Printed-ISSN:0000-0000
Digital-ISSN:0000-0000

Vol. 1 No. 1 2018

Sustainable

Structure & Materials

(SSM)

An International Journal

www. SSMIJ.com

Sustainable
Structure & Material
An International Journal

Sustainable Structure & Material
An International Journal

Printed- ISSN: On progress, **Digital- ISSN:** On progress, **Frequency:** twice a year (2 issues per volume)

Printed, Published and owned by
Mohammad Ali Mosaberpanah

Printed at
ISATIS. Ltd

Website: www.SSMIJ.org

Sustainable Structure & Material
An International Journal

About SSM Journal

Sustainable Structure and Material (SSM) is an international peer-reviewed, Open Access journal that publishes twice a year with original research articles as well as review articles in all areas sustainable structure and building materials. The journal welcomes submissions across a range of disciplines and publishes both theoretical and practical studies. Contributions from academia and from industry are equally encouraged.

SSM provides permanent archiving for electronic scholarly journals. It operates a fully open access publishing model which allows open global access to its published content. SSM is in the process to get many leading abstracting and indexing databases.

Sustainable Structure and Material (SSM) provides a valuable dispersion of research and development in the field of sustainable structure and building materials. The journal publishes a wide range of international research which describes simulation, laboratory, and numerical study on different projects as well as review articles and short discussions and communications.

The aim of Sustainable Structure and Materials is to develop an inter-disciplinary platform for the dissemination of knowledge and practice on the engineering and architecture issues concerning all aspects of building design, technology, energy and environmental performance use of new materials and up-to-date technologies.

The journal covers the following dimensions or categories of a Sustainable Structure and Materials, but is not restricted to:

- Materials and new technologies included: cement, mortar, reinforced concrete, Self-healing concrete, bricks, additives, corrosion technology, ceramics, timber, different types of fibers, recycled materials, sealants, and adhesives.
- New designs, re-design, repair and maintenance, restoration, and rehabilitation of the following: bridges, high-rise buildings, dams, civil engineering structures, silos, highway pavements, tunnels, sewers, roofing, housing, and heritage buildings.
- All dimensions of sustainable structure included: various contexts of environmental, social, cultural development and economic angles and managed over many measures of time and space.

Sustainable Structure & Material
An International Journal

CONTENTS

Sustainable Structure and Materials, *Vol. 1, No .1, (2017) 1-11*
DOI: https://doi.org/10.26392/SSM.2018.01.01.001

Sustainable Innovative Materials for Interior Architecture Using Biomimicry

Joyce Lodson*[1], Faraneh Sahraiyan Jahromi[2]

[1] *Master of Architecture, Faculty of Architecture, Eastern Mediterranean University*
[2] *PhD candidate, Faculty of Architecture, Eastern Mediterranean University*
*Corresponding author/ E-mail: lodsonjoyce@gmail.com

(Received January 9, 2018, Revised January, 20, 2018, Accepted February, 01, 2018)

ABSTRACT. *Over the years, man has been on a quest to discover solutions to challenges facing the world. Biomimicry is among the emerging discoveries which offer a lot of potential for solutions to world environmental challenges, especially in the area of sustainability. This paper reviews some ways in which biomimicry has been sustainably applied in interior architecture. A number of plants and animals were identified as models whose natural characteristics have been mimicked and applied to interior spaces. Among the specimens identified is the shark whose skin has been used as biomimetic model for a germ resistant surface material. The samples presented in this paper are sustainable and offer good options for addressing environmental challenges. This paper thus calls for more research to be done with a view to finding other sustainable biomimetic innovations which can be applied to our interior spaces.*

Keywords: Biomimicry, Sustainability, interior space, innovation, application

1. INTRODUCTION

Various challenges abound in the world today which touch different aspects of human and environmental life. From health to transportation, construction to climate change, waste to environmental degradation, the world's problems have been on the increase. Over the years, man has been on a quest to discover solutions to these challenges. Responses to these problems have brought about interesting discoveries in the fields of art and science. Biomimicry is among the emerging discoveries which offer a lot of potential for solutions to world environmental challenges.

According to the Biomimicry Institute, biomimicry is the science and art of emulating nature's best biological ideas to solve human problems. Nature here is an all-inclusive word which includes animals, plants and even microbes. Biomimicry gets its name from two Greek words; bios, meaning life and mimesis meaning to imitate [1]. Meanwhile, the Biomimicry Institute has stated its goal to be creation of products, processes, and policies—new ways of living—that are well-adapted to life on earth.

With biomimicry, exciting solutions are emerging which have the potential to address issues of sustainability. This is because nature has, over millions of years, been able to discover appropriate, long-lasting and workable solutions to the problems that bedevil mankind today. Advocates of biomimicry have argued that the earth has had over 3.85 billion years of evolution to shape the designs of the natural environment in the best way that is suited for the survival of itself and of its inhabitants [2]. Examples of how nature has taken care of problems which man is grappling with today can be seen all around us. For instance, astronomical amounts of energy are expended every year in our buildings just to create conducive indoor temperatures, yet termites are able to build mounds with comfortable interior temperatures and yet zero fossil fuel consumption. It is very obvious therefore that nature indeed has a lot to teach us if only we are willing to learn.

Janine Benyus, who founded the Biomimicry Institute, makes this profound statement: “Nature is imaginative by necessity, and has already solved many of the problems we are grappling with today” [3]. Thus more and more experimental studies are looking into the world of plants and animals all in an effort to bring out designs which can complement nature rather than destroy it.

Biomimicry, though seemingly a recent terminology, has actually been practiced by man for hundreds of years. Some of the greatest minds in history, from whom wonderful innovations were born, received inspiration by observing the systems and creations of nature. An early example of such is Leonardo da Vinci who developed the idea of enabling humans to fly by getting inspiration from birds. Many years later, the Wright brothers also received the same inspiration through the study of birds and were able to draw up plans for developing a human ‘flying machine’. The ideas were eventually brought to fruition with the creation and flying of the first airplane in 1903 [1].

Today’s scientists, designers and architects have also seen the endless inspirational ideas which nature offers. Within the architectural discipline for instance, new innovative ideas have emerged on ways to apply biomimicry to solve problems such as indoor thermal comfort, hygiene, aesthetics, durability, lighting and a host of others. This paper has evaluated some of these biomimetic samples from nature which have found application in interior spaces and which have positive implications towards addressing sustainability in our buildings.

1.1 Problem Statement

With the many challenges facing the world today, especially in the area of environmental degradation and depletion of natural resources, there is a need for man to go back to the study of nature, not just for the purpose of learning about it but rather for the purpose of learning from it [1]. The knowledge which man can obtain from nature is immeasurable and this knowledge can be applied to virtually every area of human and environmental life. Biomimicry emerges as a very good and exciting option open to architects and designers for dealing with sustainability in design of buildings and interior spaces.

Considering the various studies done on biomimicry and the innumerable potentials it offers for interior spaces, there is a need for the findings to be collated and presented in a detailed framework guide for ease of application by architects and designers. That is what this paper has attempted to do.

1.2 Aims and Objectives

The aim of this research paper is to collate examples of sustainable biomimetic samples which are suitable for interior spaces and to present them in a detailed framework so that architects and interior designers can make reference to them when the need arises. The aim will be achieved through a number of objectives which are:

1. To identify natural specimens from nature which have been used as biomimetic models.
2. To identify the unique inspirational characteristics of these specimens which have been adopted to provide solutions for design needs in interior spaces.
3. To consider the sustainable characteristics of each of these specimens.
4. To draw up a tabled framework of the specimens, their characteristics and possible areas of application in buildings and interior spaces.

1.3 METHODOLOGY

The methodology used in this paper is purely qualitative and basically relied on documentary survey. This involved a review of related literature from journal articles, thesis, books and other on-line data sources.

2. LITERATURE REVIEW

2.1 BIOMIMICRY: A GENERAL OVERVIEW

Many inspirational sources are available from which designers get numerous solutions to various challenging problems. One of such sources is nature. A comprehensive study of plants, animals and other living organisms with a view of understanding their workings and methods of addressing environmental challenges has become a current trend which many designers are pursuing. This practice, known as biomimetics, was first introduced by Otto Schmitt in the 1950s [4].

Biomimicry emerges as a great resource within the sphere of design and innovation, for the creation of sustainable projects. With biomimicry, designers are now able to develop projects that are environmentally friendly, resource efficient, cost effective while at the same time able to promote output of workers. Biomimicry also has the potential to impact positively in the areas of education and health.

Biomimicry should however be seen not as a style in itself but as an instrument for design development. El-Zeiny (2012) points to the fact that biomimicry is more than just copying or replicating an organism or system but rather it is a careful scrutiny of the organism or ecosystem in order to obtain its fundamental design principles which are then deliberately applied in emerging technology and designs. He insists that in biomimicry, biology is the central instrument which must be utilized for solving problems and arriving at a purposeful design. The question behind every biomimetric design should be "how would nature do it?" [5].

Various literature studies have pointed to diverse ways in which the process of biomimicry can be applied in design. Among the different options available, two possible approaches stand out. These have been classified by El-Zeiny (2012) and Yurtkuran et al (2013) as the problem-based approach (Top –Down Approach) and the solution-based approach (Bottom-Top Approach).

The problem-based approach proposes that real problems should first be identified in existing or proposed designs and then solutions looked for in nature to solve the problem while the solution-based approach seeks to identify a definite quality or characteristic in an organism or within the ecosystem and then look for how to incorporate that quality into a design in such a way that it responds to a human need. [5]; [4].

Yurtkuran et al have also stated that for the various processes to work, it becomes essential to set up a framework for the application of biomimicry in design. This idea for a framework is supported by Zari (2007) who suggests three elements upon which to base a design according to biomimicry model. These are: organism, behavior and ecosystem. Zari goes further to explain that a design can be designed according to the features and qualities of an organism, the behavior and workings of an organism or the entire ecosystem of an organism and its surroundings. All three elements can be reproduced and used to develop a design [18].

Royall (n.d.) meanwhile, asserts that nature has the potential to serve as a biomimetic instrument in three possible ways: as mentor, as measure and as model. Nature as a mentor essentially means that nature is the teacher and we as its students get to learn from what nature has to teach us. Nature as measure sets nature up as a yardstick for assessing how well our designs stand up according to ecological standards. Nature as model presents nature as a kind of prototype offering us different forms and processes which we attempt to copy [20].

3. SUSTAINABLE BIOMIMETIC EXAMPLES APPLIED TO BUILDINGS AND INTERIOR SPACES

Biomimetic examples in buildings are many and have been used to address various issues such as thermal comfort, hygiene, finishings, lighting and durability among many others. The following examples are ways in which sustainable applications have been developed using bio-mimicry for use in buildings and interior spaces.

3.1 Human Skin - Biomimetic Application: Window Insulation

The skin is known to be the largest organ of the human body (Fig.1). According to Rankouhi (2012), it makes up 15-20% of body weight. Skin plays a number of important functions in the body which include protection, excretion and enabling the experiential sensations of touch and feeling. Another very important function of skin is that of maintaining body heat and regulating fluid. This occurs when there are increases in environmental temperature. The blood vessels (Fig.2) close to the skins surface respond by dilating, leading to increased loss of body heat through convection. The reverse happens when the skin is exposed to cold. There is contraction of the blood vessels as the body tries to maintain its temperature; thus less heat is lost to the environment [6] [17].

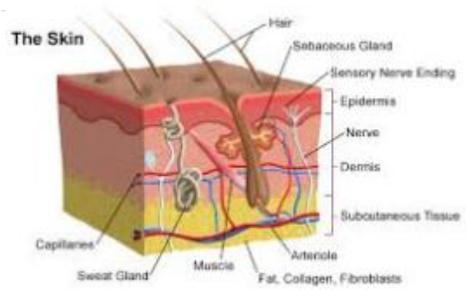


Fig-1: Section through the Human Skin

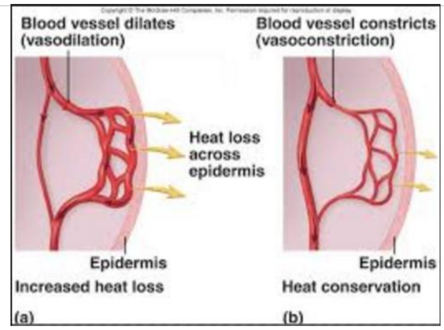


Fig-2: Dilated and Constricted Blood Vessels

A team of researchers at the University of Toronto led by Professor Ben Hatton drew upon the skins' temperature regulatory ability to address the problem of heat loss in buildings through windows. Considering that as much as 40% of energy is lost through windows, the team applied the biological concept explained above to minimize heat loss in winter and to maintain low temperatures in buildings in summer [6].

According to Freeman, their solution involves attaching transparent, malleable sheets of elastomer to normal regular glass window panes. The elastomer sheets, which are made from polydimethylsiloxane (PDMS) have small conduits running along their length. These conduits permit room temperature water to pass through (news.engineering.utoronto.ca) in much the same way that blood vessels transport blood. By so doing, temperatures can be cooled by as much as 7-9 degrees. These sheets can be used effectively at both small and large scales (Fig.3).

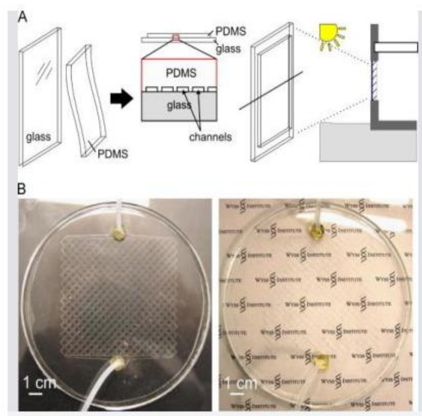


Fig-3: A Schematic of the Composite Window Structure
B. The Artificial Vascular Network Layer

3.2. Shark Skin – Biomimetic Application: Sharklet Surface Texture

Sharks are a well-known marine wildlife with very clean skin. Their skin is made up minute tooth-like features called "dermal denticles or placoid scales [7]. These tiny scales help the shark in a number of ways: they offer protection for the shark from predators, they aid the shark to move sleekly though water with minimal friction and they also prevent marine organisms from attaching themselves to the shark's skin, a phenomenon known as bio-fouling.

By studying the ability of shark skin to avoid bio-fouling, a team of researchers from the University of Florida were inspired to create a material with a structured underlying layer which they called Sharklet AF (Fig.4) the material is potentially similar to the placoids found in shark skin [7]. This synthetic surface material hinders the growth of disease causing microbes. Sharklet technologies have been able to produce these film- based surface protection products to be applied to surfaces which might likely be exposed to germs and bacteria such as in hospitals and public restrooms. Potentials exist for creating workshop mats from these skins whose surface adhesion properties can be enhanced by applying adhesive to the back side of the skins.

The products are free of disinfectants, chemicals and toxins which are harmful to the environment, and rely on the Sharklet pattern alone to inhibit bacterial growth . This makes them a viable and sustainable product.

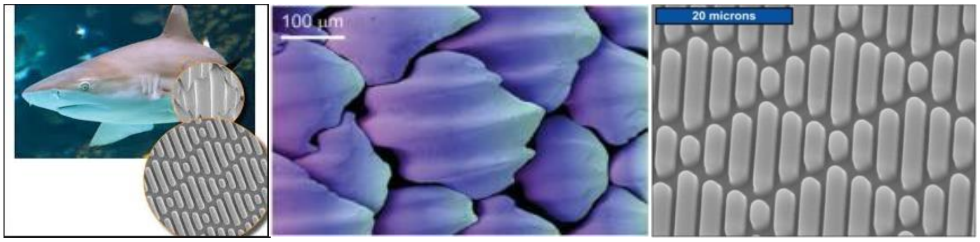


Fig-4 (a) Image of a shark skin showing the details of placoid scales. (b) SEM image of a Sharklet AF pattern that mimics that of a shark skin.

3.3.Gecko Feet – Biomimetic Application: Dry Adhesion Geckskin

The gecko is a wall climbing creature much like a lizard with an amazing ability of gripping surfaces with the skin of its feet (Fig.5) this gives it the unique advantage of clinging to all types of surfaces, both rough and smooth, and also of being able to detach itself at will. Very minute hairs found on the feet of the make this possible. According to Das et al (2015) the foot of a Tokay gecko has about 5000 tiny features (setae of mm2) which enable it to produce 10N adhesive force with approximately 100 mm2 of pad area 42. Das et al (2015) also explain that the strong adhesive force does not impede its movement because of the gecko's ability to curl and flake its toes while attaching and detaching, thus enabling it to move with ease [8].

Drawn from the inspiration of the gecko, scientists have sought to make materials which have dry adhesion qualities much like that of the gecko. The TacTiles introduced by Interface in 2006 is an example of one such product (Fig.6). This glue-free installation system for modular carpets is probably one of the first known biomimetic building products to be introduced into the market [9]. TacTiles have flexible backing systems which hug the floor, creating dimensional stability without glue and enabling the tiles to connect to each other with nothing sticking to the subfloor (interface.com). Hu adds that these products have an advantage of being environmentally friendly and having ease of application when compared to other locally used adhesives used in carpeting [9].

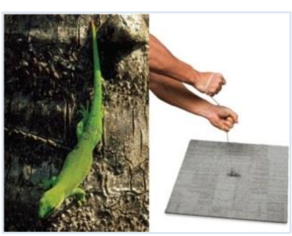


Fig-5: Gecko

Fig-6: materials like the gecko

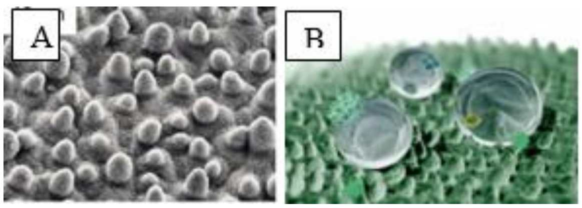
Another product is the synthetic 'geckskin', a new super adhesive based on the mechanics of gecko feet. The Geckskin device produced by scientists and biologist at the University of Massachusetts Amherst has a maximum force of 700

Fig-7: synthetic 'geckskin'

pounds and is able to adhere to very smooth surfaces such as glass [8]. This synthetic skin can easily attach and detach everyday objects such as televisions or computers to walls (Fig.7). It can also be used for medical, industrial, clothing and home appliances, Geckskin is an ideal sustainable product which is reversible, renewable, and biodegradable [11].

3.4. Self-Cleaning and Water Repellant Plant Leaves - Biomimetic Application: Self –cleaning Paints

Certain plants have been known to have water repellent tendencies. One common example is the lotus plant. Both the flower and leaf of the lotus plant have a rough, bumpy exterior which naturally wards off dust and dirt thereby creating a clean surface. The smallest of wind drafts are able to cause a slight change in the angle of the plant which in turn enables dirt to be removed without much effort [1]. Dirt is also carried along with any water droplet that rolls of the leaf (Fig.8, 9).



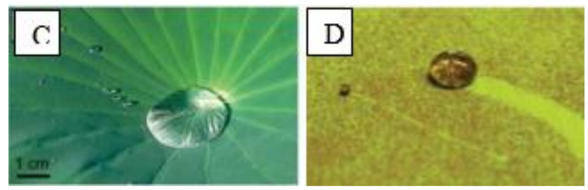


Fig-8: A&B. Clsoe-up of a lotus leaf. The roughness of the leaf surface results from the co-existence of micrometer sized bumps and nanoscale hair-like structures. **Fig-9** C. Water dropletrs rolling on a leaf. Fig. 9. D. Water drop collecting dirt from the surface of a lotus leaf.

This water repellant tendency became the focus of the German company, Ispo, who conducted a research on it and were able to emerge with a paint having similar properties. The paint (Fig.11) employs a micro-structure modeled after the hydrophobic leaves of the lotus plant which minimizes the contact area for water and dirt making it naturally resistant to the growth of mold, mildew and algae [12] (Fig. 10). According to Buczynski, this paint is not only cost effective but is also environmentally friendly thus making it a sustainable product. The idea has led to the development of other building materials such as paints, tiles, textiles and glass which can be used with minimal maintenance and material replacement costs [12].

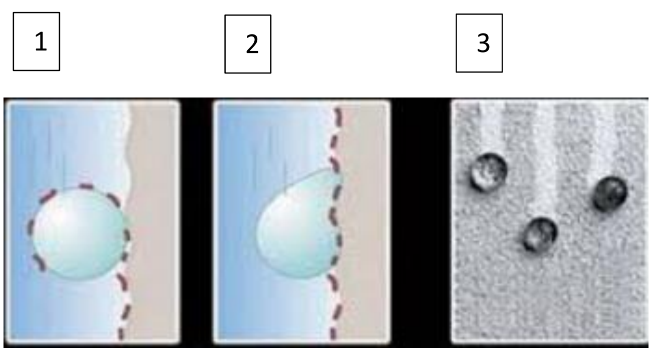


Fig-10:
1. How a raindrop cleans a lotus leaf.
2. The effect of a raindrop on a normal surface
3. The effect of raindrop on a building exterior covered with Lotusan pain

Fig.11: self-cleaning paint

3.5. Squid - Biomimetic Application: Strain Induced Color Changes in Materials

Squids are marine creatures of the cephalopods family (Fig.12). Many cephalopods like squid and cuttlefish are able to quickly blend in with their surroundings by changing color. This process is made possible by chromatophores, cells that contain a sac filled with pigment. When the squid's muscles surrounding a cell contract, the sac is squeezed to appear larger, creating an optical effect that makes the squid look like it is changing color [13].

Figure-12: changing color squid

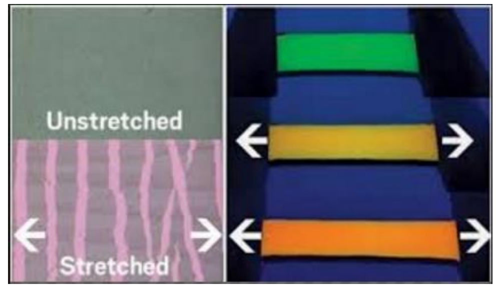


Figure-13: reversibly from transparent to opaque

Drawing inspiration from the squids' ability to change its appearance, researchers have designed polymeric materials that change appearance reversibly in response to mechanically induced folds and deformations [14]. Jacoby goes on to explain the workings of this process by stating that when this material is stretched by 40%, its appearance changes distinctly yet reversibly from transparent to opaque (Figure.13). Thereby the optical changes result from stretch-induced microscopic cracks and folds that trap and scatter light. The material can find possible application as mechanical sensors, optical switches, and color-changing smart windows [14].

3.6. Selaginelia Lepidoplylla- Biomimetic Application: Wooden skin and Marco Wooden Velcro*The*

Selaginelia Lepidoplylla is an ancient plant which can resurrect after the dry season. The plant can survive decades without water (Fig.14). It is noted for its ability to survive almost complete withering; during dry weather in its native habitat, its stems curl into a tight ball and uncurl only when exposed to moisture [19]. The outer stems of the plant bend into circular rings in a relatively short period of dryness, whereas inner stems curl slowly into spirals due to the hydro-actuated strain gradient along their length.

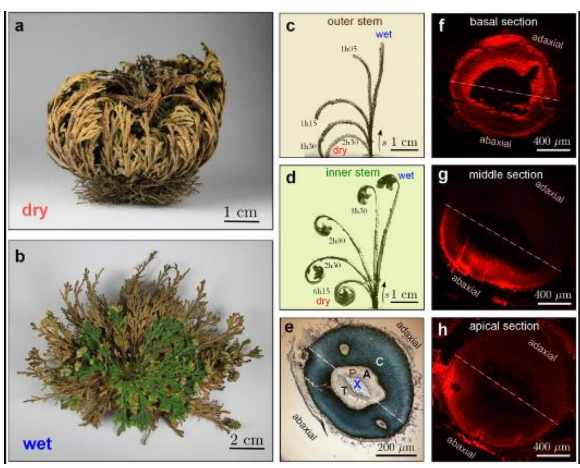


Fig-14: Morphology and composition of the resurrection plant Selaginella lepidophylla.

Inspired by the plant Selaginelia Lepidoplylla, Elaine Ng Yan Ling was able to weave interactive textiles (Wooden Skin and Marco Wooden Velcro) crafted of layers of veneer combined with fabric, dyes and reflective surfaces which react with environmental conditions such as moisture, heat, light intensity or mechanical force to form decorative systems that curl and expand or shrink (the fabricklab.com). The 'macro velcro' tiles are characterized by a large-scale hook-and-loop internal pattern and are cut into a shape that resembles a flower petal; clusters of three form floral sculptures that can be combined for a particularly striking visual effect [10]. They can be applied in interior spaces either on walls or as spatial dividers (Fig.15).

Fig-15: Elaine Ng's Macro Velcro' Tiles

3.7. Termite Mounds- Biomimetic Application: Thermal regulation of interior space

Termites are one of nature's extraordinary engineers. They naturally regulate the internal temperature of their dens by building vertical chimneys to remove heat and gas [15]. With a system of carefully adjusted convection currents, air is sucked in at the lower part of the mound, down into enclosures with muddy walls, and up through a channel to the peak of the termite mound. The industrious termites constantly dig new vents and plug up old ones in order to regulate the temperature [16].

A building which has been constructed to operate along these principles is the Eastgate Center in Zimbabwe (Fig.16). This 333,000 square-foot shopping and office complex was constructed with vertical atriums that pull heat up and out [15]. The concrete slabs of the building are kept cool when the night air is pulled in through intake fans. Bonanate explains that though the building doesn't have a conventional air conditioning or heating system, it expends 90 percent less energy to heat and cool by using a ventilation system that cost about one-tenth the price of an air conditioning system in a comparable sized building [15].

Fig-16: Left: Termite Mound, Right: Eastgate Centre- Zimbabwe

3.8. Spider's Web- Biomimetic Application: UV coated Glass Façade

It has been estimated that a large number of birds are killed each year in North America as a result of collisions with glass on man-made structures. This is because of the reflective and transparent nature of glass which cannot be seen by the birds. To prevent this occurrence it became necessary to look for ways to make these transparent glasses visible to birds. To do this, researchers went back to study UV reflective silk strands of some spiders' webs (Fig.17). Birds have the ability to see an ultraviolet spectrum thereby enabling them to avoid flying into the web. From the principles of the web, Ornilux Glass was developed. This glass has a patterned UV coating which mimics the design of a spider web and yet remains transparent to the human eye (Fig.18).

Ornilux is available as double-glazed insulated glass with either a low-E or solar protective coating and can be found in buildings across Canada and the U.S., including The Bronx Zoo's Center for Global Conservation and a renovation in progress at the Great Neck Library [15,21].

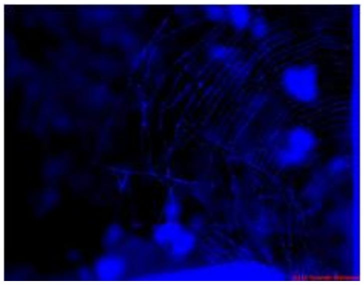


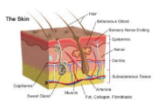
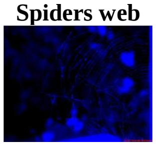
Fig-17: A spider web as seen by a bird, reflecting UV light.

Fig-18: Ornilux Glass

4. Discussion of the findings:

This study has focused primarily on evaluating some ways in which biomimicry can be applied in the field of interior architecture. Though biomimicry is a relatively new term in interior design, sustainable bio-inspired products and materials are on the increase. Biomimicry when used as a problem solving methodology has the potential to address innumerable issues in our buildings and interior spaces. For instance, the samples which have been presented in this paper have shown that biomimicry can be applied to a wide range of areas to address innumerable issues. Indoor thermal control is one such area where unnecessary energy demands for heating and cooling can be significantly reduced by applying the principles of biomimicry. Thus we can say that the principle of biomimicry helps to provide more innovative and smarter designs that are connected to the natural environment The various selected natural models discussed in this paper together with their unique qualities, potential areas of application and measure in which sustainability has been addressed have been categorized in the table below.

Table-1: Summary of Biomimetic Samples, Characteristics, Areas of Application and Possibilities for Sustainability

Nature'sModel	**Unique Quality of Unique**	**Biomimetic Product**	**Characteristic of Product**	**Broad Area of Application**	**Environmental Solutions/ How Sustainability Is Addressed**
Human Skin 	Heat regulation through blood vessel dilation and constriction	Optically clear, flexible elastomer sheets, bonded to regular glass window panes	Water filled channels running through sheets to maintain temperature	Window Insulation	Less energy loss 7-9 degrees additional cooling
Shark skin 	Ability to avoid bio-fouling	Sharklet Surface Material	Hinders the growth of disease causing microbes	For hygiene - To be applied to surfaces exposed to germs and bacteria	Product is free of pollutants such as dis-infectants, chemicals and toxins
Gecko Feet 	Unique ability to grip all surfaces	TacTile	Flexible backing systems which cling to floor, without glue	Adhesive – for carpets	Virtually zero VOC's, 90% lower environmental footprint than traditional carpet adhesives
Gecko Feet 	Unique ability to grip all surfaces	Geckskin	Is able to adhere to very smooth surfaces such as glass	Adhesive – for wall appliances	100% renewable resources natural fibers as well as natural rubber. Reversible, renewable, and biodegradable.
Lotus Plant Leaves and Flowers 	Self - cleaning ability	Wall paints (tiles, textiles, glass, etc.)	The paint is naturally resistant to the growth of mold, mildew and algae	Hygiene, self-cleaning paint	Lotusan- a paint which can reduce environmental impact and is cost effective
Squid 	Color changing ability	Materials with color changing ability	The material changes its appearance distinctly yet reversibly from transparent to opaque	Smart materials: mechanical sensors, optical switches, color-changing smart windows.	Ability of automatically changing color make it cost effective material
Selaginelia Lepidoplylla 	Ability to resurrect after the dry season	Wooden Skin and Marco Wooden Velcro	Ability to curl, expand or shrink after exposure to environmental conditions	Interior Décor – used on walls or as spatial divider	Recyclable and environmental friendly
TermiteMound 	Naturally regulates internal temperature of dens	Eastgate Centre Zimbabwe	Vertical atriums pull heat up and out	Thermal regulation of interior spaces	90% less energy consumption 10% cost of air-conditioning system
Spiders web 	UV reflective silk strands	UV coated glass	Visible to birds yet transparent to human eye	Glass façade - bird strike protection	Low-e coatings providing energy efficiency thereby significantly affecting the overall heating, lighting, and cooling costs of a building.

5. Conclusion and Recommendations

Sustainability has become a major issue which is being discussed globally as the world seeks solutions to the many problems confronting it. For sustainability to be adequately addressed, natural solutions from nature must be sought for. This requires designers and architects to look for ways to include biomimicry in their designs as biomimetics not only provides solutions to many of earth's current challenges but also offers exciting prospects for future design innovations.

This paper has examined a number of natural organisms which have special properties that have found biomimetic applications in buildings and interior spaces. These properties have been applied to address design solutions such as window insulation, indoor thermal control, smart color changing windows, germ resistance and self-cleaning paints among others.

Though biomimicry innovations are as yet quite limited within the field of interior architecture, it is believed that many more options abound which future research is likely to uncover. This paper thus calls for more research to be done with a view to finding other sustainable biomimetic innovations which can be applied to our interior spaces.

REFERENCES

1. Vierra, S. (2016, September 09). Biomimicry: Designing to Model Nature. Retrieved 28/12/2016 from https://www.wbdg.org/resources/biomimicry-designing-model-nature
2. Benyus, J. (2009). Biomimicry - Innovation inspired by nature. New York: Harper Collins.
3. Benyus, J. (1997). Biomimicry-Innovation inspired by nature. New York; harper Collins
4. Yurtkurana, S., Kırlı, G., Taneli, Y. (2013). Learning from Nature: Biomimetic Design in Architectural Education. Social and Behavioral Sciences 89, pp 633 – 639
5. El-Zeiny R.M.A. (2012). Biomimicry as a problem solving methodology in interior architecture Social and Behavioral Sciences 50, pp 502 – 512
6. Freeman, R. (2015, July 30). Geckos, Human Skin and Whale Fins: How Biomimicry Inspires Green Building. Retrieved 31/12/2016 from https://www.poplarnetwork.com/news/geckos-human-skin-and-whale-fins-how-biomimicry-inspires-green-building
7. Genzer, J., & Marmur, A. (2008). Biological and synthetic self-cleaning surfaces. MRS Bulletin, 33.
8. Das, S., Bhowmick, M., Chattopadhyay, S.K., & Basak, S. (2015). Application of biomimicry in textiles. Current Science, 109 (5).
9. Hu, R. (2015). 3 Trends in biomimicry. Retrieved January 3, 2017, from http://www.interiordesign.net/articles/11109-3-trends-in-biomimicry/
10. Hu, R. (2013). Beijing design week 2013 Wuhao presents new work by Mian Wu and climatology by the Fabrick lab (a.k.a. Elaine Ng Yanling). Retrieved 30/12/2016 from http://www.core77.com/posts/25631/Beijing-Design-Week-2013-Wuhao-Presents-New-Work-by-Mian-Wu-n-Climatology-by-the-Fabrick-Lab-aka-Elaine-Ng-Yanling
11. Geckskin. Retrieved 30/12/2016 from https://geckskin.umass.edu/
12. Buczynski, B. (2013, February 02). Eco-friendly House Paint inspired by the self-cleaning lotus flower. Retrieved 03/01/2017 from http://ecosalon.com/eco-friendly-house-paint-self-cleaning-lotus-flower/
13. Treacy, M. (2012, May 3). Color-Changing Squid Inspire Technology that Could finally get Us That Invisibility Cloak. Retrieved 04/01/2017 from http://www.treehugger.com/biomimicry/color-changing-squid-could-inspire-smart-clothing.html
14. Jacoby, M. (2016). Strain- induced color changes in biomimetic materials. Concentrates, 94 (29), pp 9.
15. Bonanate, L. (2015, July 31). Biomimicry: Designs By Nature. Retrieved 28/12/2016 from http://greenhomenyc.org/blog/biomimicry-designs-by-nature/
16. Doan, A. (2012). Building in Zimbabwe Modeled After Termite Mounds. Biomimetic Architecture: Green
17. Rankouhi, A.R. (2012). Naturally Inspired Design Investigation into the Application of Biomimicry in Architectural Design. Master of Architecture, The Pennsylvania State University.
18. Zari, M. P. (2007). Biomimetic Approaches to Architectural Design for Increased Sustainability. Paper presented at the SB07 NZ Sustainable Building Conference, Auckland, New Zealand.
19. Lebkuecher, J., W. Eckmeier (1993). Physiological Benefits of Stem Curling for Resurrection Plants in the Field. Ecology. 74 (4): 1073–1080.
20. Royall, E. (n.d.). Defining Biomimicry: Architectural Applications in Systems and Products
21. Mosaberpanah, M. A., & Khales, S. D. (2013). The Role of Transportation in Sustainable Development. In ICSDEC 2012: Developing the Frontier of Sustainable Design, Engineering, and Construction (pp. 441-448).

Sustainable Structure and Materials, *Vol. 1, No. 2 (2018) 12-20*
DOI: https://doi.org/10.26392/SSM.2018.01.01.012

A REVIEW ON SELF-HEALING CONCRETE USING BACTERIA

Chigozirim G. Iheanyichukwu*[1], Sadiq A. Umar[1], Prince C. Ekwueme[1]

[1]*Student, Department of Civil Engineering, Faculty of Graduate Studies and Research*
*Corresponding author/ E-mail address: chigozirimgoodnews@gmail.com

(Received December 25, 2017, Revised January 15, 2018, Accepted February 09, 2018)

ABSTRACT. *Recent interests in the field of Bio-technology and Civil Engineering have raised the topics on the precipitation of Calcium Carbonate by certain bacteria strains. The relationship between cracks and possible self-healing techniques; artificial and natural are considered. Importance has been laid on the bio-mineralization process and the mechanism of bacterial concrete. The methods of application of these artificial substances that aid the self-healing process in concrete and the effects of engineered self-healing in concrete are discussed in this review.*

Keywords: Concrete, Crack sealing, Self-healing, Bacteria, Autogenous healing, Permeability, Bio-mineralization

1. INTRODUCTION

Concrete is a material widely used for construction that can withstand compressive loads but needs steel in order to resist tensile stresses; its brittle nature makes it susceptible to cracks. Cracks pave way for the ingress of aggressive and potentially harmful fluids or substances such as sulfate, chlorides and carbonates. These aggressive fluids permeate inside the concrete, affecting the reinforcement by corrosion, thereby reducing the durability of the concrete structure. Cracks may not be regarded as failure of the concrete but the introduction of harmful substances create the need to seal these cracks by repairing the structure. The rising costs associated with repairs have led researchers to consider alternatives of crack sealing with growing interests in crack healing. Studies on the subject of self-healing have shown promise in the use of organic and inorganic materials for sealing cracks. The introduction of bacteria into the concrete mixture is one of such organic methods and works by precipitation of calcium carbonate to fill up cracks in concrete. This paper contains an extensive review detailing the different methods whereby bacteria can be applied to concrete in order to achieve self-healing.

2. CRACKS AND SELF-HEALING

Joshi et al [1] defines healing as “the phenomenon of restoration of concrete structure from a state of damage”. Gupta et al [2] describes self-healing as “an emerging concept of delivering high quality materials combined with the capability to heal damages and it has received much attention in past decade for application in building structures. Therefore, an effective self-healing mechanism may be able to reduce repair and maintenance works substantially and concomitant environmental and economic impacts”. Concrete has been found to repair itself over time when cracks have widths less than 0.2mm, when cracks exceed this width, man-made solutions can be applied [3, 4]. Man-made solutions have incorporated different means of self-healing with different levels of viability.

2.1 Autogenous Healing

Different researches have been carried to find out how concrete heals itself and different results have been obtained. Huang et al [5] has identified three mechanisms of autogenous self- healing as continuous hydration of unhydrated cement, the recrystallization of calcium hydroxide, and the formation of calcium carbonate. Li et al [6] reports that a relationship exists between the cement composition and crack healing properties, and mixes having higher binder particles tend to have better crack healing properties and this occurrence is caused by delayed hydration of unhydrated cement when in contact with water that passes through cracks [7].

In the absence of stress and in the presence of water, calcite is formed which closes up the cracks that are present on the concrete surface. The rate at which the crack is healed dependent on the concentration of water and the rate at which calcium carbonate is formed.

2.2 Autonomous Healing

Different mechanisms have been proposed by different researchers detailing artificial solutions with their major advantages being that they can close up cracks in concrete with widths greater than 0.1mm. Huang et al. [5] categorizes autogenous mechanisms of healing concrete into:

- Use of mineral admixtures which reacts with water that penetrates the surface of the cracked concrete
- Use of adhesive agents that hardens and connects the cracked surfaces
- Use of bacteria which precipitates calcium carbonate to repair cracks.

These mechanisms can be applied to the concrete via different methods and have a wide range of applications with respect to natural self-healing.

3. BIO-MINERALIZATION

The use of bacterial spores as a method of self-healing follows the mechanism of formation of calcite from autogenous healing. The process by which living organisms produce minerals through metabolic activities from their interaction with the environment is Bio-mineralization. Joshi et al [1] defines Microbially Induced Calcium Carbonate Precipitation (MICCP) as “the capability of microbes to form calcium carbonate extracellularly through a metabolic activity”.

Zhang et al [8] noted that the factors affecting the rate of calcium carbonate precipitation are: the amount of calcium present in the concrete matrix and the external environment, the pH of the concrete matrix, the presence of dissolved carbon and the availability of (nucleation) sites where the precipitation can occur via bacterial metabolism (usually the bacterial cell walls). The formation of calcium carbonate can be mediated through different metabolic pathways

3.1 Autotrophic-mediated Pathways

In autotrophic pathways (non-methylotrophic methanogenesis, oxygenic photosynthesis and anoxygenic photosynthesis) precipitation of calcium carbonate is done by the dissolution of carbon dioxide in the presence of calcium ions from the environment. Castanier et al [9] noted that the bacterial spores “induce CO2 depletion of the medium or of the immediate environment of the bacteria. When calcium ions are present in the medium, such depletion favors calcium-carbonate precipitation”. Table-1 shows the different metabolic pathways by which Calcium Carbonate formation can occur

Table -1: Different pathways of Bio-mineralization for MICP [10]

Autotrophic bacteria	**Heterotrophic bacteria**				
non-methylotrophic methanogenesis	Assimilatory pathways	Dissimilatory pathways			
	Urea decomposition	Oxidation of organic carbon			
an oxygenic photosynthesis		Aerobic		Anaerobic	
		Process	e–acceptor	Process	e–acceptor
oxygenic photosynthesis	Ammonification of amino acids	Respiration	O_2	NO_x reduction	NO_3^-/NO_2^-
		Methane oxidation	CH_4/O_2	Sulfate reduction	SO_4^2

.

3.2 Heterotrophic-mediated Pathways

Castanier et al [9] defines two processes that could possibly occur simultaneously, which are passive precipitation and active precipitation. These processes involve two metabolic cycles: Sulfur cycle which occurs when Sulfur Reducing Bacteria (SRB) is used in an anoxic where organic matter is sufficient and the Nitrogen cycle which involves the conversion of amino acids in the presence of dissolved oxygen, organic matter and calcium into ammonia, the denitrification of nitrogen in the absence or low amounts of oxygen or the decomposition of urea or uric acid in the presence of oxygen and organic matter; all three pathways produce carbonates ions while ammonia is the metabolic end product. The production of ammonia increases the pH of the environment creating an alkaline environment which conforms to the pH of the concrete microstructure.

4. METHODS OF APPLICATION

Different modes of incorporation of the bacterial agents into the concrete have been researched and while some are not feasible, some have shown promise. Gupta et al [2] in their report highlighted two major methods of application: directly to the concrete and by means of encapsulation (in polymeric capsules, in additives, in lightweight concrete aggregate, and in special mineral compounds). Muhammad et al [12] depicted a table showing bacteria could be sprayed or injected into the concrete material or the concrete could be cured in bacterial culture to prevent or heal early age cracking. In addition to the above mentioned methods, Huang et al [5] also reported the use of vascular systems which are embedded inside the structure.

4.1 Direct Application

Jonkers et al [1] and Luo et al [11] studied the effect of direct application of bacterial spores to the concrete mix and determined that while it is a viable option (the spores precipitated calcite when examined within the 7 days of placement but the precipitate could not be found after 28 days), it could not be sustainable because the spores would die off due to the increased pH and the reduced pore size in the concrete microstructure. The repair rates at different cracking ages were also studied with respect of crack width (range 0.1mm to 0.5mm). An 85% healing rate was recorded with curing by water and the use of wet-dry cycles reporting the best restorative performance. Luo et al [11] also concluded that early age cracks were healed efficiently in contrast to late age cracks which they attributed to lack of protective shell for the spores and the distance to the nutrients which caused a low survival rate of the spores.

4.2 Encapsulation

Spores can be encapsulated physically or chemically. Experience and applications from self-healing in polymers, the food industry and the pharmaceutical industry have been useful for the process of encapsulation of spores. This is an efficient method of supplying spores within the concrete matrix with long term effects.

4.2.1 Polymeric Capsules

Report by Wang et al [13] where polymeric microcapsules were used to encapsulate the spores with precursors (nutrients such as calcium nitrate, urea and yeast extracts) and showed 48%-80% healing ratio compared to a 50% healing ratio via autogenous healing. Gupta et al [14] defined the optimum dosage of the capsule application as 3% because higher doses of 5% could result in increase in permeability and reduction of the compressive strength of the structure.

4.2.2 Special Cement Additive

Hydrogel encapsulation of bacteria by Wang et al. [15] resulted in a 40%-90% increase in the healing efficiency of the spores, provides water for bacterial growth while decreasing the water permeability of the concrete by about 68%. The addition of spores does not affect the workability of the concrete but reduces compressive and tensile strengths due to the formation of voids from the capsules.

4.2.3 Light Weight Aggregate

Jonkers [16] experimented with Expended perlite and expanded clay to immobilize and encapsulate spores with precursor compounds. Soft aggregates such as clay aggregates when ruptured, exposes the bacteria to air which triggers the precipitation process. Crack healing of widths of 0.46mm were recorded and while the soft plane of the aggregates might draw crack towards them, the spores were still viable after 6 months. The use of soft aggregates however was found to reduce the strength of the structure making them unfeasible for structural applications. [17]

4.2.4 Application of Mineral Compounds

Gupta et al, [14] defines “Diatomaceous earth (DE) is a type of mineral compound rich in silica and formed from shell of microorganisms called diatoms”. Wang et al. [18] immobilized bacteria in DE and when it cracks and the spores are exposed to air or water, urea is hydrolyzed and calcium carbonate is formed from the precursor (Calcium Nitrate).

The width of healing is dependent on the medium used for the immersion – water based or nutrient based medium nonetheless smaller crack widths were almost or completely healed. Usage of DE in large quantities leads to the mortar drying up due to the fine particles of the DE leading to a higher water absorption rate. Table 2 shows a summary of bacteria species and encapsulation materials that have been tested with respect to self-healing and its application and the findings associated with the research for each specie.

Table -2: Summary of capsule materials, bacterial species and their self-healing properties [2]

Species of bacteria used	Encapsulated (Capsule material)	Directly added	Mechanism	Major findings	Reference
Spore forming bacteria (species not mentioned)		X	Not mentioned in the study	a) High early healing was observed by water curing b) Higher the cracking age, lower is the extent of healing	[11]
Bacillus		X	Decomposition of calcium source to precipitate carbonate	a) Calcium source affects healing ratio- calcium glutamate performs better than lactate b) Bacteria remained viable for 4 months	[19]
Bacillus cohnii	X (Clay aggregates)		Metabolic conversion of calcium lactate	a) Crack width of 0.15 mm with length 8 cm completely sealed b) No loss of viability up to 6 months	[16]
Bacillus Sphaericus	X (immobilized in PU and silica gel inside glass)		Ureolytic decomposition of calcium nitrate	a) PU immobilized bacteria specimens showed lowest permeability b) Higher bacteria activity in silica sol c) Higher strength recovery in case of PU immobilization	[15]
Bacillus Sphaericus	X (Diatomaceous earth)		Ureolytic decomposition of calcium nitrate	a) Highest reduction of water absorption was observed in bacteria containing specimen b) Dosage of DE must be carefully adjusted because it causes loss in concrete workability	[20]
Bacillus Sphaericus	X (Melamine based capsules)		Ureolytic decomposition of calcium nitrate	a) Crack healing ratio of 48% to 80%; highest crack width healed is 970 µm b) Permeability recorded for bacteria specimen is about 10 times compared to control c) highest reduction in crack area in case of wet-dry cycle	[21]
Bacillus Sphaericus	√ (hydrogel) – one component (only bacteria) and two component (bacteria and nutrient) system		Ureolytic decomposition of calcium nitrate	a)Maximum crack sealing of 500 µm under wet-dry cycles b) Permeability decrease of 68% for specimens containing hydrogel encapsulating both bacteria and nutrients together	[12]
Bacillus Sphaericus	√ (Sodium alginate based hydrogel)		Ureolytic decomposition of calcium nitrate	Bacterial activity was observed only for encapsulated samples at crack face measured by oxygen consumption	[15]
Bacillus Subtilis	√(Lightweight aggregates and graphite nano-platelets)		Decomposition of calcium lactate	a) Bacteria can be distributed uniformly in concrete when immobilized in graphite nano-platelets (GNP) due to fine particle size and uniform dispersion of GNP b) Bacteria immobilized in GNP showed high self-healing when samples were pre-cracked at early stages (3 day and 7 day) c) Lightweight aggregates are more effective when samples are pre-damaged at later stage (14 day and 28 day)	[22]

4.3Vascular Method

A vascular network can be built in the structure by pre embedding smooth glass tube bars into the concrete and removing them later, leaving spaces in the structures where the bacterial spores can be injected or pumped into the canals if cracks intersect these spaces [23-25]. In this case, to the holes or tunnels created in the structure, the healing agent can be applied over long periods of time leading to higher healing rate and greater efficiency of the healing process. The fig-1 shows a modified version of the vascular system proposed by C. M. Dry [26].

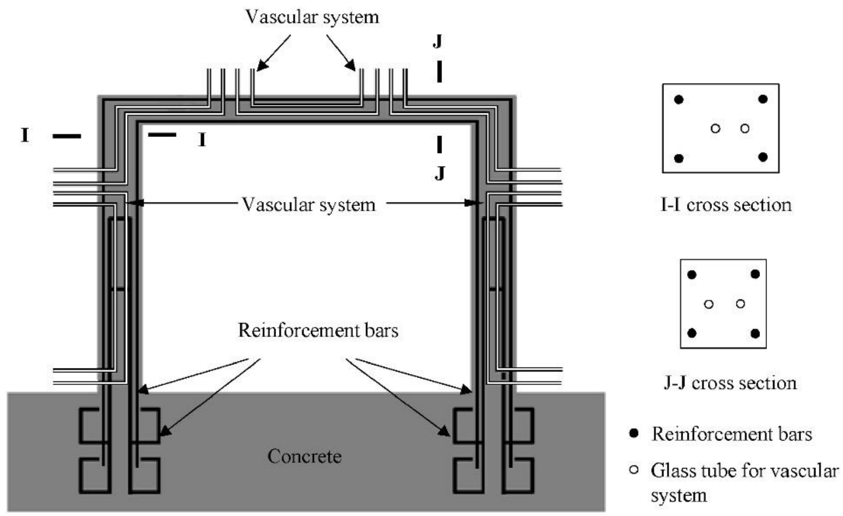


Fig-1: Modified Vascular System for self-healing [5]

5. EFFECT OF BACTERIA ON CONCRETE PROPERTIES

5.1 Precursors and Setting Time

The effect of the addition of precursors into the concrete mix resulted in mixed results. Depending on the type of nutrient use for bacterial spores in concrete, the setting time can be accelerated or retarded. Calcium Lactate delays setting time whereas Calcium Formate and Calcium Nitrate quickens the setting time. [27, 28]

5.2 Compressive Strength

Using bio concrete could increase or decrease the compressive strengths of the concrete depending on the bacterial species used, the percent of cement replaced with pozzolans, the use of admixtures such as Rice Husk Ash and Fly Ash and the mode of supply of bacteria to the concrete structure.[29, 10, 30-33]. Tables 3 points out bacteria types, their compressive strength increase with respect to control concrete and the concentration of cells per milliliter of concrete.

Table -3: Bacteria types and their compressive strengths with respect to normal concrete [10]

S.NO	Bacteria used	Best results	Bacterial concentration	Reference
1	Bacillus sp. CT-5	Compressive strength 40% more than the control concrete	5×10^7 cells/mm^3	[28]
2	Bacillus megaterium	Maximum rate of strength development was 24% achieved in highest grade of concrete 50 Mpa	30×10^5 cfu/ml	[31]
3	Bacillus subtilis	Improvement of 12% in compressive strength as compared to controlled concrete specimens with light weight aggregates	2.8×10^8 cells/ml	[22]
4	Bacillus aerius	Increase in compressive strength by 11.8% in bacterial concrete compared to control with 10% dosage of RHA	10^5 cells/ml	[34]
5	Sporosarcina pasteurii	Compressive strength 35% more than the control concrete	10^5 cells/ml	[35]
6	AKKR5	10% increase in compressive strength as compared to control concrete	10^5 cells/ml	[36]
7	Shewanella Species	25% increase in compressive strength of cement mortar compared with the control mortar	100,000 cells/ml	[37]

5.3 Permeability (Water and Chloride ions)

Ingress of harmful fluids is directly related to permeability. The activity of bacteria in the concrete reduces the permeability because the pores are filled with Calcium Carbonate from precipitation. Some spores (Pasteurii spp.), reduces the absorption rate of water and reduces the rate of chloride penetration [33, 39]. Aerius spp. decreases water absorption and porosity which increases durability and also reduces the amount of charges passing through the concrete [35]. Ingress of Chloride ions is dependent on the internal pore and capillary structure of the concrete and the pore and capillary structure is determined by factors such as mix design, degree of hydration, curing, etc. Comparing control concrete to bio-concrete, Bio-crete enhances the resistance of concrete to Chloride penetration [36, 32]

5.4 Microstructure

Research carried out using Scanning Electron Microscopy (SEM) showed that rod shaped bacteria which carry out calcite precipitation improved the micro structure of concrete. The addition of additives further enhances the micro structure by filling up voids in the concrete micro structure. [39, 32, 40, 41].

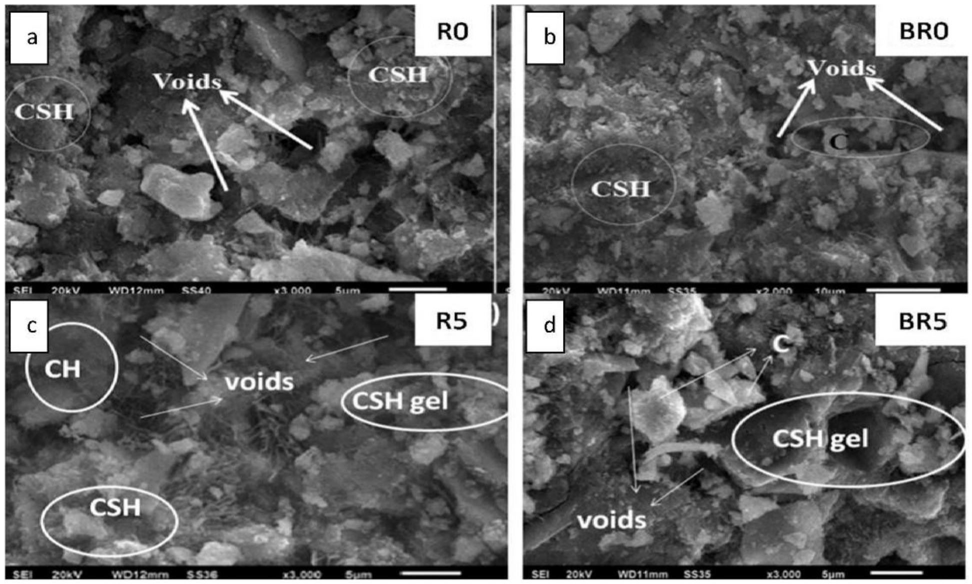


Fig -2: Scanning electron microscope (SEM) Images showing a. Normal Concrete b. Bacterial Concrete c. 5% RHA Concrete d. Bacterial concrete with 5% RHA [10]

6. CONCLUSION

While, the study of bacterial concrete is still far off from being cost efficient or general feasible for use in all conditions, it shows promising interest and can be used in controlled environments. Gupta et al [2] suggested that to make bacterial concrete commercially viable the cost of production should be reduced or by making the design more viable for long life applications so that it would work under continuous cycle of loading and extreme conditions.

Bacteria induced self- healing has drawn much attention due to its ability to be applied or long term constructions, eco-friendly and being well-matched with the concrete mix. It can be applied to virtually any structure (under-ground structures, bridges, pavements, etc.) as its application is versatile due to the different modes of application.

While more research is needed to consolidate its shortcomings such as the time it takes to heal cracks which usually take longer for larger widths of cracks; a more sustainable approach needs to be found to make it a more viable option in the industry. The ability of bacterial concrete to heal cracks deeper in the concrete should also be studied. The nutrients required for use by the bacteria should also be considered and the cost of obtaining them could be reduced. The cost and efficiency of the bacterial concrete with respect to conventional repairs should also be looked into to make it cheaper and accessible. Bio-concrete can be the future of sustainable engineering but research needs to assess the life cycle and means to further improve the current life cycle of the system.

Over the past few years, the interest in bacterial concrete has been astounding and the research and studies conducting have been quite progressive which leads us to believe that its implementation in the industry isn't far.

REFERENCES

[1] Joshi, S., Goyal, S., Mukherjee, A., & Reddy, M. S. (2017). Microbial healing of cracks in concrete: a review. Journal of industrial microbiology & biotechnology, 44(11), 1511-1525.
[2] Gupta, S., Dai Pang, S., & Kua, H. W. (2017). Autonomous healing in concrete by bio-based healing agents–A review. Construction and Building Materials, 146, 419-428.
[3] Wiktor, V., & Jonkers, H. M. (2011). Quantification of crack-healing in novel bacteria-based self-healing concrete. Cement and Concrete Composites, 33(7), 763-770.
[4] Zhang, J., Mai, B., Cai, T., Luo, J., Wu, W., Liu, B., ... & Deng, X. (2017). Optimization of a Binary Concrete Crack Self-Healing System Containing Bacteria and Oxygen. Materials, 10(2), 116.
[5] Huang, H., Ye, G., Qian, C., & Schlangen, E. (2016). Self-healing in cementitious materials: Materials, methods

and service conditions. Materials & Design, 92, 499-511.
[6] Zhang, J., Liu, Y., Feng, T., Zhou, M., Zhao, L., Zhou, A., & Li, Z. (2017). Immobilizing bacteria in expanded perlite for the crack self-healing in concrete. Construction and Building Materials, 148, 610-617. Chicago
[7] Hammes, F., & Verstraete, W. (2002). Key roles of pH and calcium metabolism in microbial carbonate precipitation. Reviews in environmental science and biotechnology, 1(1), 3-7.Chicago
[8] Luo, M., & Qian, C. (2016). Influences of bacteria-based self-healing agents on cementitious materials hydration kinetics and compressive strength. Construction and Building Materials, 121, 659-663.
[9] Castanier, S., Le Métayer-Levrel, G., & Perthuisot, J. P. (1999). Ca-carbonates precipitation and limestone genesis—the microbiogeologist point of view. Sedimentary Geology, 126(1), 9-23.
[10] Vijay, K., Murmu, M., & Deo, S. V. (2017). Bacteria based self healing concrete–A review. Construction and Building Materials, 152, 1008-1014.
[11] Luo, M., Qian, C. X., & Li, R. Y. (2015). Factors affecting crack repairing capacity of bacteria-based self-healing concrete. Construction and building materials, 87, 1-7.
[12] Muhammad, N. Z., Shafaghat, A., Keyvanfar, A., Majid, M. Z. A., Ghoshal, S. K., Yasouj, S. E. M., ... & Shirdar, M. R. (2016). Tests and methods of evaluating the self-healing efficiency of concrete: A review. Construction and Building Materials, 112, 1123-1132.
[13] Wang, J. Y., Soens, H., Verstraete, W., & De Belie, N. (2014). Self-healing concrete by use of microencapsulated bacterial spores. Cement and Concrete Research, 56, 139-152.
[14] Guo, Y. C., Wang, X., Yan, Z., & Zhong, H. (2015). Current progress on biological self-healing concrete. Materials Research Innovations, 19(sup8), S8-750.
[15] Wang, J. Y., Snoeck, D., Van Vlierberghe, S., Verstraete, W., & De Belie, N. (2014). Application of hydrogel encapsulated carbonate precipitating bacteria for approaching a realistic self-healing in concrete. Construction and building materials, 68, 110-119.
[16] Jonkers, H. M. (2011). Bacteria-based self-healing concrete. Heron, 56 (1/2).
[17] Li, V. C., & Yang, E. H. (2007). Self healing in concrete materials. In Self healing materials (pp. 161-193). Springer, Dordrecht.
[18] Wang, J. Y., De Belie, N., & Verstraete, W. (2012). Diatomaceous earth as a protective vehicle for bacteria applied for self-healing concrete. Journal of industrial microbiology & biotechnology, 39(4), 567-577.
[19] Xu, J., & Yao, W. (2014). Multiscale mechanical quantification of self-healing concrete incorporating non-ureolytic bacteria-based healing agent. Cement and concrete research, 64, 1-10.
[20] Wang, J., Mignon, A., Snoeck, D., Wiktor, V., Van Vliergerghe, S., Boon, N., & De Belie, N. (2015). Application of modified-alginate encapsulated carbonate producing bacteria in concrete: a promising strategy for crack self-healing. Frontiers in microbiology, 6, 1088.
[21] Wang, J., Jonkers, H. M., Boon, N., & De Belie, N. (2017). Bacillus sphaericus LMG 22257 is physiologically suitable for self-healing concrete. Applied Microbiology and Biotechnology, 1-14.
[22] Khaliq, W., & Ehsan, M. B. (2016). Crack healing in concrete using various bio influenced self-healing techniques. Construction and Building Materials, 102, 349-357.
[23] Reinhardt, H. W., & Jooss, M. (2003). Permeability and self-healing of cracked concrete as a function of temperature and crack width. Cement and Concrete Research, 33(7), 981-985.
[24] Reynolds, D. (2009). Lightweight aggregates as an internal curing agent for low-cracking high-performance concrete (Doctoral dissertation, University of Kansas).
[25] Huang, H., Ye, G., & Shui, Z. (2014). Feasibility of self-healing in cementitious materials–By using capsules or a vascular system?. Construction and Building materials, 63, 108-118.
[26] Sangadji, S., & Schlangen, E. (2012). Self Healing of Concrete Structures-Novel approach using porous network concrete. Journal of Advanced Concrete Technology, 10(5), 185-194.
[27] Dry, C. M. (2001, April). Design of self-growing, self-sensing, and self-repairing materials for engineering applications. In Smart Materials (Vol. 4234, pp. 23-30). International Society for Optics and Photonics.
[28] Mihashi, H., & Nishiwaki, T. (2012). Development of engineered self-healing and self-repairing concrete-state-of-the-art report. Journal of Advanced Concrete Technology, 10(5), 170-184.
[29] Jonkers, H. M., Thijssen, A., Muyzer, G., Copuroglu, O., & Schlangen, E. (2010). Application of bacteria as self-healing agent for the development of sustainable concrete. Ecological engineering, 36(2), 230-235.Chicago
[30] Siddique, R., Nanda, V., Kadri, E. H., Khan, M. I., Singh, M., & Rajor, A. (2016). Influence of bacteria on compressive strength and permeation properties of concrete made with cement baghouse filter dust. Construction and Building Materials, 106, 461-469.
[31] Siddique, R., & Chahal, N. K. (2011). Effect of ureolytic bacteria on concrete properties. Construction and

Building Materials, 25(10), 3791-3801.
[32] Xu, J., & Yao, W. (2014). Multiscale mechanical quantification of self-healing concrete incorporating non-ureolytic bacteria-based healing agent. Cement and concrete research, 64, 1-10.
[33] Andalib, R., Majid, M. Z. A., Hussin, M. W., Ponraj, M., Keyvanfar, A., Mirza, J., & Lee, H. S. (2016). Optimum concentration of Bacillus megaterium for strengthening structural concrete. Construction and Building Materials, 118, 180-193.
[34] Achal, V., Mukerjee, A., & Reddy, M. S. (2013). Biogenic treatment improves the durability and remediates the cracks of concrete structures. Construction and Building Materials, 48, 1-5.
[35] De Muynck, W., Cox, K., De Belie, N., & Verstraete, W. (2008). Bacterial carbonate precipitation as an alternative surface treatment for concrete. Construction and Building Materials, 22(5), 875-885.
[36] Siddique, R., Singh, K., Singh, M., Corinaldesi, V., & Rajor, A. (2016). Properties of bacterial rice husk ash concrete. Construction and Building Materials, 121, 112-119.
[37] Chahal, N., Siddique, R., & Rajor, A. (2012). Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of concrete incorporating silica fume. Construction and Building Materials, 37, 645-651.
[38] Achal, V., Pan, X., & Özyurt, N. (2011). Improved strength and durability of fly ash-amended concrete by microbial calcite precipitation. Ecological Engineering, 37(4), 554-559.
[39] Zhang, Y., Guo, H. X., & Cheng, X. H. (2015). Role of calcium sources in the strength and microstructure of microbial mortar. Construction and Building Materials, 77, 160-167.
[40] Nosouhian, F., Mostofinejad, D., & Hasheminejad, H. (2015). Concrete durability improvement in a sulfate environment using bacteria. Journal of Materials in Civil Engineering, 28(1), 04015064.
[41] Chahal, N., Siddique, R., & Rajor, A. (2012). Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete. Construction and Building Materials, 28(1), 351-356.
[42] De Belie, N., & Wang, J. (2016). Bacteria-based repair and self-healing of concrete. Journal of Sustainable Cement-Based Materials, 5(1-2), 35-56.
[43] Jonkers, H. M., & Schlangen, E. (2008). Development of a bacteria-based self-healing concrete. In Proc. int. FIB symposium (Vol. 1, pp. 425-430).
[44] Ling, H., & Qian, C. (2017). Effects of self-healing cracks in bacterial concrete on the transmission of chloride during electromigration. Construction and Building Materials, 144, 406-411. Chicago
[45] Palin, D., Wiktor, V., & Jonkers, H. M. (2017). A Bacteria-Based Self-Healing Cementitious Composite for Application in Low-Temperature Marine Environments. Biomimetics, 2(3), 13.
[46] Qian, C., Chen, H., Ren, L., & Luo, M. (2015). Self-healing of early age cracks in cement-based materials by mineralization of carbonic anhydrase microorganism. Frontiers in microbiology, 6.
[47] Sangadji, S. (2017). Can Self-healing Mechanism Helps Concrete Structures Sustainable?. Procedia Engineering, 171, 238-249.
[48] Tziviloglou, E., Wiktor, V., Jonkers, H. M., & Schlangen, E. (2016). Bacteria-based self-healing concrete to increase liquid tightness of cracks. Construction and Building Materials, 122, 118-125.
[49] Zhang, Y., Guo, H. X., & Cheng, X. H. (2015). Role of calcium sources in the strength and microstructure of microbial mortar. Construction and Building Materials, 77, 160-167.
[50] Zhang, J. L., Wu, R. S., Li, Y. M., Zhong, J. Y., Deng, X., Liu, B., ... & Xing, F. (2016). Screening of bacteria for self-healing of concrete cracks and optimization of the microbial calcium precipitation process. Applied microbiology and biotechnology, 100(15), 6661-6670.
[51] Pareek, S., & Oohira, A. (2011, June). A fundamental study on regain of flexural strength of mortars by using a self-repair network system. In Proceedings of the 3rd International Conference on Self Healing Materials, Bath, UK (Vol. 2729).
[52] Mihashi, H., & Nishiwaki, T. (2012). Development of engineered self-healing and self-repairing concrete-state-of-the-art report. Journal of Advanced Concrete Technology, 10(5), 170-184.
[53] Luo, M., & Qian, C. X. (2016). Performance of Two Bacteria-Based Additives Used for Self-Healing Concrete. Journal of Materials in Civil Engineering, 28(12), 04016151.
[54] Kim, H. K., Park, S. J., Han, J. I., & Lee, H. K. (2013). Microbially mediated calcium carbonate precipitation on normal and lightweight concrete. Construction and Building Materials, 38, 1073-1082.

Sustainable Structure and Materials, *Vol. 1, No. 1 (2018) 21-29*
DOI: https://doi.org/10.26392/SSM.2018.01.01.021

AREVIEW ON STUDIES OF THE MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE

M. Alsheltat*1, A. Ramadhan1

[1]*G Student, Department of Civil Engineering, Cyprus International University, Cyprus*
*Corresponding author/ E-mail address: mohamed.alsheltat@gmail.com

(Received January 05, 2017, Revised February 05, 2018, Accepted February 06, 2018)

ABSTRACT. *In this study ,We have reviewed many researches and papers that have recently been interested in the self-compacting concrete, its properties and additives, some of the studies focused on the use of specific additives in the self compacting concrete and the study of the effectiveness of these additives and their impact on the different properties of the concrete and its durability and performance, and we summarized the most important results, especially the results related to mechanical properties. Through the data available in recent previous studies, we studied the mechanical properties of self compacted concrete compared to normal vibrated concrete. the comparison was for compressive strength and tensile strength. We also presented a summary of the effect of use of various admixtures on the mechanical properties of self-compacted concrete, which may be useful in comparing the additives on the basis of their effect on the properties of self compacting concrete And to know the characteristics that need to be studied or increased research around them.*

Keywords: self compacting concrete, flowability, compressive strength, tensile strength, silica fume. Slag, Metakaolin. glass fiber.

1.INTRODUCTION

Self compacting concrete (SCC) was produced at the end of 1980 and is considered one of the high performance concrete types. For more than 20 years, concrete has been used in applications ,Several studies were conducted in this period [1].

In recent years there has been worldwide interest to study Self compacting concrete and its properties, especially in the last 5 years , Several research papers were presented at International Rilem Symposium on self compacted Concrete 2016 , Washington conference , in which the papers were classified on the basis of concrete properties.

Self compacting concrete (SCC) is a high performance concrete that consolidates under its own weight and adequately fills all voids without separation segregation, bleeding or any other heterogeneity of materials without need for mechanical uniformity , It also improves the resistance and durability of the hardened concrete and this makes it suitable in practical applications. use of plasticizers and powders admixtures is very important to achieve flow ability ,stability and impermeability of (SCC), Self - compacting concrete also improves the durability of hardened concrete. It increases compressive strength, tensile strength and bending. The concrete resistance of sulphates & chlorides increases . It is environmentally friendly . it reduces carbon dioxide emissions and reduces noise resulting from dynamic compaction. [1]

The following are the main results of some research: V. R . Sivakumar. et al (2017) investigated the effect of glass fiber and Metakaolin on mechanical, and durability properties of self- compacting concrete and the results was GF increase spelt strength, no effect on compressive strength, improve chloride resistance, decrease workability ,MK improve strength and durability of SCC The optimum cement replacement ratio was 0.8 % in GF reinforced SCC

[2]. And Serkan Subas . et al (2017) studied the use of waste ceramic powders as filler material in self compacting concrete , they found that WCP increase the flow ability , But decrease the compressive strength and bond strength. [3]. O.R. Kavitha. et al (2016) studies on friendly and durable Self- compacting concrete blended with metakaolin, it found : SCC with MK substitution improve the durability such as resistance to sulfate attack and decrease the permeability, also decrease the CO2 emission, and SCC containing 10%MK are considered the optimal [4]. Also Payal Painuly, and Itika Uniyal (2016) conducted a study on the many researches carried out during (1989 to 2011) and Search papers were classified based on SCC admixtures, He has proposed appropriate tests for fresh concrete. for plasticizer the Slump flow, V - funnel, L - flow, U-box are used . and we use the slump flow, J-ring test, L-box test and U-tube tests for mineral admixture SCC [1]. S.S. Vivek, G. Dhinakaran. (2017). An Experiment study on SCC durability by using binary blend self compacting concrete using GGBFS, SF and MK as mineral admixtures He found that Cement replacement with 50% GGBFS, 20% MK and 5 to 10% of SF was the optimum of SCC mixes [5]. A. Farzampour . et al (2016). The effect of temperature on concrete is discussed , and notes that cured concrete at low temperatures can never reach the strength of the concrete

the usage of lower water-cement ratios is recommended in cold weather curing [6]. Wu - Jian Long . et al (2016). The study concluded that , The compressive strength and splitting tensile strength decrease , and the shrinkage strain increases by using recycled aggregates. In SCC and decrease the workability .Use fibers improve the strength of recycled aggregates SCC [7]. Peiyu Yan, and others (2016) . studied creep behavior of high self -strength consolidation of concrete and they found The creep coefficient of concrete increases with the decrease of concrete strength at same loading age , and Chinese standards. for calculating the creep coefficient need to be adjusted [8]. Yudong Dang , et al (2016) . Under the experimental condition of this study , the difference in drying shrinkage between SCC with and without internal curing for large specimens is less pronounced than the small specimens . It is indicated that , for real concrete structures with larger cross-section, the laboratory tested shrinkage of internally cured SCC might be overestimated [9]. Ying Ma and Jueshi Qian. et al (2016). found that Cement with low alkali sulphate content will be useful for performance of SCC. compressive strength and drying shrinkage of SCC will be increasing [10]. B. Craeye , et al (2016).Based on an experimental study, they conclusions were: Gamma radiation during hard SCC negatively affects the development of strength the porosity of cementitious materials increases due to the gamma rays placed on the concrete [11] . Surong Luo , et al (2016). The study of Effect of Fly Ash on Resistance to Chloride Ion Penetration of SCC under Abrasion found that : fly ash increase to chloride resistance of SCC and The abrasion resistance strength of SCC increased with curing age and decreased with the increase of addition of fly ash. [12] . Katotriotou , (2016). studied Self-compacting concrete (SCC) with Multiwall carbon nanotubes (MWCNTs) .the properties of 28 days 0.1%w MWCNTs SCC were compared with control SCC without the nanoscale fiber. Observed that the flexural strength increased by 53 % , Young`s modulus by (68 %) , also improving workability of SCC [13] . Qi Cao, Yinliang Cheng, (2016). studied the effects of fibers on properties of SCC, by using Hooked end steel fibers and polypropylene fibers in the mixes. they resulted no effect on compressive strength. And increasing split tensile strength was observed [14]. Yakhlaf1, et al (2016). Case Study of mechanical properties of carbon fiber on reinforced self compacting Concrete (CFRSCC).the study results were carbon fibers improved the segregation resistance , filling ability, passing ability, splitting tensile strength , flexural strength (w/b < 0.40) , and The toughness (w/b = 0.35).but the compressive strength decreased by increasing carbon fiber [15] . Mohamed K. , et al (2016). The study of the Effect of Crumb Rubber (RC) Content on SCC Structure by testing reinforced SCRC beams . Their conclusions were; Increasing the CR caused reduction in the flow ability , passing ability, and compressive strength . 10% to 15% CR replacement improve ductility, and toughness but reduction in the flexural strength [16] . Mohamed K. Ismail and Assem. A. Hassan. (2016). Studied Bond Strength of SCRC And Their conclusions were : Increasing CR in both SCRC and VRC mixes caused a reduction in workability , compressive , tensile strengths and bond strength. [17] . Iris González-Taboada1, et al (2016). Used the Recycled coarse aggregate (RCA) in self compacting concrete mixes. and investigated time - dependent fresh of SCRC . the result of experimental test was : the concrete with Recycled coarse aggregate have high water absorption, low workability ,and low strength [18]. Yasser Khodair , Mahmood Raza. (2016) They Investigated the quality of concrete made from recycled asphalt pavement RAP and SCC, by testing the properties of the produced concrete . they tested other mixtures containing SCC and a different proportions of fly ash, slag, recycled asphalt pavement . the Conclusions were 75% FA and 75% S can be used in concrete mixtures as a partial replacement portland cement using RAP as a replacement for coarse aggregate decreased the workability , compressive strength , and tensile strength [19]. Marco daSilva , (2015) . investigated the fresh, and hardened properties of high strength fiber reinforced self compacting concrete containing rounded river aggregates , The study concluded that . the river aggregates (RA) increases the workability of the concrete than the crushed gravel . but the adding (RA) decreases the compressive strength and tensile strength of SSC. the adding steel fiber in concrete mix increase the ductility of concrete significantly [20]. S. M. Dumne , (2014). investigated effect of superplasticizers on properties of fiber self compaction concrete contained fly ash (FASCC) , by experimental study , and he found that use fly ash improves the workability of concrete. also increases compressive strength .concrete (10% fly ash) is The optimum to the best workability and strength [21]. Deepika ,et al (2014). used the fly ash and silica fume in self compacting concrete mixes by investigated the fresh, and hardened properties , he used binary blend as replacement material of cement contained from 50%fly ash and 50% silica fume, and he tested mixes with varies binary blend by replaced cement (10%,15%,20%,30%) of cement weight. the results were: At 10% binary blend resulted good compressive strength. but adding of fly and silica fume decreased the compressive strength and no improvement workability [22]. K . S . Johnsirani , et al (2013). Studied the properties of Quarry Dust SCC, with sand replacement of quarry dust (QD) (0% . 25% . 50% . 75% . 100%) , using fly ash and supperplasticizer in mixtures. and they concluded the following: QDSCC (50%) or more ,the flowability , filling ability and segregation resistance was not satisfied because of the high fineness of quarry dust . and SCC with QD (25%) or more , the compressive strength decreased. w/c (0.4) was the optimum for using quarry dust in SCC [23]. Dhiyane, shwaran , S al (2013). Investigated the durability of self compacting concrete with fly ash And their fresh and hardened properties They made durability tests such as Sulphate Attack test, and Water Absorption test ,and they found that 30%fly ash were the best for workability, strength and durability . They also noticed that the slight change in VMA dosage causes a significant change in the properties of the (FASCC). [24]

2 . THE MECHANICAL PROPERTIES OF SELF COMPACTING CONCRETE

Studies of mechanical properties of SCC have been very interesting recently. The main mechanical properties of concrete are compressive strength, tensile strength, the modulus of elasticity.

2.1 Compressive Strength

Compressive strength is the main characteristic in the list of concrete properties generally And is affected by several factors such as water, shape, properties, aggregates properties, (SCC) offers higher compressive strength to normal vibrated concrete (NVC) due to improved internal microstructure, reduced voids , increased bond strength between concrete particles, bond strength between concrete and reinforcement in reinforced concrete with reduced water admixture (HRWR) and improved viscosity modify agents (VMA) The type and quantity of plasticizer,(VMA), and mineral admixtures affect the compressive strength of the SCC produced. Therefore, the proper type and the optimum quantity should be selected by testing the experimental mixtures, [25] . The following (table.1, figure .1) shows a comparison between the compressive strength of both NVC and SCC. data from the previews papers for some SCC types .

Table -1: The compressive strength of NVT and SCC

N0	NVT compressive strength (Mpa) /28 days	SCC compressive strength (Mpa) /28 days	SCC Mix type	Data source
1	62.5	65.2	Without mineral admixtures	[5]
2	35	31	RCA	[26]
3	57.9	62.4	flow slump(700-800)mm	[27]
4	30.12	48.44	FA, W/C 0.3	[28]
5	27.55	46.33	FA, W/C 0.4	
6	21.66	39.55	FA, W/C 0.5	
7	35.47	38.07	Lime stone , flow slump(550 - 650)mm	[29]

8	35.85	38.21	Lime stone , flow slump(660- 750)mm	
9	37.87	39.22	Lime stone , flow slump(760 - 850)mm	
10	39.52	38.89	10% SF	[30]

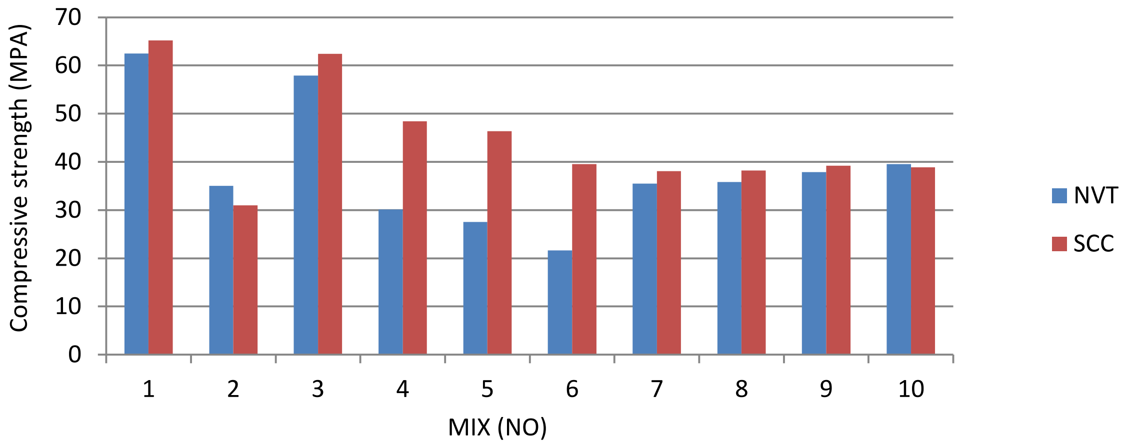


Fig -1: Compressive strength for NVT, SCC

2-2 Tensile Strength

The tensile strength is considered to be an indicator of the cracks in the concrete. tensile strength value is about (0.15 to 0.2) compressive strength. Three test methods to determine the tensile strength , direct tensile test, the split tensile test and the flexural tensile test. A direct tensile test is difficult in practice, and the test of split tensile gives greater values than direct tensile results and is higher than the flexural tensile test. Fibers and Powder clearly affect the tensile strength of SCC, [25]. The following (table.2, figure . 2) shows a comparison between the tensile strength of both NVC and SCC. data from the previews papers for some SCC types.

Table -2: The tensile strength of NVT and SCC

N0	NVT Split tensile trength (Mpa)/28 days	SCC Split tensile strength (Mpa) /28 days	SCC Mix type	Data source
1	4.5	4.25	RCA	[26]
2	3.9	4.2	flow slump(700- 800)mm	[27]
3	3.71	3.69	10% SF	[30]
4	2.92	3.77	W/C 0.3	[31]
5	2.6	3.37	W/C 0.4	
6	2.07	2.76	W/C 0.5	

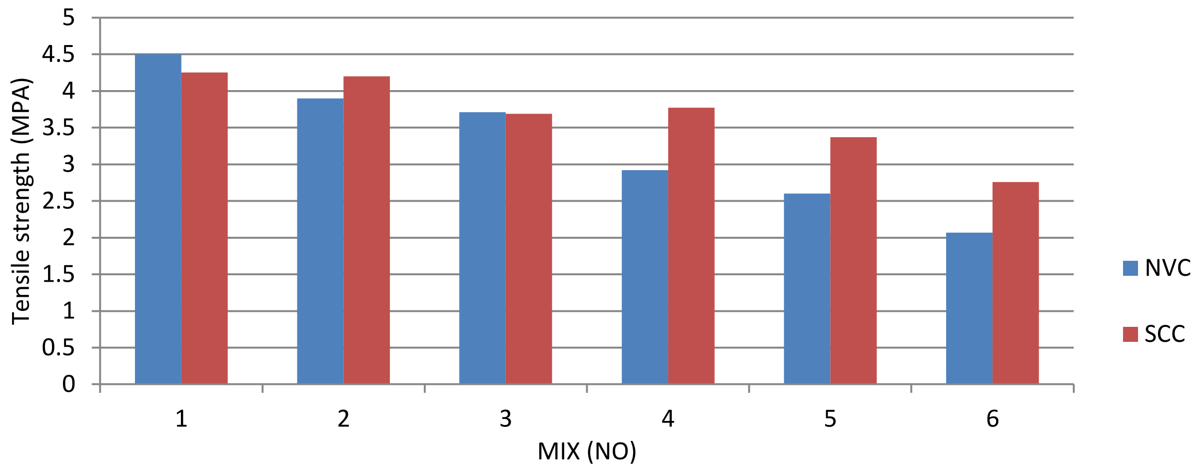


Fig -2: Tensile strength for NVT, SCC

2-3 Modulus of elasticity

Modulus of elasticity is the ratio between stress and strain and is influenced by the elasticity coefficient of the used aggregate, the volume of aggregate and the ratio of the binder in concrete mix. The type , grade , and amount of aggregates in self compacting concrete have an important effect on the elasticity coefficient by using a high elastic modulus of aggregates that gives higher elastic modulus of concrete [25]. In general, self compacted concrete is usually better in terms of compressive and tensile strength due to the ratio of the binder which improves the microstructures and reduces the permeability, which is reflected greatly on the performance of concrete. Various admixtures were used in the self compacted concrete industry which had a direct effect on the mechanical properties of SCC as indicated in the recent studies, which we will discuss as follows.

3. DISCUSSIONS

From table 1,2, and Figure 1,2, we note that the compressive & tensile strength of SCC was approximately equal to or greater than the normal vibrated concrete NVC for most data . Thus , the most important objectives achieved by the SCC is to keep strength of concrete at the same level without the need for a vibrated compaction.

By comparing the types of SCC based on additives with their mechanical properties, in order to compile the above list of points of interest in previous studies in a table in a short and useful manner as shown in Table 3:

Table -3: the different admixtures types and properties of self compacting concrete

Type of SCC	SCC PROPERTIES							Ref No
	workability	Comp. strength	Tensile strength	Flexural strength	Sulfate resist	Chloride resist	Optimum replace %	
SF	+	+	+	+	+		5-10	[1]
GGBFS	+	+	+	+	+		50	
MK	+	+	+	+	+		20	
MK	+	+	+	+			10	[4]
GF	-	0	+	+		+	0.8	[2]
WCP	+	-	-					[3]
RCA	-	-	-					[7]
RCA	-							[18]
MWCNTs	+	+		+				[13]
Type of SCC	SCC PROPERTIES							Ref No
	workability	Comp. strength	Tensile strength	Flexural strength	Sulfate resist	Chloride resist	Optimum replace %	
HSF,PP	-	0	+	-				[14]
CF	+	-	+	+				[15]
CR	-	-		-				[16]
CR	-	-	-					[17]
RAP	-	-	-					[19]
RA	+	-	-					[20]
FA	+	+				+	10	[21]
FA	+	+	+	+	+	+	30	[24]
50%FA + 50%SF	+	-					10	[22]
QD	-	-	+				25	[23]

* (+) positive effect . (-) negative effect . (0) no significant effect . ( ) no investigated

It could be derived from table as follow:

▪ The admixtures : fly ash (FA) , silica fume (SF), ground granulated blast furnace slag (GGBFS) , and Metakaolin (MK). have excellent effects on self compacting concrete, they clearly improve the workability, strength and durability of self compaction concrete in many papers as mentioned above , Also note that Admixture : Multiwall carbon nanotubes (MWCNTs) have very good effect on compressive and tensile strength and therefore we have to study the durability conditions on SCC by using this material.

▪ The admixtures : glass fiber (GF) , carbon fiber (CF) , Hooked end steel fibers and polypropylene fibers (HSF,PP) , are good materials that improve tensile strength only, but have a negative effect on some of other properties , especially strength of concrete thus may be useful to use along with other admixtures .

▪ The materials : waste ceramic powders (WCP) used as an replace to cement ,and river aggregates. (RA) used as an replace to crushed aggregates, increased the workability .and negative effect on the other properties. also the use of quarry dust (QD) as an replace to sand in SCC. increased the tensile strength only.

▪ The use of the recycled coarse aggregate (RCA) , recycled asphalt pavement (RAP) ,and Crumb Rubber (CR) have a negative effect on SCC properties.

▪ In the paper [23] the using binary blend contained (50%fly ash+50% silica fume) which is why the weak results of the properties of self compacting concrete .

▪ In these papers, Table 1 shows the emphasis on the study of the properties of fresh concrete and strength of hardened concrete tests. Despite the importance of the properties of the durability , many of these properties have been overlooked , such as chloride resistance.

4. CONCLUSION

Based on the review of above research papers , the following concludes:

▪ In general, self compacting concrete has a positive effect on the mechanical properties of concrete in the case of the most suitable choice of mixtures.

▪ Self compacting concrete usually improves mechanical properties compared with normal vibrated concrete.

▪ Choosing the appropriate tests of fresh self compacting concrete depends on the type of admixtures (mineral admixtures - or plasticizers)

▪ The curing temperature affects the target concrete strength .

▪ As a result of the significant development in this area, it is necessary to revise and amend the standards if necessary.

▪ The size of the samples in the laboratory does not give accurate results in the drying shrinkage, test which is higher than what actually occurs .

▪ Cement with low alkali sulfate content will be useful for performance of self compacting concrete.

▪ For all types of admixtures , an optimal ratio should be determined by testing experimental mixes.

▪ In the case of admixtures consisting of two or more materials , the optimum proportions of the components of admixture should be determined through experimental mixtures.

▪ fly ash , silica fume, ground granulated blast furnace slag , and Metakaolin are more effective in improving concrete performance.

▪ glass fiber and carbon fiber increase the tensile strength but they have negative affect on the other properties.

▪ The results of the studies conducted on recycled materials such as waste ceramic powders , recycled asphalt pavement, recycled coarse aggregate, are not encouraged to be used in the self compacting concrete industry.

▪ Studies have shown little benefit from the use of certain materials such as crumb rubber , river aggregates and quarry dust in the concrete industry.

▪ Good results for workability and resistance tests on self compacting concrete may not achieve high performance concrete if the durability properties are neglected.

REFERENCES

[1] Payal Painuly , Itika Uniyal ” Literature Review on Self Compacting Concrete ” International Journal of Technical Research and Applications e – ISSN : 2320-8163, Volume 4, Issue 2 (March-April, 2016), PP. 178-180.

[2] V . R . Sivakumara , O . R . Kavithab , G . Prince Arulrajc , V . G . Srisanthid ,” An experimental study on combined effects of glass fiber and Metakaolin on the rheological, mechanical , and durability properties of self – compacting concrete ” , Elsevier B . V . Applied Clay Science ,147 (2017) 123–127.

[3] Serkan Subas , Hakan Öztürk , Mehmet Emirog ˘lu , “ Utilizing of waste ceramic powders as filler material in self – consolidating concrete ”, Construction and Building Materials 149 (2017) 567 – 574 , Düzce University , Turkey . 2017 Elsevier Ltd

[4] O. R. Kavitha, V. M. Shanthi , G. Prince Arulraj, V .R. Sivakumar ” Microstructural studies on eco - friendly

and durable Self-compacting concrete blended with metakaolin", India , Applied Clay Science 124–125 (2016) 143–149 , 2016 Elsevier.
[5] S.S. Vivek, G. Dhinakaran," Durability characteristics of binary blend high strength SCC " , Thanjavur , India , Construction and Building Material, 146 (2017) Elsevier Ltd.
[6] A. Farzampour , and A. Radlinska " The Effect of Temperature and Humidity on Strength Development of Grouts " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[7] Wu-Jian Long , Jin-Guang Shi, Wei-Lun ,Wang and Xiao, Liang Fang " Shrinkage of Hybrid Fiber Reinforced Self-Consolidating Concrete with Recycled Aggregate " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[8] Peiyu Yan, Zhikai Zhou , Qiang Wang,Wang , Xiao, Liang Fang" Study on the Creep Behavior Of High – Strength Self - Consolidating Concrete " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[9] Yudong Dang, Tao Zhang, Zhenghong Yang, Zhengwu Jiang, Hui Zhang, Qingchun Guo , Xincheng Li " Influence of Moist Curing Age and Sample Size on Strength and Drying Shrinkage of Internally Cured Self-Consolidating Concrete" , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[10] Ying Ma and Jueshi Qian " Effect of Alkali Sulfate on Workability, Strength and Volume Stability Related to SCC " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[11] B. Craey e, G. De Schutter and . Gérardy . " Hardening Self - Compacting Mortar Exposed to Gamma Radiation " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[12] Surong Luo , Wenda Wu ,Yong Li , and Jianlan Zheng . " Effect of Fly Ash on Resistance to Chloride Ion Penetration of SCC under Abrasion " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[13] M.K. Katotriotou , Ch.A. Argyriou, P.A. Danoglidis,M.G. Falara,G.D. Panagiotakis , and M.S. Konsta-Gdoutos ", Nanoscale Fiber Reinforced SCC: Impact of MWCNTs on the Fresh Properties and Mechanical Properties" , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[14] Qi Cao, Yinliang Cheng ," Workability and Mechanical Properties of Expansive Self - Consolidating Concrete Reinforced with Hybrid Fibers " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[15] M. Yakhlaf, Md. Safiuddin, K.A. Soudki, A. El baden , " Case Study of Mechanical Properties of Carbon Fiber Reinforced Self-Consolidating Concrete" , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[16] Mohamed K.Ismail, and Assem A. A. Hassan " Effect of Crumb Rubber Content on Structural Behaviour of Self - consolidating Concrete " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[17] Mohamed K . Ismail , and Assem A . A. Hassan " Experimental Investigation on Bond Strength of Self - Consolidating Rubberized Concrete" , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[18] Iris González – Taboada , Belén González - Fonteboa , Fernando Martínez-Abella, Nicolas Roussel and Sindy Seara – Paz " Time - Dependent Fresh Behaviour of Self-Compacting Concrete with Recycled Concrete Coarse Aggregate " , 8th International RILEM Symposium on SCC, Washington DC, USA, May 2016.
[19] Yasser Khodair and Mahmood Raza" Self-Consolidating Concrete Prepared with Recycled Asphalt Pavement and High Volume of Supplementary Cementitious Materials " , 8th International RILEM Symposium on SCC , Washington DC, USA, May 2016.
[20] Marco Antônio da Silva , Marco Pepe, Rodolfo Giacomim Mendes de Andrade, Michèle Schubert Pfeil, Romildo Dias Toledo Filho " Fresh Rheological and mechanical behavior of High Strength Steel Fiber – River Gravel Self Compacting Concrete " , Construction and Building Materials 150 (2017) 606 – 618, Elsevier Ltd.
[21] S. M. Dumne" Fresh Effect of Superplasticizer on Fresh and Hardened Properties of Self - Compacting Concrete Containing Fly Ash " , American Journal of Engineering Research (AJER) p-ISSN : 2320-0936 Volume-03, Issue-03, pp-205-211, (2014).
[22] A.Deepika, Dr S.Krishnamoorthi, G.S.Rampradheep," STUDY ON PROPERTIES OF SELF CONSOLIDATING CONCRETE WITH FLY ASH AND SILICA FUME", International Journal of Innovative Research in Science , Engineering and Technology
(An ISO 3297: 2007 Certified Organization) Vol. 3, Issue 4, April 2014.
[23] K.S. Johnsirani,Dr. A. Jagannathan, R. Dinesh Kumar ," Experimental investigation on Self Compacting Concrete using Quarry Dust" , International Journal of Scientific and Research Publications, ISSN 2250-3153 , Volume 3, Issue 6, June 2013.

[24] Dhiyaneshwaran , S , Ramanathan, P, Baskar, and Venkatasubramani, R. “Study on Durability Characteristics of Self-Compacting Concrete with Fly Ash” , Jordan Journal of Civil Engineering, Volume 7, No. 3, 2013.
[25] Aurelia Bradu, Nicolae Cazacu, “Mechanical properties of self compacting concrete ” , Tehnical University „Gheorghe Asachi” from Iassy, 2016.
[26] Batham Geeta, Bhadauria S. S., Akhtar Saleem “ A Review: Recent Innovations in Self Compacting Concrete ” International Journal of Scientific & Engineering Research, Volume 4, Issue 11, ISSN 2229-5518, November-2013.
[27] Raya Harkouss, Bilal Hamad ,“Overview Studies of High Strength Self consolidate- ing Concrete ” World Academy of Science, Engineering and Technology, Vol : 8, No :6, 2014
[28] Prashant Kumar, Rakesh Kumar, K Gupta, “ Study on Normally Vibrated Concrete to Self - Compacting Concrete ” Journal of Ceramics & Concrete Technology Volume 1 Issue 3, October 2016
[29] Aurelia, Nicolae, , and Petro, “ Compressive strength of self compacting concrete” Universitatea Tehnică „Gheorghe Asachi” din Iaşi Volumul 62 (66), Numărul 2, 2016 .
[30] Asha Deepthi, Deva1, Gopala Krishna Sastry, “ A Comparative Study on Mechanical Properties of Normal Vibrated Concrete and Self Compacting Concrete” International Journal of Civil and Structural Engineering Research, ISSN 2348-7607, Vol. 2, Issue 2, pp: (93-100), Month: October 2014.
[31] Cristian Druta,“ Tensile Strength and Bonding Characteristics of Self Compacting Concrete” The Department of Engineering Science, Louisiana State University, August 2003.

Sustainable Structure and Materials, *Vol. 1, No. 1, (2018) 30-36*
DOI: https://doi.org/10.26392/SSM.2018.01.01.030

SURVEY OF SUSTAINABLE CRITERIA ON BUILDING DESIGN

Faraneh Sahraiyanjahromi*[1], Mohammad Ali Mosaberpanah[2],

[1]*PhD candidate, Faculty of architecture, Eastern Mediterranean University*
[2]*Assist. Prof. Dr. Faculty of civil engineering, Cyprus international University*
*Corresponding author/ E-mail address *Faraneh.Sahraeyan@gmail.com*

(Received December 29, 2017, Revised January 24, 2018, Accepted February 08, 2018)

ABSTRACT. *Due to the rapid deterioration and depletion of natural resources which are utilized in the building construction industries globally, decision makers are now looking forward to the inclusion of some useful criteria's into achieving sustainable views on building designs. This stems from their increased knowledge of possible sustainable solutions to these problems from various researches or studies been carried out into innovated methodologies and technologies necessary in achieving sustainability to buildings. Building designs should account for long service life, protection of natural resources, habitat of some plant and animal species especially the endangered ones, maintaining the quality of the atmospheric air and effectively utilizing the natural sources of energy such as the sun and wind. The performance of buildings could be explained by different parameters like the environmental load, the indoor environmental quality, and the primary energy source. In sustainable building designs, it is beneficial to classify the important design indicators in order to reach various optimized design solutions or by developing a more alternative design answer. Sensitivity design and analysis makes it possible to detect the important factors in respect to performance of buildings and to concentrate design and optimization of sustainable structures like buildings. This paper will consider effective sustainable criteria in three major fields which include the: economy, society, and environment.*

Keywords: Sustainable development, building criteria, design

1. INTRODUCTION

The promotion of sustainability development (SD) concept has been a significant central point for lovers of the environment when it is to be used for engineering purpose. Asthe Brundtland reported that “sustainability development aims to meet the needs of the present generation without compromising the ability of future generations to meet their own needs” [1]

A number of sustainability development assessment methodologies exist [2]. By using the kinds of criteria in practice for evaluating the performance of key components of industries, the Global Reporting Initiative [3]. The World Business Council for Sustainable Development [4], and the standards development [5] were the key drivers for managing the sustainability in constructions. Glavic and Krajnc [6] defined and developed a standardized package of sustainability indicators for companies supporting all important aspects of sustainability development.

According to KEI [7], “Indicators and composite indicators are increasingly recognized as a useful tool for policy making and public communication in conveying information on countries performance in fields such as economy, environment, society, or technological development”.

As Bebbington et al. [8] expressed “There is a widely recognized need for individuals, organizations and societies to find models, metrics and tools for articulating the extent to which, and the ways in which, current activities are unsustainable”.

As stated by Ness et al. [9] “The purpose of sustainability assessment is to provide decision-makers with an evaluation of global to local integrated nature–society systems in short and long term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable”.

In the assessment of a building’s sustainability the building is divided into three groups which are its design, maintenance, and rehabilitation. If the structure’s design is according to specific criteria’s on sustainability, in the future, there will be less reasons to worry about problems or issues which may be related to sustainability factors.

It therefore means that it will be important to have in place specific criteria’s that will enable us have buildings that meet a sustainable life, but first we should be ready industrially. To design sustainably, means to have a sustainable structure and to have a sustainable idea. In this article, the design process is divided into 8 categories which are: Architectural Engineering, Interior Design, Structural Engineering, Environmental Engineering, Materials Engineering, Electrical Engineering, and Mechanical Engineering. For every category, some criteria related to that science is defined.

2. SUSTAINABLE FRAMEWORK DEFINITION

Sustainability is a very hot topic these days, as every year, several seminars and conferences in different levels are held almost all-round to find a world solution in having a green future. Pollution is one of the reasons why we as humans try to create something which would be sustainable. One of the most important developments in this field is the Pressure State Response (PSR).It is operates according to the idea of effect and cause of phenomena. The format defines the impression of social activities which apply ‘pressures’ on the environment and also effects in changing the quality and quantity of environmental conditions. Therefore, the society responds to these changes through sectored policies (the ‘societal response’), which are economical, environmental, and for its revision [10]. The society acts like a reaction to “pressure” piece over human activities. PSR-framework of OECD [11] is given in Fig.1.

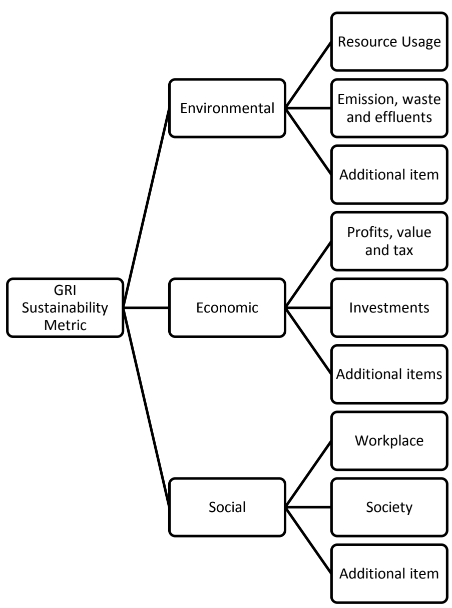


Fig-1: PSR-framework of OECD [11]

For evaluating criteria, at first, the frame work should be defined. According to Global Reporting Initiative (GRI), sustainability reporting is considered in three dimensions (Fig. 2), 1. Environmental 2. Social, and 3.Economic. Also The United Nations Commission on Sustainable Development (CSD) offered a monitoring framework that the various sustainability parameters for performance assessment of government towards SD goals [12]. This framework has four dimensions which is included as: economic, environment, social, and institutional and it is divided again into 15 main indicators and 38 sub-indicators as given in Fig. 3

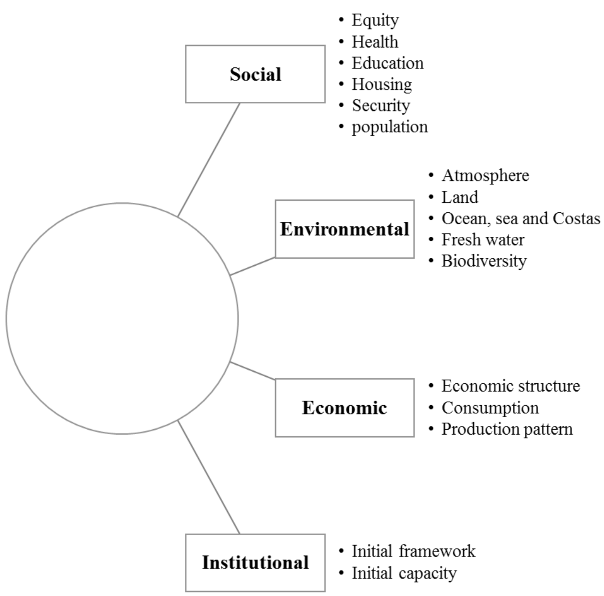


Fig-2: GRI of sustainability reporting [3]

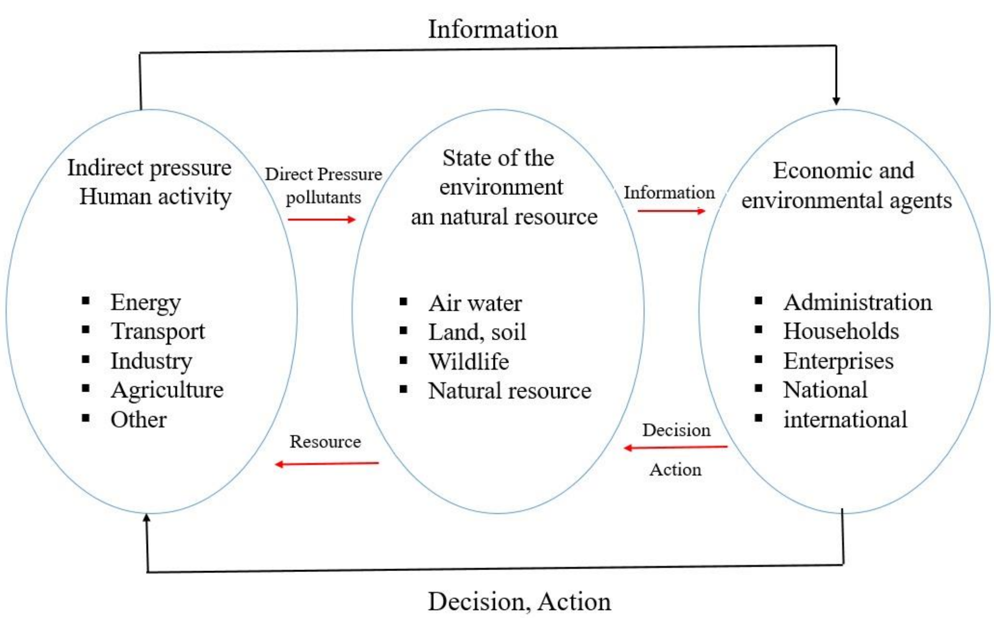


Fig-3: assessing the performance based on different sustainability indicators [12]

3. DESIGN BUILDING SUSTAINABILITY

When using sustainable criteria's in building designs, one of the most important parts of sustainable development is to have green buildings [13]. Design processes can be divided into three parts 1.Preliminary Design, 2.Execution Design and 3.Construction Completion. The Sustainable criteria should be able to make assessments at each stage of a building's design and construction, on the basis of target performance, design specification and forecast performance. Options for the consideration of improvements at each stage should also be given [14].

Design building involves the collaboration of 8 kinds of sciences: which are Architectural Engineering, Interior Design, Structural Engineering, Management Engineering, Environmental Engineering, Materials Engineering, Electrical Engineering, and Mechanical Engineering, they should all have very close relation together in order to give a sustainable building. The criteria which are used in Table1, are defined according to engineering sciences.

3.1. Architecture engineering

This is one of the most important aspects in building designs as it is connected to architecture [15]. It involves getting ideas from the owner and using ones creativity to design a sustainable building which would maximize the utilization of resources. Table 1 shows the parameters which can help to design a sustainable building.

Table-1: Architecture Survey

No	Criteria	Remarks
1.1	Day Lighting	Design according the use of daylight (efficient use of natural light) to achieve minimum day lighting standards
1.2	Well Plan	Preventive of useless place
1.3	Drying space	Provision of adequate drying space – based on the number of bedrooms within the dwelling
1.4	Home Office	Provision of a compliant home office space
1.5	Flexibility	Evaluate ease of movement and comfort such as: floor area per occupant, ceiling height, adaptation to IT equipment, and availability of refreshment space.

3.2. Interior design

Interior design is the next step after the architectural design and it should involve the design of a building according to sustainable criteria. In this part of design, the interior Designer should use from available sustainable materials or resources to home furnish the building with minimum cost. Lighting is also one of the important things in interior design, suitable distribution of lighting can be useful for sustainability, also using suitable colors can be effective to a number of parts in a house [16,22]. Table-2 illustrates these effective parameters.

Table- 2: Interior Design

No	Criteria	Remarks
2.1	Lighting	Internal lighting that does not exceed the maximum average wattage across the total floor area - 9 watts/m2
2.2	Furnishing	Using Sustainable furnishing
2.3	Suitable Coloring	Design according Mental Society needs

3.3. Structural engineer

Structural engineers are connected with the safety and resistance of buildings against the effects of natural and unnatural loads for examples earthquakes, landslides and a missile attack on a structure [17]. It is important that the structural engineer designs buildings with maximum efficiency and friendliness with the environment, table 3 shows the effective criteria in building design.

Table-3: Structure engineering survey

No	Criteria	Remarks
3.1	Reliability	Interruption of building functions in the event of a disaster or an accident is taken into consideration as a functionality issue. Design according to functionality level retained by each building equipment type during an emergency situation under Reliability.

3.2	Natural Event Resistance	Design according Potential threats to human life such as building collapse during a disaster and compromised occupant comfort during strong winds or flood or earth quake is taken into consideration as environmental factors for the space within hypothetical boundaries.

3.4. Material engineer

Material science is very important in sustainability [18], because there are a lot of effective parameters in the design of buildings by using materials which do not pollute the environment and can be renewable in the future. Also, the material designer should pay enough attention in providing materials which act as good insulators to thermal and sound parameters. Table-4 shows the related criteria to material engineering to have sustainable design.

Table-4: Materials engineering survey

No	Criteria	Remarks
4.1	Environment Impact of materials	Using re-recycled materials for as: roofs, external walls, internal walls, windows and upper and ground floors.
4.2	Avoiding the use of Materials with pollutant Content	To reduce the environmental load associated with use of resources, it is important to reduce the amount of the resources used, and also to reduce the use of materials that include pollutants. This Criterion evaluates performance in reducing the emission of pollutants associated with the use of resources.
4.3	Responsible Sourcing of Materials	Design according the responsible sourcing tier levels of the applicable new materials.
4.4	Reducing Usage of Non-renewable Resources	Regard depletion of non-renewable resources as an environmental problem beyond the hypothetical closed space, and evaluate efforts to reduce consumption of such resources. Specifically, evaluate reduction in the resource usage volume itself.
4.5	Sound Insulation	Using sound insulated materials to prevent noise from reaching interiors, and sound absorption to stop reverberation of sound that penetrates the room.
4.6	Thermal Insulation	Using Thermal insulation in external walls, ground floors, roofs and building services is assessed as a minimum requirement.

3.5. Environmental engineering

This branch of engineering considers building designs on the environment as detailed as possible. The environment is divided into sub details like the marine environment (water), the soil environment (land), and atmospheric environment (air). The designer should spot all of the design result on environment [14,21], these criteria is available as table-5

Table- 5: Environment engineering survey

No	Criteria	Remarks
5.2	Natural Energy Using	Design according direct use of natural energy (light, Solar, water heater, and ventilation etc.)
5.3	Water Recourses	Regard water shortage due to rapid use of large volumes of mains water as an environmental problem beyond the hypothetical closed space, referring to whether or not there are efforts for saving water, using rainwater, and reusing greywater.
5.4	Consideration of Global Warming	Design according to the direct use of natural energy (light, Solar, water heater, and ventilation etc.)
5.5	Consideration of local Environment	Regard water shortage due to rapid use of large volumes of mains water as an environmental problem beyond the hypothetical closed space, referring to whether or not there are efforts for saving water, using rainwater, and reusing rain water.
5.6	Consideration	Evaluate the following CO2 reduction initiatives using the quantitative LCCO2

	of Surrounding Environment	indicators: [1] Efforts to reduce operating energy affecting climate change [2] Use of existing structural frames and recycled construction materials, which contribute to the reduction of embodied CO2 related to the manufacture of construction materials [3] Efforts to extend building lifespan that contribute to LCCO2 reduction Assessment is performed based on the emissions rate (%) relative to LCCO2 (kg CO2/year-m2) of a reference building with level 3 performance in all assessment categories except this item(excluding LR1 Energy) and equivalent to the evaluation standard for building owners as referred to in the Energy Conservation Law.
5.7	Using Renewable Technologies	Consider the reduction of atmospheric pollutants emitted from buildings or from within the property. This includes measures such as the control of pollutants from the operation of building equipments and pollutants removal by plants. Considering efforts that contribute to mitigation of the heat island effect of surrounding areas. This includes enhanced airflow leaving the site, greening of the building, and reductions in solar absorption and artificial heat discharge.
5.8	Consideration of Emission Pollutions	Consider noise, vibration and odor generated during the operation of the building. Noise and vibration generated during the operation of the equipment are evaluated according to whether measures for source elimination and propagation control have been established. Assessment of odor is based on reduction measures for odors generated from chemical substances designated under the Offensive Odor Control Law and from organic waste. Buildings that are vulnerable to damage from wind hazards (e.g. large structure buildings) should be carefully considered during the design stage.
5.9	Safety	Design and use of renewable versus old technology

3.6. Electrical engineering

Electricity is one of the most important but expensive energy sources in the world [19], according to the design criteria below in table-6 we will be closer in having a sustainable building in the field of electricity.

Table- 6: Electrical engineering survey

No	Criteria	Remarks
6.1	Setting Lighting	Implementation lighting that does not exceed the maximum average wattage across the total floor area according standards
6.2	Safety	Energy efficient external space and security lighting
6.3	Display Energy devices	Design according to Energy display device displays both electricity and primary heating fuel consumption data Exemplary credit –energy display device that is able to record consumption data.
6.4	Lighting Controllability	That is able to record consumption data lighting control (systems managing brightness and lighting positions).
6.5	Control of Illuminance	Illumination should be flexible to increase or decrease of brightness

3.7. Mechanical engineering

Mechanical engineering is the last one in this category, this deals with room temperature control, humidity control and type of air conditioning system. Table-7 shows these criteria in mechanical engineering [20]:

Table- 7: Mechanical engineering survey

No	Criteria	Remarks
7.1	Room Temperature Control	Design according the setting, control and maintenance management systems for interior temperature,
7.2	Humidity Control	Design according humidity and air conditioning, and the related equipment.
7.3	Type of Air Conditioning System	Design according low cost and friendly with environment
7.4	Ventilation	Design to have good system to ventilate of building

4. CONCLUSION

A good design is the strong base for the production or manufacturing of a service or goods irrespective of location, economy or the society at large. If the construction which the owner wants to build is to be sustainable, therefore the design criteria should be sustainable. In this article, building design is divided into 8 categories: Architectural Engineering, Interior Design, Structural Engineering, Management Engineering, Environmental Engineering, Materials Engineering, Electrical Engineering, and Mechanical Engineering. For every category, a definition and a brief explanation on some of the criteria in making a sustainable building is given. With more consideration in the future we can define more criteria in having a sustainable future for our posterity.

5. References

[1] WCED – World Commission on Environment and Development, 1987. Our Common Future. Oxford Univ. Press, Oxford.
[2] Ramachandran, N., 2000. Monitoring Sustainability: Indices and Techniques of Analysis. Concept Publishing Company, New Delhi.
[3] GRI – Global Reporting Initiative, 2002a. The Global Reporting Initiative – An Overview. Global Reporting Initiative, Boston, USA, Available at www.globalreporting.org (2004).
[4] WBCSD – World Business Council for Sustainable Development, 1997. Signals of Change: Business Progress Toward sustainable Development. Geneva, Switzerland.
[5] OECD – Organisation for Economic Co-operation and Development, 2002. An Update of the OECD Composite Leading Indicators. Short-term Economic Statistics Division, Statistics Directorate/OECD, Available at http://www.oecd.org (2004).
[6] Krajnc, D., Glavic, P., 2005. A model for integrated assessment of sustainable development. Resource Conservation Recycling 43, 189–208.
[7] KEI, 2005. Knowledge Economy Indicators, Work Package 7, State of the Art Report on Simulation and Indicators.
[8] Bebbington, J., Brown, J., Frame, B., 2007. Accounting technologies and sustainability assessment models. Ecological Economics 61, 224–236.
[9] Ness, B., Urbel Piirsalu, E., Anderberg, S., Olsson, L., 2007. Categorising tools FOS sustainability assessment. Ecological Economics 60, 498–508.
[10] OECD, 1993. Core Set of Indicators for Environmental Performance Reviews. Paris.
[11] OECD, 1998. Towards Sustainable Development: Environmental Indicators. OECD, Paris.
[12] Labuschagnea, C., Brenta, A.C., Ron, P.G., Van Ercka, P.G., 2005. Assessing the sustainability performances of industries. Journal of Cleaner Production 13, 373–385.
[13] GRI – Global Reporting Initiative, 2002b. Sustainability Reporting Guidelines 2002 on Economic and Social Performance. Global Reporting Initiative, Boston, USA, Available at www.globalreporting.org (2004).
[14] Altecnic: Technical specifications of water meters www.altecnic.co.uk
[15] Rees, J. (1997) „Tube house indoor air quality‟, unpublished Advanced Studies in Architecture Report, The University of Adelaide Department of Architecture.
[16] UK Rainwater Harvesting Association (UKRHA) www.Kara.org
[17] Environmental agency Intelligent metering for water: potential alignment with energy smart metering Science Report – SC070016 /SR2 (WP3)
[18] BS8542:2012, Calculating Domestic Water Consumption in Non Domestic Buildings
[19] O‟Hara, S. U. (1998) „Economics, ethics and sustainability: redefining connections‟, International Journal of Social Economics, 25(1): 43–62.
[20] Pears, A. (2001) Pitfalls in consideration of energy in life cycle analysis, unpublished paper, presented at seminar RMIT Centre for Design, Melbourne.
[21] Mosaberpanah, M. A., & Khales, S. D. (2013). The Role of Transportation in Sustainable Development. In ICSDEC 2012: Developing the Frontier of Sustainable Design, Engineering, and Construction (pp. 441-448).
[22] Sahraiyan, F., & Tümer, E. (2017). Adaptive Reuse of Industrial Buildings: Case Study of Tenten Factory in Famagusta. Journal of Engineering and Architecture, 5(1), 50-60.

Sustainable Structure and Materials, *Vol. 1, No. 1, (2018) 37-44*
DOI: https://doi.org/10.26392/SSM.2018.01.01.037

MECHANICAL PROPERTIES OF FIBER REINFORCED POLYMER COMPOSITE – A REVIEW

Ali Salim Ali Minnah*[1], Abdelrahman Miftah Akoush[1]

[1]Engr.&Department of Civil Engineering, Cyprus International University, Mersin 10, Turkish Republic of Northern Cyprus
**Corresponding author/ E-mail address: alisalemsalem55@gmail.com*

(Received December 29, 2017, Revised January 24, 2018, Accepted February 08, 2018)

ABSTRACT. *Fiber reinforced plastic composites or as called fiber-reinforced polymer, consists many rewards such as its ultimate strength, its low density, and easier processing procedures. Thus, the fiber-Reinforced polymer is used in many fields for instance: in automotive, constructions, as well as in aerospace. Merging two or more fibers into one mixture polymer matrix guides to develop the hybrid composite. The mechanical properties of single fiber-reinforced polymer composite can be improved by the process of Hybridization. The resin and aggregates can be seen as a polymer concrete composite material signs. The (FRPs) are used instead of the steel in both rehabilitation and construction projects because of their non-corrosive and their light weight Thus they are non-magnetic, inert from the prospective of the chemical composition, also they can be applied easily. In addition, they are suitable economically for strengthening, rehabilitating and seismic retrofit of columns, beams, joints, and many more other uses in structures. In this paper, the mechanical properties of the Fiber-Reinforced Polymer (FRP) is presented in this paper.*

Keywords*:* Composite, Mechanical Properties, Fiber, Resin, Polymers, Fibres

1. INTRODUCTION

The usage and importance of the polymer is in demand more and more in these days. It can be used in (PMC), when are employed beside cement, (PIC) polymer impregnated concrete, which is used in polymerized and soaked cement concrete is used. (PC), polymer concrete, where the cement paste is replaced by polymer. ACI, 1999, (2007) [1]. These composites have some main concerns as to the usual cement concrete, for instance: it is rapid in hardening, its large mechanical strain, its practical chemical resistance, etc. on the other hand it is not cheap material. The utilization domain of polymer concrete always interchangeable: PMC is used in making floors and bridge overlays; PC was used in 1958 in the United States of America for building; nowadays, it is used for marbles and, labs and I repairing overlays for bridges. Aggarwal L.K., Thapliyal P.C., Karada S.R., 2007 [2]. The ordinary Cement resembles the polymer concrete in terms of its ingredients unless the hydraulic binder is replaced by polymer material. The performance of polymer concrete accounts for the polymer properties Abdel-Fattah H, (1999) [3], (Banthia, N., and Macdonald, 1996) [4].

The composite empolyed in dry state could be silicates, quartz, crushed stone, limestone, calcareous, granite, clay, etc. In general, can be employed as filler. Several types of finer substance are employed such as: fly ash, silica fume, cinder, etc. Cheng-Hsin C., Huang R., (2006) [5] and Erhard,Gunter, (2006) [6]. Filler, specifically fly ash, will increase the characteristics of polymer concrete Ehsani, M.R, 1994. Fiber reinforced polymers revealed many positive actions over steel including its significant resistance for corrosion, it resists the fatigue, low coefficient of thermal expansion, also, it is light in weight. F.R.P. has higher specific stiffness and an equally high specific strength in the direction of fiber alignment. Utilizing of F.R.P. provides a high structural effectiveness, and their density is low which makes physical utilization which is sample. unluckily, F.R.P. are also not cheap, high costs of F.R.P substance are of`ten offset by savings in reduction in usual maintenance, higher life period and of reduction in costs of labour ACI, 1999 [1].

2. WORKABILITY

All fiber reinforcement's success is specifically based on the finishing of the spreading of homogenous mixtures, in the concrete, the spraying and casting and the interface with the cement. There would be a deteriorating effect on workability of the concrete if more percentage of fiber is added particularly which have small diameters. This is because there is a bigger combined surface area in small diameters of fibers. Additional water and cement or admixtures are on extra demand, in which the outcome there would be a spectacular effect on the concretes workability. Peng Zhang and Qing-fu Li (2013) [18] stated that the concretes workability includes silica fumes and fly ash, in which additional polypropylene fibers decreases. Moreover, fresh concretes fluidity decreases, and the fresh concretes cohesiveness amplifies with also the increase of the fiber volumes fractions.

The workability of the mix lessens with the increase in fiber content s observed by Atis C.D.and Karahan O., (2009) [19]. When the dosage of the circular PET fibers weight goes beyond 1%, the concrete mix is hardly workable. Despite the fact that there is use of plasticizer, fibers in high amounts are not recommended due to the fact that concrete is not workable any more.

Several properties that were investigated by Mohammadi Y. et al., (2008) [20] which included aspect ratios that was different and then evaluated with concrete. It could be argued that in the end that here is a decrease in the workability and there is an increase in the fiber content. It is observed by Antonio Domingueset a., (2015) [16] that the movement of the aggregate is hindered by the fibers, resultant there is a loss in the portability and the strength, which is course reduction in the ratio of the fibers is shortened. However, there is a loss in the post crack strength of the tough fiber reinforced concrete. It could be argued in the conclusion that the maximum size of aggregate to be reduced or the content of mortar in the concrete to be increased. If there is an increase in the content of fiber from 0 to 2% the outcome in the slump value would decrease from 230mm (for 0%) to 20mm (for 2%) as studied by Faisal Fouad wafa (1990) [21]. It could be analyzed that the fibers that are hooked are performing better when they are being compared fibers that are straight due to the fact that during the mixing balling was prevented. As concluded by Libre N.A., et al., (2011) [25] there is a lesser effect on the workability of the fresh mix in the PP fibers when they are being compared to steel fibers. It has been analyzed that the dangers of separation in the lightweight concretes is reduced because of the effects of blocking by the polypropylene and fiber steels. The fibers that are different like steel and polypropylene have a lasting effect that reduces the aggregates sedimentation, the surface bleeding and increased in uniformity in the light weight concrete (LWC). It is analyzed that there was decrease in the slump by 54.2%, which was because of the adding of steel in the LWC.

3. COMPRESSIVE STRENGTH

The definitive resistance which was given by the block of concrete right before the yielding the exerted compressive loads could be defined by the concretes strength. Even though the plain concrete disastrously failed during the compression tests, the plastic fiber reinforced concrete failed due to the happening of the many minor cracks that were on the surface. It was inspected by Spadea S.et al., (2015) [22] that the very shortly incorporations nylon recycling fibers reductionpower pressure of investigated (up to -37.0%). Kim S.B.et al., (2009) [27] observes that the power pressure decreases in around 1.0 to 9.0% and of about 1.0 to 10.0% in the polyethylene terephthelates recycling PET, and reinforced specimen of polypropylene when comparing to the normal sample. Inspected by the Atis C. D, and Karahan O., (2009) [19] that the strength which was at 7.0, 28.0, and a time of 1 year. The rise that was inspected was up to 10% and the fall was up to 6% of the specimen of the concrete which was reinforced with steel fibers. In the end it is argued that the variations are because of the complications in giving a spreading of homogenous fibers which are in the specimen.

It is concluded that circular PET fibers contained in the concrete do not show any noteworthy increase in the compressive strength. It is analyzed by silva D. A., et al., (2005) [28] that adding extra PETF fibers has no major influence mortars compressive strength. The FRCs might increase when the volume of the fiber increased. The compressive strength was increased by 14.2% when the outcome was compared to the plain concrete. It was analyzed by Y. Mohammadi et al (2008) [20] that the compressive strength was 2% fiber volume fraction of steel fibers in a maximum of 26% increase. The finest volume fractions were reported by this percentage of fiber. Experimental investigation on the light weight concrete which is reinforced with the volume fractions (0.0%, 0.5%, 1.0%, 1.5% and 2.0%) as conducted by H.T Wang and L.C Wang, (2013) [23]. In the end it is concluded that improve in the compressive strength in some limit.

Faisal Fouad Wafa (1990) [21] stated that there was no important blow on the concrete compressive strength because of the fiber volumes fractions percentage. It was analyzed by Patil Shweta and Rupali Kavilkar, (2014) that with the incorporations of steel fibers the compressive strength was lessened by 31.10%. During the observation the maximum decline was 1.50% fiber breakage. N.A. Libre et al., (2011) [25] studied the effects of steel fibers compressive power.It was analyzed that when the steel fibers were added the compressive strength of concrete was reduced by half.

As analyzed by C.SelinRavikumar and T.S. Thandavamoorthy, (2013) [26] the concretes compressive strength with glass fiber was directly proportional to the fiber content. The experimental inspection was done by D.A. silva et al., (2005) [28] the different fiber content on the concrete. The increase in the content of the fiber was directly proportional to the compressive strength. Comparative experimental inspection was done by P. S. Spadea et al (2015) [22] about the NFRC and PFRC. Nylon fiber improved the concretes unified strength by 6.3% as observed and then they were compared with PP reinforced concrete. The increase was because of the better distribution and the nylon fibers superior tensile strength. As investigated by Banthia, N., and Macdonald, R. (1996) [4] the PP fiber content (0%, 0.050%, 0.10%, 0.20% and 0.30%) had the effect on the plain concretes compressive strength. There was no major impact observed on the normal concrete, and while the concrete together with silica fumes verified a rise in strength by 23.0%.

4. FLEXURAL STRENGTH

The resistance that is offered by the block of concrete right before the application of bending stresses persuaded by necessary loading. It was reported by S.B. Kim et al., 2009) [27] that there was a rise of 25.0%, 31.0% and 32.0% in flexural strength that was reused by P.E.T reinforced sampie at 0.5%, 0.75% and 1.0% of fiber size sequentially. However, there was no major effect analyzed on the steel fibers flexural strength at low volume fractions as reported by C.D. Atis and O. Karahan, (2009) [19]. But the volume fraction at 1%, the flexural strength had risen by 15% and there was improvement shown.

It was concluded by D. Foti, (2013) that the PET fibers in the concrete are not showing any major rise in the flexural strength. It was examined by D.A. silva et al., (2005) [28] that there was no major impact on the mortar's tensile strength when they added PET fibers. It is because that plain mortar causes the first crack in that close relationship. As examined by H.T Wang and L.C Wang (2013) [23] the adding of steel fibers improved the flexural strength greatly.

As examined by Y. Mohammadi et al., (2008) [20] the final rise with resulted in 100 percent in unvarying flexural energytheamount of the solid fiber of 2.0% with 100% longthy steel fibers in concrete. It was studied b yFaisal fouadwafa (1990 [21] that the finest rise in the flexural strength was 67% and was examined by adding 1.5% of hooked fibers. There was a 2% straight incorporation of straight fibers, which raised 40% of flexural strength compared to plain concrete. The hooked fibers fraction at 2% volume fractions, the flexural strength dropped because of the complications in the consolidations and achievement of the uniform distribution.

It was studied by Patil Shweta and Rupali Kavilkar, (2014) [24] that the SRFC is keeping volume fractions fiber volume at 1.50% and raising the aspect ratio by 70.0% which rose by 58.650% in flexural strength. Moreover, by making the aspect ratio constant at 70.0% and then raise the size fraction of fibers by 2.50%, the increase of flexural strength was by 116.69%.

It was studied by N.A. Libre et al., (2011) [25] that a rise in flexural strength by 200% was observed by adding steel fibers. Moreover, there were some improvements when 0.4% of polypropylene fibers were added. As studied by C. Selin Ravi kumar and T.S. Thandavamoorthy, (2013) [26] that there was 0.5% glass fiber added in the volume fractions, the flexural strength was enhanced by 42% and when adding 1% volume fraction the flexural strength was increased by 75%. It was observed by H.T Wang and L.C Wang, (2013) [23] tht at 3% volume fractions flexural strength was more and adding fibers which compared to 0.0%, 1.0% and 2.0% fibers. In addition, there was 49% amplification in the flexural strength when the steel fibers were added. It was investigated by Patil Shweta and Rupali Kavilkar, (2014) [24] that effects in different P.P fiber amount (0%, 0.05%, 0.1%, 0.2% and 0.3%) in plain concretes strength and with the concrete existence different binding. The confidence stage of 99%, it was examined that the strength was raised by 387% with 0.3% fiber content added.

5. TENSILE STRENGTH

The materials that offer the resistance opposing the longitudinal stresses are calculated in relation to the longitudinal stress which is required to break the materials that usually what is called tensile strength. It was reported by S. Spadea et al., (2015) [22] that there as improvement of 35% in tensile strength and the fracture properties of the cement properties were enhanced by adding R-Nylon Fibers.

It was observed by C.D. Atis et al. (2009) [19] that the incision strength is amplified by 3.0%, 5.0%, 32.0% and 71.0% concrete with and without the fiber volume fractions which are 0.25%, 0.5%, 1% and 1.5%. It was observed by Nanni, A., M.S. Norris and N.M. 1993 [12] that the volume fiber of steel fiber is straight proportional to the tensile strength of concrete. It is studied by H.T Wang and L.C Wang, (2013) [23] that the incision tensile strength significantly improves by adding steel fibers, and different variations were observed in tensile strength from 3.990 MPa to 7.680 MPa. This credit of increase is to the cracking arrests by the steel fibers. It was studied by Y. Mohammadi et al., (2008) [20] that the rise in the tensile strength was 27.0%, 51.0% and 59.0% for volume fractions when adding 1%, 1.5% and 2% of steel fibers to the concrete shuffle. There is a 2% mix ratio of volume fractions which consists of short fibers which are 35% and long fibers which are 65% and in accumulative increase of tensile strength by 59%. The studies of Faisal fouadwafa, (1990) [21] that 57% was the maximum of enhancing the strength of concrete when added 1.5% volume fractions of steel fibers. It is reported by N.A. Libre et al., (2011) [25] that including both steel and polypropylene fibers would augment the tensile strength by 116%.

It was studied by C. Selin Ravi kumar and T.S. Thandavamoorthy, (2013) [26] when adding 0.5%-part size of glass fiber., the tensile strength would be enhanced by 20%, and while the tensile strength was amplified by 37% when 1% glass fiber was added. It was observed by S.B. Kim et al., (2009) [27] that there is more tensile strength when 3% of volume fraction is added than 0%, 1% and 2%. In addition, there was 49% enhancement in the tensile strength when steel fibers were added as shown in table 1. It was examined by D. A. Silva et al., [28] that nylon FRC spitting tensile strength was augmented by 6.7%. The better diffusion of nylon fibers that are mixing in the water is the reason why there is a slight increase. Nearly all carbon fibre is obtained from a standard industrial fibre is known polyacrylonitrile fibre, also called as PAN. Most PAN fibre is utilized to produce acrylic fibre. It is further used to obtain carbon fibre with a pyrolyzing process, which implies it is burned to ultra-high temperatures to eliminate all components excluding the carbon. Most carbon fibre is sold at this position and it has a tensile modulus of 33 million pounds per square inch (MSI) shown in table 1. Carbon fibre is often time created utilizing two principal schemes: by the practice of Polyacrylonitrile (PAN) and from the pitch. Pitch is a viscoelastic material that is comprised of aromatic hydrocarbons. Pitch is fabricated via the distillation of carbon-based materials. Table 1 reviews the impact mechanical agents of fibre such as, Carbon (PAN and Pitch), ARAMID (Kevlar 29, 49, 129, 149 and Twaron, Technora respectively) and GLASS (E- Glass and S- Glas) S.B. Kim et al (2009) [27].

Table- 1: Typical Mechanical Properties of Fibers

FIBER TYPE		**Tensile Strength [MPa]**	**Modulus of Elasticity [GPa]**	**Elongation [%]**	**Coefficient of Thermal Expansion [x10^{-6}]**	**Poisson's Ratio**
CARBON						
PAN	High Strength	3500	200-240	1.3-1.8	(-1.2) to (-0.1) 7 to 12	-0.2
	High Modulus	2500-4000	350-650	0.4-0.8		
Pitch	Ordinary	780-1000	38-40	2.1-2.5	(-1.6) to (-0.9)	N/A
	High Modulus	3000-3500	400-800	0.4-1.5		
ARAMID						
Kevlar 29		3620	82.7	4.4	N/A	0.35
Kevlar 49		2800	130	2.3	(-2.0) to(59)	
Kevlar 129		4210 (est.)	110 (est.)	--	N/A	
Kevlar 149		3450	172-179	1.9	N/A	
Twaron		2800	130	2.3	(-2.0) to(59)	
Technora		3500	74	4.6	N/A	
GLASS						
E-Glass		3500-3600	74-75	4.8	5.0	0.2
S-Glass		4900	87	5.6	2.9	0.22
Alkali Resistance Glass		1800-3500	70-76	2.0-3.0	N/A	N/A

6. MODULUS OF ELASTICITY

The concretes stress strain curve of slope, the materials relative limit is contained by the effectiveness which is defined by the concretes elasticity. For the low-levelstresses, the value is constant however it is reduced when high level stresses and concrete cracks are developed. It is studied by "C.D. Atis and O. Karahan (2009)[19] that steel fiber in concrete contains 0.25% of volume fractions and 0.5% slightly greater value of elastic modulus compared to fiber less concrete. Usually with a growing in the fiber content the modulus of elasticity is reduces. It is studied by D.A. silva et al., (2005) [28] that the elasticity modulus of mortar in flexural test had nearly no major effect. It is examined by S.B. Kim et al (2009) [27] that PET and PP concrete which are recycled had value depress in the elastic modulus in contrast to plain concrete. It is also shown in Table 2 that with the increase in fiber content the modulus of elasticity is decreased.

Table -2: Properties of Composites and Comparison with Steel

Property	Steel	Aramid Fibre Reinforcement Polymer	Carbon Fibre Reinforcement Polymer	Glass Fibre Reinforcement Polymer
Tensile Strength, Mpa	300-450	1720-2540	600-3690	480-1600
Elastic modulus, Gpa	200	41-125	120-580	35-51
Rupture strain, %	7-13	1.9-4.4	0.5-1.7	1.2-3.1
Limiting strain, E	.0035	.002	0.01	0.02
Performance factor,Φ	.75	.9	0.8	0.4

Fibre-reinforced plastic (FRP) (similarly described as a fibre-reinforced polymer, or fibre reinforced synthetic) is a composite substance manufactured from a polymer matrix augmented with fibres. The fibres are normally carbon, glass, aramid. Figure 1 shows the Classification of reinforced Polymer. Monomers formed polymers and polymers are classified into synthetic and natural. The synthetic further categorized into thermosetting and thermoplastic respectively. Thermoplastics can be remelted back into a liquid, whereas thermoset plastics always remain in a stable solid state. While natural is further classified as organic and inorganic S.B. Kim et al (2009) [27].

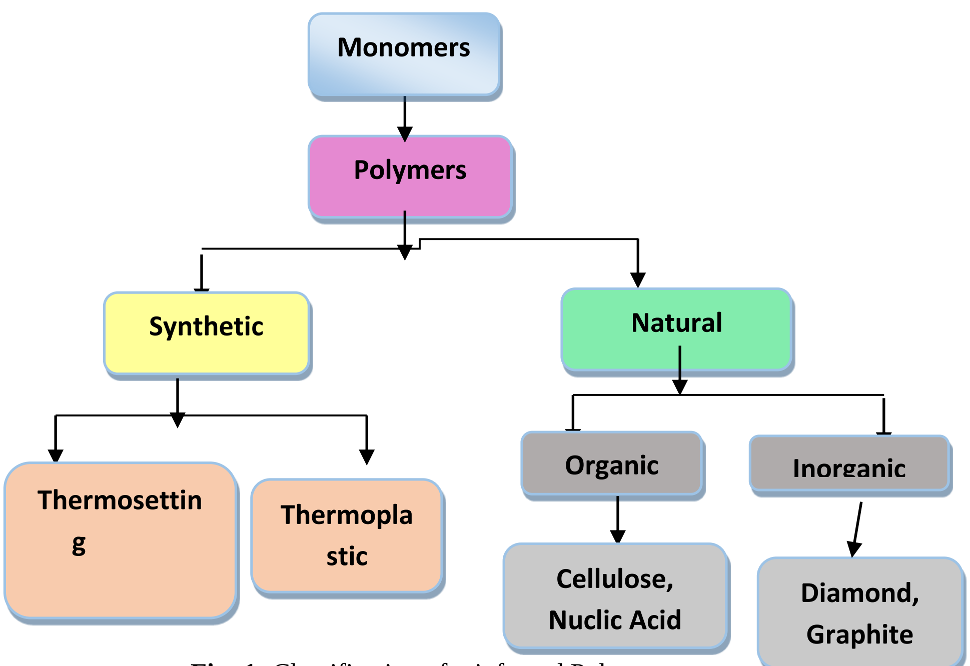


Fig -1: Classification of reinforced Polymer

7. DURABILITY

Significant issues remain unresolved with respect to the long-term durability of composites in concrete construction. There are two major concerns: one relates to the longevity of the composite itself in a deleterious environment, and the other relates to the durability of the bond between the FRP and concrete. A synopsis of our understanding with respect to the durability of the composites is presented in Tables 3 and 4 Harja M., Barbut 2009 [9], Harja M., Barbut (2008) [8] .A compendium of papers related specifically to the durability of the bond is given in APPINDEX A. A detailed treatment of bond durability appears elsewhere (Karbhari V. M 1996) [10]. Table 3 and 4 (Part A and Part B) described the durability of composite of fibre based on their types, with regard to water absorptions taken within the duration of 1 day, thermal expansion, heat, and ultra-violate radiation respectively. In Table 3 and 4 it can be seen that Aramid is attacked when heated while E -Glass and S-Glass have a strong affinity under heat.

Table -3: Durability of Composites (Part A)

MATERIAL	Water Absorption(%/24 hr)	Thermal Expansion ($*10^{-6}\,^0C$)	Heat	UV radiation
Fiber Phase				
Glass E-Glass	-	5.4	GR	GR
S-2 Glass	-	1.6	GR	GR
AR-Glass	-	6.5	GR	GR
Carbon PAN-type	-	-	GR	GR
Pitch-based			GR	GR
Aramid	0.05	-5.2	A	A
Concrete Steel		10-13	-	-
Matrix Phase				
Polyester resin	0.15-0.60	-		A
Vinyl ester resin	0.1-0.2	-	A	A
Epoxy resin	0.0	-	A	GR

(Legend—GR: Generally Resistant; A: Attacked; SA: Slightly Attacked)

Table- 4: Durability of Composites (Part B)

MATERIAL	Weak Acids	Strong Acids	Weak Alkalis	Strong Alkalis	Organic solvents	Oxygen/Ozone
Fiber Phase						
Glass E-Glass	SA					GR
S-2 Glass	GR	A	SA	A		GR
AR-Glass	GR					GR
Carbon PAN-type	GR	GR	GR	GR	GR	GR
Pitch-based	GR	GR	GR	GR	GR	GR
Aramid	GR	SA	A	SA	A	A
Matrix Phase						
Polyester resin	SA	A	A	A	SA	A
Vinyl ester resin	GR	GR	GR	GR	GR	SA
Epoxy resin	GR	SA	GR	GR	GR	GR

(Legend—GR: Generally Resistant; A: Attacked; SA: Slightly Attacked)

7.1 Effect of Alkaline Environment

The structure weakness is due to the high alkaline environment and dissolves the fiber happens because of the deteriorations of the natural fibers mixed with the Portland cement. Studies. Peng Zhang and Qing-fu Li, (2013) [18] examined he fiber reinforced concrete (FRC) that mixed with the coir and sisal fibers. when the samples were revealed to alkaline suspension, the fibers were degraded and varied in tensile strength were found after measuring.

Ca+2 ions were reported to have negative effect on fibers. The durability of coconut and sisal fibers after conditioning them with alkaline solutions. Coconut and sisal fibers were immersed in a sodium hydroxide (NaOH) solution for a period of time of 420 days the results showed that the coconut and sisal maintained respectively 60.9%

and 72.7% of their original strength. While the fiber immersed in the Ca (OH)2 solution, the researcher pointed out that the original strength was lost totally because of the crystallization of fiber pores after a period of 300 days.

7.2 Freeze-Thaw Resistance

A specimen such as concrete may break in case water seeps into the cracks of the specimen and freezes. However, the specimen offers resistance to the periodic freezing and fusion which is labeled as freeze-thaw resistance. Peng Zhang and Qing-fu Li, (2013) [18] studied the effects of varying in size fraction of fiber on FRC in an experiment. The experimental results showed that freeze-thaw resistance increased until fiber volume fraction rose to .08%, but then decreased when it was further increased from 0.8% to 0.12%. The results from the experiment suggest that increasing fiber volume decreases the space between the fibers. This essentially means that the number of weak interfaces and the overlapping interfaces of adjacent fibers rises with increasing volume making the micro structure very loose, and thus reducing the freeze-thaw durability of concrete. According to studies made by C.D. Atis and O. Karahan, (2009)[19] , a concrete sample with sword fiber has a little higher freeze-thawing resistance when compared with plain concrete. Other studies made have proposed the steel fiber amount fraction has a great impact in first-resisting ability of steel fiber. Frost damage is significantly reduced when steel fiber volume is 1.5%. Be that as it may, the ice opposing property of concrete is largely lowered with the presence of 2% steel fiber content.

7.3 Permeability

The application of pressure or other forms of duress such as thermal, mechanical and chemical may lead to the creation of cracks in a concrete specimen thereby enhancing its permeability. This permeability may lead to the deterioration in concrete specimen (Peng et al., 2013)[16] investigated the effect of the presence of polypropylene (P.P) fibers on the permeability of a concrete specimen. Findings suggested that the permeability of concrete containing silica fume and fly ash was reduced in the presence of polypropylene (PP) fibers. Results also showed that the permeability of mix decreases with increasing fiber volume fraction. Studies by Mutukumar M., Mohan D.J., (2014) [11] also reveal that permeability decreased considerably following a rise in fiber content and increasing curing age. Water permeability of steel fiber reinforced concrete is not majorly affected by a change in aspect ratio.

7.4 Carbonation Depth

The carbonation depth of a specimen helps to identify the carbonation resistance of concrete under the action CO2 pressure. The process is facilitated by the act of diffusion where C02 moves from the surface of the sample to the inside. As the depth of diffusion rises, carbonation intensity also reis. (Peng et al. 2013) [16] watched in carbonation protection climbed consistently with rising volumes of polypropylene fiber fractions. The reinforced the above view and explained that the capillary channels in the mortar are blocked by the fibers making the pores smaller, and hence inhibit the diffusion of CO2 by reducing micro cracks in the concrete specimen.

8. CONCLUSION

The findings from the studies above can be summarized as follows: -

The addition of fibers negatively impacts the permeability of a fresh mix and is further reduced with increasing fiber volume fraction.

Since individual fibers have varying responses to the strength of the specimen, there is no correlation observed between the compressive strength of specimen due to addition of fibers.

The presence of fibers usually facilitates properties like ductility, flexibility, tensile strength, drying shrinkage and toughness in materials.

Freeze-thaw resistance, permeability, carbonation depth and fire resistance are tests that help to establish the increase in durability of cement-based products with the addition of fibers.

It has been established that fiber reinforcement polymers can be used for the development of high and ultra-high-performance concrete with high quality designs and utilization, the performance of fiber reinforced cement-based material can be maintained.

ACKNOWLEDGEMENT

We wish to extend my profound appreciation to the Cyprus International University for their support. We also thank our friends and colleagues for the contribution.

REFERENCES

[1] ACI Committee 440, State of the Art Report on Fiber Reinforced Plastic Reinforcement for Concrete Structures, ACI 440R-96, American Concrete Institute, 1999.
[2]Aggarwal L. K., Thapliyal P.C., Karada S.R. Properties of Fiber Reinforced Polymer Concrete. *Constr. Building of Materials.* 21, 379–383 (2007).
[3]Abdel-Fattah H., El-Hawary M. Flexural Behaviour of Polymer concrete. Constr. *Building of Materilas.* 13, 253–262 (1999).
[4]Banthia, N., and Macdonald, R. Durability of Fiber Reinforced Polymer Composites, Report to CHBDC Committee 16, The University of British Columbia, Vancouver, 1996.
[5]Cheng-Hsin C., Huang R., Wu J.K. et al. The Role of Fiber Reinforced Concrete Technology in Weight of Structures Constr. Build. Mater., 20, 706–712 (2006).
[6]Erhard, Gunter. Designing with Plastics. Trans. Martin Thompson. Munich: Hanser Publishers, 2006.
[7]Ehsani, M.R., Rehabilitation of the Infrastructure with Advanced Composite Materials. Repair and Rehabilitation of the Infrastructure of the Americas, Proceedings. NSF, Mayaguez, Puerto Rico, 1994, pp 193-205.
[8]Harja M., Barbut¸ M. Rusu L. Properties of Fiber Reinforced Polymer Concrete. *J. Appl. Sci.*, 9, 88–96 (2009).
[9Harja M., Barbut¸ M., Rusu L. et al., Properties of Fiber Reinforced Polymer Concrete. Environ. Eng. Manag. J., 7, 289–294 (2008).
[10]Karbhari V. M. and Engineer M. Effect of Environment Exposure on the External Strengthening of Concrete with Composites-Short Term Bond Durability, Journal of Reinforced Plastics and Composites, Vol. 15, December 1996, pp 1194-1216.
[11]Mutukumar M., Mohan D.J., Properties of Fiber Reinforced Polymer Concrete. Polymer Res., 12, 231–241 (2004).
[12]Nanni, A., M.S. Norris and N.M. Bradford, Lateral Confinement of Concrete Using FRP Reinforcement. Fiber-Reinforced-Plastic Reinforcement for Concrete Structures, International Symposium. ACI SP-138, 1993, pp 193-209.
[13]Sen R., Shahawy M., Sukumar S and Rosas J. Durability of Carbon Fiber Reinforced Polymer (CFRP) Pretensioned Elements under Tidal/Thermal Cycles, ACI Structural Journal, Vol. 96 No. 3, May-June 1999, pp 450-459.
[14]Tighiouart B., Benmokrane B. and Gao D. Investigation of bond in concrete member with fibre reinforced polymer (FRP) bars. Construction and Building Materials, Vol. 12, 1998, pp 453-462.
[15]Toutanji H. A. and Gomez W. Durability Characteristics of Concrete Beams Externally Bonded with FRP Composite Sheets, Cement and Concrete Composites, Vol. 19, 1997, pp 351-358.
[16]Antonio Domingues de Figueiredoa and Marcos Roberto Ceccato (2015) Workability Analysis of Steel Fiber Reinforced Concrete.
[17]C. SelinRavikumar and T.S. Thandavamoorthy (2013) glass fiber compressive strength .
[18]Peng Zhang and Qing-fu Li, (2013). Water impermeability of fly ash concrete composites containing silica fume and polypropylene fiber.
[19]C.D. Atis and O. Karahan (2009)Properties of steel fiber reinforced fly ash concrete.
[20]Y. Mohammadi et al., Strength Development of Hybrid Steel Fibre Reinforced Concrete. IJSCER. Vol. 2, 4, 2008 .
[21]Faisal Fouad wafa (1990) Properties and Applications of Fiber Reinforced Concrete.
[22]Spadea et al (2015) Bespoke Reinforcement for Optimised Concrete Structures.
[23]H.T Wang and L.C Wang. Effect of weight and drop height of hammer on the flexural impact performance of fiber-reinforced concrete, 2013.
[24]Patil Shweta and Rupali Kavilkar (2014) Study of Flexural Strength in Steel Fiber. Reinforced Concrete.
[25]N.A. Libre et al., (2011) Improving mechanical properties of lightweight Porcelanite aggregate concrete using different waste material.
[26]C. Selin Ravi kumar and T.S. Thandavamoorthy (2013 'Case studies of Strengthening and Repairing of Civil Engineering Structures with FRP and Chemical Nationalconference at Adhiparasakthi Engineering.
[27]S.B. Kim et al., (2009) Dynamic tensile test and specimen design of auto-body steel sheet at the intermediate strain rate.
[28]D. A. Silva, A. M., Betioli, P. J. P. Gleize, H. R. Roman, L. A. Gómez, J. L. D. Ribeiro. Degradation of recycled PET fibers in Portland cement-based materials. Cement and Concrete Research, 35, 9, 2005.