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Etude de l'influence de l'incorporation dans le béton des déchets recyclés issus du broyage des pneus usagés et verre broyé sur leurs caractéristiques et comportement.

(Performance behavior of concrete made with waste rubber aggregates from grinding used tires and glass waste.)

Présentée par :

Samiha Ramdani

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Devant le jury composé de :

Pr. MELLAS Mekki	Professeur	Président	Université de Biskra
Pr. GUETTALA Abdelhamid	Professeur	Rapporteur	Université de Biskra
Pr. José Aguiar	Professeur	Co-rapporteur	Université de Portugal
Pr. TAALLAH Bachir	Maitre de Conférences	Examinateur	Université de Biskra
Dr. MEZGHICHE Bouzidi	Maitre de Conférences 'A'	Examinateur	Université de Biskra
Pr. BEDERINA Madani	Professeur	Examinateur	Université de Laghouat

ABSTRACT

This study presents experimental results about the effect of incorporating waste rubber aggregates in combination with waste glass powder or silica sand powder obtained from dune natural sand, on the performances of cementitious mixtures. Rubber aggregates (RW) were used to replace crushed sand in concrete mixes with ratios of 10%, 20%, 40% and 60%, while glass powder (GP) and natural sand powder (SP) were used to replace 15% of the cement weight. Nine different mixtures of concrete with the separate wastes and with the combination of them were designed and prepared. The mixtures were characterized in the fresh, hardened states and durability by means of workability, fresh density, compressive and tensile strengths, propagation of ultrasonic waves, deformability and sulfuric acid attacks, water permeability tests and SEM analysis. The water/binder ratio and superplasticizer percentage of all mixtures were maintained constant. The results showed that the strength increased with the incorporation of glass powder and rubber aggregates, especially with 10% and 20% RW contents. In addition, the developed rubberized concrete with the incorporation of glass powder presented higher fresh density and deformability, compared to the cementitious rubberized mixtures without GP. Furthermore, the simultaneous incorporation of rubber waste and glass powder enhanced the concretes workability due to the low GP and RW water absorptions. Moreover, mixtures containing 15% GP also performed satisfactorily against sulfuric acid attack and water permeabilities. This is indications that GP plays an important role in the decrease of the porosity of the mixture. Finally, a detailed microstructural analysis using scanning electron microscopy was performed and analyzed. Comparisons of the effects of artificial powder glass bottle waste material with a powder of natural sand on the performance of concrete were made concerning properties.

Key words: rubber waste aggregates; glass powder; wastes combination; mechanical strength; deformability; rubberized concrete.

RESUME

Cette étude présente des résultats expérimentaux sur l'effet de l'incorporation d'agrégats de caoutchouc usé de broyage de pneus usagés en combinaison avec de la poudre de verre ou de la poudre de sable de dune celui obtenue à partir de broyage mecanique de sable naturel, sur les performances des mélanges de ciment. Des granulats de caoutchouc (RW) ont été utilisés pour remplacer le sable concassé dans les mélanges de béton dans des proportions de 10%, 20%, 40% et 60%, tandis que de la poudre de verre (GP) et de la poudre de sable naturel (SP) ont été utilisées pour remplacer le ciment en poids. Neuf formulations différentes de béton avec les déchets séparés d'une part, d'autre part combiné ont été préparées. Les mélanges ont été caractérisés à l'état frais, durci et durable, au moyen de la maniabilité, de la densité fraîche, des résistances à la compression et à la traction, de la propagation des ondes ultrasonores, de la déformabilité et des attaques à l'acide sulfurique, de la perméabilité à l'eau et des analyses de SEM. Le rapport eau /ciment et le pourcentage de superplastifiant de tous les mélanges ont été maintenus constants. Les résultats ont montré que la résistance a été augmenté avec la présence des granulats de caoutchouc ansi que la poudre de verre dans les mélanges, en particulier avec des teneurs en caoutchouc (RW) des taux 10% et 20%. En outre, le béton caoutchouté développé avec incorporation de poudre de verre présentait une densité à l'état frais et une déformabilité supérieures à celles des mélanges caoutchoutés à base de ciment sans GP. De plus, l'incorporation simultanée de déchets de caoutchouc et de poudre de verre a amélioré l'ouvrabilité du béton en raison de la faible absorption d'eau de GP et de RW. De plus, les mélanges contenant 15% de GP ont également donné des résultats satisfaisants contre l'attaque de l'acide sulfurique et les perméabilités à l'eau. Ceci indique que le GP joue un rôle important dans la diminution de la porosité du mélange. Enfin, une analyse microstructurale détaillée utilisant la microscopie électronique à balayage a été réalisée et analysée. Des comparaisons des effets des déchets de bouteilles en verre de poudre artificielle avec une poudre de sable naturel sur les performances du béton ont été effectuées concernant les propriétés.

Mots clés: agrégats de déchets de caoutchouc; poudre de verre; combinaison de déchets; force mécanique; déformabilité; béton caoutchouté.

ملخص

تعرض هذه الدراسة نتائج تجريبية حول تأثير دمج حبيبات نفايات المطاط مع مسحوق نفايات الزجاج أو مسحوق الرمل الذي تم الحصول عليه من خلال طحن رمل الكثبان الطبيعي ، على أداء الخرسانة الأسمنتية. حيث تم استخدام حبيبات المطاط (RW) لاستبدال الرمل الخشن في الخلطات الخراسانية بنسب 10 ٪ ، 20 ٪ ، 40 ٪ و 60 ٪ ، في حين تم استخدام مسحوق الزجاج (GP) ومسحوق الرمل الطبيعي (SP) لاستبدال 15 ٪ من وزن الاسمنت. تم تصميم وتجهيز تسعة أشكال وخلطات مختلفة من الخرسانة مع دمج النفايات المذكورة وكذلك كلا على حدى. درسنا خصائص الخلائط في الحالات اللزجة والصلبة و كذلك قابلية مقاومتها على المدى الطويل عن طريق دراسة انتشارها والكثافة ومقاومة قوى الضغط والشد وانتشار الموجات فوق الصوتية وهجمات التشوه اثر التعرض لحمض الكبريتيك ونفاذية المياه والتحاليل المجهرية. خلال هذا العمل تم الحفاظ على نسبة الماء / الاسمنت ونسبة الملدن لجميع المخاليط ثابتة.

أظهرت النتائج أن القوة زادت عند دمج مسحوق الزجاج والحبيبات المطاطية، وخاصة عند نسبتي 10 ٪ و 20 ٪ من حبيبات المطاط ، بالإضافة إلى ذلك ، فإن الخرسانة المطاطية مع دمج المسحوق الزجاجي توفر كثافة عالية وقابلية للتشوه كبيرة مقارنة بالمخاليط المطاطية الأسمنتية بدون مسحوق الزجاج .

علاوة على ذلك ، أدى الدمج المتزامن لنفايات المطاط ومسحوق الزجاج إلى تعزيز قابلية الخرسانة للتدفق نظرًا لانخفاض خاصية الامتصاص لدى الحبيبات المطاطية والمسحوق الزجاجي للمياه. علاوة على ذلك ، فإن الخلائط المطاطية التي تحتوي على 15٪ من مسحوق الزجاج أثبتت أيضًا بشكل مرض مقاومتها ضد هجوم حمض الكبريتيك ونفاذية الماء. هذه دلائل على أن المسحوق الزجاجي يلعب دورًا مهمًا في تقليل مسامية الخليط. وأخيرا، تم إجراء تحليل مجهريه مفصلة باستخدام المجهر الإلكتروني للمسح الضوئي وتحليلها. تم إجراء مقارنات لتأثير مادة نفايات الزجاج المسحوقة الاصطناعية مع مسحوق الرمل الطبيعي على أداء الخرسانة.

<u>**الكلمات الأساسية**</u>: حبيبات نفايات المطاط؛ مسحوق زجاجي؛ مزيج النفايات؛ قوة الضغط؛ التشوه؛ الخرسانة المطاطية.

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PUBLICATIONS

International Journal Papers

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- S. Ramdani, Abdelhamid Geuttala « influence de l'incorporation dans le béton des déchets recyclés issus du broyage des pneus usagés sur leurs caractéristiques et comportement, 3 em Workshop,caractérisation des géomatériaux, le 9 et 10 novembre 2015 l'université de Biskra.

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I. Introduction

The construction industry is a vast user of energy and natural resources. Particularly, in Algeria, millions of tons of aggregates and cement are consumed in the field of construction and public works. So, developing sustainable construction and building materials with less environmental impact from recycled wastes is attracting increased interest.

Among the many sources of waste generation, about 270 million of discarded tires are disposed of at landfills, stockpiles or illegal dumps has become representing a very serious threat to the ecology [1] and the number would reach 1200 million tires yearly by 2030 [2]. Locally, in Algeria alone, about 26.000 tons of worn tires are generated every year [3]. The rise in tires consumption has main causes, the increase in world population and the fact that there are an increasing number of people whose utilized cars.

Disposal of used tires by burning is one of the cheapest and easiest methods; however, it causes serious fire hazards and environmental pollution [4,5]. In France, which produces over than 10 million scrap-tires per year, the supply of landfills decreased starting in July 2002; due to a new law that forbids any new landfill or burned tires in the country [6].

Unfortunately, the statistics indicate that the percentage of recovery in Algeria does not exceed 10% of the waste produced. Particularly, tire scrap has only 50% of which are valued and reused in civil and geotechnical engineering work, as the project of stability of an embankment road using the tyresol technique, situated at Bousmail city (northern of Algeria) [7] or to produce road mats .

Contrariwise, researchers worldwide up the challenge to assess the usability of this industrial waste in cementitious materials, however, their performance has to be defined. The most recent studies related to the use of rubber aggregates and chips obtained from the used tires milling as a partial replacement of fine and coarse aggregates should be highlighted [8-23].

The concrete manufactured by fine or coarse aggregates have been shown to be more sustainable alternative than the control one, in terms of deformability index, failure strain and ductility [10,18-21]. However, investigations made so far on rubberized concrete show that these materials were associated with low compressive strength and density compared to the conventional concrete [8,9,13-17]. After that, efforts have been carried about improving the strength and durability of rubber cementitious materials. Many works had mentioned the use of pre-treated RW (rubber wastes) by immersion in NaOH solution [22], by the use of styrene butadiene rubber (SBR) [23] and silane coupling agent as cementitious layer [17] to increase the adhesion between the cement paste and the rubber particles. Other studies have been carried out based on the incorporation of additive materials into rubber mixtures such as silica fume (SF) as pointed by Obinna et al. [24] and Topçu et al. [25]. Lime stone [17], fly ash and metakaolin were also used to enhance the properties and the durability of concrete with tire rubber waste [26].

The glass bottle is another type of recyclable waste according to the program set up by the Algerian Ministry of Environment. It estimated the possibility of generating 50,000 tons a year. Cement-based materials using recycled glass bottles and used tires as raw material (substitution of sand and cement), can provide environmental (ecological) and socioeconomic benefits.

Historically, the use of recycled glass waste in concrete is not new. Early efforts were conducted in the 1960s to use crushed waste glass as a replacement for aggregate. However, these attempts were not satisfactory due to the strong reaction between the alkali in cement and the reactive silica in glass, namely ASR [27]. For that raison, studies are in progress to valorize glass powder waste in the cement industry for the development of new cement. The usability of fine glass powder as a value-added product as it could replace a proportion of an expensive concrete constituent, such as Portland cement was possible [28,29].

The Recyc Quebec [30] analysis showed that valorizing glass bottles as GP in concrete can allow for its transportation within a radius of 8950 km without environmental impacts compared to landfilling. So, using GP as a cement replacement has very little environmental impact [31]. The results of this research were a challenge for use of glass powder waste in the production of concrete. Abdo Ali et al. [32] and others [33,34-40]. It has been proven by those studies that glass powder enhanced the mortar and concrete compressive strengths and durability performances; in addition, the increase in its fineness is a key point for its potential expansion behavior (ASR). Glass powder waste (GP) used as a partial replacement of cement at various construction sites (in Quebec-Canada between 2006 and 2012), including interior and exterior slabs and structural wall elements [41].

Locally, Algeria is rich in very large amounts of unused dune sand. This material is practically not exploited; in spite of the possible characteristics which it presents. Additionally, Care et al. [42] have shown by studding the effect of inert mineral additions on hydration of mortars, the degree of hydration for short-term of mortars containing chemically inert additions were always higher than that of the reference mortars and have confirmed the improvement of the hydration of cement with inert additions. So, the possibility of using the dune sand powder as a part mass addition to Portland cement can provide a new binder with different physical and mechanical proprieties.

I.1 Objectives

Developing a new cementitious composition to produce an eco-concrete from waste tire rubber and waste glass bottle, which are in abundance in the Algerian nature, to benefit from its advantages in the field of civil construction is the main objective of this study. This aim can be decomposed into the following specific objectives:

1. Developing mix composition of rubberized concrete;
2. Obtaining physical and mechanical properties of rubberized concrete;
3. Durability and microstructure study of rubberized concrete;
4. Development of mix compositions related to combined rubber aggregates as fine aggregate with glass powder as cement replacement;
5. Assessment of physical, mechanical, durability and microstructure performance of rubber-glass concrete;
6. Comparative study on the performance of rubber-glass concrete and rubber-sand concrete.

I.2 Structure and content of the thesis

This thesis is composed by seven chapters. Its content can be summarized as follows:

Chapter 1 presents the Introduction of this thesis along with its objectives.

Chapter 2 reviews the state of the art of used rubber waste and glass waste to a developed material for Sustainable Construction. Including some of its strength properties and durability that has received attention by researchers.

Chapter 3 deals with a characterization of the materials used during the experimental work of this thesis along with a description of the tests.

Chapter 4 addresses to the study of the separate effect of rubber waste aggregates and glass bottle powder waste on the performances of concrete. Also, comparative study about the effect of sand powder modified concrete is investigated in this chapter. The physical, mechanical properties of the new mixtures and its durability and microstructures are investigated and analyzed.

Chapter 5 ; in this chapter, eco-mixtures contain combined rubber aggregates waste and glass powder prepared. Chemistry activity of glass powder particles has been investigated. Further, comparative mixtures of the separate effect of rubber waste and dune sand powder were made in this chapter.

Chapter 6 presents the general conclusions of thesis along with suggestion for further investigation on the field of the study.

CHAPTER TWO

States of Art

II.1 Introduction

In this part, the review of the relevant literature will be presented. Presenting an overview of what has been done in previous researches.

II.2 General Information on the studied

II.2.1Tire rubber waste

Used tires can be classified as special encombrants industrial waste because of their voluminous nature does can be collected under the same conditions as household and similar waste [43,44]. In 2002, according to the national cadastre of special waste, the production of special industrial waste is 325,000 t / yr, and the quantity in stock is 2,008 500 tons. Particularly, used tires represent the largest share of rubber waste (over 85%) [45], where about 26.000 tons of worn tires are generated every year in Algeria [3]. In addition, it is estimated that almost 1.2 billion new tires are produced annually worldwide and disposal at the end of their life [46] and more than 50% of them are discarded without any further use [47,48]. Generally, the main sources of rubber waste are the tire management and utilization. Examples, UK produces around 4.3 × 108 kg of waste tires a year [49, 50] and Japan produces 2.1 × 108 kg of tire wear debris [51].

A tire is defined as a continuous pneumatic covering made of natural rubber or synthetic rubber or a combination of natural and synthetic rubber encircling a wheel, whether new, used or retreaded [52]. Due to their non-decomposition nature, tire waste is characterized by the negative impacts that may affect health public and the environment when treated by landfilling or disposed in an inappropriate way without treatment: they occupy a large surface area and pollution problems, including ground water pollution, air pollution, and soil contamination. However, the good thing about worn tire is that still retains many qualities, making it a real raw material [53]. Such as;

- Elasticity
- Strength of the structure
- Draining ability
- Calorific power
- High carbon content
- Durability
- Amortization

II.2.1.1 Principal Components of a tire

Polymers may be divided into two main groups: thermoplastics and thermosetting materials. Rubber from the used tire waste classified as thermosetting material which cannot be softened or remolding by heating again due to the crosslinked structure of rubbers and presence of stabilizers and other additives, which makes it difficult to reuse waste tires in making new tires. The basic material composition and chemical components of tire material is presented in the table 1.1 and table1.2 respectively [54,55].

Table.1.1. Typical constituent materials of tires [54].

Composition Weight (%)	Car tire	Truck tire
Natural rubber	14	27
Synthetic rubber	27	14
Black carbon	28	28
Fabric, filler	16-17	16-17
Accelerators, and antiozonants		
Steel	14-15	14-15

Table.1.2. Chemical components of a tire [55].

	Car tire	Truck tire
Element	**%Wt**	**% Wt**
Carbon	89.48	89.65
Hydrogen	7.61	7.50
nitrogen	0.27	0.25
Sulfur	1.88	2.09
Oxygen	<0.01	<0.01
Chlorine	0.07	0.06
Ash	3.9	5.5

II.2.1.2 Methods and potential of the utilization of waste tires in the world and in Algeria

At the end of 1950s, only about one fifth of the rubber hydrocarbon used by the United States and Europe was reclaimed. By the middle of 1980s less than 1% of the worldwide polymer consumption was in the form of reclaim. At the beginning of 20^{th} century half of the rubber consumed was in the form of reclaim. It is expected that in 21st century most of the scrap rubber will be recycled in the form of reclaim because of day to day increase in environmental awareness [56]. Tire wastes are recycled or treated by landfill, incineration or other methods depending on how each country adopts it, especially the developed countries which are very concerned with the production of tires. Unfortunately, there is a poor culture with respect to the 3R Principles (reduce, reuse, recycle) in Algeria [57].

There are two kinds of pneumatic waste:

- Used Non-Reusable Tires that need to be disposed of or directed to another utilisation.
- Used Reusable Tires that need to be retreaded or sold as used tires [58].

a) Landfill mode

Landfill is one of the early methods of disposal of discarded tires. In 1977, approximately 70% of the scrap rubber, primarily as tires, was discarded as landfills [59]. Moreover, in 1994, 75-80% of scrap tires are buried in landfills In USA. However, disposal of whole tire has been banned in the majority of landfill operations because of the bulkiness of the fires and their tendency to float to the surface with time [60].

Particularity, in Algeria, the piling up of scrap tires in open dumps is still common until now. To limit it, since 2001, the Algerian government has chosen to eliminate the municipal solid waste (as waste tire) by landfill technique, which is a waste storage underground. It has launched an ambitious program of landfill sites throughout the country, 65 of it were recorded, during the period from 2001 to 2005, 16 were completed, 28 in progress and 21 in the study phase [61]. Furthermore, at the end of 2007, this number has increased following the results of the pilot projects, notably that of Oueld Fayet, it has grown to 80 projects, of which 20 have been completed, 34 under construction and 26 under study and 15 new projects. The wilayas concerned are Skikda, El-Taref, Annaba, Guelma, Souk Ahras, Batna, Tebessa, Media, Tizi-Ouzou, Setif, Biskra, Algiers, M'Sila, Ouargla, Blida, Djelfa, Jijel, Bejaia and Chelf [62].

The main advantages of this technology are the following: a universal solution that provides ultimate waste disposal; relatively low cost and easy to implement to other waste management technology. However, this technology also has several disadvantages such as landfills requiring a large surface area and pollution problems, including ground water pollution, air pollution, and soil contamination. So, we can conclude that this method is the most unwanted one due to environmental problems and has no future possibility.

b) Energy mode

Energy recovery is mainly the use of discarded tires as a substitute fuel for energy production; this energy serves to provide heat or electricity [63]. This technology was introduced in Britain in 1865 with the British Destructor and exported to the United States and Europe [64]. Additionally, incineration has been widely applied in many developed countries, especially those with limited space for landfill such as Japan and many European countries. Example, China has several household incineration factories, including the one in Shanghai, which is supposedly the largest one in China. The facility is designed to have a daily garbage handling capacity of 3,000 tons and generate around 270 million kilowatt-hours of power per annum [57]. Moreover, including the use of scrap tires as fuel in cement kilns [65,66]. This process is still in use, but it creates new problem of air pollution and is also a low value recovery process of the waste rubber.

In Algeria, incineration is applied only for hospital waste, while it is absent for the discarded tires because the use of natural gas in industry cement is preferred.

c) Material recovery mode

Material recovery is the idea of reducing the number of waste tires that accumulate in landfills through used it as raw material, according to ASTM D 6270-08, 2014, rubber tire wastes may be classified as particulate rubber (buffing rubber, granulated rubber, ground rubber, and powdered rubber), rough shred, tire-derived aggregate, tire shred, and whole tire. Table 1.3 and Table 1.4 summarize the established standard nomenclature and size of rubber tire wastes as suggested by ASTM D6270-08, 2014 [67].

Table.1.3. ASTM D-6270 classification of the recycled scrap tires based on their size [67].

Classification	*Lower Limit, (mm)*	*Upper Limit, (mm)*
Chopped Tire	*Unspecified dimensions*	
Rough Shred	50*50 *50	762* 50* 100
Tire Derived aggregate	12	305
Tire Shreds	50	305
Tire Chips	12	50
Granulated Rubber	0,425	12
Ground Rubber	-	<0,425
Powered Rubber	-	<0,425

Table.1.4. Nomenclature and sizes of rubber tire wastes according to ASTM D6270 [67].

Designation	Shape	Size
Granulated rubber	Non-spherical	Below 425 lm (40 mesh) to 12 mm
Ground rubber	Non-spherical	Below 425 lm (40 mesh) to 2 mm
Powdered rubber	Non-spherical	Below 425 lm (40 mesh)
Rough shreds	_	Larger than 50 mm 9 50 mm 9 50 mm, but smaller than 762 mm 9 50 mm 9 100 mm
Tire chips	Basic geometrical shape	Between 12 and 50 mm
Tire-derived aggregate	Basic geometrical shape	Between 12 and 305 mm
Tire shreds	Basic geometrical shape	Between 50 and 305 mm
Whole tire	_	Unprocessed

We describe in the following section the main recovery methods:

- **Retreading**

It is a strategy that comprises of reconstituting the track of the used tire to expanding its life. The tread of a reusable used tire replaced with a new one. The careful tires retreads are regarded as reliable and safe as new tires [68].

- **Valorization in public works**

Used tires are commonly used in construction light embankments and in the reinforcement of dikes and various embankments like the PNEUSOL system. This Tire-soil combination are able to support significant traction efforts and are either entirely or partially cut in order to be combined in layers or superposed, by means of metal fasteners [69].

Several achievements with PNEUSOL technique have been made in the world and in Algeria.

At 2005, in the city of Bou Ismaïl in the wilaya of Tipaza, Algeria, a pilot project of an experimental plate with the pneusol technique was realized, which consisted in the execution of an embankment Figure.1.1. Another project of landslide stability was realized in the Wilaya of Tizi Ouzou Figure.1.2.

Figure.1.1. Pilot Project Pneusol- Bou Ismaïl.

Figure.1.2. Stability of a landslide - Tizi ouzou.

- **Rubber crumb**

Rubber crumb is obtained by grinding non-used reusable tires or retread waste. The grinding can be mechanical, or cryogenic. The crumb is used in the manufacture industrial and sports flooring, the production of sound insulation materials, anti-cracking membranes for road use [70] or anti-vibration membranes intended for railway platforms, casters, paving slabs, damping floors, noise barriers, play grounds, it can also be used as a railway support to reduce noise and vibration.

It is also used as a binder in bitumen's (Figure.1.3), which improves the acoustic characteristics of the asphalt as well as its resistance to cracking during freezing and thawing. It also promotes the adhesion of vehicles [71].

- **Rubber aggregates:**

They are particles of rubber of a size larger than that of the crumbs.

1. Synthetic Turf

The aggregate of rubber is used for filling sports fields to improve the amortization and thus avoid injury (Figure.1.4). It guarantees the same quality of play all season, reducing watering and maintenance [72].

2. Play area

Rubber aggregate is a promising material in the play area industry due to its light weight and elasticity (Figure.1.5). These elements promote to determine a significant absorption of shocks and to guarantee a high level of safety for play areas [72].

3. Equestrian Ground

The advantages of uses rubber aggregates in the fabrication of the equestrian ground (Figure.1.6) are: improve flexibility, improve drainage, less abrasive than sand, no dust creation.

Figure.1.3. Rubberized asphalt technology.

Figure.1.4. Synthetic turf for stadiums.

Figure.1.5. Play area.

Figure.1.6. Equestrian ground.

3. Concrete

In order to reduce the natural aggregate consumption, efforts have been made to find alternative aggregates. The use of scrap tire rubber particles in concrete as an alternative aggregate is one of the environmentally-friendly resources that supports sustainable development aims.

II.2.2 Glass bottle waste

According to the services of MATE, Algeria has the capacity to recover a quantity of waste estimated at 760 000 tons per year, which represents 3.5 billion DA, while the glass represents 50,000 tons / year. Glass waste is classified as urban solid waste. Regarding the capital Algiers, the rate of the glass waste for the year 2008 is 1.68%, more in the city of Mostaganem in the West region, the rate of the glass waste in 2004 was 2.8 % [73].

The most common type of glass is formed by melting a mixture of silica (SiO_2), soda ash (Na_2CO_3), and lime ($CaCO_3$) at high temperatures. In the glass industry the term "glass" is predominantly used for silicate glasses, i.e. materials containing a high share of silica (SiO_2), formed under ambient cooling conditions from the molten state into an amorphous glass structure.

The main types of glass, according to physico-chemical composition, are:

1. Soda-lime glass.

2. Lead crystal and crystal glass.

3. Borosilicate glass.

4. Electric glass, also called E glass the first three categories account for more than 95% of all glass produced.

Soda-lime glass industry mainly produces “soda-lime” glass. It is composed of: 71-75% silicon dioxide (SiO_2 derived mainly from sand), 12-16% sodium oxide (Na_2O derived from soda ash – Na_2CO_3), 10-15% calcium oxide (lime, CaO, derived from limestone – $CaCO_3$) Low levels of other components [74].

Glass Packing Institute in the United States considers that glass is 100% recyclable, and recycled glass can be substituted for up to 95% of the raw materials used in the manufacturing process. In addition, many works were carried out in laboratory and field conditions on recycled glass as natural sand replacement and powder glass as cementitious material replacement. Accordingly, valuable researches have been conducted to show that there are no major issues of concern regarding the fresh and hardened properties of concrete [75]. In Hong Kong, some of these specialty glass-concrete products have been successfully commercialized and are gaining wider acceptance [76]. Moreover, solid waste as glass is one of most important sources of biomass potential in Algeria, which can be used as renewable energy sources [77].

II.2.2.1 *General Application of glass waste*

Ground glass could be added to clay during manufacturing of brick to save energy costs and produce bricks that are more resistant to frost damage [78]. In addition, Hadlington et al. [79] quoted from Dryden Aqua Company that tiny glass particles could be used as filtration media for purifying water. The colored glass (green or amber) have been ground into particles of less than a tenth of a millimeter, during this process a net negative electrical charge will be left on the particles surfaces, which enables them to attract grays.

Another application of glass waste that has been used as aggregate in road construction or bituminous concrete pavements is popularly known as glassphalt [80]. Moreover, the glass waste could be exploited in a variety of uses, including fiber glass insulation, glass fiber, abrasive, art glass, landscaping, reflective beads, hydraulic cement, and other applications [81].

II.3 Properties of composites based on used tire waste

Used tire waste can be incorporated into mortars and concretes in the form of aggregates or crumbs. The performances obtained are presented in what follows [8-23]. Accordingly, rubberized concrete was found to possess good esthetics, acceptable workability, and a smaller unit weight than normal concrete. However, rubberized concrete did not perform as well as normal concrete under repeated freeze-thaw cycles. It exhibited lower compressive and tensile strength than that of normal concrete. Unlike normal concrete, rubberized concrete had the ability to absorb a large amount of plastic energy under compressive and tensile loads. It did not demonstrate the typical brittle failure, but rather a ductile, plastic failure mode.

II.3.1 *The effect of rubber aggregates on the characteristics of fresh and hardened concrete*

II.3.1.1 Consistency

Many authors have studied the consistency of concrete and mortar modified with crumb and rubber aggregates [15-18,25,82-87]. They observed a decrease in rubberized concrete workability with increasing rubber content due to increasing the viscosity of the mixture. Aslani et al. [11] practiced the replacement of natural aggregates with three sizes of rubber aggregates 2mm, 5mm and 10mm at volume ratios of 10%, 20%, 30%, and 40% to promote the physical and mechanical properties of Self-compacting concrete. They observed a decrease of slump and attributed the reason for this decrease to the rubber aggregates shape which affects the concrete consistency. In addition, Neil et al. [60] and Bravo et al. [95] suggest that the size of the rubber aggregate and its shape obtained by Cryogenic grinding of used tires (round aggregates) showed greater slump value as mechanically ground rubber aggregates (long angular particles) this is due to the low specific surface area and the low roughness of the tire aggregates in the cryogenic process. Supporting of these finding, Ganjian E et al. [9],

Taha et al. [90] and Khitab et al. [91] observed that the replacement of natural aggregates with Chipped or Shredded Rubber aggregates reduced the slump of the given concrete more than if replaced it with crumb rubber or ash of rubber.

Although the majority of investigations show that rubber aggregates lead to a decrease in concrete workability [22,88,89], contrary to the studies carried out by some authors [14,92,93,], have indicated a different conclusion. For example, the study of Khaloo et al. [92] indicated a different conclusion compared to other authors. Indeed, according to this study, concrete incorporating RW. has acceptable slump and workability in terms of ease of flow and placement and finishing. However, their results (Figure.1.7) show that the ordinary procedure for evaluating workability is not appropriate for this cementitious composite.

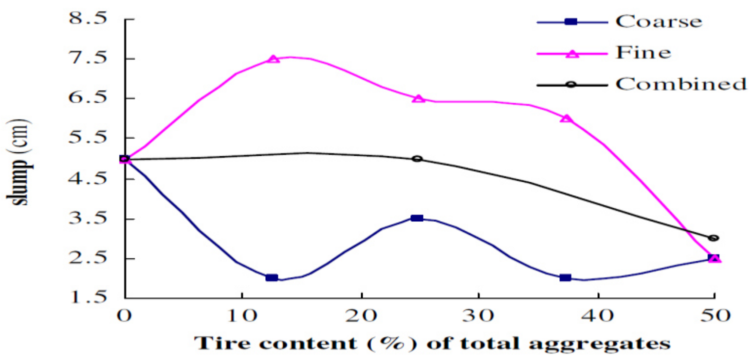


Figure.1.7. Influence of G.C. on slump [92].

Another observation concerning the flow of the rubberized self-compacting concrete made by Topcu et al. [94], show that the increase in the rubber amount leads to the decrease in T50 time and increase in workability. Other groups of workers indicated the importance of increasing the amount of superplasticizer or the combination of superplasticizer and viscosity agent to having sufficient fresh concrete properties [96, 97].

II.3.1.2 Density

The density of a concrete depends on its composition, especially the density of the aggregates used. There is general agreement about the fact that introduction rubber particles (RP) in the mortars or concrete decrease its unit weight [2,15,16,21,60]. This is due to the lower density of RP compared to the natural one. In addition, the reduction of rubbercrete unit weight is attributable to the air entrainment in the matrix; this increase is related to the non-polar nature of the rubber, which would cause air in the matrix [98,99]. Kardos et al [100] found that an increase in air content when crumb rubber was added into the concrete. Nadal Gisbert et al.

[101] explained that the increase of the rubber content in the concrete reduces the density of the concrete due to the gaps surrounding the rubber.

C. Albano et al. [93] said that when traditional concrete mix comparing with concrete‑scrap rubber mix (particle size 0.59 mm) the density diminishes (20‑29%) and being this effect more notorious when rubber percentage is 10 wt%. In a similar way, previous studies have found that the crumb rubber particles substitution generally leads to a reduction in density in parallel with these particles content increase [16,91,102,103]. Moreover, the size and the shape of the rubber granulate has an influence on the density of the mixtures. For the same rubber content, mixtures of fine rubber granules have lower densities than those containing coarse rubber aggregates [23,104, 105].

The potential use of this type of concrete is very interesting in terms of weight gain. The reduction in weight leads to savings in the transport of manufactured items and productivity gains on implementation. Moreover, the rubber can also produce light weight concrete for special purposes.

II.3.1.3 Compressive strength

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. As we know in the literature that compressive strength is a good indicator of concrete mechanical properties in the hardened state. The sand, gravel and cement content play an important role in the strength of the concrete. Therefore, replacing the sand, coarse aggregates or cement with rubber leads to the formation of a weaker matrix, which leads to a lower compressive strength.

The most of investigations show that rubber granulates lead to a decrease in the strength of concrete [9-11,13-18]. E. Güneyisi et al. [106] replaced the coarse aggregate by tire chips for five mixture having contents of 5%, 10%,15%, 20%, and 25% by volume . It was noticed that the compressive strength of SCRC at 28 days decreased with increased rubber content.

Li-Jeng Hunag et al. [107] treated the compressive strength of the controlled low-strength rubber lightweight aggregate concrete (CLSRC). The results of the 1-day-age CLSRC group concrete with 20% replacement is approximately 0.3 MPa lower than the compressive strength of the control group concrete at the same age. At 30% replacement, the compressive strength of the controlled low-strength rubber lightweight aggregate concrete (CLSRLC) group concrete is 0.1 MPa lower. At 40% replacement, the compressive strengths are not significantly different, possibly because the CLSM enters the aggregate-particle separation stage, which results in a decrease in compressive strength.

The compressive strength reduction is due to the fact that rubber aggregates are more flexible, soft and more elastic than the cement matrix [9,60,108,109,110] and the interfaces zone between them and the cement paste are even wider and porous than with natural aggregates.

Add to this, due to the above reasons, the mechanical strength is reduced when the crumb rubber is introduced into the concrete. Firstly, the distribution of rubber particles in the concrete mixture is non-homogenous, due to the lower specific gravity compared to other materials [111]. Secondly, the hydrophobic nature of rubber particles takes bubbles into the concrete mixture and increases the air content [1]. Add to this, it can be due to the deformability of the rubber particles against the surrounding cement paste, which resulted in initiating cracks around the rubber particles in a similar way to what occurring in the ordinary concrete with the air voids; and the possible reduction of the concrete matrix density which largely relied on the density, size, and hardness of the aggregate [112,113].

Moreover, it has been shown from the previous document that the large size of particles rubber leads to a high decrease in strength and it is also accompanied by a drop in the modulus of elasticity. The authors [114], [115] reported that chipped rubber result in greater strength losses compared to crumb rubber. In addition, the reduction of compressive strength can be avoided if the replacement of rubber does not exceed 20% of the total aggregate content [116]. More than that, Huang et al. [117] in their work attributed the strength gain that happens when smaller size is used, to the reduction of the stress and strain concentrations in the concrete.

However, the application of rubber concrete is limited due to its low compressive strength; researchers have worked to find solutions to improve this important propriety of it. The interfacial behavior of the rubber-cement matrix of rubberized concrete was improved by selecting better rubber types, surface modifiers, mixing methods, supplementary cementing materials [16,17,118]. Among the mineral additions used to improve the interface area between the rubber and the cement matrix: silica fume [24,119], fly ash [26], slag, rice ash, since have the property of reacting with the lime released during the hydration of Portland cement and forming new C-S-H, which contribute to improving compressive strengths at early age and late ages of concrete.

Concerning the surface modifiers of rubber, studies have revealed that the change of smooth rubber surface texture to a rough surface by different treatments could develop a better bond of the surface of the rubber grains before their introduction into the mixture which improve the poor link observed between the rubber and the cementitious paste [120,121].

Polypropylene fibers was used also by Hesami et al. [122] to modified rubber concrete, which resulted in significant increases of compressive and tensile strengths. Also, steel fibers combined with silica improving the strength of rubbercrere [123].

II.3.1.4 Tensile strength

The concrete cannot resist to the tensile strength but remains this important property since it allows to estimate the load under which the cracking develops. As we mentioned about the compressive strength, the unanimity of researchers admits in the literature that rubber granules are detrimental to the tensile strength. The results of splitting tensile strength tests according to Brazilian method show a reduction pattern concretes containing 15% or 25% rubber by total aggregate volume [15]. Khalil et al. [18] the test showed considerable decrease in the indirect strength with the increase in rubber content. The recorded split tensile test was on the average of 8.75%with respect to the compressive strength of the studied mixes. Osama Youssf et al. [125] shows the effect of rubber content on concrete splitting tensile strength measured at 28 days concrete age. Generally, the tensile strength decreased with rubber content increase (Figure.1.8). Using 10%, 20%, 30%, 40%, and 50% rubber content decreased the concrete tensile strength by 15.0%, 40.1%, 44.1%, 48.9%, and 58.5%, respectively.

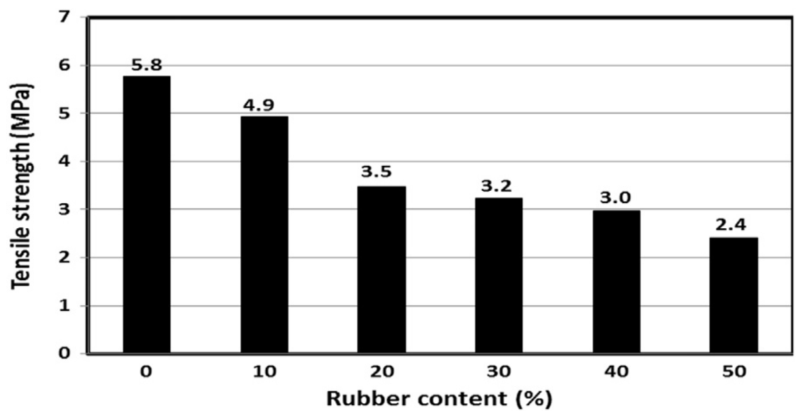


Figure.1.8. Effect of rubber content on concrete tensile strength [125].

The strength reduction observed in the rubberized concrete with increasing rubber content may be attributed to two reasons as reported by Khatip [126]. First, because the rubber particles are much softer (elastically deformable) than the surrounding cement paste, on loading, cracks are initiated quickly around the rubber particles in the mix, which accelerates the failure of the rubber–cement matrix. Secondly, due to the lack of adhesion between the rubber particles and the paste, soft rubber particles may behave as voids in the concrete matrix.

In addition, it is observed that split tensile strength of concrete reduces when replacing 5% coarse aggregate with tire crumbs [91]. However, when they add some chemicals epoxy resin to the rubber mixtures the behavior of the split tensile of 28 days becomes more than the simple tire rubber concrete [16,91]. Nano-silica also proved that insignificantly improved the tensile and the compressive strengths of rubber concrete [127]. Also, previous studies have proved that steel fibers improved tensile strength, durability, impact resistance, and toughness of concrete considerably, at the same time, preventing the crack propagation [128, 129].

II.3.1.5 Flexural strength

A loss of flexural strength is associated with the replacement of the natural aggregate in a concrete or mortar with rubber granules with a high degree of substitution [18,124,130,131], this reduction is still linked to the low adhesion between the rubber particles and the cement paste.

The ratio of the flexural strength to the compressive strength of the rubber concrete with 5%, 10% and 15% rubber is 1.08, 1.16, 1.26 times that of the ordinary concrete, respectively [132]. This indicates that the rubber concrete is better in anti-cracking performance than the ordinary concrete. Increasing the rubber contents increases the toughness and reduced the stiffness and peak load of the concrete, which is in accordance with previous analogous investigations [133].

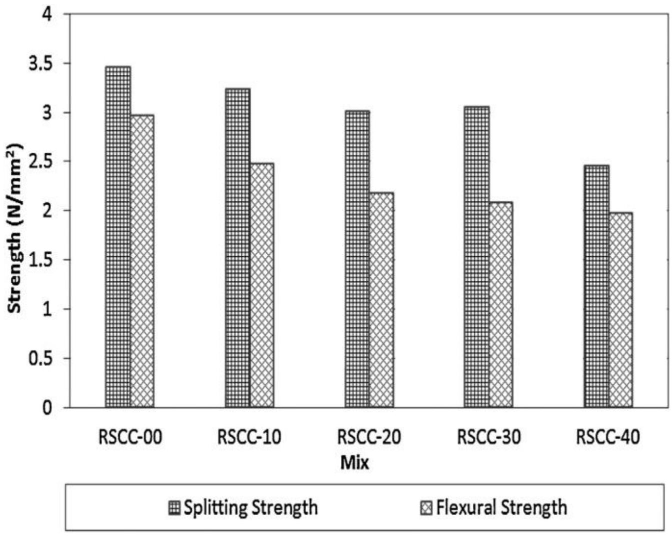


Figure.1.9. Splitting and flexural strength for all mixes [18].

In addition, the results indicate that the addition of large rubber content might cause a significant reduction in the deformation capacity of concrete [134]. The flexural strength of concrete decreased gradually as the rubber content increased, and the flexural strength of mixtures with 3% silica fume containing 5%, 10%, 15% and 20% rubber was reduced by 5.7%, 12.6%, 21.2% and 21.6%, respectively, compared with the flexural strength of the corresponding RSRAC without rubber.

The particle size of the rubber waste affected the flexural strength in a significant way. The rubber crumb is small and can improve the compactness of the mixture, which behave better with respect to the flexural strength than coarse rubber chips [9,14,135].

II.3.1.6 Static and dynamic modulus of elasticity

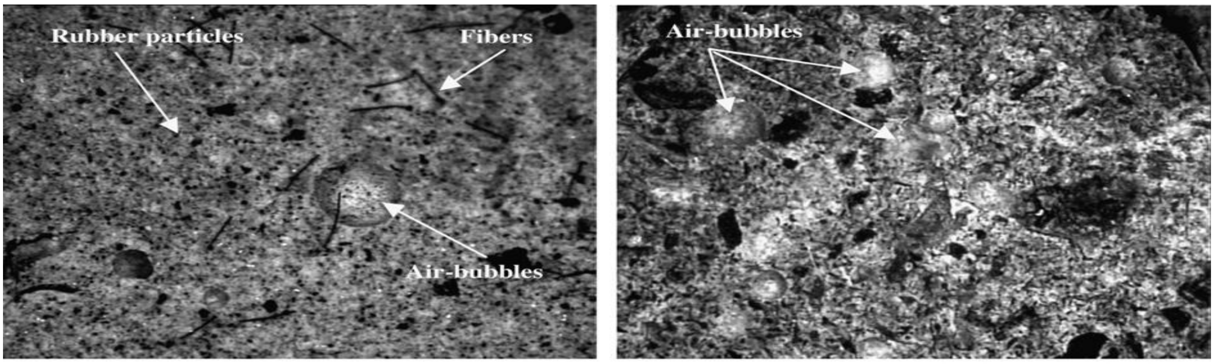
In case of shock, the concrete has little plastic deformation for this the incorporation of rubber granules in the latter can eliminate these impacts and absorbed the energy of shock. The incorporation of the rubber in the concrete can therefore lower the stiffness of the concrete, imparting a more elastic behavior with higher level of rubber replacement.

Jie Li et al. [11] studies the effects of crumb rubber and its size fine (ranging from 400 to 600 µm), coarse (ranging from 10 to 15 mm) on the mechanical properties of recycled construction and demolition (C&D) aggregates as the base/subbase layers of pavement. Based on the experimental test results, it was found that the inclusion of both coarse and fine rubbers led to an increase in the deformability index and failure strain compared to the control one.

In the same context, the experimental study of Mohammad Saberian et al. [12] about the effects of crumb rubber and rubber size on permanent deformation behavior of recycled concrete (RCA) and crushed rock (CR) aggregates showed larger permanent strains and slower decrease in permanent strain rate for CR samples by increasing the crumb rubber content.

Erhan Guneyisi et al. [15] showed that the static elastic modulus decreased with increasing rubber content in a fashion similar to that observed in both compressive and splitting tensile strengths. With increasing the rubber content to 50% of the total aggregate volume, the modulus of elasticity reduced to about 6.5 and 8.0 GPa for w/cm ratios of 0.60 and 0.40, respectively. This indicates a general reduction of about 83% in the elastic modulus in all concretes.

The addition of rubber particles reduces the modulus of elasticity from approximately 25 GPa for cement paste to 6 GPa for composite containing 50% of rubber [99]. This reduction could be attributed to the fact that the voids were being filled by the inclusion of higher percentages of the rubber, and, therefore, the brittleness of the specimens increased (Figure.1.10).



Composite (20% of rubber particles) Composite (50% of rubber particles)

Figure.1.10. Optical picture of discontinuous air-voids distribution in the composites (magnification·35) [99].

In addition, the stress-strain diagrams of 7, 28-days and 6-month of normal and rubberized concretes were tested by the same author, he found that control concrete reached the ultimate strain around 0.002, while the concrete having 15 % coarse rubber mixture showed similar behavior as normal concrete. He also mentioned that with mixture of coarse rubber particles maximum strain points fall while the strain increases at the failure point in rubberized concretes stress-strain values change between 0.003 and 0.005 against maximum strains. In addition, the examination of the max strain values obtained from stress-strain diagrams show that these values can reach to 0.007 and 0.008.

Eehab Khalil et al. [18] concluded that the strain energy is reduced as the percentage of the rubber increases and most of the rubber mixes would fail at the same strain value except for the large rubber replacement value of 40% (Figure.1.11).

Also, Turatsinze et al. [96] states that the use of rubber aggregates should be considered as a suitable solution for improving the strain capacity of SCC before macrocracking localization (Figure.1.12). It is an interesting property for enhancing the durability of cement-based structures when resistance to cracking due to imposed deformation is a priority and is an interesting approach to control shrinkage cracking, which particularly affects large cement-based areas such as slabs and pavements.

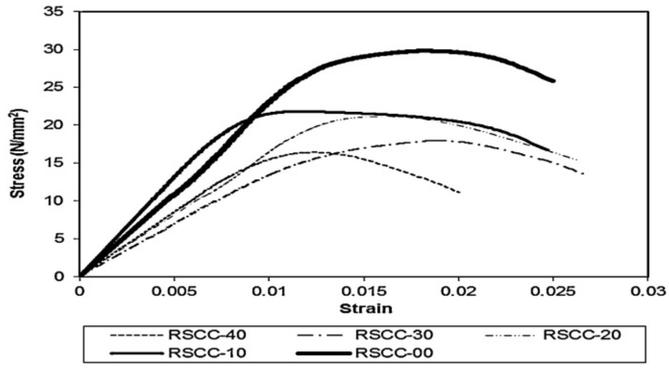


Figure.1.11. Compression stress–strain curves [18].

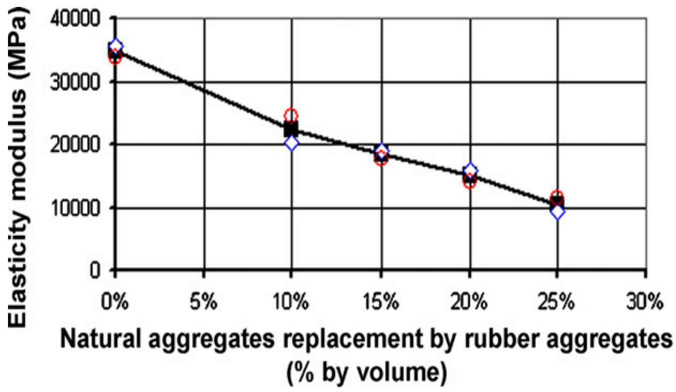


Figure.1.12 . Effect of rubber aggregate content on the modulus of elasticity [96].

Some of the most beneficial properties of rubberized concrete include its behavior under dynamic loading, making the enhancement of these properties desirable in comparison with the brittle and rigid behavior of conventional concrete.

Uygunog˘lu et al. [136] tested the effect of incorporated 50% rubber aggregates on the dynamic elasticity modulus of self-compacting mortars. They mentioned that the results of the dynamic modulus of elasticity of the self-placing mortars were 28.0, 24.8, 24.0 and 22.6 GPa, and the values for self-placing mortars incorporating 50% of the rubber aggregates were 14.7, 11.0, 10.6 and 7.1 GPa with ratios E / C = 0.40, 0.43, 0.47 and 0.51 respectively. Concluded that the decrease in elastic modulus due to the rubber content was 47.4%, 55.8%, 55.7% and 68.4% respectively for E / C = 0.40, 0.43, 0.47 and 0.51.

Herrnandez et al. [137] has investigated the dynamic characteristics of rubberized concrete material. They found that the rubberized concrete showed possible advantages in reducing or minimizing the vibration and impact effect due to the unique elasticity properties of the rubber material.

The measured dynamic modulus of the concrete has been reduced as the percentage of rubber particles increases [138,139]. This decrease is may be due to the nature of the rubber aggregates which have an absorbing capacity of acoustic vibrations of about 21 times that of the hardened cement paste [103].

Similar to the results of the compressive and tensile strengths, the effect of fine rubber granules on the dynamic modulus of elasticity is, therefore, less than that of coarse rubber aggregates for the same replacement rate [140].

II.3.1.7 Water absorption

The amount of absorbed water is related to the porosity of the specimens and gives an index of the microstructure state of them. When several researches have shown that the introduction of particles of rubber (crumb or aggregate) reduces the water absorption of the composites.

Benazzouk et al. [141-142] concluded that the presence of rubber particles reduces hydraulic diffusivity by decreasing water absorption. Also, Segre et al. [143] reported that the use of rubber granules as a partial substitution of sand reduces capillary water absorption. This reduction may be due to the hydrophobic nature of rubber particles that have fewer pores accessible to water [23,143].

Contrary to those results, Obinna Onuaguluchi et al. [24] discovered that crumb rubber increased the porosity of concrete. Matthew et al. [144] indicated that the rubber in concrete will increase water penetration depth and the water absorption coefficient. Thomas et al. [65] also found the water absorption of rubberized concrete was higher than the control mix concrete. Also, Gupta et al. [145] found an increase in water absorption of both tested groups with the increase of rubber replaced ratio.

Moreover, Ling et al. [146] produced rubber-concrete paving blocks (RCP) by using rubber as a partial substitute for fine sand and coarse sand. Two particle sizes of crumb rubber: 1 – 3 mm and 1 – 5 mm were used with volume fraction of rubber varied as 0 %, 10 %, 20 % and 30 % named T1, T2, T3 and T4, respectively. They found that the increase of crumb rubber content from 10 % to 30 % increased the water absorption by about 17 % (Figure.1.13). However for water absorption and voids after immersion and boiling in the water, the control specimens showed higher values compared to the RCPB containing crumb rubber. This may be due to high level and proper compaction applied in commercial plant to RCPB containing crumb rubber, where rubber particles help to fill and accelerate pores in concrete mixture (improve microstructure) because rubber particles are much softer (elastically deformable) than the surrounding particles.

The increase in water absorption can attributed to the fact that rubber aggregates leads to a less compact and porous mix and to the low adhesion between aggregates rubber and cement paste, in addition to the appearance of cracks and the increase of occluded air in the mixture, promote the absorption of water and make the rubberized mixture more sensitive to water infiltration compared with control mixtures which are denser thus absorbing less water [147].

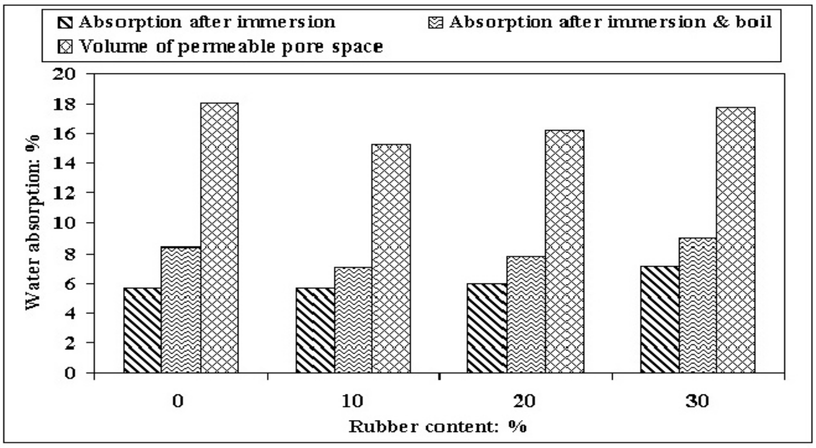


Figure1.13: Relationship between crumb rubber content and water absorption [146].

II.3.1.8 Drying Shrinkage

Shrinkage is one of the most important phenomena influencing the long-term behavior of concrete structures. Drying shrinkage is known to be mainly caused by capillary tension caused by the loss of water from the capillary pores [148]. The most investigations related to rubberized concrete found that rubber reduces the influence of shrinkage on concrete.

For examples, Yong Yu et al. [149] given information about the effects of rubber size on the drying shrinkage properties of mortars modified with rubber. To achieve this objective, they tested three groups of rubber with major particle sizes of 2–4 mm, 1–3 mm, and 0–2 mm. The drying shrinkage results of the rubberized mortars appeared to depend on the size as well as crumb rubber content. Also, they concluded that the shrinkage of mortars increased with the rubber contents, whereas mortars containing smaller rubber particles appeared to shrink much more than those with large rubber particles.

Also, Boudaoud and Beddar [150] studied the characteristics of normal-strength concrete with recycled tires rubber aggregates (size 10 – 12 mm) with ratio comprised from 0- 30%.

They observed that the shrinkage of the mixtures after 28 days was reduced by approximately 35 % for the highest rubber content and the reduction was decreasing almost linearly with decreasing rubber content. Moreover, the rubber additive delays initiation of shrinkage cracks and limits the width of cracks significantly concluded by Nguyen et al. [151].

Canova et al. [152] compared normal-strength concretes containing rubber powder (≤ 0.5 mm particle size) which comprised 6 – 12 % volume of aggregate. They mentioned that shrinkage after 28 days was reduced by 12 – 33 % compared to reference concrete without rubber powder. Add to this, the shrinkage depends not only on the amount of rubber, but also on the size. Rubber crumbs have been reported to have less shrinkage compared to rubber in powder form [153].

In contradiction to the previous results, Yu and Zhu [154] found shrinkage of cement mortars to increase with increasing rubber content and decreasing particle size. Shrinkage after 140 days was increased by 5 – 30 %.

In the same context, Turatsinze et al. [155] investigated the effect of rubber aggregates on the free and restrained shrinkage of rubberized mortars. They replaced natural sand with crumb rubber aggregate with percentages of 0%, 20%, and 30% by volume. The maximum size of both sand and rubber aggregate was 4 mm. The same curing condition for free and restrained shrinkage (20 0C and 50% R.H) was applied. Their results show that free shrinkage (length change with time) increased with incorporation of crumb rubber in concrete mixture.

Another study conducted by [156] revealed that when fine aggregates are replaced by 5% and 10% rubber aggregates, drying shrinkage increases by 24% and 34% respectively. This is may be due to the weak bond between the rubber and the cement paste and the deformable nature of the rubber aggregates.

II.3.2 *The effect of rubber aggregates on the concrete durability*

II.3.2.1 Water permeability ratio

The durability of the material is often highly related to its capacity to resist the water absorption and particularly in the presence of dissolved aggressive ions and also depends on the crack width, length and number. Due to the surface characteristic of rubber particles, the adhesion between rubber particles and matrix is low. This situation causes plenty of porosities. The porosities in concrete result in high permeability characteristic.

Güneyis et al. [15] treated rubberized concrete specimens under the water permeability test. They observed the lowest water permeability value of 25 mm was achieved at SF10R0 concrete while the maximum 150 mm was observed at SF0R25 and SF10R25.

Li-Jeng Hunag et al. [107] Showed that the permeability ratio increases with the rubber particle replacement percentage. In addition, when the rubber particle replacement percentage is 40%, moisture begins to leak away due to an excess of pores, so the permeability ratio cannot be measured correctly.

Besides, Ganjian et al. [9] have examined the use of tires as a substitute for filler in concrete. They used rubber granulate as a substitute for coarse aggregate of the concrete components and rubber dust in 5%, 7.2% and 10% weight substitute was used to replace cement. They concluded that the replacement of rubber increases water permeability depth in the concrete mixtures. The substitution of 5% and 7.5% tire rubber showed mechanical properties similar to the control sample and it's classified as low permeability according to DIN standard.

Other researchers [157,158] have an agreement that the rubber composites are weaker regards to penetration of water (under pressure) and chemical actions, because of their depth permeability.

Ganesanet al. and Gesoğlu et al. [105,159] reported a contrary behavior. Increasing the rubber content decreases the water permeability because the rubber particles act as a barrier to the passage of water.

II.3.2.2 Resistance to acid attack

Sulfuric acid can take place in chemical waste, ground water, acid rains in which it can be one of the components especially in industrial zones. So, determination the resistance of cementitious materials to the sulfuric acid attack is so important. It is noteworthy that until now there is no clear agreement about the effect of sulfuric acid in rubberized concrete behavior.

In the study of the performance of high strength rubberized concrete in aggressive environment, Thomas et al. [2] reported that at 28 days the percentage loss in weight was found gradually increasing from the control mix to the specimen with 7.5% crumb rubber and then it started to decrease in all the mixes up to 20% replacement of crumb rubber. Add to this, the development on acid attack resistance of rubberized concrete can explained by the presence of crumb rubber particles, whose serves to holding the constituent particles of the concrete from breaking away by preventing the formation of cracks and material separation. While in the concrete with no crumb rubber or less amount of crumb rubber, more cracks were developed and the constituent materials were easily separated.

Contrariwise, F. Azevedo et al. [26] found on concrete incorporate fine aggregates with RW by 5%, 10%,15% levels that the increase in the rubber percentage leads to mass loss degree.

II.3.3.Conclusion

The bibliographic synthesis carried out in this work relating to composites based on rubber granulates mainly shows that:

- RW was used mainly as replacement aggregates for traditional concrete aggregates: as fine aggregates for substitution of natural sand and coarse aggregate for substitution of gravel.
- With the incorporation of the aggregates of RW, the composites elaborated were gained in fluidity and lost their mechanical performances.
-Their densities in the dry state also decrease with the increase in the rate of rubber aggregates (GC). This is attributed to the low density of the rubber as well as the increase of the air entrainment in the matrix related to the hydrophobic nature of the rubber.
-GC incorporation affects static and dynamic modulus of elasticity with increasing rubber content. The rubber absorbs the ultrasonic waves, leads an increase in the deformability index and failure strain.
- Generally, the introduction of particles of rubber (crumb or aggregate) reduces the water absorption of the composites.
- The weak link between the rubber particles and the cement paste seems to be the main reason for the penetration of water under pressure.
-The most investigations found that rubber aggregates reduces the influence of shrinkage on concrete.

II.3.4 The effect of waste glass on the characteristics of fresh and hardened concrete

One of the possible applications of glass waste is its valorization in the manufacture of cements and concretes; the recycling of glass waste as alternative aggregates or powders is a particular interest since it considerably reduces the problem of waste storage and, on the other hand, can contribute to the preservation of natural aggregates. However, utilizing waste glass as aggregates show a negative effect via the Alkali- silica reaction, while glass powder finely grounded was a positive effect on the physical, mechanical and durability of cementitious materials. Research works carried out so far in the development of new binder from waste glass powder showed that much has already been investigated and also that an environmental friendly alternative to Portland cement is rising.

In this section, we have compiled some of the related works.

II.3.4.1 Consistency

So far, there is no general agreement on the glass concrete slump; it was often discussed, yet rarely well understood. There many works reported that glass waste powder can increase the concrete and mortar flow. As reported by Soliman et al. [31] when studied the ultra-high-performance concrete using glass powder, they showed that the flowability of concrete increased slightly when the GP content increased. This slight improvement was due replacing cement particles with GP particles, which have low water absorption and smoother surfaces. Another explanation for workability increasing with increasing GP content is cement dilution, which tends to reduce the formation of cement hydration products in the first few minutes of mixing. Therefore, there are insufficient products to bridge various particles together.

Also, Ali et al. [32] showed similar observation that the increase of glass powder cement replacement level increases concrete slump. These results agree with the test results of water requirement to produce the standard consistency cement paste where the use of glass powder decreases the required water content to produce the same consistency. This behavior may be due to the glassy surface and low water absorption of glass powder or may be attributed to the coarser particles of glass powder compared with cement. Another agreement [33] said that there is a systematic increase in slump as the plotted against glass powder content. Glass powder more glass powder in the mix increases. The slump ranged from around 40mm for the reference mix (i.e. 0% glass powder) to 160mm at 40% glass powder.

In addition, the slump and air-content values were within the designed ranges. More detailed laboratory studies showed that GP enhances concrete workability [41]. Moreover, Esraa et al. [160] investigated the effect of using recycled glass waste, as a partial replacement of sand on the fresh and hardened properties of self-compacting concrete. They observed that the slump flow increased with the increment of recycled glass content.

Despite the study's findings that slump increases as glass waste content increases in concrete mixtures, another studies have reported the opposite effect. As reported by Vandhiyan et al. [161]. The test results showed that the use of glass powder has a negative effect on concrete workability. According to Topçu et al. [162] and Ismail et al. [163], waste glass concrete exhibits slightly smaller slump values than plain concrete. Also, in a study on workability by Kou and Xing, glass powder minimally decreases the workability according to flow table results [164]. By the same way, Bashar Taha et al. [165] have concluded that the presence of recycled glass sand in concrete reduces its compaction compared to the control mix.

II.3.4.2 Unit weight

Concrete mixes containing waste glass generally had lower dry densities than mixes without waste glass, due to the glass having a lower specific gravity than general rock and due to the higher air content of concrete with it [164,165]. Similar to that reported by Topçu et al. [162] where crushed green soda glass was reduced to 4-16 mm to replace coarse aggregate in proportions of 0-60%. They observed that the unit weight of concrete made with glass is generally lower than that of concrete made without glass due to the glass particles (WG) having a lower specific gravity than general rock. Add to this, the low air content in concrete containing a high proportion of WG is thought to be connected to the smooth surface of WG which helps decrease the porosity of the interface zone between the WG and cement paste.

Another explanation reported by Tan et al. [166] mentioned that the sharper edges and higher aspect ratio of glass particles resulting from the crushing process and the brittle nature of glass enabled more air to be retained at the surface of glass particles in comparison to natural aggregates. The tendency of air content increase may be due to the that glass particles have an irregular shape compared to natural aggregates, resulting in a larger relative surface area that maintains more air which reducing unit weight of mixtures [167].

II.3.4.3 Compressive strength

As the workability of glass concrete, there is disagreement too about the effect of waste glass on the compressive strength of concrete and mortar.

The addition of waste glass decreased the compressive strength for all concrete mixes at 7 and 28 days [168]. This decrease in compressive strength is may be due to the high brittleness of glass leading to cracks which result in incomplete adhesion between the Waste Glass and cement paste, while the poor geometry and reduced specific gravity of glass leads to a heterogeneous distribution of aggregates reported by Topcu et al. [162].

Also, Park et al. [167] found that concretes at a later ages (Four-week) with 30%, 50%, and 70% glass replacement of natural aggregate displayed a reduction in compressive strength, resulting in 99.4%, 90.2%, and 86.4% compressive strength relative to that of reference one. This finding is similar to that conducted by Tung-Chai Ling et al. [169].

Contrary to those findings, Taha mentioned that the compressive strength of the concrete mixes did not exhibit distinguished differences when recycled glass sand was used to replace natural sand [165]. However, the replacement of cement with glass powder (GP) yielded higher compressive strength values. The concrete mixtures with 10% and 20% GP exhibited higher mechanical properties at both 56 and 91 days due to the pozzolanic reaction of the GP with the hydrated cement product, which took place at a later age [31]. Moreover, when the GP content increased in the concrete mixture, the w/c increased, which accelerated cement hydration. More portlandite can be generated, and more GP pozzolanic reaction developed, which yielded the successive strength improvement.

Add to this, Ali et al. [32] practiced the use of waste glass powder obtained from grinding of crushed containers and building demolition to produce glass powder blended cement as concrete additives. The considered glass powder contents were 0.0%, 5.0%, 10.0%, 15.0%, 20.0% and 25.0% by weight of cement. Concerning the strength of concrete they observed that the use of glass powder as cement replacement up to 10% improves slightly the mortar compressive strength at the considered ages. However, the increase of replacement level more than 10% decreases the mortar compressive strength.

In addition, in this study portland cement (PC) was partially replaced with 0-40% glass powder [33]. There is an increase in compressive strength at 10% glass powder compared to the control one.

Chemical composition of glass powder can affect the strength of the cementitious material as reported by M.C. Bignozzi et al. [35] increasing glass formers content in the glass leads to a further reduction of alkali–silica reaction (soda-lime and fluorescent lamp glasses). However, the amount of glass modifiers (e.g. fluorescent lamp glass) negatively influences the pozzolanic reaction. Comparing soda-lime and fluorescent lamp glasses, the higher amount of Na_2Oeq + PbO and the lower amount of the glass stabilizers CaO + MgO for LMP promotes an high degree of sodium dissolution, which is involved in gel formation, thus modifying its chemical composition and, as a consequence, its mechanical properties.

According to [29,31,38,39] the amorphous silica in glass powder appeared more active with lime and forms C-S-H at a later stage of hydration.

Maddalena Carsana et al. [38] the reference mortar had 28-day compressive strength of about 66 MPa, while the substitution of cement with 30% of waste glass powder led to a strength of 53–57 MPa (depending on the fineness of the addition). The compressive strength of mortars with glass reached at later age high values, comparable or even higher than those of the reference mortar and mortar with fly ash (Figure.1.14).

Omran et al. [41] provides the results obtained from the various field sites for the different curing times of concrete modified with glass powder. The SAQ-GP yielded a higher f_c at early age and on the long-term (2 years) than the SAQ-Ref. GP concrete mixtures of 30 MPa was achieved, with the two mixtures recording values were 36 and 32 MPa, respectively. Also, they concluded that the advantage of using GP in concrete lies with continued strength gain at later ages due to pozzolanic activity.

Besides, the level of substitution of glass powder influences the mechanical performance of cementitious materials [41,170,171].

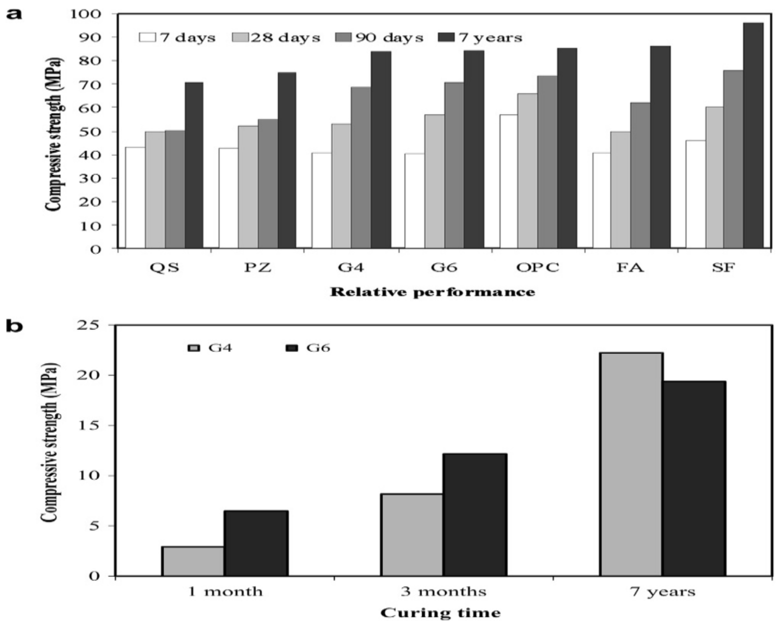


Figure.1.14. Compressive strength measured after 7, 28 and 90 days and 7 years of curing on cement mortars with different mineral additions (a) and compressive strength of lime-glass mortars as a function of time (b) [38].

Hongjian Du et al. [172] observed a generally strength decreases with GP content more than 15% at 7 days. However, at 28 and 91 days, no reduction in strength was observed for concrete with 15 and 30% GP, due to the pozzolanic reaction between GP and cement hydration products. Instead, concrete with 15 and 30% GP possessed higher compressive strengths. The amorphous silica in the glass would dissolve in an alkaline environment such as due to OH^- ions in the pore solution of cement paste. Thereafter, it could react with calcium hydroxide (CH) to form secondary calcium silicate hydrate (C-S-H), a process known as pozzolanic reaction which can be expressed by $CH + S + H \rightarrow C\text{-}S\text{-}H$, moreover, At 91 days, peaks corresponding to CH can be obviously seen for OPC and 30GP paste, which means that CH remains even after 91 days of pozzolanic reaction with glass powder [161].

Nathan Schwarz et al. [173] compared the effect of glass powder and fly ash of concrete. The results of the compressive strength show the 28 day compressive strengths of concretes with

10% glass powder replacing cement were found to be higher than that of fly ash concretes at the same replacement level, whereas the 90 days strength of fly ash modified concretes were higher than the corresponding glass powder modified concretes. However, the strength difference was only of the order of 5%, suggesting that concretes with 10% of cement replaced either by glass powder or fly ash will behave in a similar manner as far as mechanical properties are concerned.

II.3.4.4 Flexural and tensile strengths

The flexural and tensile strengths behavior of the cementitious materials modified with glass waste is similar to that of the compressive strength [38,39,41,174]. Examples, the study practiced by Mehmet Saribiyik et al. [174] replacement of glass powder into the mixture caused the flexural strengths of the samples to increase more when compared to the increase in the amount of resin. This increase is directly proportional to the ratio of glass powder used in the mixture.

II.3.4.5 Static and dynamic modulus of elasticity

Studies indicate that introducing glass aggregates in concrete leads to a decrease in the modulus of elasticity (ME). Topçu and Canbaz [162] observed that with the highest glass aggregate incorporation ratios in concrete the ME decreased. Moreover, they found a remarkable decrease of modulus of elasticity as the incorporation ratio of glass aggregates increases. Similar to those conducted by [175,176].

In regards to the effect of particles size of glass waste, it seems that the incorporation of glass powder in cementitious materials enhances the ductility of them. Niang et al. [177] incorporated glass powder (GP) with Blaine fineness =440 m^2/kg to replace 20 % of cement in too concrete. They observed that the ductility and toughness of concrete with 20 % GP were similar or slightly higher than that for concrete. In addition, they concluded that in all studies cases, the concretes made with 20 % GP showed good structural behavior. Similar observation obtained by Yildirim et al. [178] stating that the specimen with 5% glass powder replacement in concrete has the highest value, and that with 10% glass replacement has a better value than the specimen without it.

II.3.4.6 Water adsorption

The decrease of VPV and WA is an indication of the improvement of the durability of the cementitious material [32].

From the research work carried out in this area by Dhirendra Patel et al. [179] it is well established that using glass powder (GP) in replacing O.P.C up to 10–20% with a fineness of (75–63 μ) gives satisfactory results concerning water adsorption of mortar. The work presented revealed a reduction in water absorption about 5% for GP75 and GP63 mortar cubes at 5% substitution level and at maximum substitution level say 20% this value was 30 and 34% respectively. This can be due to the negligible surface water retention property of GP as compared to particles of cement matrix and improved microstructure, which in turn down the percentage of water absorption. Similar findings observed by Mehmet Saribiyik et al. [174].

For the effect of glass powder in water adsorption of concrete, Yildirim et al. [178] pointed that the water absorption decreases from 6.46 to 6.05 when the GP reaches 10% level, however, the Water absorption increased when it is higher than 10% in the concrete. This increase is remarkable when the fraction is 20%.

Similarity, Loïc Rodierto et al. [180] when evaluated the potential to use glass powder finely grounded in the cement industry. They partial substitute cement by 10% by weight of glass powder (GP), which leads to a decrease of 15% of the volume of permeable voids and water absorption in comparison to Control (mortar without mineral addition).

They explained this result by the good reaction between the amorphous silica present in GP and the lime produces CS-H, which fills the capillary pores.). Finally, they concluded that the glass powder can be used as partial replacement up to 10% by weight to improve the durability of cementitious materials.

II.3.4.7 Durability

II.3.4.7.1 Permeability

Understanding of the structure and behavior of concrete with waste glass could help to improve concrete properties and make concrete more durable. Characteristics like permeability are important to designing concrete structure since an overall picture of concrete quality.

It seems that using glass waste finely grounded as partial replacing of cement or sand in cementitious materials decrease the water penetration depth [41,181]. In this regards, Xin et al. [181] mentioned that relative to the plain concrete, the water penetration depth was reduced by 54, 65, 68 and 80% for cement replacement level of 15, 30, 45 and 60%, respectively. Moreover, they concluded that the depth of water penetration continuously decreases with higher glass powder content. Add to this, Hongjian et al. [172] found that concrete with 15% Glass powder additive showed much lower water penetration depth compared to the reference concrete. The refined pore structure is the main reason for this reduced permeability.

Aladdine [182] stated that the pores connectivity more or less relative to the proportional rate of substitution. He said that the reduction of pore connectivity can be due to the filling capacity by the resultant hydration products or by the unreacted filler particles.

II.3.4.7.2 During shrinkage

Drying shrinkage found to decrease with the addition of glass powder. Dhirendra et al. [179] treated the effect of tow glass powder fineness GP75M and GP63M on the drying shrinkage of mortar. The results with (0%, 10%, 20%) replacement with glass powder showing, that GP63M has the lower drying shrinkage and close to control. Moreover it will be increased as the replacement level is going up. They explained those results by the ability of fine glass powder grains to adhere with those of cement which in turn improved accumulated fine particles in cement–glass powder interaction regime. This causes to reduce the water demand of the mixes which reflected an increase in drying shrinkage.

Other researchers found that the addition of 10% recycled waste glass slightly reduces the drying shrinkage compared to the reference one. However, when the amount of recycled waste glass is increased to 30%, the sample shows a slight increase in shrinkage [183]. They explained that by the lower cement content results in a low content of bound water, which means more evaporable water is present; on the other hand, the reduction of cement cannot produce enough calcium hydroxide for the pozzolanic reaction of glass powder, which produces a lower amount of C-S-H gel. As a consequence, the water loss of samples containing high dosage recycled waste glass in dry air condition also contributes to the high total drying shrinkage.

II.3.4.7.3 Resistance to sulfuric acid attack

Research on the resistance to sulfuric acid attack of composites based on glass waste is very limited in the literature.

Ling and Poon [169] studied self-compacting architectural mortar using recycled blue glass as aggregate replacement and metakaolin as cement replacement. They treated the effect of different particle sizes of glass aggregates on the mass loss of self-compacting mortar subjected to 3% sulfuric acid attack. Results showed that including glass aggregates in mortar significantly reduced mass loss, up to 100% replacement rate.

Wang [184] studied the effect of LCD glass powder proportions on cement mortar performance, testing the mass loss less after five cycles of one day drying and one day immersion in concentrated H_2SO_4 solution. Results show that 10% replacement content was optimum for lower mass loss from 10 to 50% substitution. Moreover, increments in mass loss were also registered in specimens with glass powder replacement exceeding 20%.

Hocine et al. [185] investigated the effects of different glass powder contents as cement replacement on the behavior of mortars in a sulfuric acid environment. The substitution levels were 15%, 30% and 45% GP. Reference mixtures, shows the worst resistance to H_2SO_4 attack, with 39.1% mass loss registered after 12 weeks' immersion. However, mortars with GP, mass loss decreased gradually with GP replacement dosage. After 12 weeks' immersion time, 3%, 10% and 15% differences were calculated between M0 and MGP15, MGP30 and MGP45, respectively. These results confirm the higher resistance of mortars containing GP, especially with high GP replacement levels.

II.3.4.8 Alkali-silica reaction (ASR)

Using waste glass as coarse or fine aggregates or as cement replacement material was hindered because of the risk of alkali–silica reaction (ASR) property.

Some of researchers like Topçu et al. [186] reported that the ASR caused expansion and internal stresses in the concrete in direct proportion to the amount of glass in the concrete. Moreover, according to other works, Alkali–silica reaction (ASR) problems were noticed in concretes containing larger particle sizes [187,188]. In this regards, several results report the existence of a critical size that would enable the pozzolanic reaction without the subsequent formation of an expansive gel as a result of the alkali-silica reaction [189-192].

Add to this, D. Serpa et al. [193] concluded that waste glass could be used with natural non-reactive aggregates without deleterious expansion, depending on its replacement content.

Contrary, in some cases [194,195] the expansion of mortar found to decrease as the glass replacement level increases. It was found that using glass waste as form of powder finely grounded can mitigates expansion of mortar.

Zainab Z et al. [196] demonstrated that the finely crushed waste glass helped reduce expansion by 66% compared with the control mix. Also, it is found that with the increase in waste glass contents to 20%, there is a clear reduction in the expansion of the specimen (equal to 66%) as compared to the control mix. This decrease in the expansion of the specimens is related to the reduction of available alkali due to the consumption of lime (librated by the cement hydration process) by reaction with fine waste glass and the expected reduction of the system alkalinity.

II.2.4 Conclusion

The bibliographic synthesis carried out in this work on composites based on glass waste essentially shows that:

- The recycled glass waste has been used mainly as aggregate and filler in concrete and mortars.
- With the incorporation of aggregates or glass powder, the composites developed were generally lightened, lost or gained their mechanical performance according to the rate of substitution and particle size.
- Generally, glass powder enhances the fluidity of cementitious materials.

- Glass powder can safely be introducing to concrete when is finely grounded.

-Indeed, for economic and environmental reasons, the use of recycled glass in cement and concrete has attracted the interest of many municipalities which encouraged further studies.

CHAPTER THREE

Research Plan and Methodology

III.1 Introduction

This chapter describes the research plan and methodology in this thesis. In the first part of this chapter following sections, we will present the characterization of the basic materials for the preparation of the concretes envisaged. These are the physicochemical, mechanical and mineralogical characteristics of cement, sand, coarse aggregates, mixing water, rubber granules, glass waste powder, natural sand powder, and superplasticizer. Subsequently, manufacturing procedures, mixing sequences, placement, and conservation of different test pieces.

In the second part, we described the materials and methods used in the research in the fresh and hardened state.

III.2 Characteristics of the materials used

III.2.1 Cement

A local ordinary Portland cement (CEM II 42.5) produced by the cement plant of Hadjar Soud (Department of Skikda, northern of Algeria), complying with Algerian Standard NA 442 was used as a binder for all the mixtures. CEM II has a mean compressive strength at 28 days of 46 MPa, its absolute density and specific area were 3.1 g/cm^3 and 3.48 g/cm^2 respectively (see the Table.2.1). Its chemical composition is given in Table.2.2. The laser granulometry curve is shown in Figure.2.1 and the photomicrograph at a magnification of 5.000, in Figure.2.2. Also, the Figure.2.3. presented the cement XRD analyses.

Table.2.1. Physical properties of the studied portland cement.

Material	Apparent density (Kg/cm^3)	Absolute density (Kg/cm^3)	Normal consistency (%)	Setting time (min)	Blaine specific surface (g/cm^2)
Portland cement	1057	3100	29	154	3.48

Table.2.2: Chemical compositions of the used Portland cement.

Chemical composition	(%)	Clinker composition	(%)
CaO	56-63	C_3S	50-65
Al_2O_3	4-6	C_2S	10-25
SiO_2	19-27	C_3A	9-12
Fe_2O_3	2.5-3.5	C_4AF	7-11
MgO	1-2		
Na_2O	0.1-0.6		
K_2O	0.3-0.6		
Cl^-	0-0.2		
SO_3	2-3		
Free CaO	0.5-2.5		

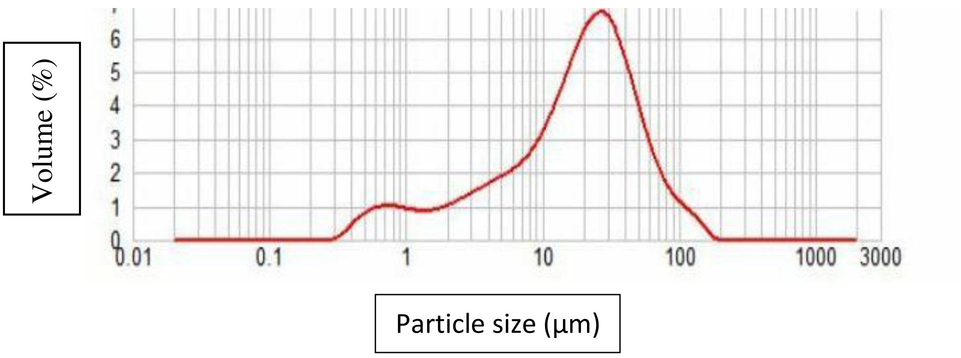


Figure.2.1. Laser granulometry curve of cement.

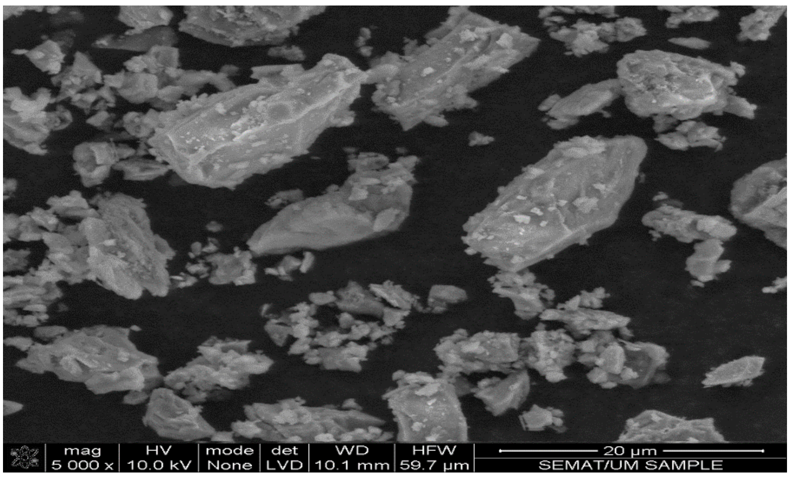


Figure.2.2. Cement photomicrograph (X 5000).

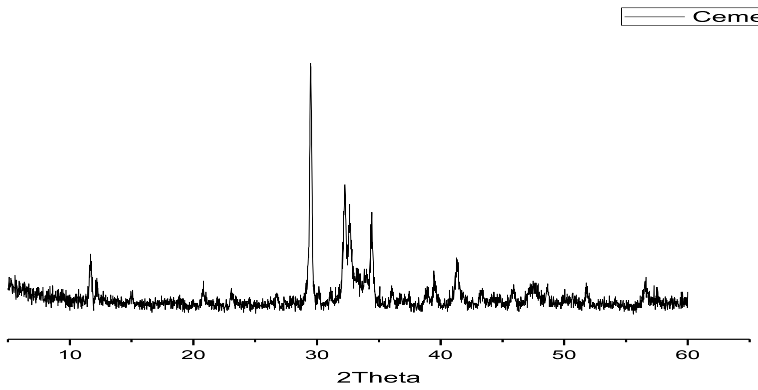


Figure.2.3. Cement XRD analyses.

III.2.2 Mineral additions

In order to study the influence of the incorporation of mineral additions on the behavior of concrete in fresh and hardened states, two additions were used in this study. The additions were prepared at the Laboratory of Biskra. A ball mill with a capacity of 400 g was used for grinding. The configuration of the balls and the grinding time were kept constant throughout the procedure.

III.2.2.1 Waste glass bottle powder (GP)

This powder is the outcome of the glass bottles recovery in landfills. It was obtained by selecting only the bottles of the same color (green). These were cleaned, crushed and finely grounded (Figure.2.4) by an electric mill without any treatment. The absolute density of this waste is 2.18 g / cm^3.

According to the usual classification of the French standard NF XP 18-540; the glass powder was classified as filler material because 74% of the particles passed though the sieve of 36 µm (Figure.2.5). Chemical analysis determined using X-ray fluorescence technique (XRF) is presented in table.2.3. The basic component (73.6%) was the silica dioxide (SiO_2) and the proportion sum of SiO_2, Al_2O_3 and FeO_3 was 75.8% (>70%) allowing to the used glass powder to be classified as a good pozzolan according to the ASTM C618-02 norm. The morphology of glass powder using scanning electron microscopy (SEM) at a magnification of 5.000 is shown in Figure.2.6. The absence of peaks in the diffraction diagram of the glass powder (Figure.2.7) confirms its amorphous state.

Figure.2.4. glass powder waste.

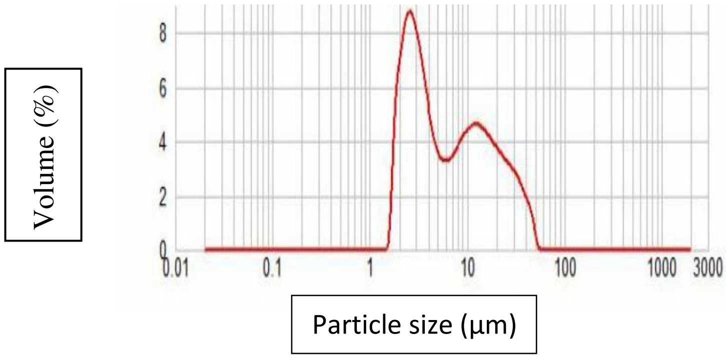


Figure.2.5. Laser granulometry curve of glass powder.

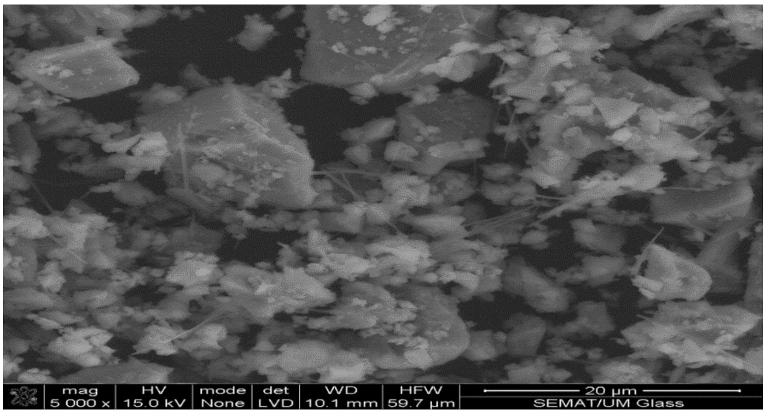


Figure.2.6. Glass powder photomicrograph (X 5000).

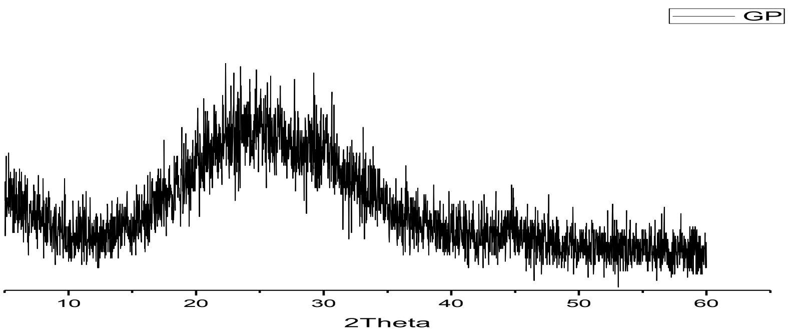


Figure.2.7. Glass powder XRD analyses.

Table.2.3. Chemical compositions of glass and sand powders.

Chemical compound	GP (%)	SP (%)
SiO_2	73.60000	93.60000
TiO_2	0.02560	0.09700
Fe_2O_3	0.79700	1.48000
Al_2O_3	1.44000	1.70000
CaO	8.04000	2.25000
MgO	2.78000	0.15300
SO_3	0.23600	0.03550
Cr_2O_3	0.04700	0.23600
ZnO_2	0.00773	0.01510
BaO	0.01380	0.00776
K_2O	0.34400	0.29600
Na_2O	12.60000	0.02900
Sn	//	0.00478

III.2.3 Natural sand powder (SP)

The sand powder (Figure.2.8) was obtained by mechanical grinding (electric mill) of the same natural sand utilized in the mixtures. Its absolute density was 2.54 g/cm^3. Its chemical composition and distribution size are reported in Table 2.3 and Figure.2.9, respectively. The principal component (i.e.SiO_2) rate is 93.6%, much important compared to the glass nature one. Its photomicrograph and (XRD) analyses are shown in Figure.2.10 and Figure.2.11. respectively.

Figure.2.8. sand natural powder.

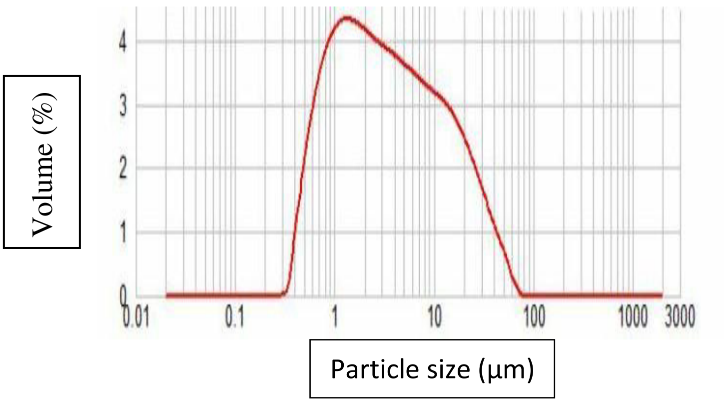


Figure.2.9. Laser granulometry curve of sand powder.

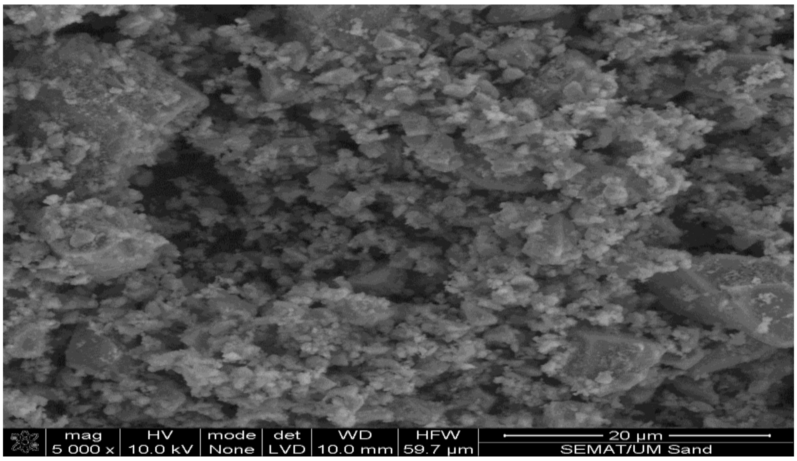


Figure.2.10. Sand powder photomicrograph (X 5000).

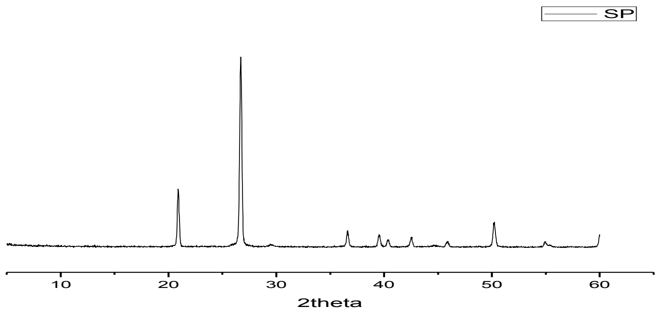


Figure.2.11. Sand powder XRD analyses.

III.2.4 Fine aggregates

These are natural sand (NS) and artificial crushed sand (CS). The NS was collected from Boussada (Department of Msila, northern Algeria). It has a siliceous nature with 93.6% of SiO_2. Its fineness modulus and absolute density were 1.33 and 2.54 respectively while its sand equivalent assessing its cleanliness was equal to 70. Figure.2.12. exhibits its particle size distribution as well as that of CS, RW and coarse aggregates.

The (CS) was collected from a career located at Ain Touta in Souk Ahras department (eastern Algeria). It is a calcareous sand with an absolute density of 2.51 and a fineness modulus of 3.51. Its maximum particle size, as determined by sieving method, was 4.5 mm (Figure.2.12).

III.2.5 Coarse aggregates

Two types of calcareous gravels collected from the same career of Ain Touta, having 3/8 mm and 8/15 mm in dimensions, were used to manufacture the reference concrete. These properties have been measured by using NF P18-560 , NF P18-554 and NF P18-573. Their distribution curves, as presented in Figure.2.12, are continuous and their absolute density and water absorption were 2.5 and 1.75% respectively. More information were sammarized in the Table.2.4.

Table.2.4. Physical properties of coarse aggregates.

Material	Apparent density (Kg/cm)	Absolute density (Kg/cm)	Porosity (%)	The water content (%)	Absorption coefficient (%)
Rgavel (8/15)	1300	2500	48	0.79	2.55
Graval (3/8)	1300	2500	46	0.76	2.55

III.2.6 Rubber waste aggregates (RW)

Rubber waste aggregates (without steel fibers) used in this study were obtained by mechanical grinding of worn tires from a local factory (Algeria). Their dimensions were ranged between 0.2 and 4 mm (Figure.2.12). Its absolute density, as calculated according to ISO 2781-2008 code, was found to be 0.98 g/cm^3 and its aspect is shown in Figure.2.13.

III.2.7 Superplasticizer

Superplasticizer used in the concrete mixes named Master Glenium 24, is based on modified ether polycarboxylic according to the standard EN 934-2:2012. It ensures high water reduction, high performance and very long workability.

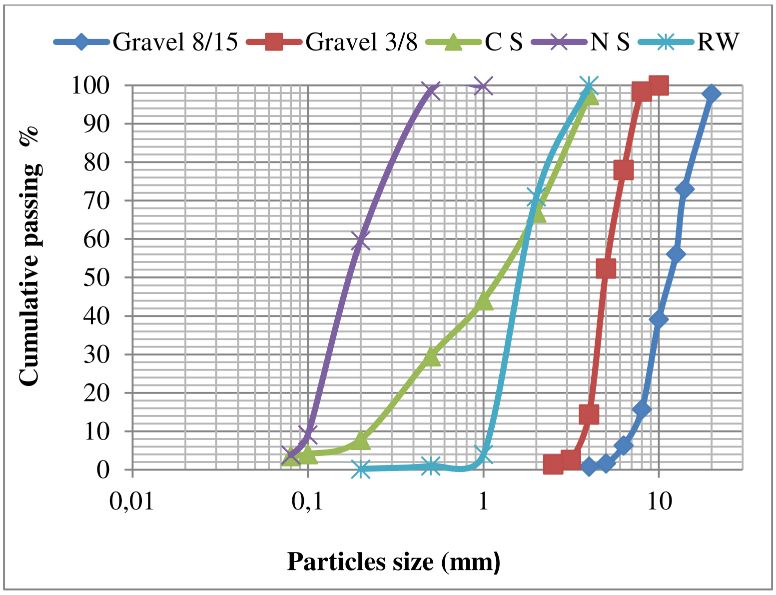


Figure.2.12. Grain size analysis of the used raw materials.

Figure.2.13. The aspect of Rubber waste aggregates.

III.2.8 mixing water

The mixing water used is tap water from the LRGC laboratory of Biskra university. Its quality complies with the requirements of standard NF P 18-404.

III.3 Formulation of the studies concretes

III.3.1 Reference concrete

In order to adopt the compositions of the concretes to be used for the study of physico-mechanical and durability characteristics, we sought to formulate a basic preliminary composition on the basis of mechanical criteria.

III.3.1.1 Tests the type of different sand and the granular effect

The systematic study of mechanical resistance of the studies mixtures according to the type of sand (dune sand and crushed sand) and the particle size distribution of aggregates (combination of them), allowed us to choose the optimum mix of the reference concrete (C-ref) without any additive (rubber aggregates, glass powder, and dune sand powder), having optimal mechanical strengths. The cement dosage was fixed to 400 kg/m^3. Quantities of granular components were obtained by Deux-Gorisse method [73] while water and superplasticizer were determined experimentally on the basis of slump test (NF EN 12350-2) to achieve a slump value about 60 mm corresponding to a plastic concrete.

- A1: in the first mixture we used siliceous dune sand collected from the wilaya of Tebessa (Algeria), having absolute density of 2.68 Kg/m^3 (its physical characteristics and chemical composition are summarized in Table 2.5. and Table.2.6 below respectively), Coarse aggregates 3/8 and 8/15 (mentioned in the previous section III.2.5), Portland cement CEM 42.5 (details mentioned in the previous section III.2.1).
- A2: in the second one, combination of two types of sand was made; the same dune sand utilized in the first composition and the calcareous sand (CS) (all details presented in previous section III.2.4), Coarse aggregates 3/8 and 8/15 and Portland cement CEM 42.5 were used too to prepare the concrete.
- A3: in the third mixture, we utilized the natural sand which collected from Boussada and the calcareous sand (CS) (all details presented in previous section III.2.4), in addition, the Coarse aggregates 3/8 and 8/15 and the Portland cement CEM 42.5.

The resulting compositions are recorded in Table 2.7 below.

Table.2.5. Physical properties of dune sand collected from the wilaya of Tebessa.

Material	Apparent density (Kg/cm)	Absolute density (Kg/cm)	Porosity (%)	Fineness modulus (M.F)	ES (%)	Water absorption (%)
Dune sand of Tebessa	1610	2680	40	2.5	2.66	80.52

Table.2.6. Chemical composition of the dune sand collected from the wilaya of Tebessa.

Chemical composition	TS (%)
SiO_2	96.50000
TiO_2	0.04420
Fe_2O_3	0.65500
Al_2O_3	1.70000
CaO	0.50700
MgO	-
SO_3	-
Cr_2O_3	0.09400
ZnO_2	0.00758
BaO	0.44900
K_2O	0.34400
Na_2O	12.60000
Sn	//

TS: Tebbesa dune sand.

Table.2.7: Compositions of the concretes according to the utilized sand type.

Formulation	Cement (kg)	Dune sand (kg)	CS (kg)	Coarse aggregates (kg)		Water (L)	SP-Plast (%)	W/C
				3/8	8/15			
A1	400	627.76	-	189.45	947.32	172	0.5	0.43
A2	400	92.29	553.3	155	930	172	0.5	0.43
A3	400	87.47	484.2	103.32	1050.6	172	0.5	0.43

SP-Plast=Superplasticizer.

The mechanical strengths (compressive and tensile strengths) obtained are presented in Table 2.8 and Figure 2.14.

Table.2.8. Mechanical strengths results of the studies compositions.

Compositions	Compressive strenght (MPa)	Tensile strenght (MPa)
A1	23.25	3.88
A2	34.32	4
A3	40.08	4.66

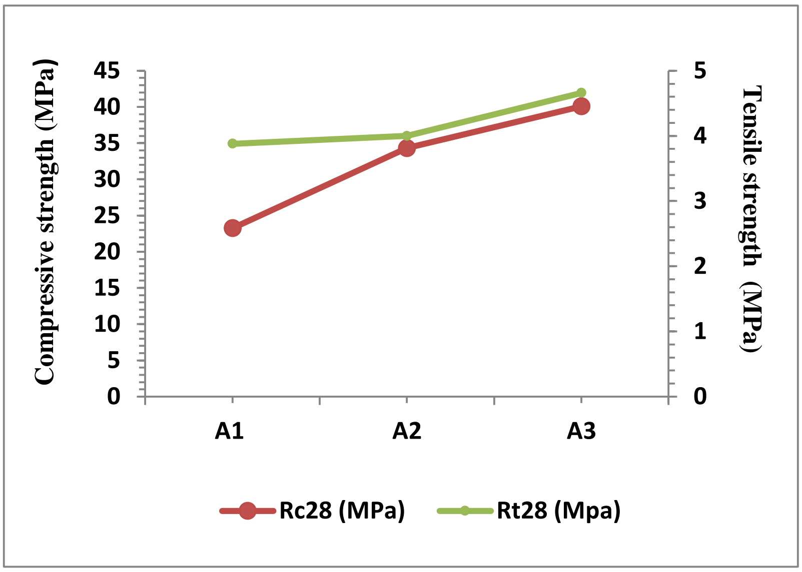


Figure.2.14. Compressive and tensile strengths of the studies mixtures.

The investigations were meant to find out the mixture with the highest compressive and tensile strengths. They were performed on cylindres of concrete specimens. The results show that the most promising mixture (A3) has a compressive strength around 40.08 MPa after 28 days curing, 28 days tensile strength, as determined in accordance with ASTM C496 = 4.66 MPa, average slump = 60 mm, fresh density = 2.47 and W/C = 0.43.

Moreover, when we compare between the three mixtures (A1, A2, A3) it can be seen that combination the dune sand of boussada with CS in mixes more suitable than combination this later with the dune sand of tebessa and in turn more suitable than utilizing the dune sand alone in terms of strengths of concrete. So, the particle size distribution of aggregates marked their influence to the strengths of concrete, similar to those conducted by [6,197]. This is may be due to the higher absorption of the crushed sand (presense of fine elements) compared to siliceous sand, the quantity of the mixing water in crushed sand concrete is decreased. The water excess which should normally remain to create pores in the composite is therefore smaller [197]. According to the same authors the good granular distribution also gives better results. In addition, CS-Concrete also presents another advantage of economic nature: thanks to its high content of fine elements, CS does not need the use of any filler. Moreover,t he pore volume (porosity) of limestone sand concrete is consequently reduced which improves the compactness and the mechanical properties of the material [198].

Reference concrete (C-ref) designed with various combinations of local natural aggregates shows acceptable plastic workability, also generate acceptable and greater strengths compared to other mixes as shown in Figure.2.14. In addition, it appears homogeneous (Figure.2.15) and easy to handle and vibrate in the molds.

From this composition (C-ref) that we launched a campaign of formulation of concretes incorporating aggregates of rubber which we present in what will follow.

Figure.2.15. Physical appearance of the basic concrete (C-ref).

III.3.2 Mix design of rubber mixtures

It was mentioned in a previous chapter that the replacement of natural aggregates with tire rubber aggregates considerably decreases the concrete and mortar strengths. For that, efforts have been carried out to improving the strength of rubber cementitious materials in many ways such as the incorporation of by-products to the basic mixtures. Silica fume, metakaolin, slag waste, brick waste, fly ash, limestone filler has been adopted as an alternative for filling the voids and contributing to the improvement of the compressive strength of these mixtures.

However, the utilization of glass powder waste (GP) and sand powder (SP) in replacement of cement into rubber cementitious materials had not been studied in spite of its pozzolanic reaction with the lime. In our work, the finer glass and sand powders were added as weight replacement of cement to the basic rubber mixtures to compensate for the loss of compactness associated with the incorporation of RW (rubber waste).

The main two reasons for tested the effect of dune sand powder on the rubbercrete performances are:

- The comparison between the effect of addition artificial filler (glass powder) and other natural (dune sand powder) rich in silica and with different vitreous phase; on the same type of concrete.
- The valorization of the huge amount of dune sand present in southern Algeria in the manufacture of cement.

Also, those mixtures has the eco-efficient advantage of containing a content of two industrial byproduct.

Due to the significant difference between the density of crushed sand (2.51) and that of rubber aggregates (0.98), and also because of the hydrophobic nature of the later, segregation was observed when rubber aggregates were added to the mixture, they tend to rise to the top surface of the concrete volume during the vibration especially for the high volume replacement ratio. For that, we choose the lowest W/C ratio and using also the superplasticizer to mitigate this segregation (Figure.2.16).

In addition to this, we thinking that the use of surface treatment of rubber aggregates or the use of chemical components or resin should be avoided in order to understand the effect of these wastes on concrete behavior and also to result in economical materials.

Figure.2.16. The dispersion of rubber aggregates in the composite.

In this part of the work, 15 different mixtures were prepared with the same water/binder ratio at 0.43 level and superplasticizer percentage at 0.5% to more understand the effect of the additions on the concretes behavior, one control concrete (C-ref) for comparison and 14 others with different amounts of rubber waste (RW), glass powder (GP) and sand powder (SP). The fifteen mixtures proportions are listed in Table.2.9.

Rubber aggregates (RW) were used to replace crushed sand in concrete mixes with ratios of 10%, 20%, 40% and 60%, while glass powder (GP) and natural sand powder (SP) were used to replace 15% of the cement weight.

The concretes studied were designated by XRW, XRWYGP, XRWYSP, while, RW,GP and SP designates rubber granulates, glass powder and sand powder respectively. X and Y are the rates variables (%) of RW, GP and SP respectively.

III.3.2.1 Mixing and curing of the studies specimens

During this important operation that has a noticeable impact on the final product, the dry solid components were mixed for 3 min. Once the mixture was homogeneous, a solution containing 80% of water with the totality of the superplasticizer was added and mixed for 2 min. After that, the 20% of water was added and the mixtures were mixed for more 2 min. All mixtures were prepared in a inclined-axis concrete mixer, capacity of 115 liters (Figure.2.17) in a labratory and then cast in steel moulds. After removing from the steel moulds 24 h later, the mixtures were cured in clean water at 21-23°C until the age of the tests (Figure.2.18). The tendency of crumb rubber to the top of the sample during vibration is possible, due to their low specific gravity. For that reason, vibration with poker was utilized to make the rubberized mixtures more homogeneous.

Table.2.9. Mix proportions per cubic meter of concrete.

Mixes	C kg	NS kg	CS kg	Gravel 3/8 kg	Gravel 8/15 kg	RW kg	GP kg	SP kg	W L	SP-Plast
C-ref	400	87.47	484.2	103.32	1050.6	-	-	-	172	2
10RW	400	87.47	436	103.32	1050.6	19	-	-	172	2
20RW	400	87.47	387	103.32	1050.6	38	-	-	172	2
40RW	400	87.47	290	103.32	1050.6	76	-	-	172	2
60RW	400	87.47	194	103.32	1050.6	113	-	-	172	2
0RW15GP	340	87.47	484.2	103.32	1050.6	-	60	-	172	2
0RW15SP	340	87.47	484.2	103.32	1050.6	-	-	60	172	2
10RW15GP	340	84.93	436	101.72	1050.6	19	60	-	172	2
20RW15GP	340	84.93	387	102.05	1050.6	38	60	-	172	2
40RW15GP	340	84.93	290	102.72	1050.6	76	60	-	172	2
60RW15GP	340	85.57	194	103.32	1050.6	113	60	-	172	2
10RW15SP	340	87.47	436	103.32	1050.6	19	-	60	172	2
20RW15SP	340	87.47	387	103.32	1050.6	38	-	60	172	2
40RW15SP	340	87.47	290	103.32	1050.6	76	-	60	172	2

60RW15SP	340	87.47	194	103.32	1050.6	113	-	60	172	2

Component nomenclature: C=Cement, NS=Natural Sand, CS=Crushed Sand, RW=Rubber Waste, GP=Glass Powder, SP=Sand Powder, W=Water, SP-Plast = Superplasticizer.

Figure.2.17. Concrete mixer.

Figure.2.18. Water Curing of the mixtures.

III.4 Experimental test procedures

III.4.1 Slump test

Slump test is to determine the workability or consistency of the studies concretes according to the standard NF P 18-451. Particalarity, it was used to investigate the influence of RW, GP and SP on their workability. For that reason, as we mentioned in previous sections, we have kept a constant W/C for all the mixes.

First, we cleaned and appled oil on the internal surface of the cone. Second, the mold was placed on a smooth horizontal base plate. Third, We fill the mold with the concrete mix prepared in 4 approximately equal layers and tamp each one with 25 strokes. firth, we have to clean the concrete in excess of the surface with a trowel and clean the water leaked out between the mold and the base plate. After that, the mold was raised from the concrete slowly in a vertical direction. Finaly, the slump was measured from the difference between the height of the mold and that of height point of the specimen. Each reported value was the average of measurements of three tests for all mixtures.

III.4.2 Fresh density

Fresh density values can give a first indication concerning the compactness of the concrete. For that, the density of studied concretes specimens was performed to characterize the influence of the added wastes content on the compactness of the mixtures. The determination of the mixtures density was calculated by dividing the mass by the volume of the concrete cube specimens of 100 mm is a side after table vibration directly according to the following procedure: Density (Practical Δ) = (filled mold mass - Mass empty mold) / volume of the mold (under the NF EN 12350-6 code). Each reported value was the average of measurements of three tests for all mixtures.

III.4.3Compressive strength test

The compressive strength test was performed at 7 and 28 days in accordance with the standard ASTM C39. The moulds were cylinders 160 mm x 320 mm. The demoulding occurred after 24 h. The specimens were cured in water at a temperature of 21±2 °C. The compressive strength was obtained from an average of three tests. The compressive strength measurements were carried out using an automatic testing machine with a capacity of 3000 kN (Figure.2.19, Figure.2.20).

III.4.4 Tensile splits strength test

The tensile strength test was determined following the standard ASTM C496. Two cylinders with the same dimensions were prepared for each mixture and cured in water at temperature 21±2 °C until the age of 28 days. In the splitting test, the concrete cylinder is placed horizontally between the press platens and the load is increased to the point of rupture by indirect traction, which occurs as a split along the vertical diameter of the press.

Figure.2.19. Machine used for compression test. Figure.2.20. Specimens after compression test.

III.4.5 Ultrasonic pulse velocity test

The incorporation of the crumb rubber into the concrete affects the air voids and compactness. Therefore, the ultrasonic pulse velocity test is necessary to assess the influence of crumb rubber on the compactness of the specimens. The ultrasonic pulse velocity test (non-destructive) was used following NF EN 12 504-4 standard. It's consists on holding the two poles for computing the pulse velocity, each one in the sides of the cylinder (160 mm x 320 mm) and reading the transmission time. Pulse velocity was calculated by employing the following equation: $V = \frac{L}{T}$ (1)

Where, "V "is pulse velocity (m/sec), "L" is the distance between two transducers (mm) equal to 320 mm, and "T" is the transmission time (sec). The ultrasonic pulse velocity measurements were performed using two specimens of each mixture.

III.4.6 Deformability and static modulus of compressive test

The deformability test was performed to determine the stress-strain behavior and the static modulus of elasticity of the mixtures, with the agreement of ASTM C469 standard using a compressometer/extensometer model 55-C0221/D under the axial compression action (see Figure.2.21). Three cylindrical specimens of 160 mm x 320 mm of each mixture were produced and cured for 28 days. Controls hydraulic press with a capacity of 3000 KN was used to apply the load. The stress–strain curves were determined by measuring the relative displacement of datum points on the cylinder surface during extensometer experiment three times for all the mixtures.

Figure.2.21. Experimental set-up of stress-strain measured during compressive test.

III.4.7 Modulus of elasticity Edyn

From the velocity of propagation of the ultrasonic waves, it is possible to calculate the elastic modulus of elasticity Edyn according to the following expression:

$E_{dyn} = V^2\rho\ [(1 + \nu)\ (1 - 2\nu)/(1 - \nu)]$

V: speed of the train of waves (m / s).

ρ: apparent density of test pieces (kg / m^3).

υ: the fish coefficient, we will take v = 0.2, the usual value for concretes.

III.4.8 Resistance to Sulfuric Acid Attack

The test conducted in the present investigation consists in the immersion of 150×150×150 mm^3, concrete specimens with 28 days curing in a solution of 10% sulfuric acid during the 28 days. Note that before being immersed the specimens in a the acid solution the weight of the them was assessed. The resistance to acid attack was then assessed by the difference in weight of dry specimens before and after the acid attack at 28 days, followed a variation of the ASTM C-267 (Standard test methods for chemical resistance of mortars, grouts, and monolithic surfacing and polymer concretes) (Figure.2.22).

Figure.2.22. loss weight of specimens immersed in sulfuric acid.

III.4.9 Water permeability

The test was carried out using cubic specimens with 150x150x150 mm of size. After 28 days of water curing, the specimens were placed in an oven at 105° until the specimens reached the constant mass. The water permeability of concretes was measured with respect to TS EN 12390-8 at an age of 28 days. The test cell assembly being used had the capacity to test three cubes at a time for each type of curing. Once the specimens were assembled in the test cells, a water pressure of 500 ± 50 kPa was applied for 72 hours. During the test, we have to observe the appearance of the surfaces of the test specimen to make sure that water not exposed to the surface. In the event of a leak, question the validity of the test and record the event.

After 72 hours, the specimen was separeted perpendicular to the injected face and turn into two pieces by splitting test, the depth of water penetration is measured using a caliper. The variation in the amount of water passed through the test tube is then measured as a function of time, which makes it possible to determine the coefficient of permeability of the material kp.

The coefficient of permeability is calculated according to the equation:

$$Kp((m/s)\times 10^{-5})=(Q.H/F(P1-P2)\tau).\mu k$$

When:

- Q: Amount of water flowing through the test tube (cm^3).
- H: Height of the test piece (cm).
- (P1 - P2): Pressure difference between the two faces of the test piece (bars).
- τ: Test time (s).
- μ: Viscosity of the water.
- k: Coefficient that takes into account the diameter of the specimen.
- F: Section of the test piece (cm^2).

A experimental pilot of the water permeability test equipment is given in Figure.2.23.

(a) *(b)*

Figure.2.23. (a) experimental set-up of water permeabilities, (b) measurement of penetration depth.

III.4.10 Scanning electron microscopy (SEM) analysis

This analysis is carried out at the SEMAT physics laboratory of the University of Minho Portugal using a scanning microscope (Figure.2.24, Figure.2.25) to make a complete analysis of the microstructure of concretes with an analysis of the various components used in the composition of the concretes used in this study. This test aims to demonstrate the quantity and dimension of voids and the interface bond between the binder and rubber aggregates of the concrete modified with RW, GP and SP. Different magnification have allowed us to see the interaction between the RW aggregates and the cement paste.

Figure.2.24. Machine used to take SEM image.

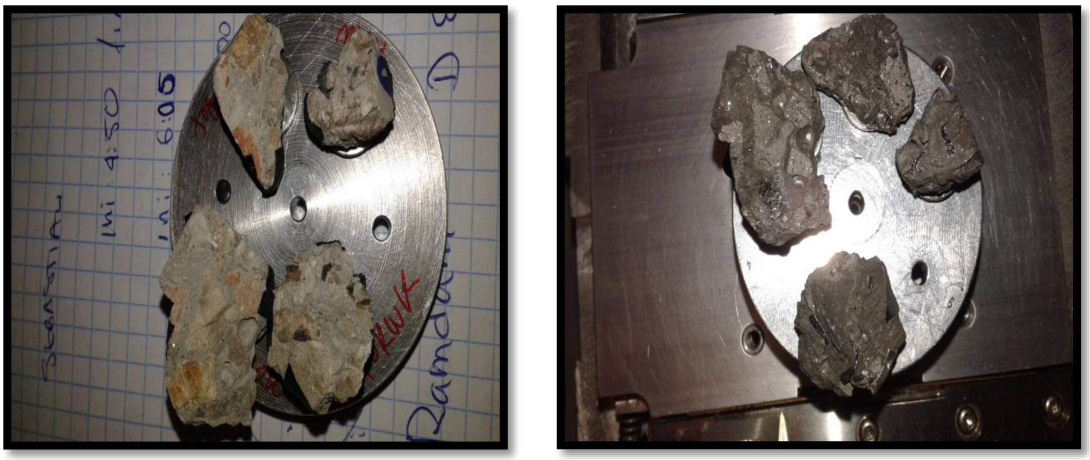


Figure.2.25. Concrete samples for SEM test.

CHAPTER FOUR

Investigation of the separate effect of the rubber aggregate, glass powder wastes and dune sand powder on concrete mixes

IV.1 Introduction

In this chapter we present all the experimental results obtained on eco-composites based on rubber granulates as partial replacement of crushed sand at 10%, 20%, 40%, 60% levels and replacement of 15% of cement by glass and dune sand powders.

IV.2 Results and interpretations

IV.2.1 In the fresh state

IV.2.1.1Workability

For the formulation of the study concretes, we chose to prepare mixtures with ratio W / C and percentage in superplasticizer constant (as indicated in the previous chapter 3); in order to obtain comparable consistency refluxing the effect of the content of the rubber aggregates in mixtures. This choice will allow us an easy installation and will facilitate the comparison of the characteristics in the hardened state of the different mixtures. The slump results of the studies rubber mixes are presented in Figures.2.26, 2.27 and Table.2.10.

Table.2.10. Slump values of concretes based on rubber aggregates.

N°	Formulation	Slump values (cm)
1	C-ref	6
2	10RW	5.5
3	20RW	5
4	40RW	4
5	60RW	4.5
6	0RW15GP	7.5
7	0RW15SP	7

From the values presented in Figure 2.26, it was observed that there was a global decrease in the slump of the following mixes (10RW, 20RW, 40RW and 60RW) and with respect to RW replacement rates; in particular, the slump values reduced from 6 cm (C-ref) to 5.5 cm (10RW), 5 cm (20RW), 4 cm (40RW) and 4.5 cm (60RW), respectively.The most likely explanation of this decrease in workability is the hydrophobic nature, particles shapes and cracks of rubber aggregates (Figure.2.13), part of the water trapped between this cracks serves for segregation and less homogeneous of the mixtures.Similar to Aslani et al. [10] who's attributed the reason for this slump decrease to the rubber aggregates shape which affects the concrete consistency. And similar resultes observed by Valeria et al. [199].

Moreover, may be due to the decrease of the absorbed water amount in mixes caused by the replacement of the crushed sand aggregates as confirmed . This explanation confirms all previous results, such as increasing the compactness with the increasing of limestone sand proportion.

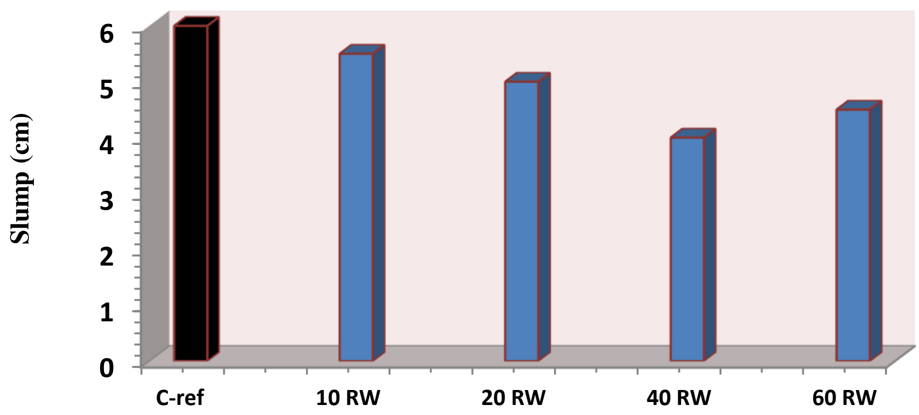


Figure.2.26. Workability of the rubber concretes.

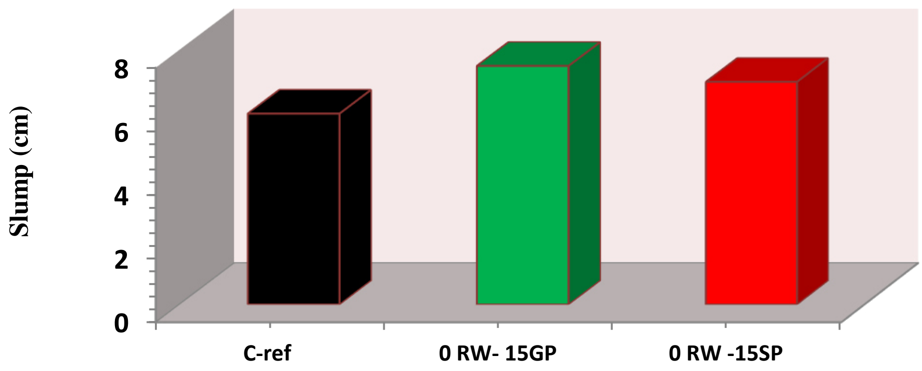


Figure.2.27. Workability of the glass and sand powders concretes.

In the hight level of RW incorporation 40% and 60%, the concrete becomes more fluid because of the excess of the mixing water. Indeed, once the cement is almost totally hydrated, excess water makes the cement grains more distant, the cohesion is weakened and therefore the material becomes more fluid [200].

Furthermore, it should be concluded that the slump test for the 60RW mixe has become difficult to perform so that the highest level of rubber aggregate mixtures requires another method of measuring the workability.

Regarding the effect of glass and sand powders (GP and SP) replacement on the reference concrete workability (Figure.2.27), it can be observed that slumps increases from 6 cm (C-ref) to 7.5 cm and 7 cm for (0RW15GP) and (0RW15SP) mixes, respectively. So far, there is no general agreement on the glass concrete slump; it was often discussed, yet rarely well understood. The slump increase of glass mixes (without rubber) may be due to the low water absorption of the glass powder which raises the percentage of water in the matrix, then, in turn, increases the workability.

In the same context, the effect of SP replacement on slump values of reference concrete is close to those with GP, only about 1 cm of difference due to the lower GP water absorption compared with SP. In addition, may be due to the minor difference in quantities of individual compounds between glass and sand powders (Table.2.3). Also, SP particles are closer to spherical shape than GP particles as shown in (Figures.2.6 and 2.10). Moreover, this can be attributed to the difference between SP and GP grains distribution (Figures.2.9 and 2.5), while the sand powder has a unimodal distribution, glass powder is bimodal. Guettala et al. [201] studied the effect of partial replacement of cement with sand powder; they reported that the granular effect relates to all the modification, was induced by the presence of the mineral additions in the granular structure of the cementitious materials in a fresh state.

IV.2.1.2 Fresh density

The fresh density of all the rubberized mixtures was measured after the concrete mixing directly and the results are shown in the following figure.2.28.According to the best-fitted line (with a correlation coefficient of R^2 = 0.974), a linear relation between densities, rubber content is observed. It shows a systematic reduction in density with the increase of rubber content from 0 to 60%; it was ranged from 2477 kg/m^3(reference concrete) to 2275 kg/m^3 for the 60RW mix. Indeed, the decreases recorded in the density are not very important and are 0.28, 3.18, 5.4, and 8.15% for 10%, 20%, 40%, and 60% respectively, compared to the control concrete.

This reduction can be explained by the segregation caused by the rubber aggregates during the mixing of concrete which leads to the development of air content. The occluded air entrained by the RWs favoring the increase of the porosity and consequently contributes to the lightening of the eco-concrete. It should be noted that the results obtained are similar to those obtained by other authors [1, 202-204].In addition, the low density of rubber aggregates (0.98)is the main factor that explains this reduction.

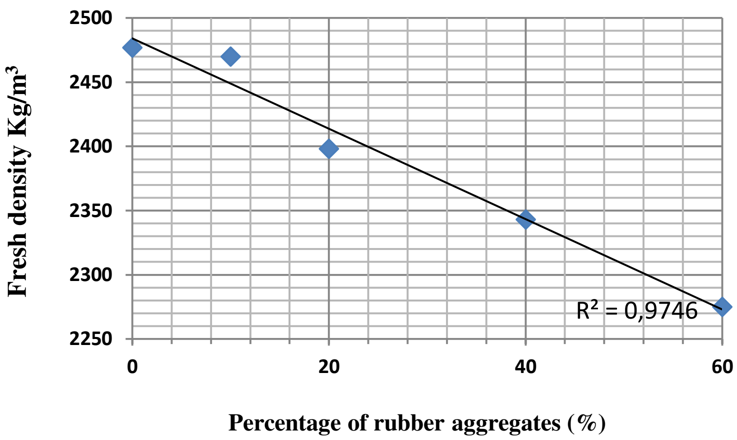


Figure.2.28. Relationship between fresh densityof rubberized concretes and percentage of rubber aggregates.

The effect of GP and SP in the density of concretes was observed on the Figure.2.29. One can see a very slight reduction in the mixes 0RW15GP and 0RW15SP about 0.32% and 0.68% compared to the reference concrete. This is due to the low GP and SP densities (2.18 g/cm^3 and 2.54 g/cm^3 respectively) in comparison to the cement which were replaced (3.1 g/cm^3).

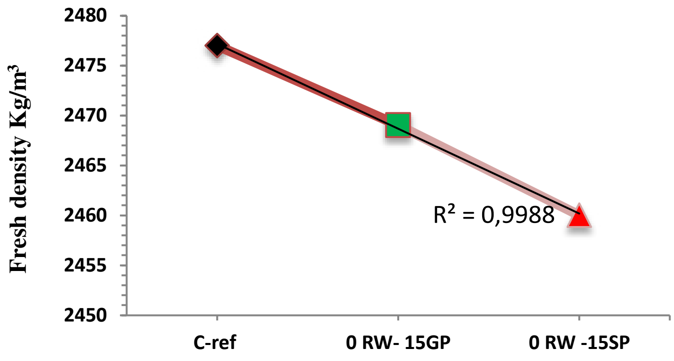


Figure.2.29. Fresh densities of the glass and sand powders concretes.

IV.2.2In the hardened state

IV.2.2.1Compressive and tensile strengths

It is well recognized that the compressive performance of concrete depends on the compactness of the cement matrix, the aggregates and the interfacial transition zone (ITZ) between the matrix and those aggregates.

The 7, 28 and 90 days compressive strengths (R_{c7}, R_{c28} and R_{C90}), as well as the 28 days tensile strengths (R_{t28}) obtained on 16cm x 32cm cylinder specimens for rubber mixes are reported in the Figure.2.30 and the Table.2.11. It is well known that addition of rubber wastes in cementitious composites leads to compressive and tensile strength loss [3,10,11,14-16,29]. Particularly, it should be mentioned that the loss in R_{c28} of the mixes 10RW and 20RW, is about 16.27 % and 25.75 % respectively, with respect to reference concrete (C-ref). In R_{t28}, it is about 1.51% and 3% respectively. In addition, the mixes with higher rubber percentages

40RW and 60RW show a significant compressive strength loss; estimated at 48.26% and 64.95%, respectively. It is to be noted that the R_{c28} loss is greater than that of R_{t28}. These results agree with the earlier field investigation [6,14-17]. Moreover, the compressive strength gradually decreased as the rubber content increased from 0 to 60%, and similar test results can be found in previous studies [205,206].

This strength loss by the week bond between the crumb rubber as organic material and the binder of cement as inorganic material. There are two possible reasons for the decrease of compressive strength after being rubberized. First, the difference between elastic modulus and compressive strength of the rubber particles and paste cement is the main cause [15]. The other reason is that rubber particles have high hydrophobicity, which increases the porosity of the concrete matrix and consequently reduces its strength [94]. Also, the reduction in splitting tensile strength is ascribed to the same factors which affected the compressive strength of specimens [10,11,25,29].

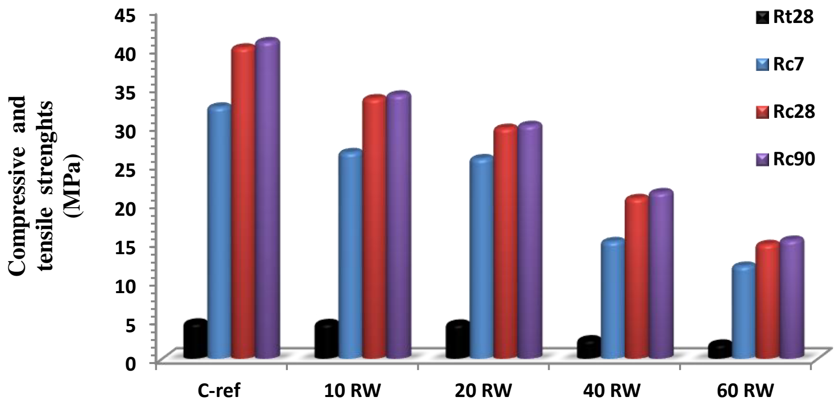


Figure.2.30. Compressive and tensile strenghts of rubber mixes.

The results in Figure.2.31 show that both glass waste powder and sand powder plays an important role in increasing compressive strength at later ages. A slight gain in compressive strength at 28 days was observed for the 0RW15GP and 0RW15SP mixtures by 7.58% and

5.18% respectively compared to the reference one. It shoud be noted that the gain more important in glass powder concrete. This resistance gain is due according to [194] to the good pozzolanic activity of the glass powder which makes it able to consume portlandite $Ca(OH)_2$ produced by the hydration of the cement. It would also be due to the GP filler effect which also makes the mixtures more homogeneous and more compact.In addition, Shayan et al. [207] reported that the development of compressive strength is slow for up to 28 days of age, but at 404 days all mixtures develop resistances of 55 MPa on average, exceeding that of the 40 MPa control.

Concerning the results of the SP effect on concrete strength, our results similar to those conducted by some researches were have shown that the dune sand powder (DSP) is able of developing a pozzolanic reaction in a cementitious medium, thereby the analysis by X-ray diffraction highlighted the pozzolanic role of DSP (partial pozzolanic reactivity) [208-210].

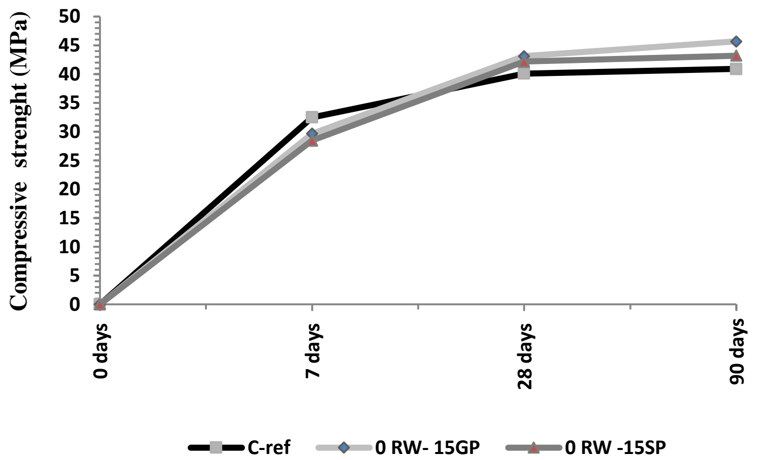


Figure.2.31. Compressive strenght of glass and sand powders mixes.

Another remarkable result is the resistance acquired over the long term (beyond 3 months) for eco-concretes of 15% GP, which exceeded those of the reference concretes (C-ref). For example: Rc_{90} (C-ref) = 40.89 MPa, Rc_{90} (0RW15GP) = 45.67 MPa, a difference of 11.69%, and for the mixe of (0RW15SP) the difference was 5.67%.

Table.2.11. The effect of RW and GP, SP powders on concrete strength.

Concretes	Compressive strength (MPa)			Gain and loss on $Rc_{7,28,90}$ (±%)			Tensile strength (MPa)
	7 days	28 days	90 days	7 days	28 days	90 days	28 days
C-ref	32.49	40.08	40.89	/	/	/	4.66
10RW	26.64	33.56	34.03	-18	-16.27	-16.77	4.59
20RW	25.86	29.76	30.13	-20.40	-25.75	-26.31	4.52
40RW	15.21	20.74	21.5	-53.18	-48.26	-47.41	2.48
60RW	12.03	14.84	15.39	-62.97	-64.95	-62.36	1.93
0RW15GP	29.65	43.12	45.67	-8.74	+7.58	+11.69	4.66
0RW15SP	28.44	42.16	43.21	-12.46	+5.18	+5.67	4.61

- **Compression failure mode**

Figures.2.32-2.37show the failure pattern of specimens after 28 days compressive and split tensile tests, respectively.

1. The control concrete exhibited brittle and sudden failure under compression loading (Figure.2.30)and those of the GP and SP-based concretes alone 0RW15GP and 0RW15SP, when a lear break was observed.
2. The rubberized concretes shows more ductile failure (plastic deformation) under compression loading, micro horizontal cracks was observed especially in the mixes with hight rubber content 40RW and 60RW (Figures.2.33-2.36).
3. Figure.2.37 shows the failure pattern after the split tensile test for the 40RW and 60RW mixes.

Figure.2.32. Failure pattern of reference concrete specimens.

Figure.2.33. Failure pattern of 10RW concrete specimens.

Figure.2.34. Failure pattern of 20RW concrete specimens.

Figure.2.35. Failure pattern of 40RW concrete specimens.

Figure.2.36. Failure pattern of60RW concrete specimens.

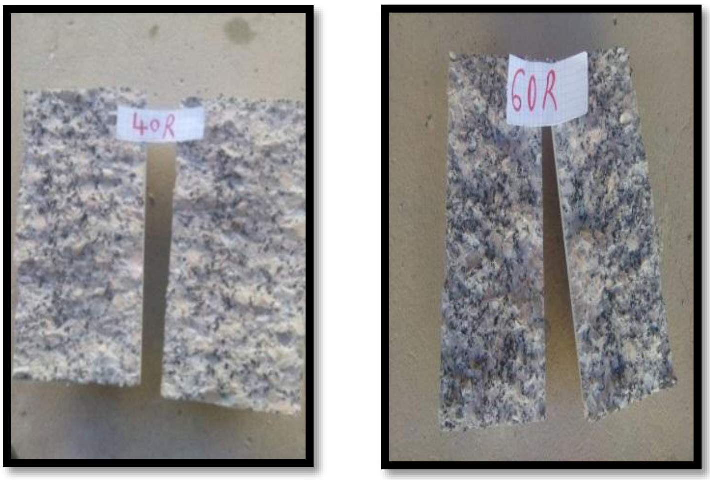


Figure.2.37. 40RW and 60RW specimens failure pattern after split tensile test.

IV.2.2.2 Ultrasonic pulse velocity

Figure.2.38 and Table.2.12 presente all the results of the experimental tests carried out on the eco-concretes studied at the age of 28 days. The evolution of ultrasonic pulse propagation velocities was examined as a function of RW, GP and SP.It can be noted that, as expected, the rubber content in the concrete increases, pulse velocity decreases and thus, concrete strength decreases. The pulse velocity values ranged from 4640 m/s (C-ref) to 3940 m/s (60RW). It is of the value 4540 m/s for the rate of RW of 10%, of the value of 4320 m/s for the rate of RW of 20%, 3985 m/s for the rate of 40% and 3940 for the rate of 60% RW. The loss recorded was

2.15%, 6.89%, 14.11%, 15.08% for the following mixes 10RW, 20RW, 40RW and 60RW respectively.

Li-Jeng Hunag et al. [107] reported that the ultrasonic pulse velocity of concrete increases as the rubber particle replacement percentage decreases. In addition, this decrease is due to the difficulties of compaction of mixtures containing a higher volume of rubber aggregates which gives rise to higher porosity [136]. This explanation confirmed by the systematic relationship between the compressive strength and the ultrasonic pulse velocity shows by our mixtures results.Moeover, this reduction for as is probably due to the relatively slowing down of ultrasonic pulses when they pass through cracks, voids and flaws filled with air or water caused by the addition of rubber aggregates. Also, the rubber aggregates have higher sound insulation coefficient than mineral aggregates.Furthermore, accordding to [204,211] may be this is due to that the rubber-based composite has ultrasonic wave attenuation capabilities as well as vibration damping.

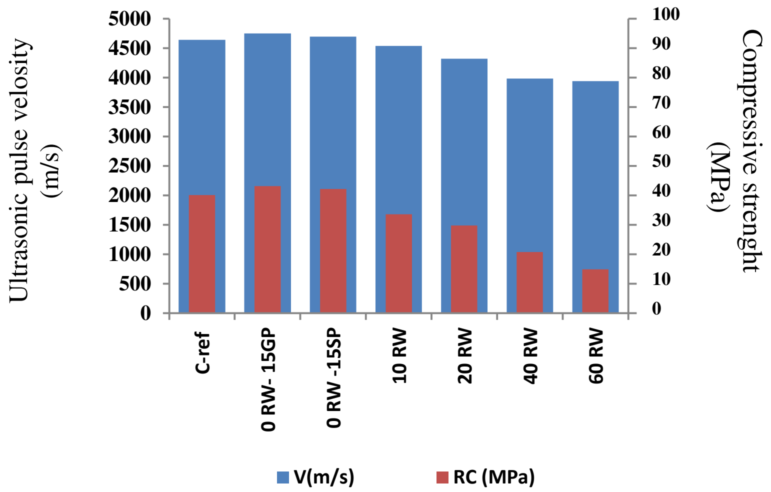


Figure.2.38.The ultrasonic pulse velocity and the corresponding compressive strength of the rubber and glass, sand powders mixes.

Concerning the ultrasonic velocities recorded on concretes based on GP alone and SP alone they are greater than that of the refernce one by 2.37 % and 1.25% respectively (Figure 2.38).

The fillers effect caused by the high fineness of both GP and SP is, in our opinion, the main reason for this increase.It was observed that this increase was greater for GP-based concrete may be due to the difference in the form and size distribution of GP and SP particles.

Table.2.12. The defference on ultrasonic pulse velocity of the studies concretes compared on C-ref.

Concretes	Ultrasonic pulse velocity V (m/s)	The difference (±%)
C-ref	4640	/
10RW	4540	-2.15
20RW	4320	-6.89
40RW	3985	-14.11
60RW	3940	-15.08
0RW15GP	4750	+2.37
0RW15SP	4698	+1.25

We can mesured the dynamic module of elasticity from the relation between him and the ultrasonic propagation velocity under the equation of :

$E_{dy} = V^2K$ (GPa) , where $K = \rho\ [(1 + \nu)\ (1 - 2\nu)/\ (1 - \nu)]$

$\nu = 0.2$;

ρ= Density of concrete.

We present in Figure 2.39 and Figure.2.40 the calculated E_{dy28}modulesfor the studies mixtures of this chapter.

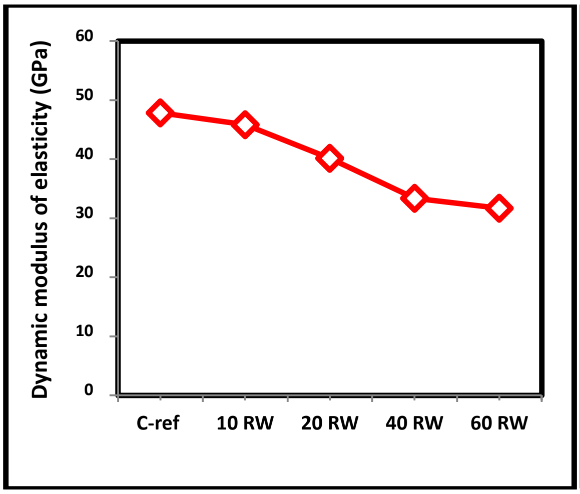


Figure.2.39. E_{dy28} of rubber mixes.

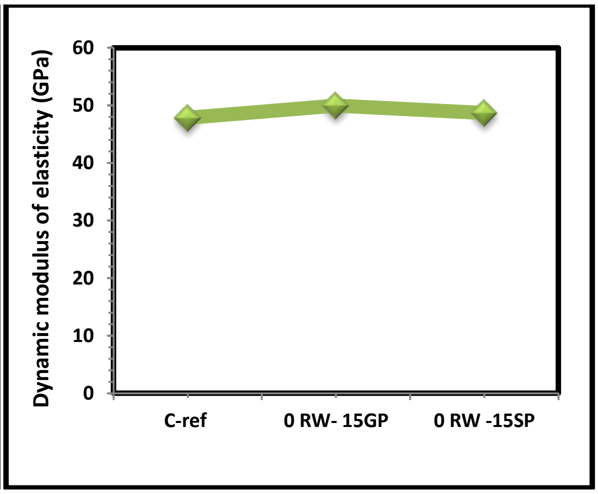


Figure.2.40. E_{dy28} of GP and SP alone mixes.

From Figures 2.341 and 2.42, it is observed that the dynamic modulus of elasticity decreases with the decrease in the compressive strength of the rubberized specimens. There is also a similar trend with the level of rubber aggregates substitution.

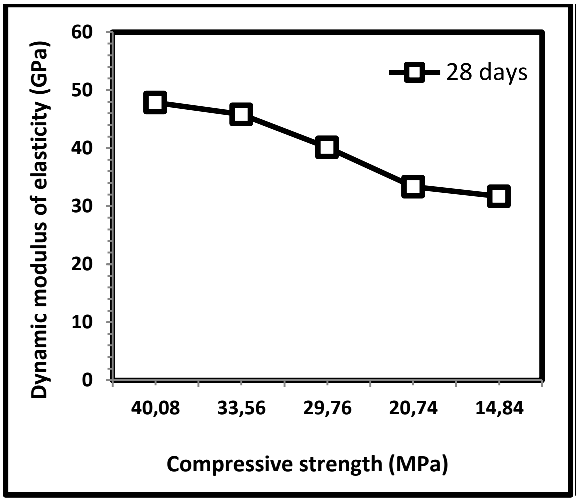


Figure.2.41.E_{dy28}according to the $R_{c28}$of the rubberized mixtures and the C-ref.

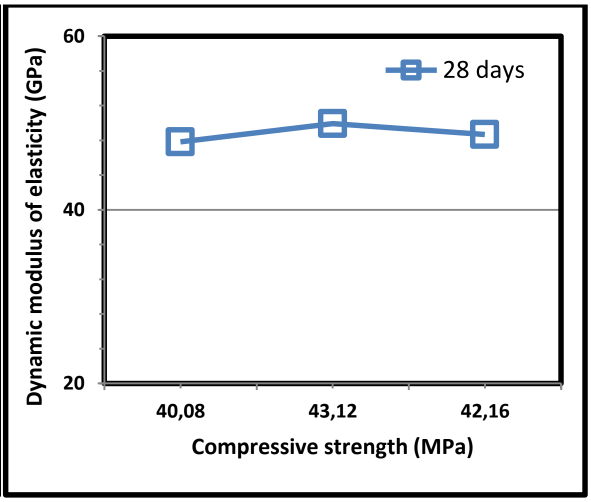


Figure.2.42. E_{dy28}according to the $R_{c28}$of the glass and sand powders concretes and the C-ref.

IV.2.2.3 Deformability static modulus

This test consists to investigate the difference between the behavior of rubber-base concrete and the reference one under the compression load. Does the rubber composites have the ability resist to existing cracks in building structures more than the control concrete?.

The partial volume incorporation of rubber aggregate, replacing fine aggregate, was found to reduce the modulus of elasticity of concrete (Figure.2.43) and (Table.2.13). Each curve represents the average results of three tests conducted at the same age and conditions. For the rubberized concrete, the values of static elastic modulus were 34.49 GPa, 29.03 GPa, 21.69 GPa, 15.19 GPa and 13.10 GPa for C-Ref, 10RW, 20RW, 40RW and 60RW mixtures, respectively (Figure.2.44). It can be seen that the increase in rubber aggregate content leads to increasing strain and decreasing static elastic modulus during the reduction in maximum stress. These results similar to that of Aslani et al. [10]. They incorporated three crumb rubber sizes 2 mm, 5 mm and 10 mm at volume ratios of 10%, 20%, 30%, and 40% on the self-compacting concrete. The results indicated that higher strains are generated at lower stress states as the percentage replacement of rubber aggregates is increased. Compared to the brittle reference concrete behavior, the rubberized concrete specimens show ductile behavior. Indeed, the increase in rubber content conducts to the increase in the ductility. In addition, during rubberized concrete failure, a high deformation was detected. When the stress-strain curves are compared, it is easy to note that C-ref is the strongest and the most brittle. However, the mixes 10RW and 20RW have hardening and malleable strain phase until failure, which showed a ductile failure mode compared to the C-ref one. Moreover, 40RW and 60RW have shown great deformability and elastic-plastic behavior mode. Likewise, the mixture with the high rubber content 60RW is the weakest compared to the reference concrete. It should be noted that for the reference concrete (C-ref) the maximum average peak-stress before failure is 39.78 MPa with the corresponding average strain ε=0.137 %. For the rubberized samples, these were 32.84 MPa, ε= 0.192 %, 28.86 MPa, ε= 0.375 %, 20.89 MPa, ε= 0.448 % and 13.93 MPa, ε= 0.281 % for 10RW, 20RW, 40RW and 60RW, respectively.

In earlier studies, Dong et al. [17] and Noaman et al. [21] have noted that the rubberized concrete exhibited ductile behavior and differed from that of traditional concrete. According to the same authors, the increase in rubber content led to the increase in ductility and strain capacity, defined as the strain at the maximum stress. Comparable results and analysis were reported by several authors [11,16,19-21].

Table.2.13. Deformation propreities of rubber mixes.

Concretes	Modulus of elastisity(GPa)	Average strain (%)	Peak-stress (MPa)
C-ref	34.49	0.137	40.89
10RW	29.03	0.192	34.03
20RW	21.69	0.375	30.13
40RW	15.19	0.448	21.5
60RW	13.10	0.281	15.39

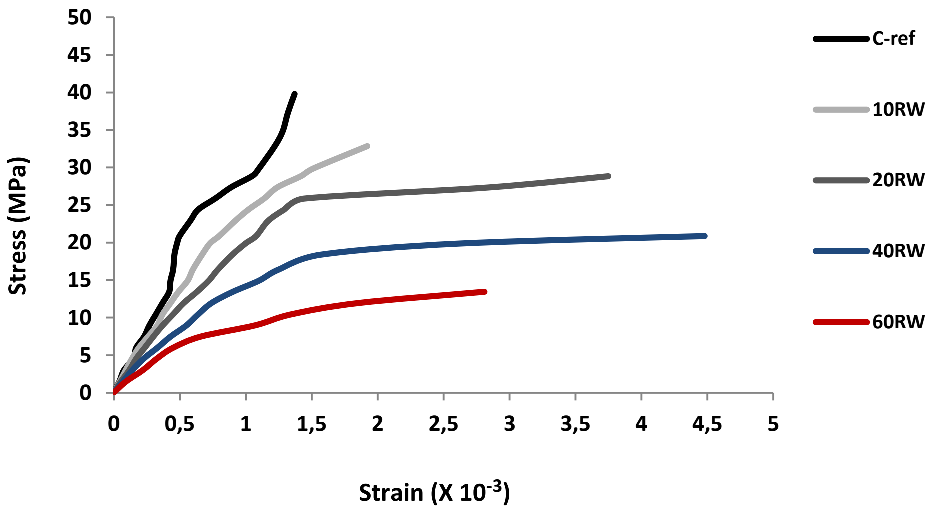


Figure.2.43.Stress-Strain curves of rubberized concrete with different rubber contents.

When we compare the curves of Figure.2.43 found that they are totally different for each concrete category. It should be noted that the mix with 40% rubber replacement (RW) have the best strain of 0.448% and then follow it the mix with 20% RW by 0.375 %. Those mixes are recommended for concrete road applications and for the slaps under machines when there are vibrations. Figure.2.45. represente the physical appearance of rubber concrete specimens under the deformability test.

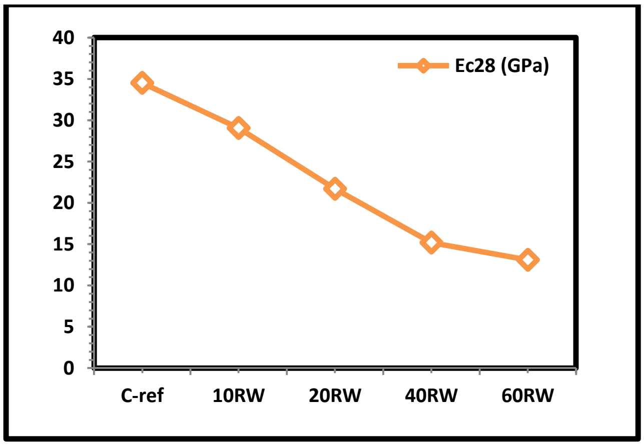


Figure.2.44. Elastic modulus of rubber mixtures.

Figure.2.45. Physical appearance of rubber concrete specimens under the deformability test.

IV.2.2.4Resistance sulfuric attack acid H_2SO_4

Sulfuric acid can take place in chemical waste, ground water, acid rains in which it can be one of the components especially in industrial zones. So, determination the resistance of cementitious materials to the sulfuric acid attack is so important. It is noteworthy that until now there is no clear agreement about the effect of sulfuric acid in rubberized concrete behavior.

- ***The weight loss***

In this study The damage of concrete specimens onsulfuric acid attack was observed and evaluated by the weight losses calculated with respect to the weight of the samples not attacked by the acid and expressed as a percentage.The results relating to concrete containing different percentages of rubber aggregates (RW), GP or SP in a solution of 10% $H_2SO_4$are presented in the following Figure.2.46. and Figure.2.47, respectively.

It is found for the rubberized mixtures that the increase in the rubber percentage affected the mass loss positively at all (RW) levels compared to the reference one. It means that the reference concrete specimens have recorded maximum loss in mass of 1.75% and the specimens modified by only rubber aggregates the 40% (RW) have recorded the least loss in mass of 1.5%.However, it should be mentioned the loss in mass gradually decreasing for the mix with 0% (RW)was 1.75% and that in the mix with 10% (RW) was 1.72%, the mix with 20% (RW) was 1.68%, the mix with 40% (RW) was 1.5% and the mix with 60% (RW) was 1.58%. Noted that the loss of weight of the attacked concretes is due to the lixiviation phenomenon of the constituents of the cement paste and the formation of expansive sulphate compounds. Progressive dissolution of the constituents of the cement paste as portlandite [Ca $(OH)_2$] which is preferentially put in solution because, among the different hydrated constituents of the cement paste, which has the most important solubility for ordinary temperatures. After the dissolution of portlandite, the other hydrates such as calcium aluminates, hydrated calcium monosulfoaluminate, ettringite and hydrated calcium silicates (HSCs) are, in turn, gradually dissolved. According to [212] the corrosion of cementitious composites due to the action of sulfuric acid can be characterized by the following reactions.

$$Ca\,(OH)_2 + H_2SO_4 \longrightarrow CaSO_4.2H_2O$$

$$CaSiO_2.2H_2O + H_2SO_4 \longrightarrow CaSO_4 + Si\,(OH)\,4 + H_2O$$

$$3CaO.Al_2O_3.12H_2O + 3(CaSO_4.2H_2O) + 14H_2O \longrightarrow 3CaO.Al_2O_3.3CaSO_4.32H_2O$$

Where in this context Gupta et al. [2] reported that at 28 days the percentage loss in weight was found gradually increasing from the control mix to the specimen with 7.5% crumb rubber and then it started to decrease in all the mixes up to 20% replacement of crumb rubber. According to the same authors, the development on acid attack resistance of rubberized concrete can explained by the presence of crumb rubber particles, whose serves to holding the constituent particles of the concrete from breaking away by preventing the formation of cracks and material separation. While in the concrete with no crumb rubber or less amount of crumb rubber, more cracks were developed and the constituent materials were easily separated.

These results, in our opinion, can be due to the large volume occupied by the rubber aggregates in the particles constitutive of the concrete which leads to less of cementitious surface attacked by the sulfuric acid; note that tire rubber aggregates contain carbon black, antioxidants, and chemical stabilizers to enhance resistance to wear, chemical decomposition respectively.Figures.2.48, 2.49 and 2.50represented the physique aspects of the sulfuric acid attacked specimens of the studies mixtures.

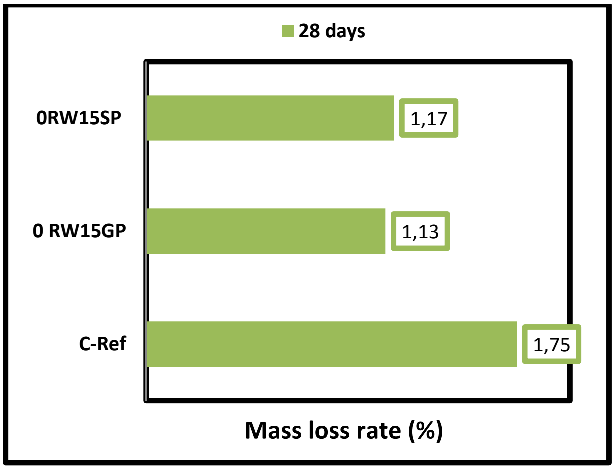


Figure.2.47. Mass loss of GP and SP concretes attacked by H_2SO_4 solution.

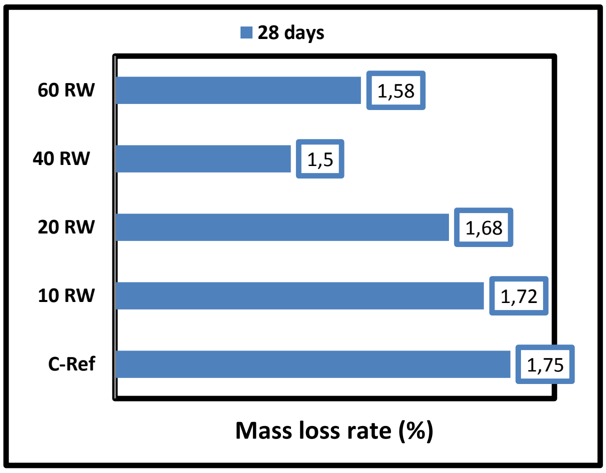


Figure.2.46. Mass loss of GCconcretes attacked by H_2SO_4solution.

Figure.2.48. 28 days C-ref, 10RW, 20RW acid attacked specimens respectively.

It is concluded that the presence of rubber aggregates improve the strength of the prepared concretes against sulfuric acid attack. Also, 10RW15GP and 10RW15SPmixes showed a gain of weight at 28 days compared to the reference concrete (Figure.2.47).It can be confirmed that glass powder waste and sand powder played an important role to enhace the modified concretes to resist the attack of sulfuric acid H_2SO_4. The weight loss was 1.75%, 1.13% and 1.17% for C-ref, 0RW15GP and 0RW15SP respectively; this gain may be reflex the decrese of porosity of concretes by the filler effect of GP and SP. Moreover, this can be explained by the pozzolanic reaction which fixes the lime, serving to a reduction of the capillary pores by the formation of new CSH gels thus blocking the absorption of the acid solution [213].

Figure.2.49. 28 days 40RW, 60RW, 0RW15GP acid attacked specimens respectively.

Figure.2.50. 28 days 0RW15SP acid attacked specimens and the aspect of measuring weight.

From the first days of the immersion of the study concretes in 10% H_2SO_4 solutions, we visually observed a lixiviation of the cement paste, it appears crystallized gypsum, the test pieces had a superficial coat of white paste (Figure.2.51), the white color indicates that the exposure in sulfuric acid caused the extensive formation of gypsum ($CaSO_4$, $2H_2O$), on the surface of the specimens.

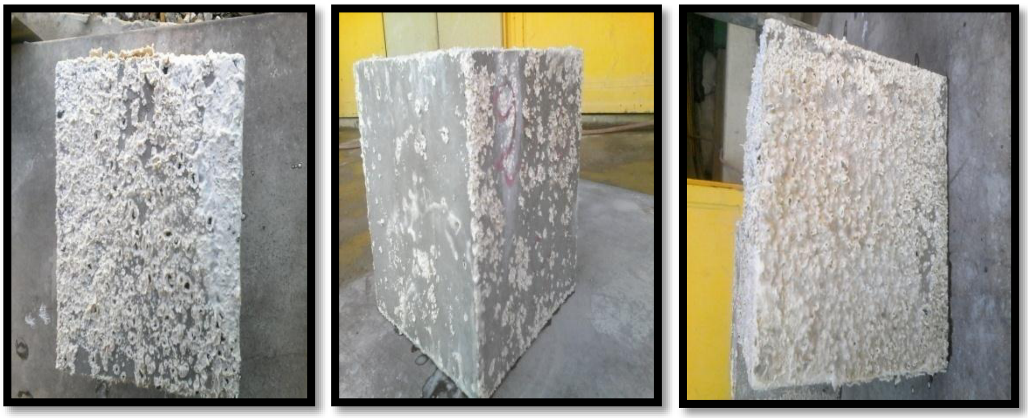


Figure.2.51. Surface of sulfuric acid attacked concrete specimens.

IV.2.2.5 Water permeability

The volume of permeable voids is an important property of concrete affecting solutions transport mechanisms through the concrete, such as water. The variations of depth of water penetration for the studies mixtures at 28 days are reported in Figure.2.52. As expected by the authors, the depth of water penetration was observed to be increasing with the increase in the percentage of crumb rubber in concrete. It was to be noted that the lowest water permeability value of3.5 cm was achieved with reference concrete while the maximum 14 cm was observed at 40 % RW mix. It should be mentioned that at 60% RW content the water permeability test was not able to be made and we measured the penetration time until specimens failure was 3 minutes. As [15] concluded that at a high rubber particle replacement percentage of 40%, moisture begins to leak out because of the excess of pores, so the permeability ratio cannot be measured correctly.

These results were similar to those reported by [15,16,24,25].The main reason for increasing the permeability of the GC-containing concrete is due to the weak bond between the rubber aggregates and the cement paste. Obinna et al. [24] explained the permeability increasing of rubberized concrete to the increased void content due to the propensity of lightweight crumb rubber to float in mixtures coupled with the composite material elastic behavior under an applied force, which made the compaction of specimens containing crumb rubber difficult and ineffective. Furthermore, Erhan Güneyisi et al. [25] related to the surface characteristic of rubber particles, and the low adhesion between rubber particles and matrix; this situation causes plenty of porosities. Consequently, the increasing of voids with the increasing RW content resulted in progressively increasing of the water absorption values.

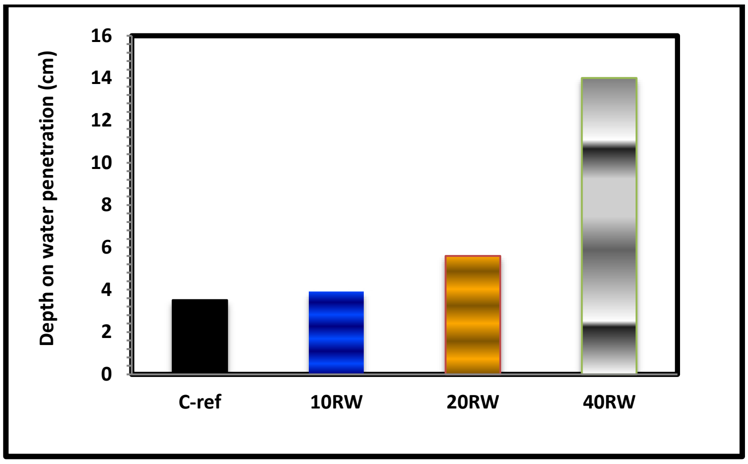


Figure.2.52.Depth on water penetration of rubber mixes.

With respect to the effect of GP and SP (Figure.2.53), it can be seen that the depth water penetration decreases clearly with the presence of 15% content of either glass powder or sand powder on the modified mixtures. The decrease obtained is 37.14 % and 20 % respectively compared to C-ref. It can be concluded that GP and SP causes a modification of the porous structure of the hardened concrete (the reaction of the glass powder and sand powder fillers with the $Ca(OH)_2$), by the formation of an additional C-S-H gel able to filling of the capillary pores of the concrete).

The photos in Figures.2.54 ad 2.55that follow are an illustration of the different penetrations observed.

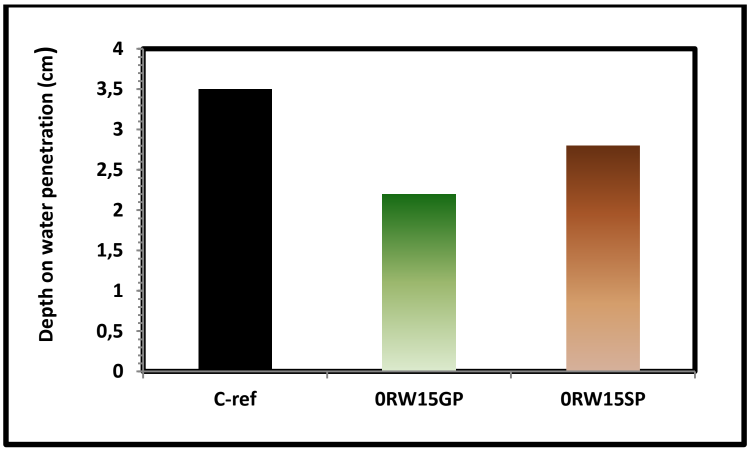


Figure.2.53.Depth on water penetration of glass-concrete and sand concrete.

Figure 2.54. Depth of penetration of pressurized water of GC-based concretes of 10RW, 20RW and 40RW respectively.

Figure.2.55. Experimental aspect and specimens of water permeability.

IV.2.2.6 Porosity and zone transition with SEM observation

Figures (2.56-2.61)show samples of reference concrete, glass concrete alone and rubber concrete of 10% RW with differents magnification.Through the scanning electron microscope (SEM) images, we confirmed that the structure of cement paste made with GP and reference paste is different. It is visible that the mixture modified with GP has a compact microstructure compared by the reference one. It can also be seen that the partial replacement of cement by 15% GP led to a decrease in the percentage of voids, those observations confirmed the previous resultes. This is due to the filler effect of the finer particals of glass waste. Also, due to its pozzolanic reaction properties which improves hydration rate and produced a second generation of C-S-H gel, improves the interfacial transition zone and compacts the microstructure of cement matrix; this leading to improve the mechanical and physical properties of cementitious composites as confirmed our results en previous sections.

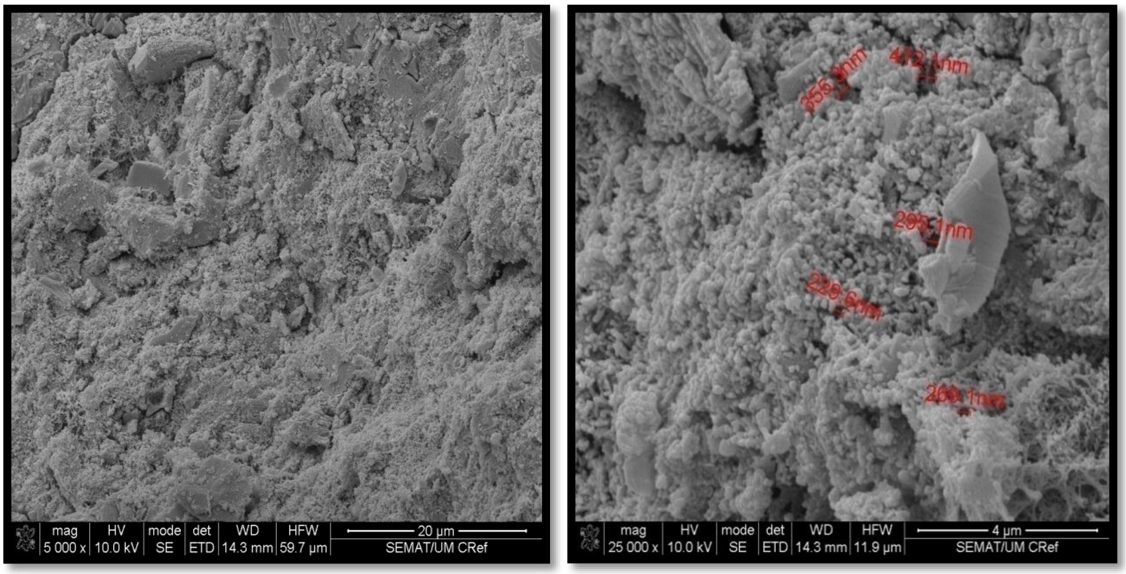


Figure.2.56. SEM image of the reference concrete at 90 days (X 5000, X 25000).

Concerning the rubber concrete with 10% RW the microstructure is marked by the presence of zones of weak cohesion as alluded to earlier, the adhesion between the rubber and the cement paste is poor and this results in micro-scale gaps in the interfacial transition zone

(ITZ). This is evident in the thick ITZ shown around the rubber particles, also, there are sometimes areas of good compactness. It should be noted that a weaker interface of rubber composite can be the start of the cracks of the structure.

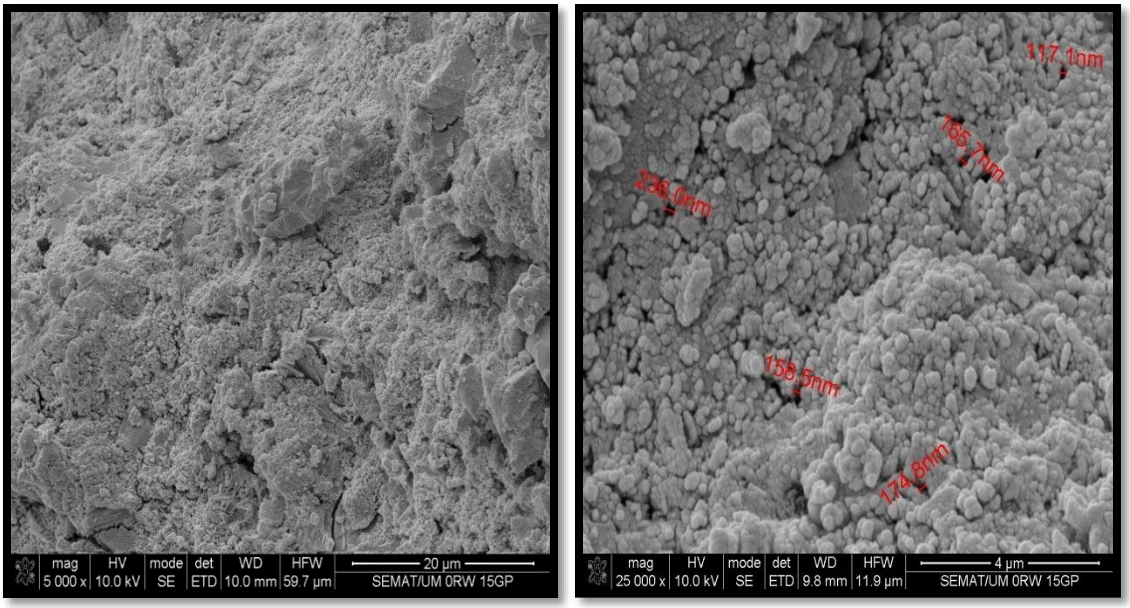


Figure.2.57. SEM image of mixture contained 15% GP at 90 days (X 5000, X 25 000).

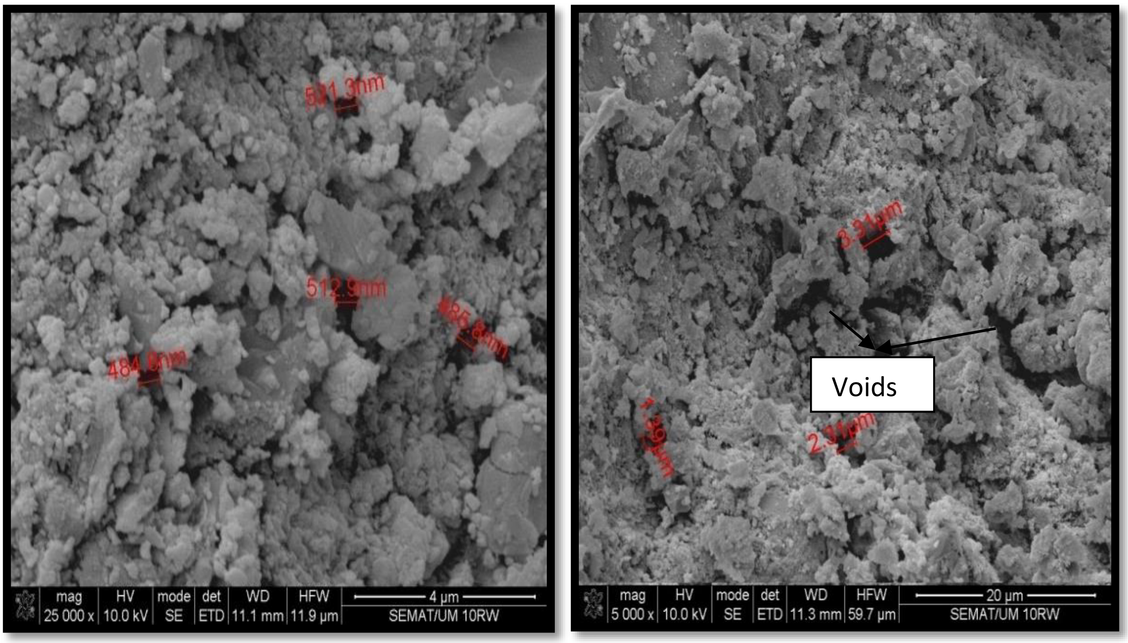


Figure.2.58. SEM image of mixture contained 10RW at 90 days (X 5000, X 25 000).

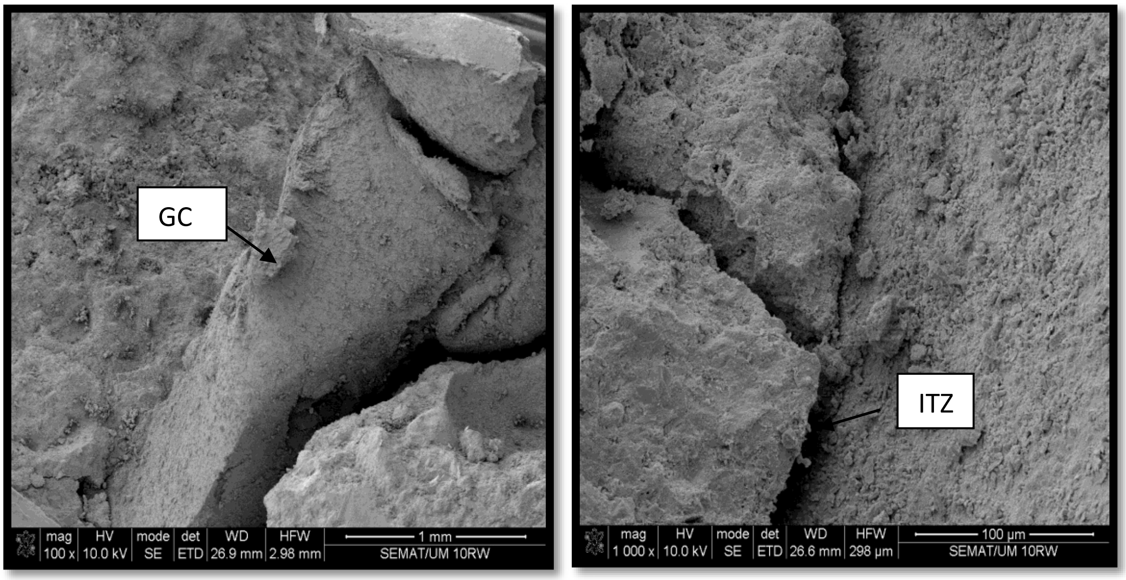


Figure.2.59. SEM image of mixture contained 10RW at 90 days (X 5000, X 25 000).

IV.3 Conclusion

- Concretes modified by rubber aggregates (RW) show a decrease in fresh densities due to the low density of RW and the occluded air entrained during mixing.
- GP and SP fillers improved the fresh density and the workability of reference concrete.
- The workability of the high rubber content concretes became so difficult to measure, so another method should be recommended.
- All compressive strength of rubber composites are less than that of reference one, due to the hydrophobic nature of rubber aggregates and the week bond between them and the cement paste. However, 10RW and 20RW mixes still have acceptable compressive and tensile strengths.
- An improvement in the mechanical strengths of C-ref filled with GP and SP was noted.

- The incorporation of the rubber aggregates could allow relaxing the stresses and enlarger the strain which reducing the formation and / or the propagation of cracks (ductile behavior) compared to the reference concrete C-ref, GP-concrete and SP-concrete which having a brittle fracture.
- The presence of rubber aggregates improve the strength of the prepared concretes against sulfuric acid attack at 10%, 20%, 40% and 60% RW content.
- Both GP and SP improve the durability of concretes against attacks by sulfuric acid. This can be explained by the pozzolanic reaction which fixes the lime released from the hydration of the cement, allowing a reduction capillary pores and the formation of additional C-S-H gels.
- An increase in permeability to water has been demonstrated. This shows that high porosity has been generated and a network of interconnected micro-cracks has been created allowing a rapid flow of water.
- GP show more effectiveness on the fresh and hardened properties of concrete than SP.

CHAPTER FIVE

Development and Investigation of the Performance of rubberized concrete and chemistry activity of glass, natural sand powders particles effects on their proprieties

V.1 Introduction

In this chapter we present all the experimental results obtained on eco-composites based on combination of rubber granulates as partial replacement of crushed sand at 10%, 20%, 40%, 60% levels and replacement of 15% of cement with glass powder or dune sand powder.

V.2 Results and interpretations

V.2.1 Workability

All data of the studies concrete with the separate wastes and combined of them were shown in the following Figure.3.1. Where data of separate effect of the rubber waste and the powders are compared to the effect of combined of them (RW-GP) and (RW-SP) on concrete. The slump values were 5.5 cm, 6.5 cm and 5.5 cm for the mixes (10RW), (10RW15GP) and (10RW15SP) respectively; and 5 cm, 6.5 cm and 7 cm for the mixes (20RW), (20RW15GP), (20RW15SP) respectively. It can be seen that the incorporation of the combined (RW-GP) granulates allowed an increase of workability in the studied rubberized concrete. This may be due to the capacity of the fine particles of glass powder to filling the voids between the particals and releasing the water from these voids, creating a new porosity network.

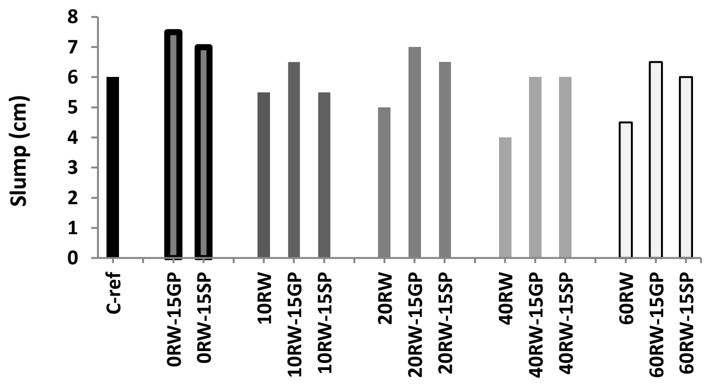


Figure.3.1. Slump test of the studies mixtures.

Furthermore, it can be explained by the synergetic effect of the difference in particle's shape and size of both, cement and glass powder which created a friction between them that leads to increasing workability. The same reasons can explain the workability increase of rubberized concrete modified with SP. Concluded glass and sand powders can improve rubberized concrete flow.

V.2.2 Fresh density

The evolution of the fresh density for the different series is illustrated in Figure 3.2.The fresh density values obtained from the reference rubberized concrete (10RW), (20RW), (40RW), and (60RW) were 2470 kg/m^3, 2398 kg/m^3, 2343 kg/m^3 and 2275 kg/m^3 respectively; and the corresponding values of fresh density modified with GP were 2464 kg/m^3, 2401 kg/m^3 and 2400 kg/m^3 and 2356 kg/m^3. After comparing these results it can be noticed that the combined replacement of (RW-GP) in concrete creates a compromise between the separate effects of them. This synergetic effect can be attributed to the ability of GP specific area (finer amorphous silica) to fill the voids caused by crumb rubber addition, where it is greater than cement it replaced. This effect appeared more evident on the 40RW15GP and 60RW15GP mixes by a gain in fresh density with 2.43% and 3.56% rates, respectively. A very slight reduction in the 10RW15GP mix was recorded with 0.24 %, may be due to the low GP density (2.18). Ali et al. [32] studies the replacement of cement by GP on mortar, they concluded that the use of glass powder refines the pores of cement paste and this reflects the mortar and concrete properties.

A similar behavior with a little reduction was observed for the mixtures with the same crumb rubber replacement ratios when SP was added to the concrete but, with lower effectiveness especially with the high rubber aggregates levels 40% and 60%. The corresponding values of fresh density modified with SP were 2452 kg/m^3, 2398 kg/m^3 and 2316 kg/m^3 and 2124 kg/m^3

compared to those of rubber mixes alone2470 kg/m^3, 2398 kg/m^3, 2343 kg/m^3 and 2275 kg/m^3 ,respectively.

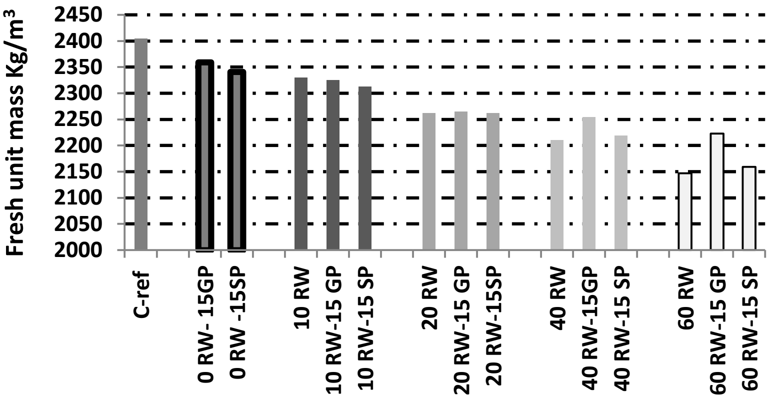


Figure.3.2. Fresh density of the studies concretes.

V.2.3 Compressive and tensile strengths

Figures (3.3-3.7) are presented the results of the compressive strength of combined (RW-GP) and (RW-SP) mixes at 7, 28 and 90 days and the tensile strength of them on 28 days.

Compared to the rubberized concrete mixtures, the combined GP with RW on concrete affects the accompanied decrease of compressive strength at 7 days (R_{c7}) with respect to the RW contents. This indicates that the hydration reactions are slow with the replacement of the part of cement by glass powder at the early age (7 days). It can be due to the slow rate of reaction between SiO_2 from glass powder and $Ca(OH)_2$ from cement which led to a reduction of hydration products (C-S-H), accompanied by a decrease in the amount of C_3S and C_2S (the three are responsible for the concrete strength) in the mixtures. Our results share a number of similarities with Soliman et al. [31], Ali abdo et al. [32] and Valeria et al. [199] findings of the negative effect of glass powder on cementitious materials compressive strength at an early age (7days). However, R_{c7} of the composed (RW-SP) mixes is also observed to be lower compared with the rubberized mixtures, when is higher compared to the ones modified with GP. This may be due to the better solubility of SP in water, which resulted from the small chemical stabilizers amount (CaO + MgO = 2.4) when compared to the GP one (CaO + MgO = 10.82%). Guettala et al. [201] investigated the partial replacement of cement by sand powder in cement pastes and confirmed that in the first seven days, the compressive strength is low for all samples, whereas the following periods, the compressive strength increases significantly.

A pronounced increase in the 28 days compressive strength of all mixes modified with GP and SP compared to the C-ref and the common rubberized concrete is frequently accompanied by the improvement in other properties such as tensile strength (Figure.3.5). It is established that the combined incorporation of (RW-GP) and (RW-SP), respectively, mitigates the negative effect of used RW separately on the concrete strength at the late time. This beneficial effect of glass powder on the compressive strength rubberized concretes was much higher for RW contents of 10% and 20% by a gain of 7.3 % and 5.24 %, respectively.

This can be explained by the good effect of GP large specific area (1,32 m^2/g) on the bond between rubber particles and the surrounding cement paste. This good effect enhances the interfacial transition zone bonding, which, in turn, significantly enhances the compressive strength of the rubberized concretes. Moreover, it seems that there is a synergetic effect of glass powder and cement, which can be explained by the GP pozzolanic behavior, after increasing the reaction through time, with calcium from portlandite $Ca(OH)_2$. Can be explained by the increase of the chemical composition of the binder, especially SiO_2 from glass powder which led to decreasing the calcium hydroxide (CH) quantity and producing a more C-S-H gel, which in turn, decreasing the voids percentage in the mixtures. As reported by Greenberg [214],that the second phase of C-S-H formed, able to improve rubbercrete strength showed by the equation (1).

$$SiO_2(s) + Ca^{2+}(aq) + 2OH^{-}(aq) = n1CaO \cdot SiO_2 \cdot n2H_2O(s) \quad (1)$$

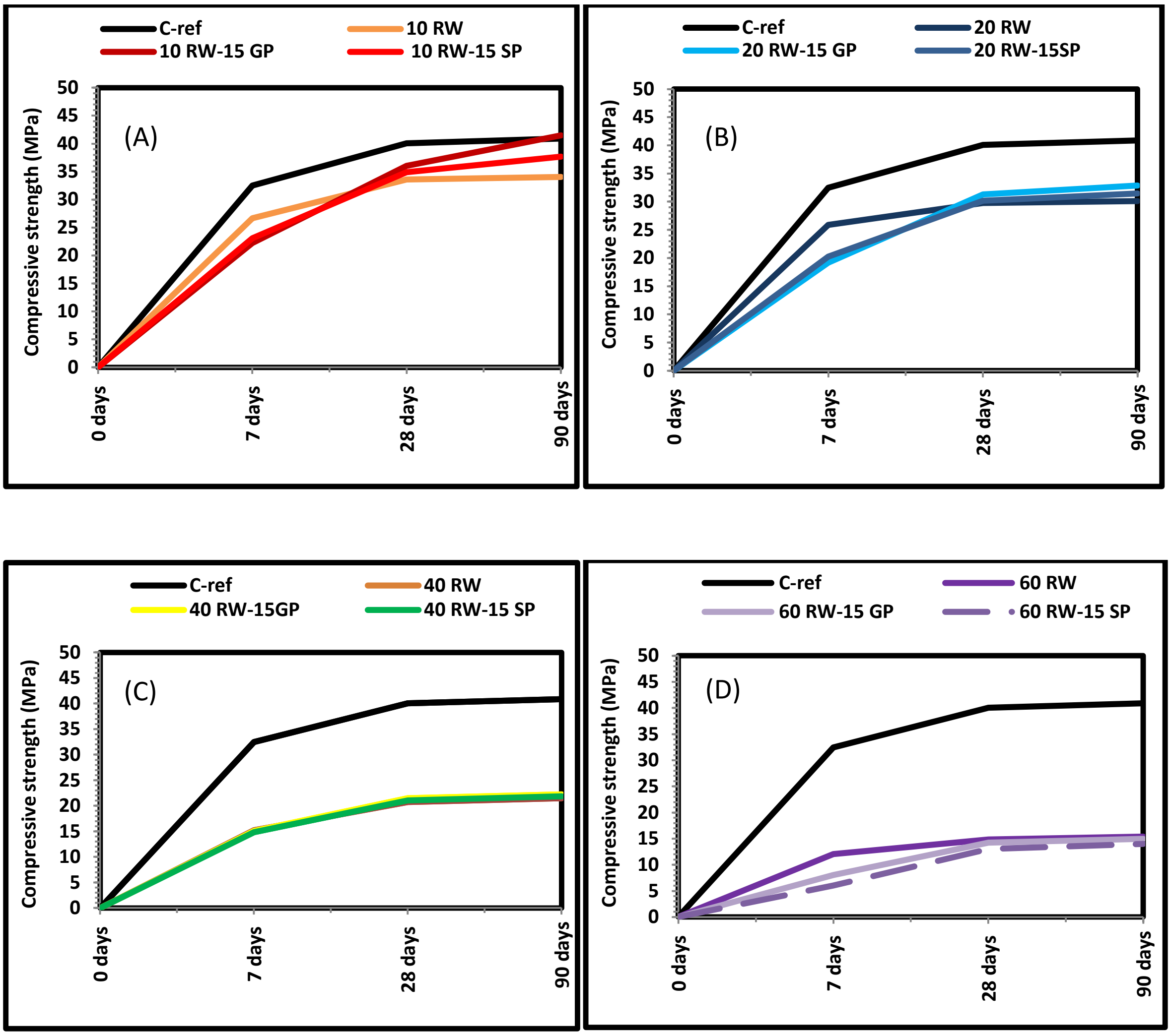


Figure 3.3.Compressive strength of concretes as a function of: a) combination of RW (10%) and GP or SP, B) combination of RW (20%) and GP or SP, C) combination of RW (40%) and GP or SP, D) combination of RW (60%) and GP or SP.

According to [32,34,43,51,214], the amorphous silica in glass powder appeared more active with lime and forms C-S-H at a later stage of hydration. The mix with 10% RW and 15 % GP is the best one compared to the common rubberized concretes, which is associated to a high compressive strength above 36.01 MPa at 28 days. With the same mixture, the 90 days compressive strength was superior to both the reference concrete without, and with RW and achieved 41.46 MPa.This result has further strengthened our confidence that glass powder becomes more effective for concrete strength with time.

Regarding the 28 days strength of composed (RW-SP) concretes, results clearly show the positive combined effect to minimize the strength loss associated with the use of rubber waste separately. As the dune sand powder is siliceous, can have the same physical and pozzolanic benefits than other additions, despite its crystalline character [208]. In the same way, the small content of portlandite provided by the presence of dune sand powder in the cement paste, translated the partial pozzolanic reaction, which contributes to increasing the strength and the compactness of the paste.

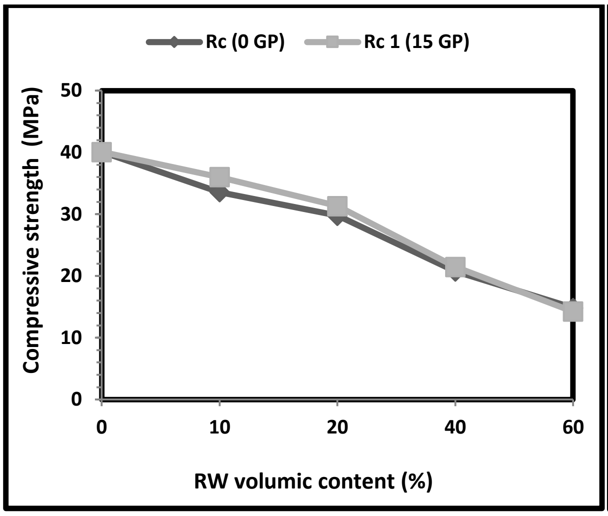


Figure.3.4. Effect of GP incorporation with RW the 28 days compressive strength.

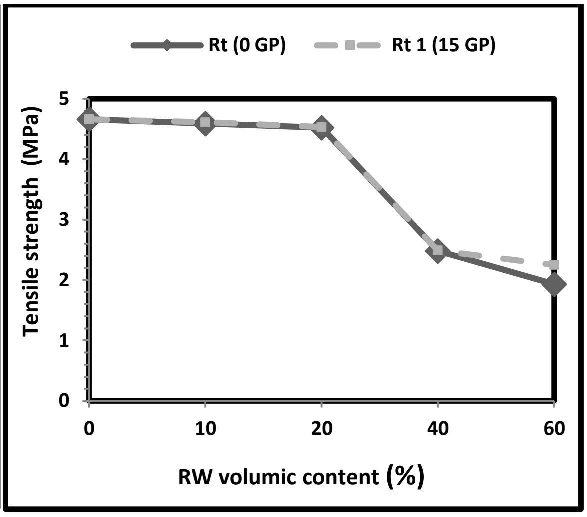
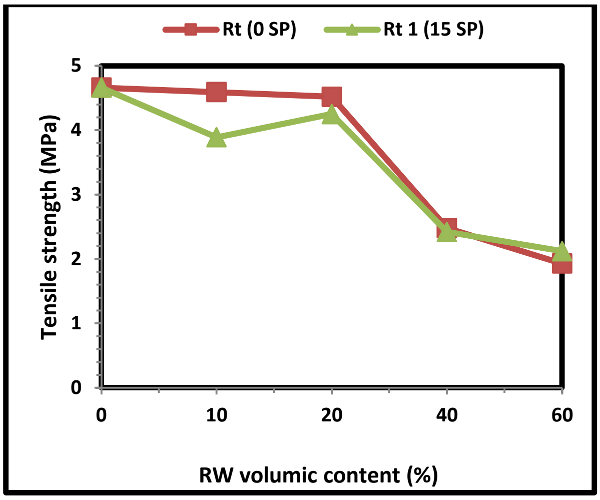


Figure.3.5. Effect of GP incorporation with RW on on the 28 days tensile strength.

It is evident that GP is more effective than SP concerning concrete strength. For example, (10RW15SP) and (10RW15GP) mixes have 10.16% and 14.49% increase in 28 days compressive strength respectively. The difference may be explained by the role of the varied particles size, surface texture, grain distribution and the pozzolanic reaction of the powders.



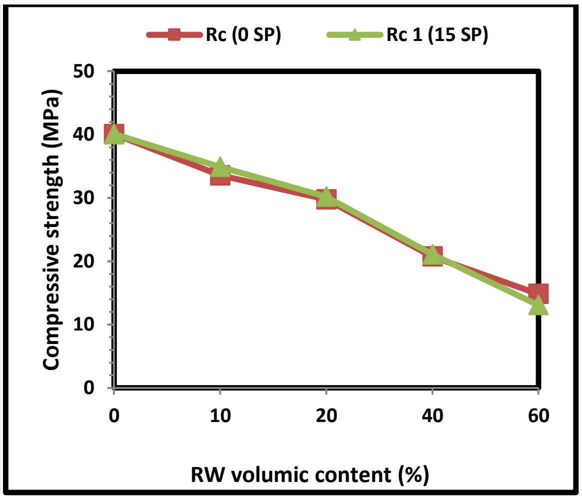


Figure.3.6. Effect of SP incorporation with RW on the 28 days tensile strength.

Figure.3.7. Effect of SP incorporation with RW on the 28 days compressive strength.

Concerning tensile strength for the mixtures in the presence of the GP and SP with respect to the rubberized control, a slight improvement was detected. We should mention the following examples of the mixes 10RW15GP, 10RW15SP; they were improved 0.43% and 0.21% respectively.

V.2.4 Ultrasonic pulse velosity

The evolution of ultrasonic pulse propagation velocities was examined as a function of RW, SP, GP and the combination of them. To compare the combined effect of RW and (GP and SP) replacement of CS and cement, respectively, with the separate effects; the experimental results relative to the 28 days speed ultrasonic pulse velocity were regrouped in Figure.3.8.

It has been found that the combined mixtures have a higher 28 days ultrasonic pulse velocity than that of the mixtures containing only RW aggregates, except the 60RW15SP mixture which was negatively affected. It should be noted that the improvement was great with GP than SP. It also can be seen that for C-ref, 0RW15GP and 0RW15SP the pulse velocity were 4640 m/s, 4750 m/s and 4698 m/s, while those of 10RW, 10RW15GP and 10RW15SP mixtures were 4540 m/s, 4725 m/s and 4660 m/s. It may be concluded that the combined incorporation of the (RW-GP) and (RW-SP) compacts and creates a condensed matrix.

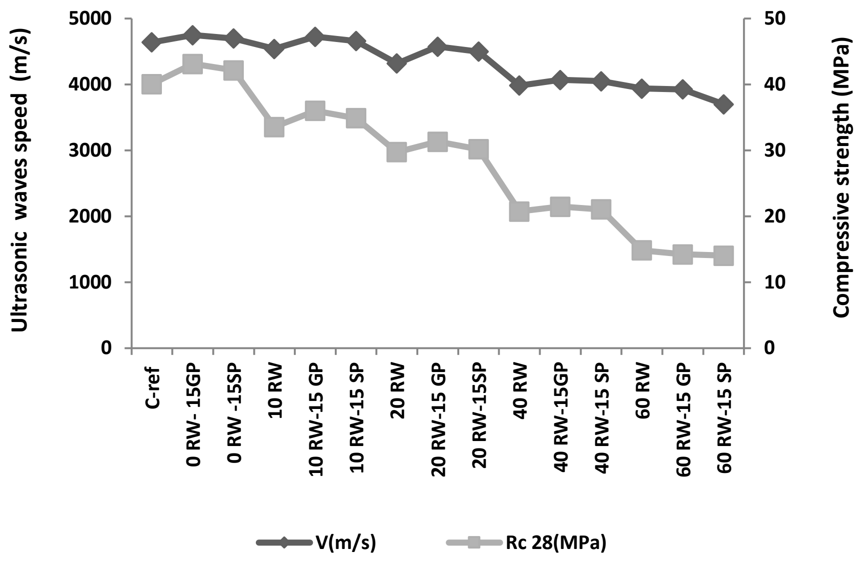


Figure.3.8.The ultrasonic pulse velocity and the corresponding compressive strength of the mixtures.

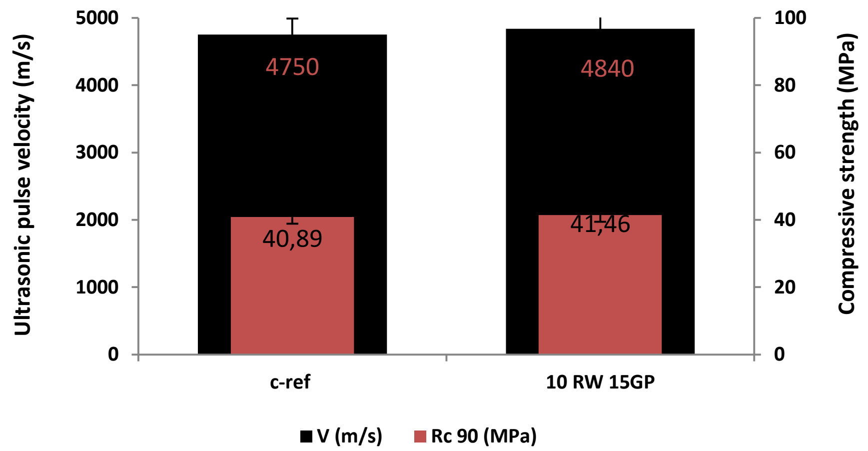


Figure.3.9. Effect of glass powder on 90 days compressive strength and ultrasonic pulse velocity of the mixtures C-ref and 10RW15GP.

This can be due to the same reasons mentioned in the section (1.3) for the compressive strength at 28 days.The improvement of the porosities due to the GP and SP fillers effect can explain this difference. Moreover, There is an apparent calibration relationship between the $R_{c28}$of the concrete and its ultrasonic pulse velocity.

V.2.5 Deformability static modulus

Strain-stress curves are shown in Figure.3.10. For the following mixes: C-ref, 10RW, 20RW , 10RW15GP, 20RW15GP at 28 days. The effect of the combination of the (RW-GP) incorporation on the elastic modulus (E_c) is shown in Figure.3.11. It was equal to 29.5 GPa and 24.77 GPa for 10RW15GP and 20RW15GP respectively. It should be mentioned that the average value of peak stress for the mixes 10RW15GP and 20RW15GP were 34.83 MPa, and 29.85 MPa corresponding to the average values of a strain of ε = 0.207 % and ε = 0.387 %, respectively. A slight increase in the elasticity modulus and in the strain corresponding to the peak stress was recorded. This incresase may be due to the positive synergy between the rubber waste and the glass powder. It may be noted that combining the (RW- GP) in concrete slows the elastic and plastic deformations and improves the energy of specimen's deformation before failure compared to those modified with rubber aggregates alone. Glass powder is able to increase the strength and deformation of the rubber mixes, by enhancing their capacity of deformability.

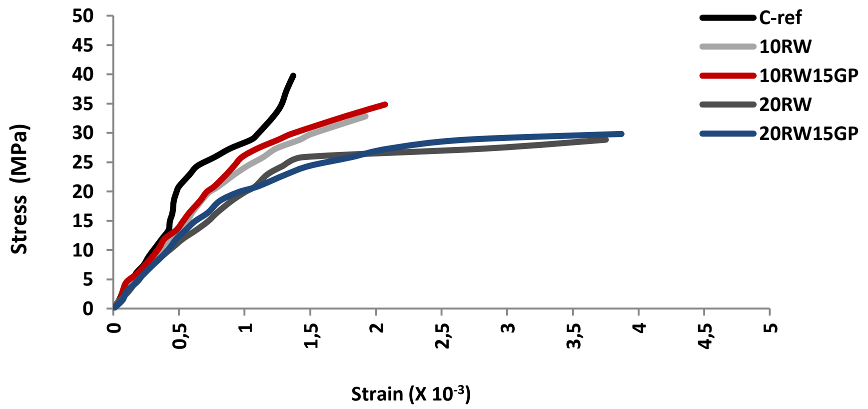


Figure .3.10. Stress-Strain curves of rubberized concrete with and without glass powder.

Comparable conclusions were achieved by Noaman et al. [21] and Omran et al. [41]. The (RW-GP) concrete becomes to be more ductile and more resistant than rubberized concrete.

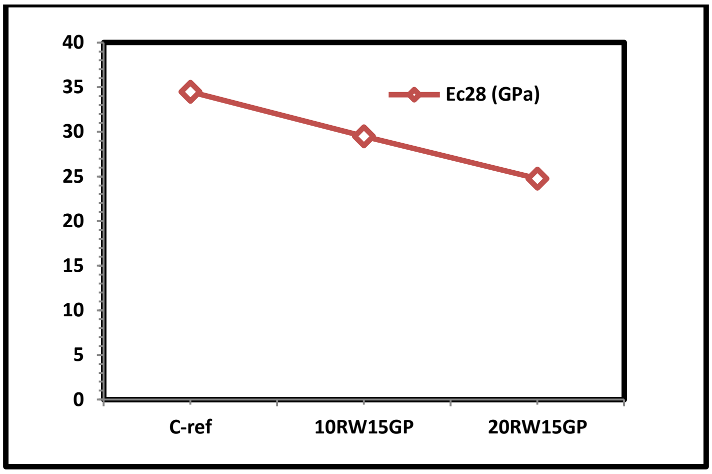


Figure .3.11. Modulus of elasticity of combined RW and GP wastes.

V.2.6 Sulfuric attack acid H_2SO_4

The results relating to concrete attacks containing different percentages a combination of the 2 wastes (rubber aggregates and GP) and a combination of rubber aggregates and SP in a solution of 10% H_2SO_4 are presented in Figures (3.11 and 3.12) which will follow.

The mixes with combined use of the rubber waste and GP show a resistance to sulfuric acid attack higher than the reference mix (Figure.3.14). It should mentioned that the loss mass values of the following mixes 0RW15GP, 10RW15GP, 20RW15GP, 40RW15GP and 60RW15GP is 1,13%, 1,34%, 1,12%, 1,08% and 1,56% respectively compared to the reference concrete value of 1,75%.These results confirm previous findings about the fact that the presence of pozzolanic admixtures was found to lower the detrimental effect of acid attack on concrete [16,31,32]. Moreover, F. Azevedo et al. [26] concluded that the new mixes with rubber wastes, fly ash and metakaolin could be recommended for sulfuric acid resistance applications.

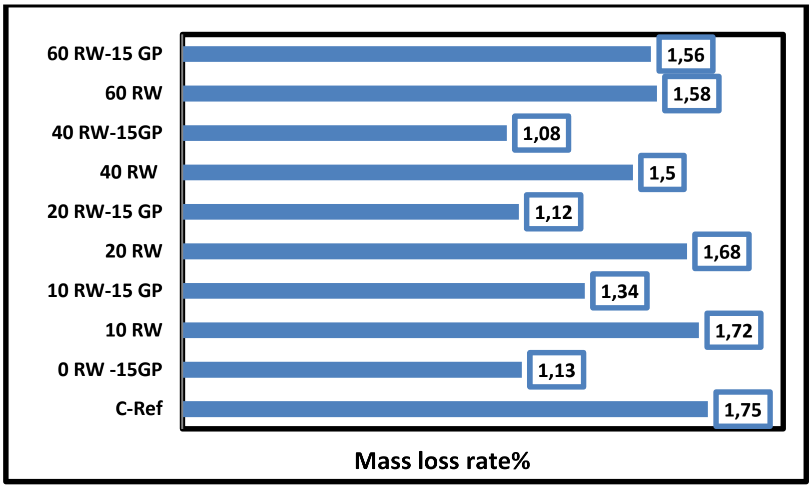


Figure.3.12. Mass loss of rubber mixes modified with GP.

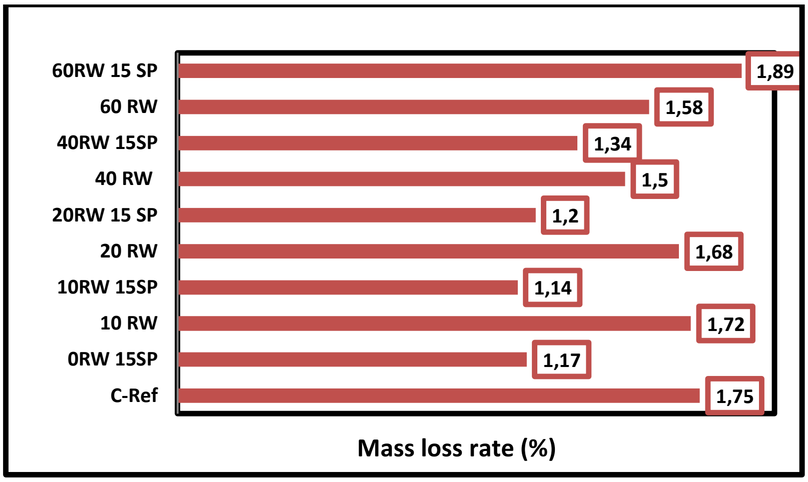


Figure.3.13. Mass loss of rubber mixes modified with SP.

Add to this, Hocine Siad et al. [185] shows that the worst resistance to H_2SO_4 attack was recorded by the reference mortar, however in mortars with GP, mass loss decreased gradually with GP replacement dosage. Bases to the results, it is revealed that combined introducing RW and GP into concrete exhibits better resistance to the sulfuric attack acid then both rubberized concrete and reference concrete. This is may be due to the synergetic effect between RW and GP to compensate the resistance of concrete against the sulfuric attack acid. It is interesting to conclude that combined the tow wastes increased the capacity of concrete resist to the acid attacks. Moreover concerning the effect of glass powder on concrete durability, Erhan Güneyisi et al. [15] explained this positive effect of glass powder in the sulfuric attack acid resistance by the improved characteristics of the pore network, the filling effect of glass particles and the conversion of CH to C–S–H.

20RW15GP

10RW15GP

60RW15GP

40RW15GP

Figure.3.14. compined (RW+GP) wastes specimens immersed in sulfuric acid at 28 days.

From the results, it is the percentage of 15% GP combined with 40% RW which allows the least losses of weight. Also, concerning those which combined with SP, 10RW15SP was the least one. This can be explained by the pozzolanic reaction of the finer SP particles which fixes the lime, allowing a reduction of the capillary pores by the formation of the 2nd generation C-S-H gels thus blocking the absorption of the acidic solution.

20RW15SP 10RW15SP

40RW15SP 60RW15SP

Figure.3.15. compined (RW+SP) specimens immersed in sulfuric acid at 28 days.

V.2.7 Water permeability

The effect of combined GP With the 10%, 20%, 40% and 60% rubber content, respectively, on the water depth permeability, could be seen in Figure.3.16. A significant improvement was observed by addition of glass powder to the mixes 10RW and 20RW. The depth on water penetration value of 2.88 cm and 4.3 cm was obtained for 10RW15GP and 20RW15GP compared to 3.9 cm and 5.6 cm for 10RW and 20RW mixes respectively. As examples, the difference on water depth penetration between rubber mixes with 10% GC, 20% GC, 40% GC and the corresponding glass-rubber mixtures were respectively of +26.15%, +23.21%, and +5.71. At 60% GC the test of water permeability was failed. It should be noted that with the combined use of the rubber aggregates waste and glass powder, the concretes had lower water permeability. So, we can state that glass powder improves pore structure and durability of concrete. When, Seong et al. [215] reported since the capillary porosity is related to permeability, the addition of LGP (Glass powder) may reduce permeability to contribute to improvement of the material durability.

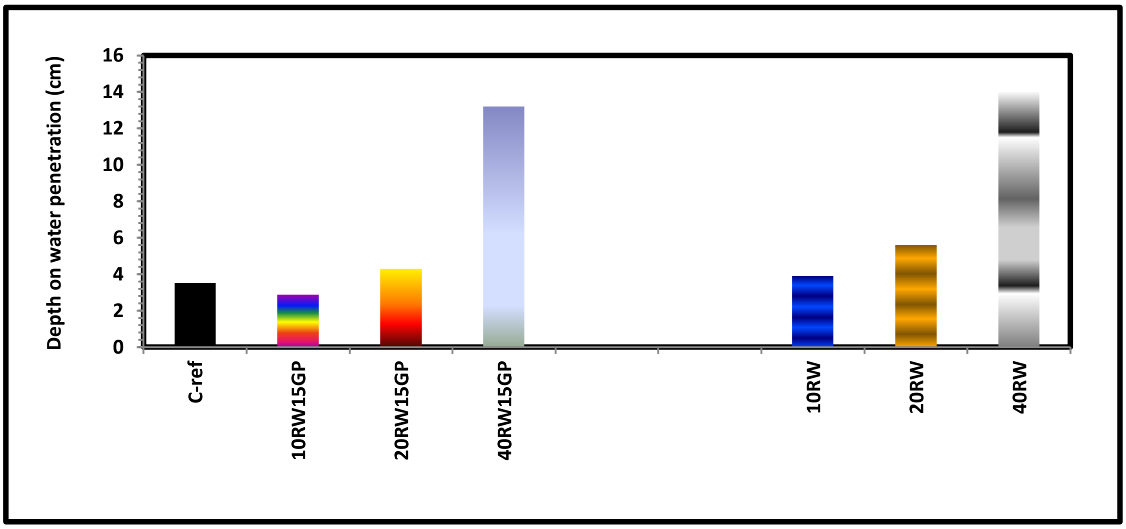


Figure.3.16. Depth on water penetration of glass-rubber mixes.

The authors explained the reason for this improvement by the ability of glass powder for improving the adhesion between the rubber particles and the cement matrix which allows a reduction in the size of the voids and micro-cracks; it has consequently reduced the micro-ducts by which water can penetrate. Similar work by Güneyisi [25] on the simultaneous use of GCs and silica fume has led to better homogeneity and improved pore structure of the composite as a result of the contribution of silica by micro-filling.

Figure.3.17. represents the improvement in penetration depth water under pressure of the mixtures with the combination of the two wastes (RW+GP).


10RW 10RW15GP


20RW 20RW15GP


40RW 40RW15GP

Figure.3.17. Depth of penetration of pressurized water of RW+GP-based concretes of 10RW, 20RW and 40RW respectively.

Based on these results, it is established that the combined incorporation of RW and SP has a positive effect on the depth of penetration of water under pressure (Figure.3.18).

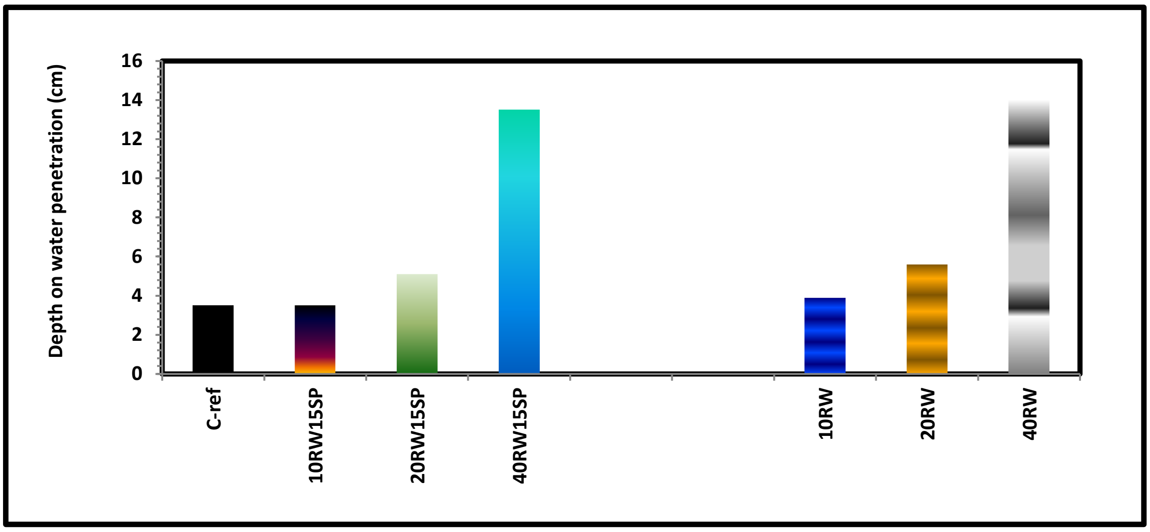


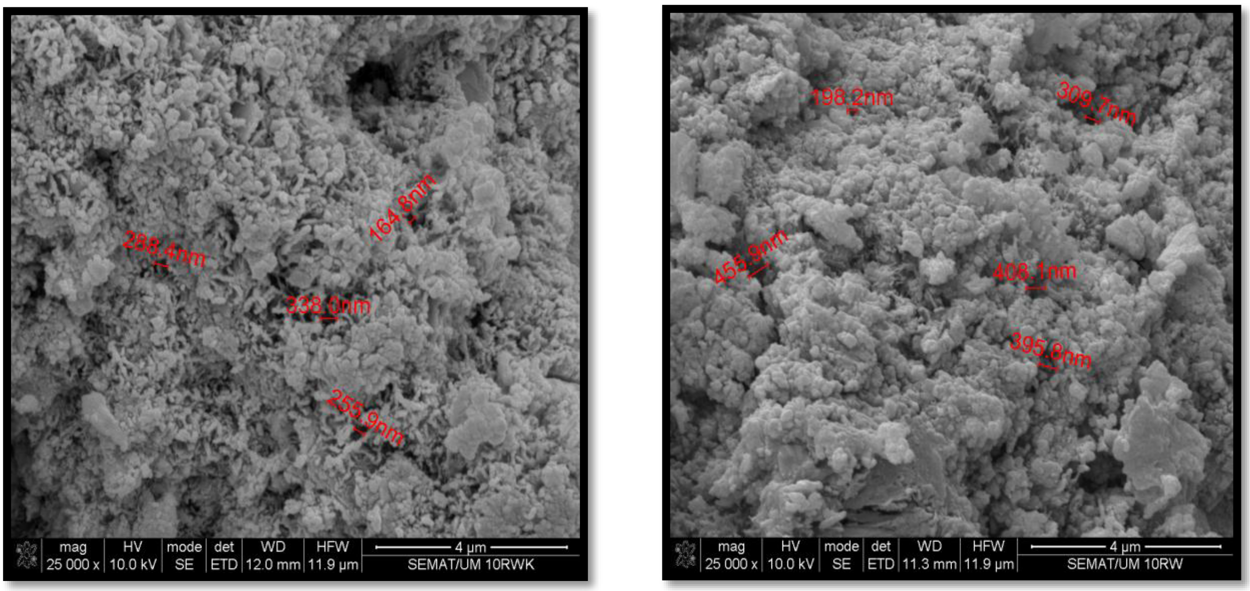
Figure.3.18. Depth on water penetration of sand-rubber mixes.

It decreases for all the contents of utilized rubber aggregates compared to that of the concrete with rubber waste alone and also with reference concrete. The gain was +10.25%, +8.92% and +3.57% for 10 % RW, 20% RW and 40% RW respectively.

We concluded that the difference in GP and SP behavior may be due to difference on the fineness, their chemical composition, their structure (glassy or crystalline), their pozzolanic activity and their solubility in alkaline medium govern their cementing properties in concrete. Also, their content in amorphous phase is a key factor in the reactivity of them.

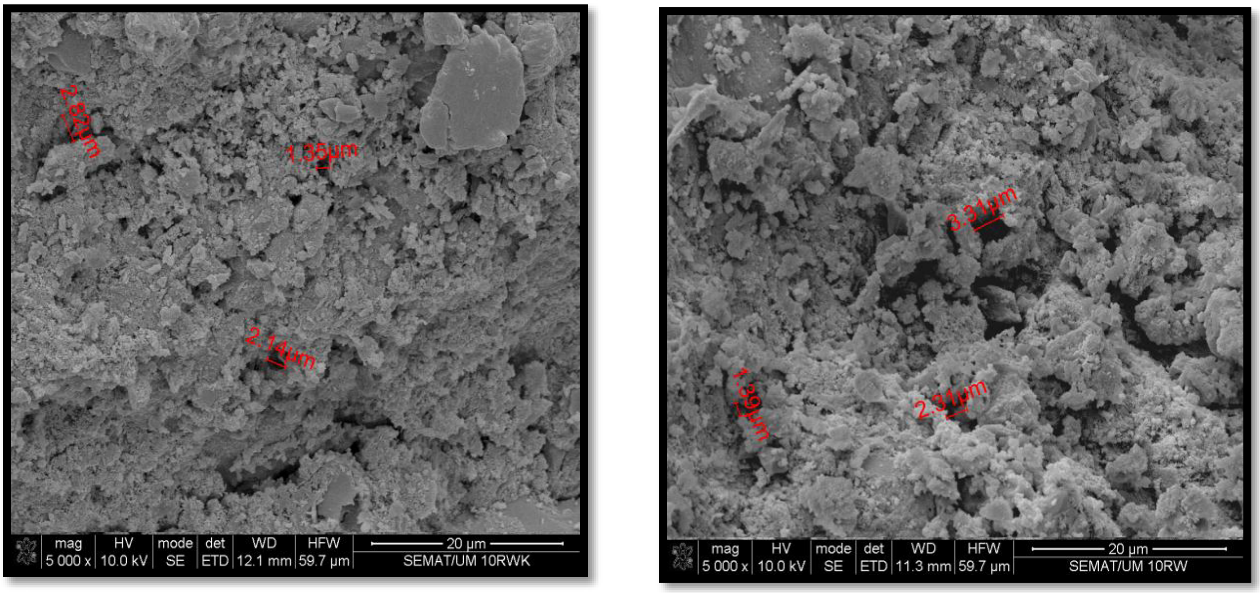
V.2.8 Porosity and zone transition with SEM observation

Figures (3.19 and 3.20)show samples of combined glass-rubber concrete of 10% GC with differents magnification (X100, X5000, X25000). Through the scanning electron microscope (SEM) images, the microstructure of the concretes 10RW and 10RW15GP looks different and more compacted for mix modified with 15% GP. As can be seen in the micrographs, when the waste glass content added to the rubber mix, the voids between the crystals and gels decreased. These results prove the positive effect of GP on the evolution of the strength and durability of concretes as presented in previous sections of the work. This behavior may be associated mainly with the pozzolanic activity of waste glass. Miranda et al. [216] note that the microstructure showed a reduction of void content with the presence of waste glass powder. Moreover, in these micrographs, note that the weak link between rubbers aggregates and the cement paste shown to be improved with the incorporation of the glass powder (Figure.3.21).



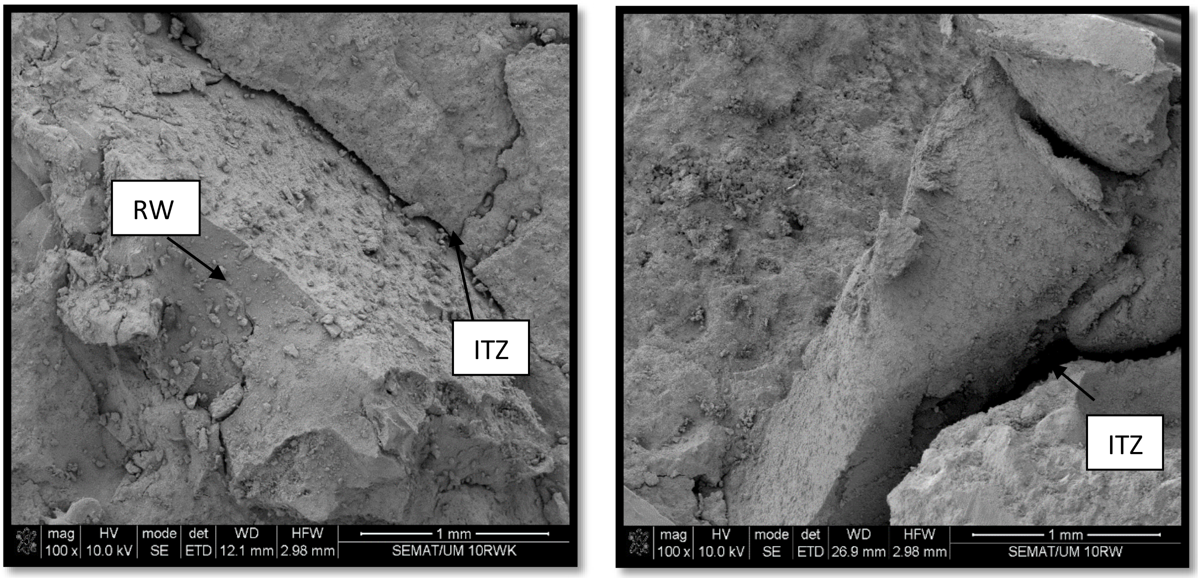
10RW15GP　　　　　　　　10RW

Figure.3.19. SEM image of mixture contained 10RW and 10RW15GP at 90 days (X 25 000).



10RW15GP　　　　　　　　10RW

Figure.3.20. SEM image of mixture contained 10RW and 10RW15GP at 90 days (X 5000).



10RW15GP 10RW

Figure.3.21. SEM image of mixture contained 10RW and 10RW15GP at 90 days (X 100).

V.3 Conclusion

- By combining the two RW and GP wastes, we can concluded that it is possible to obtain an improvement of the different physico-mechanical and durability characteristics of the concretes. The beneficial effects ofone makes it possible to compensate for the disadvantages that could be presented by the other. The same observation was recorded about combining RW with SP in concrete.
- There is a minor improvement on the tensile strength of (GP-RW) and (SP-RW) mixes.
- The mix with 10% RW and 15 % GP acheived the best compressive strength compared to the common rubberized concrete, which is associated to a high compressive strength above 36.01 MPa at 28 days.

- All compressive strength values of combined (RW-GP) and (RW-SP) are superior to those obtained with mixtures contain separate wastes and powders.
- A decrease in permeability to water has been demonstrated. This shows that high porosity has been mitigated in the presence of (GP-RW) and (SP-RW) in the same mixes.
- Accordingly to ASTM C618, as per the minimum requirement for a pozzolan, the proposed local waste raw material will be good pozzolanic additive which can play a micro filler role within the concrete matrix.
- Combining the (RW- GP) in concrete slows the elastic and plastic deformations and improves the energy of specimen’s deformation before failure compared to those modified with rubber aggregates alone.

General conclusion

In this work, the performance of eco-concrete based on rubber aggregates from used tires was investigated experimentally.

The different eco-concrete mixtures represented below:

- 1 Mixtures: siliceous dune sand crushed sand, coarse aggregates 3/8 and 8/15, rubber aggregates (0/4 mm) to replace crushed sand , Portland cement CEM 42.5, superplasrisizer, and water.
- 2 Mixtures: the same components (without rubber aggregates) with fillers of glass powder in substitution for cement.
- 3 Mixtures: the same components (without rubber aggregates) with fillers of dune sand powder in substitution for cement.
- 4 Mixtures: The same components of 1 mixtures with combined rubber aggregates as crush sand replacement and glass powder waste in substitution for cement.
- 5 Mixtures: The same components of 1 mixtures with combined rubber aggregates as crush sand replacement and dune sand powder waste in substitution for cement.

Based on the results the main following conclusions can be drawn:

- Rubber aggregates significantly reduce reference concrete density and affect their physical and mechanical performance due to low density of RW and voids provided by their presence into the cement matrix, in addition, the poor bond between them and the paste cement. In fact, the fresh density, workability, water permeability, compressive and tensile strength of the elaborated eco-concretes have been deteriorated.

- Higher fresh density was observed for the mixtures prepared by rubber aggregates and glass powder or sand powder. It can be concluded that the composed (RW-GP) particles in concrete create a compromise on fresh density between the separate effect of RW and GP replacement.
- Moreover, the durability of these eco-concretes has been improved notably the resistance to attacks against H_2SO_4 evaluated by the weight loss, the loss decreased with RW increase compared to the reference concrete, however, durability indicators related to the water permeability of these composites were affected negatively.
- The presence of rubber aggregates on cement mixtures could allow relaxing the stresses and enlarger the strain which reducing the formation and / or the propagation of cracks (ductile behavior) compared to the fragile reference concrete.
- The glass powder residue is mainly composed of amorphous silica and the principal crystalline component is $CaCO_3$. GP meets the standard specifications ASTM C618 in terms of chemical composition.
- The combination of the RW and GP offers enhanced workability of concrete due to the low GP and RW water absorptions.
- The maximum 28 days compressive strength was obtained by the rubberized concrete modified with glass powder. It was achieved by the 10RW15GP mixture and attained 36,01 MPa.
- The decrease of compressive and tensile strengths verified at 28 and 90 days for rubberized concrete with the addition of glass powder. This is may be due to the

positive synergy brought by the combination of RW, GP and cement which mitigates the loss of used RW separately in the mixtures. It can be determined that glass powder finely grounded can be used as a good pozzolan in cementitious materials.

- At 90 days the mixture 10RW15GP achieved compressive strength value superior to both, the reference concrete without, and with RW reaching 41.46 MPa. This confirms that glass powder became more effectiveness at a later age.
- Glass powder needs a supplementary agent for dissolving the amorphous silica to react with the lime at an early age.
- Glass powder as an artificial material showed a more advantageous behavior than natural sand powder, for 15% cement replacement by mass.
- An improvement in the mechanical strengths of C-ref filled with GP and SP was noted, where it is more grater with GP.
- The simultaneous incorporation of rubber waste and glass powder increases the ductility of concrete by slowing the elastic and plastic deformations and improving the energy of specimen’s deformation before failure.
- When GP and SP fillers are introduced into the rubberized cementitious matrix, this combination leads to a decrease in water permeability and increases the resistance against sulfuric acid for all RW substitution rates compared to reference concrete.
- SEM images confirmed the effect of rubber aggregates and glass powder on mechanical and durability proprieties.
- This study supports the large-scale recycling of scrap tires as aggregates and glass bottle as filler to be used in the production of concrete. It will surely bring enormous environmental benefits.

- In regions with low silico-calcareous aggregates the RW can cover part of the demand for construction aggregates.
- From another point of view, replacing the cement by the waste glass powder (nanoparticles) on concrete can be a start to replacing silica fume too by waste glass powder and exceed great economic benefits.
- In Algeria, dune sand is an abundant material, used the sand powder in cementitious materials as additives can minimize the cost of the concrete and mortar.
- Rubberized concrete can be used for non-load bearing purposes such as noise reduction barrier, slaps under machines applications submitted to severe dynamic actions like railway sleepers.

In conclusion, an interesting alternative to produce an environmentally concrete by the use of these two wastes and local materials has been proven by this study.

Perspectives

- Sustainability studies are needed beyond 9 months to reach the stability limit.
- Rubberized concrete have been to be very effective against shrinkage cracking. Further investigation need to clear this performance.
- We think that the glass powder an early age can be more effective if treated under heat analysis, so investigations about the purpose need to make.
- It is important to investigate the performances of rubberized concrete under a high temperatures and fire.
- The creep of rubberized concrete should be investigated.

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