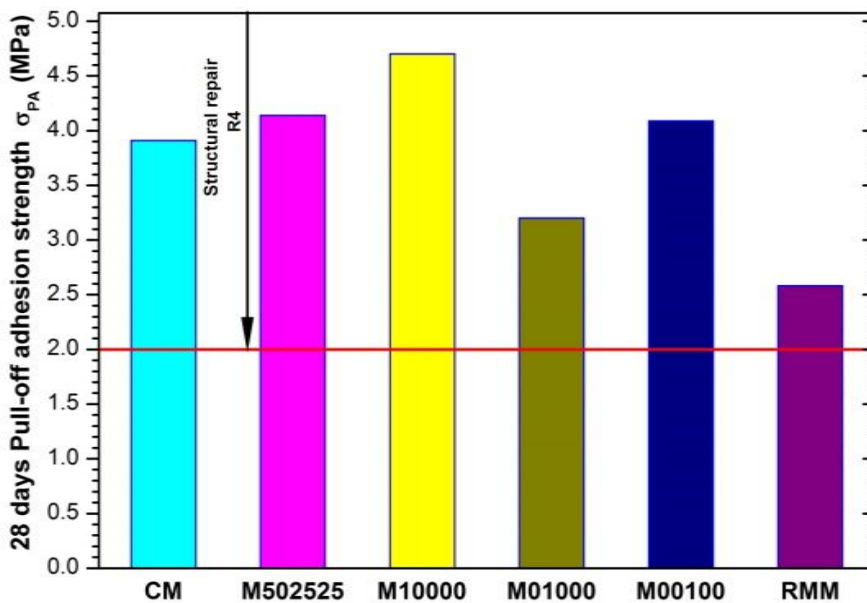


Figure III.11. Bond strength results obtained by pull-off test of different mortars.

From the results in figure.III.11, it can be remarked that the adhesion between the ready mixed mortar (RMM) and substrate concrete is characterized by lower bond strength (2.6 MPa) compared to all fiber mortars and control mortar (MC). This may be due to the low hydration rate, which leads to weak chemical bonds and low cohesive forces which decrease

the bond strength. These results proved that mortar M100/0/0 has an excellent bond strength (4.5Mpa) which improves the good dispersion of short fiber.

Table III.5. Bond strengths and failure modes of mortars tested.

Type of mortar	Average bond stresses (MPa)	Failure mode
CM	3.9	In substrate
M502525	4.1	In substrate
M10000	4.6	In substrate
M01000	3.1	In substrate
M00100	4.00	In substrate
RMM	2.6	Interface (concrete-mortar)

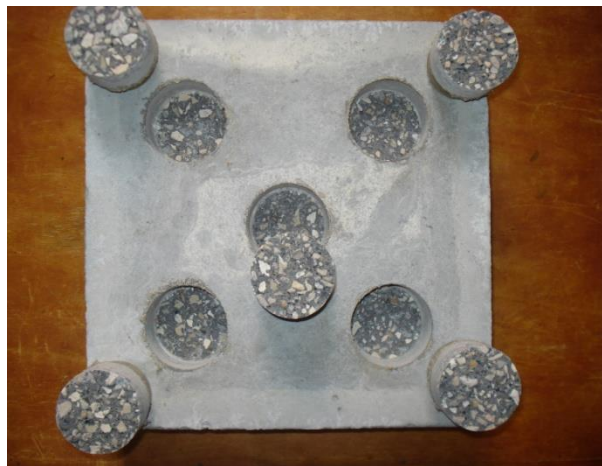


Figure III.12. Failure modes of pull-off test in substrate.

All our samples have the same concrete failure mode (in substrate), except the RMM (in interface concrete-repair mortar) as shown in figure. III. 12, which means that the results obtained for the developed repair mortars show only the tensile strength of concrete. Thus, it can conclude that these results cannot prove the effect of sisal fibers in mortars cause the tensile strength of concrete is lower than the tensile strength of our mortars. Therefore, a failure that occurs in the concrete substrate indicates that the bond strength is greater than that of the substrate concrete. For the RMM mortar, the failure strength estimated is the bond strength. Moreover, whatever the type of mortar, the bond strength is greater than the minimum value (2MPa) for structural repair (**R4**) required by the standard **EN1504-3**. In

addition, Momayez et al.[71] have concluded that the pull-off test provides the most conservative bond measurement because it is not influenced by friction or other forces that are present in other methods .

III.6.2 Slant shear

The bond strength of slant shear was calculated by dividing the maximum load by the bond area .The bond strength results obtained by slant shear test of different mortars are shown in figure.III.13. Clearly show that the additions of short fibers have significant influence on the shear bond strength. Compared to the control mortar, the recorded bond strength decreases in the order of M00100 and RMM by 43.25%, 37.5%, respectively.

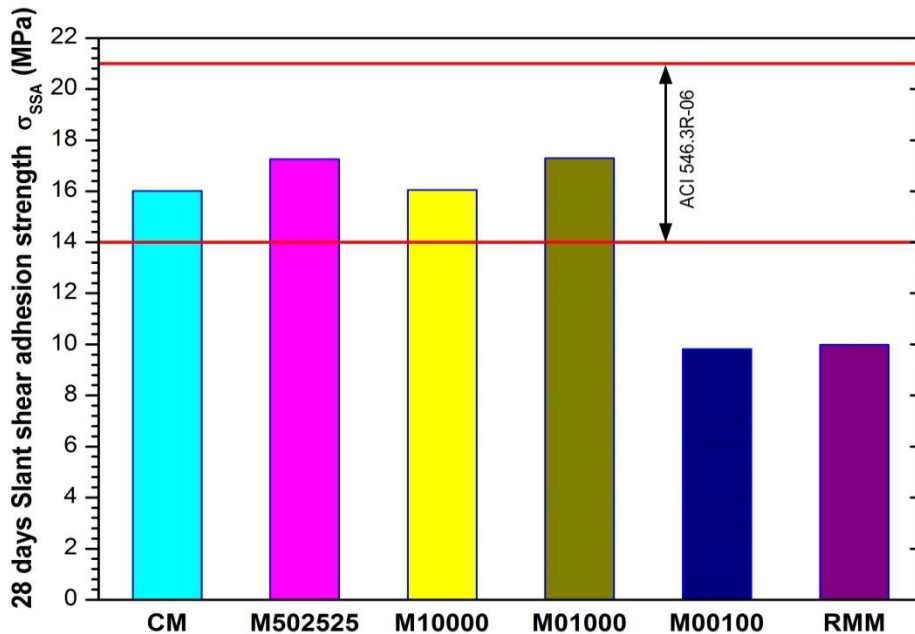


Figure III.13. Bond strength results obtained by slant shear test of different mortars.

Thus, the addition of fibers enhances the bond strength by between 3 and 12.5 %, The **ACI 546-3R-06** Concrete Repair Guide specifies an acceptable bond strength in the range of 14–21 MPa, for slant shear test at 28 days in selecting appropriate repair materials.

III.6.3. Splitting tensile strength

The splitting tensile test provides a measure of the indirect tensile capacity of the composite interface. The results obtained from the splitting tensile test when applied to composite cubic

specimens at 28 days are shown in figure.III.14. The bond strength is the average of three values obtained from different test specimens.

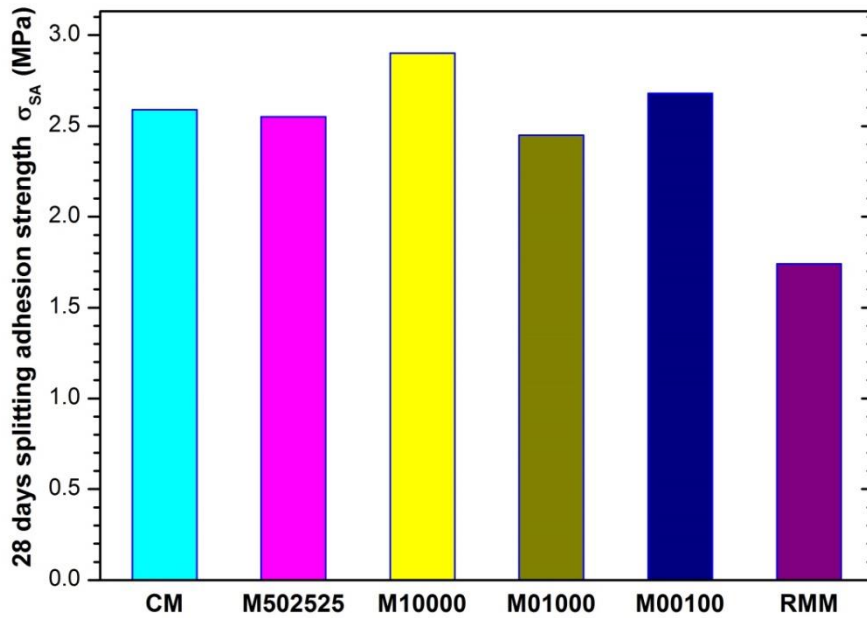


Figure III.14. Bond strength results obtained by splitting tensile test of different mortars.

One may clearly see from the figure.III.14 that the maximum strength value (2.9 MPa) was obtained for M10000 mortar, while the minimum value of the splitting tensile strength with RMM was 1.7 MPa. The bond strength of M10000 and M00100 mortars increased by 11.54% and 4%, respectively, than that of CM mortar. Contrariwise, it can be seen that mortar RMM has lower adhesion strength than that of mortar CM of about 34%.

It was found that the high bond strengths were recorded with the M10000 repair mortar, which shows the good distribution of short fibers in the matrix and improves the compatibility between the repair mortar and substrate concrete.

These values were found greater than 2.1 MPa, which represents an excellent bond quality, in terms of bond strength, according to the classification of the bond quality proposed by Sprinkel and Ozyildirin[72]. In addition, the European Standards **EN 1504–3** indicates that the tensile strength (bond strength) must be at least 2 MPa in the case of structural repairs, and 1 MPa in non-structural repairs. The results obtained in this study are satisfactory as they are all greater than 1.5 MPa.

III.7. Effect of shrinkage on adhesion strength

The pull-off test is one of the most important tests to improve the durability of concrete repair. The durability of repair mortar is strongly affected by cracking due to drying shrinkage and the quality of the adhesion with the substrate. A good quality bond between a repair mortar and concrete substrate is an important requirement for assessing efficiency of repair. The effect of shrinkage on bond strength is studied in this parameter. Figure III.15 summarizes the pull –off bond strength after 28 days of different mortars. From the results, it is clear that the bond between repair mortars and concrete gives excellent results. The bond strength σ_{PA} enhances with the increase of fiber length. An increase of pull –off bond strength with M00100 of by 5.71 %, compared to CM control mortar.

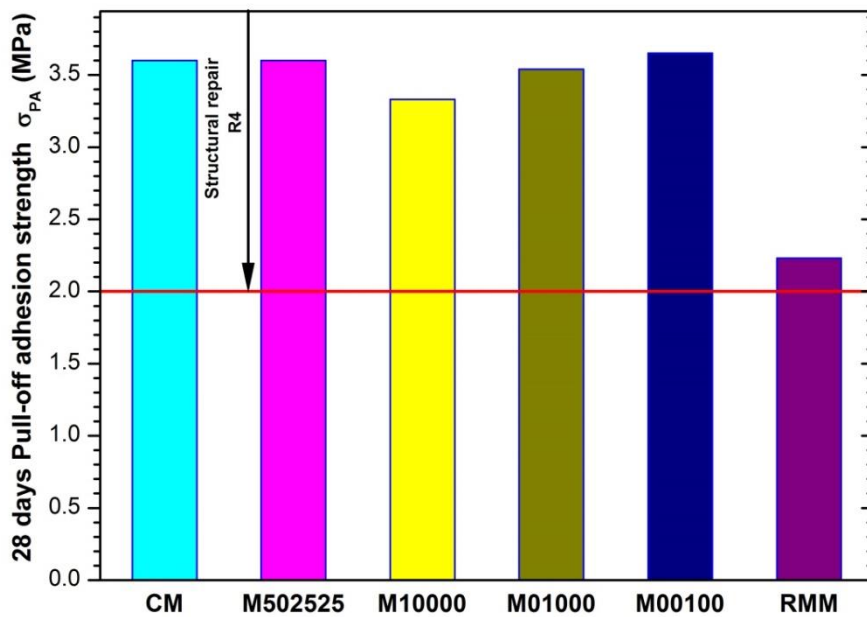


Figure III.15. Effect of shrinkage on adhesion strength.

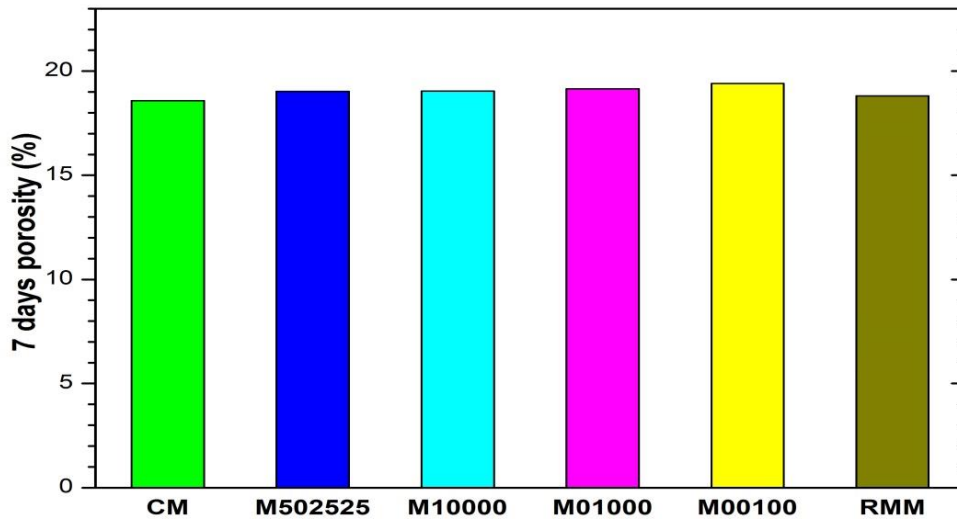
Moreover, it can mention that the bond strength values of all mortar are greater than 2 Mpa, which explains that the good dispersion of fiber limited the cracks caused by shrinkage, these last one effected on the interface (mortar-concrete) zone ‘overlay interface zone. **Krobba et al**[73] reported that the rate of cracking caused by the shrinkage is one of the factors affecting the adhesion between mortar and concrete.

All developed repair mortars samples have the same failure mode (in substrate), which means that the results obtained show only the tensile strength of concrete. Thus, these results cannot prove the effect of sisal fibers in mortars cause the tensile strength of concrete is lower than the tensile strength of our mortars. For the RMM mortar, the failure mode in the interface strength estimated is the bond strength.

III.8.Durability

III.8.1. Porosity

Porosity is often used to characterize the resistance to penetration of substances in concretes and mortars. Porosity influences concrete properties such as compressive strength, permeability, shrinkage and creep. In the light of durability, porosity has a significant influence on transport properties. The porosity values of fiber reinforced mortars increase with an increase of fiber length as shown in Figure III.16 .The M00100and M01000 mortars are slightly higher by 12.5%, 6.25%, respectively, compared to ready mixed mortar at 28 days. However, there is no notable difference in porosity between control mortar and fibers mortars.



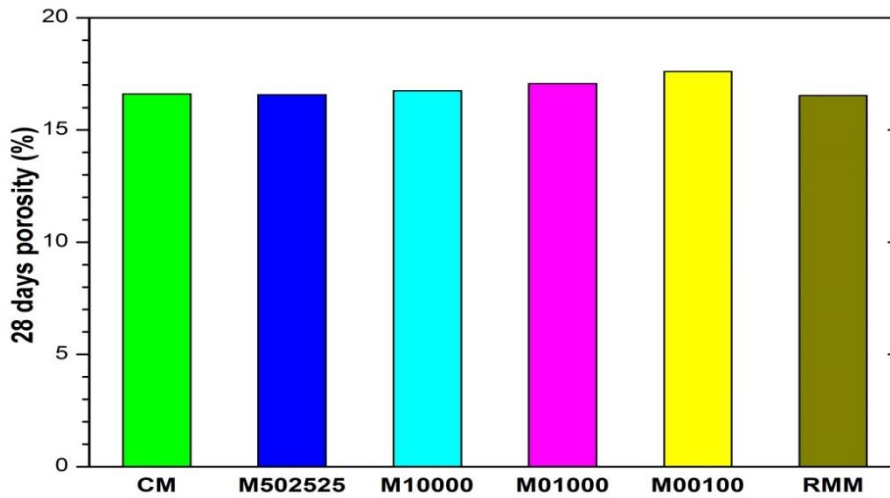


Figure III.16. Porosity results of different types of mortar.

It can be explained that the increase in fibers length leads to disturbance of the grain arrangement which influences directly on the compactness and consequently increases the porosity. **Aamer Bhutta et al** [74] concluded that it is possible that fibers tend to clump together during mixing, entrapping water-filled pores that subsequently turn into voids. These results are in agreement with **Dawood et al**[75].

III.8.2. Water absorption by capillary (sorptivity)

The water absorption by capillary is one of the tests which are used to measure the durability-related transport process. The sorptivity is defined as the rate of water uptake by a porous material when exposed to a water source. A typical plot of the cumulative water absorption per unit surface area as a function of the square root of time is shown in figure III.17. It can be seen that the cumulative weight of water absorbed per unit surface area (g/cm^2) in the specimens increased with the square root of time for the different types of repair mortars at 28 days. Similar trends were observed for all the types of mortars.

As it can be seen in figure III.18, all the sisal fiber reinforced mortars presented similar sorptivity coefficient to the control mortar, which indicates that the fibers have insignificantly effect in sorptivity. This may be due to the low content of fiber (0.20%). The hydrophilic character of natural fibers is responsible for the water absorption in the composites, and therefore a higher content on fibers leads to a higher amount of water absorbed, as reported **Espert et al** [76]. The results are in agreement with **A.A.Okeola et al**[43] Furthermore,

Chapter III Results and discussions

whatever the type of mortar, except the RMM mortar, the sorptivity coefficient is lower about 100% than the minimum value for structural repair required by the standard EN1504-3. This can be a good indicator of the durability of the elaborated mortars.

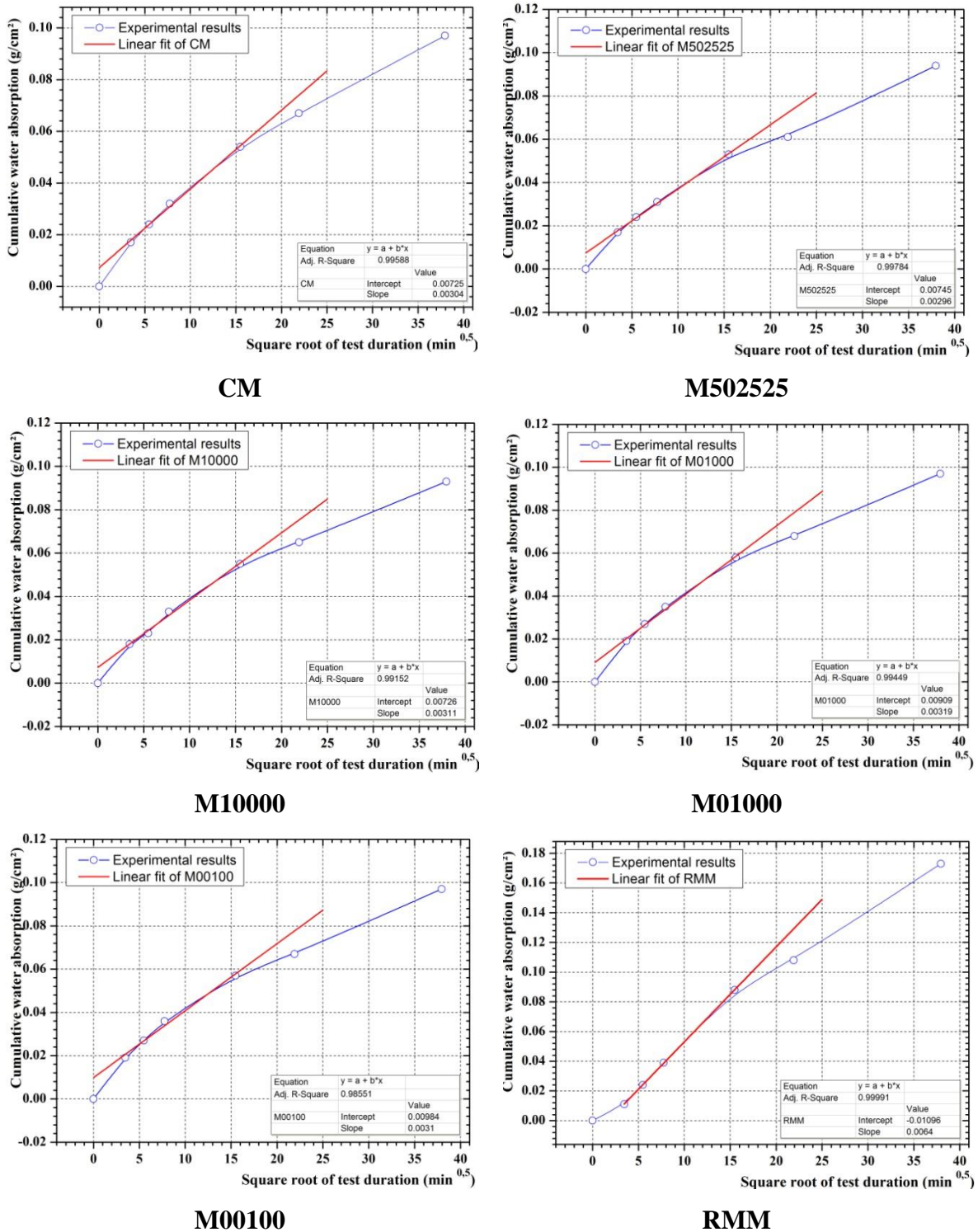


Figure III.17. Relationship between cumulative water absorption and time at 28 days.

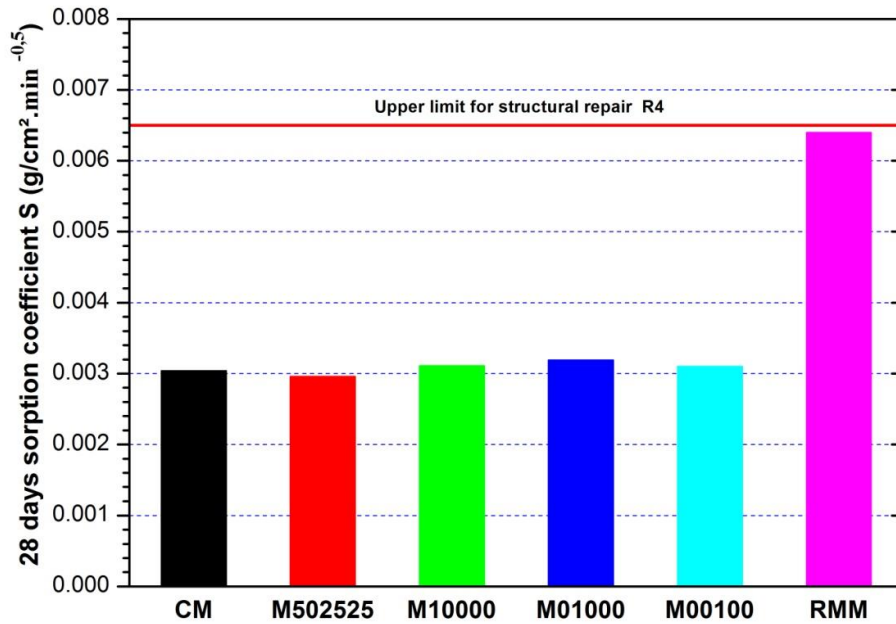


Figure III.18. Comparative study of the sorptivity coefficient of different mortars.

III.9. Conclusion

The main objective of this experimental work is to exploit local materials and natural resources such as dune sand, limestone sand and sisal fibers for the development of a self-compacting repair mortar that meets the compatibility and durability requirements. The results of this investigation provide the dimensional compatibility of our repair mortars, which showed an excellent bond performance between the elaborated repair mortars and substrate concrete.

General conclusion

General conclusion

This work took place over a period of six months, and was integrated into the general research activity of the team "Structure Rehabilitation and Composite Materials (SRACM)" of the Structure Rehabilitation and Materials Laboratory (SREML) at the University of Laghouat.

During this work, we were interested in the contribution to the formulation of a repair mortar based on dune - limestone sand and sisal fibers. This work had the dual objectives of promoting sustainable development through the enhancement of local materials and providing professionals in the construction sector of repair mortar, at low cost, efficient and meeting all technical requirements. The experimental program drawn up within the framework of this work required making of more than 200 specimens of various sizes.

This work investigated the effect of sisal natural fiber on compressive strength, flexural strength, (total, autogenous, drying) shrinkage, dynamic elasticity modulus, sorptivity, porosity and bond strength of repair mortar. Hence, the conclusions can be summarized as follows:

- The results obtained show an enhancement of the flexural strength of repair mortars with sisal fibers compared to those of mortars without fibers.
- The M01000 gives the best flexural behavior about 7.6MPa at 28th days, compared to control mortar, which means that the fibers of sisal have significantly changed this behavior by improving the ductility and toughness of repair mortar.
- The presence of sisal fiber in the mix decreases the compressive strength, these decreases are 5, 14 and 21% for M10000, M01000, and M00100 compared to the control mortar (without fiber); hence sisal fiber cannot improve the compressive strength of repair mortars.
- The ready-mixed mortar exhibited high shrinkage and poor adhesion properties of repair mortars.
- The introduction of the fiber into the mortars allowed significantly more efficient crack control.
- The presence of a high percentage of short fibers reduces the endogenous shrinkage.
- The sisal fiber addition has not an effect on drying shrinkage.
- The M100/0/0 gives the lowest shrinkage compared to other mixes, which leads to higher ability in controlling shrinkage.

General conclusion

- The dynamic modulus of elasticity decreases with increasing the length of the fibers. A decrease in E_d of 6.45 % and 10% for M01000 and M00100, compared to control mortar (CM) is noticed.
- The adhesion strength of different mortars is greater than the minimum value (2MPa) provided by the standard 1504-3.
- From the pull-off test results, all the mortars exhibited 100% of failure in the substrate (cohesive failure).
- The addition of short sisal fibers can significantly increase the shear bond strength.
- The bond strength recorded by slant shear is greater than the others; this is because of the influence of compressive force on the interface bond strength. Splitting prism strength and pull-off strength are close; the reason is that they follow the same failure mode in tension.
- The use of sisal fibers enhances the slant shear strength about 3% and 12.5%.
- Generally, the inclusion of fibers increased the tensile stress at splitting failure.
- The results of the slant shear and splitting tensile tests proved that the mechanical bond strength between the substrate and the repair mortar is significantly influenced by the addition of fiber, with the short fiber providing the most superior mechanical bond.
- The M10000 gives the higher splitting tensile strength, which shows the good distribution of short fibers in the matrix and improves the compatibility between the repair mortar and substrate concrete.
- The porosity increase with an increase of fiber length.
- The M00100 and M01000 mortars are slightly higher by 12.5%, 6.25%, respectively, compared to ready mixed mortar at 28th days.
- The M00100 showed longer saturation times than the other mortars.
- The M502525 had little effect on the amount of water absorbed than that RMM mortar, which explains that sisal fiber have a little effect on water absorption.
- The dispersion of 5 mm length sisal fibers are considerably better than those of 10mm length sisal fibers. So these fibers can discharge the absorbed water more effective.
- The use of sisal fibers allows to obtain a repair mortar less expensive, more eco-friendly and better in the mechanical strength, which makes of sisal a good candidate to produce sustainable mortar and green buildings.

General conclusion

From the overall results of this study, the cementitious mortar based on the dune-crushed limestone sand reinforced with sisal fiber seems to be a very promising material for repair and rehabilitation of concrete structures. The superior mechanical bond performance and impermeability characteristic could be translated into efficient and durable concrete repair, which could result in reduced number of repair interventions during the service life of concrete structures.

Recommendations

Further research is needed to complete:

- The durability of mortars reinforced with sisal fibers.
- The mechanical behavior of mortars with a treatment of sisal fibers
- The effect of the different degrees of roughness of the substrate on the bond strength.
- The effect of sulfate attack on the durability of repair mortar based on dune limestone sand reinforced with sisal fibers.
- The effect of temperature on the durability of repair mortars.
- The microstructures and fractures properties of repair mortars'

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Annexes

Annexes

A.1 superplasticizer Technical Data Sheet

NOTICE TECHNIQUE

2 1 1 9

MEDAFLOW 30

Conforme à la norme EN 934-2: TAB 1, TAB 3.1
ET TAB 3.2 NA 774.

**Super plastifiant
Haut réducteur d'eau**

DESCRIPTION

Le **MEDAFLOW 30** est un super plastifiant haut réducteur d'eau de la troisième génération. Il est conçu à base de polycarboxylates d'Ether qui améliorent considérablement les propriétés des bétons.

Le **MEDAFLOW 30** permet d'obtenir des bétons et mortiers de très haute qualité.

En plus de sa fonction principale de superplastifiant, il permet de diminuer la teneur en eau du béton d'une façon remarquable.

Le **MEDAFLOW 30** ne présente pas d'effet retardateur.

DOMAINES D'APPLICATION

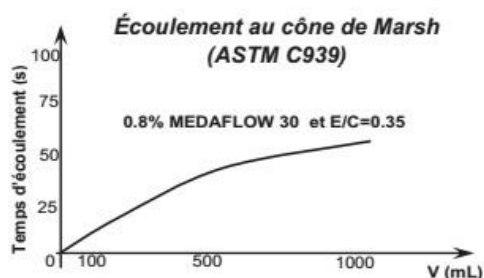
- Bétons à hautes performances
- Bétons auto - plaçant
- Bétons pompés
- Bétons précontraints
- Bétons architecturaux.

PROPRIÉTÉS

Grâce à ses propriétés le **MEDAFLOW 30** permet :

Sur béton frais :

- Obtention d'un rapport E/C très faible
- Amélioration considérable de la fluidité
- Une très bonne maniabilité
- Éviter la ségrégation
- Faciliter la mise en œuvre du béton



Sur béton durci :

- Augmenter les résistances mécaniques à jeune âge et à long terme (voir tableau).
- Diminuer la porosité
- Augmenter la durabilité
- Diminuer le retrait et le risque de fissuration

Désignation	Rc (MPa)		
	3J	7J	28J
MEDAFLOW 30 (1.4%)	39.2	54.7	62.2

CARACTÉRISTIQUES

- Aspect Liquide
- Couleur Brun clair
- pH 6 – 6,5
- Densité 1,07 ± 0,01
- Teneur en chlore < 0,1 g/l
- Extrait sec 30%

MODE D'EMPLOI

Le **MEDAFLOW 30** est introduit dans l'eau de gâchage.

Il est recommandé d'ajouter l'adjuvant dans le béton après que 50 à 70% de l'eau de gâchage ait déjà été introduite.

DOSAGE

Plage de dosage recommandée :

0,5 à 2,0 % du poids de ciment soit 0.46 à 1.85 litre pour 100 Kg de ciment.

Le dosage optimal doit être déterminé sur chantier en fonction du type de béton et des effets recherchés.

CONDITIONNEMENT ET STOCKAGE

Les renseignements donnés dans cette notice sont basés sur notre connaissance et notre expérience à ce jour. Il est recommandé de procéder à des essais de convenance pour déterminer la fourchette d'utilisation tenant compte des conditions réelles de chantier.



A.2 Sika monotrope 650 technical data sheet

Construction

Notice technique
Edition Juin 2017
Numéro 6.60
Version n°106.2017
SIKA MONOTOP 650

SIKA® MONOTOP 650
Mortier de réparation fibré prêt à gâcher

Mortier de classe R3 selon la norme EN NF 1504-3

Présentation	Le SIKA MONOTOP 650 est un mortier monocomposant à base de ciment, fibres, charges spéciales et adjuvants. Après gâchage à l'eau, on obtient un mortier de réparation de couleur gris clair.
Domaines d'application	<ul style="list-style-type: none"> ■ Réparation des bétons ■ Resurfaçage des bétons avant application de peintures ■ Bourrage des joints de prédalle.
Caractères généraux	<ul style="list-style-type: none"> ■ Facilité d'application en sol, en mur, en plafond, grâce à sa consistance pâteuse. ■ Présente un aspect fini « prêt à peindre » après 24 heures à 20°C. ■ Adhère parfaitement sur la plupart des supports (béton, mortier, pierre, brique).
Agréments, essais officiels	P V CNERIB : DTEM /105/2017.
Caractéristiques	
Coloris	Gris clair
Conditionnement	Sac de 25 kg
Stockage	Le produit doit être stocké à l'abri de l'humidité.
Conservation	6 mois en emballage intact et non entamé.
Données techniques	
densité	Densité de la poudre non tassée : environ 1,3 Densité du mortier frais : environ 2,1.
Granulométrie	Inférieure à 1,6 mm
Épaisseur d'application	En vertical de 4 à 50 mm d'épaisseur en une seule passe. En sous face, s'applique entre 3 et 10 mm.


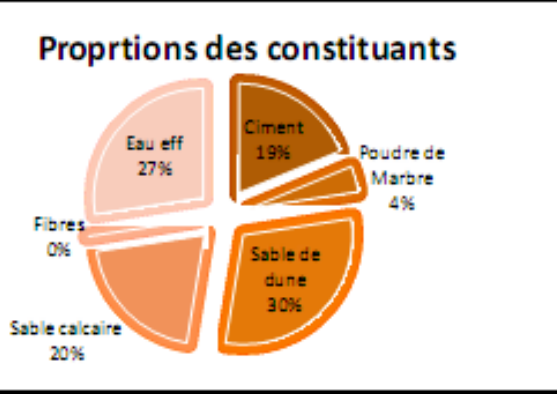


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SIKAMONOTOP 650 1/3

Annexes

A.3 Formulations of control self –compacting repair mortars.

Fiche formule mortier autoplaçant					
Opérateur : Krobba B					
Client :					
Désignation: CM					
Date d'édition:					
Proportions					
Sable /mortier Vs/Vm	0.5	Ciment	83		0
Eau/poudre Me/Mp	0.4	Poudre de Marbre	17	Sable de dune	60
Medflow 30 %	0.84	Pouzzolane	0	Sable calcaire	40
Air occulus %	1	Fumée de silice	0	Fibres %	0.00
Composition					
Eeff/P	Etot/P	S/P	Ve/VP	Vp%	Lf
0.40	0.433	1.91	1.21	22.37	mm
/m3					
Matériaux	Litre	Kg	cm3	/ 1 Litre	
Ciment	185.67	575.58	185.67	g	
Poudre de Marbre	38.03	102.68	38.03	102.68	
Sable de dune	297.00	776.66	297.00	776.66	
Sable calcaire	198.00	520.34	198.00	520.34	
Fibres					
Medflow 30		5.70		5.70	
Eau tot	293.56	293.56	293.56		
Eau eff	271.30	271.30	70% Etot	205.49	
Eau abs	22.26	22.26	30% Etot	88.07	
Air occulus	10.00				
Volume total	1000.00	2274.51		2274.51	
Résultats					
Etallement					
28	29	28.5			
Ecoulement					
					

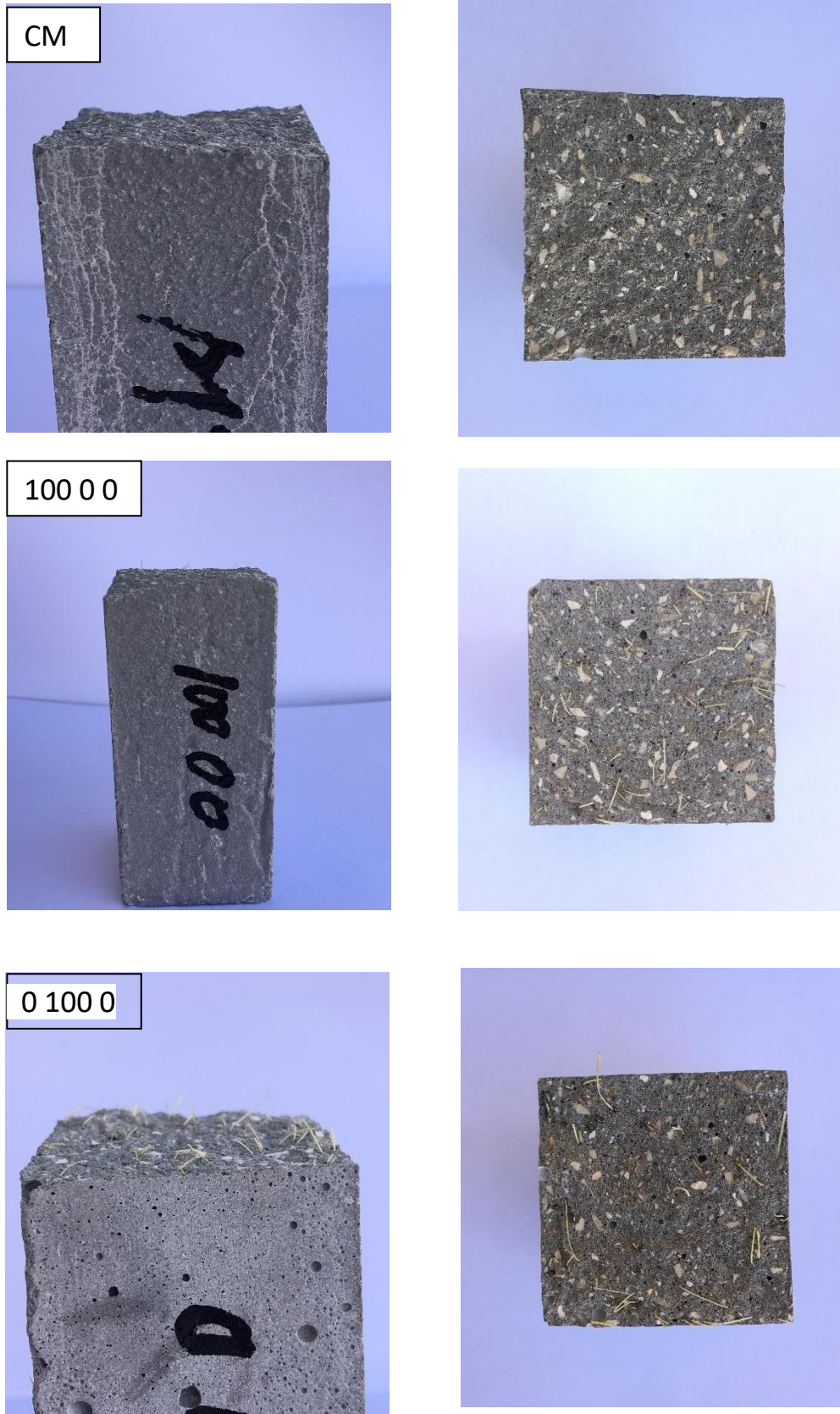


Fig1.Photos of fiber mortar taken by digital microscope



(a)



(b)



(c)

Fig2.failure mode of repair mortars: (a) Control mortar,(b)M00100,(c)Ready-mixed mortar.