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The effect of the incorporation of plant fibers on the physical and mechanical properties of latex modified sand concrete intended for repair

Presented by:

Oday Jaradat

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L'effet de l'incorporation des fibres végétales sur les propriétés physico-mécaniques des bétons de sable modifiés au latex destinés à la réparation

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بسم الله الرحمن الرحيم

ABSTRACT

This study aims to improve sand concrete's physical and mechanical properties using sisal and latex fibers to be used as repair material. Sisal fibers were used at four different ratios of the dry weight of the mixture 0.05%, 0.10%, 0.15% and 0.20%, While liquid latex was replaced by the weight of mixing water in three proportions of 15%, 25% and 35%. In this context, ideal proportions of sisal fibers (0.1% F) and latex (35% L) were combined in a single cement matrix to be used as a repair material. Workability, density, compressive strength, flexural strength, ultrasonic pulse velocity, modulus of elasticity, porosity, water absorption and shrinkage were performed for each sample. In addition, the interface bond strength and the type of failure mode will be examined between sand concrete (LMSC) as a repair material and the normal concrete substrate (NC) utilizing four different surfaces, without surface preparation (SR), hand hammer (HA), sandblasted (SB), and grooved (GR). The bond strength was measured by bi-surface shear, splitting tensile, pull-off strength tests and, Scanning Electron Microscopy (SEM) analysis was also performed to study the microstructure. The results of this study indicate that adding sisal fibers and latex to sand concrete improved most of the physical and mechanical properties of sand concrete, especially for repair. However, the adhesion strength between sand concrete (LMSC) as a repair material and normal concrete (NC) as a substrate was good, especially when treated to increase roughness. Therefore, latex-modified sand concrete reinforced with sisal fibers has the potential to repair and rehabilitate concrete structures.

Keywords: sand concrete, sisal fibres, latex, microstructure, bond strength, repair material.

RÉSUMÉ

Cette étude vise à améliorer les propriétés physiques et mécaniques du béton sableux en utilisant des fibres de sisal et de latex pour être utilisé comme un matériau de réparation. Les fibres de sisal ont été utilisées dans quatre proportions différentes du poids sec du mélange : 0,05%, 0,10%, 0,15% et 0,20%, tandis que le latex liquide a été remplacé par le poids de l'eau de gâchage dans trois proportions : 15%, 25% et 35%. Dans ce contexte, les proportions idéales de fibres de sisal (0,1% F) et de latex (35% L) ont été combinées dans une seule matrice de ciment pour être utilisées comme matériau de réparation. La maniabilité, la densité, la résistance à la compression, la résistance à la flexion, la vitesse d'impulsion ultrasonique, le module d'élasticité, la porosité accessible à l'eau, l'absorption d'eau et le rétrécissement ont été réalisés pour chaque échantillon. En outre, la force d'adhérence de l'interface et le type de mode de défaillance seront examinés entre le béton de sable (LMSC) comme matériau de réparation et le substrat de béton normal (NC) en utilisant quatre surfaces différentes, sans préparation de surface (SR), martelée à la main (HA), sablée (SB) et rainurée (GR). La force d'adhérence a été mesurée par des essais de cisaillement bi-surface, de traction par fendage et de résistance à l'arrachement. Une analyse par microscopie électronique à balayage (MEB) a également été réalisée pour étudier la microstructure. Les résultats de cette étude indiquent que l'ajout de fibres de sisal et de latex au béton de sable a amélioré la plupart des propriétés physiques et mécaniques du béton de sable, en particulier pour la réparation. Cependant, la force d'adhérence entre le béton de sable (LMSC) comme matériau de réparation et le béton normal (NC) comme substrat était bien, surtout lorsqu'il était traité pour augmenter la rugosité. Par conséquent, le béton de sable modifié par le latex et renforcé par des fibres de sisal a le potentiel pour réparer et réhabiliter les structures en béton.

Mots clés: béton de sable, fibres de sisal, latex, microstructure, force d'adhérence, matériau de réparation.

ملخص

تهدف هذه الدراسة إلى تحسين الخواص الفيزيائية والميكانيكية للخرسانة الرملية باستخدام ألياف السيزال واللاتكس لاستخدامها كمواد إصلاح. تم استخدام ألياف السيزال بأربع نسب مختلفة من الوزن الجاف للخليط 0.05٪ ، 0.10٪ ، 0.15٪ و 0.20٪ ، بينما تم استبدال اللاتكس السائل بوزن ماء الخلط بثلاث نسب 15٪ ، 25٪ و 35٪. في هذا السياق ، تم دمج النسب المثالية من ألياف السيزال (F %0.1) واللاتكس (L %35) في مصفوفة أسمنتية واحدة لاستخدامها كمواد إصلاح. تم إجراء قابلية التشغيل ، والكثافة ، وقوة الانضغاط ، وقوة الانحناء ، وسرعة النبض بالموجات فوق الصوتية ، ومعامل المرونة ، والمسامية التي يمكن الوصول إليها بالماء ، وامتصاص الماء والانكماش لكل عينة. بالإضافة إلى ذلك ، سيتم فحص قوة رابطة الواجهة و وضع الانهيار بين الخرسانة الرملية (LMSC) كمواد إصلاح والركيزة الخرسانية العادية (NC) باستخدام أربعة أسطح مختلفة ، بدون معالجة (SR) ، المطرقة اليدوية (HA)) ، وسفع رملي (SB) ، ومخدد (GR). تم قياس قوة الرابطة عن طريق اختبار القص ثنائي السطح ، اختبار شد الانفصال، واختبار قوة السحب ، كما تم إجراء تحليل المسح المجهري الإلكتروني (SEM) لدراسة البنية المجهرية. تشير نتائج هذه الدراسة إلى أن إضافة ألياف السيزال واللاتكس إلى الخرسانة الرملية حسنت معظم الخواص الفيزيائية والميكانيكية للخرسانة الرملية ، خاصة للإصلاح. ومع ذلك ، فإن قوة الالتصاق بين الخرسانة الرملية كمواد إصلاح والخرسانة العادية كركيزة كانت جيدة ، خاصة عند معالجتها لزيادة الخشونة. لذلك ، فإن الخرسانة الرملية المعدلة من مادة اللاتكس والمدعومة بألياف السيزال لديها القدرة على إصلاح وإعادة تأهيل الهياكل الخرسانية.

الكلمات الرئيسية: الخرسانة الرملية، ألياف السيزال، اللاتكس، البنية المجهرية، قوة الرابطة، مواد الإصلاح.

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List of Abbreviations

CS	Crushed Sand
RS	River Sand
SBR	Styrene Butadiene Rubber
NC	Normal Concrete
SC	Sand Concrete
LMSC	Latex Modified Sand Concrete
ITZ	Interfacial Transition Zone
SEM	Scanning Electron Microscopy
UPV	Ultrasonic Pulse Velocity
SR	Without surface preparation as reference
HA	Substrate surface treatment with hand hammer
SB	Sand-blasted on the substrate surface
GR	Grooved treatment
γ	Compactness coefficient
V	Volume
W	Water
C	Cement
SP	Super Plasticizer
L	Latex
f_s	Compressive strength
F_{max}	The max load applied
ν	The pulse velocity
L	The length of the sample
D	The damage degree
v_T	The UPV after heating
v_0	The UPV before heating
E_d	The dynamic modulus of elasticity
v	Poisson's ratio
M_1	The mass of the specimen before heating
M_0	The mass of the specimen after heating
V_1	The volume of the specimen before heating
V_0	The volume of the specimen after heating
P	Water porosity
M1	Mass dried
M3	Mass saturated
M4	Hydrostatic balance

GENERAL INTRODUCTION

GENERAL INTRODUCTION

1. General background

In recent decades, sand concrete has attracted attention as a basic building material; it was once known as agglomerated concrete (Sablocrete, 1994). It is fine concrete defined by standard NF P 18 500, revised in 1987 by AFNOR (Belhadj et al., 2014). Sand concrete is significant from an economic and environmental perspective because it promotes the use of quarry waste in its constituent parts, such as crushed sand and limestone fillers; it is also possible to utilise the dune sand, which is present in significant amounts in desert areas (Gadri, 2018). In several civil engineering projects, sand concrete is used instead of ordinary concrete (Djebien et al., 2015; Sablocrete, 1994). Several studies have worked to develop sand concrete for use in construction fields (Ammari et al., 2020; Belhadj et al., 2016). To the best of our knowledge, there are many studies have proposed sand concrete as a repair material for concrete buildings (Gadri & Guettala, 2017).

The need to use concrete in buildings has substantially grown (Dong et al., 2017). Currently, concrete constructions make up the majority of all structures (Gao et al., 2019). For various reasons, concrete structures are frequently vulnerable to deterioration and collapse (Emmons, 1993). The nature and origin of defects in concrete structures can occur due to errors in the design or construction of the structure. Still, other damages may appear during accidental loading (earthquake, unintentional overload, etc.). According to (Tayeh et al., 2014), Many concrete structures in the world need effective and permanent repair. The repair system consists of three stages: the structure to be repaired (substrate), the repair material, and the interfacial transition zone (ITZ) that forms the interface between the two materials (Emmons & Vaysburd, 1994). An interfacial transition zone (ITZ) between repair material and old concrete is the weakest part of the repair system (Tayeh et al., 2012). According to the recommendations of the standard NF EN 1504 (EN1504, 2014), the preparation of the surface is a fundamental step that must be carried out before the repair. Surface roughness is one of the elements that affects how well the repair material adheres to the old concrete. (Aaleti & Sritharan, 2019; Liu et al., 2020). Many old concrete structures were repaired following the necessary conditions and methods (Hu et al., 2021).

2. Problem statement

Sand concrete is concrete with a high proportion of fine aggregate. Quarry waste is an environmental issue; it is intriguing to investigate the viability of utilising this waste in sand concrete as sand and filler. Also, sand concrete needs to improve some physical and mechanical properties for use in many construction areas, especially repair; these disadvantages can be overcome by adding some additives to improve these properties. Therefore, the performance of sand concrete after improvement should be evaluated with additives for repair.

3. Objectives

The main objective of this study:

- Contribute to improving sand concrete's physical and mechanical properties by using sisal fibres and latex by studying each addition alone, selecting the ideal proportion for each addition, and combining them to use as a repair material.
- Ascertain the effectiveness of bond strength between normal concrete (NC) as substrate and latex-modified sand concrete reinforced with sisal fibers (LMSC) as a repair material.

4. Layout of the thesis

The thesis is divided order as follows:

General Introduction presents a general introduction to the thesis and presents our study's problem and primary objectives.

Chapter I presents the definition and history of sand concrete and the components of sand concrete (Sand, Cement, Water, Additives and Adjuvants), as well as a review of the literature on the properties of sand concrete. It also studied how to formulate sand concrete and mentioned some uses of concrete sand in repair. This chapter also presents the main findings from the repair and adhesion mechanism literature, with a detailed overview of the durability issues of the repair system and the factors affecting the compatibility of the repair materials.

Chapter II this chapter provides details of the experimental program conducted. A series of tests were conducted to evaluate the material used (Sand, filler, cement, superplasticizer, water, latex and fibre). This chapter also describes the mix proportions, preparation, curing conditions and testing of the specimen's concrete. Additionally, Repair techniques and procedures were discussed as adhesion tests of composites.

Chapter III presents the discussion on the results of tests carried out on sand concrete and normal concrete. The main objective of this chapter is to contribute to improving the properties of reference sand concrete by using additives, sisal fibres and latex, by studying each addition alone, and then selecting the ideal percentage for each addition and combining them to use as a repair material and also study the properties of the normal concrete substrate. The physical and mechanical properties are studied by performing the tests.

Chapter IV investigated the use of latex-modified sand concrete reinforced with sisal fibers (LMSC) as a local repair material. The repair material LMSC was applied to normal concrete substrates (NC) of different shapes and sizes according to the type of test in order to assess the interface bond strength and the type of failure between LMSC as a repair material and NC as substrate. To ascertain the bond strength between LMSC and NC using four different surfaces: without surface preparation as reference (SR), treatment with a hand hammer (HA), treatment sandblasted (SB), and treatment grooved (GR). The bi-surface shear, splitting tensile, and pull-off strength tests evaluated the bond strength.

General Conclusion It provides a general summary of our study of the theoretical part and the practical part. Also, it focuses on the best results of the tests obtained in terms of improvement and the possibility of use.

CHAPTER I

LITERATURE REVIEW

I.1 Introduction

Concrete structures are exposed to damage and collapse due to various reasons and factors, which makes it urgent to assess the condition of these structures and the levels of damage to them to ensure safe and sound investment for them taking the necessary measures.

The first part of this chapter discusses the definition, components and literature reviews of sand concrete. In this study, sand concrete was proposed as a repair material. This chapter also presents a detailed description of repair system durability issues and factors that affect the compatibility of repair materials.

I.2 Sand Concrete

I.2.1 Definition

Sand concrete is considered fine concrete that contains a large amount of sand with a diameter of 0/5 mm according to standard NF P 18 500 [2004] (Bédérina et al., 2005a; Belhadj et al., 2014). According to (Gadri & Guettala, 2017a), sand concrete contains a lower cement dosage when compared to mortars, and the authors also found that sand concrete has a cement dosage similar then to conventional concrete.

(Hadjoudja et al., 2014) stated that the amount of coarse aggregates in sand concrete is negligible. However, sand concrete could contain coarse aggregates in the composition but with a gravel/sand ratio of less than 0.7. The association for the promotion and development of sand concrete was created in 1988 and coordinated all research work on this material to develop concrete formulations whose characteristics should be comparable to those of conventional concretes (Zri, 2010).

I.2.2 History

Sand concrete is an ancient material that dates back to 1850-1875 with the name of 'agglomerated concrete' (Sablocrete, 1994). In the Soviet Union, the port of Kaliningrad was built of sand concrete (Chauvin, 1991). Figure 1.1 shows the Lighthouse of Port Said in Egypt in 1869, with a high of 52 m, made with sand concrete (Sablocrete, 1994).

Figure I.1. The Lighthouse of Port Said (Sablocrete, 1994).

In the last decade, using sand concrete in Germany was reduced during World War II due to the industrial development of several construction applications. In France, sand concrete was not developed in the 1970s and 1980s due to the abundance of coarse aggregates characterised by high strengths (Zri, 2010).

Due to the availability of large amounts of crushed sand from quarries, using this sand for manufacturing sand concrete has become very important (Zri, 2010). In the 1990s, sand concrete characteristics has developed by the Sablocrete project were similar to conventional concrete (Sablocrete, 1994).

I.2.3 Sand concrete components

The basic composition of sand concrete is sand, cement and water. Some additives can be used to improve sand concrete properties, such as plasticiser, fillers, fibers, etc.

I.2.3 1. Sand

Different types of sand with a diameter of 0/5 according to standards NFP 18-545 [2004] can be used to prepare concrete. Several sands with different sources can be employed in sand concrete production, such as dune sand, river sand and crushed sand from rocks.

According to (Sablocrete, 1994), the sand used in sand concrete is characterised by homogeneity and cleanliness. In the literature review, two types of sand were used in sand concrete (river and crushed sand).

I.2.3 1. River Sand

River sand can be obtained from the sedimentation of weathered rock, this type of sand is available at the bottom of the river. The particles of river sand are usually rounded and graded (Kabbani, 1967). The main composition of river sand is silica (SiO_2). The extraction of river sand leads to the deterioration of the bottom of the river and the flora surrounding the area (Patra & Mukharjee, 2017). For this, several governments worldwide imposed restrictions on the extraction of river sand (Akrout et al., 2010; Dolage et al., 2013).

I.2.3 1. Crushed Sand

The crushed limestone sand is a sedimentary rock made primarily of calcite ($CaCO_3$). Due to the rising demand for river sand and the associated environmental problems created by its depletion, numerous studies have been conducted on using different types of sand in concrete (Zhang et al., 2020). According to (Jose & Hossiney, 2016), The construction industry has identified several solutions to deal with this dilemma; therefore, crushed sand has been suggested as a partial substitute for river sand. Sand concrete gives a continuous distribution of particle size in sand concrete (Gadri & Guettala, 2017a). Crushed sand has lower workability because it requires more water than other sands, so a superplasticiser was needed to provide acceptable workability without compromising the strength of concrete qualities (Akrout et al., 2010; Bederina et al., 2013). Overall, crushed sand grains' angular shape and rough exterior enhance the connection with the cement mix (Stefanidou, 2016).

I.2.3 2. Cement

Cement is a fine powdered hydrological very binder that binds concrete components together. According to NF P15-301 [1994], Composite Portland cement, type CPJ-CEM II/A 42.5, was utilised. Table I.1 displays Portland cement's chemical makeup (Zhang & Scherer, 2011).

Table I.1: Chemical composition of Portland cement (Zhang & Scherer, 2011).

Name of compound	Oxide Composition	abbreviation	Proportion
Tricalcium silicate	$3CaO.SiO_2$	C_3S	37%-60%
Dicalcium silicate	$2CaO.SiO_2$	C_2S	15%-37%
Tricalcium aluminate	$3CaO.Al2O_3$	C_3A	07%-15%
Tetracalcium aluminoferrite	$4CaO.Al2O_3.Fe2O_3$	C_4AF	10%-18%

I.2.3 3. Water

The water used to create concrete must be clean, free of acid or alkali, and have a temperature of 20±1°C by standard NF P 18-404.

I.2.3.4. Additives

I.2.3.4.1 Superplasticisers

Since sand concrete contains fine particles, using superplasticisers is essential to enhance workability. Generally, the superplasticisers must adhere to standard NF P 18-103.

I.2.3 4.2 Filler

The Addition of filler to sand concrete improves compactness. We know the maximum diameter of aggregate in sand concrete is $D \leq 5$ mm, so it requires a high cement dose. The use of fillers helps reduce the amount of cement and fills the small spaces between sand grains (Gadri & Guettala, 2017a). According to (Sablocrete, 1994), fine elements settle into the spaces left by coarse components, improving compactness.

The Caquot theory of the dosage of the ideal binder (filler or cement), is calculated according to the following formula standard NF P 18-305:

$$c = (250 + 10f_{ck})/(D)^{1/5} \quad (Kg/m^3) \quad \ldots\ldots\ldots\ldots \text{I.1}$$

f_{ck} : the specified characteristic resistance expressed in MPa.

It is clear that when the largest diameter of the aggregate used decreases, as is the case with sand concrete, the voids increase. Hence the importance of using grouting to obtain the correct compactness of concrete (Cisse, 1996).

There are two types of fines: active fines, such as silica fume, ground slag, crushed pozzolan, fly ash, etc.) and inert fines, such as limestone or marble fines from the crushing of massive rocks). The research study is limited to using limestone filler (inert fines).

❖ Limestone filler

Limestone comes from crushed rock. Adding Limestone fillers to sand concrete is good, as it is essential in sealing small voids created by sand and thus improving its properties (Chauvin & Grimaldi, 1988). The filling effect results in more significant stress on the granular structure and thus will have a good effect on most properties (Diederich, 2010; Gadri & Guettala, 2017b, 2017a). Thus, the fillers reduce the amount of cement used so that the dosage of cement used is the same as that of normal concrete (Gadri & Guettala, 2017a). A limestone filler material reduced the concrete's shrinkage (Tanabe et al., 2008).

I.2.3.4.3 Fibres

The purpose of adding fibers to sand concrete is to reduce the consequences of shrinkage and also to improve tensile strength. The Addition of fibers to the cement matrix and their random distribution in the mixture contributes to the reduction of microcracks and the spread of cracks (Fowler, 1999).

There are various categories of fibers that can be incorporated into concrete. Fibers can be classified into four different categories: synthetic (acrylic, aramid, carbon, nylon, polyester, polyethylene, polypropylene, etc.), natural (sisal, bagasse, coconut, jute, maguey, banana, palm, bamboo, etc.), metallic (stainless, galvanised, cold drawn wire, cut sheet metal, molten material extrusion, etc.) and glass (soda lime, borosilicate, etc.). In this study, natural sisal fibers were used.

❖ Sisal fibres

Researchers began experimenting with discontinuous fibers with concrete to improve its properties since 1910 (Naaman, 1985). The shrinkage and fine cracks of sand concrete can be overcome by adding fibers, improving flexural strength and impact strength (Bouziani et al., 2014). Compounds based on plant fiber-reinforced cement are a new class of sustainable building materials (Silva et al., 2007). Dry shrinkage is one of the causes of cracks in concrete structures (Joseph et al., 1999). In concrete, a structural crack develops even before loading due to drying shrinkage and other causes; adding small discrete fibers to concrete can act as a crack arrestor and improve its static and dynamic properties (Siva Bala & Vaisakh, 2018). Concrete's tensile and flexural strength is improved using short, randomly oriented fibers to reduce microcracks (Balaguru & Shah, 1992).

Where sisal fiber was used in this study, it is a widely available plant fiber. Plant fibers are available in all regions worldwide (Brandt, 2008). Using plant fiber in compounds has no health risks to the environment (Campos et al., 2012). Sisal fiber a high cellulose content, has high tensile and flexural strength and is inexpensive compared to other plant fibers (Joseph et al., 1999). What distinguishes sisal fibers from other natural fibers is that their water absorption is low compared to other fibers . To enhance plant fiber, agents have been used that prevent the fiber from absorbing water (Gram, 1983).

Since sisal fibers is vegetarian, it needs further modification to improve compatibility with the cement matrix. In recent times, several methods have been used to enhance the bond between the fiber and the cement matrix, including treating the plant fiber before using with different materials. Many studies show that plant fibers need materials that improve their adhesion to the cement matrix to increase their durability (Li et al., 2007; Tonoli et al., 2009). (Bederina et al., 2012b, 2016) treated the plant fibers with different materials that improved the adhesion between the fibers and the sand concrete.

I.2.3.4.4 Polymers

The Addition of polymers to the cement matrix improves its properties in general. Several different types of polymers are added to concrete matrices. The most widely used polymers are latex (Soufi, 2014).

Latex is often made up of Styrene-Butadiene (SBR). Latex polymers can come in two forms, powder and liquid. Studies by (Afridi et al., 2003) have shown that liquid polymers form a film of better quality than those in powder form, in which the film is less homogeneous. Adding the Polymer to the cement matrix improves the properties, especially the tensile strength. This improvement in tensile strength is due to the improvement of adhesion in the cement matrix and the bridging of micro-cracks by the Polymer (Bureau et al., 2001).

I.2.4 Characteristics of sand concrete

I.2.4.1 Workability

Workability is one of the fresh characteristics of sand concrete, as this characteristic depends on the components of concrete, and, remarkably, sand concrete needs a higher water percentage than conventional concrete due to the exact size of the aggregate. Sand concrete may need a (water/cement) ratio greater than 0.5 (Chanvillard & Basuyaux, 1996). These high proportions are due to the large specific surface of the mixture; the coarser the sand, the better the workability because the surface to be wetted is less than that of fine aggregate. However, considering the ratio W / C + A (A = filler), we get proportions similar to ordinary concrete (Diederich, 2010). Similarly, an increase in the content of non-absorbent spherical fine granules improves workability and also reduces the amount of voids (Sablocrete, 1994). This concrete's cement dosages are 250 to 450 Kg/m^3; the optimum compactness is achieved by adding fines and superplasticiser (Gadri & Guettala, 2017a).

According to a study conducted by (Bédérina et al., 2005b) on adding limestone filler (≤ 0.08 mm) in sand concrete, using two types of sand in sand concrete: River Sand (RS) and dune sand (DS), the graphs in Figure I.2 show the different effect when adding limestone filler to three different ratios (water/cement): 0.5, 0.7 and 0.9. It can be seen that the proportion of coarse grains of sand significantly increased the workability of similar water content, and better workability was obtained when a filler was also added to it. Here we considered River Sand (RS) as a course compared to Dune Sand (DS). It can also be noted that the addition of grouting greatly contributed to the workability of all types of concrete studied (Bédérina et al., 2005b).

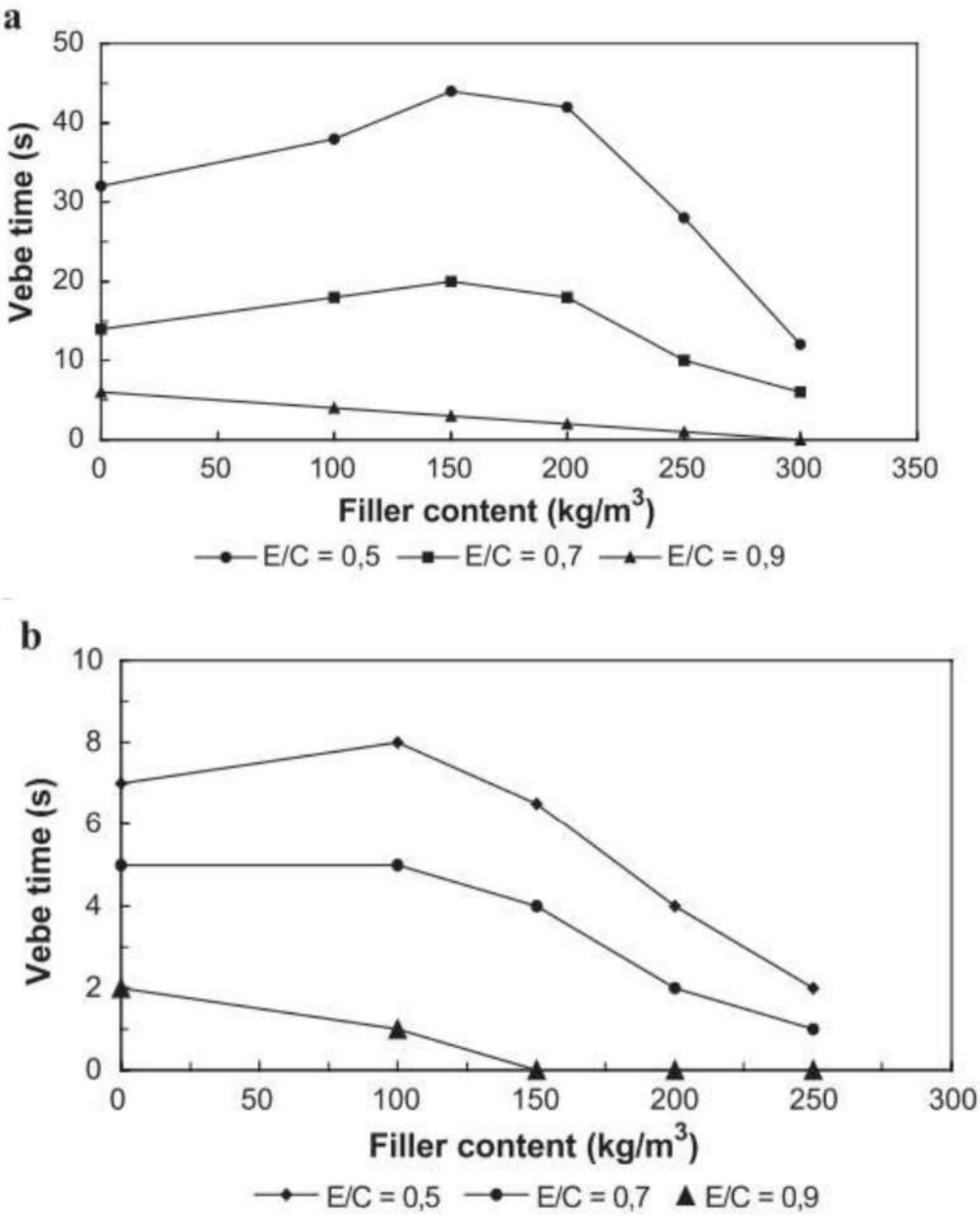


Figure I.2. Evolution in workability of the dune (a) and river dune (b) sands vs filler concentration (Bédérina et al., 2005b).

I.2.4.2 Compressive strength

Compressive strength is considered a characteristic property of concrete. Several types of research on sand concrete aimed to improve the resistance. They have shown appreciable resistances for this material, comparable to traditional concrete. For cement dosages between 250 and 450 kg/m^3, the compressive strength reached after 28 days is between 12 and 60 MPa depending on the composition, the admixture and the mode of implementation (A. Benaissa et al., 1992). Many factors affect the compressive strength of fixed cement content, such as grain size and additives (Gadri & Guettala, 2017a).

Figure I.3 shows a study carried out by (Bédérina et al., 2005b) to measure the compressive strength of three types of sand concrete with three different sizes of sand, namely River Sand (RS), Dune Sand (DS) and a mixture of River and Dunes Sand together (RDS), by adding limestone filling to all mixtures. Sand concrete composed of two sands together (RDS) gave better compressive strength, which shows that it obtained good compaction of the granular structure and thus increased the compressive strength of concrete. Also, adding limestone filler to all types of studied sand concrete improved the compressive strength with the optimum dose.

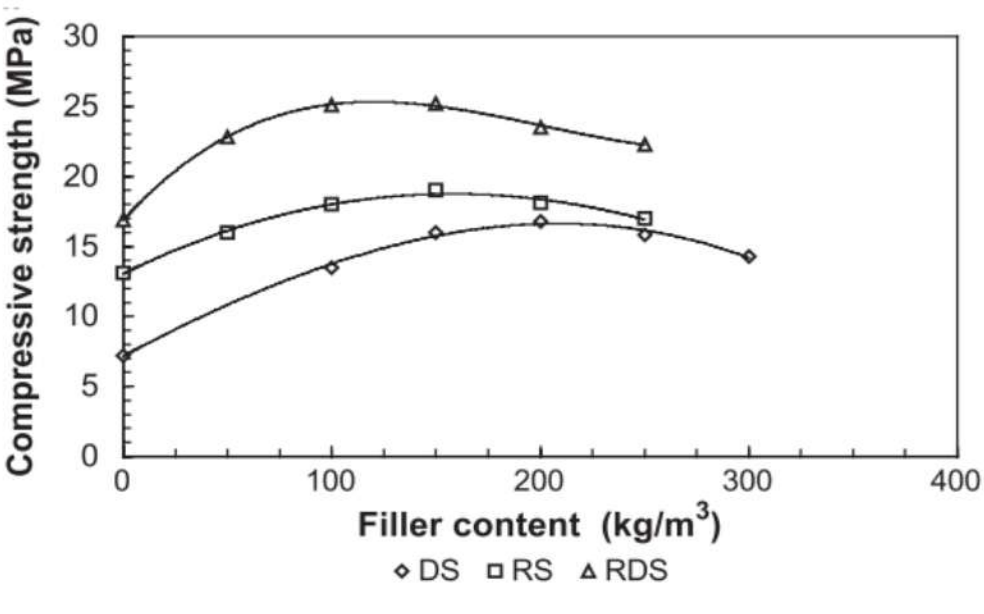


Figure I.3. Influence of filler concentration on 28-day compressive strengths (Bédérina et al., 2005b).

I.2.4.3 Flexural tensile strength

Concrete of all types is known for its low tensile strength. Still, sometimes tensile strength is essential in concrete, which requires additives that contribute to increasing this characteristic, especially if the use is in repairing concrete structures.

It should be noted that the main role of fibres in concrete can be linked to two main points (Chabane, 2012):

❖ Control crack growth in serviceable concrete by reducing crack openings, as shown in Figure I.4.

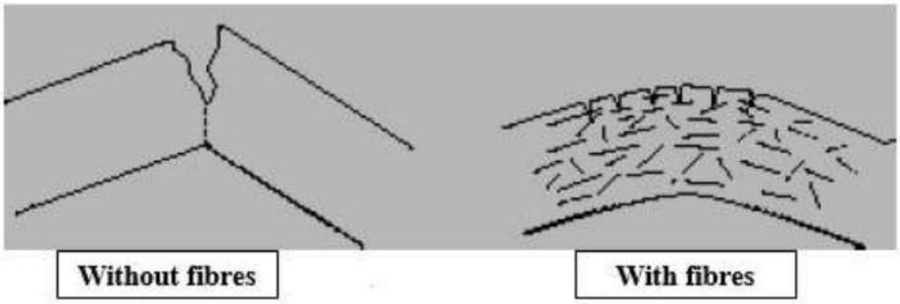


Figure I.4. Cracking in concrete without and with fibres (Chabane, 2012).

❖ Transformation of the brittle behaviour of the concrete into a ductile one increases safety during final loading states, see Figure I.5.

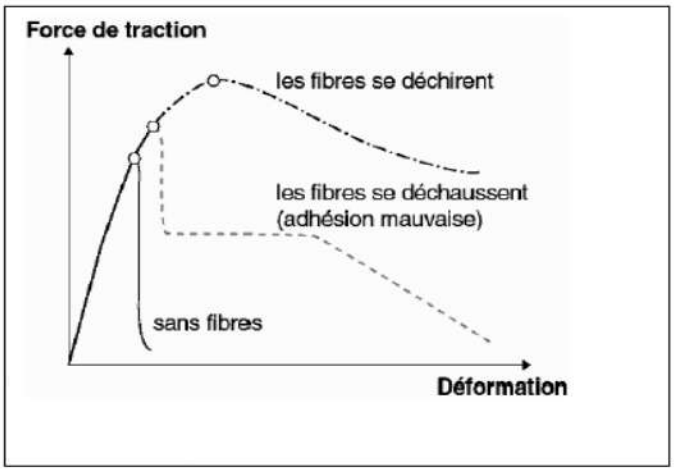


Figure I.5. Load–deformation behaviour of concrete with fibres and without fibres (Chabane, 2012).

According to research by (Ammari et al. 2020), adding steel fibres to sand concrete enhanced the flexural strength, as seen in Figure I.6. As a result, adding fibres to sand concrete enhances its qualities and encourages its application in a variety of construction sectors.

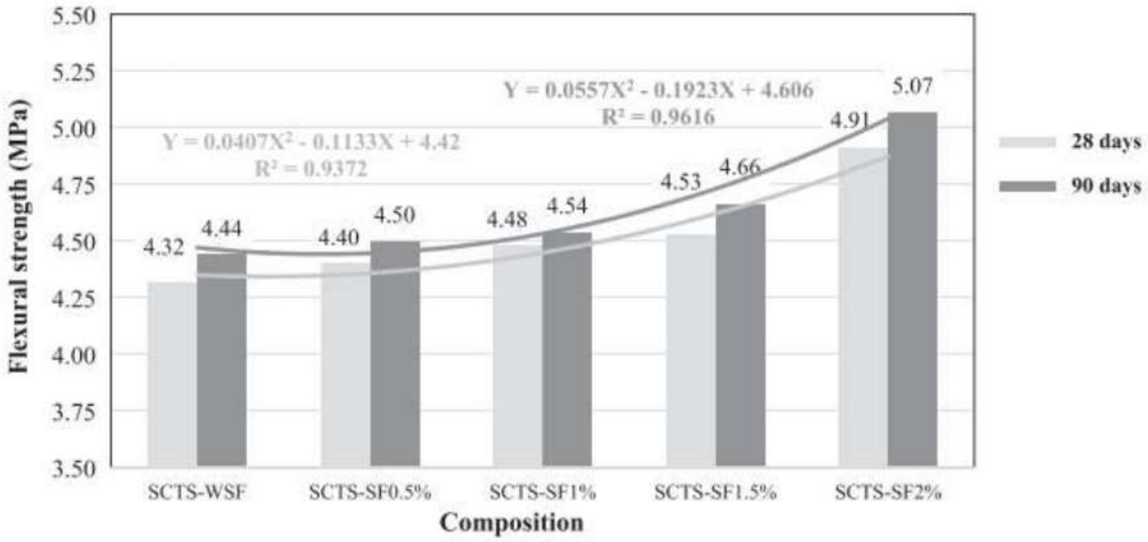


Figure I.6. Evolution of the flexural strength at 28 and 90 days according to the proportion of steel fibres (Ammari et al., 2020).

In addition, adding the Polymer to the cement matrix has improved most of the mechanical properties, especially the flexural strength.

According to the study carried out by (Ohama, 1998) on adding different types of Polymer to the cement matrix to study the bending strength, Figure I.6 shows that there is a clear improvement in the bending strength when adding polymers of all kinds in addition to that, the air-dry treatment was better than immersion in water for the polymeric cement compounds as shown in Figure I.7.

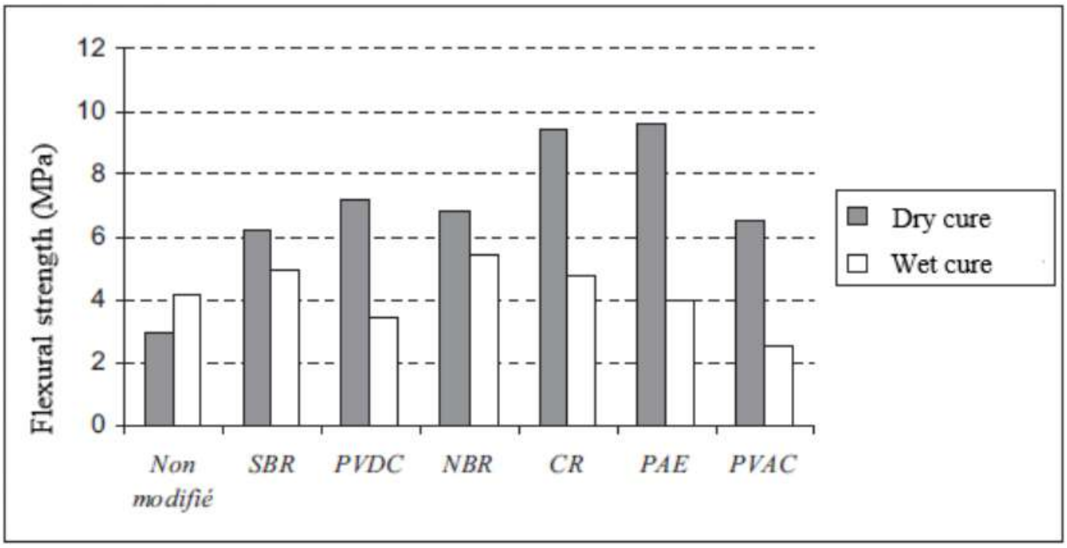


Figure I.7. Effect of Polymer Type and curing conditions on flexural strength (Ohama, 1998).

I.2.4.4 Shrinkage

Concerning shrinkage, there are two types: one, called self-drying shrinkage, takes place without contact with the external environment, while the second, called dry shrinkage, occurs in the surrounding environment. It was found that the self-drying shrinkage of sand concrete is close to that of conventional concrete if it is kept in an airtight environment (A. Benaissa et al., 1992; Sablocrete, 1994). While the dry shrinkage of sand concrete shows a very rapid development at an early age due to the high movement of premature drying. However, the drying kinetics slows down, and shrinkage stabilises.

According to the study carried out by (A. Benaissa et al., 1992), where he compared sand concrete made of sand dunes and ordinary concrete, at the age of six months, the shrinkage rate was higher than that of ordinary concrete by about 62.11% to 69.26%. Additionally, it has been shown that sand concrete displays early drying shrinkage that develops exceptionally quickly.

(Khay et al., 2010) Three different compacted sand concrete mixes were tested to evaluate their shrinkage potential. Mixes F1 and F2 are composed of crushed sand obtained from two different limestone quarries. Mix F3 is obtained from desert sand, which is found in huge quantities. Mix F1 was tested at four different w/c ratios (0.65, 0.7, 0.75, and 0.8). Mixes with a w/c ratio of 0.8 and 0.75 represent ordinary vibrated plastic sand concrete mixes, while mixes with a w/c ratio of 0.65 and 0.7 represent compacted sand concrete mixes.

Figure I.8 shows the shrinkage strain in µm/m over the first 28 days for all specimens. The curves indicate that the w/c ratio increased and the shrinkage increased. Therefore, the w/c ratio is an important parameter when considering the shrinkage behaviour of sand concrete. Values of the shrinkage strain after 28 days were plotted versus the w/c ratio and are shown in Figure I.9. Compacted sand concrete mix with a w/c of 0.65 had the lowest shrinkage strain of 220 µm/m after 28 days of age, while ordinary sand concrete with a w/c of 0.8 had the highest developed shrinkage strain of 325 µm/m. This indicates that for the same ingredients and the same cement content, compacted sand concrete developed more than 30% less shrinkage strain than ordinary sand concrete.

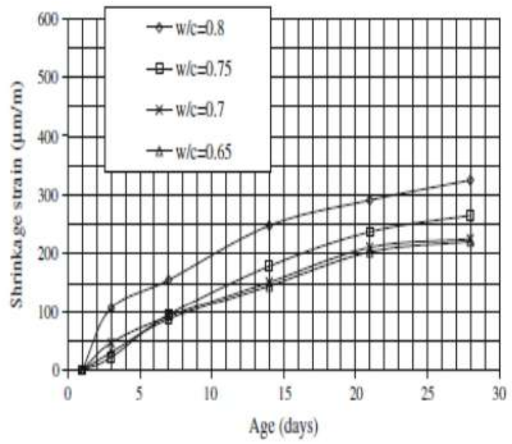


Figure I.8. Shrinkage of sand concrete mix F1 at different w/c ratios (Khay et al., 2010).

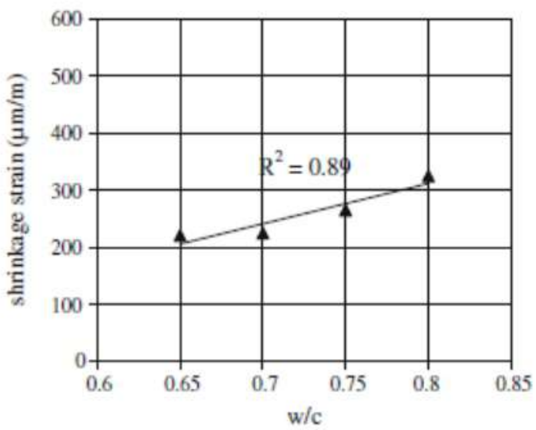


Figure I.9. Effect of the w/c ratio on the developed shrinkage strain after 28 days for mix F1(Khay et al., 2010).

Figure I.10. The results of the unrestrained shrinkage test obtained for Mix F2 at different w/c ratios. The exact same findings obtained for mix F1 were validated for mix F2. This mix, however, exhibited more shrinkage than Mix F1.

Figure I.11. show the shrinkage results for mix F3. The mix behaved in the same manner as mixes F1 and F2. An increase in the w/c ratio increased the measured shrinkage strain. A maximum shrinkage strain of 460 µm/m was obtained for this mix at 28 days and a w/c ratio of 0.75. With a w/c ratio of 0.66, the measured shrinkage strain after 28 days was 370 µm/m.

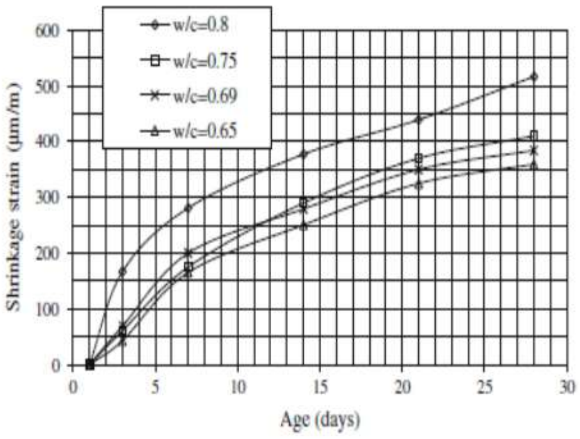


Figure I.10. Shrinkage of sand concrete mix F2 at different w/c ratios (Khay et al., 2010).

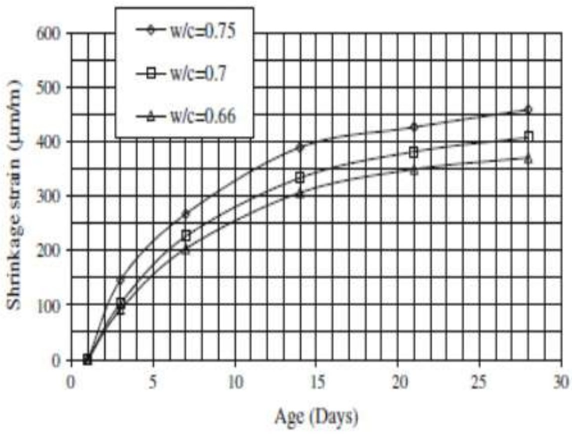


Figure I.11. Shrinkage of sand concrete mix F3 at different w/c ratios (Khay et al., 2010).

Compacted sand concrete mix F1, made with crushed sand from a limestone quarry, exhibited the lowest shrinkage strain. This could be explained by filler content. This mix had the most percentage of materials passing the 80 lm sieve (around 16% of the sand weight). This filler content is reported to positively affect the shrinkage resistance of concrete mixes since it increases the density and reduces moisture transfer across the mix (Bui & Montgomery, 1999).

In 2012, (Bederina et al. 2012a) studied the dimensional variations of sand concrete containing different wood shavings contents. They then tried to reduce the shrinkage limit values by applying different treatments to the shavings before their use. Four types of treatments were proposed: Cement treatment (CT), Lime treatment (LT), Cement +lime treatment (CLT) and Oil treatment (OT).

Figure I.12 shows the shrinkage rises by increasing the proportion of wood shavings in sand concrete. This phenomenon constitutes a disadvantage for these materials, making the treatment of wood shavings necessary. It should be noted, finally, that at an early age, sand concrete without wood presents the lowest shrinkage changes. Its shrinkage values are lower than those of wood sand concrete. In this part of the study, we will consider only one wood composition, SW-60 (B = 60 kg/m^3), to study the effect of different treatments on the improvement of wood sand concrete.

In general, all treatments used were beneficial for the improvement of the shrinkage of wood sand concrete (Figure I.13). It further shows that among the treatment tested, the oil treatment experienced the lowest drying shrinkage, which was 43.6% less than the shrinkage recorded with the same composition without any treatment. On the contrary, the cement treatment had the highest values. The lime treatment also presented good improvement (35.9% less than the shrinkage recorded with the same composition without wood treatment). If we try to classify the treatments used according to their efficacy, we note that the oil treatment is the best, followed by the lime treatment, then the cement-line treatment and finally, the cement treatment.

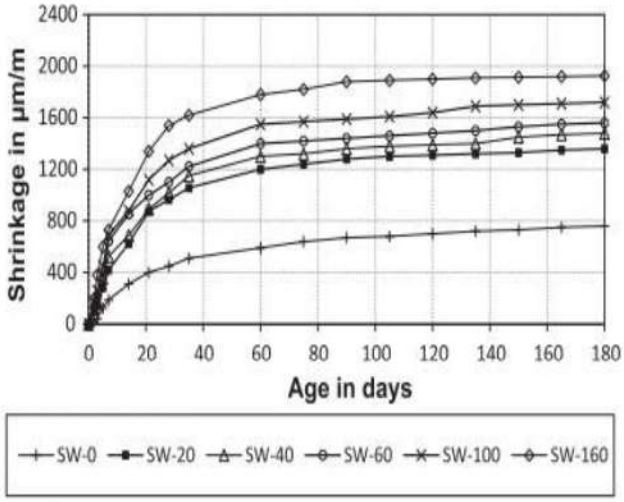


Figure I.12. Evolution of drying shrinkage according to time for different wood contents (Bederina et al., 2012a).

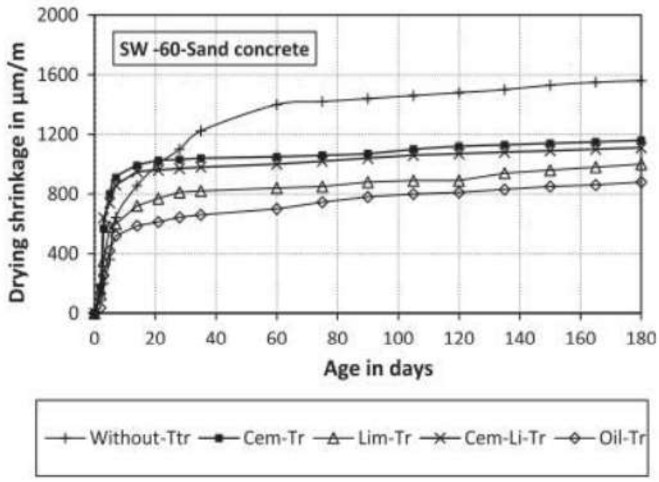


Figure I.13. Evolution of drying shrinkage according to time and type of treatment for SW-60-wood sand concrete (Bederina et al., 2012a).

I.2.4.5 Durability

Sand concrete must be durable, and durability can be defined as maintaining the quality of concrete for a long period. In particular, the durability of sand concrete is related to its interchangeability with the external environment. Therefore, it is clear that porosity, absorbance and permeability are first-order physical parameters of durability (Gadri, 2018). In fact, like conventional concrete, the same factors affect the durability of sand concrete: porosity, cracking, reinforcement corrosion, chemical attacks, etc. It is the same way to deal with it by striving for compactness by considering the particle size and integrity of the components.

The particle size and integrity of the components care in the installation and manufacture, the use of appropriate additives and compliance with certain elementary rules of implementation are all guarantees of obtaining concrete from durable and compacted sand (Djouhri, 2007). According to (A. Benaissa et al., 1993), sand concrete has a porosity range of 11 to 13%, which is fairly similar to that of ordinary concrete.

Porosity is an essential property of sand concrete and is an essential indicator of durability. Accordingly, (Gadri, 2018) studied the porosity of four different types of sand concrete and compared it with ordinary concrete, as shown in Figure I.14, where BSCR: crushed sand concrete based on limestone filler, BSFR: crushed sand concrete based on limestone filler and silica fume, BSVR: crushed sand concrete based on limestone filler and glass powder, BSDR: Dune sand concrete based on limestone filler and BO: Ordinary Concrete. The results showed that the porosity of sand concrete is greater than or equal to 12% versus the lower porosity of BO of about 8.7%. This difference is related to the W/C ratio and the composition of the cement matrix. BSVR provides the highest open porosity of 13.8%, and BSDR is about 13.5%. This is explained by the high W/C ratio, i.e. 0.62. In addition, the lowest porosity of about 12% is provided by BSFR and 12.3% by BSCR, which have the same W/C ratio, i.e. 0.60. Anyway, the porosity results obtained for the four sand concrete are slightly higher than that of ordinary concrete, which is in common agreement with those obtained by (A. Benaissa et al., 1993). In addition, according to the classification of concretes, by class of potential durability of the AFGC [2004] (UNE & DES OUVRAGES, 2004), these porosity values allow an average class for these sand concretes.

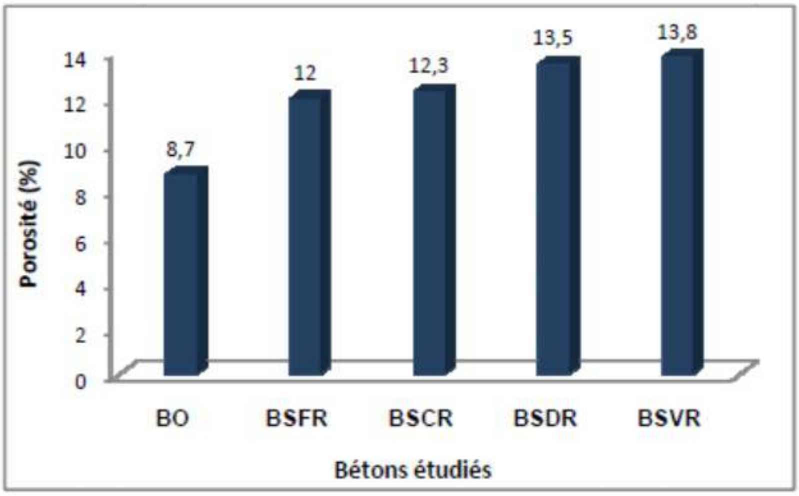


Figure I.14. Water porosity results (Gadri, 2018).

In general, adding polymers of all kinds had an influential role in maintaining the durability of the cement matrix. The Polymer modified mortar contains a porous structure where the pores can be filled with polymers or sealed with a continuous polymer film. As a result, their water absorption is lower than that of an ordinary cement matrix.

(Hassan et al., 2000) They observed a decrease in the water and oxygen permeability of a polymer-containing cement matrix compared to a regular cement matrix. Compared to a reference mortar devoid of polymers, (Ramli & Akhavan Tabassi, 2012) found a reduction in water absorption of more than 50% with modified mortar. (Shaker et al., 1997) measured the depth of water penetration of two materials, one containing SBR polymer (P/C = 15) and the other without Polymer and found a reduction of 75%.

(Ramli & Akhavan Tabassi, 2012) Studied the effect of the Polymer on the oxygen permeability of mortars modified with the following polymers: styrene-butadiene rubber (SBR), polyacrylic ester (PAE), vinyl ethylene acetate (VAE). The results showed that the permeability decreases with the Addition of Polymer to the cement matrix, and the values also depend on the type of Polymer and its effect on the cement matrix, but in general, there was an improvement in the permeability of all concrete mixtures containing Polymer regardless of its type, as shown in Figure I.15

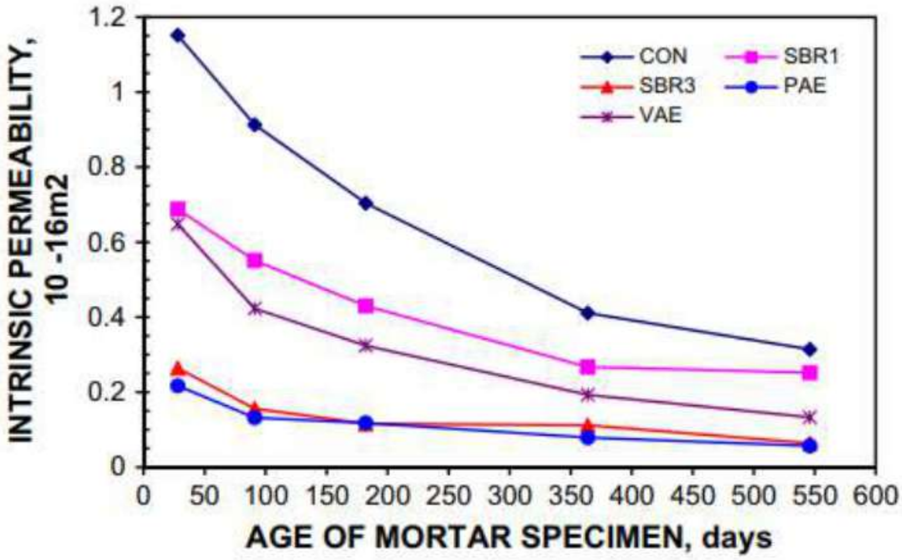


Figure I.15. Intrinsic permeability of mortar specimens under prolonged water curing (Ramli & Akhavan Tabassi, 2012).

I.2.5 Methods of formulation of sand concrete

The formulation of sand concrete depends on the selection and suitability of components to obtain properties that meet technical and economic standards. Sand concrete formulation methods target good workability, strength and long-term durability of concrete. The concrete formation is mainly based on improving the compactness of the granular structure. This compactness, defined as the ratio of solid volume to total volume, corresponds to the porosity unit's complement. The methods used are those of ordinary concrete with modifications considering the large amount of fines used (Benaissa et al., 2015).

Different researchers developed several methods for the formulation of sand concrete. Within the framework of the French SABLOCRETE project (Sablocrete, 1994), a technique has been developed for the formulation of sand concrete based on the caquot formula for determining the compactness of the granular structure; This compactness corresponds to the complement of the porosity unit. (Chauvin & Grimaldi, 1988) Presented a sand concrete formulation study, defining the amount of addition to obtain optimal compactness and resistance. Finally, to formulate sand concrete, it is necessary to combine the two parameters: workability and compactness (Gadri, 2018).

I.2.6 Uses of sand concretes in repair

In this study, the focus will be on the use of sand concrete for repair. There are many studies on the use of sand concrete for repair, examples of which are:

❖ Structure the rehabilitation of a severely degraded Naujae collector in the city of Bordeaux [France] (Sablocrete, 1994).

❖ Repair a steep embankment alongside a city street [A10, Lormont, France] (Sablocrete, 1994).

❖ Repair grain silos in Moscow: renovation work with surface reinforcement and a layer of sand concrete 6 cm thick (Chauvin, 1991).

❖ Repair of a cluttered Agrippa d'Aubigné collector in the city of Paris [France] (Sablocrete, 1994).

Finally, the latest study on the use of sand concrete for repair was the study that Gadri carried out in 2018 (Gadri, 2018), where she studied several types of sand concrete and conducted the necessary mechanical experiments to assess its adhesion strength; all the results obtained by studying it were good and fulfilled the essential purpose for repair, and based on it our focus in this study was on the use of sand concrete to repair concrete structures.

I.3 Concrete materials problems

Concrete structures are often exposed to damage and collapse due to various reasons and factors (Figure I.16) (Emmons, 1993), which makes it urgent to assess the condition of these structures and the levels of damage to them to ensure safety.

Materials concrete deterioration is its loss of performance; the degradation process of concrete needs to be previously understood before repair works.

The types and causes of flaws in concrete structures might include mistakes made during the building's design or construction, but other problems can arise from accidentally loading the structure (earthquake, accidental overload, etc.). Finally, concrete illnesses can seriously degrade the structures that need to be repaired; thus, action should be performed to enhance the structure's original function (Molez & Molez, 2005).

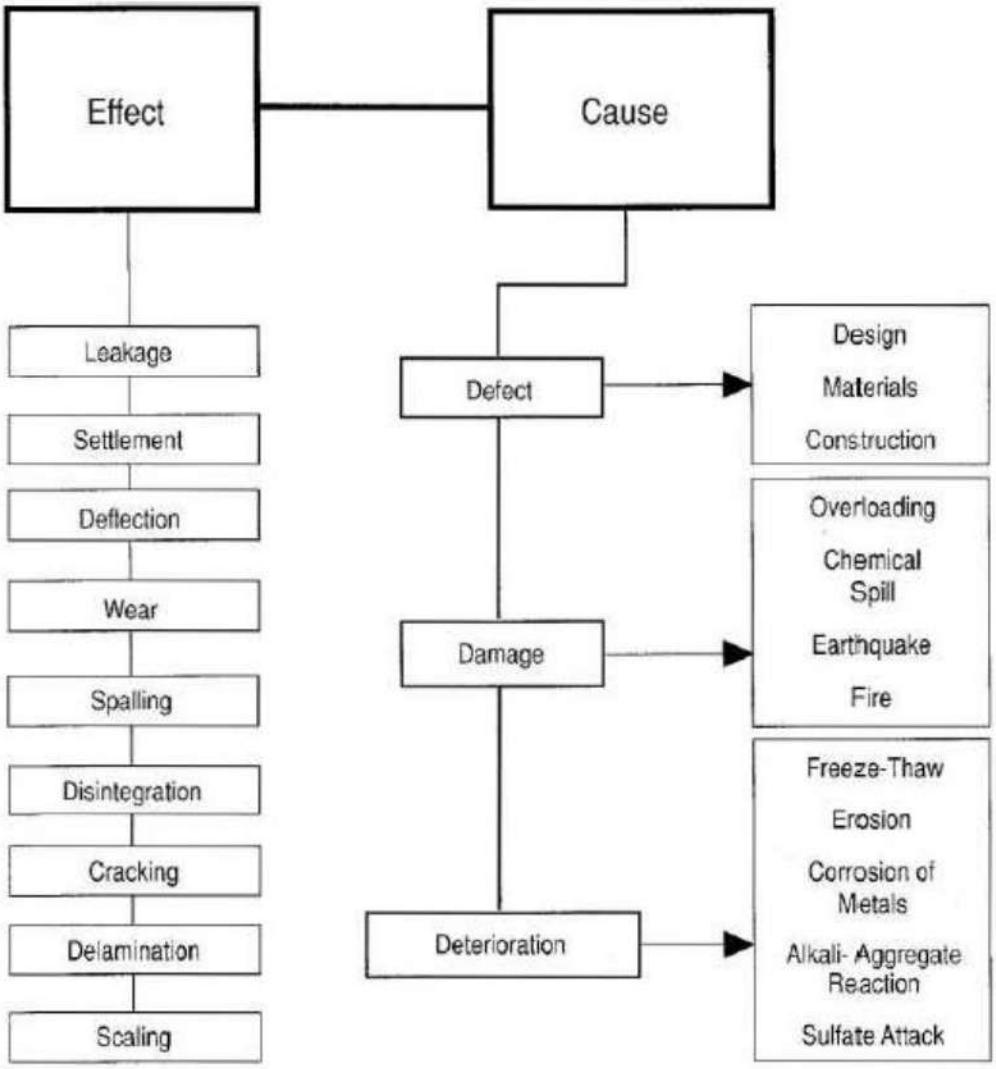


Figure I.16. Nature and origins of defects found in concrete structures (Emmons, 1993).

Corrosion of steel rebar is the most common deterioration of reinforced concrete structures (Soufi, 2014). This disease stems from the aggressiveness of the environment because it also results from design and implementation errors and thus creates cracks in the concrete cover, the first visible manifestation of concrete deterioration.

According to (Angst et al., 2009), several factors affect the corrosion process in reinforced concrete, namely:

- ❖ The state of the steel-concrete interface.
- ❖ The concentration of hydroxide ions in the interstitial solution (pH)
- ❖ The electrochemical potential of steel
- ❖ The electrochemical potential of steel
- ❖ The surface conditions of the steel
- ❖ The W/C ratio
- ❖ The degree of hydration
- ❖ The chemical composition of the steel
- ❖ Temperature
- ❖ The type of cation accompanying the chloride ion.

In general, the deterioration process of reinforced concrete goes through two stages, namely the incubation period and the development period, as shown in Figure I.17. The two stages are illustrated as follows (MAHUT, 2002):

❖ The incubation period is slow, as it cannot be visually observed, and the reason is that the concrete was unable to protect the rebar from rust, especially if the concrete was in a state of carbonation.

❖ Development period, the deterioration is already visible and tangible.

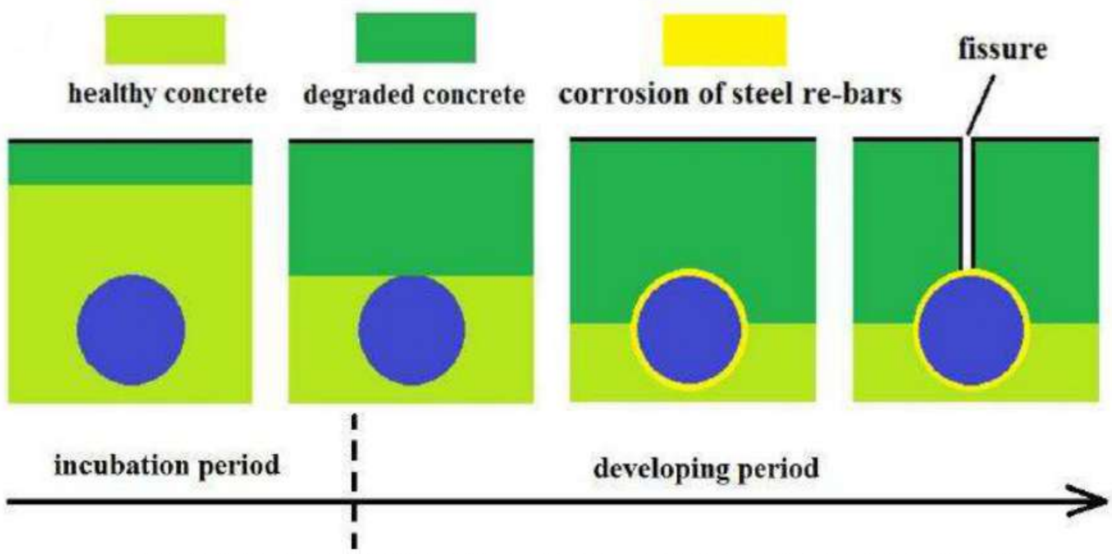


Figure I.17. Degradation of reinforced concrete cover (MAHUT, 2002).

Concrete deterioration are classified according to external (environmental) and internal (interactions) conditions. The causes of deterioration have been generally explained and categorised according to the technical manual as follows IFSTTAR (MAHUT, 2002):

❖ Damage of Physical-Mechanical :

1) Surface degradation: abrasion / erosion / cavitation / external cracking and spalling.

2) Internal cracking: gradients in humidity or temperature / freezing or thawing / crystallization pressure / structural loading / exposure to extreme high temperature (fire) / shrinkage / sensitive expansion or contraction of aggregates / bad thermal compatibility between aggregates and cement matrix.

❖ Damage of Physical-chemical :

Corrosion of steel rebar/degradation due to electrolytic action / spalling due to melting salt / alkali-aggregate reaction. Factors which affect the degradation are related to characteristics of the concrete composition, internal micro-climate, external environment, conception of design work, installation and maintenance of the structure, etc. The mechanisms of concrete degradation are principally related to major damage causes, such as carbonation, attack by chloride ions, sulphate or acid attack, freeze-thaw cycles, drying-wetting cycles, alkali reactions, etc., corrosion of steel rebar are thus induced.

❖ Chemical :

Attack by freshwater, salty sea water or chloride solution (brine) / attacked by acid or sulfates (groundwater or due to local environment) / oxidation of sulfides in aggregates/formation of secondary thaumasite and ettringite / alkali-silica reaction / alkali-carbonate reaction.

I.4 Concrete repair mechanism

Repair is generally defined as the treatment of deteriorated concrete that has lost its properties due to the various factors it has been exposed to, using the necessary methods and materials.

Concrete repair consists of two types: structural and non-structural; non-structural repair is where the thickness of the repair material is less than 100 mm, and vice versa for structural repair (Benzerzour et al., 2014).

The repair process goes through successive, inseparable main stages, beginning with an accurate diagnosis of the causes of deterioration. It is essential to understand the origin of the damage to prevent it from reappearing once the structure has been repaired. Then the preparation of the area to be repaired must be carried out carefully: removal of deteriorated concrete with special care, good cleaning and addition of reinforcing bars if necessary; finally, the appropriate application of the repair material.

Regardless of the type of repair performed, the repair system consists of three stages: the structure to be repaired (substrate), the repair material, and the transition area that forms the interface between the two materials, as shown in Figure I.18 (Emmons & Vaysburd, 1994).

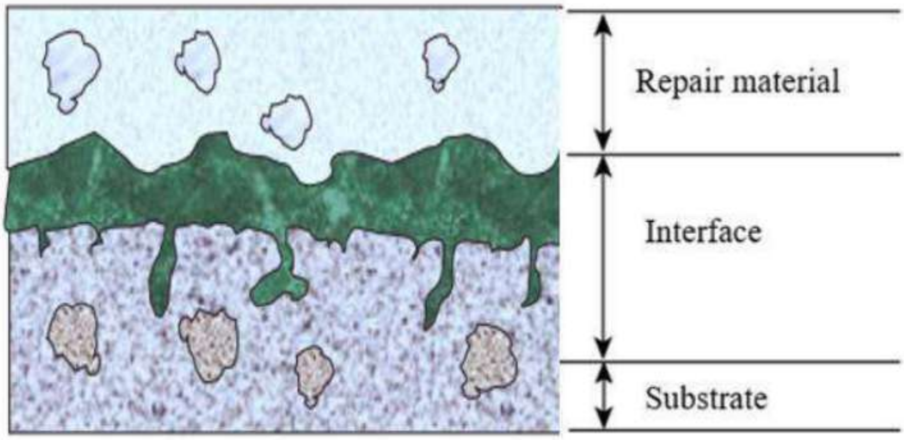


Figure I.18. Three-phase repair system (Emmons & Vaysburd, 1994).

I.5 Standard context for repair

With the increase in repair and maintenance work on degraded concrete structures, technical guides and standards. Among them, we can mention the European standard EN 1504. European standard EN 1504 (EN1504, 2014) defines products and systems for protecting and repairing concrete structures. It consists of 10 parts which are shown in Table I.2. As the repair of concrete structures is an activity that requires qualified and competent personnel, and therefore the main objective of this standard is to improve the repair mechanism.

Table I.2: Parts of standard NF EN 1504 (EN1504, 2014).

Document number	Description
EN 1504-1	Definitions
EN 1504-2	Surface protection systems
EN 1504-3	Structural and non-structural repair characteristics
EN 1504-4	Concrete injection products and systems
EN 1504-5	Bonding products and systems
EN 1504-6	Anchorage and sealing products and systems
EN 1504-7	Products and systems for preventing corrosion
EN 1504-8	Quality control and conformity evaluation
EN 1504-9	General usage principles of products and systems
EN 1504-10	Applications of products and systems quality control

I.6 Characteristics of repair materials

It is essential to know the properties of repair materials before choosing the suitable repair material to repair the condition. There are many materials for the repair of concrete structures; these are classified into three categories (Qian et al., 2014), namely Polymer or resin materials, Polymer modified cementations materials (PMC), and Cementations concretes. Each category has specific physical properties (Mailvaganam & Mitchell, 2003), as shown in Table I.3. In particular, the understanding of these properties determines the choice of repair materials that are compatible, as far as possible, with the properties of the substrate concrete.

Table 1.3: Properties of concrete repair materials (Mailvaganam & Mitchell, 2003).

Type of repair material	Polymer-based material	Polymer modified cementations	Cementations material
Compressive strength (MPa)	50-100	30-60	20-50
Tensile strength (MPa)	10-15	5-10	2-5
Modulus of elasticity (GPa)	10-20	15-25	20-30
Coefficient of expansion thermal (°C)	$25\text{-}30\times10^{-6}$	$10\text{-}20\times10^{-6}$	10×10^{-6}
Maximum service temperature (°C)	40-80	100-300	>300

Currently, most repair materials are factory-pre-formulated materials. Their compositions have become complex, combining cement, adjuvants, fibres and polymers (Soufi, 2014).

This study will focus on the Polymer modified cementitious (PMC) materials. Polymers are among the most common constituents in the composition of repair materials. Polymers are added to improve repair materials' mechanical and adhesion properties and reduce transfer properties (porosity, permeability, diffusivity of chlorides). This improvement depends not only on the type of Polymer but also on the polymer/cement ratio (Ohama, 1998). The most widely used polymers are latex.

Studies on modified materials with different polymer contents and reference materials (without polymers) showed that the tensile strength increases with the increase of the polymer modifier. This improvement in tensile strength is due to the improved adhesion of the cement matrix and the bridging of micro-cracks by the Polymer (Bureau et al., 2001; Pascal et al., 2004). Other studies show that the resistance depends on the type of Polymer, the P/C ratio, and the processing conditions (Wang et al., 2005).

According to NF EN 1504-3 [2006], which shows the characteristics and performance requirements of structural and non-structural repair products, repair materials are divided into four classes from R1 to R4, as shown in Table I.4.

Tableau I.4: Performance requirements for structural and non-structural repair products (EN 1504-3, 2006).

Item	Requirement			
	Structural		Non-Structural	
	Class R4	Class R3	Class R2	Class R1
Compressive Strength	≥ 45 MPa	≥ 25 MPa	≥ 15 MPa	≥ 10 MPa
Chloride Ion Content	≤ 0,05%		≤ 0,05%	
Adhesive Bond	≥ 2,0 MPa	≥ 1,5 MPa	≥ 0,8 MPa	
Restrained shrinkage Expansion	Max average crack width <0.05mm No crack width >0.1mm No delamination			Not required
Durability Carbonation resistance (not required if coated)	d_K ≤ Control concrete C(0,45)			Not required
Elastic Modulus	≥ 20 GPa	≥ 15 GPa	Not required	

I.7 Adhesion factors between repair material and substrate

Several studies have been conducted to determine the most critical factors contributing to the adhesion between the repair material and the substrate. We mention two factors: substrate roughness and a bonding agent.

I.7.1 Substrate roughness

According to the recommendations of the standard NF EN 1504, the preparation of the surface is a fundamental step that must be carried out before the repair. It consists in removing the deteriorated concrete from the substrate and cleaning it after its surface has become rough. This operation must be carried out with care as long as the link between the support and the reloading depends on it. The level of surface roughness is related to the chosen technique.

Several techniques are used to prepare the abutment surface, such as a jackhammer, hammer, and diamond point roller. However, these techniques generate microcracks in the support (Olivier & LAURENCE, 2001). Since the presence of cracks at the interface mainly affects the bond strength between the repair material and the concrete substrate (Courard, 2002; Garbacz et al., 2005). Microcracking weakens the interface between the repair and the concrete base. Other techniques, including sandblasting and water demolition, are applied because they have created few or no microcracks in the concrete of the substrate. In addition, it provides a sufficiently rough surface (Perez et al., 2009).

(Talbot et al., 1995) The hydro-demolition technique is good, less harmful, and offers good adhesion results. In addition, sandblasting gave excellent results in adhesion between the substrate and the repair material for most repair cases, as it provides a high roughness of the substrate without causing cracks on the substrate surface (Tayeh, Abu Bakar, et al., 2013; Valikhani et al., 2020).

According to many studies that have been conducted on adhesion, roughness plays a significant role in adhesion and bonding between the repair compound (Molez, 2003; Momayez et al., 2005).

(Tayeh, Abu Bakar, et al., 2013), A successful connection between the substrate and the repair depends on proper surface preparation. Sandblasted substrates produced the best results in tests of slant shear adhesion on surfaces of different roughnesses of substrate surface: (AC) no roughness; (SB) sandblasted; (WB) wire brushed; (DH) drilled holes; (GR) grooves (Figure I.19).

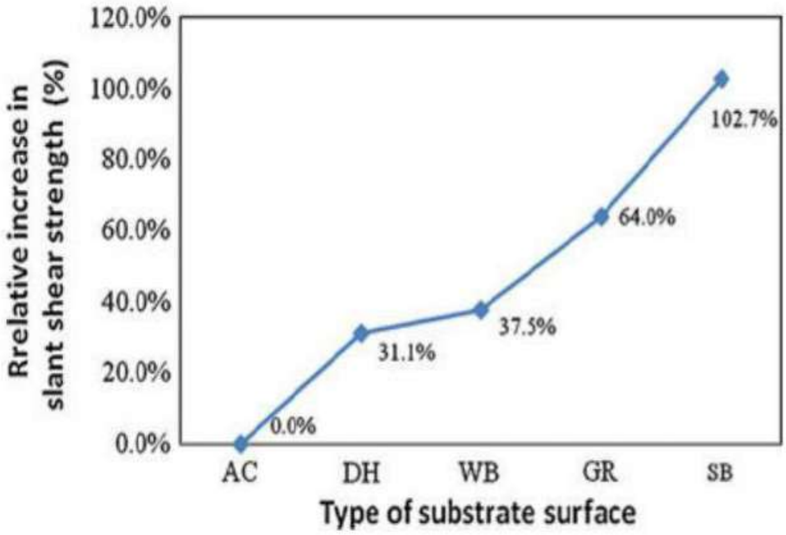
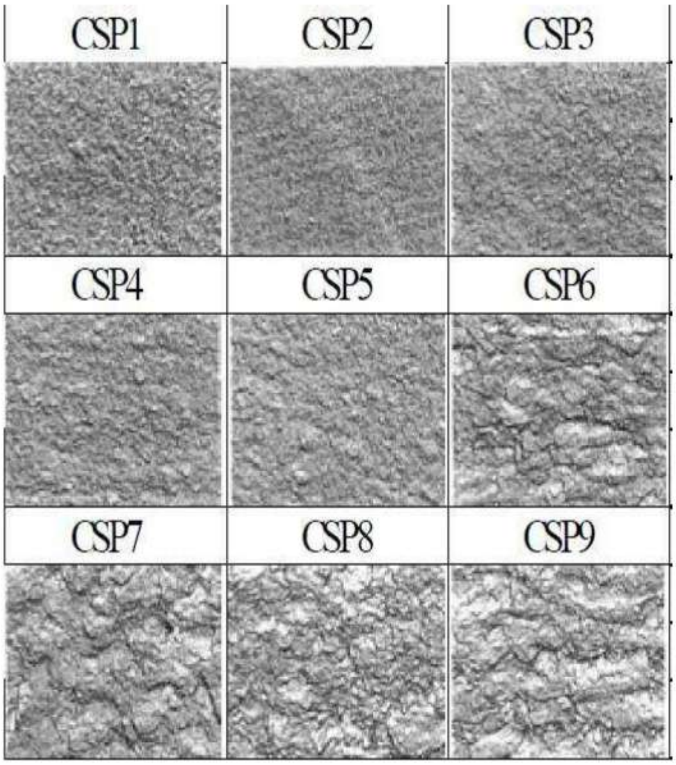


Figure I.19. Slant shear bond strength for the different types of substrate surface (Tayeh, Abu Bakar, et al., 2013).

In practice, it is necessary to determine the roughness of the prepared surface before repairing it. Various methods can be used to measure surface roughness (P. M. D. Santos & Júlio, 2013) to find out the surface roughness of the substrate to be repaired; We will mention some of them as follows:

- Concrete surface profile (CSP), by International of Concrete Repair Institute (ICRI) Guideline No. 310.2R-2013. The only recommended and often-used tool is that of ICRI (Garbacz et al., 2017). Suggested ten roughness measurement (CPS) files (Figure I.20) to determine the surface roughness of the substrate to be repaired.



Surface preparation methods	CSP
Detergent scrubbing	1
Low-pressure water cleaning	1
Acid etching	1–3
Grinding	1–3
Abrasive blasting (sand)	2–5
Steel shotblasting	3–8
Scarifying	4–9
Needle scaling	5–8
Water jetting	6–9
Scabbling	7–9
Flame blasting	8–9
Milling/rotomilling	9

Figure I.20. Model of CSP surface profiles (Garbacz et al., 2017).

❖ Sand patch test, in accordance with EN 13036-1:2010 (Čairović et al., 2017).

The surface roughness is characterised using glass or sand particles by the mean texture depth (MTD):

$\mathrm{MTD} = (4\mathrm{V})/(\pi D^2)$ (mm) ………………………………….. I.2

V = volume of granular material [mm^3]; D = diameter of circle covered by granular material [mm]

Figure I.21 shows the mechanism for conducting a sand patch test. Wherein adoption of sand patch tests by different researchers (Courard et al., 2014; López-Carreño et al., 2017).

Figure I.21. Mechanism for conducting a sand patch test (Courard et al., 2014; López-Carreño et al., 2017).

❖ Laser technique, the superficial elevation (distance from the laser beam source to the object) of each point is calculated based on the laser beam transit time. Where Figure I.22 shows the laser technique scanning process to measure the level of roughness of the substrate.

Some studies favour using the laser scanning method to assess the interphase area between repair materials and the substrate (Siewczyńska, 2012; Tayeh, Bakar, et al., 2013), although there are various other methods for measuring the substrate roughness level.

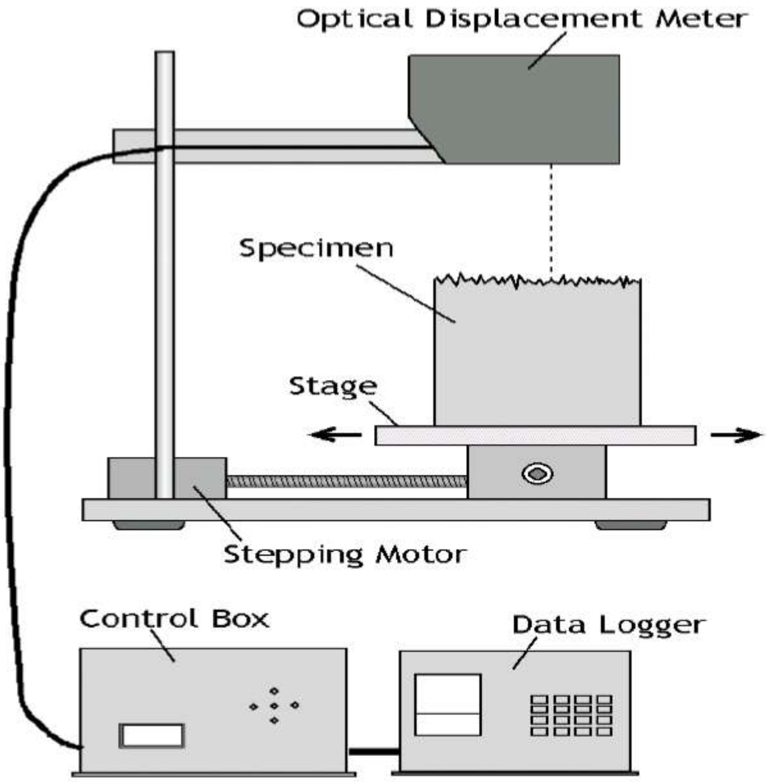


Figure I.22. Laser technique to measure the substrate's roughness level (Piotrowski, 2009).

I.7.2 Application of bonding agent

Applying a bonding agent in a repair system is a common practice. It is even recommended in certain specifications. There are various products marketed as bonding agents for repair. The most common are epoxy resins and modified or unmodified cement pastes. Many authors have studied the influence of using a bonding agent between the support and the hard facing. According to some, a bonding agent can be applied to improve the adhesive bond (He et al., 2017; Thomas et al., 2012).

When a bonding agent is required, the materials should be applied in a thin, even coat. The contact time (should not dry out). Before placing a bonding agent, check the repair area for any dust or sandblasting residue. The area should be clean and dry. Wiping the area while wearing a dark brown or black cotton glove will easily indicate a dust problem. Airblown again if the dust has settled back in the repair area. Scrubbing the bonding materials with a stiff-bristled brush works well to get the materials into surface cavities. Epoxy agents may permit a less vigorous application. Cover the area with the bonding agent, including the repair walls or edges. Overlapping the pavement surface also will help promote good bonding.

However, all researchers do not accept the benefits of using bonding agents. Santos (D. S. Santos et al., 2012) believe that the effectiveness of the bonding agent is pronounced for less rough and dry substrate surfaces. (Júlio et al., 2005) find that a surface treatment by sandblasting leads to better adhesion results than a bonding agent application. It gives lower adhesion forces at a higher cost. (Silfwerbrand & Paulsson, 1998), It Advises against using bonding agents because creating two interfaces instead of just one results in two areas of weakness.

I.8 Bonding and adhesion test methods

Adhesion tests between two composites, such as a substrate and a repair material, are essential for knowing and evaluating the bond strength and the test's failure mode. Several tests are performed to determine the interface resistance between the repair material and substrate and to estimate the performance of its bond (Gadri & Guettala, 2017b).

In short, there are a variety of tests that fall into two main categories to assess the bond strength between two layers of concrete, tensile (direct and indirect) and shear (direct and indirect) (Gadri, 2018). In Addition to the mixed mode, the mixed mode is a combination of normal and shear stresses (López-Carreño et al., 2017).

According to (López-Carreño et al., 2017), there are four types of tests to assess bonding strength: pure tension, pure shear, shear and tension (Mixed mode), and bending (Mixed mode), as shown in Figure I.23

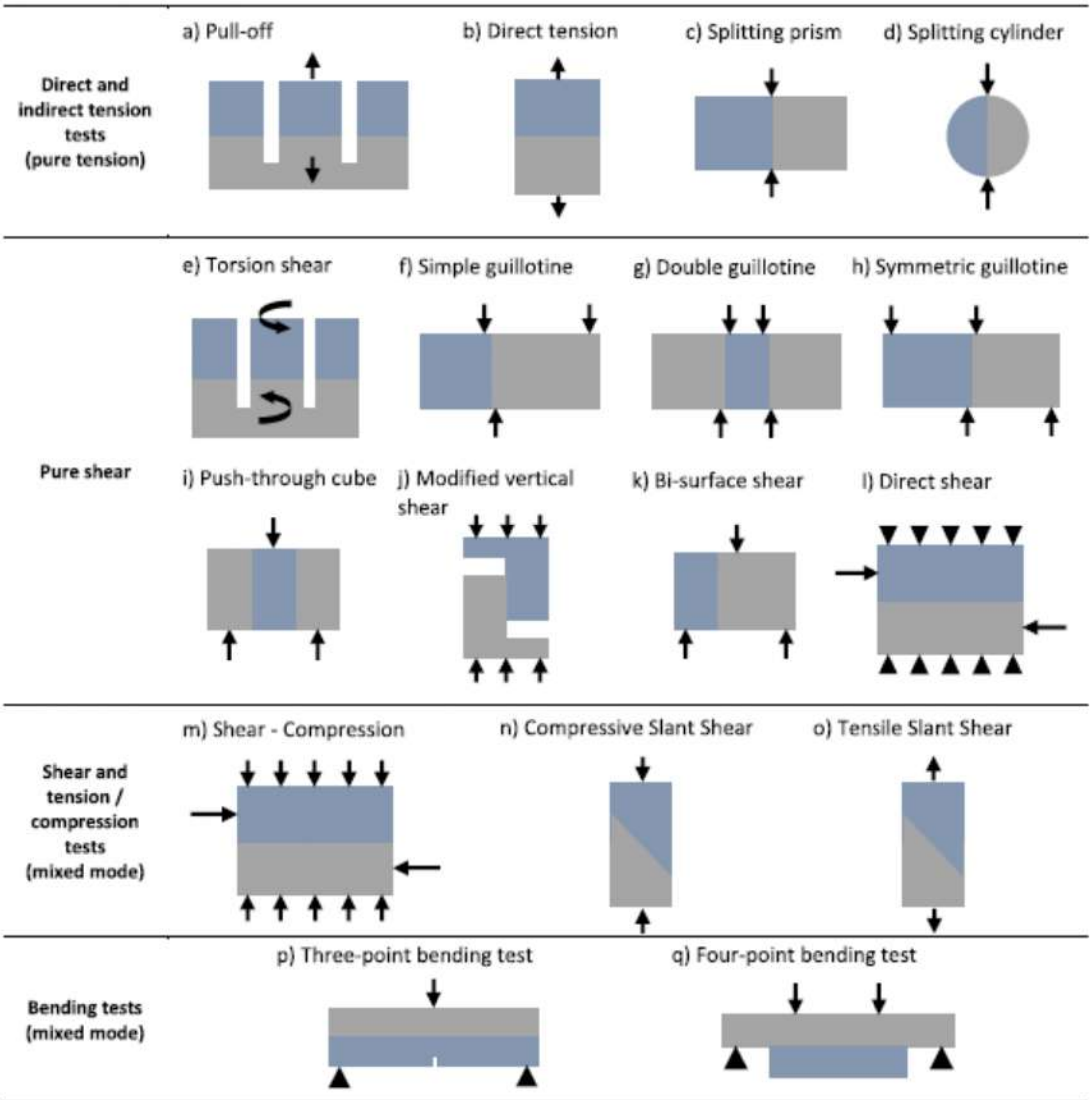


Figure I.23. Various test methods for assessing interface bond strength (López-Carreño et al., 2017).

Bending tests (p, q) has recently been used for bonding characterisation between cement-based layers (López-Carreño et al., 2017; Yucel et al., 2013) and between asphalt and Portland cement concretes (Chabot et al., 2013; López-Carreño et al., 2017).

According to (Momayez et al., 2005) studied four different types of tests: Pull-off, splitting, bi-Surface shear and slant shear, as shown in Figure I.24, where he conducted the study for two types of substrate, one with a high rough surface and one with a low rough surface, using different kinds of repair materials.

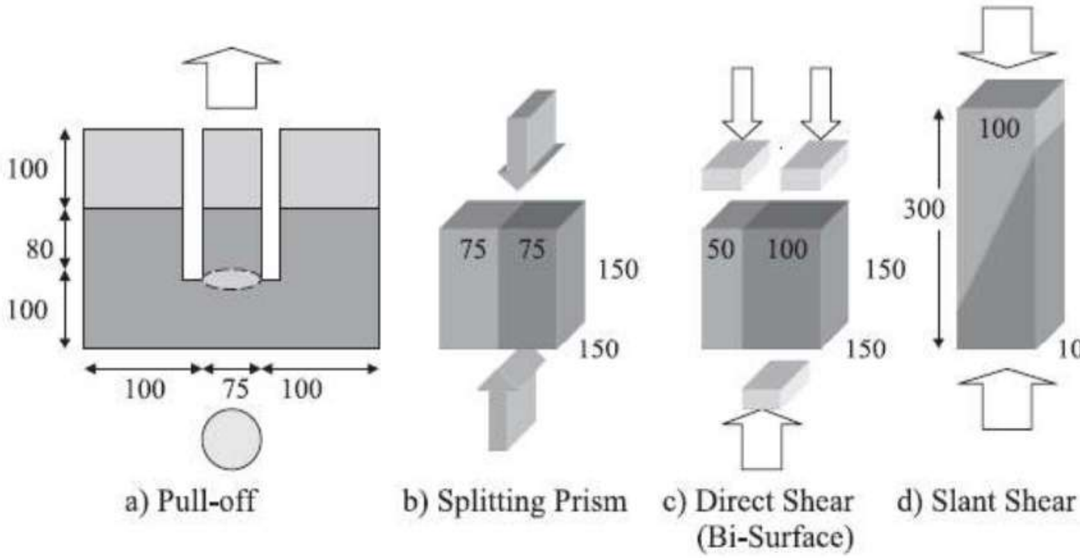


Figure I.24. Types of Tests and Dimensions of tested Specimens (Momayez et al., 2005).

Where the study shows that the measured bond strength depends mainly on the test method used and that the bond strength obtained through the different tests for each sample is directly proportional to all types of tests, meaning that the sample that obtained the best bonding strength is the same for all test methods in these study, as shown in Figure I.25

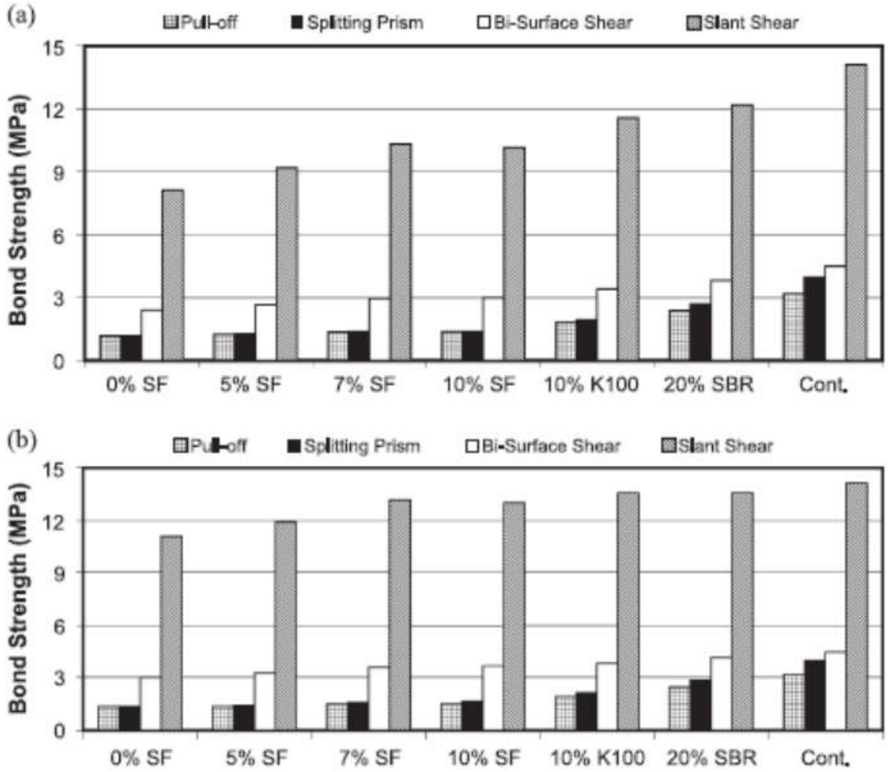


Figure I.25. Measure bond strength by different methods: (a) low roughness and (b) high roughness (Momayez et al., 2005).

The study conducted by (López-Carreño et al., 2017) showed three different types of failure for each test: Direct Tensile (DT), Laboratorio de Caminos de Barcelona (LCB), and Slant Shear (SS) tests, as shown in Figure I.26, Shows a schematic representation of the three failure types observed in the experimental program: cohesive, adhesive, and mixed mode. Cohesive failure is characterised by cracking outside the interface zone. In other words, the cracks occur in the substrate, not reaching the interface, thus indicating that the strength of the interface is greater than that of the materials of the substrates and overlays. Adhesive failure is characterised by cracking through the interface. In this situation, the interface shows a weaker behaviour than the substrate and the overlay materials. Finally, mixed failure is a combination of both modes and is caused by the emergence or the rise of secondary stresses or by the existence of different strength capacity zones along the interface.

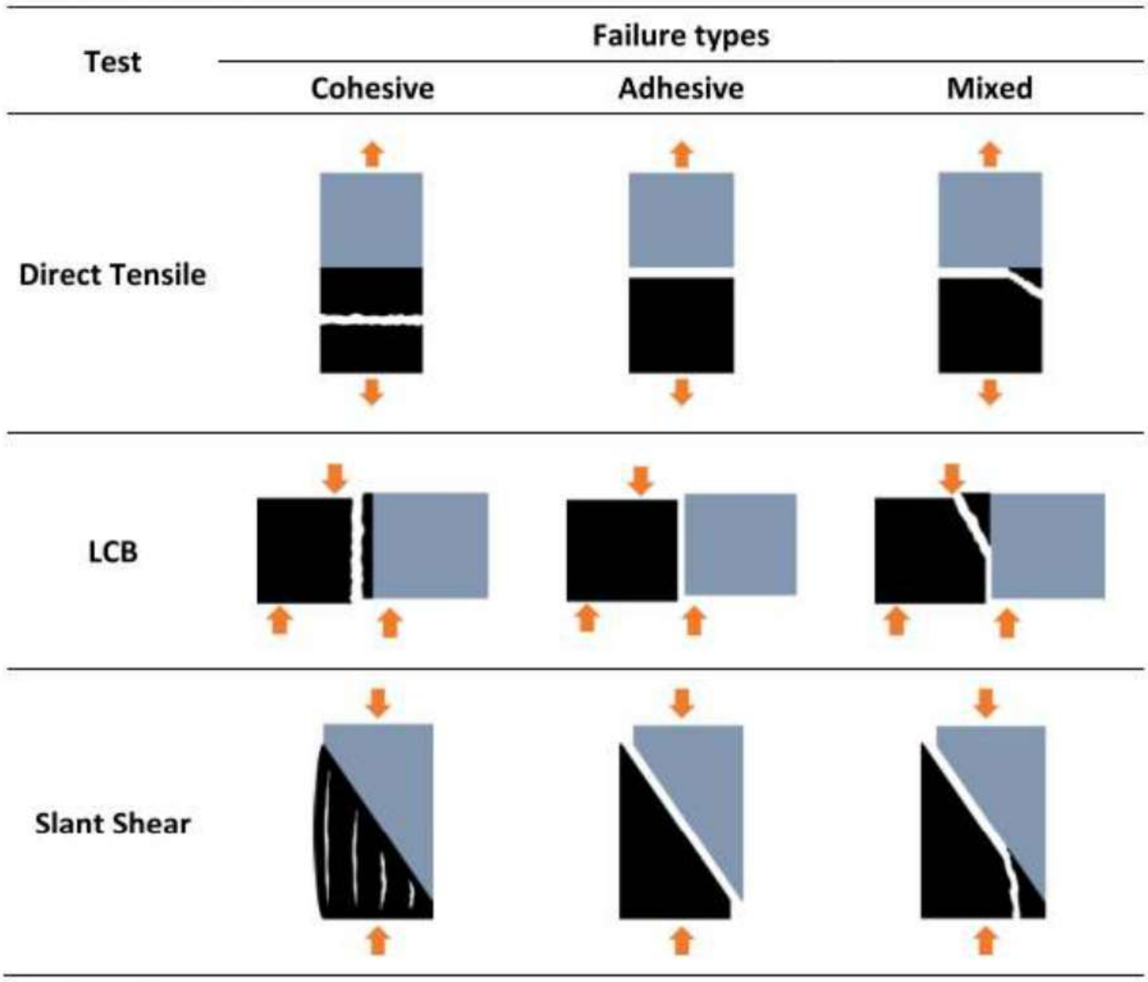


Figure I.26. Failure modes in direct tensile, LCB, and slant shear tests (López-Carreño et al., 2017).

The pull-off test method is typically designed to measure the direct tension bond strength between precast and cast-in-place concrete using standard ASTM C1583/C1583M (ASTM 2013b). In this test method, the specimen may fail in four locations: (a) failure in precast concrete ;(b) bond failure at precast/cast-in-place interface; (c) failure in cast-in-place; and (d) bond failure at epoxy/cast-in-place interface. The four failure modes are shown in Figure I.27 (Semendary & Svecova, 2020).

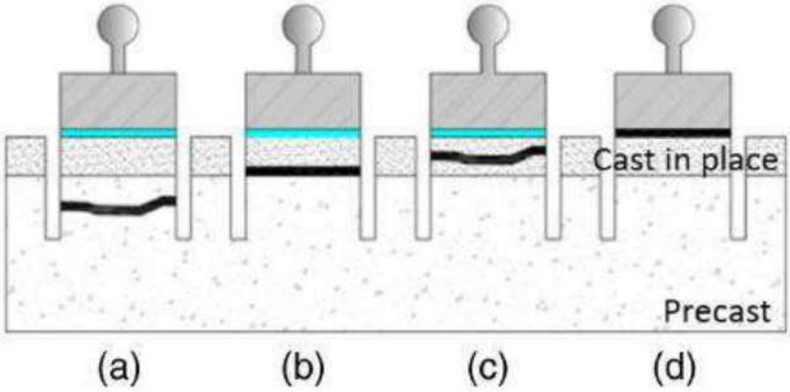
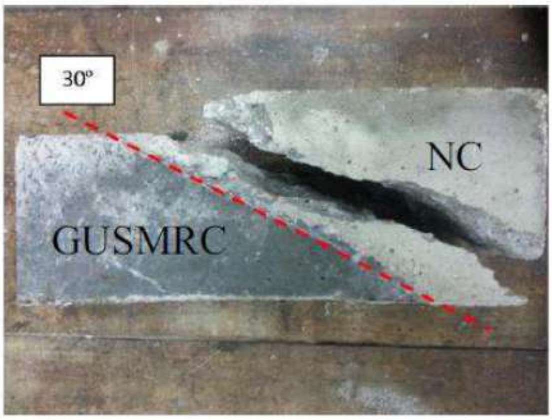
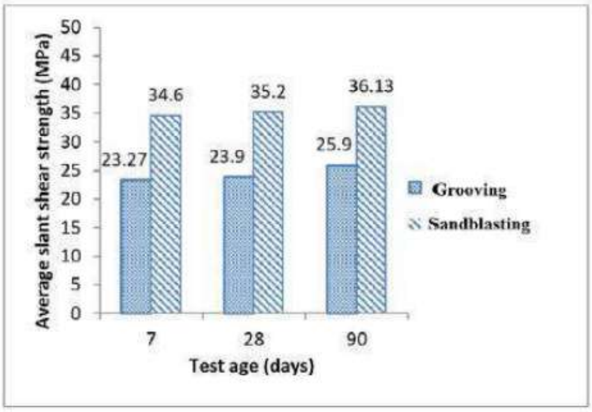


Figure I.27. Schematic of failure modes (Semendary & Svecova, 2020).

I.9 some studies on the bonding between concrete substrate and repair materials.

Where (Abo Sabah et al., 2019) studied the bond strength between a new Green Universiti Sains Malaysia Reinforced Concrete (GUSMRC) as a repair material and the existing normal concrete substrate (NC) using two types of surface treatment, namely grooving and sandblasting, using test methods: slant shear, splitting tensile, and pull-off strength tests. All the results gave satisfactory results, and this indicates that the substrate surface treatment is important, as shown in Figure I.28, the bond strength results obtained from the slant shear test and failure mode, Acceptable bond strength range for slant shear test according to ACI Concrete Repair Guide (Chynoweth et al., 1996), As shown in Table I.5, all results are excellent, and the failure mode of the substrate is evidence of strong correlation.





(a) (b)

Figure I.28. (a) Failure mode D; (b) average slant shear strength for the different types of the substrate surface at different ages (Chynoweth et al., 1996).

Table I.5: Acceptable bond strength range for slant shear test according to ACI Concrete Repair Guide (Chynoweth et al., 1996).

Days	Bond Strength (MPa)
1	2.76–6.9
7	6.9–12.41
28	12.41–20.68

With the use of scanning electron microscopy, (Tayeh et al., 2014) investigated the characteristics of the interfacial transition zone between normal concrete (NC) substrate old concrete and ultra-high performance fiber-reinforced concrete (UHPFC) as a repair material (SEM). After completing the pull-off test at 28 days, three 20 mm diameter core samples were taken from the interfacial transition zone of the pull-off test samples. As illustrated in Figure I.29, the samples represented every type of NC substrate surface preparation procedure, including As-casted (AC), Wire-brushed (WB), and Sand-blasted (SB). The interfacial transition zone was repaired with UHPFC, which SEM demonstrated enhanced the zone in terms of chemical, physical, and mechanical properties, making it stronger and denser as well as more uniform and long-lasting. Additionally, employing UHPFC extended the service life.

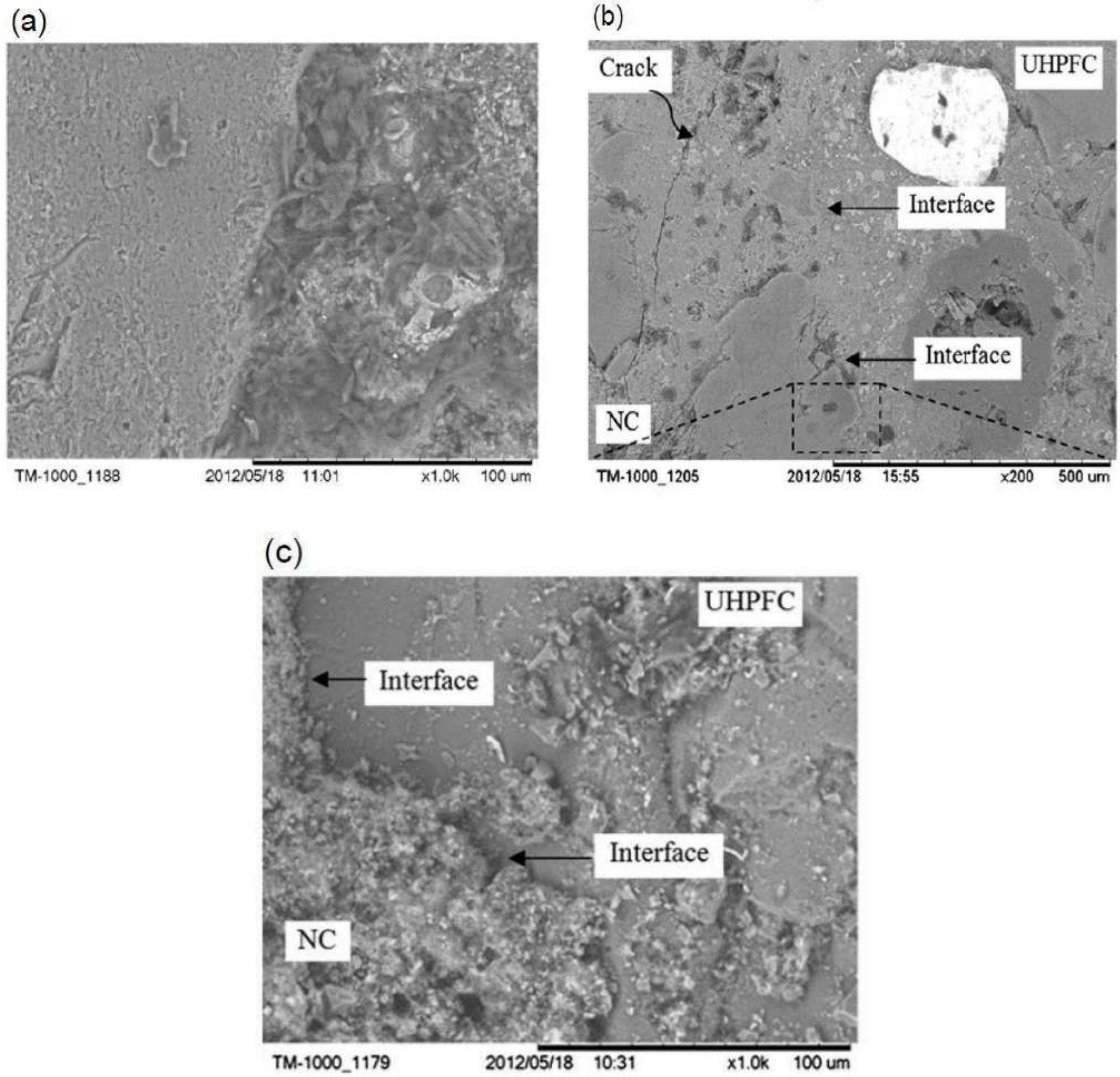


Figure I.29. SEM of the interfacial transition zone between UHPFC and NC (Tayeh et al., 2014).

According to the research carried out by (Valikhani et al., 2020), by examining the bonding strength between concrete substrates and ultra-high performance concrete, all samples were tested by the bi-surface shear test with different surface settings as follows: The concrete cube was cast monolithically (Reference), Substrate with smooth surface 'as cast' (S1-S5), Substrate with rough surface 'sandblasting' (R1-R5), Substrate with rough surface combine with mechanical connectors (RM1-RM2), Substrate with smooth surface combined with a bonding agent (SB1-SB5) and Substrate with rough surface combined with a bonding agent (RB1-RB5). The results showed that surface roughness plays the most important role in bond strength, and therefore all methods and other materials, whether bonding agents or mechanical connectors, enhance adhesion in the rough surface, as shown in Figure I.30 Average bond strength for each group of testing.

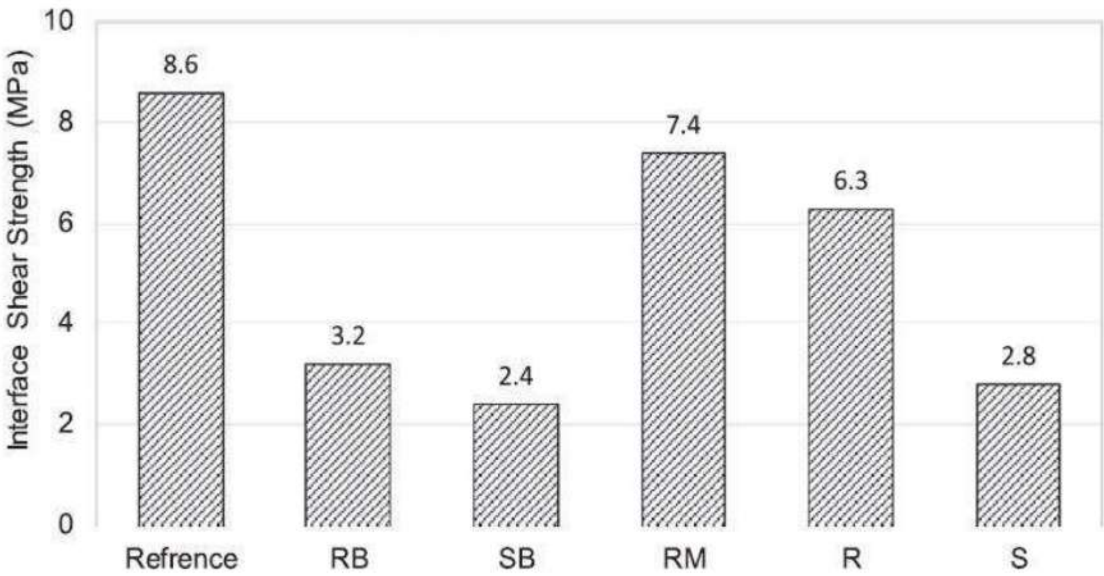


Figure I.30. Average bond strength for each testing group (Valikhani et al., 2020).

(Gadri & Guettala, 2017a) Studied two types of sand concrete as repair materials: sand concrete with 100% limestone filler (SCL) and sand concrete with 50% limestone filler and 50% glass powder (SCG). They applied the materials to two types of substrates: the first one contains a superplasticizer (OCS), and the other has no superplasticizer (OC), for three different types of surfaces: low roughness (LRG As demonstrated in Figure I.31, the high roughness (HRG), the drilled holes (DH), and lastly the low roughness (LRG) produced the best results in the flexure test. In conclusion, these findings enabled us to think favourably of sand concrete.

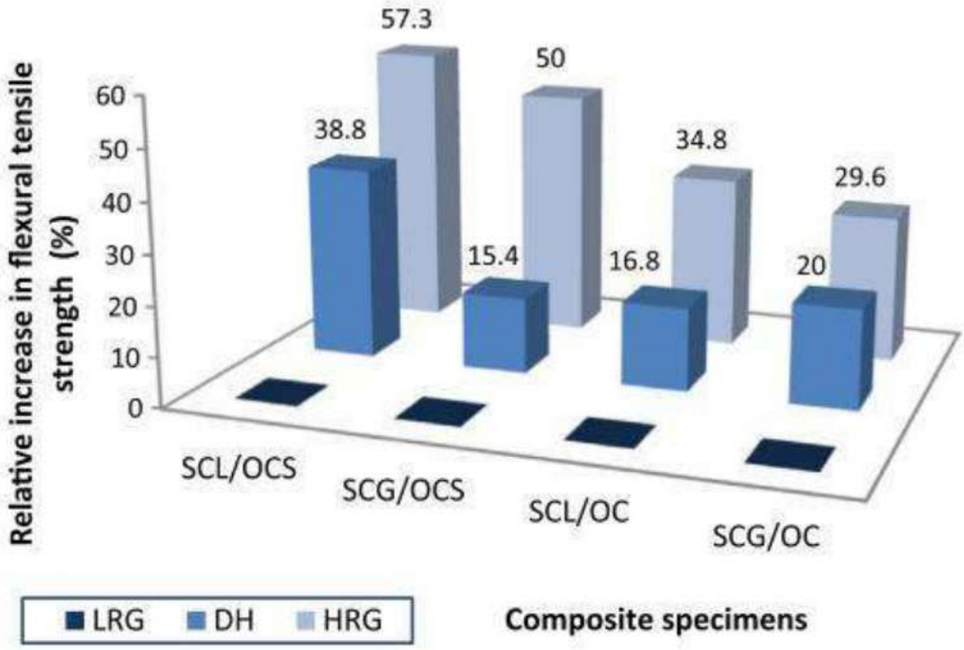


Figure I.31. Relative increase in flexural tensile strength for the different types of the substrate surface (Gadri & Guettala, 2017a).

Table I.6 presents studies on the bond strength for different treated surfaces and the test method between the substrate and the repair material.

Table I.6: Presents a group of studies on bond strength.

Reference	Test	Surface preparation	Bond strength (MPa)
(Haber et al., 2018)	Pull off test	Roughened with grooves	0.78
		Roughened with hydro-demolition	3.42
(Valikhani et al., 2020)	Bi-surface shear	As cast	2.80
		Sandblasted	6.30
		Sandblasted with mechanical connectors	7.40
		As cast with Epoxy	2.40
		Sandblasted with Epoxy	3.20
(Aaleti & Sritharan, 2019)	Slant shear test	Texture with 1.26 mm mean texture depth	14.5
		Texture with 1.59 mm mean texture depth	20.1
		Texture with 5 mm mean texture depth	18.7
		Texture with 3 mm mean texture depth	16.8
		Texture with 6.5 mm mean texture depth	16.0
(Harris et al., 2011)	Splitting Prism test	As cast	5.00
		Roughened with a wire brush	5.00
		Roughened with grooves	3.00
(Tayeh et al., 2012)	Slant shear test	As cast	8.68
		Roughened with grooves	13.9
		Roughened with drilled holes	12.3
		Roughened with sandblasting	17.8
		Roughened with a wire brush	12.8
(Gadri & Guettala, 2017a)	Flexural test	Low roughness	5.62
		High roughness	8.84
		Drilled holes	7.8

I.10 Conclusion

We have shed light in this chapter on a different set of previous studies on sand concrete by studying its physical and mechanical properties, components and formulation.

This chapter also provides insight into research activities and applications related to the use and application of concrete repair materials. A composite material with distinct mechanical and physical properties is formed by combining new and old concrete as a repair material. Thus, the compatibility of the two components drives them to a successful and effective repair of the concrete structure. The adaptability of the repair materials for concrete structures is an essential parameter for long-term repair stability.

The adhesion and bonding between the repair material and the substrate is affected by several factors that are likely to affect the adhesion, such as surface preparation or the use of a bonding agent. We have studied several tests of the strength of the bond according to previous studies, as well as the failure mode that was obtained after the test.

This study is considered development and continuation of previous studies. The purpose of studying sand concrete was to use it for concrete repair.

CHAPTER II

EXPERMANTAL PROGRAM

II.1 Introduction

This chapter initially presents most of the physical and chemical properties of the materials used in this study and also deals with the mechanism of formulation and composition of the studied concrete in terms of mixing and curing concrete; it is necessary to mix these materials properly to produce a homogeneous mixture on a large scale and thus have uniform properties. In addition, it demonstrates all experimental tests of concrete, whether mechanical or physical and the use of Scanning electron microscopy (SEM) for microstructure analysis.

This chapter also discusses the mechanism of repair techniques and procedures used in this study to prepare the substrate surfaces, apply the repair material to the substrate and treat the compound after merging the two compounds. In addition, it explains the mechanism of adhesion tests to know the bond strength and failure mode through the following tests: Bi-surface shear test, Splitting tensile test and Pull-off test.

II.2 Characteristics of the materials used

II.2.1 Sand

Two types of sand were used in this study: The first type was Crushed Sand (CS) with a diameter of 0/5mm (see Figure II.1a), which was obtained from Ain Touta (Batna). The second type was River Sand (RS), with a diameter of 0.08 to 5 mm (see Figure II.1b), which was obtained from the oued lioua (Biskra). The physical properties of the CS and RS are shown in Table II.1. Grading curves of the CS and RS are presented in Figure II.2.

II.2.2 Gravel

In this study, gravel was a crushed limestone stone with a diameter of 3/15 mm, Extracted from the Ain Touta region in the wilaya of Batna.

Table.II.1: Physical properties of crushed sand and river sand.

	Crushed sand (CS)	River sand (RS)
Apparent density (kg/m^3)	1480	1610
Specific density (kg/m^3)	2600	2500
Compactness (%)	56.92	64.40
Fineness modulus	3.03	1.92
Piston sand equivalent (%)	97.63	78

Figure II.1. (a) Crushed sand and (b) river sand.

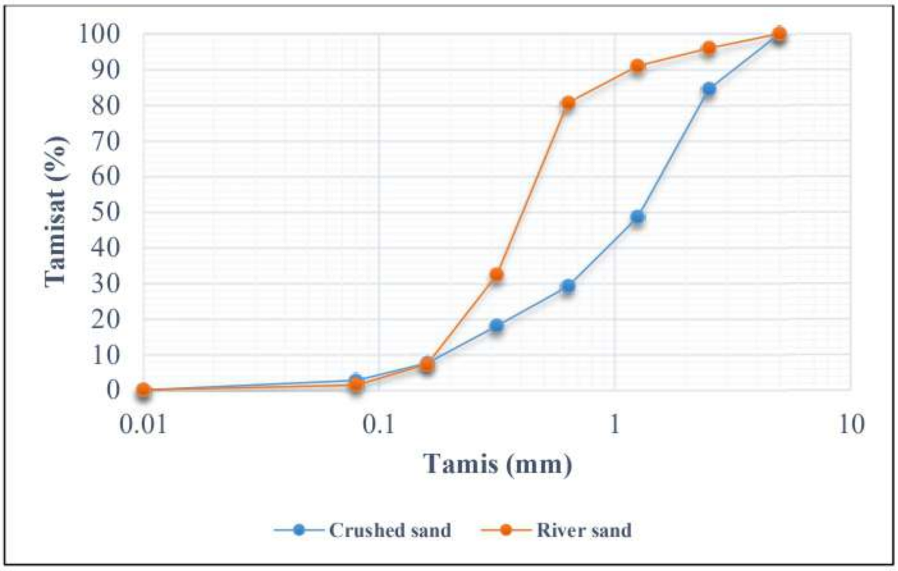


Figure II.2. Particle size distribution of two types of sand.

II.2.3 Filler

The limestone filler was obtained from the Oum Settas quarry in El-Khroub, (see Figure II.3) and sifted through a sieve with an opening of 0.08 mm. The filler is an important component of SC (Bédérina et al., 2005). The filler's physical properties and chemical compositions are shown in Tables II.2 and II.3. Limestone filler is a finely ground mineral rock that meets compactness standards according to NF P18-508 [1995] regarding mineral additions to limestone.

Figure II.3. Limestone filler.

Table.II.2: Physical properties of limestone filler.

	Limestone filler
Apparent density (kg/m^3)	1083
Specific density (kg/m^3)	2700
Specific surface (cm^2/g)	5360

II.2.4 Cement

Composite Portland cement CPJ-CEM II/A 42.5 from Ain Touta in Batna was used. Its apparent and specific densities are 1205 kg/m^3 and 3150 kg/m^3, respectively, and fineness is 370 m^2/kg. The chemical compositions of the cement are shown in Table II.3.

Table II.3: Chemical compositions of limestone filler and cement.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	SO_3	Cl-	Na_2O	MgO	LOI
Cement	21.13	5.21	3.35	62.92	0.58	2.42	0.031	0.19	1.44	1.21
Limestone filler	0.01	0.01	0.01	55.88	0.01	0.11	0.005	0.01	0.14	43.90

II.2.5 Superplasticizer

The superplasticizer used is a water-reducing 'Superior 126' type. It is a liquid solution diluted with water according to the EN 934-2 standard. The percentage used in this study is 2% (in mass) of the cement content. Its use in sand concrete is a must (Belhadj et al., 2016).

II.2.6 Water

The mixing water used is tap water from the Civil Engineering Laboratory of Biskra University. Its quality complies with the requirements of standard NF P 18-404.

II.2.7 Latex

SikaLatex, a styrene-butadiene rubber (SBR) emulsion produced by Sika and obtained from the local market, was used. Table II.4: shows the SikaLatex product information.

Table.II.4: Latex used in this study.

Composition	SBR
Form	White liquid
Density	0.997–1.037 kg/L
pH	8.0–9.5

II.2.8 Fiber

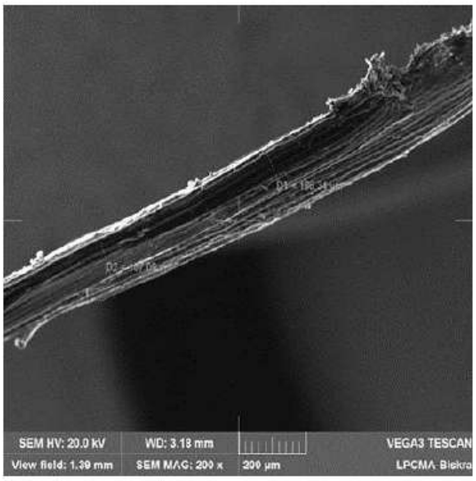
Vegetable sisal fibre obtained from the local market (Fig.II.4a) was used. Sisal fibre has better durability and strength than other vegetable fibres and has many essential features that qualify it for use as reinforcement in compounds (Li et al., 2000).

The fibre has approximately 176.72 µm in average diameter, measured at two different locations through SEM, as shown in Figure II.4b.

The mechanical properties of four different fibre lengths were studied at 20, 40, 60 and 80 mm by NF EN ISO 5079 (Norme Européenne, 1996) standards using a TEST universal testing machine at a cross-head speed of 0.2 mm/min (Figure II.4c). The results are presented in Table II.5. As the length of the sisal fibre decreases, the tensile strength increases (Bledzki & Gassan, 1999). The modulus of elasticity is not significantly affected by the change in fibre length (Kriker et al., 2005).

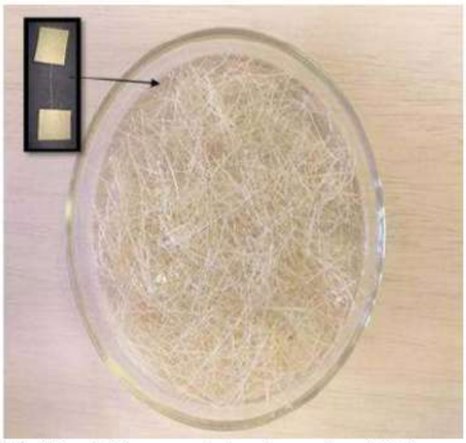
Sisal fibres with a length of 20 mm (Figure II.4d) were used in this study, which provided the best result in mechanical properties compared with the four studied fibres. A typical stress-strain curve for sisal fibre with a length is presented in Figure II.5. In other studies, short natural fibre was used as reinforcement in concrete paver blocks (Navya & Rao, 2014) and uniformly distributed and randomly oriented in the concrete matrix (Chakraborty et al., 2013). For the cement matrix with fibres, the optimal compressive strength was obtained with a lower percentage and shorter fibre length, as this method introduces minimal flaws into the matrix and ensures a more uniform distribution in the concrete (Kriker et al., 2005). Another study found that plant fibre's water absorption rate was high because of the large number of permeable pores (Soto Izquierdo et al., 2017). Therefore, a good feature of sisal fibre is that it is less absorbent than other plant fibres. After 24 h, the absorption rate was measured at 128% in accordance with ASTM C127/88.

(a) Sisal fibre bundles



(b) SEM of fibre to measure the diameter

(c) Set-up of tensile strength test



(d) Sisal fibres with a length of 20 mm

Figure II.4. Different pictures about the study of sisal fibres.

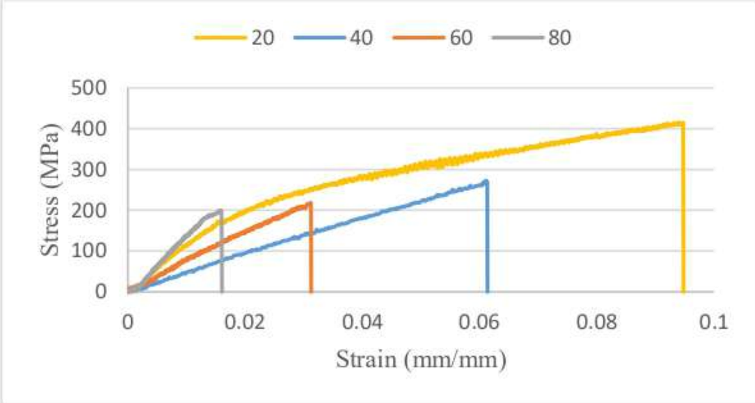


Figure II.5. Typical stress–strain curve for sisal fibre.

Table II.5: Mechanical properties of sisal fibres.

Fibre Length (mm)	Tensile strength (MPa)	Strain-to-failure (%)	Modulus of elasticity (GPa)
20	414.96	9.48	12.30
40	271.97	6.14	8.06
60	218.18	3.12	9.60
80	198.41	1.27	9.45

II.3 Formulation of the studies concretes

II.3.1 Normal concrete

Normal concrete (NC) used was designed according to the Dreux Gorisse method (George & Jean, 1998) using composite Portland cement CPJ-CEM II/A 42.5, natural river sand with fineness modulus of 1.9, coarse aggregate with a maximum aggregate size of 15 mm, water/cement ratio of 0.4, and superplasticizer. The mixed proportions are given in Table II.6.

Table II.6: Mix proportions for Normal concrete (NC).

Components	NC (kg/m^3)
River sand(0/5)	630
Gravel (3/8)	399
Gravel (8/15)	741
Cement(CPJ-CEMII/A42.5)	400
Water	160
Superplasticizer	5.2

II.3.2 Sand concrete

The sand concrete was formulated according to the methods used in previous studies (Benaissa et al., 2008; Chauvin & Grimaldi, 1988; Gadri & Guettala, 2017a). This method is based on the criterion for optimizing the compactness of the granular structure.

II.3.2 .1 Basic formulation of sand concrete

The standard cement dosage for sand concrete is 350 kg/m^3, the standard ratio adopted by most studies (Chauvin & Grimaldi, 1988; Gadri, 2018).

As for the dose of sand, two types of sand were used: river sand and crushed sand together. The amount of sand is evaluated by the mixture's compactness coefficient (γ). Compactness coefficient (γ): is the ratio to 1000 litre of the absolute volume of solids (Dreux & Festa, 1995). The compactness coefficient (γ) is equal to 0.770, corresponding to a mixture with $D_{max} \leq 5$ mm, a plastic consistency by normal vibration. The compaction coefficient: depends on the outer granular shape of the sand. The compaction coefficient of crushed sand: is 0.03, and river sand: is 0.01

The dosage of the sand is determined according to the following formula:

$$Vs + Vc = 1000\ \gamma \qquad \text{.......II.1}$$

Vc: Absolute volume for cement and Vs, absolute volume for sand and 1000 γ: Absolute volume

A. <u>crushed sand</u>

$Vs + 350/3.1 = 1000 \times 0.74 \rightarrow Vs = 740 - 113 = 627$ liter

$Ms = Vs \times \rho s = 627 \times 2.60 = 1630.2$ Kg

B. <u>river sand</u>

$Vs + 350/3.1 = 1000 \times 0.76 \rightarrow Vs = 760 - 113 = 647$ liter

$Ms = Vs \times \rho s = 647 \times 2.50 = 1617.5$ Kg

In general, water and superplasticizer were determined experimentally based on a slump test according to NF EN 12350-2 to achieve a slump value corresponding to plastic concrete to achieve workability that meets the desired purpose.

Water dosage = 245 l / m^3

The ratio W / C = 0.70

❖ Evaluation of Sand dosage

We initially selected five mixtures with different proportions of crushed sand (CS) and river sand (RS) to select the optimal mixture of sand concrete from the studied sand; Table II.7. Presents the compositions of sand concrete according to the proportions of sand.

Table II.7. Compositions of sand concrete according to the proportions of sand.

Compositions	CS (Kg/m^3)	RS (Kg/m^3)	W / C
100% RS	0	1617.5	0.7
40% CS +60% RS	652.08	970.5	0.7
50% CS +50% RS	815.10	808.75	0.7
60% CS +40% RS	978.12	647	0.7
70% CS +30% RS	1141.14	485.25	0.7

❖ Dosage of fillers (limestone)

The addition of limestone filler to the basic composition of sand concrete is necessary because of its importance in improving the structural compactness of the mixture, which leads to an increase in compressive strength (Gadri, 2018). Accordingly, we replaced an amount of the mixture sand 60% CS +40% RS with a filler of limestone.

Where five percentages of limestone filler were studied, as follows:

- 10%F: Replace 10% of sand with limestone filler.
- 12.5%F: Replace 12.5% of sand with limestone filler.
- 15%F: Replace 15% of sand with limestone filler.
- 17.5%F: Replace 17.5% of sand with limestone filler.
- 20%F: Replace 20% of sand with limestone filler.

Table II.8 shows the sand concrete compositions with limestone filler ratios. In addition, a superplasticizer (SP) was used to improve the workability of the studied mixtures, and the proportion of mixing water was also reduced.

Table II.8: Sand concrete compositions with limestone filler ratios and the addition of superplasticizer (SP).

Compositions	CS (Kg/m^3)	RS (Kg/m^3)	Filler (Kg/m^3)	SP (%)	W / C
0% F	978.12	647	0	2	0.65
10% F	877.56	585.04	162.51	2	0.65
12.5% F	853.19	568.79	203.14	2	0.65
15% F	828.81	552.54	243.77	2	0.65
17.5% F	804.43	536.29	284.4	2	0.65
20% F	780.06	520.04	325.02	2	0.65

II.3.2.2 Formulation of sand concrete with sisal fiber

Sisal fibres with a length of 20 mm with four different percentages of the total dry weight of the mixture were used for all samples without any treatment. The fibres were soaked in water for at least 24 h before use to prevent absorption of the mixing water. Treating the sisal fibres in water improved the physical and mechanical properties of the concrete (Merzoud et al., 2008).

These mixtures are listed according to the following fibre percentages:

- 0.05% F: SC containing 0.05% sisal fibre.
- 0.10% F: SC containing 0.10% sisal fibre.
- 0.15% F: SC containing 0.15% sisal fibre.
- 0.20% F: SC containing 0.20% sisal fibre.

All compositions of the studied compounds with sisal fibers are shown in Table II.9

Table II.9: Compositions of the sand concrete with sisal fibers.

Compositions	CS (kg/m^3)	RS (kg/m^3)	Filler (kg/m^3)	Sisal Fibres (kg/m^3)	SP (%)	W / C
SC	853.19	568.79	203.14	0	2	0.65
0.05% F	853.19	568.79	203.14	0.99	2	0.65
0.10% F	853.19	568.79	203.14	1.98	2	0.65
0.15% F	853.19	568.79	203.14	2.96	2	0.65
0.20% F	853.19	568.79	203.14	3.95	2	0.65

II.3.2.3 Formulation of latex modified sand concrete

Latex liquid was used in three different percentages, which were replaced by the total water weight of the mixture. These mixtures are listed according to the percentages of latex liquid as follows:

- 15% L: SC containing 15% latex.
- 25% L: SC containing 25% latex.
- 35% L: SC containing 35% latex.

Latex-modified sand concrete compositions are shown in Table II.10

Table II.10: Latex-modified sand concrete compositions.

Compositions	CS (kg/m^3)	RS (kg/m^3)	Filler (kg/m^3)	Latex (kg/m^3)	SP (%)	W / C
SC	853.19	568.79	203.14	0	2	0.65
15% L	853.19	568.79	203.14	34.13	2	0.55
25% L	853.19	568.79	203.14	56.88	2	0.49
35% L	853.19	568.79	203.14	79.63	2	0.42

II.3.2.4 Formulation of latex-modified sand concrete with sisal fibers (repair material)

The optimum proportion of the sisal fibre was determined at 0.1% and that of the latex at 35%. The fibre and latex were combined in the following mixture:

- 0.1% F + 35% L (LMSC): sand concrete containing 0.10% sisal fibre and 35% latex, As Table.II.11 shows.

Table.II.11: Compositions of Latex-modified sand concrete with sisal fibres used for repair.

Compositions	CS (kg/m^3)	RS (kg/m^3)	Filler (kg/m^3)	Sisal Fibres (kg/m^3)	Latex (kg/m^3)	SP (%)	W / C
SC	853.19	568.79	203.14	0	0	2	0.65
0.10% F+35% L	853.19	568.79	203.14	1.98	79.63	2	0.42

II.4 Mixing and Curing of concrete

II.4.1 Normal concrete

Normal concrete components were mixed according to the standard NF EN 12390-2 (Standard, 2009). The mix was then poured into the molds and covered with a wet wrapper. The samples were de-molded after 24 hours and treated in water at room temperature 20 ± 2 C° for 7, 28 and 90 days.

II.4.2 Sand concrete

In order to carry out all the tests, mixing all sand concrete specimens is carried out through several stages to obtain a homogeneous composite that meets the required purpose according to the standard EN 196-1. Before starting the mixing process, the materials must be weighed with high accuracy, and the mixer and molds should be cleaned well with a clean cloth in addition to the tools used. First, the dry mixture is mixed for a period of no less than two minutes, and then liquids, whether water, latex or superplasticizer, are gradually (Bédérina et al., 2005) added and mixed for five minutes to obtain a homogeneous paste shown in Figure II.6a.Second, fill the molds to the center and shake them through the machine in 15 strokes. We repeated the process after completing the other half, shown in Figure II.6b. Next, we covered the molds with plastic film for 24 h at 20 ± 2 °C. Then remove the samples from the molds. Finally, the samples are divided in terms of storage into two groups.

The first group in which samples containing sisal fibers without latex are stored in clean water until the time of testing at a temperature of 20 ± 2 °C and the relative humidity was 50% according to EN 196-1 standard as shown in Figure II.6c. The second group, samples containing latex, are stored in a dry environment until the day of the test as shown in Figure II.6d. (Kwan et al., 2015) showed that polymeric cement compounds, when stored in a dry and hot environment, were more conducive to improving performance.

(a) Mixing step

(b) Casting step

(c) Storage in water

(d) Dry storage

Figure II.6. Mixing steps.

II.5 Experimental test procedures of concrete

II.5.1 workability

An LCL workabilimètre apparatus was used to measure the workability of sand concrete in this study according to the standard NF P 18-452, as shown in Figure II.7. The apparatus consists of a metal box divided into two parts and fit with an electrical vibrator system with dimensions of (7.5cm×7.5cm×15cm). During operation, the concrete is poured into the first section of the box and then the dividing plate is removed. The vibrator is immediately switched on and the time is recorded when the concrete has spread uniformly across the whole box. The higher the flow rate of the mixture, the shorter the flow time.

Figure II.7. Apparatus for workability measurement (LCL workabilimètre).

II.5.2 Dry density

The specimen was dried in an oven at 60 °C until the mass stabilized. The dry density value is calculated using the specimen weight divided by volume according to the standard NF EN 18-459, where the sample dimensions were (7cm×7cm×28cm).

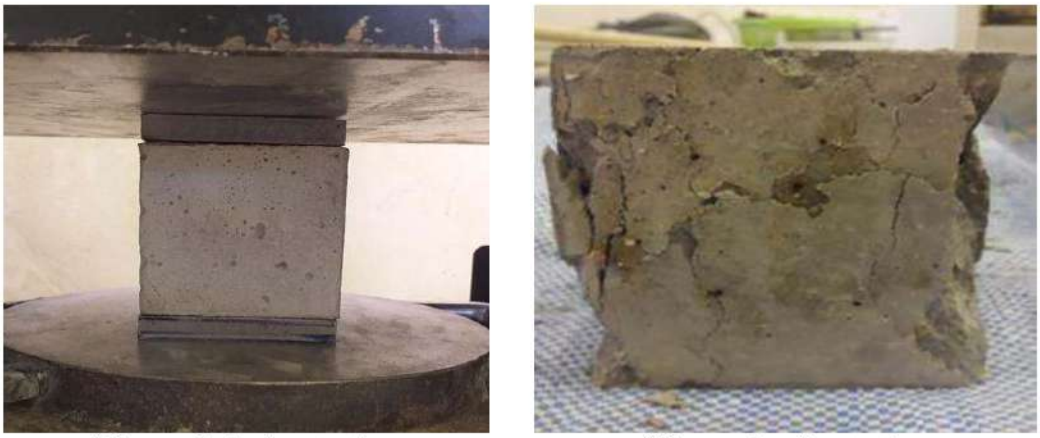
II.5.3 Compressive strength

The compressive strength of concrete can be defined as the maximum measured resistance of concrete to axial loading. The compressive strength of concrete was calculated using equation (II.2).

$$f_s = F_{max} / S \qquad \text{(II.2)}$$

Where f_s the compressive strength, F_{max} is the max load applied, and S is the area of the test specimen to which the load is applied.

A load applied (F_{max}) is obtained using a hydraulic press machine with a loading capacity of 3000 KN according to the standard NF EN 12390-3. The loading rate applied in the compressive strength tests was kept at 0.5 MPa/s until the rupture of the specimen, as shown in Figure II.8.



(a) sample before testing (b) sample after testing

Figure II.8. Test sample on a hydraulic press to determine the compressive strength.

II.5.4 Flexural strength

This test determines the flexural strength of hardened concrete using a hydraulic press machine with a loading capacity of 3000 KN according to the standard NF EN 12390-6. The loading rate applied in the compressive strength tests was kept at 0.05 MPa/s until the rupture of the specimen, as shown in Figure II.9.

Each concrete type's flexural strength was prepared using equation (II.3).

$$R_t = (1.5 \times l \times F_{max}) / (b \times d^2) \quad \text{......................................} \quad (II.3)$$

Where R_t is the flexural strength; F_{max} is the max load applied; L is the gap between the support rollers; and b, d is the lateral dimensions of the specimen.

(a) sample before testing (b) sample after testing

Figure II.9. Test sample on a hydraulic press to determine the flexural strength.

II.5.5 Ultrasonic Pulse Velocity

Ultrasonic Pulse Velocity was considered a non-destructive method and widely used to evaluate the quality of concrete. Ultrasonic Pulse Velocity tests were performed by NF EN 12504-4 standard. Ultrasonic Pulse Velocity test was based on the propagation of sound waves inside a material through a pulse transmitter on one face of a specimen and receiving the wave on the opposite face, which leads to measuring the time needed to spread the wave through the material. Ultrasonic Pulse Velocity can be measured from the path length divided by the transit time using the following equation (II.4):

$$v = l/s \quad \text{...} \quad (II.4)$$

Where v is the pulse velocity, l is the length of the sample, and s is the time, the Ultrasonic pulse velocity device used is shown in Figure II.10.

Figure II.10. Ultrasonic tester.

II.5.6 Dynamic modulus of elasticity

The calculation principle of the dynamic modulus of elasticity is based on determining the Ultrasonic Pulse Velocity (UPV) in composites. The dynamic modulus of elasticity is obtained from the following expression (Topçu & Bilir, 2009), Eq. (5):

$$E_d = (\rho \times v^2)/(g \times 100) \quad \text{(II.5)}$$

Where Ed is the modulus of dynamic elasticity (GPa), V the UPV (km/s), q is the density of the material (kg/m^3), and g is the gravitational acceleration (9.81 m/s^2).

II.5.7 Water accessible porosity

The test procedure followed was applied according to ASTM C642-06 [2006]. In order to arrive at calculating the porosity, the principle of the technique is based on inferring the volume of voids from the mass difference between the dry and saturated state.

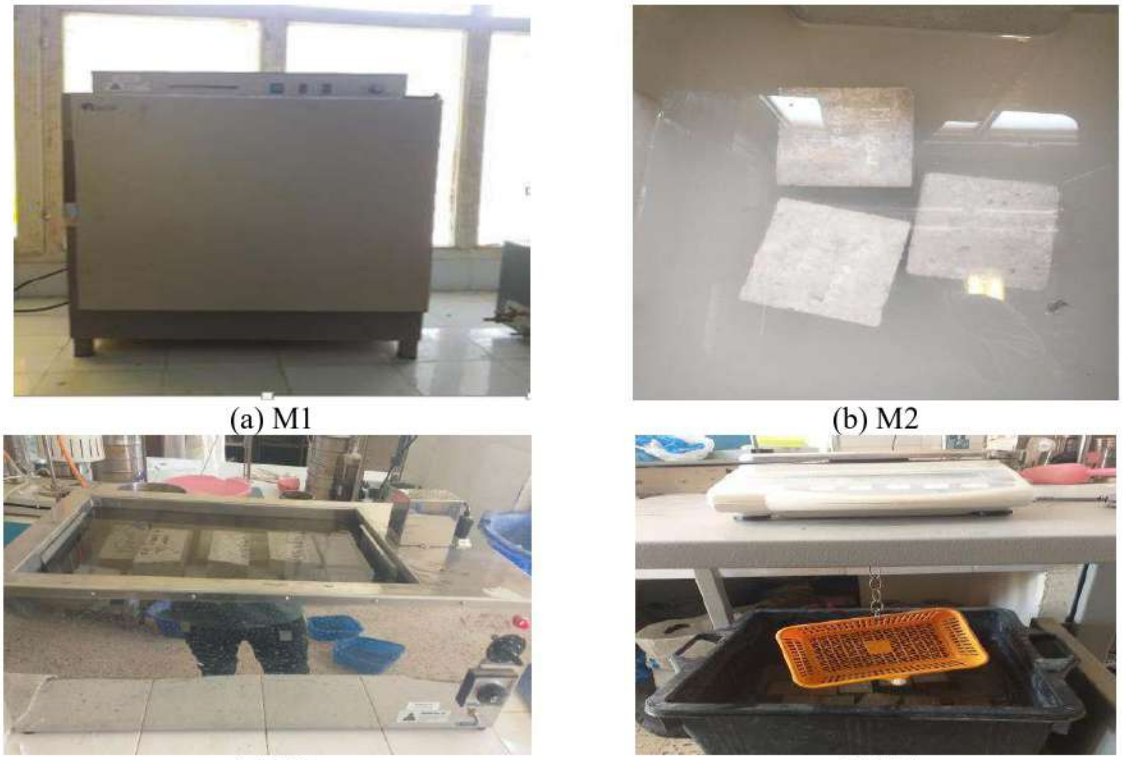
The test required the following four weighings:

- Dry mass by the oven: drying at a temperature between (100 to 110) ° C, M1 (Figure II.11a).
- Saturated mass after immersion - Immerse the test sample in water at 21 ° C, after final drying, for at least 48 h. dry on the surface by removing the moisture from the surface with a towel and determining the mass, M2 (Figure II.11b).
- Saturated mass after boiling: Place the test tube in a suitable container, covered with tap water and boil for 5 h. Leave to cool for at least 14 h until a final temperature of 20 to 25 ° C. Wipe the surface with a towel and determine the mass, M3 (Figure II.11c).

• Immersed apparent mass: Suspend the sample, after immersion and boiling, by a wire and determine the apparent mass in water by a hydrostatic weighing. Designate this apparent mass M4 (Figure II.11d).

Water accessible porosity (P) was calculated using equation (6):

$$P(\%) = [(M3 - M1)/(M3 - M4)] \times 100 \quad \text{(II.6)}$$



(a) M1 (b) M2

(c) M3 (d) M4

Figure II.11. Methods of conducting for conducting Water accessible porosity.

II.5.8 Absorption of water

In this test, concrete specimens are immersed in water for 48 hours, and then water absorbed by the sample is measured. Defines water absorption as a ratio of the water absorbed to the dry weight of the test sample according to ASTM C642-06 [2006].

The following formula gives the absorption of water percentage of the sample:

$$Ab(\%) = [(Ph - Ps)/(Ps)] \times 100 \quad \text{(II.7)}$$

Ratio Absorption of water (Ab), Sample weight before water immersion (Ps), and sample weight after immersion in water (Ph).

II.5.9 Shrinkage

All samples were prepared and kept once the molds were removed under standard conditions (ambient temperature 20 °C ± 2 °C and relative humidity 50% ± 2. Length measurements were performed using a retractometer equipped with a dial gauge with a sensitivity of 1 µm. The shrinkage measurement is therefore carried out on prismatic test specimens of dimensions (4x4x16) cm, according to the standard NFP 15-433. Specimens are equipped with metal studs at each end and placed vertically in the strain gauge, which allows the monitoring of the variation in the length of the sample. The shrinkage of each concrete is measured on two prisms every day after demolding (Figure II.12).

Let dℓ (t): the value read on the comparator at time t.

L: the basic length taken is equal to 160 mm.

The specimen has a length at the considered time:

$$\ell = (L + d\ell\,(t) \qquad \text{(II.8)}$$

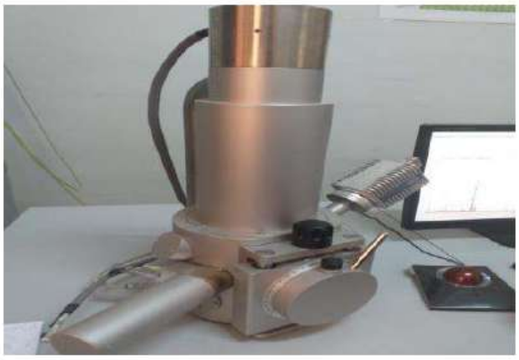
The relative variation in length is generally denoted by ε and has the expression:

$$\varepsilon\,(t) = d\ell\,(t)/L \qquad \text{(II.9)}$$

Figure II.12. Shrinkage test method.

II.5.10 Scanning Electron Microscopy (SEM) analysis

This analysis is carried out at the physics laboratory of the University of Biskra using a scanning microscope (Figure II.13) to make a complete analysis of the microstructure of concretes. This test aims to demonstrate the quantity and dimension of voids and the interface bond between components.



(a) Sample place (b) Machine used to take SEM image

Figure II.13. Scanning Electron Microscopy (SEM).

II.6 Repair techniques and procedure

II.6.1 Preparation of substrate surfaces

substrate components were mixed according to the standard NF EN 12390-2 (Standard, 2009). Mix was then poured into the molds and covered with a wet wrapper (Figure II.14a). The samples were demolded after 24 hours, treated in water at room temperature 20 ± 2 C° for 28 days (Figure II.14b), and taken out for surface preparation.

(a) Pour the mixture into the moulds (b) Treat the samples in water for surface preparation

Figure II.14. Substrates preparation.

Four types of substrate surfaces were used in this study:

- Without surface preparation as reference (SR), as shown in Figure II.15

Figure II.15. Without surface preparation as reference (SR).

- Hand hammer (HA), this method is compatible with (Gadri & Guettala, 2017a, 2017b), where the rough surface of the substrate is obtained using a hand hammer, shown in Figure II.16

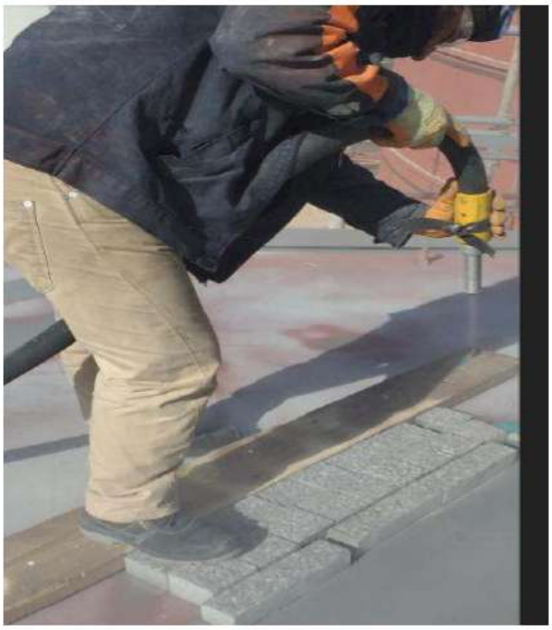
(a) (b)

Figure II.16. (a) Surface of the substrate using a hand hammer (HA) and (b) hand hammer.

- Sandblasting (SB) according to the following studies (Abo Sabah et al., 2019; Tayeh, Abu Bakar, & Megat Johari, 2013; Tayeh, Abu Bakar, Megat Johari, et al., 2013b; Tayeh et al., 2014; Valikhani et al., 2020).

We sent the samples to the sandblasting machine site for substrate surface treatment. Sand particles ranging in size from 300 mm to 2.36 mm were blasted onto substrate surfaces using a long nozzle sandblasting machine at an applied pressure of 1000 kPa. Figure II.17 shows the stages of obtaining a sandblasting surface (SB)

(a) Sandblasting machine



(b) Surface treatment by sandblasting

(c) surface of the substrate using sandblasting (SB)

Figure II.17. Stages of obtaining a sandblasting surface (SB).

• Grooved (GR) 50 x 50 mm (Abo Sabah et al., 2019; Hoła et al., 2015) (Figure II.18a).

Figure II.18b depicts the surface of the acquired substrate and the process used to achieve the treated surface using a stone rocket.

(a) (b)

Figure.II.18. (a) Surface of the obtained substrate and (b) method of obtaining the treated surface using a stone rocket.

II.6.2 Application of the repair

After surface preparation, the substrates were allowed to dry for two months to be used as old concrete (Momayez et al., 2005). Thus, the total duration before casting a repair material was 3 months; this duration for substrates NC corresponds to Tayeh et al. (Tayeh et al., 2012).

Before pouring repair material onto concrete substrates, concrete substrates surfaces were moistened for 10 min and wiped with a clean cloth (Tayeh, Abu Bakar, & Megat Johari, 2013; Tayeh, Abu Bakar, Megat Johari, et al., 2013a) as shown in Figure II.19a. Next, concrete substrates samples were placed in molds for pouring concrete substrate onto the prepared surfaces Figure II.19b.

(a) (b)

Figure.II.19. (a) Substrate fixing molds for repair materials, and (b) apply repair materials to concrete Substrates.

II.6.3 Curing of composites (NC and LMSC)

The composite specimens NC and LMSC were then placed dry environment until the day of the test, as shown in Figure II.20. According to (Kwan et al., 2015), storing modified cement compounds in a dry and hot environment is more conducive to improving performance. The bi-surface shear, splitting tensile, and pull-off tests were performed 7, 28, and 90 days after casting the composites (NC and LMSC).

Figure.II.20. Storage of composite samples (NC and LMSC).

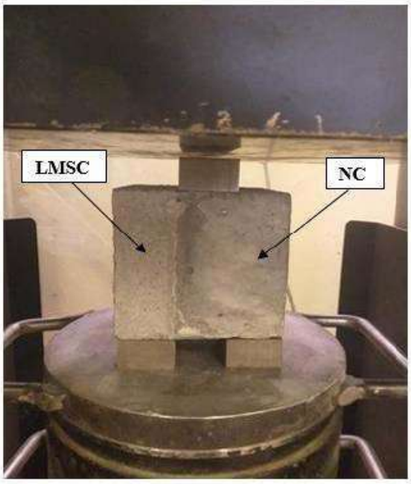
II.7 Adhesion tests of composites

II.7.1. Bi-surface shear test

The bi-surface shear test was performed as a direct shear test to evaluate the bond strength between the composite materials. The standard followed for testing was ASTM C39 (ASTM, 2012). The load was applied steadily at a rate of 0.5 MPa/s. The splitting prism specimens were 150 mm cubes. The repair material (LMSC) constitutes one-third (50 mm), and the concrete substrate (NC) is two-thirds (100 mm) of the specimen, as shown in Fig.II.21. The bond strength was calculated using Eq. (II.10).

$$\tau = \frac{P}{2bd} \qquad \text{II.10}$$

Where τ is the bond strength (MPa), P is the load at failure (N), b is the width of the specimen's cross-section (mm), and d is the depth of the specimen's cross-section (mm).



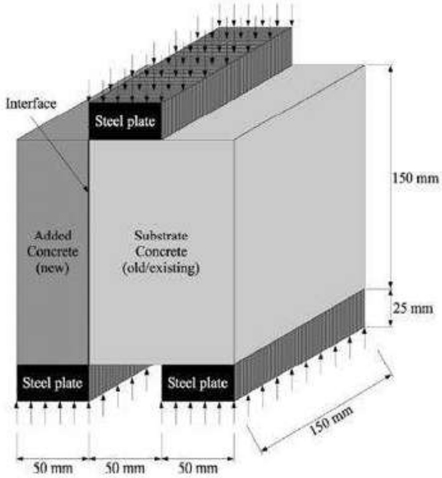


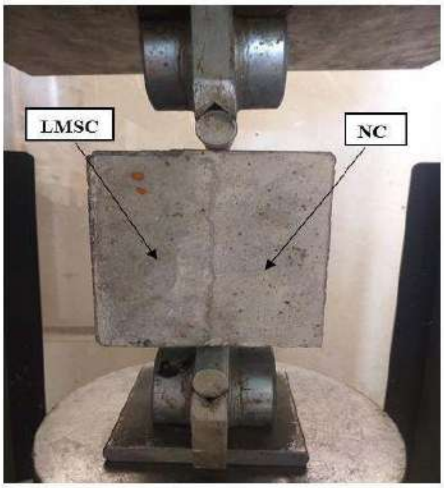
Figure.II.21. Bi-surface shear test.

II.7.2. Splitting tensile test

The splitting tensile test was conducted to evaluate the bond strength between the NC substrate and LMSC as an indirect tensile test according to ASTM C496 (ASTM, 1996). The test was performed at a loading rate of 0.05 MPa/s. The specimens were 100 mm cubes with 50% repair material and 50% concrete substrate (NC), as shown in Figure II.22. The splitting tensile strength was calculated using Eq. (II.11).

$$T = \frac{2P}{\pi b d^2} \qquad \text{II.11}$$

Where T is the splitting tensile strength (MPa), P is the applied force (N), b is the width of the specimen's cross-section (mm), and d is the depth of the specimen's cross-section (mm).



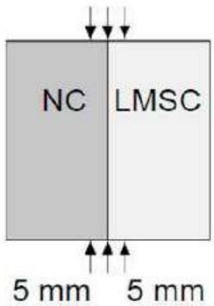


Figure II.22. Splitting tensile test.

II.7.3. Pull-off test

The pull-off test method is a tensile test used to evaluate the NC and LMSC composite's adhesion strength according to standard ASTM D4541 (ASTM, 2009). The composite sample comprised 70 mm thick NC and 10 mm thick LMSC and the overall dimensions of 300 × 300 × 80 mm. A 50 mm diameter hole was drilled into the finished samples starting at the top with a depth of 25 mm (10 mm in LMSC + 15 mm in NC), as shown in Figure II.23(a). A 50 mm diameter steel disc was then attached to the sample using high-strength glue, as shown in Figure II.23 (b). The pull-off bond strength (Spo) was calculated using Eq. (II.12).

$$Spo = \frac{Ft}{Af} \quad \text{………………………………………………………………II.12}$$

Where Ft is the tensile (pull-off) force at a failure (N), Af is the area of the fracture surface (mm^2).

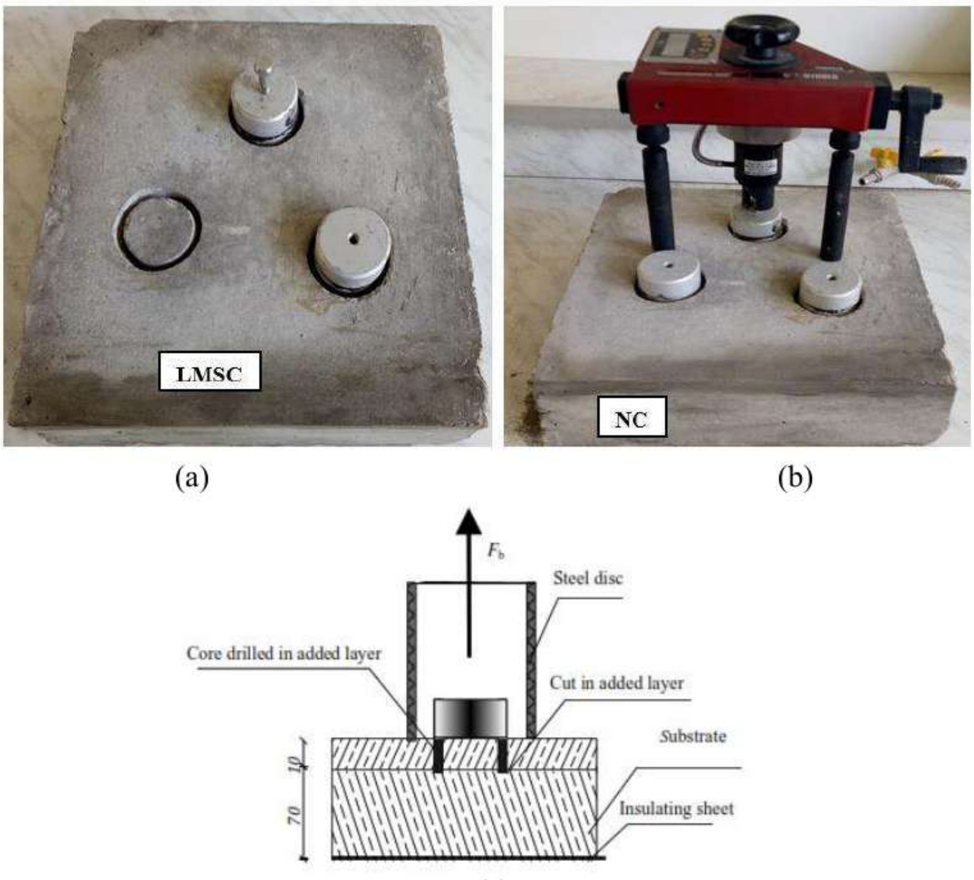


Figure II.23. Pull-off test.

II.7.4. Microstructure of the NC–LMSC interface transition zone

This microstructure analysis aimed to study the Interface Transition Zone (ITZ) between the NC and the LMSC using scanning Electron Microscopy (SEM). Samples were extracted from the ITZ after 28 days of the age of the repair material. The prepared samples represent the transition zone of all treated surfaces on the NC substrate.

II.8 Conclusion

This chapter deals with the materials used in concrete production and some of its most important physical and chemical properties. The different mixtures' composition and production processes are also identified and explained. Plus in this chapter, the mechanism of several tests to describe the physical and mechanical performance of concrete is explained and illustrated.

Finally, we have provided a detailed overview of the repair techniques and procedures. We have explained the approach for each adhesion test performed, with a complete presentation of the different adhesion shapes and dimensions.

CHAPTER III

RESULTS AND DISCUSSIONS OF THE PROPERTIES OF SAND CONCRETE

III.1 Introduction

This chapter discusses the results of tests on sand concrete and normal concrete. The results of all experiments are displayed in the form of tables or graphs.

In the beginning, the aim was to obtain a reference Sand Concrete (SC) for the basic composition of sand, filler, water ratio and superplasticizer by conducting three tests: compressive strength, flexural strength and ultrasonic pulse velocity, according to the results of the tests, the ideal proportions of the basic composition of the sand concrete were determined for the mentioned components.

The main objective of this chapter is to contribute to improving the properties of reference sand concrete SC by using additives, sisal fibres and latex, by studying each addition alone, and then selecting the ideal percentage for each addition and combining them for use as a repair material as well as study the properties of Normal Concrete (NC) as substrate. The physical and mechanical properties are studied by performing the following tests: flow, density, compressive strength, flexural strength, ultrasonic pulse velocity (UPV), modulus of elasticity, water accessible porosity, water absorption and shrinkage as well as microstructure analysis through scanning electron microscopy (SEM).

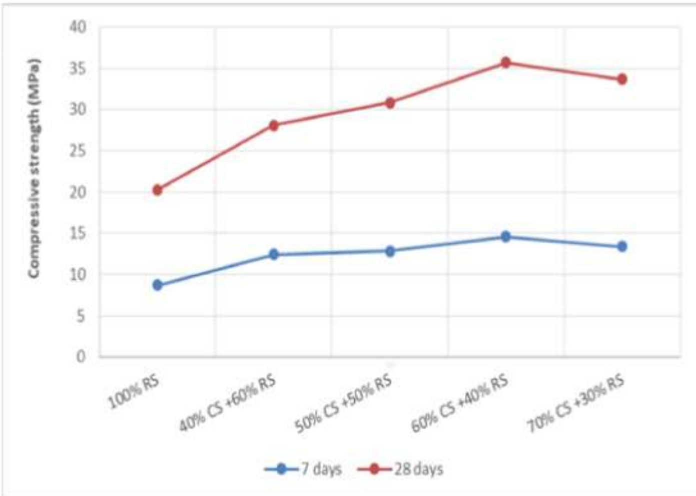
III.2 Effect of the sand mixture and proportion of the filler on the properties of sand concrete to determine the reference sand concrete (SC).

III.2.1 Determination of the sand mixture

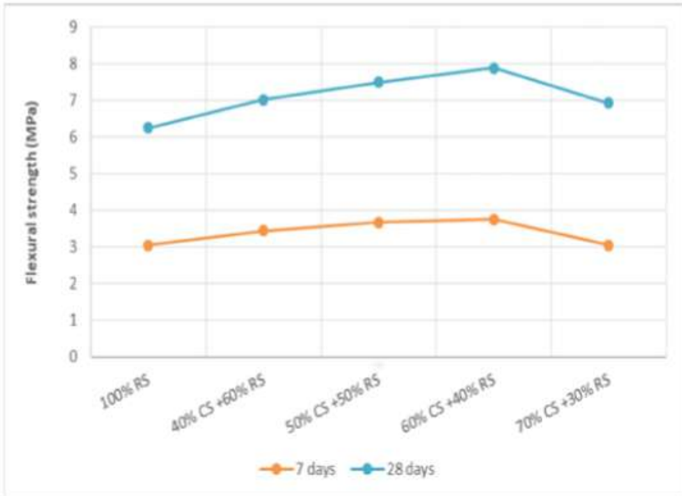
Accordingly, we have determined the ideal proportions of the sand mixture by studying some of its properties first by conducting three tests: compressive strength, flexural strength and ultrasonic pulse velocity for five samples, as shown in Table III.1 and the results obtained for tests after 7 and 28 days are shown in Figure III.1.

Table III.1: The results of concrete sand tests according to the proportions of sand after 7 and 28 days.

Compositions	Compressive Strength (MPa)		Flexural Strength (MPa)		Ultrasonic Pulse Velocity (m/s)	
	7 days	28 days	7 days	28 days	7 days	28 days
100% RS	8.70	11.60	3.05	3.2	2650	2985
40% CS +60% RS	12.41	15.67	3.44	3.59	3160	3256.7
50% CS +50% RS	12.87	18	3.67	3.83	3160	3410
60% CS +40% RS	14.59	21.15	3.75	4.14	3223.3	3466.7
70% CS +30% RS	13.4	20.3	3.05	3.88	3190	3270



(a) Compressive Strength test



(b) Flexural Strength test

(c) Ultrasonic Pulse Velocity test

Figure III.1. Results of sand mixture determination tests.

Based on the results obtained from the tests, the best result was for the sample 60% CS +40% RS; therefore, it was considered the ideal ratio of the sand mixture.

The use of sand type in concrete has been the subject of many studies because of the increasing demand for river sand, as the depletion of river sand has caused several environmental issues (J. Zhang et al., 2020). The construction industry has identified various alternatives (Jose & Hossiney, 2016; X. Zhang et al., 2019). Crushed sand has been proposed as a partial alternative to river sand, a type of limestone obtained from quarrying, as it provides continuous particle size distribution in sand concrete (Gadri & Guettala, 2017a).

According to the study (Gadri & Guettala, 2017a), all the results were good when 100% crushed sand was used to form sand concrete. This means that river sand can be dispensed with in the formation of sandy concrete, which gives us prospects for solving an environmental problem represented in dredging valleys to obtain construction sand, and quarry residues can also be exploited by grinding them to obtain crushed sand.

III.2.2 Determination of the proportion of the filler (Limestone)

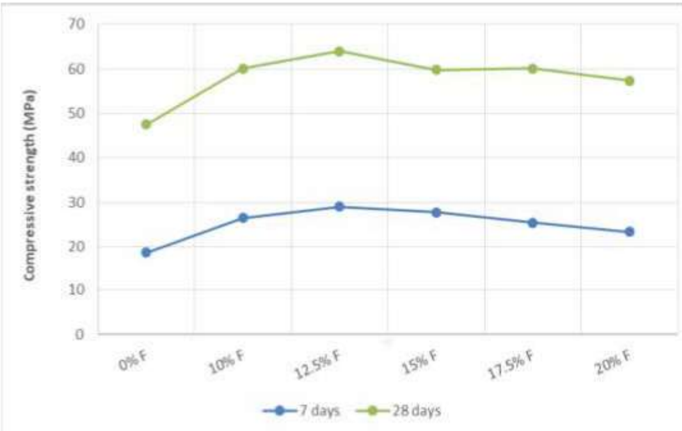
The addition of limestone filler to the basic composition of sand concrete is necessary because of its importance in improving the structural compactness of the mixture, which leads to an increase in compressive strength (Gadri, n.d.). Accordingly, we replaced an amount of sand for the mixture 60% CS +40% RS (0%F) with a filler of limestone where six percentages of limestone filler were studied.

To obtain proper workability, Water and superplasticizer were determined experimentally based on Concrete workability apparatus according to the following standard NF P18-452.

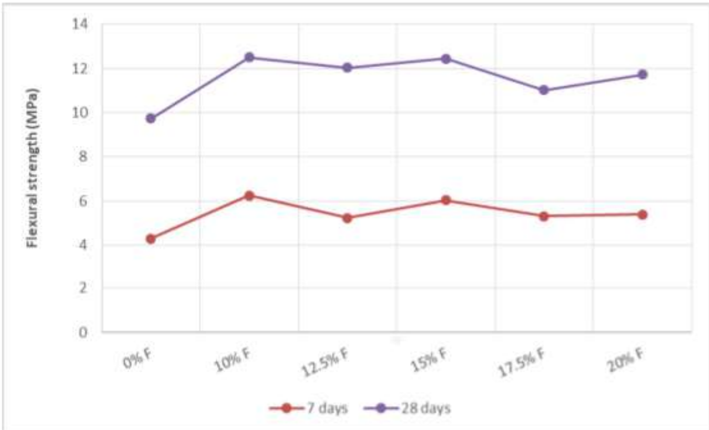
We have determined the ideal proportions of the limestone filler ratio by studying some of its properties by conducting three tests: compressive strength, flexural strength and ultrasonic pulse velocity for five samples, as shown in Table III.2 and the results obtained for the tests after 7 and 28 days are shown in Figure III.2.

Table.III.2: The sand concrete compositions' results by the limestone filler and superplasticizer ratio.

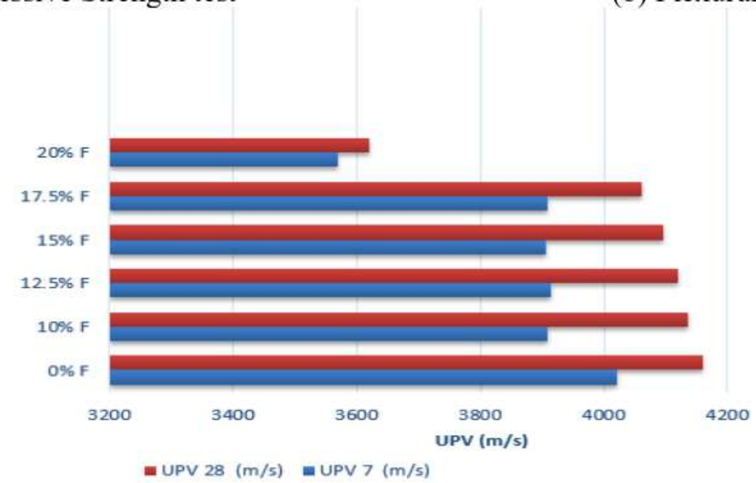
Compositions	Compressive Strength (MPa)		Flexural Strength (MPa)		Ultrasonic Pulse Velocity (m/s)	
	7 days	28 days	7 days	28 days	7 days	28 days
0% F	18.68	28.78	4.30	5.44	3583.33	3970
10% F	26.44	33.62	6.25	6.25	3823. 33	4055.00
12.5% F	28.99	34.93	5.23	6.80	3900.00	4136.67
15% F	27.67	32.10	6.02	6.41	3853. 33	4053.33
17.5% F	25.36	34.67	5.31	5.70	3736.67	4046.67
20% F	23.30	34.00	5.39	6.33	3793.33	4043.33



(a) Compressive Strength test



(b) Flexural Strength test



(c) Ultrasonic Pulse Velocity test

Figure III.2. Results of proportion of the filler determination tests.

According to the obtained results, 12.5% F was ideal for limestone filler; accordingly, the sample 12.5% F was adopted as the reference sand concrete (SC).

Adding fillers to sand concrete is suitable for sealing small voids created by sand, thereby improving its properties (Chauvin & Grimaldi, 1988). Limestone filler results in more significant stress on the granular structure and therefore has a good effect on most properties (Gadri & Guettala, 2017a, 2017b). Furthermore, using limestone filler reduces the amount of cement used, so the cement dosage is similar to that of normal concrete (Gadri & Guettala, 2017a). A study has found that adding a limestone filler material reduced the concrete's shrinkage (Tanabe et al., 2008).

Furthermore, adding a superplasticizer to sand concrete is essential because it improves quality and workability. Sand concrete requires more Water than regular concrete. Due to the size of the small particles, a plasticizer was used to reduce the mixing of Water. A plasticizer helped improve sand concrete's physical and mechanical properties and enhance its workability(Gadri & Guettala, 2017a, 2017b).

III.3 Influence of the incorporation of sisal fibres on physical and mechanical properties of sand concrete (SC)

III.3.1 Workability

The workability of all sand concrete samples with sisal fibers was calculated regarding flow time under vibration and compared with the reference sand concrete (SC). All flow values for the samples are shown in Figure III.3.

It was observed that when the percentage of sisal fibres increased, the workability decreased due to the composition and shape of the fibres that affected workability. (Siva Bala & Vaisakh, 2018) Showed that workability decreased when sisal fibres were increased in self-compacting concrete. Several studies show how adding fibre to the cement matrix affects workability (Gencel et al., 2011; Neville & Brooks, 1987).

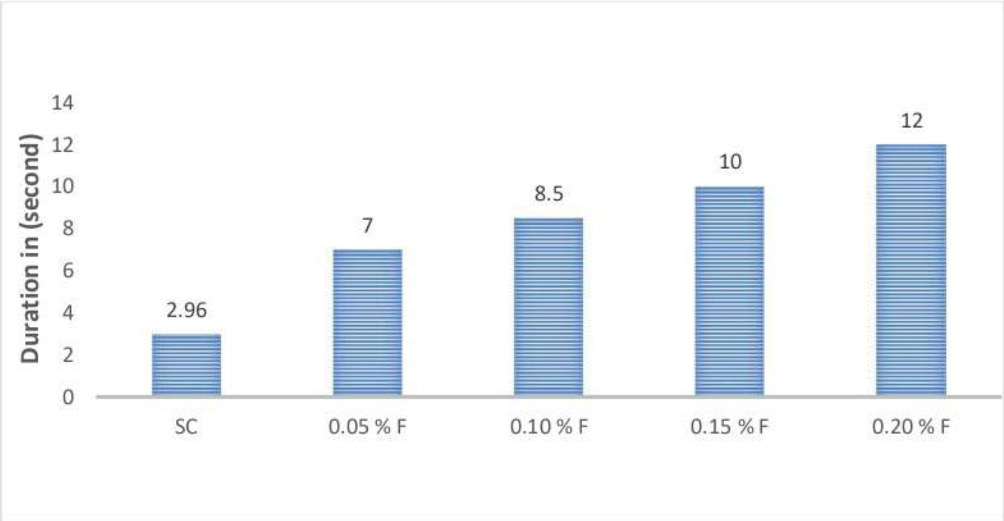


Figure III.3. Workability of sand concrete with sisal fiber compared to SC.

III.3.2 Dry density

Density was measured for all mixtures at 28 days. When adding sisal fibres, the results obtained in Figure III.4 showed a lower density than the reference sand concrete (SC).

Whereas, the decrease percentages for sisal fibers 0.05%F, 0.10%F, 0.15%F and 0.20%F respectively 14.03%, 16.74%, 18.10% and 19.46%. Vegetable fibers, including sisal fibers, are characterized by low density (Campos et al., 2012). Most studies agree that introducing vegetable fibers into concrete decreases density(Li et al., 2006; Taoukil et al., 2012).

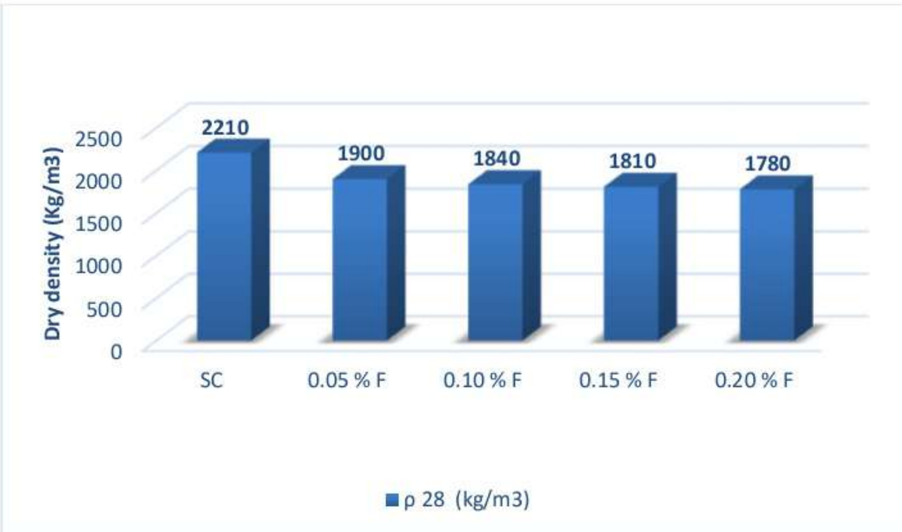


Figure III.4. Dry density of sand concrete with sisal fiber compared to SC.

III.3.3 Compressive strength

The compressive strength was measured at 7, 28 and 90 d. Figure III.5 shows all the results obtained.

When sisal fibres were added to SC at four different ratios (0.05% F, 0.10% F, 0.15% F and 0.20% F) without any treatment, a general decrease in compressive strength was observed compared with the reference SC. As the percentage of fibre increased, the compressive strength decreased. This weakness often occurs when vegetable fibres are added, especially those that have not been treated. Several studies show that the compressive strength of concrete decreases when vegetable fibres are added (Ammari et al., 2020; Bederina, Gotteicha, et al., 2012; Zhou et al., 1995).

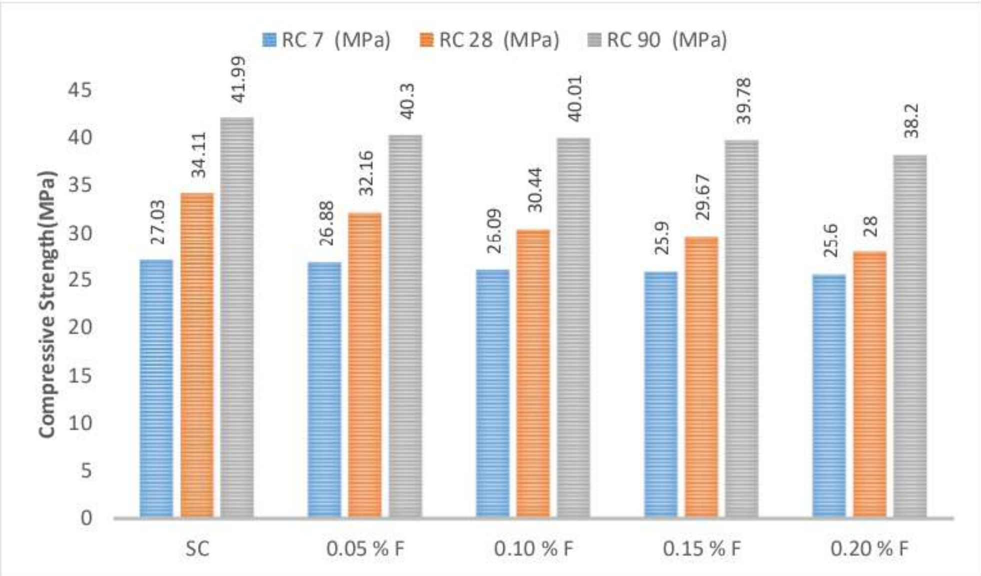


Figure III.5. Compressive strength of sand concrete with sisal fiber compared to SC.

III.3.4 Flexural strength

Figure III.6 displays all the flexural strength results obtained for all samples at 7, 28, and 120 days.

An improvement in flexural strength was observed when adding unmodified sisal fibers at the following rates: there was a good improvement in the flexural strength, Especially at 0.10% F as the optimum ratio of sisal fibers, where the percentage of improvement was at 7, 28 and 90 days, Compared to the reference sand concrete (SC) respectively (2.38%, 21.89% and 41.62%). Previous studies have shown that adding sisal fibers to concrete improves flexural strength (Nilsson, 1975; Swift & Smith, 1978). In general, the addition of vegetable fibers in concrete and mortar had a role in increasing tensile and flexural strength (Ammari et al., 2020).

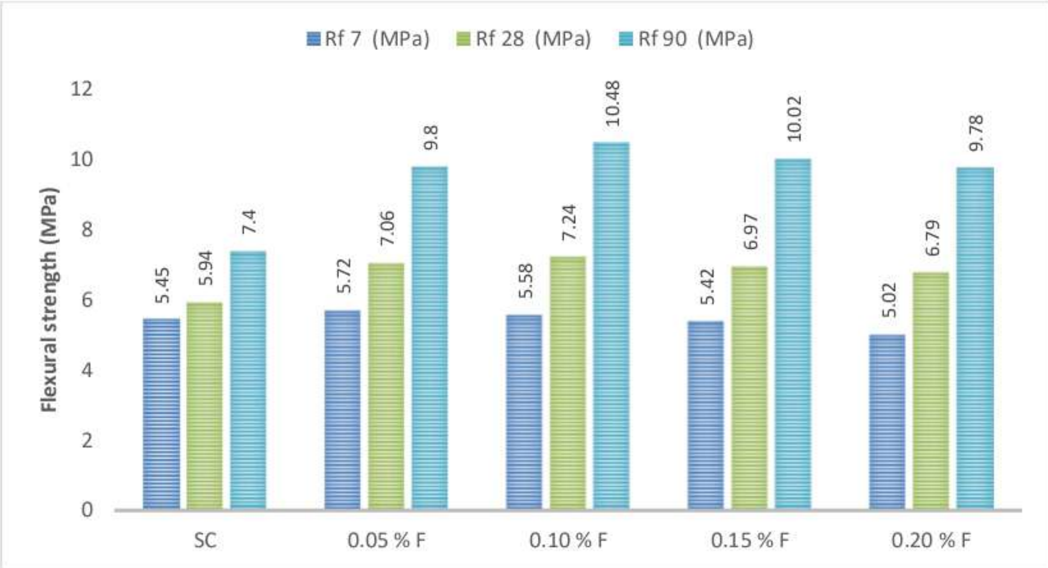


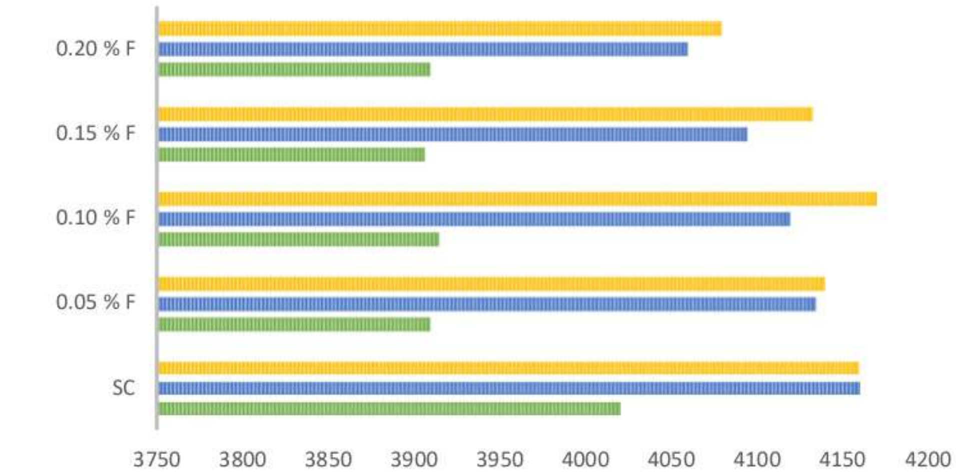
Figure III.6. Flexural strength of sand concrete with sisal fiber compared to SC.

III.3.5 Ultrasonic Pulse Velocity (UPV)

UPV is a non-destructive test to find out the mechanical properties of concrete. Figure III.7 shows all the UPV values of the studied compounds at 7 and 28 days.

Where it becomes clear to us that when adding sisal fibers to unmodified sand concrete in the four ratios: 0.05% F, 0.10% F, 0.15% F and 0.20% F, notice a decrease in the Ultrasonic pulse velocity. The higher the fiber ratio, the lower the UPV. As the decrease was compared to reference sand concrete SC was as follows (0.31%, 0.80%, 2% and 3.22%).

This decrease in the Ultrasonic pulse velocity propagation when adding untreated sisal fibers is due to the nature of the cellulosic sisal fibers tissues and also the weak adhesion between the sisal fibers and the cement matrix, which leads to voids and pores that contribute to reducing UPV, Which can be observed through the microstructure.



	SC	0.05 % F	0.10 % F	0.15 % F	0.20 % F
UPV 90 (m/s)	4160	4140	4170	4133	4080
UPV 28 (m/s)	4160	4135	4120	4095	4060
UPV 7 (m/s)	4020	3910	3915	3906.67	3910

Figure III.7. UPV of sand concrete with sisal fiber compared to SC.

III.3.6 Dynamic modulus of elasticity

Figure III.8 shows the development of the dynamic modulus of the elasticity of the studied compounds after 28 days.

As there is a clear relationship between elastic modulus and compressive strength, we can observe that the lower the dynamic modulus of elasticity, the lower the compressive strength and vice versa.

Figure 14 shows that the modulus of elasticity decreases as the percentage increases of the sisal fibers. The percentage decrease in the dynamic modulus of elasticity was approximately 16.88%, 21.88%, 27% and 32.38% for samples 0.05% F, 0.10% F, 0.15% F and 0.20% F compared to reference sand concrete SC, respectively. The weak bond between the matrix and the sisal fibrils may also have contributed to this decrease, as demonstrated by the microstructure analysis.

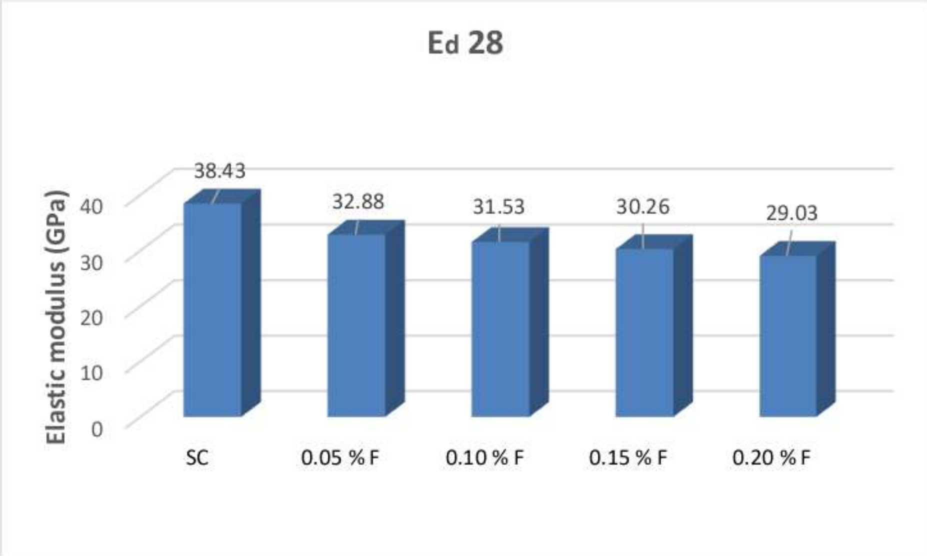


Figure III.8. Dynamic modulus of elasticity of sand concrete with sisal fiber compared to SC.

III.3.7 Water-accessible porosity and Water absorption

The results of the tests obtained after 28 days of Water accessible porosity, as shown in Figure III.9 and Figure III.10, show the samples' water absorption results.

The addition of sisal fibers in the following proportions 0.05% F, 0.10% F, 0.15% F and 0.20% F. increased the porosity and absorption to Water of the samples. The higher the percentage of these fibers in the samples, the greater the porosity and absorption of Water. This increase is due to the porous network and void resulting from the poor adhesion of sisal fibers to the concrete matrix. That can be illustrated by the microstructure and the porous network of the sisal fiber structure, which is easily penetrated, especially since there has not been any treatment for sisal fiber of these four mentioned ratios. (Soto Izquierdo et al., 2017) The water absorption rate of vegetable fibers is high due to weak permeable pores. There are many studies that prove that cement compounds based on plant residues are characterized by high porosity (Aiqin et al., 1999; Bederina, Bouziani, et al., 2012).

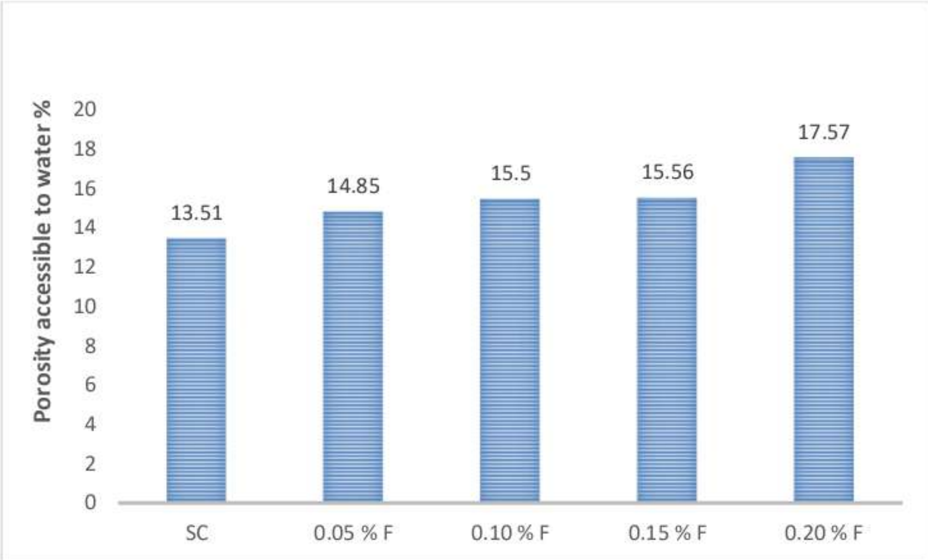


Figure III.9. Water accessible porosity of sand concrete with sisal fiber compared to SC.

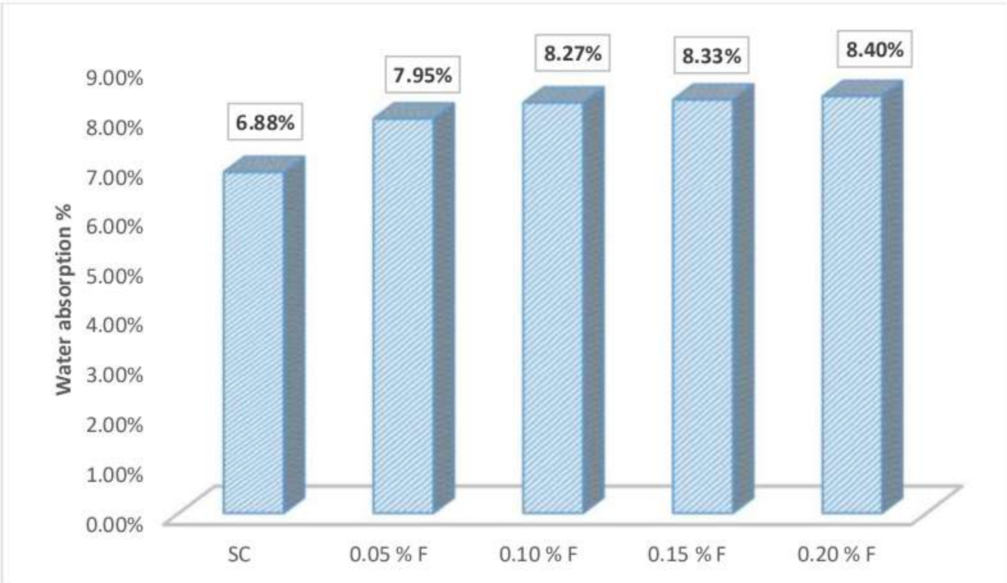


Figure III.10. Water absorption of sand concrete with sisal fiber compared to SC.

III.3.8. Shrinkage test

This test aims to monitor the dimensional variations in sample length over time from the moment the sample is removed from its mould. The shrinkage of the studied samples is measured daily for 120 days, as shown in Figure III.11

Compared with the reference SC, the shrinkage of the studied compounds decreases when sisal fibres are added in the four ratios. The decrease rates recorded after 120 d, as shown in Fig.III.12, are approximately 6.22%, 10.44%, 6.67% and 2.22% at 0.05% F, 0.10% F, 0.15% F and 0.20% F, respectively. The best percentage obtained from adding sisal fibre was 0.10% F, which gave the lowest shrinkage value of 10.44% compared with the reference SC. The largest shrinkage was observed in the first 30 days, followed by a slow shrinkage rate. (Liu et al., 2020) explained that sisal fibre effectively decreased shrinkage when added to concrete.

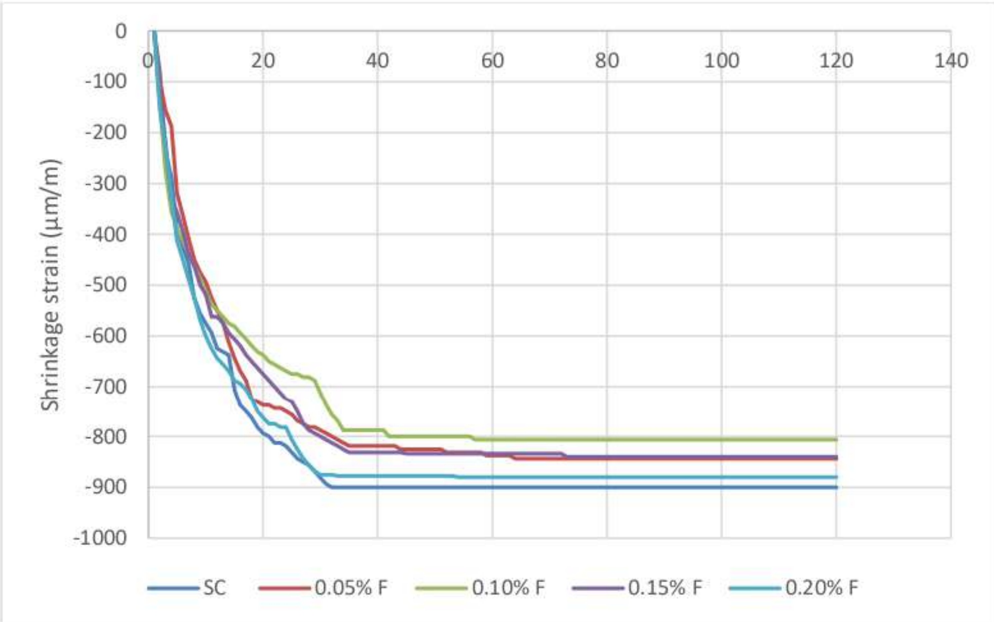


Figure III.11. Evolution of shrinkage according to time of sand concrete with sisal fiber compared to SC.

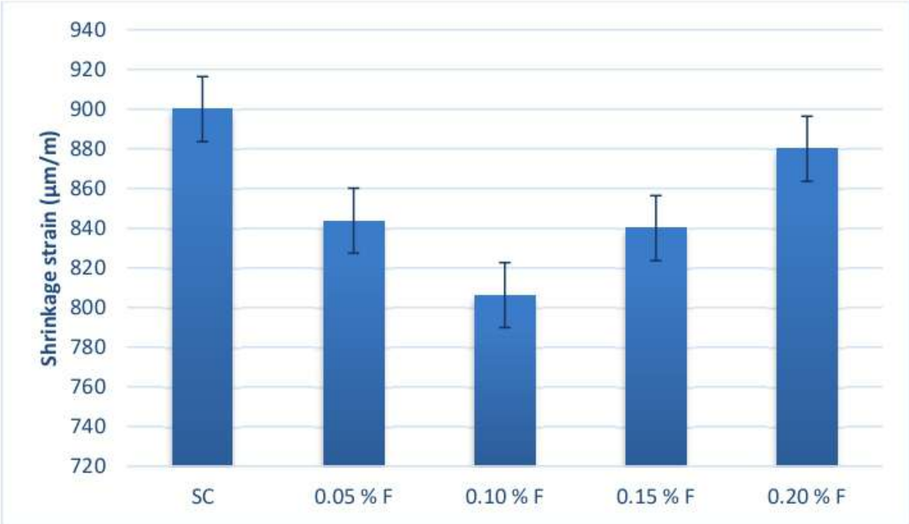


Figure III.12. Effect at 120 days- shrinkage of sand concrete with sisal fiber compared to SC.

III.4 Effect of latex addition on the physical and mechanical properties of sand concrete (SC)

III.4.1 Workability

All flow values of samples are shown in Figure III.13

When latex was added, the workability slightly decreased. This result agreed with (Barluenga & Hernández-Olivares, 2004) that workability decreased when the latex was increased. Based on the flow values of all mixtures in this study, workability was acceptable according to the NF P 18-452 standard.

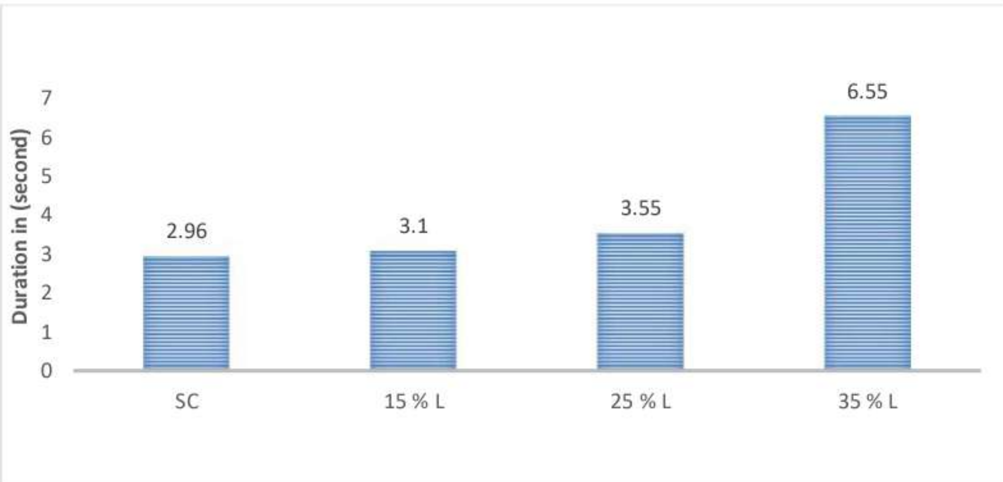


Figure III.13. Workability of latex-modified sand concrete compared to SC.

III.4.2 Dry density

Figure III.14 shows the results when adding latex to sand concrete compared to SC after 28 days. When the percentages of latex were increased, the density for 15% L, 25% L and 35% L decreased by 17.19%, 18.55% and 19.46%, respectively. The density decreased with the increase of latex because of the lower density of latex about mortar density (Barluenga & Hernández-Olivares, 2004). (Wang et al., 2005)also noted that the density decreased when the proportion of the SBR in the slurry increased.

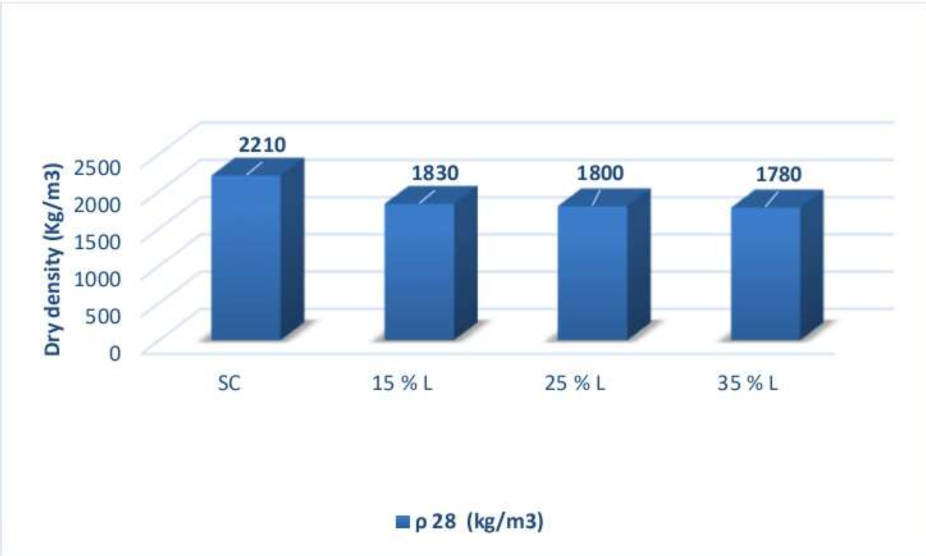


Figure III.14. Dry density of latex-modified sand concrete compared to SC.

III.4.3 Compressive strength

Figure III.15 shows all the results obtained. The compressive strength of the samples was measured at 7, 28 and 90 days.

With the addition of latex at three different proportions (15% L, 25% L and 35% L), the compressive strength decreased when the latex dose was increased. This decrease could be due to the polymeric nature of latex, which has less mechanical strength than SC components such as sand, filler and cement. This result is to the finding of (Ukrainczyk & Rogina, 2013) that when latex was added to the cement matrix, a decrease in compressive strength was observed due to the lower mechanical capacitance of the SBR polymer compared with the cement matrix. (Barluenga & Hernández-Olivares, 2004) Also noted a decrease in compressive strength when latex was added.

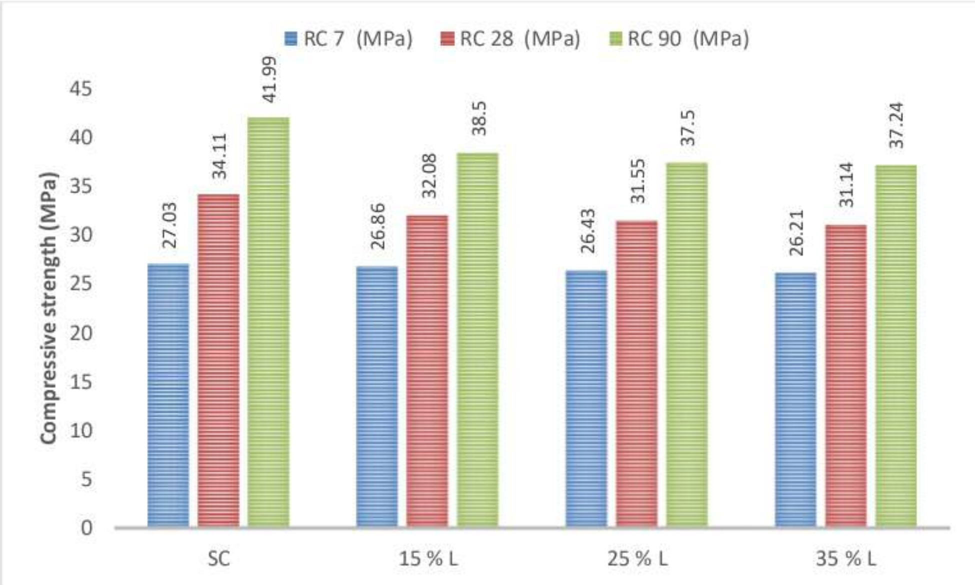


Figure III.15. Compressive strength of latex-modified sand concrete compared to SC.

III.4.4 Flexural strength

The flexural strength of the samples was measured at 7, 28 and 90 days. Figure III.16 shows all the results obtained.

The addition of latex in the percentages of 15% L, 25% L and 35% L had a noticeable effect on the increase in the flexural strength where the optimum latex ratio was at 35% L. At 7, 28 and 90 d, the improvement rates were compared with those of the reference SC (9.54%, 77.78% and 52.70%). These results are due to the important role of latex in improving the bond between the sand concrete components, which contributed to the improvement of flexural strength. Ukrainczyk et al. (Ukrainczyk & Rogina, 2013) added latex to the mortar after 1, 7 and 14 d and found an improvement in the flexural strength compared with the reference mortar by 18%, 31% and 29%, respectively. Furthermore, liquid-type SBR has significantly increased tensile and flexural strength (Barluenga & Hernández-Olivares, 2004; Ohama, 1987).

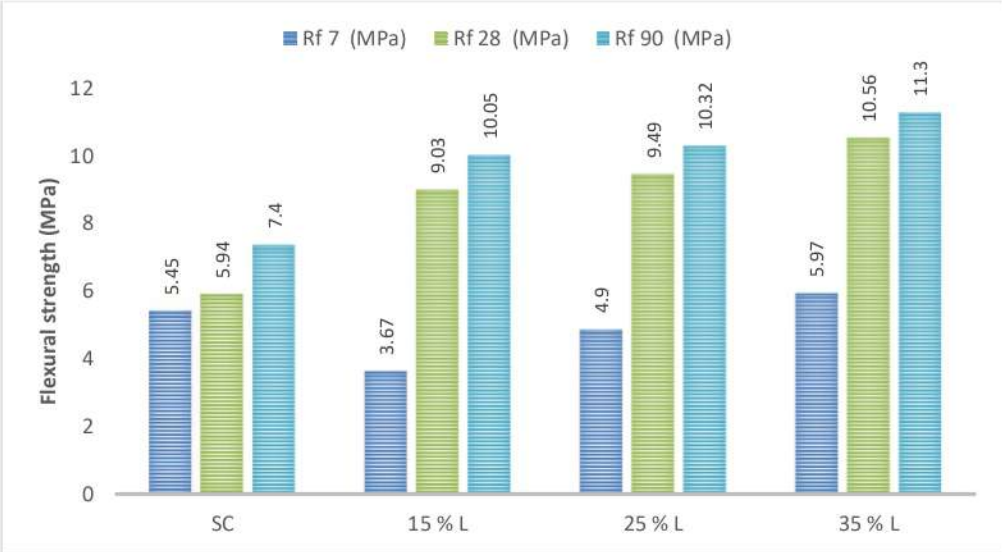


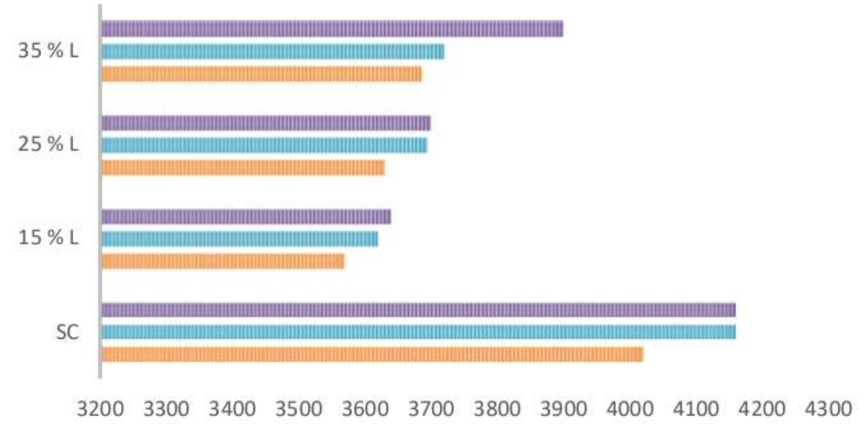
Figure III.16. Flexural strength of latex-modified sand concrete compared to SC.

III.4.5 Ultrasonic Pulse Velocity (UPV)

UPV is a non-destructive test conducted to determine the mechanical properties of concrete. Figure III.17 shows all the UPV values of the studied compounds at 7, 28 and 90 days.

When the latex emulsion was added to sand concrete, ultrasonic pulse velocity were reduced, as shown in the presented results. The decrease in UPV when adding latex had a different reason than that in fibre, where the rubbery nature of latex contributes to the reduction of UPV. This result agrees with the study by Barluenga et al. (Barluenga & Hernández-Olivares, 2004)**,** who observed a decrease in the UPV when latex was added to the cement matrix.

As this Ultrasonic Pulse Velocity decrease does not significantly affect the concrete quality, according to Standard NF EN 12504-4, all samples are of the good concrete class.



	SC	15 % L	25 % L	35 % L
UPV 90 (m/s)	4160	3640	3700	3900
UPV 28 (m/s)	4160	3620	3695	3720
UPV 7 (m/s)	4020	3570	3630	3686.67

Figure III.17. UPV of latex-modified sand concrete compared to SC.

III.4.6 Dynamic modulus of elasticity

Figure III.18 shows the development of the dynamic modulus of elasticity of the studied compounds after 28 days.

The addition of latex affected the decrease of the dynamic modulus of elasticity. As expected, the modulus of elasticity of the samples decreased with the increase of latex content. The percentage decrease in the dynamic modulus of elasticity was approximately 32.02%, 43.50% and 53.05% for compounds 15% L, 25% L and 35% L, respectively, compared with the reference SC. This decrease in modulus of elasticity can be attributed to the latex polymer's lower hardness concerning the SC components' hardness. (Ukrainczyk & Rogina, 2013)showed that the decrease in dynamic modulus with increased latex content was due to a decrease in the polymer stiffness in relation to the hardness of the mortar. Furthermore, (Grinys et al., 2020) found that adding latex to concrete did not improve the modulus of elasticity. Many studies prove that the modulus of elasticity tends to decrease with the increase of latex (Decter, 1997; Diab et al., 2013).

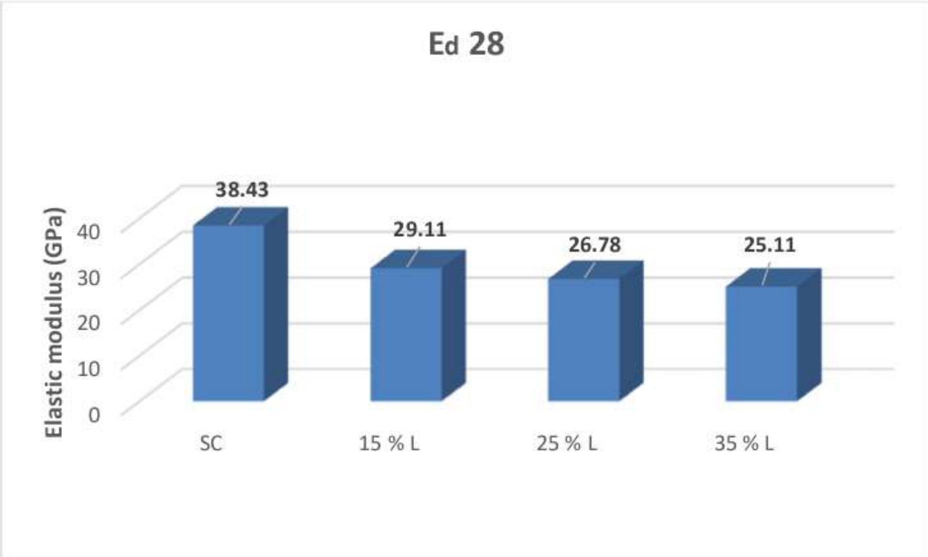


Figure III.18. Dynamic modulus of elasticity of latex-modified sand concrete compared to SC.

III.4.7 Water-accessible porosity and Water absorption

The results of the tests obtained after 28 days of Water accessible porosity, as shown in Figure III.19, and Figure III.20, show the samples' water absorption results.

The addition of latex emulsion at percentages of 15% L, 25% L and 35% L had an important role in reducing the porosity and absorption to Water compared with the reference SC. For each increase in the percentage of latex, a significant improvement in sand concrete was observed in terms of porosity and water absorption, as we obtained the lowest porosity and water absorption at 35% L. The addition of latex closes the fine cracks in the latex-modified SC by forming polymer films, which prevent cracks from spreading. (Ohama, 1998) explained that polymer-modified concrete has minimal water absorption because the pores were filled and sealed with the polymer film, thereby decreasing the permeability of this type of concrete. Furthermore, several studies have demonstrated a good reduction in the water absorption and permeability of the latex-modified cement matrix (Diab et al., 2013; Noyori, 1997; Ukrainczyk & Rogina, 2013; Yang et al., 2009).

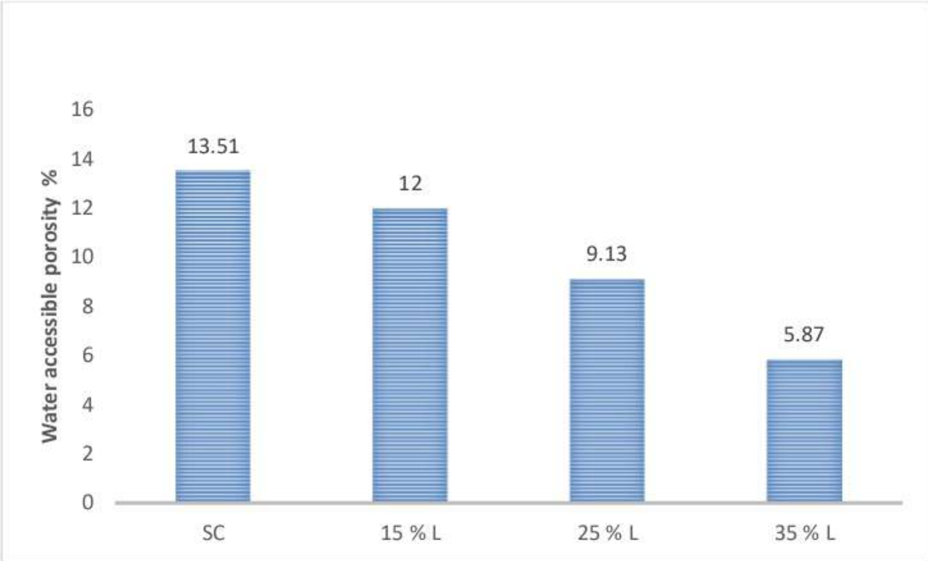


Figure III.19. Water-accessible porosity of latex-modified sand concrete compared to SC.

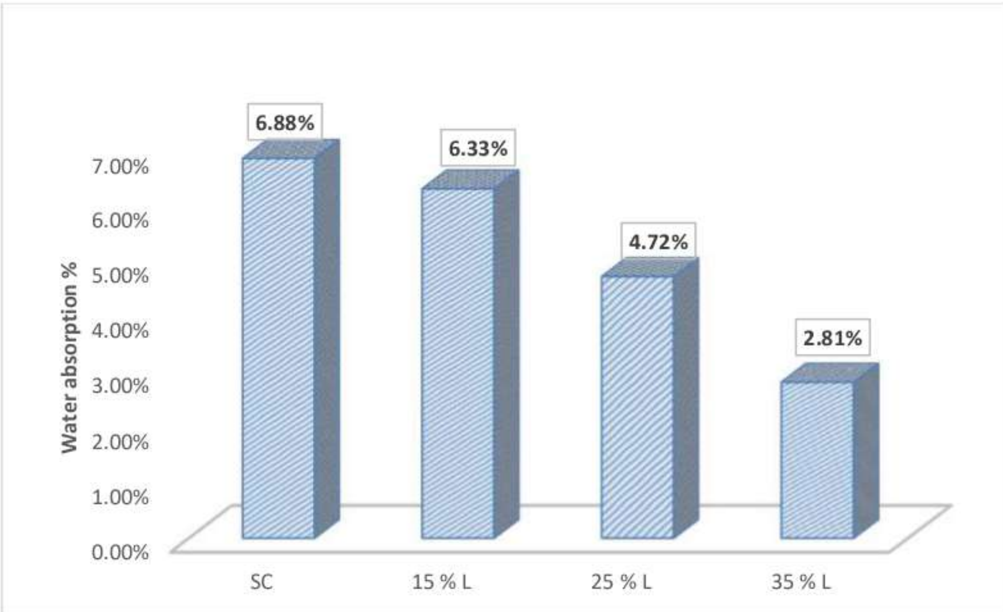


Figure III.20. Water absorption of latex-modified sand concrete compared to SC.

III.4.8. Shrinkage test

The shrinkage of the studied samples is measured daily for 120 days, as shown in Figure III.21 This test aims to monitor the dimensional variations in sample length over time from when the sample is removed from its mould.

The addition of latex contributed to reducing shrinkage compared with the reference concrete. The higher the percentage of the emulsion of latex, the greater the decrease in shrinkage, as the ideal percentage in the sample was 35% L with an improvement of 6.22% compared with SC after 120 days, as shown in Figure III.22. This improvement can be seen through the microstructure, where the internal structure of the latex-modified SC has a dense microstructure and few voids that contribute to shrinkage reduction. Furthermore, the latex helps prevent the water content of the cement matrix from evaporating. This result is in accordance with several studies showing a reduction in shrinkage with the addition of latex (Diab et al., 2013; Ohama, 1995).

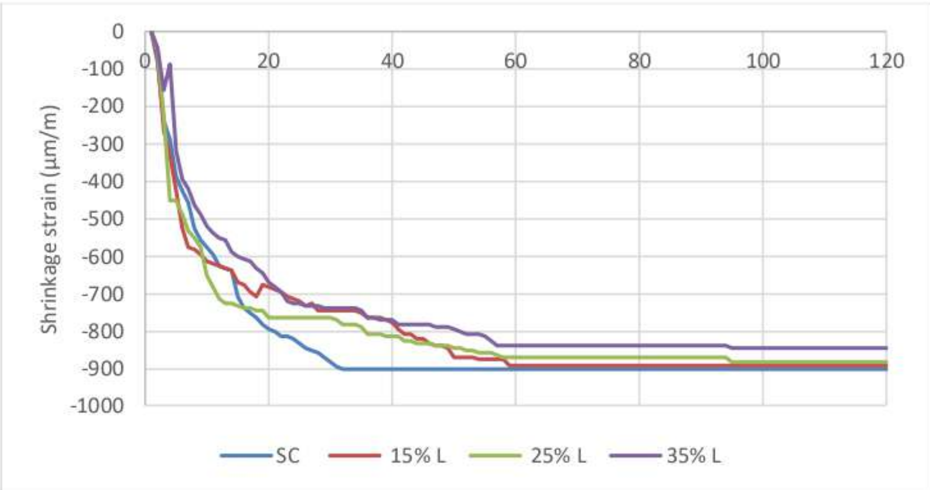


Figure III.21. Evolution of shrinkage according to time of latex modified sand concrete compared to SC.

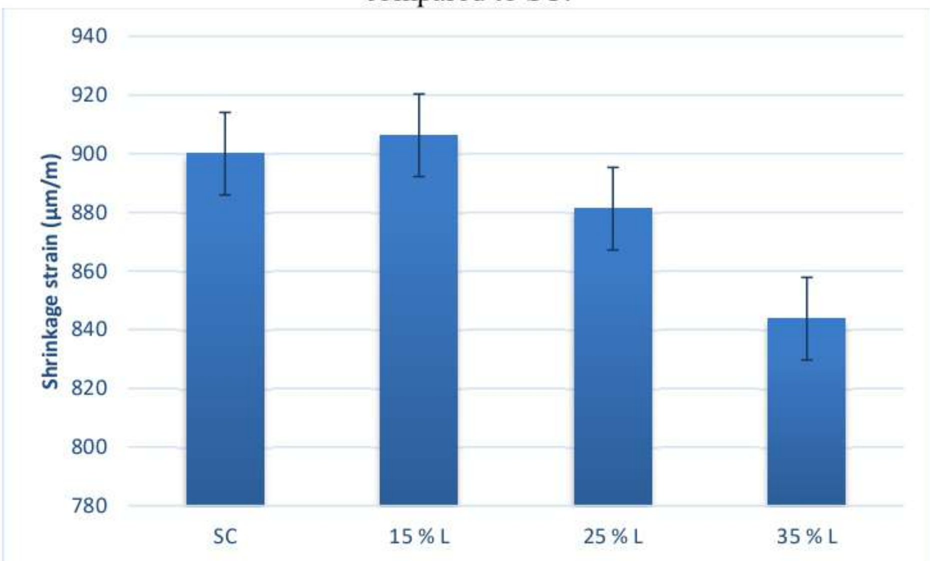


Figure III.22. Effect at the 120 days- shrinkage of latex modified sand concrete compared to SC.

III.5 Study of the properties of the repair material (0.1% F + 35% L) and substrate (NC)

III.5.1 Compressive strength

Figure III.23 shows the following samples: the ideal ratio of sisal fibers 0.1% F, the ideal ratio of latex 35% L, latex combined with sisal fibers 0.1% F+35% L, reference sand concrete SC and normal concrete substrate NC.

For the matrix in which sisal fibers were combined with latex 0.1% F + 35% L, an improvement in compressive strength was observed compared to the addition of sisal and latex fibers alone. The obtained value is similar for reference sand concrete at 28 and 90 days. This improvement is related to the change that occurred. The sisal fibers inside the cement matrix when adding the latex, which contributed to good adhesion between them, can be observed by microstructure analysis. Kundu et al. (Kundu et al., 2018) combined jute fibers with latex in concrete paver blocks, resulting in improved compressive strength estimated at 14.55% after 28 days compared to unmodified jute-reinforced paver blocks. In addition, the compressive strength obtained for the concrete substrate is within the required as shown in the obtained results.

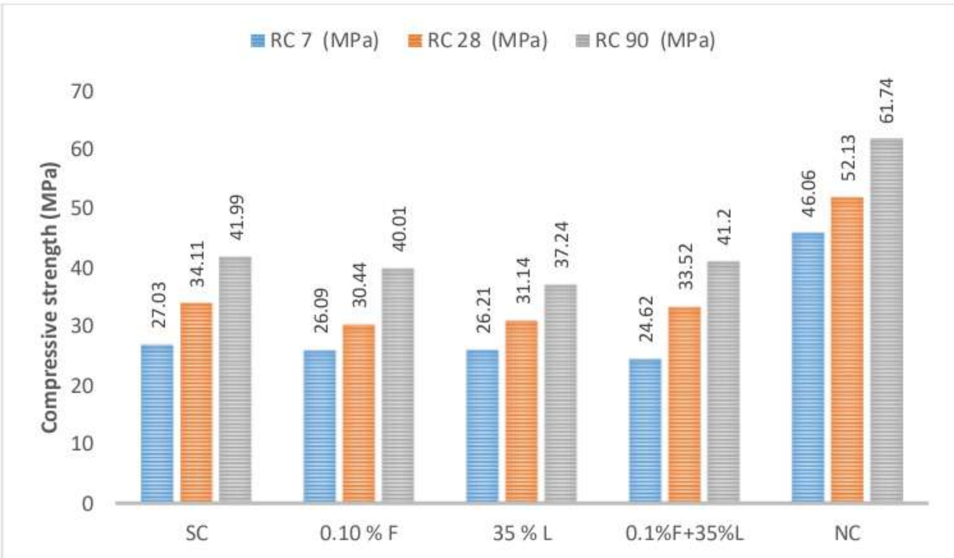


Figure III.23. Compressive strength of repair material and substrate.

III.5.2 Flexural strength

Figure III.24 shows the results obtained for flexural strength after 7, 28 and 90 days

The most important result from this study is that when the ideal proportions of sisal fibre and latex were combined (0.1% F + 35% L), it gave better results when compared to 0.1% F and 35% L, an excellent improvement in flexural strength was observed at 33.94%, 114.31% and 77.03% compared with the reference SC at 7, 28 and 90 days. This significant improvement in flexural strength can be explained by microstructure analysis. The adhesion between the fibre and the cement matrix reduced the gaps and voids when the sisal fibre was combined with the latex. This result also corresponds to the findings of Kundu et al. (Kundu et al., 2018) when jute fibres were combined with latex, resulting in increased flexural strength in the cement matrix. Ribs (Rebeiz, 1995, 1996) found that adding polymers to a cement complex containing cellulose fibre would achieve good strength within a short treatment period.

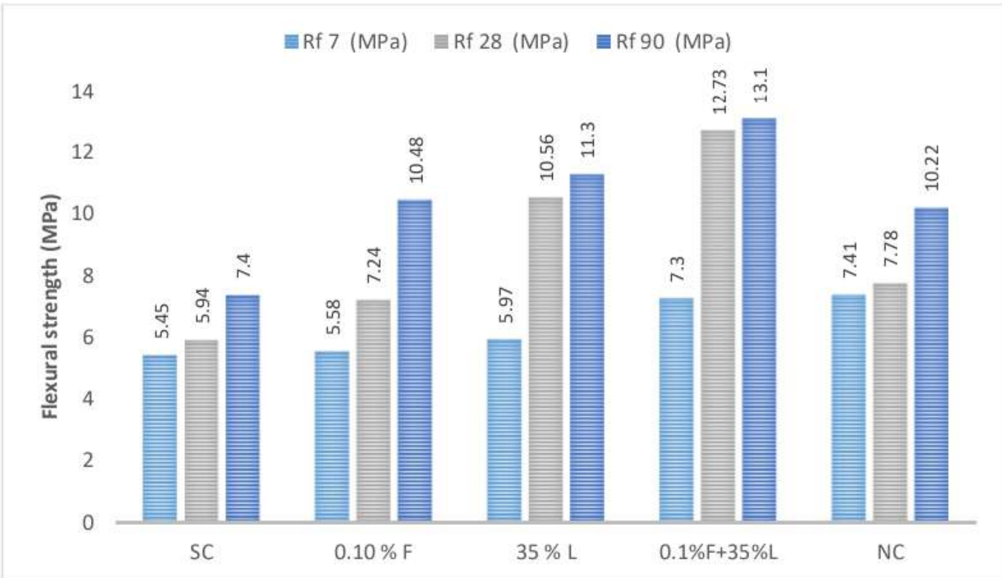
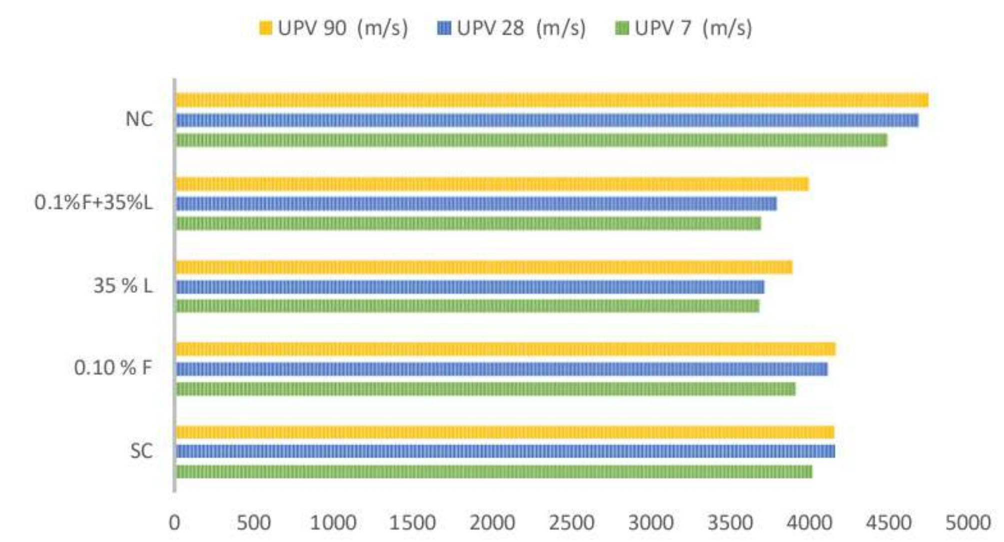


Figure III.24. Flexural strength of repair material and substrate.

III.5.3 Ultrasonic Pulse Velocity (UPV)

According to the evaluation of concrete quality according to the standard NF EN 12504-4 used in this study, the results obtained from the UPV test of all samples were in the good concrete class, as shown in Figure III.25.

As (Chahour et al., 2017) explained, the acoustic properties of different materials can be measured using UPV. Accordingly, the decrease in UPV without affecting the concrete quality is an essential and positive feature regarding sound insulation. (Cheboub et al., 2020) It also indicated that UPV values could be used to predict the sound insulation capacity of mortars.



	SC	0.10 % F	35 % L	0.1%F+35%L	NC
UPV 90 (m/s)	4160	4170	3900	4000	4750
UPV 28 (m/s)	4160	4120	3720	3800	4693.33
UPV 7 (m/s)	4020	3915	3686.67	3700	4496.67

UPV (m/s)

Figure III.25. UPV of repair material and substrate.

III.5.4 Dynamic modulus of elasticity (Ed)

Figure III.26 shows the development of the dynamic modulus of elasticity of the studied compounds after 28 days.

Due to a clear relationship between elastic modulus and compressive strength, we can observe that the lower the dynamic modulus of elasticity, the lower the compressive strength and vice versa.

In general, adding latex and fibers to the cement matrix lowers the dynamic modulus of elasticity, and according to the results obtained, adding latex and fibers together 0.1% F + 35% L increases the dynamic modulus of elasticity if it is compared with both 0.1% F and 35% L as the obtained results show.

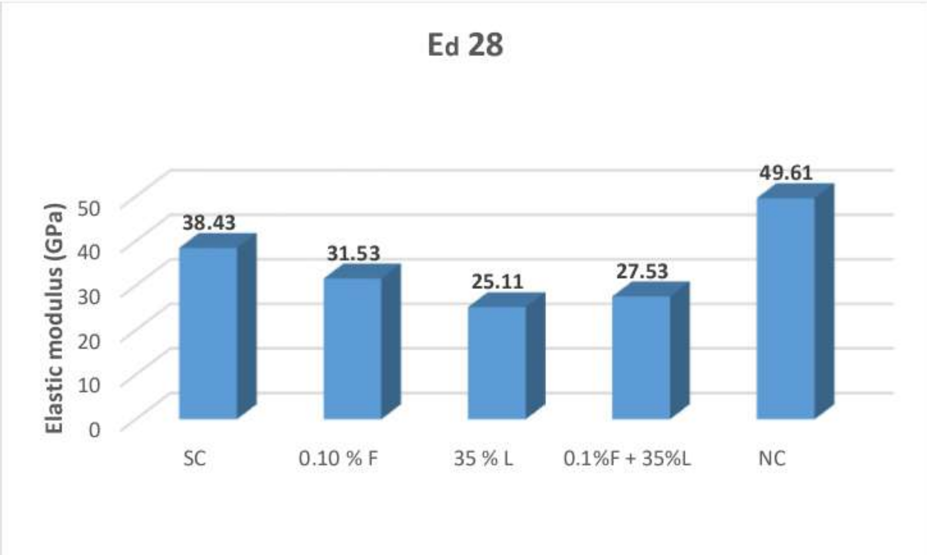


Figure III.26. Ed of repair material and substrate.

III.5.5 Water-accessible porosity and Water absorption

The addition of sisal and latex fibres (0.1% F + 35% L) in the same matrix had an important effect that can be observed from the results, as shown in Figures III.27 and III.28. The addition greatly contributed to reducing the porosity and water absorption in the latex-modified sand concrete with 0.1% F + 35% L compared with the sample added to the same percentage of sisal fibres without latex 0.1% F.

This condition can also be explained by the microstructure analysis, as the addition of latex had an effective role in the sand concrete, contributing to the reduction of voids and capillary pores and also increasing the adhesion between the fibres and cement matrix. These improvements contributed to reducing the water permeability of sand concrete.

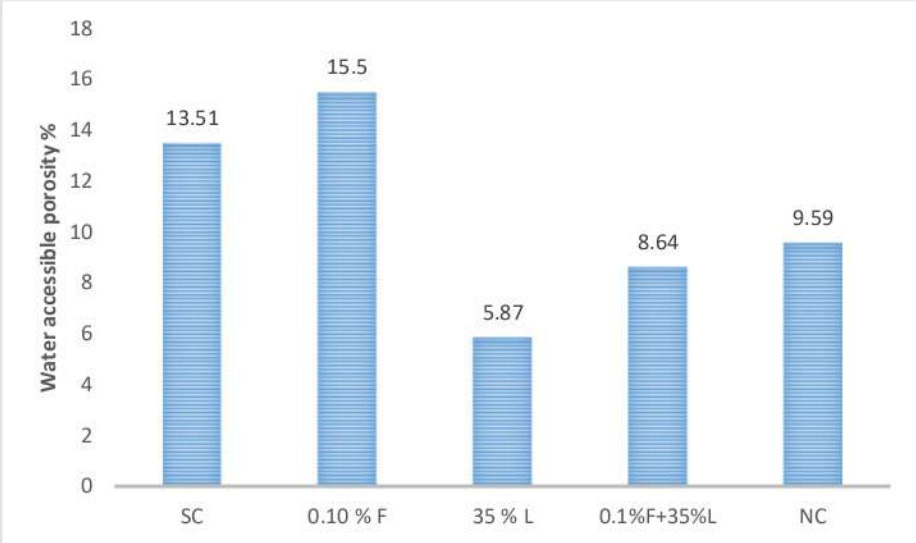


Figure III.27. Water-accessible porosity of repair material and substrate.

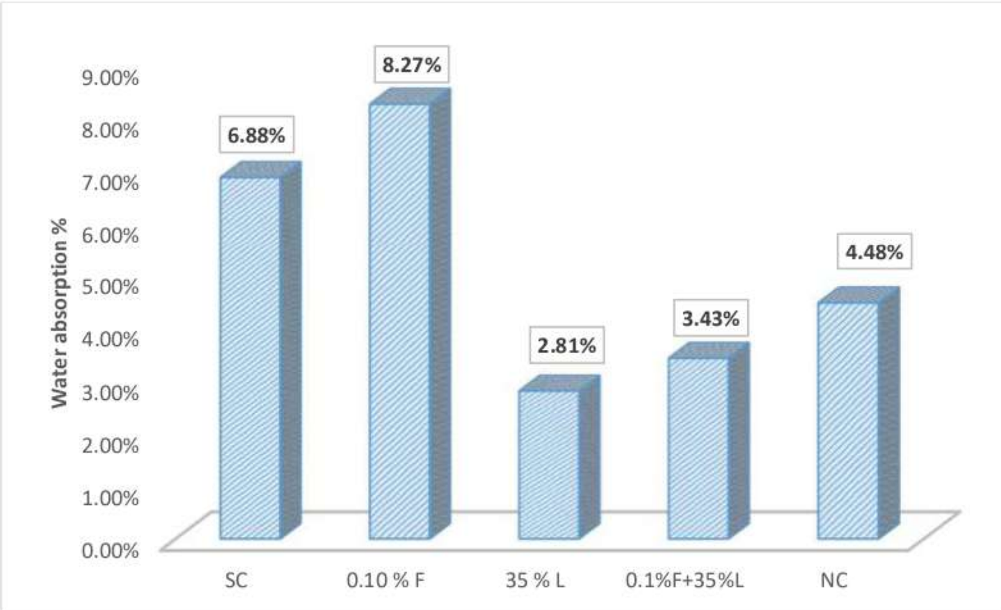


Figure III.28. Water absorption of repair material and substrate.

III.5.6. Shrinkage test

The shrinkage of the studied samples is measured daily for 120 days, as shown in Figure III.29 and Figure III.30 Effect of different treatments on 120 days shrinkage.

The best improvement occurred when the same matrix combined sisal fibre and latex (0.1% F + 35% L). The shrinkage decreased by a reasonable rate, as the percentage at 120 days was 21.53% compared with the reference sand concrete SC.

This improvement in the latex-modified sand concrete with sisal fibre can be explained by looking at the microstructure, which exhibited the strength of adhesion between the cement matrix and the fibre as well as the lack of internal cracks and voids. The sample with 0.1% F + 35% L showed the best result for most of the physical and mechanical properties obtained in this study, and therefore, we expected the sample to obtain a low shrinkage value. Son and Yeon (Son & Yeon, 2012) showed that polymer-modified concrete could reduce evaporation, which led to reduced shrinkage.

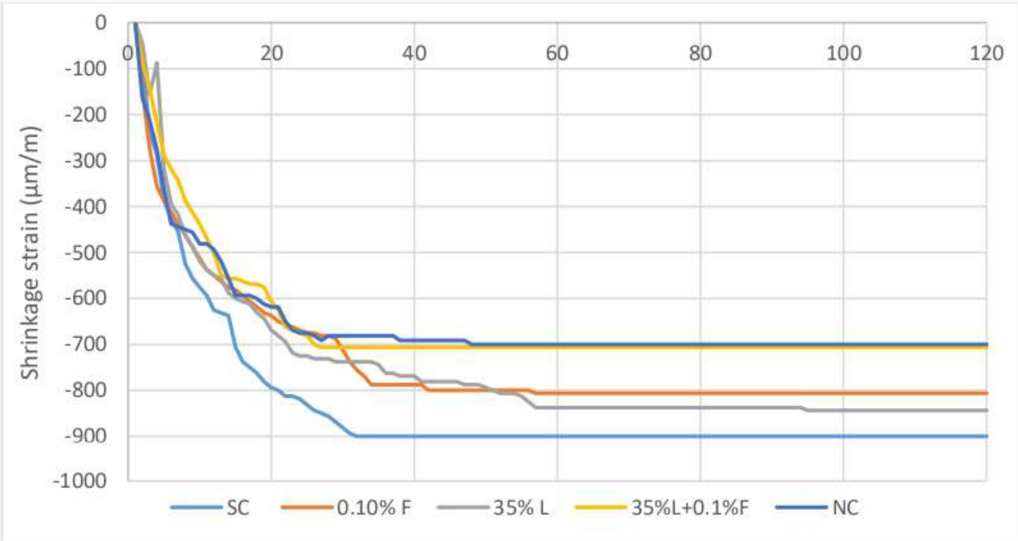


Figure III.29. Evolution of shrinkage according to time repair material and substrate.

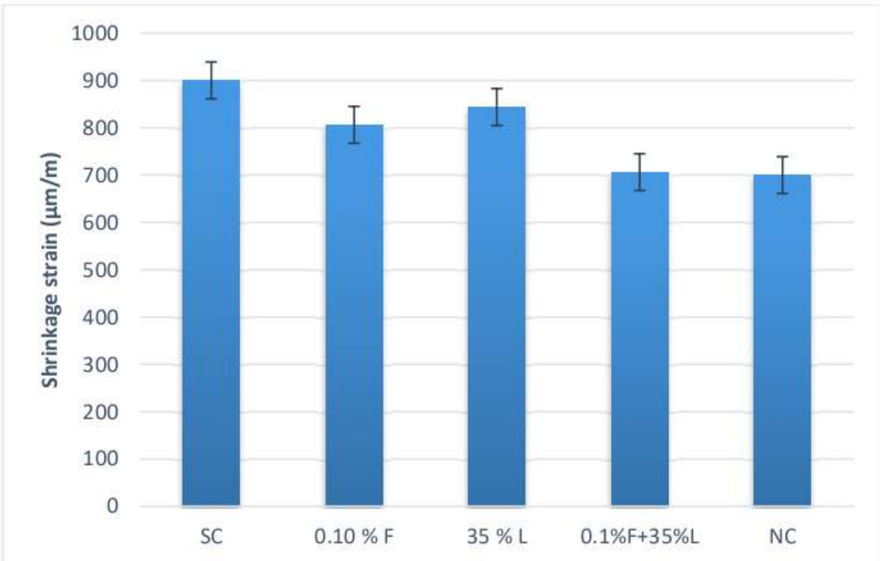


Figure III.30. Effect at 120 days- shrinkage of repair material and substrate.

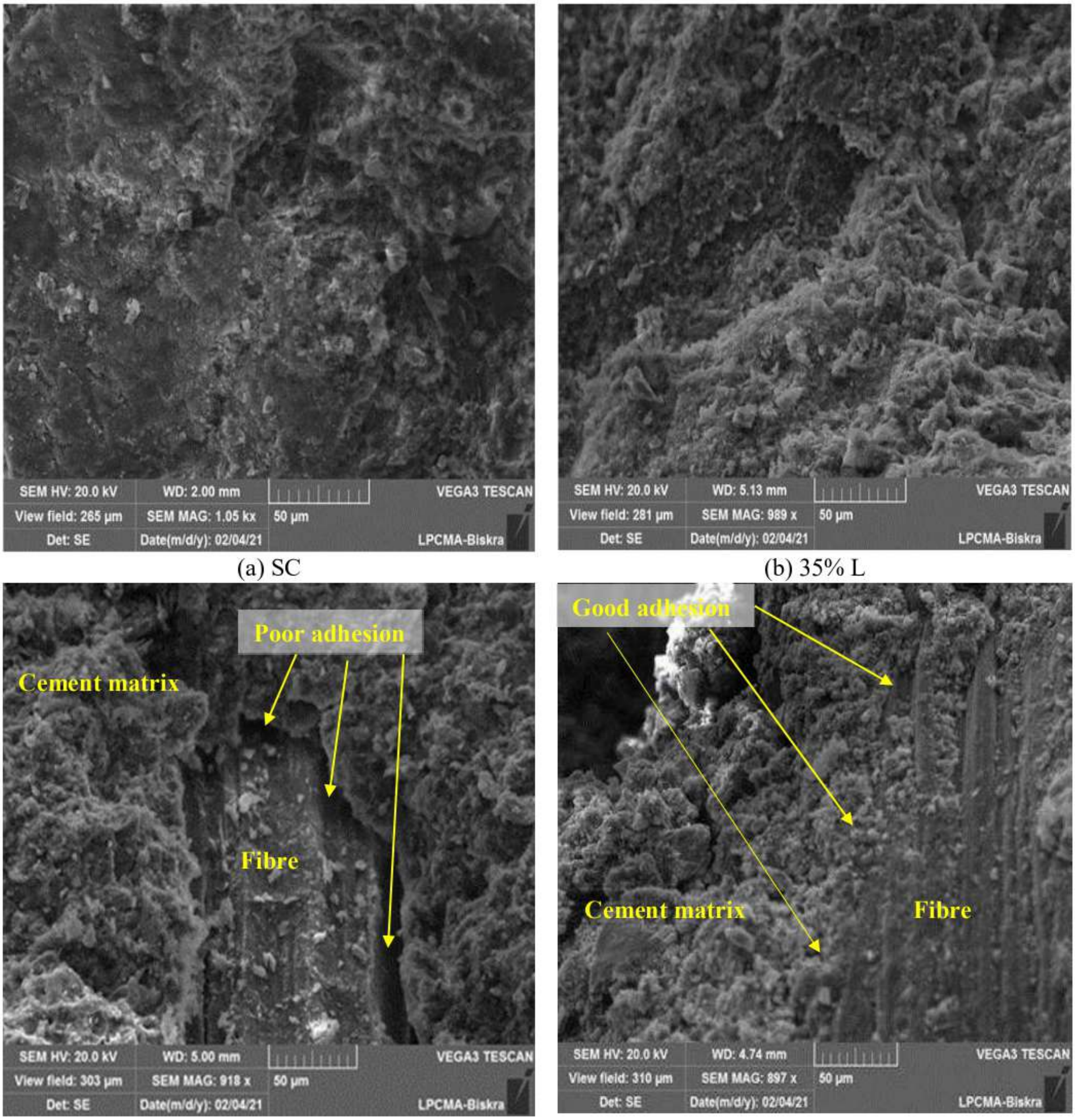
III.6 Microstructure analysis

The microstructure of four important samples was studied through SEM after mechanical shattering tests, where samples were taken from inside the cement matrix to be similar to the internal structure after 28 days of curing. The samples were as follows: the reference sand concrete SC, the ideal ratio of sisal fibres (0.1% F) and latex (35% L), and the combination of sisal and latex fibres (0.1% + 35% L).

Fig. 19a shows the microstructure of the reference sand concrete SC. Some voids and interrupted pores can be observed inside the microstructure. However, when 35% L was added to the cement matrix, as Figure III.31b shows, it significantly reduced the percentage of voids and the porousness of the cement paste. This method also contributed to forming a polymer membrane inside the cement matrix, which increased the bonding among all components. (Noyori, 1997) The latex-modified concrete had a dense microstructure, fewer pores and a better bond between the granule and cement matrix than the reference concrete. (Barluenga & Hernández-Olivares, 2004) In the binding phase, a modified polymer-cement matrix undergoes a polymer film-forming process. The SBR contains a rigid styrene group and a flexible butadiene chain that helps to produce the coherent polymer film and interpenetrating net structure with the cement grain (Jo et al., 2014). Previous studies have shown that adding latex polymer as a concrete modifier improves the microstructure (Lewis & Lewis, 1990; Ohama, 1997).

As shown in Figure III.31c, a gap exists between the sisal fibre and cement matrix, indicating poor surface-bonding adhesion between them, which increases the capillary porosity and thus negatively affects some properties of the sand concrete. The most important improvement can be observed when latex emulsion was added to the cement matrix containing sisal fibres as shown in Figure III.31d, where good adhesion occurred between the sisal fibre and the cement matrix, which led to a reduction in the gaps and pores resulting from the lack of cohesion. This condition also corresponds to the findings of (Kundu et al., 2018) when combining jute fibres with latex, where good adhesion was observed between the fibre and the matrix. The fibre interface is important in evaluating composites' physical and mechanical properties (Zhou et al., 1995). The mechanical properties of a cement matrix are highly dependent on the microstructure condition (Z. A. Siddiqi, R. Hameed, M. Saleem, Q. S. Khan, 2013).

Most of the results obtained in this study of the physical and mechanical properties were the best for the sample 0.1% F + 35% L. This condition indicates the compatibility between the microstructure analysis and test results.



(a) SC

(b) 35% L

(c) 0.1% F

(d) 0.1% F + 35% L

Figure III.31. SEM analysis of samples.

III.7 Conclusion

The aim of this chapter, at the beginning, we determined the ideal proportions of the mixture of crushed sand and river sand, which were as follows: 60% crushed sand + 40% river sand after studying five different mixtures, followed by determining the ideal ratio to replace part of the sand with limestone filling, by studying five Different ratios, where the ideal ratio of limestone filler was 12.5% filler, in addition, the percentage of Water was 227.5 liters and the superplasticizer was 2% of cement in order to obtain the reference sand concrete SC, in order to improve its physical and mechanical properties by adding sisal fibers and latex emulsion In order to obtain sandy concrete with good properties to be used as a repair material, Based on the results obtained to improve the properties of reference sand concrete SC by adding sisal fibres and latex at different proportions, and then combining the optimal ratio of the two materials as a repair material, the following conclusions are obtained:

- Adding sisal fibers in different proportions led to a good improvement in bending resistance and also reduced the shrinkage percentage. Especially at 0.1% F, considered the ideal ratio of sisal fibers, where the improvement value compared to the reference sand concrete for the flexural strength was 41.62%, while the improvement rate for reduced shrinkage after 120 days was 10.44%.
- The addition of latex emulsion was instrumental in improving most of the physical and mechanical properties of sand concrete, which was associated with the increase. The higher the percentage, the better the most of the results were, as the ideal ratio for adding latex in our study was 35%L.
- The addition of sisal fibers and the emulsion of latex in different proportions reduced the sand concrete's density.
- The addition of latex to sand concrete containing sisal fibers is the treatment to improve the function of the fibers within the cement matrix.
- Significant improvement in flexural strength of latex-modified sand concrete with sisal fibers compared to reference sand concrete after 28 days reached 114.31%, and this improvement is considered an important addition to the properties.
- The combination of sisal fibers and latex together 0.1% F + 35% L in the same sample led to a important improvement in reducing the porosity and absorption to water ratio of the latex-modified

sand concrete with sisal compared to the same sample without latex 0.1% F where the percentage of reduced Water accessible porosity was 44.26%, and the percentage of Water absorption decrease was 58.45%, respectively.

- This combination of latex and sisal fibers also contributed to a decrease in shrinkage compared to the reference matrix, by about 21.53%.
- Microstructure using optical microscopy and SEM showed that the combination of sisal fibers and latex together in the same cement matrix had an essential role in contributing to increasing the adhesion of the fibers in the cement matrix, which contributes to reducing the pores and also obtaining a more coherent and homogeneous compound between its components. This is in agreement with the results obtained in our study.
- A slight decrease in the compressive strength, Ultrasonic pulse velocity and dynamic modulus of sand concrete with the addition of sisal fibers and latex in different proportions before merging, but all the results obtained for these results are acceptable and fulfil the requirements.
- Study the physical and mechanical properties of the normal concrete substrate on which the repair material will be applied.
- Finally, the combination of sisal fibres and latex in the same cement matrix generally improved all the studied properties, and therefore it can be used as a new repair material. The next chapter presents and discusses the results obtained using 0.1% F + 35% L (LMSC) as a repair material.

CHAPTER IV

EFFECTIVENESS OF BOND STRENGTH BETWEEN SAND CONCRETE AND NORMAL CONCRETE

IV.1 Introduction

This chapter evaluates the bonding strength between Latex-Modified Sand Concrete reinforced with sisal fibers (LMSC) as a repair material and Normal Concrete (NC) as a substrate where different shapes and sizes will be used to assess the adhesion and type of failure mode between LMSC and NC.

The association of new concrete as a repair material with old concrete results in a composite of two materials with different mechanical and physical properties (Gadri & Guettala, 2017a). Thus, the compatibility of the two components drives them to a successful and effective repair of the concrete structure. The adaptability of the concrete structures' repair materials is an essential parameter for long-term repair continuity (Gadri & Guettala, 2017a).

The interfacial transition zone (ITZ) between repair material and old concrete is the weakest part of the repaired concrete complex (Tayeh, Bakar, et al., 2012). The ITZ between the old concrete to be repaired and the repair material is essential for durability and better resistance to external penetrations (Santos & Júlio, 2011; Tayeh, Abu Bakar, et al., 2013b). The adhesion and bond strength of the ITZ of the repair structure is essential to the performance and operation of the structure (Abo Sabah et al., 2019; Farzad et al., 2019).

The main objective of this study is to ascertain the bond strength between LMSC and NC using four different surfaces: without Surface preparation as Reference (SR), rough surface made with Hand hammer (HA), Sandblasted (SB), and Grooved (GR). The bi-surface shear, splitting tensile, and pull-off strength tests evaluated the bond strength. The microstructure of the interfacial transition zone was also studied using Scanning Electron Microscopy (SEM).

IV.2 Bi-surface shear strength

Table IV.1 presents values obtained from the bi-surface shear test for the composite specimens and at different ages of the test. These results are for four various kinds of surfaces. For each tested specimen, failure load was monitored, and bond strength, standard deviation (STD) and coefficient of variation (COV) were determined. Four types of failure modes for bi-surface shear test specimens was identified as shown in Figure IV.1 type A, which denotes pure interface failure; type B, which stands for interface failure with partial substrate failure; type C, which stands for interface failure with total substrate failure; and type D, which refers to substratum failure. While Figure IV.2 shows the correlation between the type of studied surfaces and the bond strength for the bi-surface shear strength test in 7, 28 and 90 days.

For the SR, the mean measured shear Bi-surface strengths were 2.68, 3.74 and 4.69 MPa on days 7, 28, and 90, respectively. Where the interfaces bonding failed for most of the compounds at an early age of 7 days, as shown in Figure IV.1.type A, but the results generally exhibit a gradual increase in interfacial bond strength with the age of 28 and 90 days, as the failure mode was the interface failure with the partial substrate failure shown in Figure IV.1.type B. As for the grooved surface, there was an improvement of 21.75% compared to the reference surface after 90 days, while the failure mode was mixed between type A and type B, as shown in Figure IV.

While it can be said that the most important improvement was for the surface treated with hand hammer and sandblasting, with an improvement rate of 63.33% and 50.32%, respectively, compared to the reference surface after 90 days, and also the failure mode of most samples was of type D as shown in Figure IV, this indicates the importance of roughness to have a good bond between the NC and LMSC.

The results show that the bonding of the composite samples with rough interfaces is good and coherent because most of the composite samples failed in the NC substrate. Many studies have proven that the coarser surfaces of the interface are better in terms of bonding between the repair material and the NC substrate (Gadri & Guettala, 2017a) get a rough surface best suited by hand hammer, and (Tayeh et al., 2014) By sandblasting.

Therefore, it can be concluded that surface treatment of the substrate is essential to improve the bonding strength between NC and LMSC. Also, the surface treated differently contributes to the bonding strength and adhesion in a short life compared to the unmodified surface (SR). This is what the results obtained in this study showed. (Tayeh, Abu Bakar, et al., 2012) Surface preparation has a strong influence on bond and adhesion.

Far from the importance of the roughness of concrete substrate surfaces in the mechanical bonding between the composite, the nature of the repair material used has an important role in the chemical bonding at the transitional region between the composite, it can be called a chemical mechanical bond (Tayeh, Abu Bakar, et al., 2012). LMSC had an influential role in the bonding at the transitional zone between the composite because it contains components that reinforced this bonding, especially polymer latex, as it increased the bonding between the interface and also contributed well to increasing the cohesion of the components of LMSC together by forming polymeric networks that connect all components (Ramli et al., 2013). The improvement in adhesion is mainly attributed to forming of a polymer film between the transition zone as it contributes to bridging the pores and cracks at this interface (Mansur et al., 2009). This novel idea of concrete, known as polymer-modified concrete, has greater physical qualities and endurance than conventional cement concrete. Various polymers, such as latex polymer, increase the properties of cement as a bonding agent (Jo, 2020) and it was demonstrated that when the latex percentage in the concrete, the adhesive strength between the modified concrete and the concrete substrate also increased (Benali & Ghomari, 2017). In addition, it improves the resistance to external penetrations and increases the durability of cement composite (Yang et al., 2009a).

In addition, LMSC paste had an important role as it contributed to filling minute voids and cracks by reaching the largest possible depth when touching the face of the concrete substrate due to the small size of the aggregate as it does not exceed 5 mm in diameter and also because it contains fine fillers.

Table IV.1: Bi-surface shear test results.

		7 days			28 days			90 days		
Surface treatment	**Specimen**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**
SR	SR1	26.1	2.61	A	31.4	3.14	A	47.7	4.77	B
	SR2	25.3	2.53	A	42.6	4.26	B	43.9	4.39	B
	SR3	29	2.9	A	38.2	3.82	B	49.1	4.91	B
		Mean(MPa)	2.68		Mean(MPa)	3.74		Mean(MPa)	4.69	
		STD (MPa)	0.19		STD (MPa)	0.56		STD (MPa)	0.27	
		COV (%)	7.26		COV (%)	15.09		COV (%)	5.74	
HA	HA1	57.5	5.75	C	69.2	6.92	D	73.3	7.33	D
	HA2	51.3	5.13	C	64.7	6.47	D	77.1	7.71	D
	HA3	60.1	6.01	D	66.3	6.63	D	79.3	7.93	D
		Mean(MPa)	5.63		Mean(MPa)	6.67		Mean(MPa)	7.66	
		STD (MPa)	0.45		STD (MPa)	0.23		STD (MPa)	0.30	
		COV (%)	8.03		COV (%)	3.42		COV (%)	3.96	
SB	SB1	51.8	5.18	D	63	6.3	D	67.8	6.78	D
	SB2	42.7	4.27	C	58.5	5.85	D	70.6	7.06	D
	SB3	48.9	4.89	C	60.1	6.01	D	73.1	7.31	D
		Mean(MPa)	4.78		Mean(MPa)	6.05		Mean(MPa)	7.05	
		STD (MPa)	0.46		STD (MPa)	0.23		STD (MPa)	0.27	
		COV (%)	9.73		COV (%)	3.77		COV (%)	3.76	
GR	GR1	33.12	3.31	A	49.6	4.96	C	56.16	5.62	C
	GR2	36.26	3.63	B	42.8	4.28	C	59.5	5.95	D
	GR3	34.33	3.43	B	47.22	4.72	C	55.73	5.57	C
		Mean(MPa)	3.46		Mean(MPa)	4.65		Mean(MPa)	5.71	
		STD (MPa)	0.16		STD (MPa)	0.35		STD (MPa)	0.21	
		COV (%)	4.58		COV (%)	7.41		COV (%)	3.61	

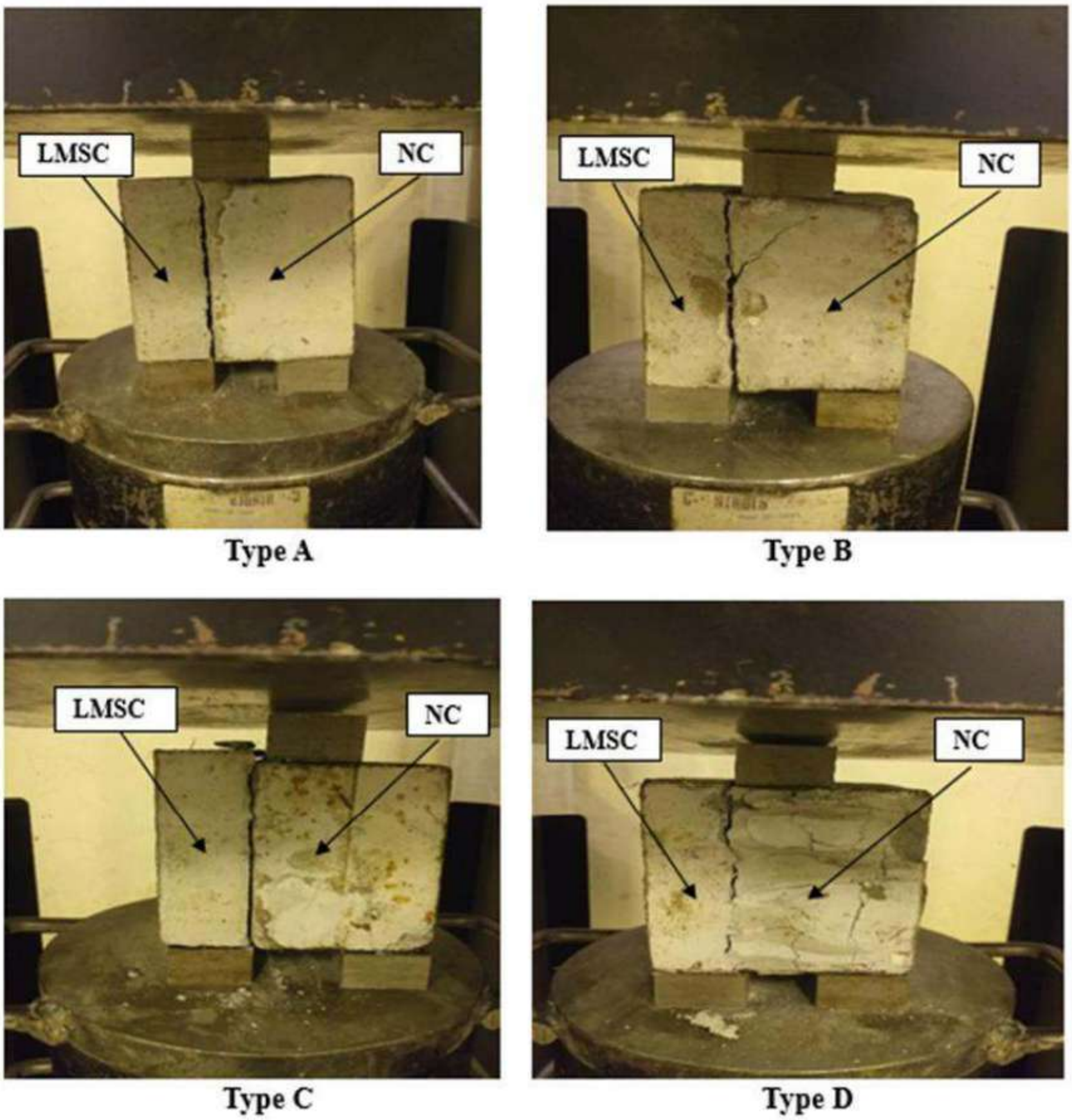
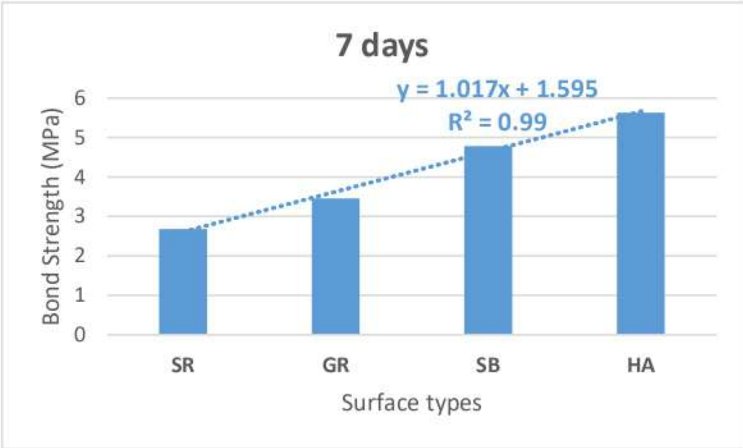


Figure IV.1. Failure of bi-surface shear specimens.



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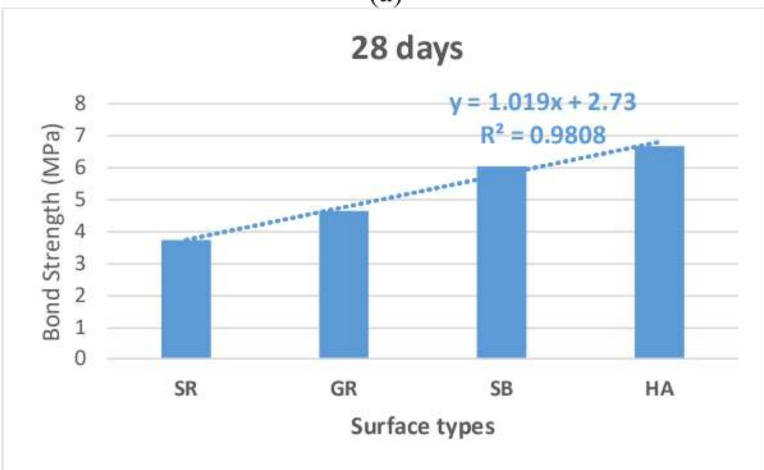

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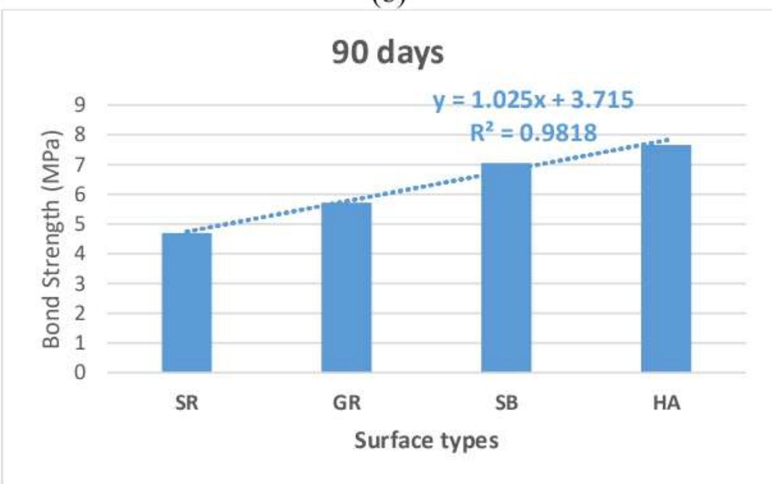


(c)

Figure IV. 2. Correlation between surface types and bi-surface shear strength at different ages.

IV.3 Splitting tensile strength

This experiment evaluates the bonding using the splitting test applied to cubic composites. Four types of surface textures were used in this experiment: SR, GR, SB and HR.

The splitting tensile strength results of composite cube specimens are shown in Table IV.2. The Figure IV.3 shows the correlation between surface type and the bond strength of the bond for all ages. The results showed that the surfaces with high roughness gave excellent results; they are the surfaces treated with (HR) and (SB), where the average bond strength after 90 days was found to equal 2.94 and 2.62 MPa, respectively.

A slight standard deviation for composite samples and all studied surfaces, confined between 0.06 and 0.21 MPa; A moderate (COV) between 3.21% and 11.04% was obtained. Also, little dispersion is observed, showing that the results are accurate. This is consistent with the study by (Gadri & Guettala, 2017a), who showed that when (COV) is less than 15%, the results are considered accurate and significant. In general, failures modes are grouped into four types, namely as shown in Figure IV.3. Type A: separation of the transition region of the composite, Type B: failure of the transition region, with a thin layer of LMSC with different regions of the substrate, Type C: failure of the mixed complex with an important layer of LMSC bound to different regions of the NC Type D: Mixed failure of the composite showing bond and strong adhesion between NC and LMSC. As evident from Table IV.2 and Figure IV.3, each compound shows a significant improvement in splitting tensile strength with respect to surface roughness. Compared with (SR) surface, which is considered a low-roughness surface, one can say that the relative increase in splitting tensile strength is more significant in the case of high-roughness substrate surfaces. Where the surfaces can be classified in terms of the bonding strength obtained from the results according to the quality of the treated surface from the best to the least as follows: hand hammer, sandblasting, grooving and the untreated reference surface, where the value of bond strength after 90 days was 2.94, 2.67, 2.17 and 1.53 MPa respectively. The percentage of improvement obtained compared to the reference surface (SR) was as follows: 92.16% for (HA), 74.51% for (SB) and 41.83% for (GR). Figure 7 shows the development of the splitting tensile strength of the composite cube specimens. Where previous studies proved that the bond strength obtained from surface treatment by sandblasting by Splitting tensile test is strong and gave excellent results (A. Garbacz et al., 2005; Júlio et al., 2004; Van Zijl & Stander, 2008), and this confirms the results obtained in this study.

Several studies showed the effect of substrate surface roughness on bonding, consistent with the results obtained (Gadri & Guettala, 2017a, 2017b; Tayeh, Abu Bakar, et al., 2013a; Tayeh, Bakar, et al., 2013, 2012).

During the application of LMSC to concrete substrates, some physical and chemical reactions occur between its components; after the curing period and the evaporation of the mixed water in the LMSC, a network structure is obtained, in which the cement hydrate and the latex polymer overlap to form a joint matrix and polymer film (Almesfer & Ingham, 2014; Anderson et al., 2003) Improving the adherence of aggregates and sisal fibers to the cement putty. This will improve their flexural strength, adhesion to various NC substrates, and durability while slowing water permeability and spreading aggressive species (Khattab, 2014; Sikora et al., 2015).In addition to the excellent wettability and workability of LMSC, which in turn increased the substrate's contact surface, contributing to the improvement of the adhesion of LMSC to the NC substrate. Important that the repair material has good workability that allows it to reach most of the contact surface represented by the surface of the concrete substrate.(Benali & Ghomari, 2017; Courard et al., 2014)

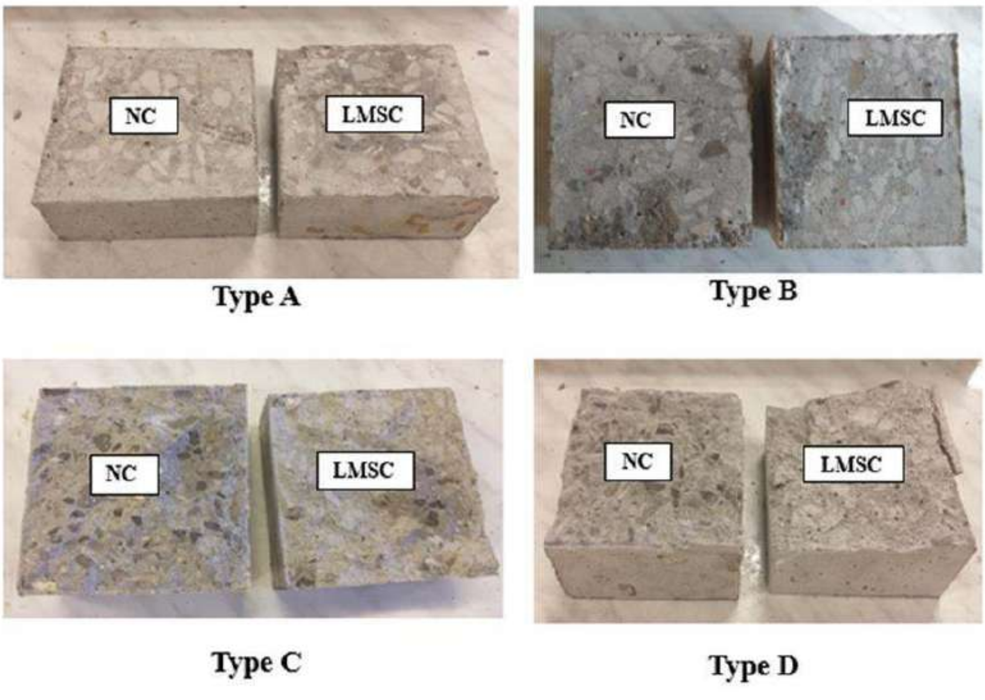
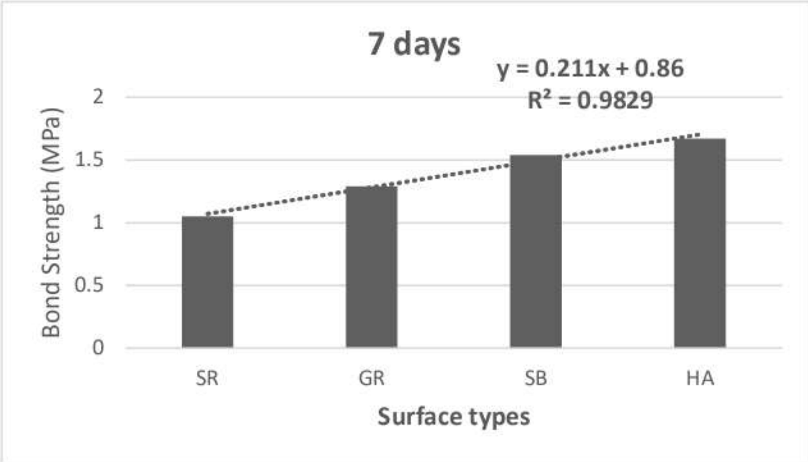


Figure IV. 3. Failure of splitting tensile specimens.

Table IV.2: Splitting tensile strength and failure mode of different composite cube specimens.

			7 days			28 days			90 days	
Surface treatment	**Specimen**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**
SR	SR1	14.5	0.92	A	22.6	1.44	B	23.1	1.47	B
	SR2	16.7	1.06	A	20.11	1.28	A	25.2	1.61	B
	SR3	18.1	1.15	A	21.22	1.35	B	23.8	1.52	B
		Mean(MPa)	1.05		Mean(MPa)	1.36		Mean(MPa)	1.53	
		STD (MPa)	0.12		STD (MPa)	0.08		STD (MPa)	0.07	
		COV (%)	11.04		COV (%)	5.85		COV (%)	4.45	
HA	HA1	24.2	1.54	C	38.76	2.47	D	44.12	2.81	D
	HA2	26.56	1.69	C	36.6	2.33	D	46.43	2.96	D
	HA3	27.77	1.77	C	40	2.55	D	47.7	3.04	D
		Mean(MPa)	1.67		Mean(MPa)	2.45		Mean(MPa)	2.94	
		STD (MPa)	0.12		STD (MPa)	0.11		STD (MPa)	0.12	
		COV (%)	6.94		COV (%)	4.47		COV (%)	3.94	
SB	SB1	22.6	1.44	C	33.5	2.13	D	41.11	2.62	D
	SB2	24.56	1.56	C	34.65	2.21	D	45.6	2.90	D
	SB3	25.44	1.62	C	36	2.29	D	39	2.48	D
		Mean(MPa)	1.54		Mean(MPa)	2.21		Mean(MPa)	2.67	
		STD (MPa)	0.09		STD (MPa)	0.08		STD (MPa)	0.21	
		COV (%)	6.01		COV (%)	3.60		COV (%)	8.04	
GR	GR1	18.7	1.19	B	28.54	1.82	B	31.97	2.04	C
	GR2	20.33	1.29	B	30.43	1.94	C	34.35	2.19	C
	GR3	21.5	1.37	B	29.6	1.89	C	36.1	2.30	D
		Mean(MPa)	1.29		Mean(MPa)	1.88		Mean(MPa)	2.17	
		STD (MPa)	0.09		STD (MPa)	0.06		STD (MPa)	0.13	
		COV (%)	6.97		COV (%)	3.21		COV (%)	6.07	



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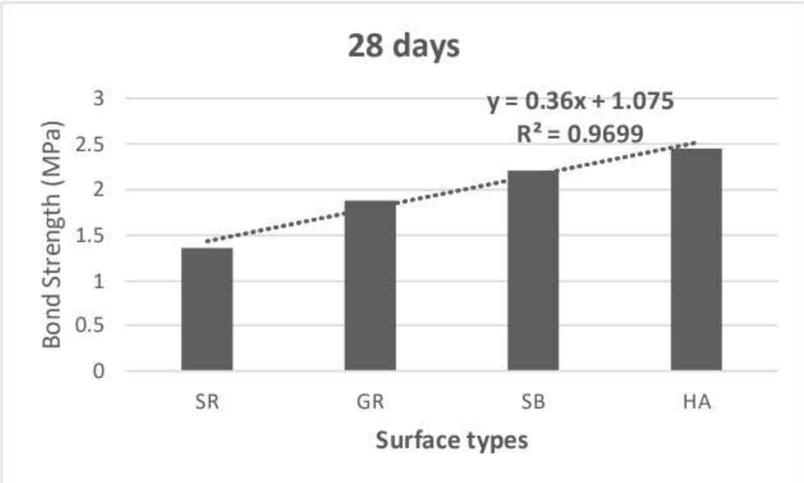

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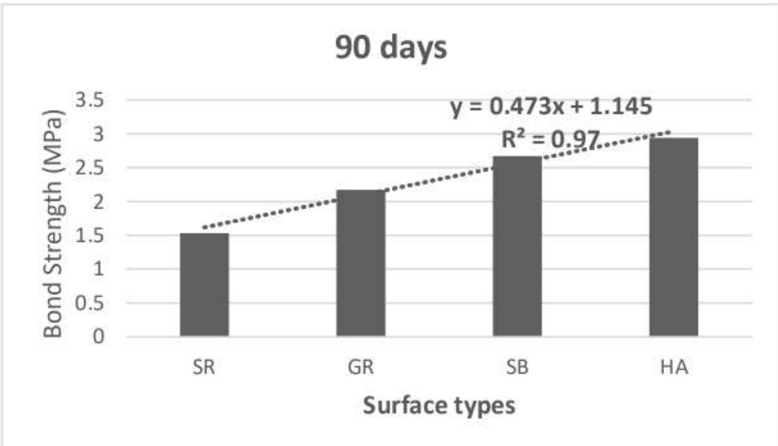


(c)

Figure IV.4. Correlation between surface types and splitting tensile strength at different ages.

IV.4. Pull off bond strength

Table IV.5 shows all the results obtained for assessing the samples' bond strength and failure modes form using the pull-off test. For each age group, three samples were tested in addition to calculating (SD) and (COV). As shown in Figure IV.5, the correlation was obtained between the different surfaces and pull-off bond strength. Failure modes can be summed up in two types, as Figure IV.6 shows, and they are:

- A: interfacial failure combined with minor NC substrate cracking or damage.

- B: substrate failure.

Table IV.5. Shows that the surfaces treated with (HR) gave better results for the pull-off bond strengths compared to all the studied surfaces at all ages. The percentage of improvement obtained by using the composite surfaces (HR) was better than (SR) in 7, 28, and 90 days by 36.31%, 40.49%, and 27%, respectively. However, the failure mode is cohesive for all ages, as shown in Type B in Figure IV.5.

While, (SB) samples were in terms of bond strength slightly less than (HR) samples and better than (GR) samples as they improved the bond strength compared to (SR) in 7, 28 and 90 days by 29.3%, 27.8% and 15.19%, respectively. The percentage of improvement for (GR) compared to (SR) at 7, 28, and 90 days was 7.64%, 23.41% and 10.97%, respectively.

However, in this study, the bond strength obtained in the reference surface condition (SR) is acceptable for The ACI concrete repair guide, as shown in Table IV.3. The bond strength of the reference surface (SR) at 7, 28 and 90 days was equal to 1.57, 2.05 and 2.37 MPa, respectively.

Thus, according to the ACI concrete repair guide, sand concrete for all surfaces studied in this paper can be considered based on the obtained bonding strength as good and satisfies the required purpose.(Chynoweth et al., 1996; Sprinkel & Ozyildirim, 2000) . Moreover, Table IV.4 evaluated the bond strength of all studied surfaces. These results indicate that the bonding between NC and the repair material is strong (Bonaldo et al., 2005; Momayez et al., 2005a)

Also, the test method has a role, according to (Naderi & Ghodousian, 2012) that the calculation of the bond strength between two layers of concrete is greatly affected by choice of the test method.

The pull-off test provides a more accurate measurement of the bond than other tests to obtain the bond strength to avoid friction when conducting the test (Momayez et al., 2005b).

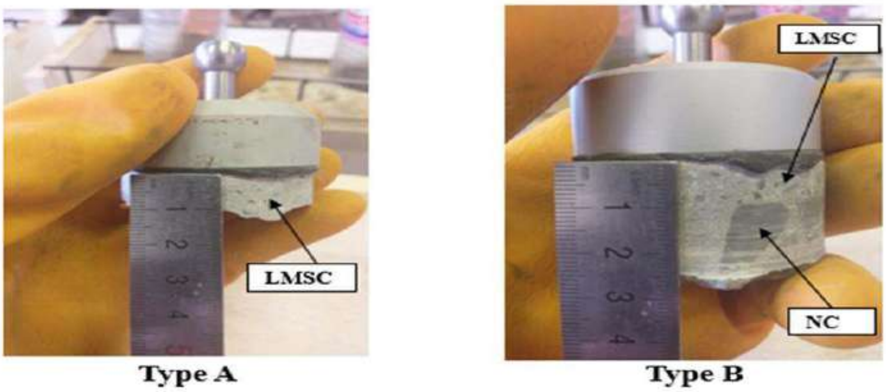
As the carboxylic acid interacts with cement hydrates containing calcium ions in the alkaline environment, it can be argued that the latex polymer particles are attached to a tiny portion of the acid, resulting in a strong link between the latex-modified cement matrix and the concrete substrates (Mansur et al., 2009; Yang et al., 2009b).

Table IV.3: Minimum acceptable bond strength range [ACI concrete repair guide] (Chynoweth et al., 1996).

Description	Days	Bond strength (MPa)
	1	0.5–1.0
Direct tensile bond	7	1.0–1.7
	28	1.7–2.0

Table IV.4: Quantitative bond quality in terms of bond strength (Sprinkel & Ozyildirim, 2000).

Bond quality	Bond strength, T (MPa)
Excellent	≥ 2.1
Very good	1.7–2.1
Good	1.4–1.7
Fair	0.7–1.4
Poor	0–0.7

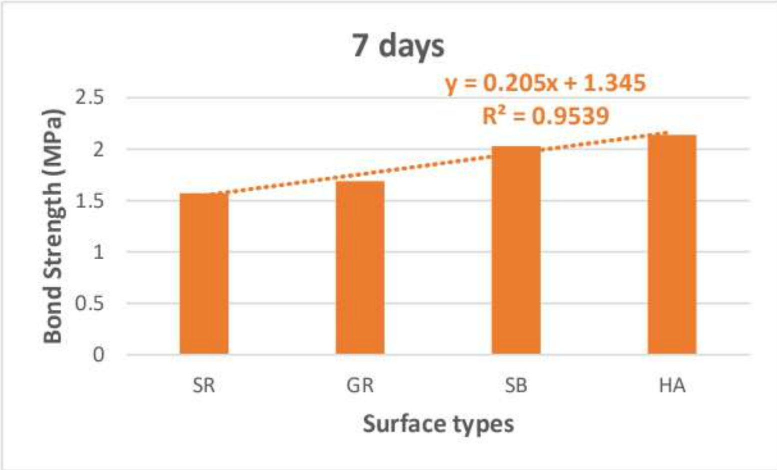


Type A Type B

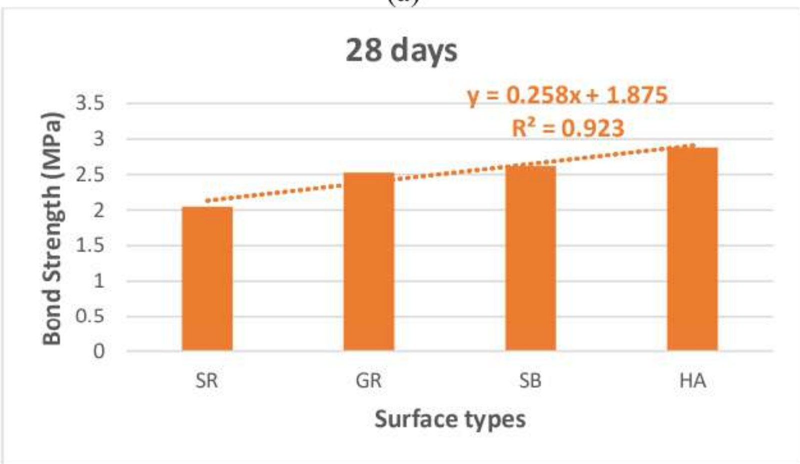
Figure IV.5. Failure of Pull-off test.

Table IV.5: Pull-off bond strength and failure modes of composite.

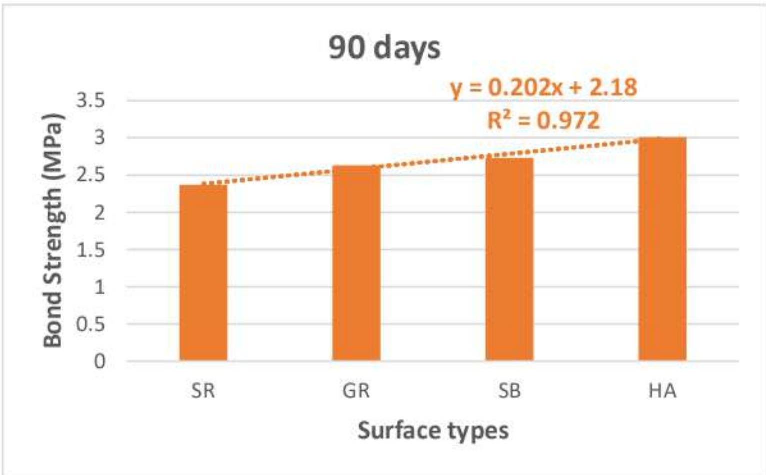
		7 days			**28 days**			**90 days**		
Surface treatment	**Specimen**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**	**Force (KN)**	**Bond strength (MPa)**	**Failure mode**
SR	SR1	2.83	1.44	A	3.91	1.99	B	4.53	2.31	B
	SR2	3.14	1.6	A	4.02	2.05	B	5.14	2.62	B
	SR3	3.28	1.67	A	4.12	2.1	B	4.26	2.17	B
		Mean(MPa)	1.57		Mean(MPa)	2.05		Mean(MPa)	2.37	
		STD (MPa)	0.12		STD (MPa)	0.06		STD (MPa)	0.23	
		COV (%)	7.51		COV (%)	2.69		COV (%)	9.73	
HA	HA1	4.34	2.21	B	6.32	3.22	B	6.142625	3.13	B
	HA2	4.02	2.05	B	5.44	2.77	B	5.514625	2.81	B
	HA3	4.22	2.15	B	5.18	2.64	B	6.064125	3.09	B
		Mean(MPa)	2.14		Mean(MPa)	2.88		Mean(MPa)	3.01	
		STD (MPa)	0.08		STD (MPa)	0.30		STD (MPa)	0.18	
		COV (%)	3.78		COV (%)	10.58		COV (%)	5.79	
SB	SB1	3.83	1.95	B	5.08	2.59	B	5.20	2.65	B
	SB2	3.98	2.03	B	5.12	2.61	B	5.36	2.73	B
	SB3	4.12	2.1	B	5.24	2.67	B	5.515	2.81	B
		Mean(MPa)	2.03		Mean(MPa)	2.62		Mean(MPa)	2.73	
		STD (MPa)	0.08		STD (MPa)	0.04		STD (MPa)	0.08	
		COV (%)	3.70		COV (%)	1.59		COV (%)	2.93	
GR	GR1	3.47	1.77	B	4.82775	2.46	B	5.024	2.56	B
	GR2	3.53	1.8	B	5.004375	2.55	B	5.161375	2.63	B
	GR3	2.92	1.49	A	5.06325	2.58	B	5.279125	2.69	B
		Mean(MPa)	1.69		Mean(MPa)	2.53		Mean(MPa)	2.63	
		STD (MPa)	0.17		STD (MPa)	0.06		STD (MPa)	0.07	
		COV (%)	10.14		COV (%)	2.47		COV (%)	2.48	



(a)



(b)



(c)

Figure IV.6. Correlation between surface types and pull-off strength at different ages.

IV.4 Microstructure of the interface between NC and LMSC

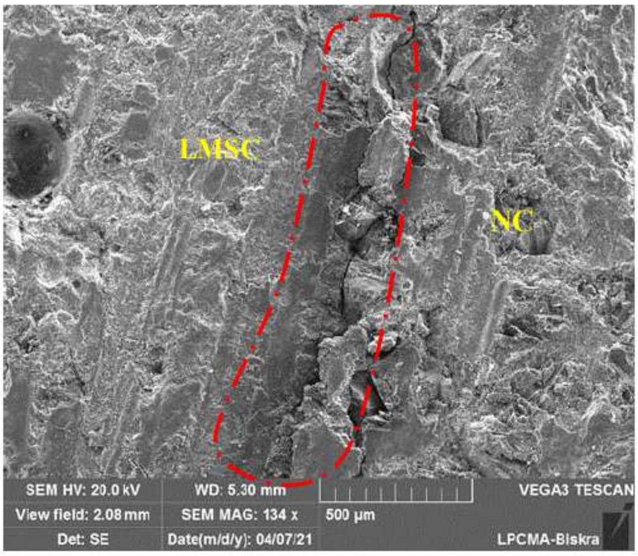
Figure IV.7 shows the microstructure of the interface between the NC and the LMSC overlays for all studied surfaces, namely SR, HA, SB and GR.

Observed that the interface transition area between NC and LMSC for HA and sandblasting surfaces is dense, strong and clearly uniform as shown in Figures C and D. This is in line with the results obtained from mechanical experiments, where it was proved that the best bonding strength was for the surfaces treated with hand hammer and sandblasting. The analysed specimens were taken from the composite specimens before any test. This is consistent with the study conducted by (Tayeh et al., 2014) of the sandblasting surface, where the bonding was strong and dense when studying the microstructure for the transition region of the composite.

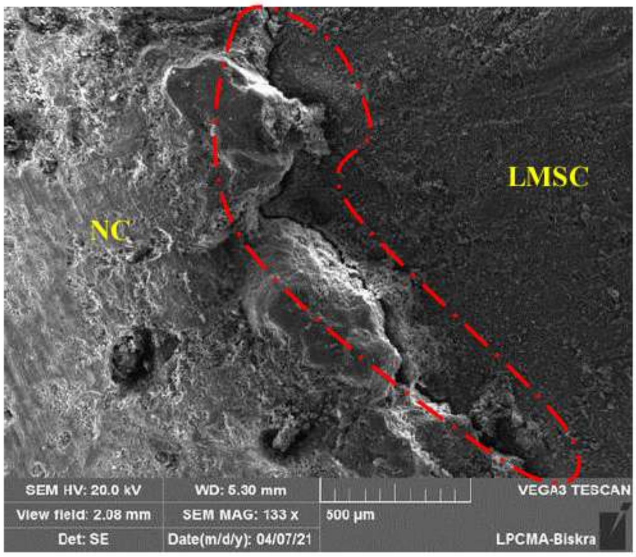
While the interfacial transition zone for the GR surface and the reference surface was found, there is a clear gap between the NC substrate and LMSC of the compound, as shown in Figures A and B. Which affects the adhesion of the composite and thus reduces the bonding strength, and this has also been proven in previous experiments.

And the more rough the surface, the larger the area for the interaction of polymer molecules and cement hydrates in the transition region, thus the extreme adhesion and higher bonding strength. It can be said that the latex polymer and cement hydrate can seep into the porous network of concrete substrates and thus adhere firmly to the substrate surfaces (Benali & Ghomari, 2017; Mansur et al., 2009). This improvement in adhesion is attributed to a chemical reaction between the surfaces of the polymer molecules, calcium hydroxide ($Ca(OH)_2$), which helps to form a strongly interconnected network between the cement matrix components and also includes the adhesion in the concrete substrate surface to improve the bonding strength. Also, the transition region becomes denser over time due to this chemical reaction. The cement substrate should have a rough surface to increase the contact surface and obtain good adhesion (Courard et al., 2014; Andrzej Garbacz et al., 2006; Mirza et al., 2014).

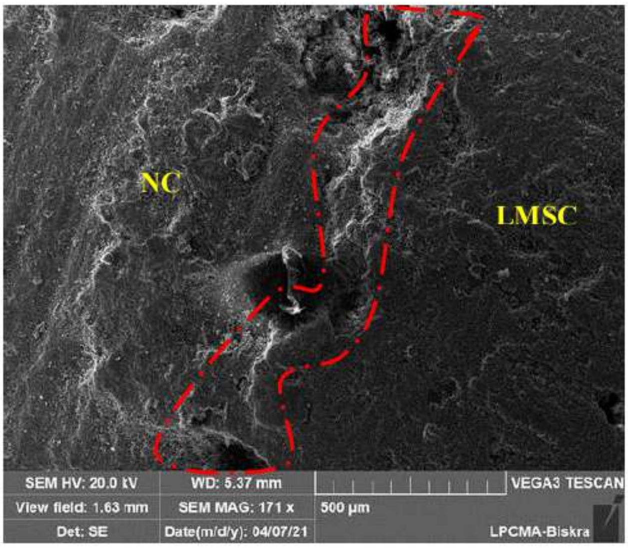
Therefore, it can be concluded from studying the microstructure of the transition zone that the adhesion between NC and LMSC depends greatly on the surface roughness. The higher the roughness level, the stronger the bond strength.



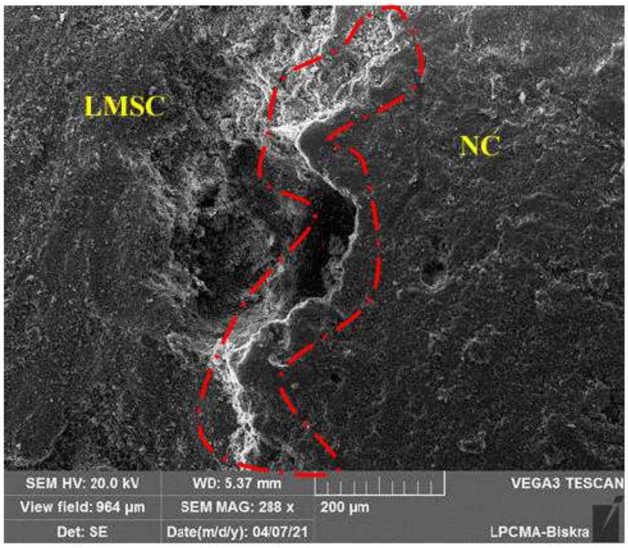
(a)



(b)



(c)



(d)

Figure IV.7. SEM of the interface zone between NC and LMSC: (a) SR; (b) GR; (c) SB; (d) HA.

IV.5 Conclusions

Based on the results obtained in this chapter from the study of mechanical properties to assess the bond strength, the results showed that Latex-Modified Sand Concrete reinforced with sisal fibers (LMSC) appears to be a promising material for repairing and rehabilitating concrete constructions.

The bond strength of the Hand-hammered (HA) and Sandblasting (SB) surfaces bi-surface shear test was substantial, as the interface failure occurred after the Normal Concrete (NC) substrate was damaged. The NC first showed crushing and crushing before interface failure. The surfaces of HA and SB showed the best bond strength in this test, reaching 7.66 and 7.31 MPa after 90 days, respectively.

The splitting tensile strength results of composite cube specimens show that the less rough surfaces have lower bond strength. Higher values recorded with composites on high-roughness surfaces were observed, where the highest average strength was found to equal 2.94 MPa for the HA surface. The results of the pull-off test showed that failure occurred in the substrates for most samples at all test ages and achieved an excellent bonding according to the ACI Concrete Repair Guide. The results showed that the HA treatment enhanced the bond strengths of the specimens slightly higher than the SB and GR treatments at 7, 28, and 90 days.

The study of the microstructure using Scanning Electron Microscopy SEM showed the Interfacial Transition Zone (ITZ) between the NC and LMSC that rough surfaces have strong adhesion and bonding compared to less rough surfaces.

The results obtained from all mechanical experiments showed that the coarser surfaces had higher bond strength, and therefore the results were compatible with all tests in terms of better surfaces: HA, SB, GR and SR. Moreover, the test results showed that the bond strength increased with time.

GENERAL CONCLUSION

GENERAL CONCLUSION

The principal purpose of this study is to improve the properties of sand concrete to obtain an optimal composition with better mechanical resistance and less shrinkage and use it as a repair material; The durability of the repair is conditional on the durability of the repair material. The main objective specified in this thesis relates, on the one hand, to the formulation and study of sand concrete as a cementations repair material and, on the other hand, to the assessment of its adaptability in interaction with ordinary concrete. The support and the level of adhesion between these two materials upon contact all along the interfacial transition zone (IZT).

For the theoretical part, we relied on previous studies, which enabled us to form a state of knowledge about sand concrete in terms of its history and components, in addition to studying its physical and mechanical properties for some previous studies (characteristics and behaviour). Also, some studies dealt with the problems of reforms and the phenomena that sustain them were reviewed, Furthermore some standards for repair materials and the mechanisms for applying the reforming material had been given more descriptive attention.

As for the experimental part, it presented the properties of all the materials used and the different test methods to obtain the properties of the studied concrete. The mechanical and physical properties of the different compositions of sandy concrete to obtain the appropriate composition for the repair was studied. The experimental part also dealt with the presentation of experimental techniques, including the curriculum followed in preparing the surfaces of the substrates and the treatment mechanism of the combined compounds together, the bond strength between the concrete substrate and the repair material was studied by conducting various tests.

Conclusions obtained in this study will be summarized as follows:

- Adding sisal fibres and latex emulsion at different proportions had a role in reducing the density of the Sand Concrete (SC).
- A slight decrease in workability, compressive strength, Ultrasonic Pulse Velocity (UPV) and dynamic modulus of SC with the addition of sisal fibres and latex was observed at different proportions before merging. However, all the results obtained are acceptable and fulfil the required levels of standard recommendations.

- Adding sisal fibres and latex emulsion improves the flexural strength of SC, especially when the sisal fibres are combined with the latex in the same cement matrix. A significant improvement in the flexural strength of the LMSC compared with the reference SC after 28 days reached 114.31%. This improvement is considered an essential added value to the properties.
- Combining sisal fibres and latex LMSC (0.1% F + 35% L) in the same sample led to an essential improvement in reducing the porosity and water absorption ratio of the LMSC compared with the same sample without latex (0.1% F). Where, the percentage of reduced water-accessible porosity was 44.26%, and the ratio of water absorption decrease was 58.45%.
- Adding sisal fibre and latex contributed to the reduction of the shrinkage rate because a good reduction was observed in shrinkage (by approximately 21.53%) of LMSC compared with the reference SC.
- Adding latex to the SC that contained sisal fibres is a necessary treatment to enhance the fibres role within the cement matrix.
- Studying the microstructure using Scanning Electron Microscopy (SEM) showed that the combination of sisal fibre and latex in the same cement matrix contributed to the increased adhesion of the fibres in the cement matrix, thereby reducing the pores and obtaining a more coherent and homogeneous compound between its components. This confirm and agreed well with the good results obtained in the present study.
- Combining sisal fibres and latex in the same cement matrix improved all the studied properties. This result added to the improvement of SC, thereby opening new research horizons for using the latex emulsion, especially for plant fibres that need treatment to improve their function in various cement compounds.
- The bond strength of the treatment with hand hammer (HA) and grooved treatment (GR) surfaces gave better performances, as observed from the bi-surface shear test. The interface failure occurred after the normal concrete (NC) substrate was damaged. The NC substrate first showed crushing before interface failure. The best bond strength obtained in this test was 7.66 and 7.31 MPa after 90 days for HA and SB surfaces, respectively.
- The splitting tensile strength results of composite cube specimens showed that the less rough surfaces had given lower bond strength. Higher values were recorded with

composites having more rough surfaces, where the highest average strength was equal to 2.94 MPa for the HA surface.

- The results of the pull-off test showed that failure occurred in the substrates for most samples at all testing ages and achieved perfect bonding according to the ACI concrete repair guide. The results showed that the HA surface treatment enhanced the bond strengths of the specimens slightly higher than the SB and GR surface treatment at 7, 28, and 90 days.
- The SEM microstructural study showed that the transition zone between the NC and LMSC with higher rough surfaces has strong adhesion and bonding compared to less rough surfaces.
- The results obtained from all mechanical experiments showed that the coarser surfaces had higher bond strength in such order. HA, SB, GR, and SR, respectively. Moreover, the results of the tests showed that the bond strength increased with time.
- Finally, based on the results of this study, latex-modified sand concrete reinforced with sisal fibers (LMSC) is repair material for concrete structures of class R3 Structural according to standard NF EN 1504-3.

PERSPECTIVES

On the highlights of the present thesis, multiple perspectives could be drawn for future work:

- Study sand concrete's mechanical behaviour (stress-strain, load-deflection, elastic modulus).
- Study of the durability in the aggressive environment of sand concrete.
- Study of the thermo-physical performance of sand concrete.
- Study the effect of different surface treatments on the bond strength of LMSC.

REFERENCES

Aaleti, S., & Sritharan, S. (2019). Quantifying bonding characteristics between UHPC and normal-strength concrete for bridge deck application. *Journal of Bridge Engineering*, *24*(6), 4019041.

Abo Sabah, S. H., Hassan, M. H., Muhamad Bunnori, N., & Megat Johari, M. A. (2019). Bond strength of the interface between normal concrete substrate and GUSMRC repair material overlay. *Construction and Building Materials*, *216*, 261–271.

Afridi, M. U. K., Ohama, Y., Demura, K., & Iqbal, M. Z. (2003). Development of polymer films by the coalescence of polymer particles in powdered and aqueous polymer-modified mortars. *Cement and Concrete Research*, *33*(11), 1715–1721.

Aiqin, W., Chengzhi, Z., & Ningsheng, Z. (1999). The theoretic analysis of the influence of the particle size distribution of cement system on the property of cement. *Cement and Concrete Research*, *29*(11), 1721–1726.

Akrout, K., Mounanga, P., Ltifi, M., & Jamaa, N. Ben. (2010). Rheological, mechanical and structural performances of crushed limestone sand concrete. *International Journal of Concrete Structures and Materials*, *4*(2), 97–104.

Almesfer, N., & Ingham, J. (2014). Effect of waste latex paint on concrete. *Cement and Concrete Composites*, *46*, 19–25.

Ammari, M. S., Bederina, M., Belhadj, B., & Merrah, A. (2020). Effect of steel fibers on the durability properties of sand concrete with barley straws. *Construction and Building Materials*, *264*, 120689.

Ammari, M. S., Belhadj, B., Bederina, M., Ferhat, A., & Quéneudec, M. (2020). Contribution of hybrid fibers on the improvement of sand concrete properties: Barley straws treated with hot water and steel fibers. *Construction and Building Materials*, *233*, 117374.

Anderson, M. D., Fowler, D. W., Sawant, S., Vipulanandan, C., Ball, J. C., Gaul, R. W., Schmidt, D. A., Vogt, R. W., Bartholomew, J. J., & Khan, M. S. (2003). *Polymer-Modified Concrete*.

Angst, U., Elsener, B., Larsen, C. K., & Vennesland, Ø. (2009). Critical chloride content in reinforced concrete—A review. *Cement and Concrete Research*, *39*(12), 1122–1138.

ASTM. (2009). *Standard test method for pull-off strength of coatings using portable adhesion testers*.

ASTM, C. (1996). 496-96. *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*.

ASTM, C. (2012). Standard test method for compressive strength of cylindrical concrete specimens. In *ASTM C39/C39M-12*.

Balaguru, P. N., & Shah, S. P. (1992). *Fiber-reinforced cement composites*.

Barluenga, G., & Hernández-Olivares, F. (2004). SBR latex modified mortar rheology and mechanical behaviour. *Cement and Concrete Research*, *34*(3), 527–535.

Bederina, M., Belhadj, B., Ammari, M. S., Gouilleux, A., Makhloufi, Z., Montrelay, N., & Quéneudéc, M. (2016). Improvement of the properties of a sand concrete containing barley straws–treatment of the barley straws. *Construction and Building Materials*, *115*, 464–477.

Bederina, M., Bouziani, T., Khenfer, M., & Quéneudec, M. (2012). Absorption de l'eau et son effet sur la durabilité des bétons de sable allégés par ajout de copeaux de bois. *MATEC Web of Conferences*, *2*, 0–6.

Bederina, M., Gotteicha, M., Belhadj, B., Dheily, R. M., Khenfer, M. M., & Queneudec, M. (2012a). Drying shrinkage studies of wood sand concrete–Effect of different wood treatments. *Construction and Building Materials, 36*, 1066–1075.

Bederina, M., Gotteicha, M., Belhadj, B., Dheily, R. M., Khenfer, M. M., & Queneudec, M. (2012b). Drying shrinkage studies of wood sand concrete - Effect of different wood treatments. *Construction and Building Materials, 36*, 1066–1075.

Bédérina, M., Khenfer, M. M., Dheilly, R. M., & Quéneudec, M. (2005a). Reuse of local sand: effect of limestone filler proportion on the rheological and mechanical properties of different sand concretes. *Cement and Concrete Research, 35*(6), 1172–1179.

Bédérina, M., Khenfer, M. M., Dheilly, R. M., & Quéneudec, M. (2005b). Reuse of local sand: Effect of limestone filler proportion on the rheological and mechanical properties of different sand concretes. *Cement and Concrete Research*, *35*(6), 1172–1179.

Bederina, M., Makhloufi, Z., Bounoua, A., Bouziani, T., & Quéneudec, M. (2013). Effect of partial and total replacement of siliceous river sand with limestone crushed sand on the durability of mortars exposed to chemical solutions. *Construction and Building Materials*, *47*, 146–158.

Belhadj, B., Bederina, M., Benguettache, K., & Queneudec, M. (2014). Effect of the type of sand on the fracture and mechanical properties of sand concrete. *Advances in Concrete Construction*, *2*(1), 13–27.

Belhadj, B., Bederina, M., Makhloufi, Z., Dheilly, R. M., Montrelay, N., & Quéneudéc, M. (2016a). Contribution to the development of a sand concrete lightened by the addition of barley straws. *Construction and Building Materials*, *113*, 513–522.

Belhadj, B., Bederina, M., Makhloufi, Z., Dheilly, R. M., Montrelay, N., & Quéneudéc, M. (2016b). Contribution to the development of a sand concrete lightened by the addition of barley straws. *Construction and Building Materials, 113*, 513–522.

Benaissa, A., Kamen, A., Chouicha, K., & Malab, S. (2008). Panneau 3D au béton de sable. *Materials and Structures/Materiaux et Constructions*, *41*(8), 1377–1391.

Benaissa, A., Morlier, P., & Tram, V. (1992). Le béton de sable un matériau non fissurant. *Revue Algérie Equipement*, *66*, 7–11.

Benaissa, A., Morlier, P., & Viguier, C. (1993). Fluage et retrait du béton de sable. *Materials and Structures*, *26*(6), 333–339.

Benaissa, I., Nasser, B., Aggoun, S., & Malab, S. (2015). Properties of Fibred Sand Concrete Sprayed by Wet-Mix Process. *Arabian Journal for Science and Engineering*, *40*(8), 2289–2299.

Benali, Y., & Ghomari, F. (2017). Latex influence on the mechanical behavior and durability of cementitious materials. *Journal of Adhesion Science and Technology*, *31*(3), 219–241.

Benzerzour, M., Gagné, R., Abriak, N.-E., & Sebaibi, N. (2014). Experimental and numerical study of the structural and cracking behavior of an overlaid slab panel under cyclic flexural loading. *Construction and Building Materials*, *52*, 24–32.

Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose based fibres. *Progress in Polymer Science*, *24*(2), 221–274.

Bonaldo, E., Barros, J. A. O., & Lourenço, P. B. (2005). Bond characterization between concrete substrate and repairing SFRC using pull-off testing. *International Journal of Adhesion and Adhesives*, *25*(6), 463–474.

Bouziani, T., Benmounah, A., Makhloufi, Z., Bédérina, M., & Queneudec Tkint, M. (2014). Properties of flowable sand concretes reinforced by polypropylene fibers. *Journal of Adhesion Science and Technology*, *28*(18), 1823–1834.

Brandt, A. M. (2008). Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering. *Composite Structures*, *86*(1–3), 3–9.

Bui, V. K., & Montgomery, D. (1999). Drying shrinkage of self-compacting concrete containing milled limestone. *1st International RILEM Symposium on Self-Compacting Concrete*, 13–14.

Bureau, L., Alliche, A., Pilvin, P., & Pascal, S. (2001). Mechanical characterization of a styrene–butadiene modified mortar. *Materials Science and Engineering: A*, *308*(1–2), 233–240.

Čairović, Đ., Zlámal, M., Štěpánek, P., Trčka, T., Škarvada, P., & Macků, R. (2017). Determination of Surface Roughness Parameters by Optical Profilometry and Sand Patch Test. *Solid State Phenomena*, *259*, 15–20.

Campos, A., Marconcini, J. M., Imam, S. H., Klamczynski, A., Ortis, W. J., Wood, D. H., Williams, T. G., Martins-Franchetti, S. M., & Mattoso, L. H. C. (2012). Morphological, mechanical properties and biodegradability of biocomposite thermoplastic starch and polycaprolactone reinforced with sisal fibers. *Journal of Reinforced Plastics and Composites*, *31*(8), 573–581.

Chabane, D. (2012). Memoire de Magister. *Thèse*, 1–138.

Chabot, A., Hun, M., & Hammoum, F. (2013). Mechanical analysis of a mixed mode debonding test for “composite” pavements. *Construction and Building Materials*, *40*, 1076–1087.

Chahour, K., Aboutaleb, D., Safi, B., Mazari, T., & Zeghad, M. (2017). Granulated foam glass based on mineral wastes used for building materials. *Building Acoustics*, *24*(4), 281–294.

Chakraborty, S., Kundu, S. P., Roy, A., Basak, R. K., Adhikari, B., & Majumder, S. B. (2013). Improvement of the mechanical properties of jute fibre reinforced cement mortar: A statistical approach. *Construction and Building Materials*, *38*, 776–784.

Chanvillard, G., & Basuyaux, O. (1996). Une méthode de formulation des bétons de sable à maniabilité et résistance fixées. *Bulletin Des Laboratoires Des Ponts et Chaussees*, *0*(205), 49–63.

Chauvin, & Grimaldi. (1988). Les bétons de sable. *Bulletin de Liaison Des Laboratoires Des Ponts et Chaussées*, *157*, 9–15.

Chauvin, J. J. (1991). le béton de sable en union soviétique. *Bulletin de Liaison Des Laboratoires Des Ponts et Chaussées (LCPC)*, *174*, 61–69.

Cheboub, T., Senhadji, Y., Khelafi, H., & Escadeillas, G. (2020). Investigation of the engineering properties of environmentally-friendly self-compacting lightweight mortar containing olive kernel shells as aggregate. *Journal of Cleaner Production*, *249*.

Chynoweth, G., Stankie, R. R., Allen, W. L., Anderson, R. R., Babcock, W. N., Barlow, P., Bartholomew, J. J., Bergemann, G. O., Bullock, R. E., & Constantino, F. J. (1996). G. Chynoweth, R.R. Stankie, W.L. Allen, R.R. Anderson, W.N. Babcock, P. Barlow, J.J. Bartholomew, G.O. Bergemann, R.E. Bullock, F.J. Constantino, Concrete Repair Guide, ACI Committee, Concrete Repair Manual, 1996, pp. 287–327. *ACI Committee, Concrete Repair Manual*, *546*, 287–327.

Cisse, I. (1996). *Contribution à la valorisation des matériaux locaux au Sénégal: application aux bétons de sable*.

Courard, L. (2002). Evaluation of thermodynamic properties of concrete substrates and cement slurries modified with admixtures. *Materials and Structures*, *35*(3), 149–155.

Courard, L., Piotrowski, T., & Garbacz, A. (2014a). Near-to-surface properties affecting bond strength in concrete repair. *Cement and Concrete Composites*, *46*, 73–80.

Courard, L., Piotrowski, T., & Garbacz, A. (2014b). Near-to-surface properties affecting bond strength in concrete repair. *Cement and Concrete Composites*, *46*, 73–80. Decter, M. H. (1997). Durable concrete repair—Importance of compatibility and low shrinkage. *Construction and Building Materials*, *11*(5–6), 267–273.

Diab, A. M., Elyamany, H. E., & Ali, A. H. (2013). Experimental investigation of the effect of latex solid/water ratio on latex modified co-matrix mechanical properties. *Alexandria Engineering Journal*, *52*(1), 83–98.

Diederich, P. (2010). *béton du sable*. Toulouse 3.

Djebien, R., Belachia, M., & Hebhoub, H. (2015). Mechanical performance of sand-lightweight concrete-filled steel tube stub column under axial compression. *Structural Engineering and Mechanics: An International Journal*, *53*(6), 1241–1251.

Djouhri, M. (2007). *Confection d'une brique à base de sable de dunes*. Ouargla, Université Kasdi Merbah. Faculté des Sciences et Sciences de l ….

Dolage, D. A. R., Dias, M. G. S., & Ariyawansa, C. T. (2013). Offshore sand as a fine aggregate for concrete production. *British Journal of Applied Science & Technology*, *3*(4), 813–825.

Dong, J. F., Wang, Q. Y., & Guan, Z. W. (2017). Material properties of basalt fibre reinforced concrete made with recycled earthquake waste. *Construction and Building Materials*, *130*, 241–251.

Dreux, G., & Festa, J. (1995). *Nouveau guide du béton: composants et propriétés, composition et dosage, fabrication, transport et mise en oeuvre, contrôle et normalisation*. Eyrolles.

Emmons, P. H. (1993). Concrete repair and maintenance illustrated, RS Means Company. *Inc., Kingston, MA*, 128–129.

Emmons, P. H., & Vaysburd, A. M. (1994). Factors affecting the durability of concrete repair: the contractor's viewpoint. *Construction and Building Materials*, *8*(1), 5–16.

EN 1504-3. (2006). *Produits et systèmes pour la protection et la réparation de structures en béton*. *3*(février 2006).

EN1504. (2014). *Norme Européenne EN 1504 Guide illustré et simplifié concernant tous les aspects de la réparation des structures en béton*.

Farzad, M., Shafieifar, M., & Azizinamini, A. (2019). Experimental and numerical study on bond strength between conventional concrete and Ultra High-Performance Concrete (UHPC). *Engineering Structures*, *186*(December 2018), 297–305.

Fowler, D. W. (1999). Polymers in concrete: a vision for the 21st century. *Cement and Concrete Composites*, *21*(5–6), 449–452.

Gadri. (2018). *Etude Expérimentale Sur La Compatibilité Déformationnelle Des Réparations En Béton De Sable*.

Gadri, K., & Guettala, A. (2017a). Evaluation of bond strength between sand concrete as new repair material and ordinary concrete substrate (The surface roughness effect). *Construction and Building Materials*, *157*(May), 1133–1144.

Gadri, K., & Guettala, A. (2017b). *Study of the adaptation of the sand concrete as repair material associated with an ordinary*. *3*, 13–20.

Gao, S., Jin, J., Hu, G., & Qi, L. (2019). Experimental investigation of the interface bond properties between SHCC and concrete under sulfate attack. *Construction and Building Materials*, *217*, 651–663.

Garbacz, A., Courard, L., & Kostana, K. (2006). Characterization of concrete surface roughness and its relation to adhesion in repair systems. *Materials Characterization*, *56*(4-5 SPEC. ISS.), 281–289.

Garbacz, A., Górka, M., & Courard, L. (2005a). Effect of concrete surface treatment on adhesion in repair systems. *Magazine of Concrete Research*, *57*(1), 49–60.

Garbacz, A., Górka, M., & Courard, L. (2005b). Effect of concrete surface treatment on adhesion in repair systems. *Magazine of Concrete Research*, *57*(1), 49–60.

Garbacz, A., Piotrowski, T., Courard, L., & Bissonnette, B. (2017). *... should be evaluated*.

Gencel, O., Brostow, W., Datashvili, T., & Thedford, M. (2011). Gencel O, Brostow W, Datashvili T, Thedford M. Workability and mechanical performance of steel fiber-reinforced self-compacting Concrete with Fly Ash. Compos Interf 2011;18:169–84. *Composite Interfaces*, *18*(2), 169–184.

George, D., & Jean, F. (1998). Nouveau guide du béton et de ses constituants [New guide of concrete and its constituents]. *Paris: Edition Eyrolles*.

Gram, H. E. (1983). Durability of natural fibres in concrete. Swedish Cement and Concrete Research Institute. *CBI Research Fo*, *1*(83), 255.

Grinys, A., Augonis, A., Daukšys, M., & Pupeikis, D. (2020). Mechanical properties and durability of rubberized and SBR latex modified rubberized concrete. *Construction and Building Materials*, *248*, 118584.

Haber, Z. B., Munoz, J. F., De la Varga, I., & Graybeal, B. A. (2018). Bond characterization of UHPC overlays for concrete bridge decks: Laboratory and field testing. *Construction and Building Materials*, *190*, 1056–1068.

Hadjoudja, M., Khenfer, M. M., Mesbah, H. A., & Yahia, A. (2014). Statistical Models to Optimize Fiber-Reinforced Dune Sand Concrete. *Arabian Journal for Science and Engineering*, *39*(4), 2721–2731.

Harris, D. K., Sarkar, J., & Ahlborn, T. (Tess) M. (2011). Characterization of interface bond of ultra-high-performance concrete bridge deck overlays. *Transportation Research Record*, *2240*(1), 40–49.

Hassan, K. E., Robery, P. C., & Al-Alawi, L. (2000). Effect of hot-dry curing environment on the intrinsic properties of repair materials. *Cement and Concrete Composites*, *22*(6), 453–458.

He, Y., Zhang, X., Hooton, R. D., & Zhang, X. (2017). Effects of interface roughness and interface adhesion on new-to-old concrete bonding. *Construction and Building Materials*, *151*, 582–590.

Hoła, J., Sadowski, Ł., Reiner, J., & Stach, S. (2015). Usefulness of 3D surface roughness parameters for nondestructive evaluation of pull-off adhesion of concrete layers. *Construction and Building Materials*, *84*, 111–120.

Hu, B., Meng, T. F., Li, Y., Li, D. Z., & Chen, L. (2021). Dynamic splitting tensile bond behavior of new-to-old concrete interfaces. *Construction and Building*

Materials, *281*, 12–23.

JARADAT, O. (2018). *ETUDE D'UN BATIMENT A USAGE D'HABITATION (R+ 8) CONTREVENTEMENT MIXTE*.

Jaradat, O., Gadri, K., & Guettala, A. (2021a). Study of the Dynamic Modulus of Elasticity of Sand Concrete Containing Crushed Sand. *International Conference on New Trends in Science and Applications (NTSA), type II*, 22–24.

Jaradat, O., Gadri, K., & Guettala, A. (2021b). The effect of crushed sand on the compactness of sand concrete. *The Second International Conference on Civil Engineering ICCE'2021*, 1–7.

Jaradat, O., Gadri, K., & Guettala, A. (2022a). *Evaluation of the effect of crushed sand on the engineering properties of concrete sand*.

Jaradat, O., Gadri, K., & Guettala, A. (2022b). Influence of crushed sand on the dynamic modulus of elasticity of sand concrete. *Journal of Physical Chemistry and Functional Materials, July*, 64–68. https://doi.org/10.54565/jphcfum.1070879

Jaradat, O., Gadri, K., & Guettala, A. (2022c). The effect of partial replacement of crushed sand on the properties of sand concrete. *The First International Recycled Cement Based Composites Congress REC, March 2022*, 1–5.

Jaradat, O., Gadri, K., Sirhan, A., & Guettala, A. (2022a). Characteristics of sand concrete using quarry sand. *1st International Conference on Innovative Academic Studies ICIAS*, *mm*, 419–423.

Jaradat, O., Gadri, K., Sirhan, A., & Guettala, A. (2022b). *Mechanical behavior of sand concrete*. 2022.

Jaradat, O., Gadri, K., Sirhan, A., & Guettala, A. (2022c). Properties of sand concrete with and without crushed sand. *2nd International Conference on Engineering and Applied Natural Sciences (ICEANS)*, *mm*, 450–453.

Jaradat, O., Gadri, K., Tayeh, B. A., & Guettalaa, A. (2021). Influence of sisal fibres and rubber latex on the engineering properties of sand concrete. *Structural Engineering and Mechanics*, *80*(1), 47–62.

Jaradat, O., Gadrı, K., & Guettala, A. (2021). Study the mechanical and physical properties of sand concrete using crushed limestone sand. *Journal of Materials and Electronic Devices*, *3*(1), 26–29.

Jo, B. W., Chakraborty, S., & Yoon, K. W. (2014). A hypothetical model based on effectiveness of combined alkali and polymer latex modified jute fibre in controlling the setting and hydration behaviour of cement. *Construction and Building Materials*, *68*, 1–9.

Jo, Y. K. (2020). Adhesion in tension of polymer cement mortar by curing conditions using polymer dispersions as cement modifier. *Construction and Building Materials*, *242*, 118134.

Jose, J., & Hossiney, N. (2016). Characteristics of Concrete Containing Waste Foundry Sand and Slag Sand. *International Journal of Earth Sciences and Engineering*, *09*(03), 54–59.

Joseph, K., Tolêdo Filho, R. D., James, B., Thomas, S., & Carvalho, L. H. de. (1999). a Review on Sisal Fiber Reinforced Polymer Composites. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *3*(3), 367–379.

Júlio, E., Branco, F. A. B., & Silva, V. D. (2005). Concrete-to-concrete bond strength: influence of an epoxy-based bonding agent on a roughened substrate surface. *Magazine of Concrete Research*, *57*(8), 463–468.

Júlio, E. N. B. S., Branco, F. A. B., & Silva, V. D. (2004). Concrete-to-concrete bond strength. Influence of the roughness of the substrate surface. *Construction and Building Materials*, *18*(9), 675–681.

Kabbani, M. J. (1967). *Various types of sand in Lebanon and their effect on the strength of concrete and mortar*. American University of Beirut (Lebanon).

Khattab, M. M. (2014). Effect of gamma irradiation on polymer modified white sand cement mortar composites. *Journal of Industrial and Engineering Chemistry*, *20*(1), 1–8.

Khay, S. E. E., Neji, J., & Loulizi, A. (2010). Shrinkage properties of compacted sand concrete used in pavements. *Construction and Building Materials*, *24*(9), 1790–1795.

Kriker, A., Debicki, G., Bali, A., Khenfer, M. M., & Chabannet, M. (2005). Mechanical properties of date palm fibres and concrete reinforced with date palm fibres in hot-dry climate. *Cement and Concrete Composites*, *27*(5), 554–564.

Kundu, S. P., Chakraborty, S., & Chakraborty, S. (2018). Effectiveness of the surface modified jute fibre as fibre reinforcement in controlling the physical and mechanical properties of concrete paver blocks. *Construction and Building Materials*, *191*, 554–563.

Kwan, W. H., Ramli, M., & Cheah, C. B. (2015). Accelerated curing regimes for polymer-modified cement. *Magazine of Concrete Research*, *67*(23), 1233–1241. Lewis, W. J., & Lewis, G. (1990). The influence of polymer latex modifiers on the properties of concrete. *Composites*, *21*(6), 487–494.

Li, X., Tabil, L. G., & Panigrahi, S. (2007). Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a review. *Journal of Polymers and the Environment*, *15*(1), 25–33.

Li, Y., Mai, Y., & Ye, L. (2000). Sisal fibre and its composites : a review of recent developments IM PA US AS DO ME US EX ON AS. *Composites Science and Technology*, *60*(2000), 2037–2055.

Li, Z., Wang, X., & Wang, L. (2006). Properties of hemp fibre reinforced concrete composites. *Composites Part A: Applied Science and Manufacturing*, *37*(3), 497–505.

Liu, J., Chen, Z., Guan, D., Lin, Z., & Guo, Z. (2020). Experimental study on interfacial shear behaviour between ultra-high performance concrete and normal strength concrete in precast composite members. *Construction and Building Materials*, *261*, 120008.

Liu, Y., Wang, Z., Fan, Z., & Gu, J. (2020). Study on properties of sisal fiber modified foamed concrete. *IOP Conference Series: Materials Science and Engineering*, *744*(1), 0–5.

López-Carreño, R. D., Pujadas, P., Cavalaro, S. H. P., & Aguado, A. (2017). Bond strength of whitetoppings and bonded overlays constructed with self-compacting high-performance concrete. *Construction and Building Materials*, *153*, 835–845.

MAHUT, B. (2002). Protection des betons par application de produits a la surface du parement. *GUIDE TECHNIQUE*.

Mailvaganam, N. P., & Mitchell, L. (2003). *Réparations pour la remise en service des ouvrages en béton*. Institut de recherche en construction, Conseil national de recherches du Canada.

Mansur, A. A. P., do Nascimento, O. L., & Mansur, H. S. (2009). Physico-chemical characterization of EVA-modified mortar and porcelain tiles interfaces. *Cement and Concrete Research*, *39*(12), 1199–1208.

Merzoud, M., Dheilly, R. M., Goullieux, A., Queneudec, M., & Habita, M. F. (2008). Optimisation of Lignocellulosic Composite formulated with a local resource: The Diss (Ampelodesma mauritanica). *Proceeding of the 7th International Congress*, 8–10.

Mirza, J., Durand, B., Bhutta, A. R., & Tahir, M. M. (2014). Preferred test methods to select suitable surface repair materials in severe climates. *Construction and Building Materials*, *50*, 692–698.

Molez, L. (2003). *Comportement des réparations structurales en béton: couplage des effets hydriques et mécaniques*. École normale supérieure de Cachan-ENS Cachan; Université Laval.

Molez, L., & Molez, L. (2005). *Comportement des r ´ eparations structurales en b ´ eton : couplage des effets hydriques et m ´ ecaniques To cite this version : couplage des effets hydriques et m ´ ecaniques*.

Momayez, A., Ehsani, M. R., Ramezanianpour, A. A., & Rajaie, H. (2005a). Comparison of methods for evaluating bond strength between concrete substrate and repair materials. *Cement and Concrete Research*, *35*(4), 748–757.

Momayez, A., Ehsani, M. R., Ramezanianpour, A. A., & Rajaie, H. (2005b). Comparison of methods for evaluating bond strength between concrete substrate and repair materials. *Cement and Concrete Research*, *35*(4), 748–757.

Naaman, A. E. (1985). Fiber reinforcement for concrete. *Concrete International*, *7*(3), 21–25.

Naderi, M., & Ghodousian, O. (2012). Adhesion of self-compacting overlays applied to different concrete substrates and its prediction by fuzzy logic. *The Journal of Adhesion*, *88*(10), 848–865.

Navya, G., & Rao, J. V. (2014). Experimental Investigation on Properties Concrete

Paver Block with the Inclusion of Natural Fibers. *Journal of Engineering Research and Applications Www.Ijera.Com*, *4*(8), 34–38. www.ijera.com

Neville, A. M., & Brooks, J. J. (1987). *Concrete technology*. Longman Scientific & Technical England.

Nilsson, L. (1975). Reinforcement of concrete with sisal and other vegetable fibres. *NASA STI/Recon Technical Report N*, *76*, 30405.

Norme Européenne, N. F. (1996). EN ISO 5079. *Fibres Textiles–Détermination de La Force de Rupture et de l'allongement de Rupture Des Fibres Individuelles. AFNOR, France*, 20.

Noyori, R. (1997). Pp. 71. *Cement and Concrete Research*, *27*(5), 711–720.

Ohama, Y. (1987). Principle of latex modification and some typical properties of latex-modified mortars and concretes adhesion; binders (materials); bond (paste to aggregate); carbonation; chlorides; curing; diffusion. *Materials Journal*, *84*(6), 511–518.

Ohama, Y. (1995). *Handbook of polymer-modified concrete and mortars: properties and process technology*. William Andrew.

Ohama, Y. (1997). Recent progress in concrete-polymer composites. *Advanced Cement Based Materials*, *5*(2), 31–40.

Ohama, Y. (1998a). Polymer-based admixtures. *Cement and Concrete Composites*, *20*(2–3), 189–212.

Ohama, Y. (1998b). Polymer-based admixtures. *Cement and Concrete Composites*, *20*(2–3), 189–212.

Olivier & LAURENCE. (2001). *La fissuration due au retrait restreint dans les réparations minces en béton: apports combinés de l'expérimentation et de la modélisation*.

Pascal, S., Alliche, A., & Pilvin, P. (2004). Mechanical behaviour of polymer modified mortars. *Materials Science and Engineering: A*, *380*(1–2), 1–8.

Patra, R. K., & Mukharjee, B. B. (2017). Properties of concrete incorporating granulated blast furnace slag as fine aggregate. *Advances in Concrete Construction*, *5*(5), 437.

Perez, F., Bissonnette, B., & Gagné, R. (2009a). Parameters affecting the debonding risk of bonded overlays used on reinforced concrete slab subjected to flexural loading. *Materials and Structures/Materiaux et Constructions*, *42*(5), 645–662.

Perez, F., Bissonnette, B., & Gagné, R. (2009b). Parameters affecting the debonding risk of bonded overlays used on reinforced concrete slab subjected to flexural loading. *Materials and Structures*, *42*(5), 645–662.

P.F.G Banfill, L. Belagraa, L. Benaggoun., (1991), The use of blended cements in polymer modified mortars for the repair of concrete", BLENDED CEMENTS IN CONSTRUCTION, Structural Research Institute, (pp. 478-491), Science

Published LTD, Elsevier

Qian, J., You, C., Wang, Q., Wang, H., & Jia, X. (2014). A method for assessing bond performance of cement-based repair materials. *Construction and Building Materials*, *68*, 307–313.

Ramli, M., & Akhavan Tabassi, A. (2012). Effects of polymer modification on the permeability of cement mortars under different curing conditions: A correlational study that includes pore distributions, water absorption and compressive strength. *Construction and Building Materials*, *28*(1), 561–570.

Ramli, M., Tabassi, A. A., & Hoe, K. W. (2013). Porosity, pore structure and water absorption of polymer-modified mortars: An experimental study under different curing conditions. *Composites Part B: Engineering*, *55*, 221–233.

Rebeiz, K. S. (1995). Time-temperature properties of polymer concrete using recycled PET. *Cement and Concrete Composites*, *17*(2), 119–124.

Rebeiz, K. S. (1996). Precast use of polymer concrete using unsaturated polyester resin based on recycled PET waste. *Construction and Building Materials*, *10*(3), 215–220.

Sablocrete. (1994). *Bétons de sable, caractéristiques et pratiques d'utilisation [Sand concrete, characteristics and use practices]*. Presses de l'Ecole Nationale des Ponts et Chaussées LCPC Paris.

Santos, D. S., Santos, P. M. D., & Dias-Da-Costa, D. (2012). Effect of surface preparation and bonding agent on the concrete-to-concrete interface strength. *Construction and Building Materials*, *37*, 102–110.

Santos, P. M. D., & Júlio, E. N. B. S. (2011). Factors affecting bond between new and old concrete. *ACI Materials Journal*, *108*(4), 449.

Santos, P. M. D., & Júlio, E. N. B. S. (2013). A state-of-the-art review on roughness quantification methods for concrete surfaces. *Construction and Building Materials*, *38*, 912–923.

Semendary, A. A., & Svecova, D. (2020). Interfacial Parameters for Bridge Connections at High-Strength Concrete–Ultrahigh-Performance Concrete Interface. *Journal of Materials in Civil Engineering*, *32*(4), 04020060.

Shaker, F. A., El-Dieb, A. S., & Reda, M. M. (1997). Durability of styrene-butadiene latex modified concrete. *Cement and Concrete Research*, *27*(5), 711–720.

Siewczyńska, M. (2012). Method for determining the parameters of surface roughness by usage of a 3D scanner. *Archives of Civil and Mechanical Engineering*, *12*(1), 83–89.

Sikora, P., Łukowski, P., Cendrowski, K., Horszczaruk, E., & Mijowska, E. (2015). The effect of nanosilica on the mechanical properties of polymer-cement composites (PCC). *Procedia Engineering*, *108*, 139–145.

Silfwerbrand, J., & Paulsson, J. (1998). Better bonding of bridge deck overlays. *Concrete International*, *20*(10), 56–61.

Silva, F. A., Melo Filho, J. A., Toledo Filho, R. D., & Fairbairn, E. M. R. (2007). Effect of reinforcement ratio on the mechanical response of compression molded sisal fiber textile reinforced concrete. *High Performance Fiber Reinforced Cement Composites (HPFRCC5)*, 175–182.

Siva Bala, P., & Vaisakh, G. (2018). Mechanical Properties of Self Compacting Concrete Containing Crushed Sand and Sisal Fiber. *International Journal of Applied Environmental Sciences*, *13*(1), 71–81.

Son, S. W., & Yeon, J. H. (2012). Mechanical properties of acrylic polymer concrete containing methacrylic acid as an additive. *Construction and Building Materials*, *37*, 669–679.

Soto Izquierdo, I., Soto Izquierdo, O., Ramalho, M. A., & Taliercio, A. (2017). Sisal fiber reinforced hollow concrete blocks for structural applications: Testing and modeling. *Construction and Building Materials*, *151*, 98–112.

Soufi, A. (2014). *Etude de la durabilité des systèmes béton armé : mortiers de réparation en milieu marin Abderrahmane Soufi To cite this version : HAL Id : tel-01067496*.

Sprinkel, M. M., & Ozyildirim, C. (2000). *Evaluation of high performance concrete overlays placed on Route 60 over Lynnhaven Inlet in Virginia*. Virginia Transportation Research Council.

Standard, B. (2009). Testing hardened concrete: Making and curing specimens for strength tests. *EN 12390*, *2*.

Stefanidou, M. (2016). Crushed and river-origin sands used as aggregates in repair mortars. *Geosciences (Switzerland)*, *6*(2).

Swift, D. G., & Smith, R. B. L. (1978). *Sisal fibre reinforcement of cement paste and concrete*.

Talbot, C., Pigeon, M., Beaupre, D., & Morgan, D. R. (1995). Influence of surface preparation on long-term bonding of shotcrete. *Materials Journal*, *91*(6), 560–566.

Tanabe, T., Sakata, K., Mihashi, H., Sato, R., Maekawa, K., & Nakamura, H. (2008). *Creep, Shrinkage and Durability Mechanics of Concrete and Concrete Structures, Two Volume Set: Proceedings of the CONCREEP 8 conference held in Ise-Shima, Japan, 30 September-2 October 2008* (Vol. 1). CRC Press.

Taoukil, D., Ajzoul, T., & Ezbakhe, H. (2012). Effect of the incorporation of wood wool on thermo physical proprieties of sand mortars. *KSCE Journal of Civil Engineering*, *16*(6), 1003–1010.

Tayeh, B. A., Abu Bakar, B. H., & Megat Johari, M. A. (2013). Characterization of the interfacial bond between old concrete substrate and ultra high performance fiber concrete repair composite. *Materials and Structures/Materiaux et Constructions*, *46*(5), 743–753.

Tayeh, B. A., Abu Bakar, B. H., Megat Johari, M. A., & Voo, Y. L. (2012). Mechanical and permeability properties of the interface between normal concrete substrate and ultra high performance fiber concrete overlay. *Construction and Building*

Materials, *36*, 538–548.

Tayeh, B. A., Abu Bakar, B. H., Megat Johari, M. A., & Voo, Y. L. (2013a). Evaluation of bond strength between normal concrete substrate and ultra high performance fiber concrete as a repair material. *Procedia Engineering*, *54*(Farhat 2010), 554–563.

Tayeh, B. A., Abu Bakar, B. H., Megat Johari, M. A., & Voo, Y. L. (2013b). Utilization of ultra-high performance fibre concrete (UHPFC) for rehabilitation a review. *Procedia Engineering*, *54*, 525–538.

Tayeh, B. A., Abu Bakar, B. H., Megat Johari, M. A., & Zeyad, A. M. (2014). Microstructural analysis of the adhesion mechanism between old concrete substrate and UHPFC. *Journal of Adhesion Science and Technology*, *28*(18), 1846–1864.

Tayeh, B. A., Bakar, B. H. A., & Johari, M. A. M. (2012). Mechanical properties of old concrete—UHPFC interface. *Concrete Repair, Rehabilitation and Retrofitting III: 3rd International Conference on Concrete Repair, Rehabilitation and Retrofitting, ICCRRR-3, 3-5 September 2012, Cape Town, South Africa*, 373.

Tayeh, B. A., Bakar, B. H. A., Johari, M. A. M., & Ratnam, M. M. (2013). The relationship between substrate roughness parameters and bond strength of ultra high-performance fiber concrete. *Journal of Adhesion Science and Technology*, *27*(16), 1790–1810.

Thomas, M. D. A., Hooton, R. D., Scott, A., & Zibara, H. (2012). The effect of supplementary cementitious materials on chloride binding in hardened cement paste. *Cement and Concrete Research*, *42*(1), 1–7.

Tonoli, G. H. D., Rodrigues Filho, U. P., Savastano Jr, H., Bras, J., Belgacem, M. N., & Lahr, F. A. R. (2009). Cellulose modified fibres in cement based composites. *Composites Part A: Applied Science and Manufacturing*, *40*(12), 2046–2053.

Topçu, I. B., & Bilir, T. (2009). Experimental investigation of some fresh and hardened properties of rubberized self-compacting concrete. *Materials and Design*, *30*(8), 3056–3065.

Ukrainczyk, N., & Rogina, A. (2013). Styrene-butadiene latex modified calcium aluminate cement mortar. *Cement and Concrete Composites*, *41*, 16–23.

UNE, C. D. E. S. B. P., & DES OUVRAGES, D. D. E. V. I. E. D. (2004). *Documents scientifiques et techniques*.

Valikhani, A., Jahromi, A. J., Mantawy, I. M., & Azizinamini, A. (2020). Experimental evaluation of concrete-to-UHPC bond strength with correlation to surface roughness for repair application. *Construction and Building Materials*, *238*.

Van Zijl, G., & Stander, H. (2008). SHCC repair overlays for RC: Interfacial bond characterization and modelling. In *Concrete Repair, Rehabilitation and Retrofitting II* (pp. 379–380). CRC Press.

Wang, R., Wang, P. M., & Li, X. G. (2005). Physical and mechanical properties of styrene-butadiene rubber emulsion modified cement mortars. *Cement and*

Concrete Research, *35*(5), 900–906.

Yang, Z., Shi, X., Creighton, A. T., & Peterson, M. M. (2009a). Effect of styrene-butadiene rubber latex on the chloride permeability and microstructure of Portland cement mortar. *Construction and Building Materials*, *23*(6), 2283–2290.

Yang, Z., Shi, X., Creighton, A. T., & Peterson, M. M. (2009b). Effect of styrene–butadiene rubber latex on the chloride permeability and microstructure of Portland cement mortar. *Construction and Building Materials*, *23*(6), 2283–2290.

Yucel, H. E., Jashami, H., Sahmaran, M., Guler, M., & Yaman, I. O. (2013). Thin ECC overlay systems for rehabilitation of rigid concrete pavements. *Magazine of Concrete Research*, *65*(2), 108–120.

Z. A. Siddiqi, R. Hameed, M. Saleem, Q. S. Khan, J. A. Q. (2013). Evaluation of Compressive Strength and Water Absorption of Styrene Butadiene Rubber (SBR) Latex Modified Concrete. *Pakistan Journal of Science'*, *65*(1), 124–128.

Zhang, J., Li, D., & Wang, Y. (2020). Toward intelligent construction: Prediction of mechanical properties of manufactured-sand concrete using tree-based models. *Journal of Cleaner Production*, *258*, 120665.

Zhang, J., & Scherer, G. W. (2011). Comparison of methods for arresting hydration of cement. *Cement and Concrete Research*, *41*(10), 1024–1036.

Zhang, X., Deng, D., Lin, X., Yang, J., & Fu, L. (2019). Mechanical performance of sand-lightweight concrete-filled steel tube stub column under axial compression. *Structural Engineering and Mechanics*, *69*(6), 627–635.

Zhou, L. M., Mai, Y. W., Ye, L., & Kim, J. K. (1995). Techniques for evaluating interfacial properties of fibre-matrix composites. *Key Engineering Materials*, *104*, 549–600.

Zri, A. (2010). *Mise en place d'une nouvelle approche de formulation d'une matrice cimentaire à base de sable de dragage: application aux bétons de sables et granulats*. Lille 1.