Use of Recycled Rubber Tire Crumbs for Waterproofing of Concrete

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Abstract: **This study describes the use and testing of recycled rubber tire crumbs as alternative construction material with waterproofing ability that could serve as a better alternative to the existing waterproofing products. This research seeks the further use of rubber tire crumbs as a waterproofing agent in concrete structures to help improve the recycling of waste materials in accordance with the principle of sustainable development. The test procedures used in this research made use of experiments like water absorption test, sorptivity test, and water permeability test, utilizing different sieve sizes of rubber crumbs. The results of the tests for the waterproofing ability of the rubber concrete mixture using these test procedures were compared with some of the waterproofing products available in the market to determine if the rubber crumbs could be an alternative. The compressive strength for non- bearing structures (600 psi) of the rubber concrete mixture has also been maintained since previous experiments with rubber components proved that the compressive ability of the concrete drastically went down. It is hoped that this research can help future studies in generating innovations with the use of rubber crumbs in construction.**

Keywords: **Waterproofing of Concrete Recycled Rubber Tire Crumbs.**

1. INTRODUCTION

1.1 Background:

Discarded vehicle tires are serious contributors to solid wastes which have historically been disposed of in landfills. This rubber waste has been considered as one of the major environmental challenges facing municipalities around the world because waste rubber does not easily decay even after a long period of landfill treatment.

Although concrete is the most popular construction material, it has some limitations -- low tensile strength, low ductility, low energy absorption, shrinkage, and cracking associated with hardening and curing. (Wang et al. 2000) Several studies performed recently have shown that application of the recycled tire rubber might improve these weak characteristics of concrete.

Rubberized asphalt has been used for decades on roadways. As proof, The Intermodal Surface Transportation Efficiency Act (ISTEA), promulgated in 1991, mandated the use of a minimum of 5% recycled rubber by weight of asphalt placed, and the per cent of rubber used was to increase gradually up to 20% by the year 1997. The mandate, however, was revoked in 1996 (Khatib et al. 1999), leaving rubberized concrete a technology infant. Many studies have since been performed to investigate the feasibility of the use of rubber in concrete. Since a number of ways to use the recycled rubber in the concrete design is possible and since there are still many factors and properties that should be investigated, it may be difficult to expect that mass production of rubberized concrete will be available in the market soon today or in the near future. However, many studies have demonstrated the mechanical and environmental advantages of the use of recycled tire as additive to cement concrete.

One of the solutions suggested is the use of tire rubber particles as additives in cement-based materials. Rubber has physical properties such as low density, and moisture absorption, as well as good thermal and acoustic insulator that makes it a good additive for concrete's waterproofing as well as insulation. By also recycling rubber tires, we can contribute in saving our environment.

1.2 Glossary:

- ***Crumb rubber*** is the name given to any material derived by reducing scrap tires or other rubber into uniform granules with the inherent reinforcing materials such as steel and fiber removed along with any other type of inert contaminants such as dust, glass, or rock. ***Crumb rubber*** is manufactured from two primary feedstock: tire buffing, a byproduct of tire retreading and scrap tire rubber. Scrap tire rubber comes from three types of tires: passenger car tires, which represent about 84 percent of units or approximately 65 percent of the total weight of U.S. scrap tires; truck tires, which constitute 15 percent of units, or 20 percent of the total weight of U.S. scrap tires; and off-the-road tires, which account for 1 percent of units, or 15 percent of the total weight of U.S. scrap tires. End product yields for each of these tire types are affected by the tire's construction, strength and weight. On average, 10 to 12 pounds of crumb rubber can be derived from one passenger tire. Overall, a typical scrap tire contains (by weight): 70 percent recoverable rubber, 15 percent steel, 3 percent fiber, and 12 percent extraneous material (e.g. inert fillers)

1.3 Preview:

The next section, section 2, contains the statement of the problem, after which the objectives, and significance of the study are explained in Section 4, section 5 then provides a Review of Previous Studies and Related Literature, while Section 6 explains the methods used in the study. The Results and discussion are then presented in Section 7, while the Conclusion and Recommendation are given in Section 8. The next section, Section 9, presents the Acknowledgement, and finally Section 10, lists the References.

Crumb Rubber Particle Size Measurement:

Different crumb rubber market segments have different crumb rubber size requirements. Within a specific crumb rubber market, each application has its own requirements in terms of particle size and purity. Although ASTM International, formerly known as the American Society for Testing and Materials (ASTM), has standards for specifying different size ranges of crumb rubber, such as 30 mesh or 80 mesh, it is often necessary for crumb rubber manufacturers to have a more detailed knowledge of the range of particle sizes, not just the maximum size. To accomplish this, some method of particle size determination is necessary.

- ***Sieve analysis*** is the most common technique for determining particle size measurement. It consists of shaking and tapping a measured quantity of crumb rubber sample through a specified number of test sieves over a specified time. The amount of sample retained on each screen is weighed and results are given as the percentage of sample retained on each screen. The recommended procedure for sieve analysis using the Rotap method is provided in ASTM 5644.

- ***Rubber Tire Crumbs*** are recycled rubber from automotive and truck scrap tires in which steel and fluff are removed during the recycling process, leaving tire rubber with a granular consistency. Continued processing with a granulator and/or cracker mill, possibly with the aid of cryogenics or mechanical means, can reduce the size of the particles further. The particles are then sized and classified based on various criteria including color (black only or black and white). The granulate is sized by passing it through a screen, with the size based on a dimension (1/4") or *mesh* (holes per inch: 10, 20, etc.)

- ***Cemen***t is a material with adhesive and cohesive properties that make it capable of bonding material fragments (**aggregates**) into a compact whole. In this process, it imparts strength and durability to the hardened mass called ***concrete***.

- ***Concrete*** is a ***composite*** material composed of water, coarse granular material (the fine and coarse aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together. The cements used in the making of concrete are called ***hydraulic cement*** – so named, because they have the property of reacting chemically with water in *an exothermic* (heat– generating) process called hydration that results in water–resistant products. The products of hydration form a viscous *cement paste*, which coats the aggregate surfaces and fills some of the void spaces between the aggregate pieces. The cement paste loses consistency (stiffens) on account of gradual loss of "free water", absorption and evaporation, and subsequently "sets", transforming the mixture into a solid mass. If the *consistency* of the cement paste is either excessively "harsh" or excessively "wet", there is a danger of segregation, and the aggregate tends to separate out of the mix; which will adversely affect the quality of the hardened concrete and result in a "honeycomb" appearance. The freshly set cement paste gains strength with time (*hardens*), on account of progressive filling of the void spaces in the paste with the reaction products, also resulting in a decrease in porosity and permeability.

- ***Permeability*** **is a** measure of the ability of a porous material to allow fluids to pass through it

- ***Portland Cement*** is the most common type of cement in general use around the world, used as a basic ingredient of concrete, mortar, stucco, and most non-specialty *grout*

- ***Aggregates*** are inert granular materials such as sand, gravel, or crushed stone that, together with water and Portland cement, are essential ingredients of concrete. Since aggregate occupies about three–quarters of the volume of concrete, it contributes significantly to the structural performance of concrete, especially *strength*, *durability and* volume *stability*. Aggregates are formed from natural sources by the process of weathering and abrasion, or by artificially crushing a larger parent (rock) mass. Other types of aggregates may be used for *plain concrete members* (Code Cl. 5.3.1) but as far as possible, preference shall be given to natural aggregates. Aggregates are generally categorized into fine aggregate (particle size between 0.0075 mm and 4.75 mm) and *coarse aggregate* (particle larger than 4.75 mm), as described in IS 383: 1970.

- ***Sand***, taken from river beds and pits, is normally used as fine aggregate, after it is cleaned and rendered free from silt, clay and other impurities; stone (quarry) dust is sometimes used as a partial replacement for sand.

- ***Gravel*** and crushed rock are normally used as coarse aggregate. The maximum size of coarse aggregate to be used in reinforced concrete work depends on the thickness of the structural member and the space available around the reinforcing bars. Generally, a maximum *nominal* size of 20 mm is found to be satisfactory in RC structural elements. However, in cases where the member happens to be very thin, the Code (CI 5.3.3) specifies that the size should be restricted to one–fourth of the minimum thickness of the member. In the case of heavily reinforced members, it should be restricted to 5 mm less than the minimum clear spacing between bars or minimum *cover* to reinforcement, whichever is smaller. In such situations, the maximum nominal size is frequently taken as 10 mm. In situations where there is no restriction to the flow of concrete, as in most plain concrete work, there is no such restriction on the maximum aggregate size. It is common to use aggregate up to 40 mm nominal size in the base *concrete* underneath foundations. The Code (CI 5.3.3) even permits the use of "*plums*" above 160 mm in certain cases of mass concreting up to a maximum limit of 20 percent by volume of concrete.

- ***Plums*** are large random–shaped stones dropped into freshly– placed mass concrete to economize on the concrete; such mass concrete is sometimes called "*Cyclopean concrete*". Mention may also be made of a special type of aggregate, known as lightweight aggregate, which (although not used for reinforced concrete work) is sometimes used to manufacture "lightweight concrete" masonry blocks, which have low unit weight and good thermal insulation and fire resistance properties. Lightweight aggregate may be obtained from natural sources of "sintered fly ash" or "bloated clay" (conforming to IS 9142 : 1979)

- ***Density*** *i*n a qualitative manner is the measure of the relative "heaviness" of objects with a constant volume.

- ***Water*** that is fit for human consumption (*potable water*) is generally considered to be suitable for concreting but when the potability of the water is suspect, it is advisable to perform a chemical analysis of the water, in accordance with IS 3025. The pH value of the water should not be less than 6. The concentration of solids in water should be within certain "permissible limits" that are specified in the Code (CI 5.4) In particular, the content of sulphates (as SO_3) is limited to 400 mg/l, while that of chlorides is restricted to 500 mg/l in reinforced concrete (and 2000 mg/l in plain concrete). Sea water is particularly unsuitable for mixing or curing of concrete. The Code also recommends testing for initial setting time of cement paste (as per IS 4031 (Part 5): 1988) and compressive strength of concrete cubes (as per IS 516: 1959), when there is doubt regarding the sustainability of the water for proper strength development of concrete. The water in a concrete mix is required not only for hydration with cement, but also for "workability."

- ***Workability*** may be defined as "*that property of the freshly mixed concrete (or mortar) which determines the ease and homogeneity with which it can be mixed, placed, compacted and finished"*. The main factor that influences workability is, in fact, the water content (in the absence of admixtures), as the "inter–particle lubrication" is enhanced by the mere addition of water. The amount of water required for lubrication depends on the aggregates type, texture and grading: finer particles require more water to wet their larger specific surface; angular aggregates require more water than rounded ones of the same size; aggregates with greater porosity consume more water from the mix. The main factor that influences workability is, in fact, the water content (in the absence of admixtures), is the "inter–particle lubrication which is enhanced by the mere addition of water. The amount of water required for lubrication depends on the aggregates type, texture and grading: finer particles require more water to wet their larger specific surface; angular aggregates require more water than rounded ones of the same size; aggregates with greater porosity consume more water from the mix. Water content in a mix is also related to the fineness of cement – the finer the cement, the greater the need for water – for hydration as well as for workability. It may be recalled that workability is required to facilitate *full placement* in the formwork (even in areas of restricted access) and *full compaction,* minimizing the voids in concrete. If a mix is too dry, bubbles of entrapped air create voids, and there is danger of *segregation.* The addition of water provides for better cohesion of the mix and better compaction, and causes the air bubbles to get expelled. However, there is a danger in adding too much water, because it would be water, rather than cement paste, that takes place of the air bubbles. This water evaporates subsequently, leaving behind voids.

Hence, even if the fresh concrete were to be "fully compacted", voids may still be present in the hardened concrete, adversely affecting its strength, impermeability, etc. Moreover there is the danger of segregation of "***grout***" (cement plus water) in a very wet mix. The excess water tends to rise to the surface of such a mix, as the solid constituents settle downwards; this is called *bleeding*.

The "optimum" water content in a mix is that at which the sum of volumes of entrapped air and of entrapped water is a minimum, and for which the density achievable (by the method of compaction employed) is a maximum. The NSCP (2010) Code recommends that the workability of concrete should be controlled by the direct measurement of water content in the mix. For this, workability should be checked at frequent intervals, by one of the standard tests (*slump, compacting factor of vee – bee)*, described in IS 1199: 1959. The NSCP (2010) Code also recommends certain ranges of slump, compacting factor and vee – bee time that are considered desirable for various "degree of workability" (very low, low, medium, high) and placing conditions. For the purpose of *mix design*, the water content is usually taken in the range of 180 – 200 li/m^3 (unless admixtures are used). If the aggregate is wet, then this should be appropriately accounted for, by measuring the moisture content in the aggregate.

Isn't normal, good quality concrete waterproof?

In order to provide sufficient workability for proper placing and compaction and to facilitate proper mixing and transportation to site, most plant-batched concrete will contain water in excess of that required to simply hydrate the cement. As concrete hardens, this excess water leaves the concrete and creates a network of fine capillaries and internal pores. Natural capillary absorption is the predominant mechanism of water transport through concrete whether or not a head of hydrostatic pressure is present. In essence, as far as water is concerned, normal concrete behaves like a dense sponge. One cubic meter of normal, good quality dry concrete will absorb the equivalent of roughly 60 liters of water in just 30 minutes! (Test in accordance with BS 1881, part 122). It is the speed of this absorption that is important as this will directly affect the level of dampness, say in a basement, or the onset of reinforcement corrosion due to dissolved chlorides being carried into the concrete by water, say in a sub-sea tunnel, the tidal zone of bridge supports or from melting slush after de-icing salt has been applied.

- **Water Absorption** refers to the amount of water absorbed by a composite material when immersed in water for a stipulated period of time.

- **Waterproofing** refers to the process of reducing a material's capillary water absorption properties or lowering its permeability to water.

- ***Waterproof* --** The term "'Waterproof" conjures up a whole range of ideas. If the structure in question is to retain water, say a water storage tank, then the designer may simply work to the design requirements of the water retaining code, BS 8007, which sets out to limit crack width. This may be achieved by utilizing a good quality, ordinary concrete, close attention to joint details and providing extra crack control reinforcement; dampness being acceptable. If, on the other hand, the structure is habitable or designed to house sensitive electronic equipment or valuable archives, then simply designing to the water retaining code is not sufficient. This is especially given so that ordinary good quality concrete provides little resistance to the passage of water vapor.

There are several degrees of *waterproofing* to be considered, all loosely defined under 4 categories in BS 8102. At the lowest level, Grade 1, there is " *Water-tight*" which simply means that water will not run or flow freely through the concrete; at the upper levels, Grades 3 & 4, there is "*Damp-pro*of", which not only requires there to be no visible water ingress but also that very high levels of "water-vapor- resistance" will be achieved. This applies whether or not hydrostatic pressures are present.

Rubber has many properties that makes it a good material for waterproofing concrete. But then, *waterproof concrete* is a misnomer because nothing can be completely impervious to water under infinite pressure over infinite time. The term waterproof for concrete has reduced capillary water absorption properties as well as low permeability to water under pressure. In line to this, the researchers focused this study in finding out a mix design incorporated by rubber tire crumbs that will reduce water absorption of concrete compared with the normal or conventional concrete in the market.

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- **Sorptivity is** defined as a measure of the capacity of the medium to absorb or desorb liquid by capillarity
- **Specimen** refers to a portion or quantity of material for use in testing, examination or study
- **Superplasticizer is a c**hemical admixture which yields higher compressive and flexural strength, lowers permeability, increases resistance to weathering, improves the bond of concrete and re reinforcement, reduces the volume change from drying and wetting, and reduces shrinkage cracking tendencies
- **Temperature Tolerance** refers to the capacity to withstand a full range of ambient temperature extremes without undergoing permanent property change.
- **Thermal Insulation refers** to the process of insulating against transmission of heat as well as to a material of relatively low heat conductivity used to shield a volume against loss or entrance of heat by radiation, convection, or conduction
- **Universal Testing Machine**, also known as a universal tester or materials testing machine or materials test frame is used to test the tensile stress and compressive strength of materials.
- **Slump Test** is an empirical test that measures the workability of fresh concrete.
- **Compressive Strength** is the maximum compressive stress that under gradually applied load a given solid material will sustain without fracture.

1.3 Preview:

The Next Section, Section 2, contains the Statement of the Research Problem, which is followed by an Explanation of the Objectives, Scope, and Significance of the Research in Section 3. Section 4 then provides a Review of Previous Studies and Related Literature, while Section 5 explains the Methods used in the Research. The Results

and Discussion are then presented in Section 6, while the Conclusion and Recommendation are presented in Section . The next section, Section 8, contains the Acknowledgement, and finally Section 9 contains the References.

2. STATEMENT OF THE RESEARCH PROBLEM

- This research sought to determine whether it would be feasible to use recycled rubber tire crumbs for waterproofing concrete. In particular, this research wanted to find out the best classification of rubber tire crumbs that would be suitable for reducing the water absorption and permeability of concrete.

3. OBJECTIVES, CIRCUMSTANCES, SIGNIFICANCE, AND SCOPE OF THE RESEARCH

3.1 General Objective:

The general objective of this research is to analyze the feasibility of recycled rubber tires for use in the field of construction. It aims to find a rubber-concrete mixture using recycled rubber tire crumbs that can enhance the waterproofing capacity of concrete.

3.2 Specific Objectives:

The study's specific objectives were (a) to utilize discarded rubber tires in the form of rubber tire crumbs in reducing concrete's permeability and water absorption—in effect make the concrete itself waterproof , (b) to try different classes of rubber tire crumbs namely Class A, Class B and Class C in the experiment to identify which is most suitable for reducing concrete's permeability and water absorption, (c) to investigate the best mix proportion that will attain a waterproof concrete characteristic that will comply with the ASTM standard test method for water absorption and permeability and sorptivity of concrete, (d) to investigate whether the rubber- concrete mixture is suitable for structural concrete (2500 psi) or for non-bearing structure (600 psi), and (e) to make a recommendation based on the results of this experiment as to which mix can be used for a structural lightweight concrete or for non-bearing structure as well as which mix has the lowest water absorption and permeability rate.

3.3 Significance of the Study:

Rubber tire wastes were already used in making asphalt mixes for paving roads and other related construction works. In line with this, the study used rubber tire crumbs as aggregates in reinforced concrete. The rubber properties such as its density, moisture absorption, and thermal insulation were factors that make it a good material for water proofing as well as for insulation benefitting the construction industry. Also, the study utilized waste materials which help in conserving our environment. This can benefit the community due to the fact that rubber tire crumbs are cheaper than other aggregates and sometimes they can be obtained at no cost at all. Because of lighter mass in the concrete mixture, when rubber tire crumbs were used, the weight of the structure would be reduced at the same time. In line with this, the researchers focused this study in finding out a mix design incorporated by rubber tire crumbs that will reduce water absorption of concrete compared with the normal or conventional concrete in the market.

This paper experimentally investigates the contribution of rubber dust or waste materials incorporated to the aggregates in the production of ordinary Portland cement mortar. The output hopes to provide preliminary information about the strength of hardened concrete mixture with 5%, 10% and 20% of rubber to the weight of sand with a cement aggregates ration 1. 2 paper, therefore, compares the variation of strength with different percentage of rubber dust.

In the early 1960's, enormous researchers have been conducted to agglomerate fibers in various types in concrete, such as plastics, nylon, asbestos, carbon or glass. (Baraidan et.al, 1989). Up to this moment, the authors does not have updates in the hope to gain wide acceptance of the incorporation of waste rubber waste dust in concrete construction to prevent its future accumulation. This lessen the unabated increasing cost of construction materials a little bit.

The growing concern for waste disposal, coupled with the environmental hazards of the present methods of recycling and the need to utilize more effectively the raw material resources available, justify a good cause for research and development of innovative building materials utilizing recycled wastes that are locally abundant. Aggregate occupies about 70% to 75% of the volume of mortar. Therefore one cubic meter of mortar alone will require at least 70 cubic meter of sand. If we can replace 20% of the volume of sand with waste rubber, 0.14 cubic meter of waste rubber can be consumed.

Hence, a contractor will benefit from this study for these dust aggregates are cheaper and sometimes even free. Then, the owner or any establishments will no longer worry about in disposing their rubber tire wastes. Generally, it is the whole community who will benefit much for it will not accumulate anymore tire wastes.

Waste Tires must not be thrown out or burned; instead it should be kept and recycled, for they possess the properties for road construction as a binder modifier in asphalt road.

3.4 Circumstances of the Study:

This study was conducted at 159 R. M. Asuncion St. Tubuan 2, Silang, Cavite during the First Semester of Academic Year 2014-2015. The experiments were conducted between the months of July and October 2014.

3.5 Scope and Delimitation of the Study:

The study focused on attaining and identifying the best rubber-concrete mixture using Class A, Class B and Class C rubber crumbs that would reduce the concrete's permeability and water absorption. This study also wanted to determine whether the output would be suitable for use in structural or non-structural members of structure, making use of ASTM standards procedures. Thus this study limited itself to waterproofing tests. Because of lighter mass in the concrete mixture, when rubber tire crumbs were used, the weight of the structure would be reduced at the same time. In line with this, the researchers focused this study in finding out a design mix incorporated by rubber tire crumbs that will reduce water absorption of concrete compared with the normal or conventional concrete in the market

4. REVIEW OF THE LITERATURE

In the late 1990s, Dr. Han Zhu, an engineering professor at Arizona State University, was amazed at the number of recyclable tires he saw while visiting a shredding plant in the greater Phoenix area. His immediate thought was to develop a way to convert them for use in concrete. Utilizing facilities at the university and the ready labor force his students provided, Zhu started putting his ideas to work. As he experimented with this concept, Zhu drafted a few other people to help him with his project. Two individuals who quickly became major players were George Way and Doug Carlson. Way is currently an engineering consultant but at the time was the chief pavement design engineer for the Arizona Department of Transportation. Carlson was a board member of the Recycle Tire Engineering and Research Foundation, a group created to explore material properties and potential engineering applications of recycled rubber. Later on, Mark Belshe, a vice president of FNF Construction, was also drawn into the mix. In 2003, Zhu accepted a professorship in China, and the crumb rubber concrete project was turned over to ASU's Dr. Kamil Kaloush.

To date, the project has dealt mostly with poured concrete, but the group got excited about the possibilities for precast applications as well.

"The vast majority of the characteristics we discovered in regard to crumb rubber would be just as valid for precast as for poured-in-place," Kaloush said. "For example, it produces a lightweight panel that is beneficial in noise control as it is well-insulated.

Also, in an environment with a number of computers and other electrical equipment, this insulation would tend to assist with static reduction in walls," he said. "I was impressed with the fact that crumb rubber concrete has excellent freezethaw characteristics," Way added. In fact, the team found that expansion/contraction was cut in half.

Yet another advantage was that shrinkage, and thus cracking, was reduced. "We took special note that cracking was reduced to the point that 45 degree cracking was virtually lost completely," said Carlson.

Obviously these were all excellent advantages. But were there any characteristics that might be considered disadvantageous? "The most obvious was strength reduction. The greater the rubber content, the more reduced the strength was," explained Kaloush. "I don't know if this was a disadvantage or not," Carlson added. "But the crumb rubber takes the place of aggregate, and as a result, more cement is needed in the formula."

Other than that short list, apparently there were no other disadvantages, said Way.

Possible applications of precast concrete utilizing crumb rubber concrete abound. "Having formally been with A-DOT, the first thing that came to mind for me are the Jersey Barriers you see on highways during construction," said Way. "The fact that they would be somewhat lighter would mean that they could be transported quicker and easier."

Easier transport isn't the only advantage. "The virtual elimination of the 45 degree cracking would particularly come into play here," said Carlson.

Kaloush added that barriers made with crumb rubber would be much more forgiving should they be run into, which would help protect the barrier itself as well as the vehicle that hits it. "It is my hope to be doing some extensive experimentation in this area in the very near future," he said.

Another possible application for concrete cast with recycled rubber is in sidewalks. Kaloush has found that the crumb rubber produces an end product this is nearly non-slip in nature. "What I envision is a situation where all your utility pipes – water, sewer, electrical, phone and TV cables – would be run under the sidewalk rather than the streets," he said. "With precast sidewalk panels, you could simply lift them up when you need to get to the pipes to work on them."

In the long run, Kaloush said that this would be far less expensive than having to constantly tear up streets to work on the pipes. "You wouldn't need new materials every time – all you would have to do is pick them up and then replace them," he said. "And look at how much more convenient it would be to close down a sidewalk rather than a street. This should be a tremendous selling point for precast proponents in trying to sell it to various cities and other municipalities."

This isn't as farfetched as it may first seem, according to Way. "In Europe, they are already utilizing a variation on this theme," he said. "While it might be difficult to retrofit a city with this program, there is so much new construction going on that this concept could really be a major innovation. All it would take is a very proactive marketing plan on the part of the precast community," added Way.

"Crumb rubber panels would be ideal for nearly all non-load bearing walls in an office building," said Kaloush. "The fact that it is lighter and a nonconductor of both noise and electricity makes it an ideal candidate for use in that capacity."

Residential housing could also benefit. "Here in the Southwest we have a lot of homes with clay tile roofs," said Carlson, explaining that strength, for the most part, is not a major concern because of the lack of snow and ice. "You could create a precast roof with a high percentage of crumb rubber that would be lightweight, help control noise going both ways and, from experiments thus far, should prove to be a good deal cooler."

Carlson was referring to the fact that Kaloush, and Zhu before him, have been running tests that seem to indicate that the crumb rubber concrete is cooler than its regular counterpart.

"These studies are inconclusive at this time, but to this point they seem to support the theory that it is cooler," said Kaloush. "I was able to take some photos with an infrared camera, and from those, at least, the crumb rubber is cooler."

The idea of a "cooler" concrete leads to a possible piece in the puzzle for battling the Urban Heat Island Affect, suggested Belshe. "That's one of the things that caught FNF Construction's attention. Any time we can make a major stride in controlling a problem like that, we become very interested."

In fact, the use of crumb rubber concrete could very well open another major area for the precast industry: "green" buildings. "If enough applications can be found and used, it might be possible to land contracts with the government and companies who feel strongly enough about the Green Building program that they make adherence to those rules a prerequisite for doing business with them," said Carlson.

Like every other innovation, crumb rubber concrete will, undoubtedly, face its share of skeptics. The experts believe, however, that end-users especially will be impressed by the fact that the process is so environmentally sound. While real evidence will need to be gathered to verify that the advantages outweigh the possible cost increase of producing crumb rubber panels, this is one area that may turn out to be a "cushy" investment.

It was estimated that more than 250.000.000 post consumption tires were accumulated annually in the 15 States of the European Union. In 1992, about 65% of the quantity produced in the then 12 member states was stored in dumps and only 35% underwent other regeneration methodologies. Ten years later, in 2002, the situation was completely overturned in the 15 member states. More than 65% of post-consumption tires were prepared for reuse/export, rebuilding, recycling and energy regeneration, whereas less than 35% was stored in dumps. Energetic and material product recycling represented the two principle types of regeneration and amounted to 44% of the total. With reference to actual codes (Dumps directive 199/31/EC), and despite the fact that the disposal in dumps of whole tires was forbidden since 2003 and that of lacerated tires since 2006, only 8 States adopted such directives. The practice of absorbing used tires in controlled dumps should be avoided because it creates another source of pollution. Tires represent a bulky refusal and require huge dump sites as more than 75% of a tire's volume is void. The presence of cavities and rubber elasticity also create mechanical instability with danger of fires in the stocked refuse mass. Furthermore, dumps can turn into a fertile habitat for the proliferation of rats and insects. To worsen matters, tires tend to re-emerge in time from the dump and microorganisms may take more than 100 years to biodegrade them. The necessity to find alternative solutions to used tires is thus clear. Moreover, the increased consumption of concrete in building construction raised the problem of impoverishment of natural resources. Such considerations confirmed the necessity to develop innovative technologies and alternative materials to improve not only the performance level of concrete but also, and above all, to support the policy of environmental protection. It must also be remembered that most developing countries had to raise their awareness regarding the recycling of waste materials but have not yet developed effective standards and laws as regards the local reuse of waste materials.

Over the past few years, a number of researches have focused on the use of different shapes and sizes of waste tires in concrete. A mixture composed of ordinary concrete (Portland cement) and rubber from recycled tires has been presented in the technical literature under the names of Rubber Concrete‖ or Rubber Modified Concrete‖. The rubber used in most cases was derived from post consumption tires of motor vehicles and trucks subjected to mechanical trituration or to cryogenic processes. Given the applications and performances required by the final product, the rubber was used as it is‖ or, in some occasions, the textile component was removed and the steel fibers unstrained. In other circumstances, the rubber surface was subjected to particular chemical pretreatments to reinforce adhesion of the rubber with the grout, obtaining a clear improvement of some final properties of the concrete. The latter solution has gained worldwide recognition in the engineering field, directing many researchers in recent years to carry out additional research on the use of waste rubber in concrete (Eldin and Senouci 1992, 1993a, b, Aliet al.1993, Leeet al.1998, Topcu, 1995,1997, Fattuhi and Clark 1996, Toutanji 1996, Huynh and Raghavan 1996, Topcu and Avcular1997, Liet al.1996, Raghavanet al.1998,Choubane et al., 1999,Segre and Joekes 2000,Pierce and Blackwell 2003, Hernandez-Olivares and Barluenga, 2004, Siddique and Naik,2004,Sukontasukkul and Chaikaew, 2006, Chouet al., 2007, Topcu and Demir, 2007,Bataynehet al., 2008, Ganjian et al., 2009).

The aim of this recent research was to assess the mechanical strength and durability performance of the concrete incorporating various contents of the ordinary Portland cement as well as to study the effect of curing methods on compressive strength of the concrete as well as the physical properties, which were investigated in terms of density, absorption and volume of permeable voids as an (porosity). Many researchers consider these physical properties as indicative of the permeability of the concrete. In other words, these were considered as an indirect method to measure the permeability and to evaluate it.

That the increase of cement content and the reduction which leads to more durable concrete because of loss of absorption and porosity characteristics, higher density and compressive strength.

Philippine Studies on Rubber:

“Rubber was introduced in the Philippines in the early 1900s when the country was going through a difficult agricultural phase. The rubber manufactured as tires and shoes mostly came from Indonesia and Thailand. In the early 1920s, rubber mills were established in Basilan, but it was only in the 1950s when local private corporations embarked on setting up rubber processing plants in Mindanao. Today, large– scale rubber plantations such as Goodyear, Goodrich, and Firestone are well established in the country along with domestic corporations such as the Menzi Corporation.

Dr. Eugenio A. Alcala, Executive Director of the Philippine Rubber Board, Inc. (PRBI) has reported that there are more than 50,000 uses of rubber, explaining that the there are two kinds of rubber used in the manufacture of products , synthetic and natural rubber. Natural rubber is preferred since it is more durable, adhesive, and impermeable. The most popular is the automobile tire. According to PRBI Director Eleazar, 70 percent of the rubber industry supplies the tire sector.

Dr. Abdul Aziz Kadir, secretary general of the International Rubber Research and Development Board (IRRDB), Malaysia, asserted that the future is bright for the rubber industry because of its wide product range. He highlighted the market for birth control (condom), rubberwood (furniture), and the niche market for rubber -based products such as medical products (surgical gloves), foam mattresses, and even artificial flowers (roses).

Moreover, Dr. Ramli Othman of the Malaysian Rubber Board (MRB) said that there is an increasing demand for rubberwood as source of latex and timer. “We are promoting the planting of latex – timber clones in both conventional and forest rubber plantations. This will make rubber production a more competitive and attractive industry.”

In the study of rubber economics presented by Dr. Hidde Smit, secretary general of the International Rubber Study Group (IRSG) based in London, he reported that the Philippine rubber industry would be soaring high in the world market by the year 2020 compared to other rubber producing countries in Asia and in other parts of the world. This is because of the high production and consumption of natural rubber in the Philippines. He also asserted that the Philippines could produce as much as 250- 350 million tons of rubber in the coming years. "We expect prices to remain high", said Dr. Smit when asked about the stability of the price of rubber in the world market. According to his report, the competition would be up between the Philippines and Vietnam, which also shows great potential in the rubber industry. On the other hand, China turns out to be a major consumer of rubber. Apparently, one–third of the world rubber production goes to China.

Water rubber materials (rubber dust in layman's term) used in this study were waste from various tire recapping centers in Cagayan de Oro City. The waste materials passes through sieve number 20 with mesh opening of 0.85 mm. Lucma (World Book, 1992 science year) said, about five percent (5%) of waste tire are recycled, chiefly by grinding them into crumbs. This rubber crumbs can be molded into a new products or mixed with asphalt for surfacing highways and athletic fields.

In Cagayan de Oro City, rubber recycling particularly waste tires are up to flower pots, water containers, and to recapping industry where the less damaged tires will be recapped (retreaded) and it is where these waste are taken. The author wishes to establish a definitive use of these waste materials in the world of construction technology as existed in other countries, while the future accumulation of these waste will be prevented if this technology gain nation acceptance that is proven to be reliable as it is referred to the Philippine standard. Garcia et.al 1996 said, experts are of the opinion that an ecological disaster of the inhabitants of the planet Earth is just around the corner. The unwanted by products of our mechanized, industrialized and urbanized environment will soon overwhelm us like a rushing avalanche unless we do something drastic to remedy by situation.

This paper experimentally investigates the contribution of rubber dust or waste materials incorporated to the aggregates in the production of ordinary Portland cement mortar. The output hopes to provide preliminary information about the strength of hardened concrete mixture with 5%, 10% and 20% of rubber to the weight of sand with a cement aggregates ration 1. 2 paper, therefore, compares the variation of strength with different percentage of rubber dust.

In the early 1960's, enormous researchers have been conducted to agglomerate fibers in various types in concrete, such as plastics, nylon, asbestos, carbon or glass. (Baraidan et.al, 1989). Up to this moment, the authors does not have updates in the hope to gain wide acceptance of the incorporation of waste rubber waste dust in concrete construction to prevent its future accumulation. This lessen the unabated increasing cost of construction materials a little bit.

The growing concern for waste disposal, coupled with the environmental hazards of the present methods of recycling and the need to utilize more effectively the raw material resources available, justify a good cause for research and development of innovative building materials utilizing recycled wastes that are locally abundant.

Aggregate occupies about 70% to 75% of the volume of mortar. Therefore one cubic meter of mortar alone will require at least 70 cubic meter of sand. If we will replace 20% of the volume of sand with waste rubber, 0.14 cubic meter of waste rubber will be consumed.

The contractor will benefit in this study for these dust aggregates are cheaper and sometimes are free. Then, the owner or any establishments will no longer worry in disposing their wastes. Generally, it is the whole community who will benefit much for it will not accumulate anymore.

Waste Tires must not be thrown out or burned; instead it should be kept and recycled, for they possess the properties for road construction as a binder modifier in asphalt road.

Since the obtained results for stability and compressive strength between sample A and D produces lesser difference compared to other samples, the researchers highly recommend sample A that contains 15% by weight of total asphalt content in designing asphalt melting waste tire rubber. Pollution control device must be used in construction procedure for melting waste tire rubber.

Cost analysis using waste tire rubber as binder modifier for bituminous road construction is recommended for further study.

5. METHODS

The study employed the *experimental method* to investigate the effect of incorporating different classification of rubber tire crumbs as part of the volume of aggregates in waterproofing of concrete and in the structural strength of the mortar. ASTM procedures were followed in selecting the materials, making and curing test specimens, and the nominal mix design for proportioning of normal concrete. The aggregate-rubber tire crumbs ratio was the independent variable used in the evaluation of water absorption rate, permeability, sorptivity and compressive strength of the concrete.

5.1 Materials Used in the Study:

The materials used in making plain concrete which is the controlled variable were Type I Portland Cement, ASTM Standard Coarse and Fine aggregates, and potable or tap water, while for the rubber-concrete mixture, Class A, B, and C rubber tire crumbs were incorporated as part of the volume of aggregates. A series of two kinds of mixes with varying percentage of rubber tire crumbs content for each class were used. The cylindrical specimens with different contents of rubber tire crumbs were cured for 7 days, 14 days, 21 days and 28 days. Testing of compressive strength was done at ASTEC Materials and Testing Center.

The crumb rubber used in this study was obtained from a local tire recapping center in Imus, Cavite which is a byproduct of tire retreading. The researchers provided scrap tires, and the local dealer gave the equivalent rubber crumbs in kilograms. The local dealer also sells crumb rubber. Four to five kilograms of rubber crumbs can be derived from a typical scrap tire. Table 1 shows the percentage content of a typical scrap tire based on its weight.

Table 1 Content of a Typical Scrap Tire

Content	Percentage
Recoverable rubber	70%
Steel	15%
Fiber	3%
Extraneous material (e.g. Inert fillers)	12%

There are three classes of rubber tire crumbs used in this study, namely, Class A, Class B and Class C. Table 2 shows classification of rubber tire crumbs based on the sieve opening used and equivalent mesh size.

Table 2 Rubber Tire Crumb Sizes

CLASS	Sieve Opening	Mesh Size
A	1.18 mm	No. 16
B	2.36 mm	No. 8
C	4.75 mm	No. 4

Cement:

The *cement* used in this study was pure Type I Portland Cement conforming to the ASTM

Standards which was procured from a local construction supplier and distributor in Silang, Cavite.

Water has a significant role to play in the making of concrete – in mixing of fresh concrete and in curing of hardened concrete. In order to ensure proper strength development and durability of concrete, it is necessary that the water used for mixing and curing is free from impurities such as oils, acids, alkalis, salts, sugar and organic materials. In this study potable or tap water was used in the mixture.

For the Coarse Aggregate, ASTM C-33 states that this should consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic-cement concrete, or a combination thereof, conforming to the requirements of this specification. Based on the ASTM C-31 and C-192, the standard specimen shall be the 6 by 12-in. [150 by 300-mm] cylinder while the nominal maximum size of the coarse aggregate must not exceed 2 inches. Nominal maximum size of the aggregate is defined as the smallest sieve opening through which the entire sample of the aggregate will pass. In this study, the maximum size of ¾ inch coarse aggregates were used which were bought from a local construction supplier and distributor in Silang, Cavite.

Since the Fine Aggregate should consist of natural sand, manufactured sand, or a combination thereof, The fine aggregate used in this study was the locally available white sand in local construction suppliers and distributor in Silang, Cavite which conforms to ASTM C33 .

5.2 Instruments used:

As to the instruments used, the researchers had to make some improvisations because some of them were unavailable. The cylinder molds that were used were PVC pipes with a diameter of 6 inches and a height of 12 inches which conforms to ASTM C-31 Standard Practice for Making and Curing Concrete Test Specimens on the Field and ASTM C-192 Standard Practice for Making and Curing Concrete Test Specimens on the Laboratory specifications for cylindrical mold. The slump cone mold was also improvised by fabricating a 1.5 mm thick metal sheet in the form of a lateral surface of a frustum of a cone with a base of 8 in. [200 mm] in diameter, the top 4 in. [100 mm] in diameter, and the height 12 in. [300 mm] with the base and the top open and parallel to each other at right angles to the axis of the cone and has foot pieces and handles which conforms to the ASTM C-143 Standard Test Method for Slump of Hydraulic-Cement Concrete.***5.3 Data Gathering and Procedure***

Mix Design:

Concrete proportions must be selected to provide workability, consistency, density, strength, and durability, for the particular application based on ACI 211.1-91.

Based on the nominal mix design method, there are two different ways in proportioning concrete mixture namely by volume or by mass. Volume method is the most common and convenient method in mixing concrete to attain the desired strength of concrete. Concrete mixture involves cement, sand, gravel and water cement ratio. Proportioning by volume method had been long practiced and it is proven effective and successful. Most construction industry used this method in proportion the mixture of the concrete. **Table 3** shows the ratio of the cement, sand and gravel mixture while **Table 4** shows the strength and use of each mixture class.

Table 3 Mixture Proportioning by Volume Method

Mixture Class	Proportion	Cement In Bag		Sand	Gravel
		40 kg	*50 kg*	*cu.m.*	*cu.m.*
Class AA	1:1.5:3	12	9.5	0.5	1.0
A	1:2:4	9	7	0.5	1.0
B	1:2.5:5	7.5	6.0	0.5	1.0
C	1:3:6	6.0	5.0	0.5	1.0

Table 4 Strength of Concrete Mixture Class

Mixture Class	Strength of Mixture	Use
Class AA	4000 PSI	Retaining walls, concrete under water
A	3500 PSI	Beams, slabs, footings, columns
B	3000 PSI	
C	2500 PSI	Plant boxes, non-critical areas

Specimen:

The ASTM C-192 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory was the basis of experimentation in this study. The cylindrical specimens that were to be subjected to compressive stress were 6 inches [150 mm] in diameter by a height of 12 inches [300 mm], four specimen per each ratio were to be casted for 7, 14, 21 and 28 days curing of concrete. On the other hand the specimens that were to be used for the water absorption and permeability test were in the form of a cube with an edge of 4 inches [100 mm].

The details of mix designation for all specimens used in the experimental program are given by **Table 5**. The cement-gravel-sand proportion used was 1:1.5:3 with a water-cement ratio of 0.5 whose standard compressive strength is 4000 psi (27.6 MPa) based on the arbitrary method of proportioning concrete mixture.

Table 5 Concrete Test Specimen Design Mix

Aggregate Reduction: 10% Fine and 30% Coarse						
Specimen Name	Rubber Crumb Class	Concrete Content (Percent of Total Volume)				
		Cement	Fine Aggregate	Coarse Aggregate	Rubber Crumbs	w/c Ratio
RC-1	A	18.18%	24.54%	38.18%	19.1%	0.5
RC-3	B	18.18%	24.54%	38.18%	19.1%	0.5
RC-5	C	18.18%	24.54%	38.18%	19.1%	0.5

Aggregate Reduction: 20% Fine and 50% Coarse						
Specimen Name	Rubber Crumb Class	Concrete Content (Percent of Total Volume)				
		Cement	Fine Aggregate	Coarse Aggregate	Rubber Crumbs	w/c Ratio
RC-2	A	18.18%	21.82%	27.28%	32.73%	0.5
RC-4	B	18.18%	21.82%	27.28%	32.73%	0.5
RC-6	C	18.18%	21.82%	27.28%	32.73%	0.5

No Reduction: Ordinary Concrete						
Specimen Name	Rubber Crumb Class	Concrete Content (Percent of Total Volume)				
		Cement	Fine Aggregate	Coarse Aggregate	Rubber Crumbs	w/c Ratio
OC	•	18.18%	27.27%	54.55%	-	0.5

5.3 Mixing and Casting Procedure:

The materials were prepared and mixed in conformity with ASTM C-192. The cement, rubber tire crumbs and fine aggregates were laid on a metal sheet and handmixed with trowel or shovel until they were thoroughly blended, and then the coarse aggregate was added and mixed again until uniformly distributed throughout the batch. Water was then added and mixed until the batch became homogenous. Slump test was done immediately after mixing to measure the degree of consistency and workability of the concrete mixture while the other portion of the mixture was placed on the mold for the cylindrical and cubic specimen and then tamped and consolidated to avoid voids and airentrainment. It was then kept in storage for initial curing. , after 24 hours they were removed from the mold. The cylindrical specimens were then immersed in water for curing in 7, 14, 21 and 28 days respectively before subjecting to compressive test. The cubic specimens were stored in room temperature.

5.4*Testing:*

5.4.1 Slump Test (ASTM C 143M-00):

The concrete slump test *Slump Test (ASTM C 143M-00)* is an empirical test that measures the workability of fresh concrete. More specifically, it measures the consistency of the concrete in that specific batch. This test is performed to check the consistency of freshly made concrete. Consistency is a term very closely related to workability. It is a term which describes the state of fresh concrete. It refers to the ease with which the concrete flows. It is used to indicate the degree of wetness. Workability of concrete is mainly affected by consistency i.e. wetter mixes will be more workable than drier mixes, but concrete of the same consistency may vary in workability. It is also used to determine consistency between individual batches.

This test method covers determination of slump of hydraulic-cement concrete, both in the laboratory and in the field. It was originally developed to provide a technique to monitor the consistency of unhardened concrete. Under laboratory conditions, with strict control of all concrete materials, the slump is generally found to increase proportionally with the water content of a given concrete mixture, and thus to be inversely related to concrete strength. Under field conditions, however, such a strength relationship is not clearly and consistently shown. Care should therefore be taken in relating slump results obtained under field conditions to strength.

5.4.2 Compressive Strength Test for Cylindrical Specimen (ASTM C 39M-01):

Compressive strength test is a mechanical test measuring the maximum amount of compressive load a material can bear before fracturing. The test piece, usually in the form of a cube, prism, or cylinder, is compressed between the platens of a compression-testing machine by a gradually applied load. The results of this test method are used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures and similar uses.

The specimens for the compressive strength of concrete test were cured for 7, 14, 21 and 28 days. The result shows that as the reduction of fine aggregate and coarse aggregate increases, the compressive strength of concrete drastically decreases.

Batches of each kind of cylinder specimen were tested after curing for 7, 14, 21 and 28 days respectively to identify its variation. The compressive strength test was done at ASTEC Materials Testing Center in No. 102 Aguinaldo Highway, Brgy. Sampaloc-1, Pala Pala, Dasmariñas, Cavite using a Universal Testing Machine.

5.4.3 Water Absorption Test in accordance with ASTM C 642:

ASTM C 642 covers the determinations of density, percent absorption of water, and percent voids in hardened concrete. This test method is useful in developing the data required for conversions between mass and volume for concrete. It can be used to determine conformance with specifications for concrete and to show differences from place to place within a mass of concrete. In this study, absorption after immersion was only conducted. There are two methods commonly used to determine if concrete is waterproof: absorption and permeability testing. Absorption tests are simple to perform and can be done by any materials lab. The test measures the weight of water absorbed into a concrete specimen over time as a result of capillary absorption, or wicking.

The cubic specimen with an edge of 4 inches [100 mm] has a volume of 64 cu.in. [1000000 cu.mm.] conforms to ASTM C-642 which states that the volume of the specimen shall be not less than 350 cu. cm. [35000 cu.mm.] (or for normal weight concrete, approximately 800 g). The specimens were weighed before oven drying and were oven dried for 24 hours at a temperature of 100 degree Celsius and weighed again. It was then cooled and submerged in water for 48 hours. The following mass was recorded after performing the test specified in the standard:

A= mass of oven-dried sample in air, g

B = mass of surface-dry sample in air after immersion, g

The value of absorption rate is now computed based on the formula:

Absorption after immersion, % = [(B – A)/A]* 100

5.4.4 Water Sorptivity Test in accordance with ASTM C 1585:

ASTM C 1585 test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. The exposed surface of the specimen is immersed in water and water ingress of unsaturated concrete dominated by capillary suction during initial contact with water.

The specimens used in the experiment were cylindrical specimens with a diameter of 4 inches and a depth of 2 inches. The standard method is condition samples in an oven for 3 days at 50 degree Celsius and kept in a sealable container for not less than 15 days after oven drying. The specimens were then weighed. After weighing, the side surface of each specimen was sealed by wax and the top portion which was not exposed to water was covered by plastic wrapper and secured with a tape. The new weight of the specimen was then recorded. The rate of absorption was conducted using a container with sticks as support for the specimen so that the face won’t have contact with the container, they were then filled by water 1 to 3 mm above the surface of the stick supports. The timer was then started when the specimens were placed above the supports. The mass was then recorded in intervals specified by the ASTM Standard. The result was tabulated and the rate of absorption was computed using the formula:

I = mt / (a* d)

where mt = the change in mass in grams, at different time (t)

a = exposed area of the specimen, mm^2.

d = density of water in g/mm^3.

5.5 Statistical Design:

The following figures show the percentage content of the volume of concrete

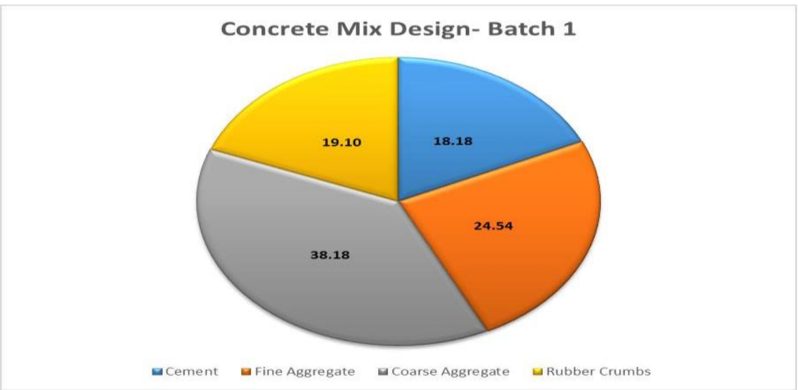


Figure 7 Aggregate reduction: 10% fine and 30% coarse

Figure 7 shows the first mix design wherein the aggregate reduction is 10 % for fine and 30 % for coarse aggregates from the nominal mix design Class AA with a ratio of 1:1.5:3 and the water-cement ratio is 0.5. The mix design was used for the specimens RC-1, RC-3 and RC-5. The design mix has 19.10 % rubber tire crumbs, 18.18 % cement, 24.54 % sand and 38.18 % gravel. They were cured for 7, 14, 21 and 28 days. This mix proportion was used for all the specimens for compressive strength, water absorption and sorptivity test.

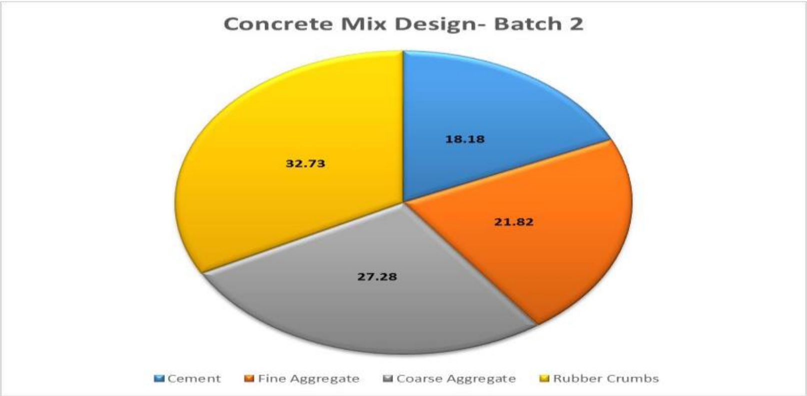


Figure 8 Aggregate reduction: 20% fine and 50% coarse

Figure 8 shows the first mix design wherein the aggregate reduction is 20 % for fine and 50 % for coarse aggregates from the nominal mix design Class AA with a ratio of 1:1.5:3 and the water-cement ratio is 0.5. This mix design was used for the specimens RC-2, RC-4 and RC-6. The design mix has 32.73 % rubber tire crumbs, 18.18 % cement, 21.82 % sand and 27.28 % gravel. They were cured for 7, 14, 21 and 28 days. This mix proportion was used for all the specimens for compressive strength, water absorption and sorptivity test.

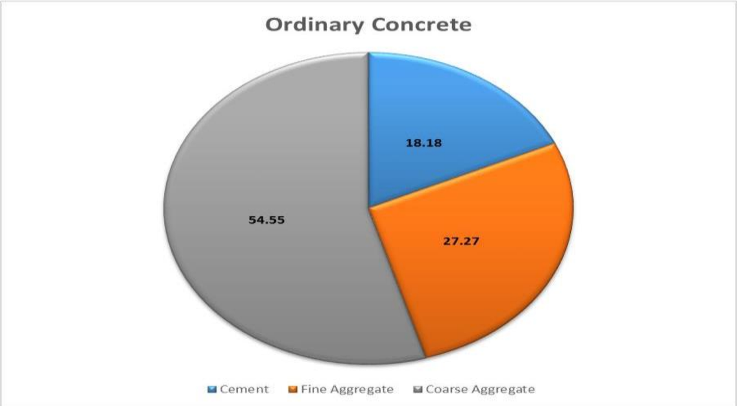


Figure 9 No reduction (Ordinary Concrete)

Figure 9 shows the first mix design wherein there is no aggregate reduction. The nominal mix design used is Class AA with a ratio of 1:1.5:3 and the water-cement ratio is 0.5. This mix design was used for the specimens OC which is the controlled variable. The design mix has 18.18 % cement, 27.27 % sand and 54.55 % gravel. They were cured for 7, 14, 21 and 28 days. This mix proportion was used for all the specimens for compressive strength, water absorption and sorptivity test.

5.6 Experiment Test Flow Chart

The flow chart shows the flow of the experiment.

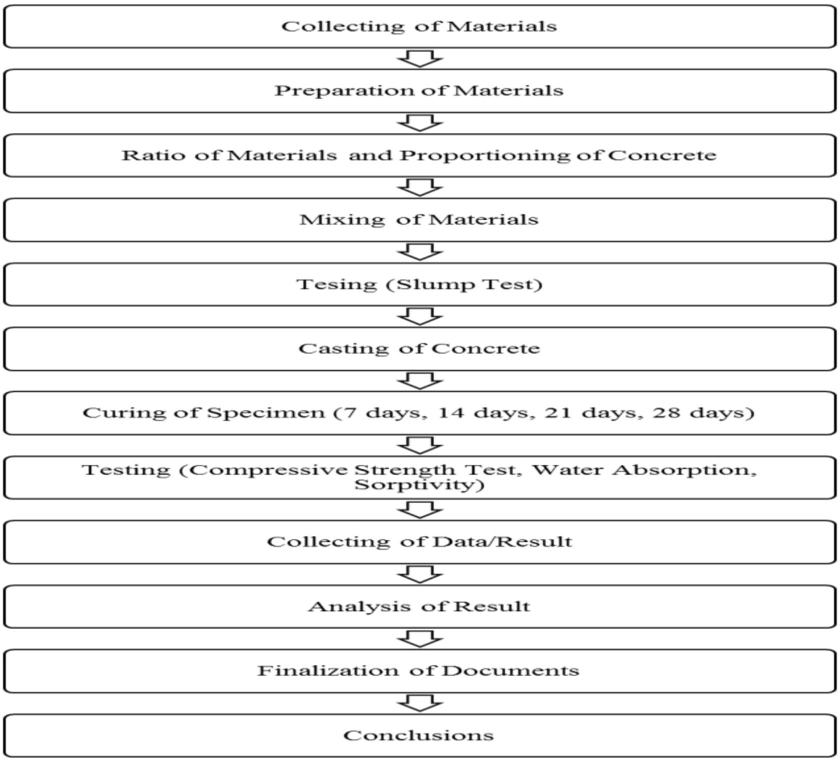


Figure 10 Experiment Test Flow Chart

6. RESULTS AND DISCUSSION

6.1 Result of Slump Test:

Table 6 Slump Test Result

SPECIMEN	**Slump Result**
RC-1	80 mm
RC-2	55 mm
RC-3	75 mm
RC-4	49 mm
RC-5	68 mm
RC-6	44 mm
OC	100 mm

Slump test measures the consistency of the concrete in that specific batch. This test was performed to check the consistency of freshly made concrete. Consistency is a term very closely related to workability. It is a term which describes the state of fresh concrete. It refers to the ease with which the concrete flows. It is used to indicate the degree of wetness. Workability of concrete is mainly affected by consistency i.e. wetter mixes will be more workable than drier mixes, but concrete of the same consistency may vary in workability. It is also used to determine consistency between individual batches. The result of the slump test is acceptable due to the incorporation of rubber. Due to incorporation of recycled rubber tire crumbs in large amount, the workability of concrete on RC-2, RC-3 and RC-5 was is lower since rubber has a low moisture absorption.



6.2 Result of Compressive Strength Test

There are three specimens made in this experiment, the cylindrical specimen with a diameter of 6 inches, and a height of 12 inches for the compressive strength test, the cube specimen with edges of 4 inches for the water absorption test and lastly, the cylindrical specimen with a diameter of 4 inches and a height of 2 inches for the rate of absorption test. These specimens were named RC-1, RC-2, RC-3, RC-4, RC-5, RC-6 which were the independent variable and OC as the controlled variable for comparison purposes. The cement contents of these design mixes are shown in **table 5.** The proponents used the nominal mix design Class AA in this study with a cement, sand and gravel ratio of 1:1.5:3. RC-1, RC-3 and RC-5 has 10% fine aggregate reduction and 30% coarse aggregate reduction while RC-2, RC-4 and RC-6 has 20% fine aggregate reduction and 50% coarse aggregate reduction.

The compressive strength test was done to investigate whether the strength of the mix design that will be used in making a waterproof concrete can be used for structural or non-bearing elements of a structure due to the fact that from previous studies wherein rubber is used as partial replacement for aggregate, its compressive strength decreases as the replacement of aggregates increases. 1. The results for the compressive strength test of the different design mixes for different number of days are tabulated below and summarized graphically in **Fig. 14.**

Table 7. 7 Days – Compressive Strength

Specimen	Weight (g)	Diameter (mm)	Length (mm)	Maximum Load (N)	Compressive Strength		Typical Fracture Patterns
					Mpa	Psi	
RC-1	10350	150.2	305	40600	2.29	330	2
RC-2	10350	150.2	305	32190	1.82	400	2
RC-3	11015	150.7	305	49230	2.76	570	2
RC-4	10665	150.6	305	44180	2.48	260	3
RC-5	11515	150.7	305	62360	3.5	360	2
RC-6	11250	150.6	305	61080	3.43	500	3
OC	12755	150.7	305	142470	7.99	1160	2

Table 8. 14 Days – Compressive Strength

Specimen	Weight (g)	Diameter (mm)	Length (mm)	Maximum Load (N)	Compressive Strength		Typical Fracture Patterns
					Mpa	Psi	
RC-1	11890	150.7	305	97050	5.44	790	2
RC-2	10200	150.6	305	36510	2.05	300	2
RC-3	11250	150.8	305	116440	6.52	950	5
RC-4	10570	151.4	305	44120	2.45	360	2
RC-5	12540	151.7	305	156870	8.68	1260	2
RC-6	11095	150.1	305	81930	4.63	670	3
OC	12970	151.6	305	348140	19.29	2800	3

Table 9. 21 Days – Compressive Strength

Specimen	Weight (g)	Diameter (mm)	Length (mm)	Maximum Load (N)	Compressive Strength		Typical Fracture Patterns
					Mpa	Psi	
RC-1	11000	150.1	305	54560	3.08	450	5
RC-2	10050	150.1	305	15580	0.89	130	2
RC-3	10450	150.9	305	69560	3.89	560	6
RC-4	10030	150.1	305	31440	1.78	260	5
RC-5	12530	150.3	305	161100	9.08	1320	6
RC-6	11835	150.4	305	91580	5.15	750	6
OC	12365	150.4	305	165490	9.32	1350	5

Table 10. 28 Days – Compressive Strength

Specimen	Weight (g)	Diameter (mm)	Length (mm)	Maximum Load (N)	Compressive Strength		Typical Fracture Patterns
					Mpa	Psi	
RC-1	11795	150	305	109820	6.21	900	3
RC-2	10125	150.1	305	45330	2.56	370	3
RC-3	11380	151.3	305	128540	7.15	1040	3
RC-4	10580	151.7	305	610610	3.8	490	3
RC-5	12125	151.6	305	148750	8.24	1190	3
RC-6	11235	151.2	305	87840	4.89	710	2
OC	12780	158.8	305	337580	18.65	2700	3

The specimens for the compressive strength of concrete test were cured for 7, 14, 21 and 28 days. The result shows that as the reduction of fine aggregate and coarse aggregate increases, the compressive strength of concrete drastically decreases

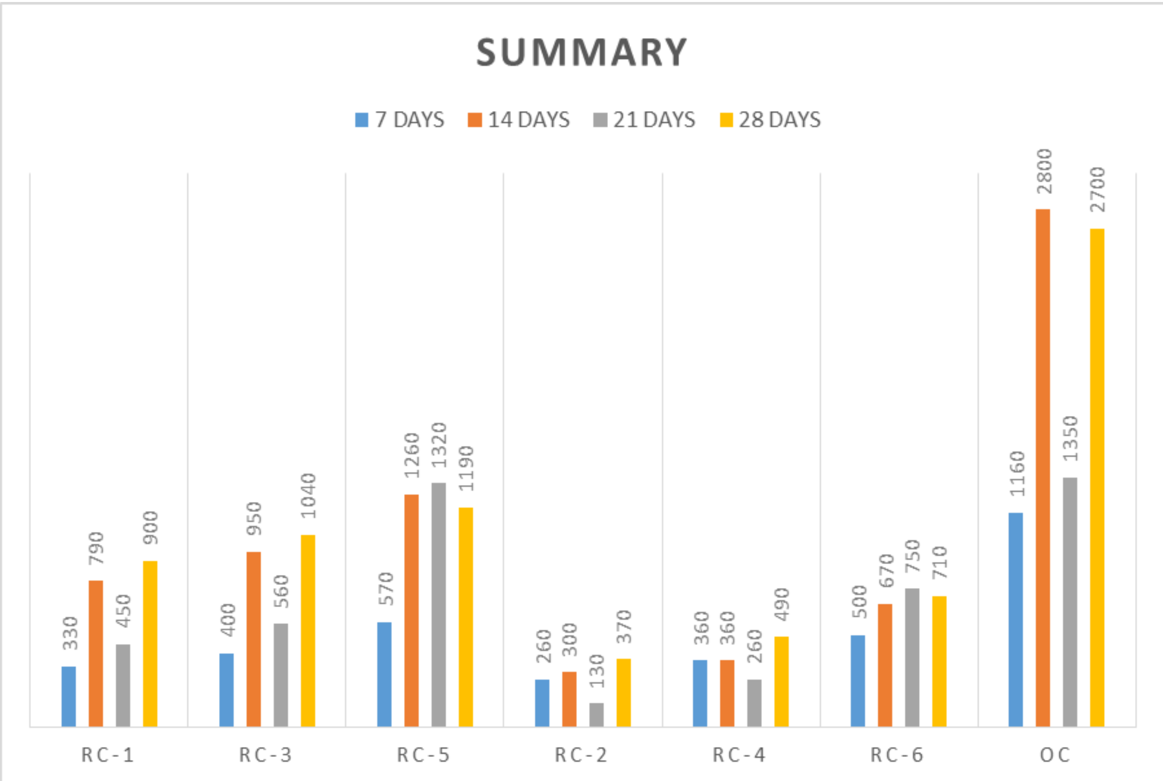
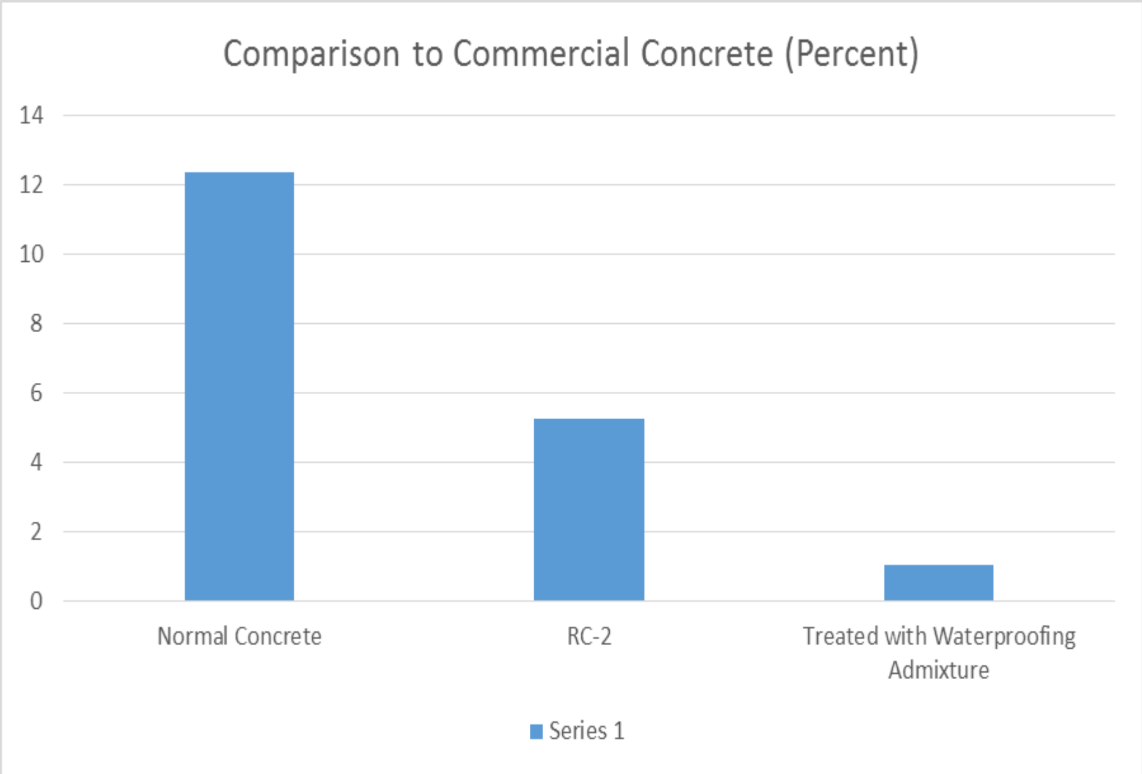


Figure 14 Summary of Compressive Strength Results

6.3 Results of Water Absorption Test

The results of the water absorption tests on the different specimens of design mixes are tabulated in **Tables 11-14** which can be found in ***Appendices 11-14***. These results show that concrete incorporated with rubber tire crumbs has a lower water absorption than ordinary concrete mix. The specimen with the lowest water absorption was the RC-2 design mix which had a water absorption rate of 7.21%. **Fig 15** compares RC-2 and Commercial Concrete in terms of their rates of water absorption while **Fig. 18** depicts a graphic summary of the rates of absorption of the different mixes.



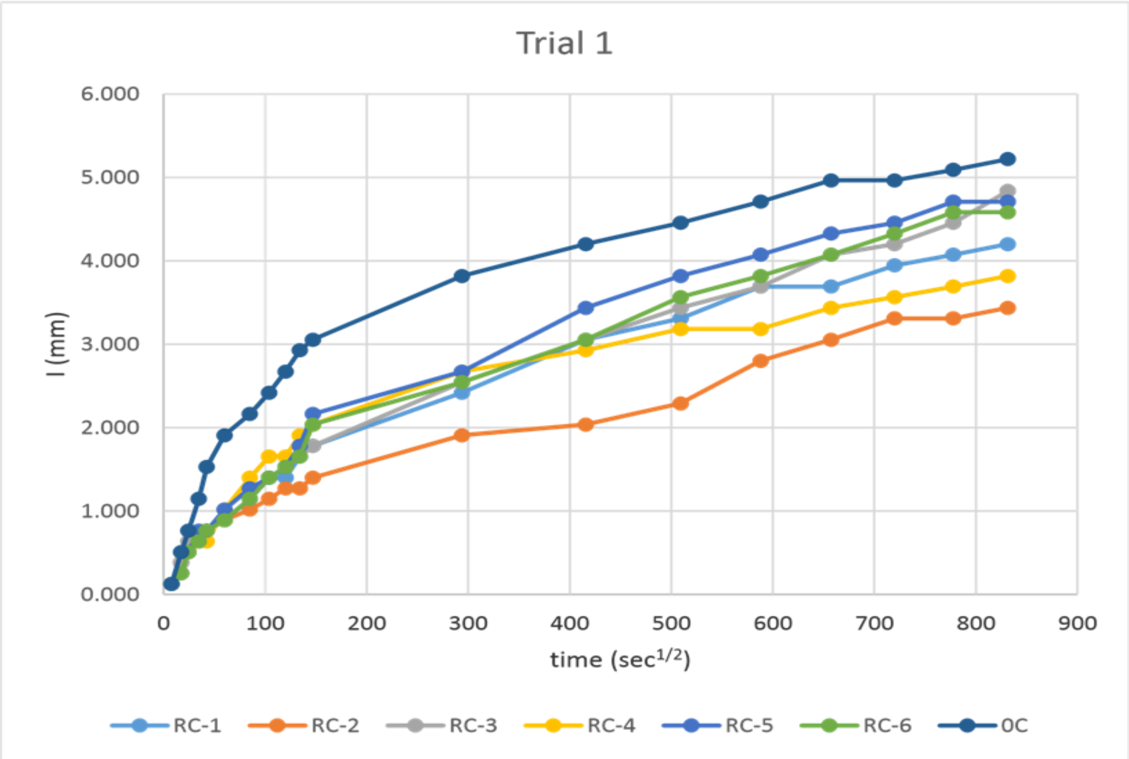


Figure 15 Comparison of Water Absorption Rate of RC-2 with Commercial Concrete

Figure 17 Oven Dried Mass Trial 1

6.4 Results of Water Sorptivity Test:

The performance of concrete subjected to many aggressive environments is a function, to a large extent, of the penetrability of the pore system. In unsaturated concrete, the rate of ingress of water or other liquids is largely controlled by absorption due to capillary rise. This test method is based on that developed by Hall3 who called the phenomenon "water sorptivity". The results of the Water Sorptivity Tests on the Different Specimens of design mixes are tabulated in **Tables 15-35** which can be found in **Appendices 15-35 .** The results from the three trials show that the mixture of RC-2 and RC-4 (with 32.73% rubber tire crumbs) had the smallest sorptivity aside from having the smallest absorption which was probably due to the fact that it had a finer sieve that prevented air voids and made the concrete more compacted which is essential in waterproofing. The results also showed that Ordinary Concrete had a higher rate of absorption than specimens incorporated with rubber tire crumbs and that the rate of absorption of the specimen progressed significantly from the start up to the 24th hour and slightly increased on the following days since the specimen's voids were occupied already. Water ponding in Ordinary Concrete was visible on the 6th hour of the test wherein the water occupied almost 25% of the specimen it was fully occupied on the 24th hour of the experiment while in specimens incorporated with rubber tire crumbs, water ponding was visible on the 3rd day of the experiment and became fully saturated on the 4th day. The results show that RC-2 had the lowest rate of absorption among the mixes incorporated with rubber tire crumbs. Hence, Rubber concrete has a potential of reducing concrete's water absorption as well as permeability.

TRIAL 1

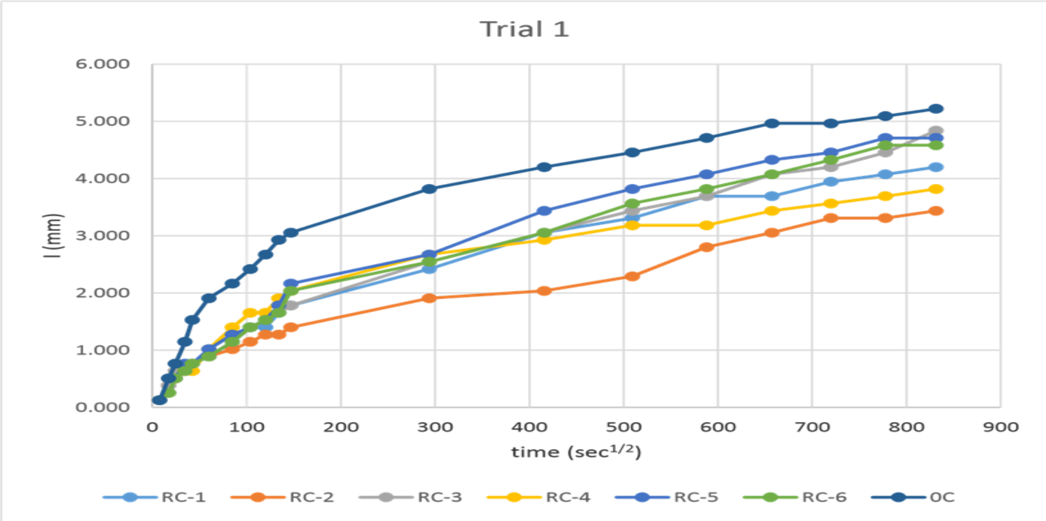


Figure 18 Trial 1 Summary of Rate of Absorption with respect to √ Time

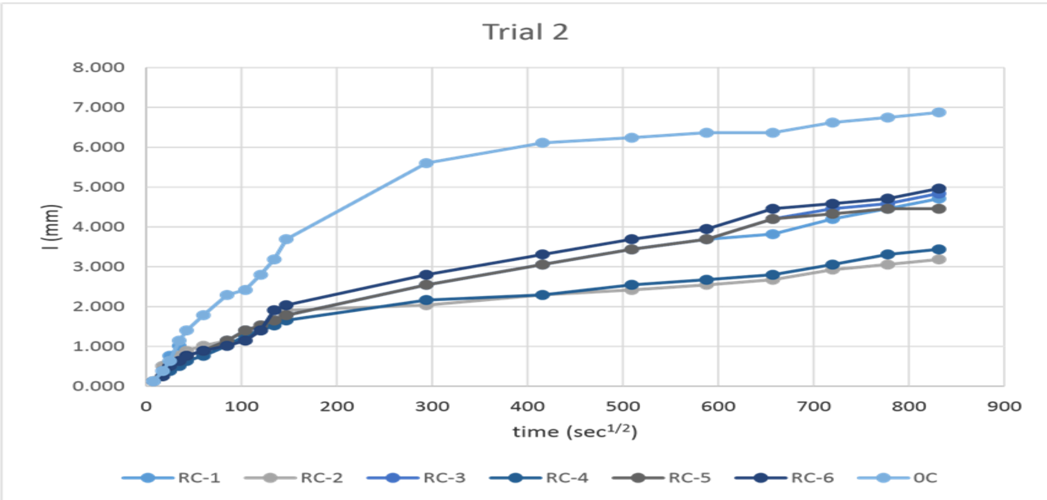
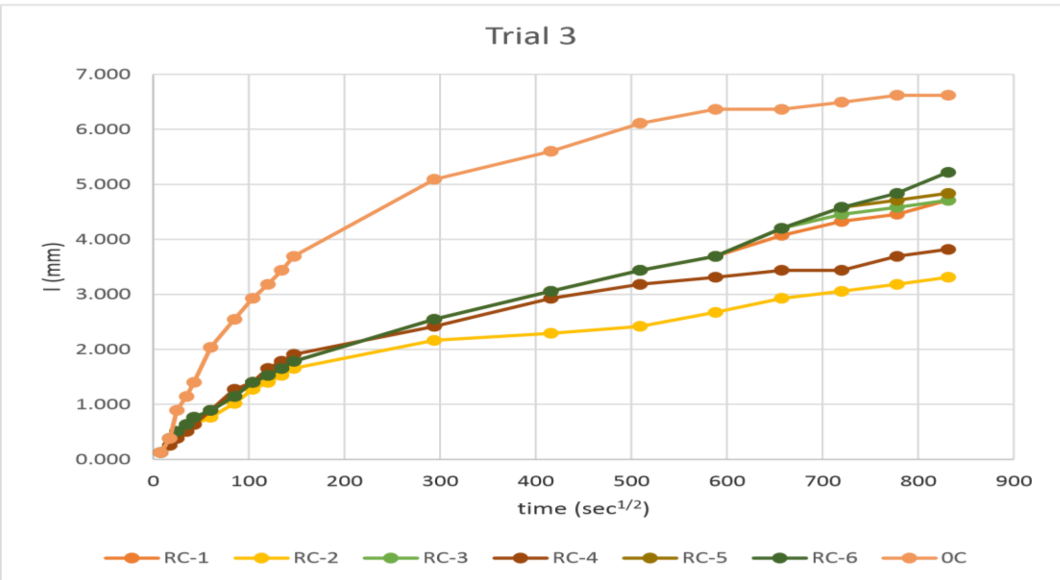


Figure 19 Trial 2 Summary of Rate of Absorption with respect to √ Time



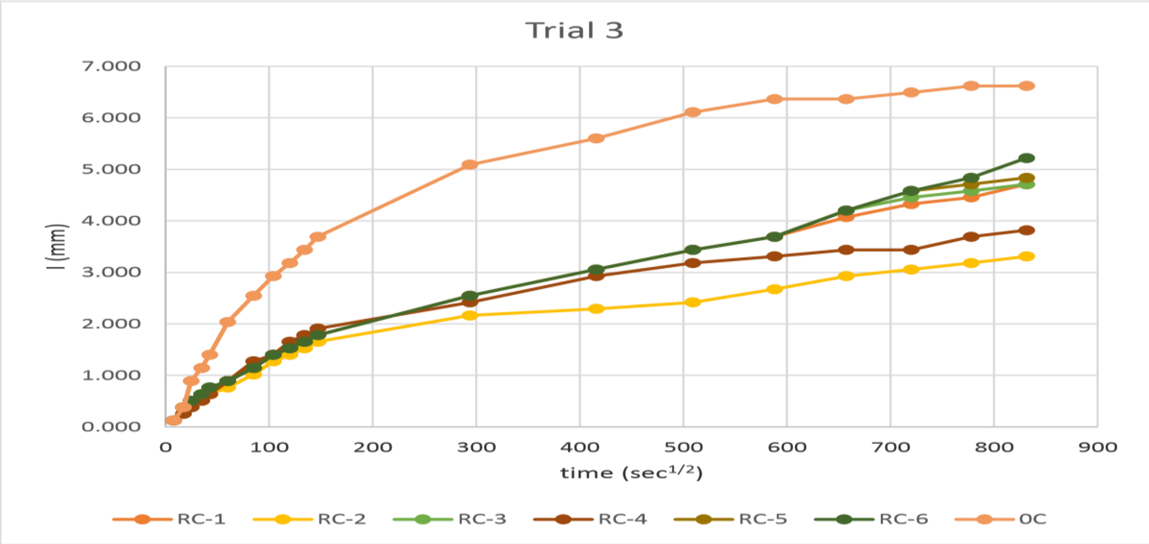


Figure 20 Trial 3 Summary of Rate of Absorption with respect to $\sqrt{}$ Time

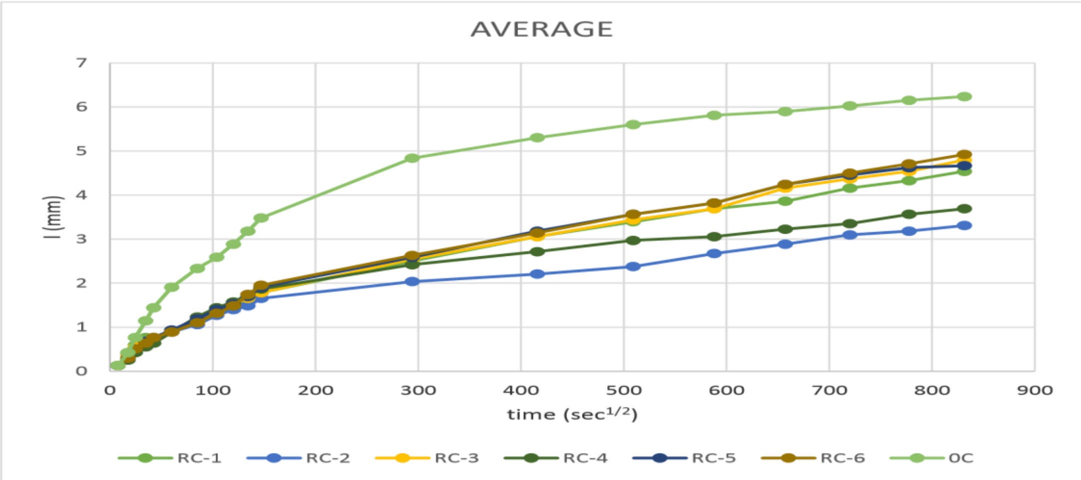


Figure 21 Summary of the average rate of absorption with respect to $\sqrt{Time}$ of all specimens

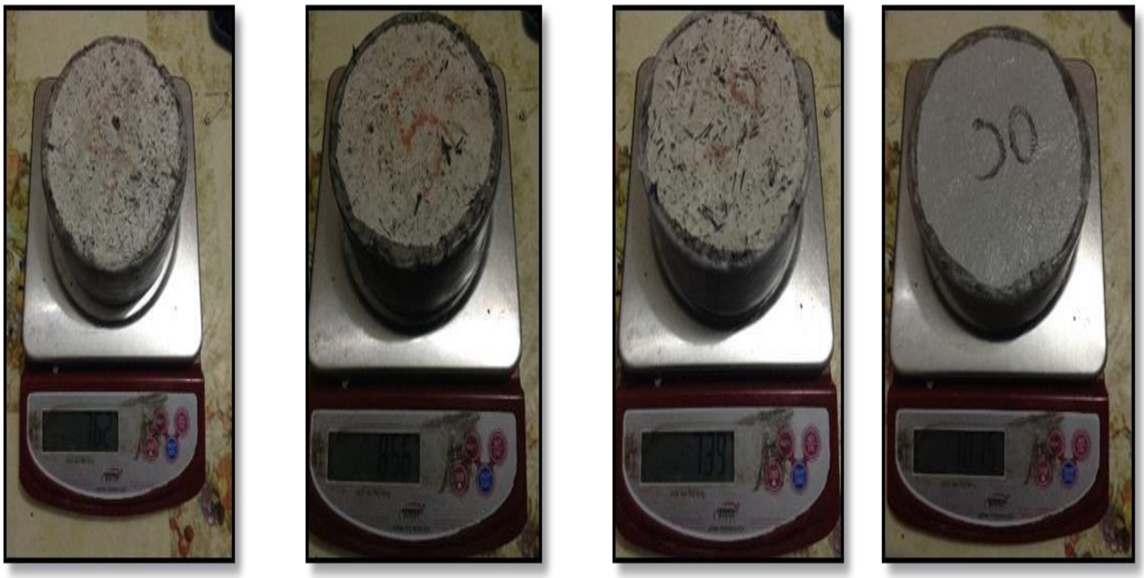


Figure 22 Mass before complete Sealing

Figure 23 Mass before Complete Sealing

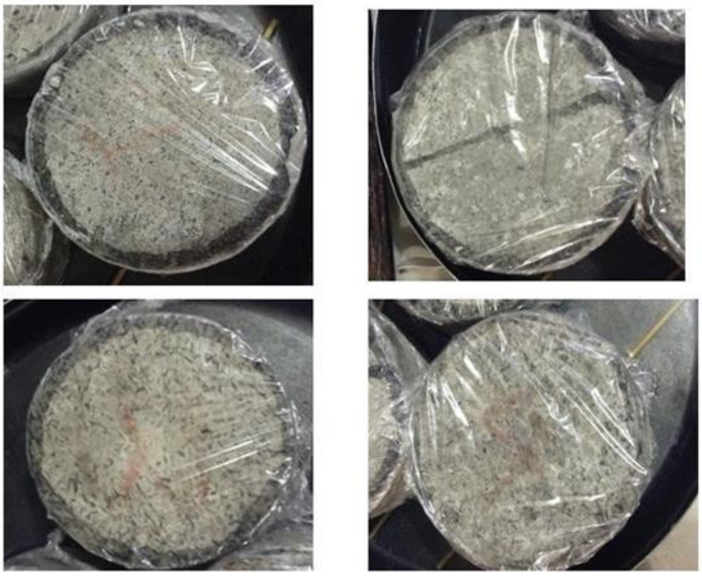


Figure 24 Water ponding at 3 hours

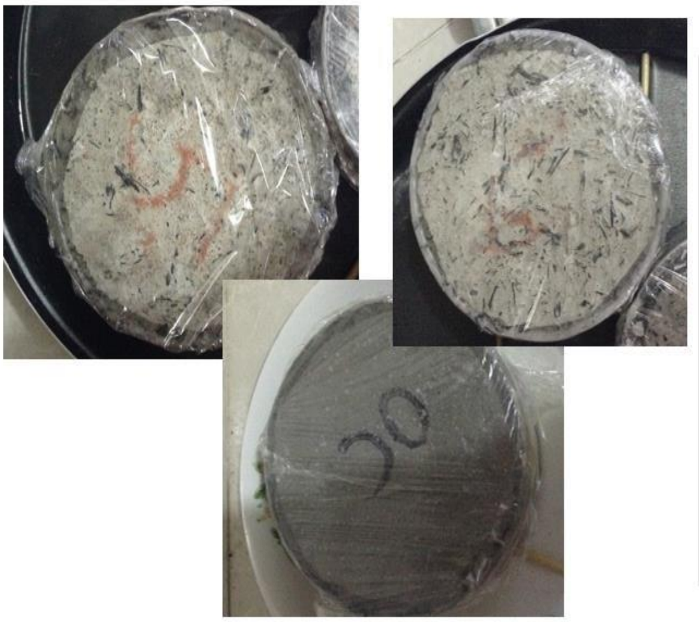


Figure 25 Water ponding at 24 hours

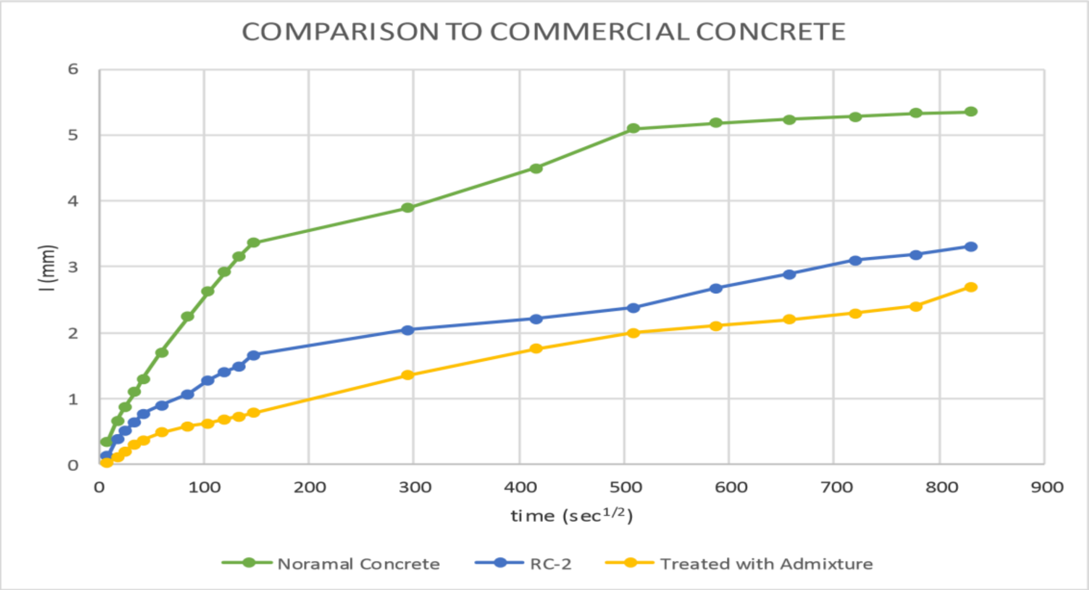


Figure 26 Comparison of rate of absorption with respect to $\sqrt{Time}$ of RC-2 with commercial concrete

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion:

On the basis of the results obtained from the experiment, the following conclusions could be drawn:

1. Recycle rubber tire crumbs be used as partial replacement of aggregated which can reduce the water absorption, permeability and sorpitivity of concrete which can make it waterproof.

2. The mixture of RC-2 and RC-4 having 32.73% of rubber tire crumbs proved that it has the smallest absorption and sorpitivity probably because it has a finer sieve that prevented air voids that made the concrete more compacted which is essential in waterproofing. However due to its rubber content, the compressive strength of these mixtures was reduced drastically but t be used for non-load bearing like fences, façade-type walls and low volume pathways.

3. RC-2 design mixture has a lower absorption than conventional concrete that is normally used in the construction industry but higher rate of absorption than commercial concrete with waterproofing chemical admixture. It has potential for waterproofing but concrete with admixture shows greater reduction of rate of absorption as well as permeability and strength.

4. RC-2 rubber concrete mixture has the lowest rate of absorption among the design mixes provided by the researchers. Compared to normal concrete that is conventionally used in the construction industry, RC-2 has lower rate of absorption. But then, compared to commercially used concrete for waterproofing incorporated by a chemical admixture, RC-2 has higher rate of absorption than that.

5. Rubber concrete has a potential of reducing concrete's water absorption as well as permeability.

7.2 Recommendations

For further investigation regarding the feasibility of recycled rubber tire crumbs for waterproofing of concrete, and for more satisfying results, the following recommendations were made:

1. Waste rubber tires must not be thrown out or burned; instead it should be kept and recycled, for they possess the properties suitable for construction material.

2. Water – cement ratio should be increased to see if the compressive strength will vary directly.

3. Due to the unavailability of steel cylinders, a PVC pipe was used to replace it, but using PVC pipe for concrete specimens does not provide optimum results in terms of concrete strength and minimizing concrete voids.

4. When placing the rubber concrete specimen to concrete molds, a strict implementation of the Standard Tamping Procedure must be observed to prevent concrete voids which is essential in reducing water absorption and permeability rate.

5. A previous experiment showed that replacing more than 20% of fine aggregates in a concrete mixture will drastically reduce its compressive strength and this was the basis in reducing the fine aggregates in this experiment. However, the 30% and 50% reduction on coarse aggregates were provided by the authors and it is recommended for future studies to try to increase the reduction of coarse aggregates to 5% to 15% and see if the mixture can still attain sufficient strength good enough for non-bearing structures.

6. The best mix proportion suited for reducing concrete's water absorption and permeability which in turn makes a concrete waterproof is the RC-2 mix which contains 32.73% Class A rubber tire crumbs of, 18.18% cement, 21.82% sand and 27.28% gravel.

7. The mix proportion that can be used for non-bearing structure is RC-5 mix which has 19.10% Class C rubber tire crumbs, 18.18% cement, 24.54% sand and 38.18% gravel.

8. A higher percentage of rubber and higher water content is recommended for further study. This is because at higher percentage of rubber with lesser water content, consistency mix is impossible to attain.

ACKNOWLEDGEMENT

The authors wish to acknowledge the invaluable editorial and secretarial assistance of Dr. Roger D. Posadas, Mrs. Merlyn Rubin Posadas, and Mrs. Gloria Dumale of the Research and Innovation Center of LPU-Cavite.

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APPENDIX - A

Table 11. Water Absorption Test Result-Trial 1

Name of Specimen	Oven Dry Mass (kg)	Dry Mass (kg)	Water Absorption (%)
RC-1	1.8655	1.996	7.02
RC-2	1.715	1.803	5.13
RC-3	1.947	2.095	7.60
RC-4	2.017	2.131	5.65
RC-5	1.863	2.020	8.43
RC-6	2.058	2.196	6.71
OC	2.323	2.60	11.94

Table 12. Water Absorption Test Result-Trial 2

Name of Specimen	Oven Dry Mass (kg)	Dry Mass (kg)	Water Absorption (%)
RC-1	1.793	1.916	6.86
RC-2	1.627	1.707	4.92
RC-3	1.872	2.012	7.48
RC-4	1.937	2.039	5.27
RC-5	1.843	1.995	8.25
RC-6	2.002	2.129	6.34
OC	2.242	2.503	11.64

Table 13. Water Absorption Test Result-Trial 3

Name of Specimen	Oven Dry Mass (kg)	Dry Mass (kg)	Water Absorption (%)
RC-1	1.728	1.862	7.75
RC-2	1.78	1.882	5.73
RC-3	1.781	1.939	8.87
RC-4	1.855	1.993	7.44
RC-5	1.84	2.020	9.78
RC-6	1.715	1.854	8.10
OC	2.134	2.42	13.42

Table 14. Average Rate of Water Absorption

Name of Specimen	
RC-1	7.21
RC-2	5.26
RC-3	7.98
RC-4	6.12
RC-5	8.82
RC-6	7.05
OC	12.33

Based on the result, concrete incorporated with rubber tire crumbs has a lower water absorption than an ordinary concrete mix, and the specimen with the lowest water absorption is the RC-2 design mix which has a water absorption rate of 7.21%

Table 15. Water Sorptivity Test Result of RC-1(Trial 1)

RC-2	✓ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	775	776	1	0.127
5 min	17.32	775	778	3	0.382
10 min	24.49	775	779	4	0.509
20 min	34.64	775	780	5	0.637
30 min	42.43	775	781	6	0.764
60 min	60.00	775	782	7	0.891
2hours	84.85	775	784	9	1.146
3 hours	103.92	775	786	11	1.401
4 hours	120.00	775	786	11	1.401
5 hours	134.16	775	788	13	1.655
6 hours	146.97	775	789	14	1.783
1 day	293.94	775	794	19	2.419
2 days	415.69	775	799	24	3.056
3 days	509.12	775	801	26	3.310
4 days	587.88	775	804	29	3.692
5 days	657.27	775	804	29	3.692
6 days	720.00	775	806	31	3.947
7 days	777.69	775	807	32	4.074
8 days	831.38	775	808	33	4.202

Table 16 Water Sorptivity Test Result of RC-2 (Trial 1)

RC-2	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	746	747	1	0.127
5 min	17.32	746	749	3	0.382
10 min	24.49	746	750	4	0.509
20 min	34.64	746	751	5	0.637
30 min	42.43	746	752	6	0.764
60 min	60.00	746	753	7	0.891
2 hours	84.85	746	754	9	1.019
3 hours	103.92	746	755	10	1.146
4 hours	120.00	746	756	10	1.273
5 hours	134.16	746	756	11	1.273
6 hours	146.97	746	757	14	1.401
1 day	293.94	746	761	19	1.910
2 days	415.69	746	762	15	2.037
3 days	509.12	746	764	16	2.292
4 days	587.88	746	768	18	2.801
5 days	657.27	746	770	22	3.056
6 days	720.00	746	772	24	3.310
7 days	777.69	746	772	26	3.310
8 days	831.38	746	773	27	3.438

Table 17 Water Sorptivity Test Result of RC-3 (Trial 1)

RC-3	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	764	765	1	0.127
5 min	17.32	764	767	3	0.382
10 min	24.49	764	769	5	0.637
20 min	34.64	764	769	5	0.637
30 min	42.43	764	770	6	0.764
60 min	60.00	764	771	7	0.891
2 hours	84.85	764	773	9	1.146
3 hours	103.92	764	775	11	1.401
4 hours	120.00	764	776	12	1.528
5 hours	134.16	764	777	13	1.655
6 hours	146.97	764	778	14	1.783
1 day	293.94	764	784	20	2.546
2 days	415.69	764	788	24	3.056
3 days	509.12	764	791	27	3.438
4 days	587.88	764	793	29	3.692
5 days	657.27	764	796	32	4.074
6 days	720.00	764	797	33	4.202
7 days	777.69	764	799	35	4.456
8 days	831.38	764	802	38	4.838

Table 18 Water Sorptivity Test Result of RC-4 (Trial 1)

RC-4	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	774	775	1	0.127
5 min	17.32	774	776	2	0.255
10 min	24.49	774	778	4	0.509
20 min	34.64	774	779	5	0.637
30 min	42.43	774	779	5	0.637
60 min	60.00	774	782	8	1.019
2 hours	84.85	774	785	11	1.401
3 hours	103.92	774	787	13	1.655
4 hours	120.00	774	787	13	1.655
5 hours	134.16	774	789	15	1.910
6 hours	146.97	774	790	16	2.037
1 day	293.94	774	795	21	2.674
2 days	415.69	774	797	23	2.928
3 days	509.12	774	799	25	3.183
4 days	587.88	774	799	25	3.183
5 days	657.27	774	801	27	3.438
6 days	720.00	774	802	28	3.565
7 days	777.69	774	803	29	3.692
8 days	831.38	774	804	30	3.820

Table 19 Water Sorptivity Test Result of RC-5 (Trial 1)

RC-5	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	862	863	1	0.127
5 min	17.32	862	864	2	0.255
10 min	24.49	862	866	4	0.509
20 min	34.64	862	868	6	0.764
30 min	42.43	862	868	6	0.764
60 min	60.00	862	870	8	1.019
2 hours	84.85	862	872	10	1.273
3 hours	103.92	862	873	11	1.401
4 hours	120.00	862	874	12	1.528
5 hours	134.16	862	876	14	1.783
6 hours	146.97	862	879	17	2.165
1 day	293.94	862	883	21	2.674
2 days	415.69	862	889	27	3.438
3 days	509.12	862	892	30	3.820
4 days	587.88	862	894	32	4.074
5 days	657.27	862	896	34	4.329
6 days	720.00	862	897	35	4.456
7 days	777.69	862	899	37	4.711
8 days	831.38	862	899	37	4.711

Table 20 Water Sorptivity Test Result of RC-6 (Trial 1)

RC-6	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	748	749	1	0.127
5 min	17.32	748	750	2	0.255
10 min	24.49	748	752	4	0.509
20 min	34.64	748	753	5	0.637
30 min	42.43	748	754	6	0.764
60 min	60.00	748	755	7	0.891
2 hours	84.85	748	757	9	1.146
3 hours	103.92	748	759	11	1.401
4 hours	120.00	748	760	12	1.528
5 hours	134.16	748	761	13	1.655
6 hours	146.97	748	764	16	2.037
1 day	293.94	748	768	20	2.546
2 days	415.69	748	772	24	3.056
3 days	509.12	748	776	28	3.565
4 days	587.88	748	778	30	3.820
5 days	657.27	748	780	32	4.074
6 days	720.00	748	782	34	4.329
7 days	777.69	748	784	36	4.584
8 days	831.38	748	784	36	4.584

Table 21 Water Sorptivity Test Result of OC (Trial 1)

OC	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	1022	1023	1	0.127
5 min	17.32	1022	1026	4	0.509
10 min	24.49	1022	1028	6	0.764
20 min	34.64	1022	1031	9	1.146
30 min	42.43	1022	1034	12	1.528
60 min	60.00	1022	1037	15	1.910
2 hours	84.85	1022	1039	17	2.165
3 hours	103.92	1022	1041	19	2.419
4 hours	120.00	1022	1043	21	2.674
5 hours	134.16	1022	1045	23	2.928
6 hours	146.97	1022	1046	24	3.056
1 day	293.94	1022	1052	30	3.820
2 days	415.69	1022	1055	33	4.202
3 days	509.12	1022	1057	35	4.456
4 days	587.88	1022	1059	37	4.711
5 days	657.27	1022	1061	39	4.966
6 days	720.00	1022	1061	39	4.966
7 days	777.69	1022	1062	40	5.093
8 days	831.38	1022	1063	41	5.220

Table 22 Water Sorptivity Test Result of RC-1 (Trial 2)

RC-1	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	775	776	1	0.127
5 min	17.32	775	779	4	0.509
10 min	24.49	775	781	6	0.764
20 min	34.64	775	783	8	1.019
30 min	42.43	775	781	6	0.764
60 min	60.00	775	782	7	0.891
2 hours	84.85	775	784	9	1.146
3 hours	103.92	775	786	11	1.401
4 hours	120.00	775	787	12	1.528
5 hours	134.16	775	788	13	1.628
6 hours	146.97	775	789	14	1.783
1 day	293.94	775	795	20	2.546
2 days	415.69	775	799	24	3.056
3 days	509.12	775	802	27	3.438
4 days	587.88	775	804	29	3.692
5 days	657.27	775	805	30	3.820
6 days	720.00	775	808	33	4.202
7 days	777.69	775	810	35	4.456
8 days	831.38	775	812	37	4.711

Table 23 Water Sorptivity Test Result of RC-2 (Trial 2)

RC-2	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	709	710	1	0.127
5 min	17.32	709	713	4	0.509
10 min	24.49	709	714	5	0.637
20 min	34.64	709	715	6	0.764
30 min	42.43	709	716	7	0.891
60 min	60.00	709	717	8	1.019
2 hours	84.85	709	718	9	1.149
3 hours	103.92	709	720	11	1.401
4 hours	120.00	709	721	12	1.528
5 hours	134.16	709	722	13	1.655
6 hours	146.97	709	724	15	1.910
1 day	293.94	709	725	16	2.037
2 days	415.69	709	727	18	2.292
3 days	509.12	709	728	19	2.419
4 days	587.88	709	729	20	2.546
5 days	657.27	709	730	21	2.674
6 days	720.00	709	732	23	2.928
7 days	777.69	709	733	24	3.056
8 days	831.38	709	734	25	3.183

Table 24 Water Sorptivity Test Result of RC-3 (Trial 2)

RC-3	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	818	819	1	0.127
5 min	17.32	818	821	3	0.382
10 min	24.49	818	822	4	0.509
20 min	34.64	818	823	5	0.637
30 min	42.43	818	824	6	0.764
60 min	60.00	818	825	7	0.891
2 hours	84.85	818	827	9	1.146
3 hours	103.92	818	829	11	1.404
4 hours	120.00	818	830	12	1.528
5 hours	134.16	818	831	13	1.655
6 hours	146.97	818	832	14	1.783
1 day	293.94	818	838	20	2.546
2 days	415.69	818	842	24	3.056
3 days	509.12	818	845	27	3.438
4 days	587.88	818	847	29	3.692
5 days	657.27	818	851	33	4.202
6 days	720.00	818	853	35	4.456
7 days	777.69	818	854	36	4.584
8 days	831.38	818	856	38	4.838

Table 25 Water Sorptivity Test Result of RC-4 (Trial 2)

RC-4	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	715	716	1	0.127
5 min	17.32	715	717	2	0.255
10 min	24.49	715	718	3	0.382
20 min	34.64	715	719	4	0.509
30 min	42.43	715	720	5	0.637
60 min	60.00	715	721	6	0.764
2 hours	84.85	715	723	8	1.019
3 hours	103.92	715	725	10	1.73
4 hours	120.00	715	726	11	1.401
5 hours	134.16	715	727	12	1.528
6 hours	146.97	715	728	13	1.655
1 day	293.94	715	732	17	2.165
2 days	415.69	715	733	18	2.292
3 days	509.12	715	735	20	2.546
4 days	587.88	715	736	21	2.674
5 days	657.27	715	737	22	2.801
6 days	720.00	715	739	24	3.056
7 days	777.69	715	741	26	3.310
8 days	831.38	715	742	27	3.438

Table 26 Water Sorptivity Test Result of RC-5 (Trial 2)

RC-5	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	908	909	1	0.127
5 min	17.32	908	910	2	0.255
10 min	24.49	908	912	4	0.509
20 min	34.64	908	913	5	0.637
30 min	42.43	908	914	6	0.764
60 min	60.00	908	915	7	0.891
2 hours	84.85	908	917	9	1.146
3 hours	103.92	908	919	11	1.401
4 hours	120.00	908	920	12	1.528
5 hours	134.16	908	921	13	1.655
6 hours	146.97	908	922	14	1.783
1 day	293.94	908	928	20	2.546
2 days	415.69	908	932	24	3.056
3 days	509.12	908	935	27	3.438
4 days	587.88	908	937	29	3.692
5 days	657.27	908	941	33	4.202
6 days	720.00	908	942	34	4.329
7 days	777.69	908	943	35	4.456
8 days	831.38	908	943	35	4.456

Table 27 Water Sorptivity Test Result of RC-6 (Trial 1)

RC-6	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	849	850	1	0.127
5 min	17.32	849	851	2	0.255
10 min	24.49	849	853	4	0.509
20 min	34.64	849	854	5	0.637
30 min	42.43	849	855	6	0.764
60 min	60.00	849	856	7	0.891
2 hours	84.85	849	857	8	1.019
3 hours	103.92	849	858	9	1.146
4 hours	120.00	849	860	11	1.401
5 hours	134.16	849	864	15	1.910
6 hours	146.97	849	865	16	2.037
1 day	293.94	849	871	22	2.801
2 days	415.69	849	875	26	3.310
3 days	509.12	849	878	29	3.692
4 days	587.88	849	880	31	3.947
5 days	657.27	849	884	35	4.456
6 days	720.00	849	885	36	4.584
7 days	777.69	849	886	37	4.711
8 days	831.38	849	888	39	49.66

Table 28 Water Sorptivity Test Result of OC (Trial 2)

OC	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	1035	1036	1	0.127
5 min	17.32	1035	1038	3	0.382
10 min	24.49	1035	1040	5	0.637
20 min	34.64	1035	1044	9	1.146
30 min	42.43	1035	1046	11	1.401
60 min	60.00	1035	1049	14	1.783
2 hours	84.85	1035	1053	18	2.292
3 hours	103.92	1035	1054	19	2.419
4 hours	120.00	1035	1057	22	2.801
5 hours	134.16	1035	1060	25	3.183
6 hours	146.97	1035	1064	29	3.692
1 day	293.94	1035	1079	44	5.602
2 days	415.69	1035	1083	48	6.112
3 days	509.12	1035	1084	49	6.239
4 days	587.88	1035	1085	50	6.366
5 days	657.27	1035	1085	50	6.366
6 days	720.00	1035	1087	52	6.621
7 days	777.69	1035	1088	53	6.748
8 days	831.38	1035	1089	54	6.875

Table 29 Water Sorptivity Test Result of RC-1 (Trial 3)

RC-1	√ Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	824	825	1	0.127
5 min	17.32	824	827	3	0.382
10 min	24.49	824	828	4	0.509
20 min	34.64	824	829	5	0.637
30 min	42.43	824	830	6	0.764
60 min	60.00	824	831	7	0.891
2 hours	84.85	824	833	9	1.146
3 hours	103.92	84	835	11	1.401
4 hours	120.00	824	836	12	1.528
5 hours	134.16	824	837	13	1.655
6 hours	146.97	824	838	14	1.783
1 day	293.94	824	844	20	2.546
2 days	415.69	824	848	24	3.056
3 days	509.12	824	851	27	3.438
4 days	587.88	824	853	29	3.692
5 days	657.27	824	856	32	4.074
6 days	720.00	824	858	34	4.329
7 days	777.69	824	859	35	4.456
8 days	831.38	824	861	37	4.711

Table 30 Water Sorptivity Test Result of RC-2 (Trial 3)

RC-2	√Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	749	750	1	0.127
5 min	17.32	749	751	2	0.255
10 min	24.49	749	752	3	0.382
20 min	34.64	749	753	4	0.509
30 min	42.43	749	754	5	0.637
60 min	60.00	749	755	6	0.764
2 hours	84.85	749	757	8	1.019
3 hours	103.92	749	759	10	1.273
4 hours	120.00	749	760	11	1.401
5 hours	134.16	749	761	12	1.528
6 hours	146.97	749	762	13	1.655
1 day	293.94	749	766	17	2.165
2 days	415.69	749	767	18	2.292
3 days	509.12	749	768	19	2.419
4 days	587.88	749	770	21	2.674
5 days	657.27	749	772	23	2.928
6 days	720.00	749	773	24	3.056
7 days	777.69	749	774	25	3.183
8 days	831.38	749	775	26	3.310

Table 31 Water Sorptivity Test Result of RC-3 (Trial 3)

RC-3	√Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	772	773	1	0.127
5 min	17.32	772	775	3	0.382
10 min	24.49	772	776	4	0.509
20 min	34.64	772	777	5	0.637
30 min	42.43	772	778	6	0.764
60 min	60.00	772	779	7	0.891
2 hours	84.85	772	781	9	1.146
3 hours	103.92	772	783	11	1.401
4 hours	120.00	772	784	12	1.528
5 hours	134.16	772	785	13	1.655
6 hours	146.97	772	786	14	1.783
1 day	293.94	772	792	20	2.546
2 days	415.69	772	796	24	3.056
3 days	509.12	772	799	27	3.438
4 days	587.88	772	801	29	3.692
5 days	657.27	772	805	33	4.202
6 days	720.00	772	807	35	4.456
7 days	777.69	772	808	36	4.584
8 days	831.38	772	809	37	4.711

Table 32 Water Sorptivity Test Result of RC-4 (Trial 3)

RC-4	√Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	809	810	1	0.127
5 min	17.32	809	811	2	0.255
10 min	24.49	809	812	3	0.382
20 min	34.64	809	813	4	0.509
30 min	42.43	809	814	5	0.637
60 min	60.00	809	816	7	0.891
2 hours	84.85	809	819	10	1.273
3 hours	103.92	809	820	11	1.401
4 hours	120.00	809	822	13	1.655
5 hours	134.16	809	823	14	1.783
6 hours	146.97	809	824	15	1.910
1 day	293.94	809	828	19	2.419
2 days	415.69	809	832	23	2.928
3 days	509.12	809	834	25	3.183
4 days	587.88	809	835	26	3.310
5 days	657.27	809	836	27	3.438
6 days	720.00	809	836	287	3.438
7 days	777.69	809	838	29	3.692
8 days	831.38	809	839	30	3.820

Table 33 Water Sorptivity Test Result of RC-5 (Trial 3)

RC-5	√Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	860	861	1	0.127
5 min	17.32	860	863	3	0.382
10 min	24.49	860	864	4	0.509
20 min	34.64	860	865	5	0.637
30 min	42.43	860	866	6	0.764
60 min	60.00	860	867	7	0.891
2 hours	84.85	860	869	9	1.146
3 hours	103.92	860	871	11	1.401
4 hours	120.00	860	872	12	1.528
5 hours	134.16	860	873	13	1.655
6 hours	146.97	860	874	14	1.783
1 day	293.94	860	880	20	2.546
2 days	415.69	860	884	24	3.056
3 days	509.12	860	887	27	3.438
4 days	587.88	860	889	29	3.692
5 days	657.27	860	893	33	4.202
6 days	720.00	860	896	36	4.584
7 days	777.69	860	897	37	4.711
8 days	831.38	860	898	38	4.838

Table 34 Water Sorptivity Test Result of RC-6 (Trial 3)

RC-6	√Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	788	78	1	0.127
5 min	17.32	788	791	3	0.382
10 min	24.49	788	792	4	0.509
20 min	34.64	788	793	5	0.637
30 min	42.43	788	794	6	0.764
60 min	60.00	788	795	7	0.891
2 hours	84.85	788	797	9	1.146
3 hours	103.92	788	799	11	1.401
4 hours	120.00	788	800	12	1.528
5 hours	134.16	788	801	13	1.655
6 hours	146.97	788	802	14	1.783
1 day	293.94	788	808	20	2.546
2 days	415.69	788	812	24	3.056
3 days	509.12	788	815	27	3.438
4 days	587.88	788	817	29	3.692
5 days	657.27	788	821	33	4.202
6 days	720.00	788	824	36	4.584
7 days	777.69	788	826	38	4.838
8 days	831.38	788	829	41	5.220

Table 35 Water Sorptivity Test Result of OC (Trial 3)

OC	√Time (seconds)$^{1/2}$	Initial Mass (g)	Mass 2	mt	1
1 min	7.75	1076	1077	1	0.127
5 min	17.32	1076	1079	3	0.382
10 min	24.49	1076	1083	7	0.891
20 min	34.64	1076	1085	9	1.146
30 min	42.43	1076	1087	11	1.401
60 min	60.00	1076	1092	16	2.037
2 hours	84.85	1076	1096	20	2.546
3 hours	103.92	1076	1099	23	2.928
4 hours	120.00	1076	1101	25	3.183
5 hours	134.16	1076	1103	27	3.438
6 hours	146.97	1076	1105	29	3.692
1 day	293.94	1076	1116	40	5.093
2 days	415.69	1076	1120	44	5.602
3 days	509.12	1076	1124	48	6.112
4 days	587.88	1076	1126	50	6.366
5 days	657.27	1076	1126	50	6.366
6 days	720.00	1076	1127	51	6.494
7 days	777.69	1076	1128	52	6.621
8 days	831.38	1076	1128	52	6.621

Table 36 Average Rate of Absorption (Sorptivity)

OC	✓ Time (seconds)$^{1/2}$	RC-1 I (mm)	RC-2 I (mm)	RC-3 I (mm)	RC-4 I (mm)	RC-5 I (mm)	RC-6 I (mm)	OC I (mm)
1 min	7.75	0.127	0.127	0.127	0.127	0.127	0.127	0.127
5 min	17.32	0.424	0.382	0.382	0.255	0.297	0.297	1.424
10 min	24.49	0.594	0.509	0.552	0.424	0.509	0.509	0.764
20 min	34.64	0.764	0.637	0.637	0.552	0.697	0.637	1.146
30 min	42.43	0.764	0.764	0.764	0.637	0.764	0.764	1.443
60 min	60.00	0.891	0.891	0.891	0.891	0.934	0.891	1.910
2 hours	84.85	1.146	1.061	1.146	1,231	1.188	1.103	2.334
3 hours	103.92	1.401	1.273	1.401	1.443	1.401	1.316	2.589
4 hours	120.00	1.485	1.401	1.528	1.570	1.528	1.485	2.886
5 hours	134.16	1.655	1.485	1.655	1.740	1.698	1.740	3.183
6 hours	146.97	1.783	1.655	1.783	1.867	1.910	1.952	3.480
1 day	293.94	2.504	2.037	2.546	2.419	2.589	2.631	4.838
2 days	415.69	3.056	2.207	3.056	2.716	3.183	3.141	5.305
3 days	509.12	3.395	2.377	3.438	2.971	3.565	3.565	5.602
4 days	587.88	3.692	2.674	3.692	3.056	3.820	3.820	5.814
5 days	657.27	3.862	2.886	4.159	3.226	4.244	4.244	5.899
6 days	720.00	4.159	3.098	4.371	3.353	4.456	4.499	6.027
7 days	777.69	4.329	3.183	4.541	3.565	4.626	4.711	6.154
8 days	831.38	4.541	3.310	4.796	3.692	4.669	4.923	6.239