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Title

Contribution to the development of a lightweight concrete based on recycled wastepaper

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Dedication

This final project is dedicated to my dear parents who have always motivated me in my studies, this represents the result of the support and encouragement they gave me throughout my schooling.

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Abstract

This work presents a study on a building material named papercrete which is a type of fibrous concrete made by shredding paper as pulp in water, with Portland cement and local sands (river and dune sand). The percent of waste paper used (10%, 20%, 30%, 40% and 50%) by weight of sand. The mechanical properties studied of the mixtures are compressive strength and flexural strength. Results showed that increasing the content of waste paper, decreases the compressive strength. However, the flexural strength is increased with content of paper up to 20%, then decrease for high percentages of paper.

Key Words: papercrete, waste paper, mechanical properties, compressive strength, flexural strength.

List of contents

Chapter II: Review on papercrete

Chapter III: Materials, Experimental protocols and results

List of figures

Chapter I : Recycling in construction field

Chapter II : Review on papercrete

Chapter III : Materials, Experimental protocols and results

List of tables

Chapter I : Recycling in construction field

Chapter II : Review on papercrete

Chapter III : Materials, Experimental protocols and results

Introduction

General Introduction

Algeria is facing a constant increase in waste production, it generates about 385.000 tonnes / year of papers valuable, this is where we got the idea of recovering waste paper by introducing it into the construction industry to encourage recycling.

Recycling is recovery and reprocessing of waste materials for use in new products. The basic phases in recycling are the collection of waste materials, their processing or manufacture into new products, and the purchase of those products, which may then themselves be recycled. Typical materials that are recycled include iron and steel scrap, aluminum cans, glass bottles, paper, wood, and plastics. The materials reused in recycling serve as substitutes for raw materials obtained from such increasingly scarce natural resources as petroleum, natural gas, coal, mineral ores, and trees. Recycling can help reduce the quantities of solid waste deposited in landfills, which have become increasingly expensive. Recycling also reduces the pollution of air, water, and land resulting from waste disposal.

The aim of this research is to study the characteristics and explore the properties of a new material based on recycled waste paper for the production construction material named papercrete incorporating local sands: river and dune sand.
The main objectives are to:

- Conduct a literature review on the state of the art.
- Develop a mix proportioning process for the production of wastepaper-based concrete.
- Study the mechanical properties of the new material.

We have divided our work into two parts, the first part deals with recycling in construction field and a review on papercrete.

The second part is devoted to the experimental work on papercrete and discusses the main results. Finally, a summary of the whole research is presented, the conclusions drawn and recommendations made based on the laboratory experimental results.

Chapter I : Recycling in construction field

I.1 Introduction

The problems related to the environment covering all around man and which is one of the indispensable milieu to ensure the sustainability of life, are increasing more and more and becoming a threatening case for nature as well as for humanity. Our natural resources are dwindling day by day due to the increase in the world's population and changing consumption habits. Global climate change has posed environmental problems in recent years, as well as the rapid decline of natural resources.

This is why it is imperative to reduce the consumption of equipment, and to use natural resources efficiently by recycling the qualitative waste to be evaluated. Therefore recycling is extremely important in terms of protection, also for the efficient use of natural resources.

Construction is one of the sectors in which raw materials are consumed the most. The field of construction seeks to minimize the incomes of manufacturing processes, as well as to reduce as much as possible the consumption of raw materials, the consumption of energy, the emissions and the use of space.

Therefore it is necessary to decrease the waste from construction and demolition activities in order to reduce the waste problems in an effective and productive way.

I.2 Recycling

Recycling is a process for treating waste (industrial or household) from products at the end of their life, which allows some of their materials to be reintroduced into the production of new products. Recyclable materials include some metals, plastics and cardboard, glass, rubble, etc.

Recycling has two major ecological consequences:

- reducing the volume of waste, and therefore the pollution it would cause (some materials take decades, even centuries, to degrade);
- preservation of natural resources, since recycled material is used instead of what should have been extracted. [1]

Fig I.1 recycling waste [2]

I.3 The importance of recycling

I.3.1 Conserving natural resources

The world's natural resources are finite, and some are in very short supply. [3]
At a fundamental level:

- **Recycling paper and wood :** saves trees and forests, we can plant new trees, but we can not replace virgin rainforest or ancient woodlands once they are lost.
- **Recycling plastic :** means creating less new plastic, which is definitely a good thing, especially as it is usually made from fossil fuel hydrocarbons.
- **Recycling metals :** means there is less need for risky, expensive and damaging mining and extraction of new metal ores.
- **Recycling glass :** reduces the need to use new raw materials like sand – it sounds hard to believe, but supplies of some types of sand are starting to get low around the world.

I.3.2 Protecting ecosystems and wildlife

Recycling reduces the need to grow, harvest or extract new raw materials from the Earth.

That in turn lessens the harmful disruption and damage being done to the natural world: fewer forests cut down, rivers diverted, wild animals harmed or displaced, and less pollution of water, soil and air.

And of course if our plastic waste isn't safely put in the recycling, it can be blown or washed into rivers and seas and end up hundreds or thousands of miles away, polluting coastlines and waterways and becoming a problem for everyone.

I.3.3 Saves energy

Making products from recycled materials requires less energy than making them from new raw materials. Sometimes it's a huge difference in energy. For example:

- Producing new aluminium from old products (including recycled cans and foil) uses 95% less energy than making it from scratch. For steel it's about a 70% energy saving.
- Making paper from pulped recycled paper uses 40% less energy than making it from virgin wood fibres.
- The amount of energy saved from recycling one glass bottle could power an old 100-watt light bulb for 4 hours and a new low-energy LED equivalent for a lot longer. [4]

I.3.4 Cuts climate-changing carbon emissions

Because recycling means we need to use less energy on sourcing and processing new raw materials, it produces lower carbon emissions. It also keeps potentially methane-releasing waste out of landfill sites.

Reducing carbon dioxide and other greenhouse gases being emitted into the atmosphere is vital for stopping disastrous climate change. [4]

I.3.5 Reduces demand for raw materials

the world's increasing demand for new stuff has led to more of the poorest and most vulnerable people (for example, those living around forests or river systems) being displaced from their homes, or otherwise exploited. Forest communities can find themselves evicted as a result of the search for cheap timber and rivers can be damned or polluted by manufacturing waste.

It's far better to recycle existing products than to damage someone else's community or land in the search for new raw materials.
-ints and it would help to minimize the whole size of landfills around the world. [4]

1.4 Types of construction wastes and recycling strategies

1.4.1 Brick

Brick wastes are generated as a result of demolition, and may be contaminated with mortar and plaster. Brick wastes are sometimes blended with other materials like timber and concrete. Currently, bricks are recycled by crushing and using as filling materials. [4]

Fig I.2 Brick waste

1.4.2 Concrete

Concrete wastes can be generated due to demolition of existing structures and testing of concrete samples etc. commonly recycling measures of concrete wastes are used crushed concrete as aggregate.

The crushed concrete aggregate has been used as a replacement to natural aggregate in new concrete, and it also has been employed in the construction of road base and trenches. [4]

Fig I.3 Concrete waste

1.4.3 Ferrous Metal

Ferrous metal is another type of wastes which not only highly profitable but also can be recycled nearly completely. In addition, ferrous metal can be recycled multiple times. [4]

Fig I.4 Ferrous Metal

1.4.4 Masonry

Masonry waste is produced as a result of demolition of masonry buildings. It can be recycled by crushing the masonry waste and used as recycled masonry aggregate.

A special application of recycled masonry aggregate is to use it as thermal insulating concrete. Another potential application for recycled masonry aggregate is to use it as aggregate in traditional clay bricks. [4]

Fig I.5 Masonry waste

1.4.5 Non-ferrous Metal

Aluminum, copper, lead, and zinc are examples of nonferrous materials wastes produced at construction sites. The majority of these materials can be recycled. [4]

Fig I.6 Non-ferrous Metal

1.4.6 Paper and Cardboard

Paper and paper board is another type of waste materials which is estimated to comprise one-third construction and demolition wastes by volume. These waste materials are recycled and reprocessed to produce new paper products. [4]

Fig I.7 Paper and Cardboard Wastes

1.4.7 Plastic

The plastic wastes are best possible for recycling if these materials are collected separately and cleaned. Recycling is difficult if plastic wastes are mixed with other plastics or contaminants.

Plastic may be recycled and used in products specifically designed for the utilization of recycled plastic, such as street furniture, roof and floor, PVC window noise barrier, cable ducting, panel. [4]

Fig I.8 Recycling Plastics

1.4.8 Timber

Timber waste from construction and demolition works is produced in large quantity all over the world. Whole timber arising from construction and demolition works can be utilized easily and directly for reused in other construction projects after cleaning, de-nailing and sizing. [4]

Fig I.9 Recycling Timber

1.5 Recycling technique

1.5.1 Recycling processes

There are three main families of recycling techniques: chemical, mechanical and organic. “Chemical” recycling uses a chemical reaction to treat waste, for example to separate certain components. The so-called “mechanical” recycling is the transformation of waste using a machine, for example for grinding. “Organic” recycling consists, after composting or fermentation, in producing fertilizers and fuel such as biogas. [5]

1.5.2 Recycling chain

1.5.2.1 Waste collection

Waste recycling operations begin with the collection of waste. Non-recyclable waste is incinerated or buried in technical landfills. The waste collected for recycling is not intended for landfill or incineration but for processing. The collection is organized accordingly.

Selective collection, also known as separate collection and often called selective sorting, is the most widespread form for waste to be recycled.

The principle of selective collection is as follows: the one who creates the waste sorts it himself. Following collection, the waste, whether sorted or not, is sent to a sorting center where different operations enable it to be sorted so as to optimize processing operations. One of these operations is manual sorting. [5]

1.5.2.2 Transformation

Once sorted, the waste is taken care of by the processing plants. They are integrated into their specific transformation chain. They enter the chain in the form of waste and leave it in the form of a material ready to use. [5]

1.5.2.3 Marketing and consumption

Once processed, the finished products from recycling are used for the manufacture of new products which will in turn be offered to consumers and consumed, to be at the end of their life, again discarded, recovered and recycled. [5]

I.6 Waste in Algeria

The deposit of household waste produced annually in Algeria includes a non-negligible recoverable fraction that the MATET services (Ministry of Spatial Planning and the Environment and Tourism.) estimate the following values: [5]

Papers 385,000 tonnes / year

Plastics 130,000 tonnes / year

Metals 100,000 tonnes / year

Glass 50,000 tonnes / year

Various materials 95,000 tonnes / year

From the national data, the following can be summarized:

- Algeria generates 10 to 12 million tonnes of household waste each year.
- Algeria has 3000 wild dumps. These landfills occupy a total area of around 150,000 hectares.
- Each year 200,000 tonnes of packaging waste is discharged in Algeria. Plastics represent 95% of this packaging and metals make up the remaining 5%.
- 200,000 tonnes of packaging waste discharges annually, only 4,000 tonnes are recovered, representing 2% of the deposit.
- Each year, 22,000 tonnes of healthcare activity waste is produced in Algeria.
- The Ministry of Spatial Planning and the Environment has programmed the production of 1,000 urban solid waste management master plans for the various municipalities of the country.
- The Ministry of Spatial Planning and the Environment has programmed the construction of 300 Technical Landfill Centers and controlled landfills. [5]
- There are 317 operational incinerators in Algeria for the destruction of healthcare activity waste.
- Each year, Algerians use nearly 300 million batteries and accumulators, or around 12 units per inhabitant. It is estimated that 70% of these batteries end up in the wild or landfill with all the risks of environmental contamination with mercury, cadmium, lead, zinc and lithium.

I.7 Classification of waste in civil engineering

The classification of waste according to its nature leads to three categories either liquid, gaseous or solid. In the card of civil engineering works there are three main families:

I.7.1 Dangerous waste (special)

Special waste is waste that, due to its composition or properties, poses a danger to human health or the environment.

This type of waste must therefore undergo a set of appropriate treatments to reduce its toxicity and the risk of contamination. They therefore require specific collection, transport, treatment, recycling and disposal channels.

There are different types of special waste depending on their origin:

- Special household waste produced by households such as aerosols, gardening products, DIY products, mercury thermometer, etc.
- Special industrial waste produced by heavy industry and companies, such as bottom ash, sewage sludge, phytosanitary waste, solvents, etc.

The waste from care activities with infectious risk and similar (DASRIA) produces hospital and veterinary care centers, such as syringes, culture media, anatomical fragments, dressings, etc. [5]

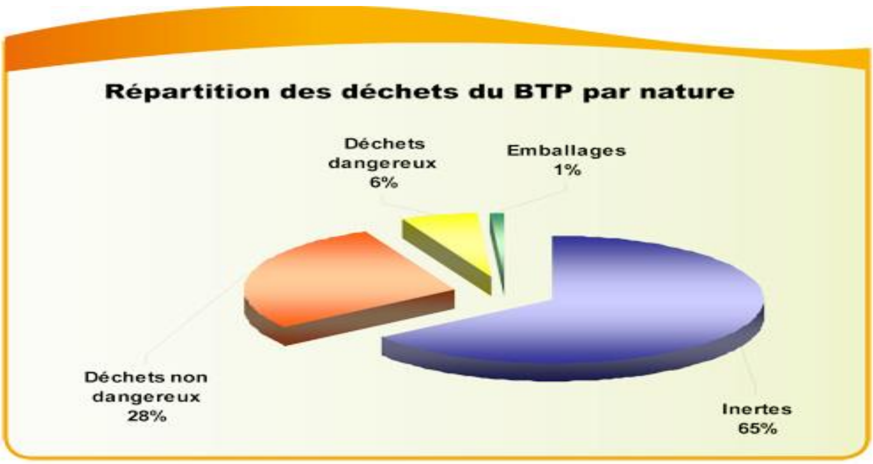


Fig I.10 Building waste compositions [5]

I.7.2 Banished waste

All non-inert and non-dangerous waste generated by businesses, manufacturers, traders, artisans and service providers. These are wastes which do not present any particular danger against people or the environment and which can be disposed of under the same conditions as household waste. These include mixtures of non-dangerous, non-inert waste, Metals, Plaster-plates and tiles, Plastics, Glazing, and other non-inert non-dangerous waste (plastic, metal, cardboard, wood). [5]

I.7.3 Inert waste

Inert waste is unpolluted mineral waste. They do not decompose, do not burn and do not produce any physical or chemical reaction. They are not biodegradable and do not deteriorate on contact with other materials in a way that may cause environmental pollution or harm human health.

This waste comes from construction, rehabilitation (renovation) and demolition activities related to the building sector, as well as activities related to the construction and maintenance of public works (roads, bridges, networks, etc.).

Among the inert waste produced by the building sector are: concrete, bricks, ceramics, tiles, gypsum-based materials. [5]

I.8 Recycling of construction site waste

In the obligation to recover as much as possible on construction site waste, it is necessary to avoid mixing the different types of waste.

The sorting of this waste carried out directly on construction sites makes it possible to recover almost 80% of this owing to different collection skips. Once separated, the different materials are sent to recovery channels.

The construction industry produces the largest volumes of waste, 500m3 per capita. In 2004, the canton of Vaud produced almost 1,200,000 tonnes of construction site waste, which is significant compared to 600,000 tonnes of all other categories of waste.

The recovery of demolition waste has gone beyond the experimental stage and is undergoing fairly significant development. As an indication, the recycling rate in certain European countries for the year 1995 is summarized in the following Table: [5]

Table I.1 Recycling rate in Europe [5]

Country	Recycled debris (million t / year)	Recycling share In production Debris (%)	Recycling share in the aggregate consumption (%)
Netherlands	7.7	64.2	6.1
UK	7.2	14.8	2.5
Belgium	2.3	30.3	2.6
Danemark	14.9	24.0	3.6
France	3	9.0	0.7
Spain	0.5	3.7	0.2

I.8.1 Elaboration of recycled aggregates

Inert waste can be transformed into recycled aggregates for use, in fill of various kinds, in form of layers on public works sites or even as aggregates for concrete.

Recycled concrete aggregates differ from natural aggregates in their composition. Indeed, recycled concrete aggregate is a composite material, whose the two constituents are :

- Natural aggregates partially crushed,
- Crushed hydrated cement paste, coating the natural aggregates.

The development of recycled aggregates based on demolition and construction waste consists of reducing the largest element using a hydraulic breaker, cutting the long elements using a shear, then crush the materials according to the desired particle size.

In general, inert demolition waste can be treated in facilities specially designed for this purpose. They can be three:

Mobile: the installations are mounted on a trailer or semi-trailer and can be easily transported from one intervention site to another.

Semi-mobile: the installations are mounted on metal structures and can be moved without problem using suitable handling equipment.

Fixed: the installations are mounted on foundations. [5]

I.8.2 Recycling operation

A study devoted to the recycling of the inert fraction of demolition materials, carried out in France in 1992 by the National Union of producers of recycling aggregates, shows that: Recycling by a mobile installation, in addition to the fact that it requires large demolition sites (30,000 tonnes minimum), presents difficulties in terms of product marketing, for several reasons:

Competitiveness often less favorable than in large cities. Short material evacuation times (duration of the site), Offers products located outside the organized circuit.

Recycling by a fixed installation collecting demolition materials over a large geographic area (half of a department, for example) is technically feasible but more economically uncertain because the cost of collection must be attractive than the cost

of disposal in charge. Thus for a demolition site located 50 km from the recycling facility, the cost of landfill, to be dissuasive, should be higher than the cost of transport to the facility.

Equal prices met for transporting natural aggregates over a distance of around 20 km. The competitiveness rule can be translated as follows, at an equal price returned to the implementation site:

The recycled aggregates bear an additional cost, from the installation, which corresponds to a transport distance of 20 km. Which is to say that natural aggregates benefit from an additional transport possibility of approximately 20 km. [5]

I.8.3 Construction and demolition waste

Among the so-called inert waste, some could be recycled, which further reduced the extraction of aggregates while extending the life of the landfills which they currently contribute to saturating. These recyclable materials are in two product categories:

Demolition materials and construction waste are the main source of recycling aggregates and can also be used as materials for civil engineering: coarse materials (reinforced concrete, aerated concrete), softer materials (brick, tiles, ceramics, etc.).

The spoils of natural land are directly recoverable in materials for civil engineering work of development: coarse elements, gravels and sands, Earths. [5]

I.9 Interest of recycling in the field of civil engineering

Currently, most of the aggregates used on the market are natural aggregates from quarries or from the extraction of river beds or sea beds. These products offer the advantage of relatively consistent quality and continuous supply. [6]

Recycled aggregate cannot currently be considered as a replacement material that would prevent the exploitation of natural deposits, but it can slow down this process.

The distribution of the different types of aggregates is carried out as follows:

- natural aggregates: around 43 million tonnes per year (+/- 58%), concrete manufacturing alone consumes 15 million tonnes;
- marine aggregates: around 4 million tonnes per year (+/- 5.5%);
- artificial aggregates: around 2 million tonnes per year (+/2.25%);
- sands / gravel: approximately 11 million tonnes per year (+/- 14.75%);
- recycled aggregates: 14 million tonnes per year (+/- 19.5%).

I.10 Motivaing people to recycle more

In a time where people want to do their part to help the environment, materials are being recycled more now than ever before. With materials such as paper, cardboard, glass, plastic, and aluminum eligible to be recycled, more is being kept out of landfill sites and less energy is being used to produce more. [7]

Here are some ideas to encourage people to recycle more.

I.10.1 Signage

In order to get people to recycle more in their home or office, consider posting signs in strategic areas such as over recycling bins and garbage cans. Ensure the signs specify what can be recycled as well as what materials can be mixed together. These signs will inform people of the materials that they possibly have in their possession that can be recycled and they can then make an informed decision of how to dispose of them.

I.10.2 Place bins near garbage

When people need to dispose of things, it is a natural reaction to through them in the garbage. Recycling processes have come a long way over the years but the reality is there are still way more garbage bins available than recycling bins, making it easier to trash things rather than recycling them.

Placing recycling bins near or next to garbage bins may be effective in getting people to recycle more. Together with the signs detailing what is eligible to be recycled, people will be made aware of what is recyclable and can then make a conscious choice regarding what to do with their materials.

I.10.3 Offer incentives

While people should recycle because it is the right thing to do and is instrumental in reducing harm done to the environment, sometimes this is not enough. Therefore, incentives should be considered to encourage people to recycle more.

To get those present to recycle more, consider an incentive program for your home or office. Whenever someone recycles materials instead of throwing them in the trash, they will get something in return. This can be in the form of prizes, sweets, or special meals. The incentive does not have to be big or expensive and it may be just enough to push someone to recycle eligible materials that they have.

I.10.4 Hold drives

People enjoy being part of teams and contributing to a common cause. As a result, recycling drives have been successful in encouraging the collection of recyclable materials and usually people turn out in droves.

To encourage others to recycle more consider holding a drive. This can come in the form of days or weeks where specific materials are collection. For example one day or week can be designated for can collections, another for paper, and another for plastic. Set goals for people to achieve and report your findings at the end of the specified time period. This will allow your goal to be specific and people can see whether or not it was attained.

Combine your drive with incentives and you may enjoy even more success, getting those who usually do not recycle to participate in the process.

I.11 Bibliographic synthesis

Our research in recycling shows us the possibility of using wastes in the field of civil engineering.

Inert wastes can be transformed into recycled aggregates for use as aggregates for concrete.

The more we recycle reuse and reduce, our earth will be less polluted. Because Today recycling is no longer an option but a necessity. It is not possible to recycle all of our waste ... but an effort on the part of households, urban communities and industrialists can help us move towards this objective, because great efforts are still to be made in terms of collection.

Chapter II : Review on papercrete

II.1 Introduction

Papercrete is a construction material which consists of cement and fine aggregate. It is perceived as an environmental friendly material due to the significant recycled content, by the presence of cement.

It is a construction material which consists of paper slurry, sand and Portland cement. This increase in the popularity of using environmental friendly, low-cost and light weight construction materials in building industry has brought about the need to investigate how this can be achieved by benefiting the environment as well as maintaining the material requirements affirmed in the standards.

As natural sources of aggregates are becoming exhausted, it turns out urgent to develop. The majority of abandoned paper waste is accumulated from the countries all over the world causes certain serious environmental problems.

Papercrete, known by alternative names such as fibrous concrete, padobe and fidobe, low carbon construction material, 45% of discarded papers is recycled annually; 55%thrown away or goes in to the land fill. [8]

Table II.1 Waste paper percentage recycling rate and quantity disposed in landfill in some selected countries. [9]

Country	Percentage Recycling rate of wastepaper	Reference Year	Wastepaper disposed into landfill	References
USA	65%	2012	48 million tons	Nepal and aggarwal,2014
South Africa	57%	2011	728 743 tones	Department of Environmental Affairs (2012)
Europe	71.7%	2012	10 million tones	CEPI,2014
	67.5%	2010	22 million tones	CEPI,2009

II.2 History

As a partly recycled material, it sparked new interest in the 1990s. In the early 1990s, Eric Patterson and Mike McCain, while working independently, came up with the idea of mixing paper with cement. The first, a printer, was looking for a way to recover its waste paper. He crushed a batch of paper, mixed it with cement, using a kitchen mixer and thus invented a new type of material.

At the same time, Mike McCain worked with a very similar product. He developed a blender with a storage tank, mounted in the back of a car, to which he added a mower blade. He thus kneaded a mixture of water, paper and cement. [10]

Fig II.1. Papercrete [11]

II.3 Innovation of papercrete

Papercrete is a material originally developed 80 years ago but it is only recently rediscovered. It is a fibrous cementious compound comprising waste paper and Portland cement.

These two components are blended with water to create a paper cement pulp, which can then be poured into a mould, allowed to dry and be utilized as a durable building material. It should be noted that Papercrete is a relatively new concept with limited scope. Papercrete has three derivatives, namely fibrous concrete, padobe and fidobe. The fibrous concrete is a mixture of paper, Portland cement and water. There are no harmful by-products or excessive energy use in the production of Papercrete. Padobe has no Portland cement. It is a mix of paper, water and earth with clay. The clay is the binding material, Instead of using the cement, earth is used in this type of brick. This earth should have clay content of more than 30%.With regular brick, if the clay content is too high the brick may crack while drying, but adding paper fiber to the earth mix strengthens the drying block. It gives flexibility which helps to prevent cracking. Fidobe is like padobe, but it may contain other fibrous materials. [12]

II.4 Literature survey

Some information has been published on uses of papercrete, other information was found on how people made the material. However, there is a lack of information on the engineering properties of the material. A particular mix of papercrete is not defined so it was difficult to know what the composition of that mix was in order to verify the results.

In 2006, Fuller [13] conducted a research to determine whether or not papercrete has suitable mechanical and physical properties to be used as construction material for homes. The parameters that he studied are the (K), thermal resistance (R), bond Young's modulus (E), thermal conductivity characteristics, and creep behavior. The stress versus strain graphs suggest that papercrete is a ductile material that can sustain large deformations. Cement plays an important role in the compressive strength and behavior. Specimens with higher proportion of cement In 2006, Gallardo et al. focused their investigation on the viability of using paper mill sludge as an alternative material exhibit larger Young's modulus.

This can be applied as a partial replacement of fine aggregates in manufacturing fresh concrete intended to be used for low cost housing project. Based on the results of this study, they concluded that the most suitable mix proportion is 5 to 10% replacement of paper sludge to fine aggregates. Any further percentage replacement higher than 10% would result in a decrease in both compression and tensile strength. The reduction of concrete strength can be attributed to the high water- cement-ratio and the absence of silica compound in paper sludge, which is essential for bonding and structuring of fresh concrete. Superplasticizer was only beneficial to concrete with paper mill sludge in terms of water and reduction density.

In 2007, H. Yun et al.[13] worked on mechanical properties of papercrete by taking various samples and experimenting on them and have concluded the average compressive strength which includes 5% paper-cement replacement ratio was 34 MPa and water-binder ratio hardly affected compressive strength of papercrete. According to paper replacement ratio, compressive strength affected rapidly. According to them, the density of papercrete was decreased when the replacement ratio of waste paper of papercrete increased. The splitting tensile strength also decreased by including higher replacement ratio of waste paper.

In 2008, Gunarto et al.[13] conducted laboratory study on papercrete making papercrete panel and cube sample with size 420×420×7 mm and 50×50×50 mm respectively .They took the volume ratio of paper-cement mixture as 2, 3 and 4 making in two conditions, one without admixture and the other with 0.2% sugar admixture. According to their research, the water absorption was 56.93% at volume ratio of paper-cement mixture 2 with sugarcane admixture and the highest absorption at volume ratio of paper-cement mixture 4 was 84.23%.

In 2011, Malthy and Jegatheeswaran [13] conducted an experimental study which investigated the potential use of paper waste for producing a low-cost and light-weight composite brick as a building material .

They investigated three different mix proportions of fly-ash-mixed papercrete blocks with and without sand. In all three bricks, the compressive strength was more than the required, i.e., 3.5 MPa. The bricks have water absorption more than 20%. Papercrete blocks did not burn with an open flame. They smoldered like charcoal but if the interior plaster and exterior stucco is provided on the bricks, the bricks would not burn at all. The results showed that the effect of high-level replacement of paper wastes does not exhibit a sudden brittle fracture, and it reduces the unit weight dramatically and introduces a smoother surface compared to the current conventional bricks and concrete blocks in the market. They concluded that papercrete bricks can be used for walls and as wooden board substitute and as best alternative for conventional bricks. [13]

II.5 Components

The various materials include:

- Portland Cement
- Paper
- Sand
- Water

II.5.1 Ordinary Portland Cement

- The Portland cement was invented by John Aspidin which is fine gray powder.
- Among the various kinds cement it is the most commonly used as binding material. It is a mixture of chalk or limestone together with clay.
- Cement is a binder, a substance used in construction that sets, hardens and adheres to other materials, binding them together.

- Cement is seldom used solely, but is used to bind sand and gravel (aggregate) together.
- Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete. [14]

II.5.2 Paper

Paper is a natural polymer which consists of wood cellulose, which is the most abundant organic compound in the planet. Cellulose is made of units of monomer glucose (polysaccharide).The links in the cellulose chain are a type of sugar as ß-D-glucose. Despite containing several hydroxyl groups, cellulose is water insoluble.

The reason is the stiffness of the chains and hydrogen bonding between two OH groups on adjacent chains. The chains pack regularly in places to form hard, stable crystalline regions that give the bundled chains even more stability and strength. This hydrogen bonding is the basis of papercrete strength.

By applying a force on the paper the hydrogen bond between the water and the cellulose molecule is broken. Coating cellulose fibers with Portland cement creates a cement matrix, which encases the fibers for extra strength to the mix. The links in the cellulose chain are a type of sugar: ß-D-glucose and the cellulose chain bristles with polar -OH groups.

These groups form many hydrogen bonds with OH groups on adjacent chains, bundling the chains together. Viewed under a microscope, it is possible to see a network of cellulose fibers and smaller offshoots from the fibers called fibril which becomes coated with Portland cement. When these networks or matrices of fibers and fibrils dry, they intertwine and cling together with the power of the hydrogen bond. [14]

II.5.3 Water

Water is an important ingredient of papercrete as it actively participates in the chemical reaction with cement.

Water should be free from organic matter and the pH value should be between 6 and 7. [14]

II.5.4 Sand

It is a granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. Sand can also refer to a textural class of soil or soil type; i.e., a soil containing more than 85 percent sand-sized particles by mass.

The composition of sand varies, depending on the local rock sources and conditions, but the most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO_2), usually in the form of quartz. The second most common type of sand is calcium carbonate. [15]

II.6 Properties of papercrete

II.6.1 Compressive Strength

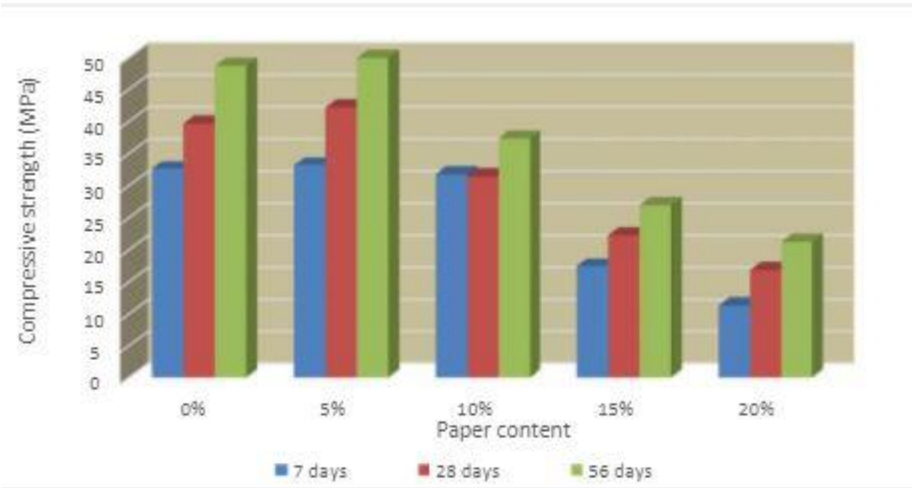


Fig II.2. Results of compressive strength of concrete [13]

II.6.2 Tensile Strength

Iqbal.N and Al. concluded on their tests on papercrete that the Compressive strength, and tensile strength for mixes decrease with increasing of amount of wastepaper. While the mixture with, (5%) indicate strength nearly equal to that of reference mix. [13]

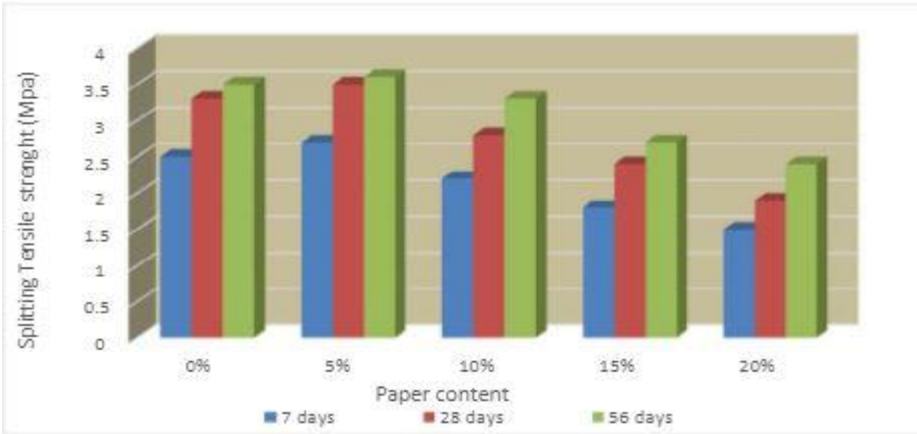


Fig II.3. Results of tensile strength of concrete [13]

II.6.3 Weight and Density

They also concluded that adding waste paper to concrete mix led to increase in water absorption and decrease in dry density for all mixes used except the mixture with 5% of paper pulp. The results of dry density indicate that lightweight concrete could, be produced by adding waste, paper. [13]

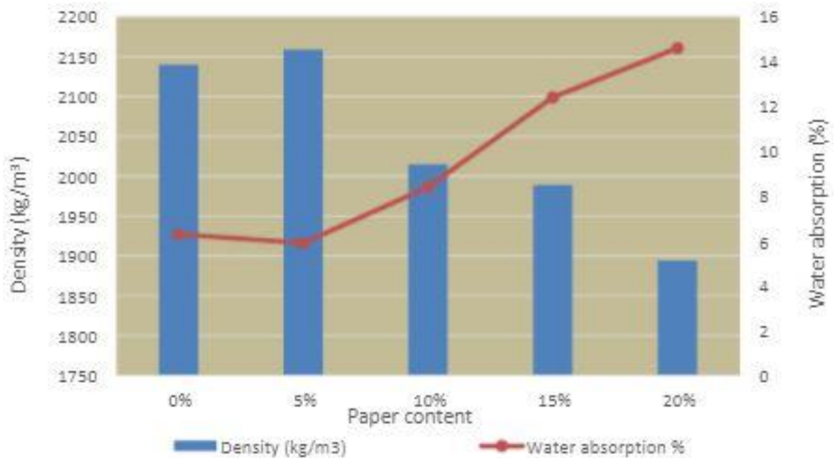


Fig II.4.Variation of density with water absorption [13]

II.6.4 Thermal Conductivity and Insulation

For the thermal conductivity they concluded that Addition of paper pulp leads to reduced thermal conductivity, this reduction is improvement with increasing the addition, of paper pulp. [13

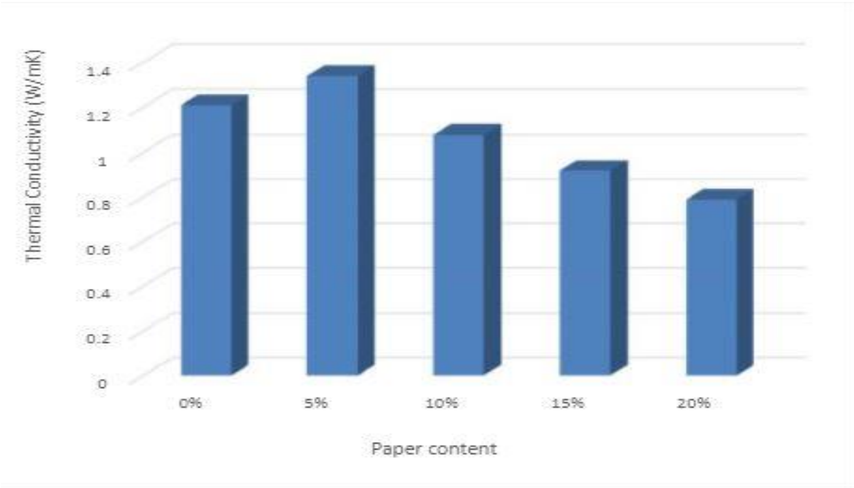


Fig II.5. Results of thermal conductivity of concrete [13]

II.7 Conclusion

From this review on papercrete we conclude that :

- The Compressive strength, decrease with increasing of amount of wastepaper.
- The density of papercrete is less than the ordinary bricks density.
- The Addition of paper pulp leads to reduce thermal conductivity.
- Papercrete bricks light weight and more flexible.
- Papercrete encourage the recycling of waste paper.

Chapter III : Materials, experimental protocols and results

III.1 Introduction

Papercrete is a material consisting of waste paper, Portland cement and sand. Which they are mixed by the use of water to create paper cement pulp, which can then be placed into a mold, allowed to dry and be used as a durable building material.

In this chapter we are going to study the characteristics of every material used in the mixture and explore the properties of the papercrete.

III.2 Materials

III.2.1 Dune sand

Dune sand is very available in the desert areas. The sand used is brought from Laghouat.

Fig III.1 Dune sand [16]

III.2.2 River sand

Also called "alluvial sand", it is distinguished by its round shape and hardness, and it comes from the movement of water on the rocks.

Fig III.2 River sand [17]

III.3 Characterization tests of sand

III.3.1 Specific gravity

The specific gravity of fine aggregates is determined with a pycnometer according to EN 1097-6 [18] by the following relation:

$$\rho_s = \frac{w_s}{w_s-(w_3-w_2)} \times 1000$$

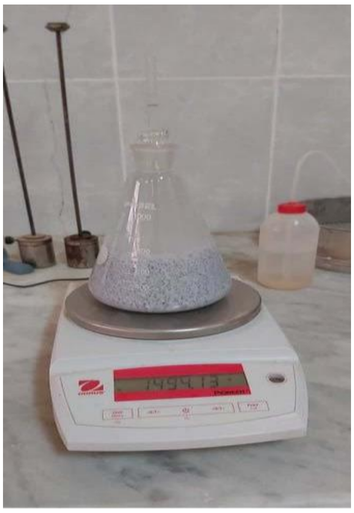
Where:

w_s: dry weight (g)

w_2 : weight of the pycnometer filled with water (g)

w_3 : weight of the pycnometer filled with sand and water(g)

Specific gravity of sand



Specific gravity of paper

Fig III.3. Specific gravity

Operating mode

- Filling a picnometer with water M1.
- Weighing 300 g of sand or wet paper, we obtain M2.
- Putting the sand or paper in the picnometer filled with water we obtainM3.

The results of the absolute density are summarized in the following table:

Table III.1. Specific gravity of the sand and paper

sand	river sand	dune sand	paper
Specific gravity	2600 g/cm^3	2900 g/cm^3	1065 g/cm^3

III.3.2 Bulk density

According to NF p18-555 [19], the bulk unit weight of fine aggregate ρ is determined as:

$$\rho = \frac{w_s}{v}$$

w_s: weight of aggregate

V: volume of the container

Fig III.4. Bulk density

Operating mode

- we weigh an empty container M1.
- we pour in the container the dry sand in successive layers without compaction (we used the funnel or our hands).
- we adjust it using a metal ruler.
- we weigh the filled container M2.
- we calculate the mass W_s=M2-M1.

The results of the bulk density are summarized in the following table:

Table III.2 : Bulk density of the sand and paper used

Sand	river sand	dune sand	paper
Bulk density	1.50 g/cm^3	1.45 g/cm^3	0.62 g/cm^3

III.3.3 Absorption

According to NF P18-555 [19] the absorption AB of fine aggregates is difined as:

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

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

W_a: saturated weight dry surface (g)

Fig III.5.Absorption test

Operating mode

- we took a quantity of sand we leave it 24 hours immersed in water.
- after 24 hours we dried a quantity of this sand until it becomes wet using a dryer. and we filled a cone with 3 layers of sand each layer is pricked by 25 strokes, we weigh Wa.
- we put the wet mass in the oven for 24h.
- we weigh the dry mass Ws.

The absorption coefficient results are summarized in the following table:

Table III.3. Sand absorption coefficients used.

Aggregates	alluvial sand	Dune sand
ABS (%)	1.5	2.5

III.3.4 Sand equivalent

The sand equivalent Es of fine aggregate is determined according to EN 933-8 [20] by:

$$Es = \frac{h_2}{h_1} \times 100$$

Where:

h_1= height of sand plus clay (cm).

h_2= height of sand (cm) measured visually or with a piston.

ESV = visually sand equivalent.

ESP = piston sand equivalent.

Fig III.6. river sand

Fig III.7.dune sand

Operating mode

- we weigh 120g of sand.
- The washing solution is poured into the test tube up to the first mark.
- We poured the sand into the test tube and tap the bottom to eliminate the air bubbles.
- Let it soak for 10 min then shake in the electric stirrer.
- We washed the edges of the test tube and then start washing the sand through the tube until the solution reaches the second mark.
- Leave to sediment for 20 min.
- We Measured the heights:
- H1 the height of dirty + clean sand.
- H2 the height of the clean sand measured by the piston.
- H'2 the height of clean sand measured by the ruler (visual height).

The results of the sand equivalent are summarized in the following table:

Table III.4. Sand equivalent results

Material	river sand	dune sand
ES piston	81	85
ES visual	87	96

Table III.5. Cleanliness recommendations for the sand [21]

ES	Nature of sand
ES<60	Clayey sand
60≤ES<70	Slightly clayey sand
70≤ES<80	Clean sand
ES>80	Very clean sand

From the table above, we can conclude that both of dune and river sand are very clean sand.

III.3.5 Sieve analysis

The Sieve analysis realized on fine aggregate is determined according to NF EN 12620 [22] gives the size graduation of the used sand.

Fig III.8. Sieve analysis

Operating mode

- We dry up the sand and weigh 2kg.
- We put the dry sand on the sieve series.
- The whole series of sieves are placed on the vibrating machine.
- We start the machine, and leaved it for 15 minutes.
- Weigh the cumulative in each sieve.

Table III.6. The particle size distribution of river sand

Sieve size (mm)	Amount retained (g)	Cumulative amount retained (g)	Cumulative percent retained (%)	Percent passing (%)
5	0	0	0	100
4	27.23	27.23	1.3615	98.6385
3.15	31.38	58.61	2.9305	97.0695
2.5	35.30	93.91	4.6955	95.3045
0.630	248.13	342.04	17.102	82.898
0.315	388.98	731.02	36.551	63.449
0.125	1054.40	1785.02	89.251	10.749

Table III.7. The particle size distribution of dune sand

Sieve size (mm)	Amount retained (g)	Cumulative amount retained (g)	Cumulative percent retained (%)	Percent passing (%)
1.25	0	0	0	100
0.8	0.19	0.19	0.0095	99.9905
0.5	1.86	2.05	0.1025	99.8975
0.315	89.39	91.44	4.572	95.428
0.2	1706.45	1797.89	89.8945	10.1055
0.125	173.61	1971.5	98.575	1.425
0.1	11.90	1983.4	99.17	0.83

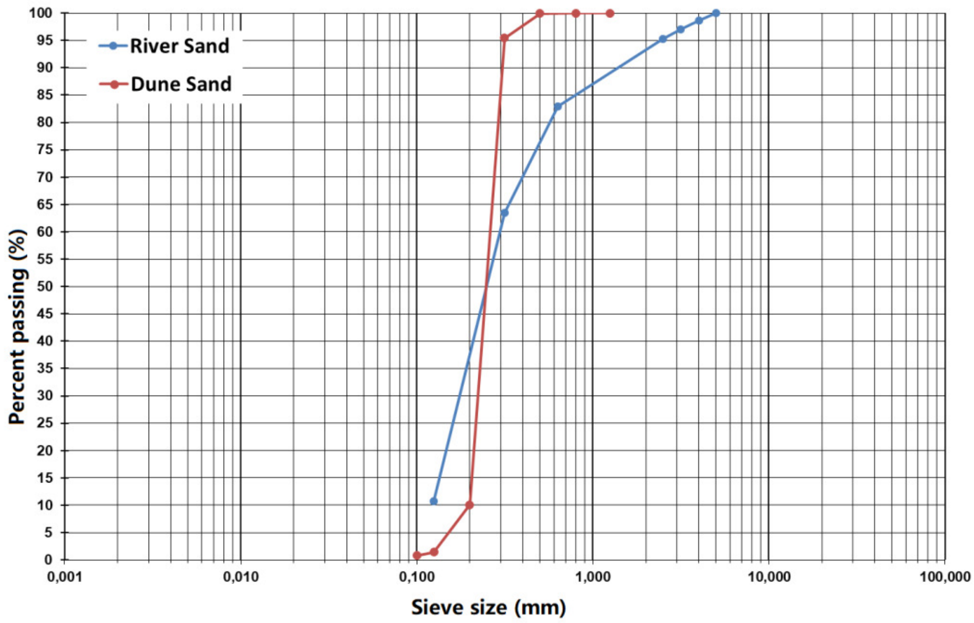


Fig III.9. Size graduation of river (alluvial) and dune sand

III.3.6 Fineness modulus

Fineness modulus of sand (fine aggregate) is an index number which represents the mean size of the particles in sand. It is calculated by performing sieve analysis with standard sieves. The cumulative percentage retained on each sieve is added and subtracted by 100 gives the value of fineness modulus.

$$FM=\frac{\Sigma cumulative\ percent\ retained}{100}$$

The fineness modulus of the river sand obtained from the test carried out is:
FM= 1.51
From this result we can say that the sand used is a fine to medium sand

The fineness modulus of the dune sand obtained from the test carried out is:
FM = 2
From this result, we can say that the sand used is very fine sand.

III.4 Cement

The cement used in this study is a Portland cement CEM **Π /B-L 42.5 N (**Fig III.10) It is produced by M'sila cement factory (Algerian company). (Table III.8) gives the different properties of the used cement .

Fig III.10. Cement

Table III.8. Cement characterization results [23]

properties	Standards	results
Specific gravity	NF P18-555	3.1 g/cm^3
Bulk density	NF P18-555	1.13 g/cm^3
Fineness	EN196-6	3700 cm^3/g

III.5 Water

The water used in this experimental part is potable water from the laboratory of the Civil Engineering Department of Laghouat.

III.6 Paper

The paper used in this study is a previously used paper.

Fig III.11. Paper

III.6.1 Preparation of paper pulp

The process we followed for the preparation of paper pulp is from YD shermale ,MB Varma [12] with some modifications.

The papers which were collected, could not be used directly, before mixing with other ingredients, the collected papers are passed through a shredding machine (Fig III.12), and all the torn pieces of paper were immersed in water (Fig III.13).

The papers were kept in water for 1 to 2 days, and they soon degraded into a paste like form. After that period, excess water is removed, the paper is mixed (Fig III.14) until a pulp is obtained, and the wet paper pulp is ready to be used (Fig III.15).

Fig III.12. . Shredding machine

Fig III.13 Paper immersed in water

Fig III.14. Mixing paper

Fig III.15. Wet paper pulp

III.7 Formulation of papercrete

The main materials used for papercrete mix preparation were waste paper, Portland cement, dune sand and river sand, Potable water.

Six types of mixes are prepared for each sand with variying , $\frac{W}{C}$ for each river and dune sand.

Mix proportions by volume in percentages are indicated below:

Table III.9. papercrete mixture with river sand

percentage	Cement (g)	Sand (g)	Paper (g)	w/c
0%	450	1350	0	0.55
10%	450	1215	135	0.55
20%	450	1080	270	0.55
30%	450	945	405	0.55
40%	450	810	540	0.55
50%	450	675	675	0.55

Table III.10. papercrete mixture with dune sand

Percentage	Cement (g)	Sand (g)	Paper (g)	w/c
0%	450	1200	0	0.6
10%	450	1080	120	0.6
20%	450	960	240	0.6
30%	450	840	360	0.6
40%	450	720	480	0.6
50%	450	600	600	0.6

III.8 Mixing method

The mortar is mixed according to EN 196-1 [24].

- The weighings of each percentage are prepared.
- The water is introduced into the mixer tank, then the cement is poured in and started the mixer at low speed.
- After 30s of mixing the sand (river or dune) and the wet paper pulp are introduced during the following 30s.
- The mixer is set to high speed while mixing for another 30s.
- The mixer is stopped for 1min 30s, during the first 15 seconds all the mortar adhering to the walls and the bottom of the mixer is removed using a squeegee.
- Resumed mixing at high speed for 60s.
- The mortar is ready to be poured into 40* 40* 160 mm prismatic molds.
- The molds are greased with burnt oil and the 1st layer of the mixture is poured.

- The mold is placed in the shock table at 60 shocks.
- The same thing is done with the 2 nd and the 3 rd layer.
- The molds are left to dry for 24 hours , to be ready to unmold.

When the molds are dry, after 24 hours they are unmolded and left in the open air for 7 days

Fig III.16. Mortar mixer

Fig III.17. Shock table

Fig III.18. Molding of mortar

Fig III.19. Dry papercrete brick in open air

III.9 Tests on hardened papercrete

Compressive and flexural strength are measured after 7 and 28 days of age on prismatic specimens (40 ×40×160) mm using testing machine with a maximum charge load of 100 KN. According to EN 196-1 [24].

Fig III.20 Testing machine

III.9.1 Flexural strength

For a bar with a rectangular cross-section subjected to a 3 point flexural, the flexural strength ρ_f is calculated as follows:

$$\rho_f = \frac{3}{2} . \frac{F.L}{b^3},$$

Where :

ρ_f: flexural strength (N/mm^2)

F: maximum load (N)

I: distance between the two supports on the tension surface of the beam (1=100 mm)

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

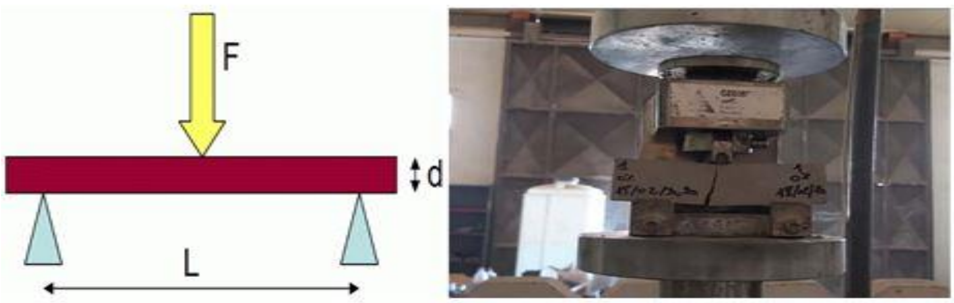


Fig III.21. Third point flexural test

III.9.2 Compressive strength

The compressive test is carried test with a charging speed of 240 KN/s. The compressive strength ρ_{comp} is calculated as follows:

$$\rho_{comp} = \frac{F_c}{S}$$

Where :

ρ_{comp}: compressive strength(N/mm^2)

F_c: maximum compressive load (N)

S: cross section of the beam (s=b×b)(mm^2)

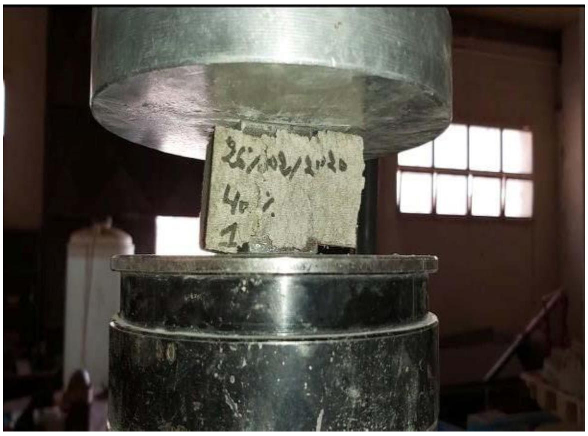


Fig III.22. Compressive test

III.10 Results and discussions

Table III.9 and Table III.10 summarize the results of the flexural strength and compressive strength at 7and 28 days of papercrete mixtures respectively.

Table III.11. Flexural strength and compressive strength at 7 days

Percentage of paper	flexural strength (MPa)	compressive strength (MPa)
0%	2.50 ± 0.12	13 ± 0.84
10%	2.54 ± 0.12	11 ± 0.71
20%	2.58 ± 0.12	9 ± 0.58
30%	2.42 ± 0.11	4 ± 0.25
40%	1.22 ± 0.05	3 ± 0.22
50%	0.91 ± 0.04	2 ± 0.12

For the results of 28 days we did not have time to do the compressive and flexural strength tests, so we just estimate the values from the 7 days results.

Table III.12. Flexural strength and compressive strength at 28 days

Percentage of paper	flexural strength (MPa)	compressive strength (MPa)
0%	3.84 ± 0.25	19 ± 0.91
10%	3.90 ± 0.25	17 ± 0.81
20%	3.96 ± 0.26	14 ± 0.67
30%	3.72 ± 0.24	6 ± 0.28
40%	1.87 ± 0.12	3 ± 0.14
50%	1.4 ± 0.09	3 ± 0.14

III.10.1. Compressive strength

Figures III.23 and III.24 show the variation of the compressive strength of papercrete mixtures at 7 and 28 days respectively. The results show that the addition of paper waste resulted in a significant reduction in papercrete compressive strength compared with the reference mixture.

The maximum strength value is reached in 0% (19 mpa) which is the reference mixture, and the minimum strength value is reached in 50% (3 mpa).

This reduction increased with increasing percentage of paper content. Losses in compressive strength were noticed during the duration of 7 days as in the 28 days.

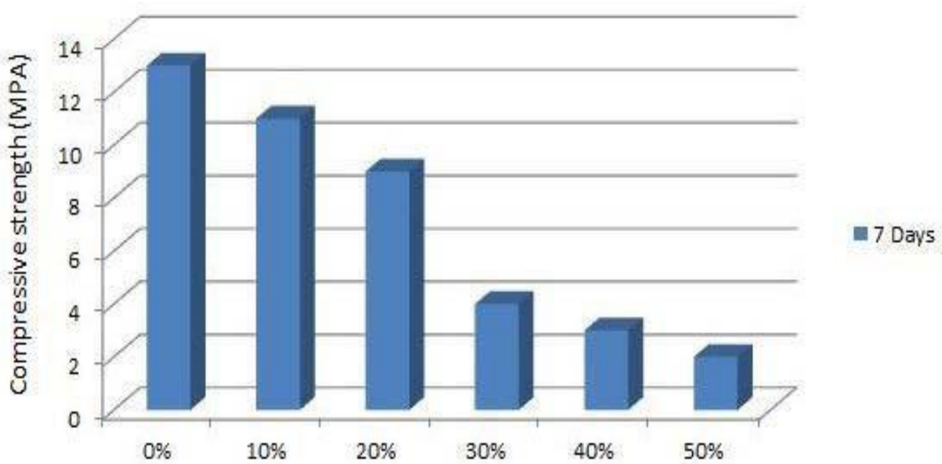


Fig III.23. Compressive strength of mixtures at 7 days

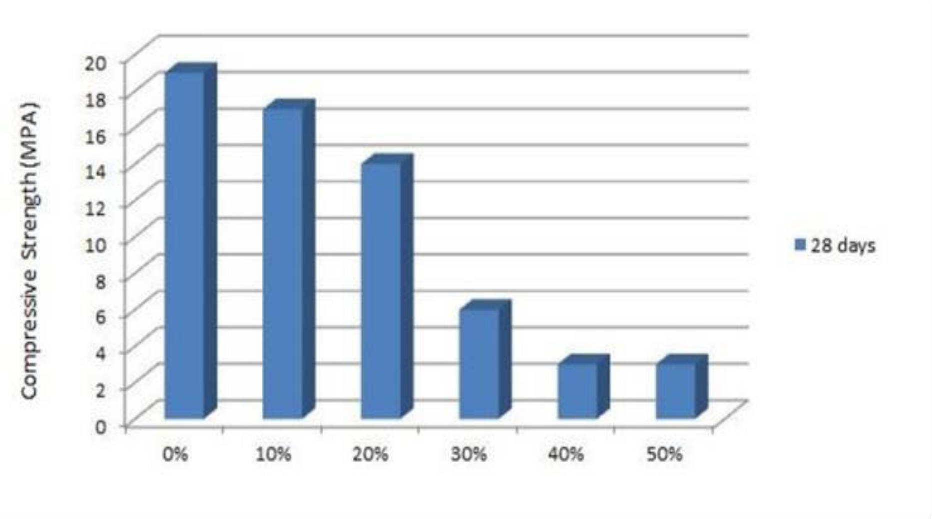


Fig III.24. Compressive strength of mixtures at 28 days

III.10.2 Flexural strength

The flexural strength of papercrete beams were obtained by conducting flexural test on specimens of size (40 ×40×160) mm by two point load method. Figures III.25 and III.26 show the variation of the flexural strength of papercrete mixtures at 7 and 28 days respectively. For (10%, 20%) mixtures the flexural strength increased with the increase of the amount of wastepaper, the strength were higher than the reference mixture.

That means that the waste paper plays the role of fibers and the fibers work in flexural strength.

For (30%, 40%, 50%) mixtures the strength decreased with the increase of the amount of wastepaper.

The maximum strength value is reached in 20% (3.96 mpa), and the minimum strength value is reached in 50% (1.4 mpa).

These observations were noticed during the duration of 7 days as in the 28 days.

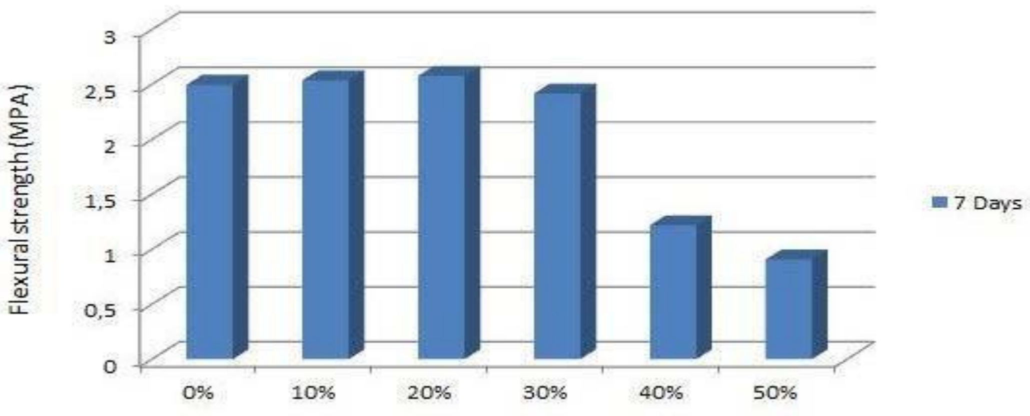
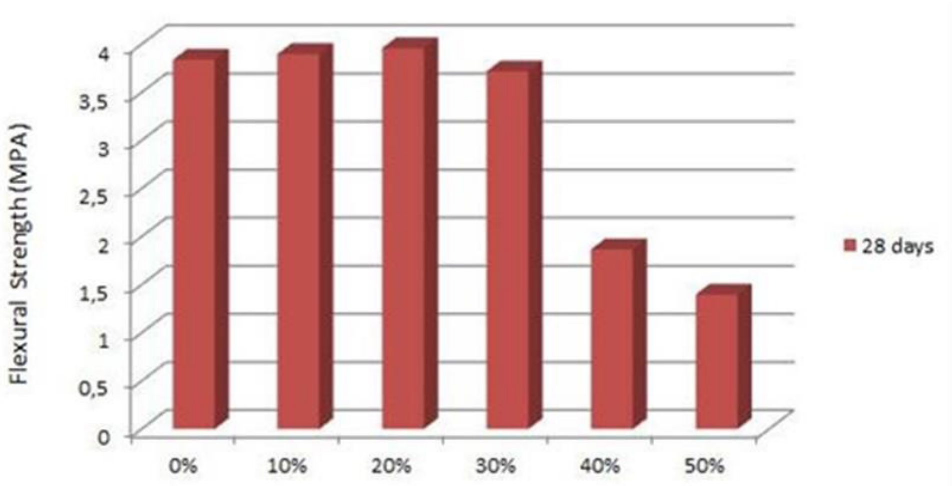


Fig III.25. Flexural strength of mixtures at 7 days



FigIII.26.Flexural strength of mixtures at 28 days

III.11 CONCLUSION

Based on the experimental work results in this investigation, the following conclusions can be drawn:

- For dune sand, we could not finish the tests due to the current situation.
- The cement used matches the specifications of current cements.
- The Potable water is acceptable for mixing papercrete.
- From the compressive strength results we conclude that the addition of waste paper leads to a reduction in the resistance during the duration of 7 days as in the 28 days.

● From the flexural strength results, the highest value was reached for the mixture with 20% of paper was (3.96 mpa).

● Comparing our results with results of previous research we can say that we found almost the same results in compressive strength the reduction increased with increasing percentage of paper content. While in flexural strength we did not found the same results.

General conclusion

General conclusion

The objectif of this study was to study the characteristics and explore the properties of a new material based on recycled waste paper intended for construction.

The results obtained show that:

- The highest flexural and compressive strenghts are reached at 28 th day of age for all mixtures.
- The maximum strength value is reached in 0% (19 mpa) which is the reference mixture in the compressive strength and the maximum strength value is reached in 20% (3.96 mpa) in the flexural strength.
- The results of compressive strength test shows a significant reduction This reduction increased with increasing percentage of paper content.
- Based on previous research they found that papercrete is far lighter a material than concrete or wood and has good water absorption and insulation capacity, and is environment friendly, has high strength to weight ratio.
- Papercrete can be developed as a material which is suitable for low cost housing and temporary shelters and offices and can help reduce carbon footprint.
- By using paper in buildings we can significantlu reduce the amount of paper landing in the landfills.
- The reuse of wastes is essential from various perspectives:

✓ It helps to save and sustain the natural resources which are not replenished;

✓ It decreases the pollution of the environment and it also helps to save and recycle energy in the production process.

Recommendations

- Use a treatments for papercrete for exemple burning the waste paper.
- use other binder such as plaster or lime.
- Add a superplasticizer to the mixture.
- Use other types of waste paper for exemple old newspapers, carboards…

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ملخص

نقدم في هذا العمل دراسة على مادة بناء تسمى خرسانة الورق وهو نوع من الخرسانة الليفية يتم تصنيعها عن طريق تمزيق الورق، على شكل عجينة في الماء مع الإسمنت البورتالندي والرمل المحلي (رمل الواد، كثباني).

النسبة المئوية للورق المستخدم وهي (10٪، 20٪، 30٪، 40٪ و50٪) بوزن الرمل. الخصائص الميكانيكية المدروسة للمخاليط: قوة الانضغاط، قوة الانثناء وجدنا أنه كلما زادت كمية نفايات الورق، كلما انخفضت مقاومة قوة الضغط. على العكس لاحظنا ان مقاومة الانحناء تزداد بزيادة كمية الورق حتى نسبة 20 %وتنخفض باستعمال كميات كبيرة.

الكلمات المفتاحية: خرسانة الورق، نفايات الورق، الخصائص الميكانيكية، قوة الانضغاط، قوة الانثناء.

Résumé

Ce travail présente une étude sur un matériau de construction appelé béton de papier qui est un type de béton fibreux fabriqué en déchiquetant du papier avec du ciment Portland et des sables locaux (alluvionnaire, dunaire). Le pourcentage de papiers recyclés utilisé à savoir (10%, 20%, 30%, 40% et 50%) en poids de sable. Les propriétés mécaniques étudiées des mélanges sont la résistance à la compression et la résistance à la flexion. Nous avons constaté que plus nous augmentons le pourcentage du papier, plus la résistance à la compression diminue. Par contre, la résistance à la flexion augmente avec l'augmentation du pourcentage du papier jusqu'à 20% et diminue pour des dosages élevés.

Mots Clés : béton de papier, papiers recyclés, propriétés mécaniques, résistance à la compression, résistance à la flexion.