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應用飛灰、矽砂及回收骨材於透水混凝土之透水性及抗壓強度研究

Permeability and Compressive Strength of Recycled Aggregate, Fly Ash, Silica Sand for Pervious Concrete

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中文摘要

再生骨材可用來描述可用於建築之經過絞碎之營建廢棄物, 材料來源於混凝土或瀝青回收而來。2000年以後, 混凝土業已開始在營建混凝土中中使用拆建廢料。由於拆除舊建築物可得到再生骨材, 減少了購置骨料的費用，減少其碳足跡，從而永續發展。 本研究採用來自台灣雲林斗六的營建廢棄物，透過實驗證明以再生骨材代替天然粗骨料的可行性。再生骨材代替天然粗骨料之重量含量為0%, 10%, 20%, 30%, 40%和50%, 再以飛灰、矽砂及水泥摻合來製作混凝土圓柱體，並於澆置後28天進行抗壓強度和滲透試驗。試驗結果混凝土的抗壓強度隨著再生骨材含量增加而降低, 透水性則隨著再生骨材之增加而增加。同時當以飛灰替代15%水泥, M20 (1：1.5：3) 的混凝土效果最佳, 同時建議透水混合物中再生骨材含量20%可以達到所需的強度。

關鍵詞：再生骨料, 透水混凝土, 飛灰, 鉻鐵粉灰, 抗壓性, 透水性

ABSTRACT in English

Recycled aggregate is a term used to describe crushed concrete or asphalt from construction debris that is reused in other building projects. Recycled aggregate is produced by crushing concrete, and sometimes asphalt, to reclaim the aggregate. In recent years the concrete industry has started using Construction and Demolition (C&D) waste in structural concrete application owing to the availability of waste from the demolition of old structures and the reduction in the cost of acquiring aggregates. This can allow the concrete industry to reduce its carbon footprint and thus help it to continue to grow without harming the environment. The RCA is sourced from local construction and demolition (C&D) waste in Douliu, Taiwan. This thesis manifests the results of experimental investigations carried out to study the feasibility of using RCA in the concrete making as partial replacement of natural coarse aggregate (NCA). The RCA is used as a partial replacement of natural coarse aggregate (NCA) in pervious concrete at 0%, 10%, 20%, 30%, 40%, and 50% by wt. Fly ash and Silica Sand are used as the source material which is partially replaced by cement as the mineral admixture with the replacement of natural coarse aggregate (NCA). The experimental program is conducted to study the mechanical properties (such as compressive strength) and durability properties (such as permeability) of concrete cylinders by using recycled aggregate. Compressive strength of the above pervious concrete is measured at 28 days, while permeability of the above pervious concrete is measured after 28 days of curing specimens. Results show that the compressive strength of pervious concrete decrease with the incorporation of RCA which furthermore decreases with an increase in RCA contents. The measured permeability of pervious concrete gets favorably affected by the incorporation of RCA. It is also observed that the pervious concrete made with M20 (1:1.5:3 ratio) having fly ash as a partial replacement cement with the replacement of 15% gave best results when

permeability and compressive strength both were a factor of judgment, experimental results revealed that up to 20% replacement of recycled aggregate in pervious mix can achieve the desired strength and it can be recommended percentage of RCA in the concrete industry.
Keywords: Recycled Aggregate, Pervious concrete, Fly ash, Ferrochrome ash, Durability properties, Mechanical properties

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ABBREVIATION

RCA: Recycled coarse aggregate

FA: Fly ash

PC: Pervious concrete

FA: Fine aggregate

CA: Coarse aggregate

SP: Superplasticizer

MPa: Mega pascal

RAC: Recycled aggregate concrete

Chapter 1

INTRODUCTION

1. GENERAL

In the past few decades, the construction industry has developed remarkably creating construction and demolition waste (C&DW) through reconstructing/improving the conventional framework during the economic development of a country. It was reported that there were 850 million tons of C&D produced in India and European union individually for FY2016 obstructing our path for sustainable development. The cement industry is the second-largest carbon dioxide producing industry which further increases when this cement as concrete is used in construction projects and constitutes for 33% of ozone depletion. When these old conventional buildings are demolished then these concrete waste is dumped in landfills which do not decay and keep using our land space. After including handling, excavating, demolishing, and transporting the financial bearing for the same increase furthermore as well as their carbon outflow. Thus the replacement of virgin aggregate with recycled aggregate can be a possible solution for the more sustainable construction. Recycled aggregate cannot be directly used in the conventional construction process without proper experimental procedures and reiterations. To be used as a proper construction material recycled aggregate must create a balance between economic cost and quality standards. The use of RAC is a bit of a financial savy choice if standard quality measures are considered. Therefore, an up-gradation must be made in mechanical and durability property of recycled concrete. Nowadays, prestressed precast concrete is very popular. Since the high grade of concrete is used, aggregate from these demolition wastes would have high strength. Several researchers investigated the performance of these wastes as recycled aggregate separately; hence there is a need to compile and analyze the performance of recycled aggregate in a single platform.

1.2 Industrial waste Material as Mineral Admixture of Blended Cement:

In the developing country, a massive amount of natural resources are used in the form of concrete ingredient for the construction of high rise buildings, bridges, and dams. The ingredients used for concrete comes from destroying natural form and hence the environmental imbalance occurs and with this human activities also produces waste from industries and agriculture such as FA, RHA, ground granulated blast furnace slag (GGBS), SF, MK, and materials from a demolished structure. The consumption of OPC in the world increases up to 2.5 million tons to 1.3 billion tons annually and it caused CO_2 emission [V. Ponmalar., 2015]. This creates an interest to utilize the alternative for cement in construction field. The use of sustainable material would reduce the demand for cement and natural resources for concrete production. Past research reveals that concrete manufactured using waste materials and by-products of the industry have superior qualities as compared to conventionally made concrete. These types of materials are utilized in altered quantities in the concrete mix either as a fractional replacement to cement or as mineral admixtures. Concrete manufactured with this material fly ash and ferrochrome ash shows enormous improvement in compressive strength, flexural strength, tensile strength, and durability comparing to the predictable control mix concrete (Das et al., 2014). The performances of two materials are highlighted below.

1.2.1 Fly Ash (FA):

Fly ash is waste generated at thermal power stations. Flushing is a powder, fine, soft and glassy material that is collected from a corrosive case by a bag filter. It is a construction materials which can be used in the concrete mix and replaced by the portland cement and it will make a low maintenance cost. Fly ash will give better strength from a different age. So this product will use in the construction work. It is also a friendly environmentally way out, which meet the show specifications. It contributes to leadership in energy and environmental design points.

1.2.2 Silica Sand:

Silica exists in natures in many forms but out of those most important are crystalline form such as quartz, Tripoli tridymite, etc. Silica sand is a primary product that contains quartz and coal as well as other product basically it is a loose granular material ranging in between 1.18 mm to 600 microns (used in the construction industry). Silica sand is a low priced product but contains a high proportion of silica nearly around 99% of SiO_2. Before the application of silica sand, it goes through many processes which include washing, sizing to remove unrequired sizes, cleaning of grains, and finally chemical processing to remove iron and other elements. It is generally white, pinkish, or brown color due to the presence of iron oxide. In 2016 global Silica sand production reached 280 million tons in a single year.

1.2.3 Recycled Coarse Aggregate (RCA):

Recycled Aggregate is extracted through the dispensation of debris generated as of demolition of concrete structures and other construction debris such as waste concrete, rejected precast concrete members, broken masonry, concrete roadbeds, and asphalt pavement, leftover concrete from ready mix concrete plant and the waste generated from different laboratories. Reused aggregates are made out of original aggregates and old adhered mortar. Mainly the different source of recycled aggregate are:-
1) Mortar, 2) Recycled Brick, 3) Waste ceramic, 4) Wall and Floor Tiles, 5) Precast RCA
The physical properties of reused aggregates rely upon both adhered mortar quality and the amount of adhered mortar. RA can be comprised of blocks, plates, and different random materials, for example, glass, woodland, cardboard, resilient and different trash alongside pulverized concrete. Recycled aggregate contains crushed and uncrushed parent aggregate covered with mortar, and little bits of masonry, waste ceramic and solidified mortar. Research on reused aggregate demonstrates that the water absorption limit of RA is higher than that of waste clay bricks, mortar, waste ceramic floor, and wall tiles and this is a direct result of porosity of adhered mortar. A few scientists contemplated that the compact density, apparent density and bulk density of NA is 12%, 3.3% & 13.3% higher than that of brick aggregate.

1.3 General properties and necessity:

1.3.1 Properties of Pervious concrete:

In general, the strength of pervious concrete depends on factors like water to cement ratio, aggregate gradations, cement content, and compaction level. The pervious concrete mix is stiff as compared to its conventional counterpart. Mostly high slumped pervious concrete is used for the concrete mix as they tend to have low slump such as 20 mm. The shape of aggregate also plays an important role in determining the workability of the concrete mix as pervious concrete made with uniformly sized aggregate requires less paste to provide the desired workability as compared to angular aggregates. Typical void contents range from 20 to 25% whereas density comes in the order of 1600 kg/m^3 to 2000 kg/m^3. The average permeability of the pervious concrete varies with the density of the mixture as well as with the aggregate size when the aggregate size is bigger the permeability is also larger. But most of the time it has been seen to fall in the order of 80 to 720 liters per minute per m^2. Water cement ratio is inversely proportional to compressive strength as when water-cement Ratio increases paste flowing from the aggregates increases whereas lower water-cement ratio reduces the adhesion between the aggregate finally decreasing the compressive strength.

1.3.2 Need for Pervious Concrete with recycled aggregate:

To address the problem of runoff and groundwater recharge we require technologies like Permeable pavement which are generally made with pervious concrete, these pavements provide a pathway to water to infiltrate down through roads, walkways, and parking lots [4-6]. Permeable pavements are made of different types of pervious materials but there is one common material in all permeable pavements that is aggregate, the amount of aggregate used in the pavement can vary largely depending on the type of pavement and aim behind building it. As reported by Mehta and Meryman [9], the concrete industry requires approximately 20 billion tons of raw material every year which was going to increase by 51 billion tons in the year 2020 [10]. As the rate of consumption is increasing the demand for aggregate is also increasing in countries like India therefore minimizing the environmental effect and carbon dioxide emission is turning a big problem for developing countries and the world.

1.4 Significance of Research:

The number of waste-producing industries has been increasing daily. The natural resources are depleting simultaneously. As a result of non-utilization of these wastes, the environment and groundwater are being polluted. In such a critical situation the recycling waste management has become the topmost global environmental concern. Reusing the wastes produced in the industry is more beneficial than their disposal. As a lot of natural wealth is used in the construction manufacturing, so proper utilization of industrial wastes in the construction industry can pave a path for the benefit of our atmosphere by preventing the over-application of our natural wealth. The waste products generated in the industry has been widely accepted in concrete manufacturing, demolished of old structures. This has encouraged many researchers in exploring and evaluating technologies. As the demand for aggregate, which is a major component of concrete, will continue to increase in the future, it is essential to use alternative cementations materials in order to reduce carbon emissions. The wastes from the ferrochrome industry utilized in this study are fly ash in addition to other byproducts of the industry are silica fume. The possibility of the utilization of these waste materials in the concrete making is explored in this research.

1.5 Gap in Research Area:

Previous researchers used silica fume and fly ash along with lime as partial replacement of cement, however, this combination of different mineral admixtures like silica sand, fly ash in preparation of recycled aggregate in pervious concrete is not been addressed in the literature. Since the production of lime released a huge amount of CO_2, use of silica sand and fly ash without lime may produce better sustainable concrete. The literature review revealed that using reused aggregate in pervious concrete is not explored. Hence a detailed investigation of compressive strength of pervious concrete by using reused aggregates containing fly ash and silica sand is needed. The effectiveness of different mineral admixtures from industrial waste with respect to permeability will also be explored.

1.6 Objectives of the present study:

The specific objectives of the present study are as below: -

1. In this study, primarily the objective is to utilize industrial waste such as recycling aggregate which is available in huge quantities in Taiwan. Fly ash and silica sand is supplemented with other mineral admixture from industrial waste as a fractional substitute for the cement to eliminate the additional requirement of lime.

2. To carry out a literature review for detailed analysis and understanding with the help of recycled aggregate.

3. To find out the percentage use feasible for construction.

4. To study the effect of recycled aggregate on durability and mechanical the behavior of concrete by using mineral admixtures like fly ash and silica sand based pervious concrete.

5. To Study the variation in strength with the replacement of recycled aggregate in concrete.

6. To carry out the impact of waste materials on the environment.

7. To utilize the recycling waste material into beneficial project work.

1.7 Organization of the Report:

The current research was organized into five chapters. Following are the brief summarized of the report:-

Chapter-I Presents the introduction which contains general study related to the topic, the research gap and objective of the study.

Chapter-II Presents a general overview and discussions of literature from various journals and publications**.**

Chapter-III Performance of recycled aggregate on mechanical and durability properties of pervious concrete by using fly ash and silica sand are presented in this chapter.

Chapter-IV Results with a detailed discussion of the study carried out on the behavior of pervious concrete by using silica sand and fly ash with partial replacement of coarse aggregate by recycled aggregate is presented in this chapter.

Chapter-V Overall conclusions of the study with various recommendations from the author are presented in the last chapter to bring out the outcome of the present work.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature review on the materials:

2.1.1 Literature review on Recycled aggregate:

Oikonomiu (2005) analyzed the optimal recipes for the manufacture of ecological mortars via plastic recycling waste. Mortars containing plastic waste have the gain that their production is less polluting, as it does not contain excessive strength intake and finalized with the improvement of new building substances.

Khatib (2005) studied the characteristics of concrete incorporating reprocessed aggregates from waste materials. He used recycled fine aggregates to study mechanical properties. He used 0-100% recycled aggregates replaced by fine aggregate. Concrete containing recycled aggregate exhibited more strength properties than control concrete after 28 days.

Rakshvir et. al. (2006) studied recycled aggregate-based concrete. The mechanical and physical characteristics of recycled aggregate-based concrete samples. For increment in reused aggregate content, the mechanical strength had recorded maximum declination at ten percent.

Evangelista et. al. (2007) concluded that the utilization of reprocessed fine aggregates in concrete does not deteriorate the compressive strength of samples, for partial replacement up to the range of thirty percent.

Rao et.al. (2007) reported the various methods in which debris and wastes of construction can be utilized for concrete manufacture. Authors also suggested that the use of these waste materials could be useful in the production of concrete.

B. Cachim (2009) presented the substitution of natural aggregates (NA) by properties of concrete made with crushed bricks. The bricks had been beaten in an effort to gain a usable aggregate. The properties like workability and the density of fresh concrete, compressive strength, splitting tensile strength, modulus of elasticity behavior of hardened concrete are studied. Substitution proportions of natural aggregates by way of beaten bricks 15% and 30%.

Anna Halica et al (2013) investigated the effect of partial replacement of cement by ceramic and alumina waste in recycled aggregate concrete. He concluded that alumina and ceramic waste have an affirmative effect on concrete for properties such as strength and abrasion resistance.

C Thomas et al (2016) studied the effect of adding recycled aggregate for a precast mix. He in his research observed that replacing recycled aggregate up to 20 percent showed significant results as it acquired desired strength.

C. Zheng et. al. (2018) investigated the effect of the substitution of natural coarse aggregate with either recycled concrete aggregate (RCA) or recycled clay brick aggregate (RBA) at the compressive strengths of the hardened concrete.

M. C. S. Nepomuceno et. al. (2018) presented the substitution of coarse aggregates (NCA) by recycled ceramic mixture (RCA). Concretes were produced with RCA replacing NCA in absolute volume percentages of 0%, 10%, 30%, 50% and 75%. The partial replacement of NCA by means of RCA, regardless of the mechanical overall performance of concrete decreases with the increasing substitute of NCA with the aid of RCA.

M. Panizza et. al. (2018) analyze the assessment of metakaolin-slag potassium silicate geopolymer mixtures containing concrete and clay aggregates from Construction and Demolition Waste (C &D Waste). Based on the experimental outcomes it's been visible that the geopolymers with Construction and Demolition Waste (CDW) confirmed promising properties to be used in building elements despite 50% of aggregates and extra are used inside the concrete.

K. Rashid et. al. (2018) analyzed the compressive strength test after 7, 28, 90 and 180 days of curing. All type of recycled materials are utilized & adversely affected compressive strength, especially after curing age 180days.

S. El-Dieb et. al. (2018) completely replaced cement with ceramic waste powder (CWP) on the performance of fresh and hardened properties of concrete. In this investigation, concrete mixtures incorporating CWP as cement replacement with different replacement levels (i.e., 10%, 20%, 30% and 40% by mass) were examined. Three concrete grades with different cement contents were used (i.e., 25 MPa, 50 MPa, and 75 MPa). The fresh concrete workability retention of the mixtures was evaluated by measuring time to reach zero slumps. Compressive strength development with age (i.e., 7, 28 and 90 days) and drying shrinkage strain at 120 days was measured. The chloride ion penetration and bulk electrical resistivity were conducted to evaluate the durability performance of the mixtures. The use of 10% CWP replacement level was adequate for strength improvement, replacement levels between 10% and 20% could be used to improve workability retention while a level of 40% replacement was needed for durability enhancement.

J. Zhang et. al. (2018) investigated the effect of the accelerator on the rapid-hardening properties of controlled low strength materials (CLSM) and evaluate the workability, mechanical properties of controlled low strength substances. Fly ash is used as a source material. Redbrick is used as a recycled aggregate which is collected from the construction and demolition (C&D) waste.

2.1.2 Literature Review on fly ash:

Llyod et.al. (1987) performed an investigative study on the role of fly ash in a gain of early strength in mortar prepared by a fractional substitute of cement with fly ash. Six different proportions of fly ash were used for fractional substitute of cement by weight, the percentages of fly ash ranged from ten percent to sixty percent. The author used fly ash having class F. A reference sample was prepared using OPC cement having no fly ash. Compressive strength test and tensile strength test of the prepared concrete samples were done for various time periods starting from 3 days to 90 days.

Gengying et. al. (2005) observed that the gain in compressive strength for the cement mortar comprising coarse fly ash required a larger duration of time in comparison to the reference sample.

Brito et.al. (2012) made a comparative study in the carbon dioxide emissions from cement the production which is produced due to reactions of calcium carbonate and due to the combustion of fuel used for combustion. Cement industry contributes five percent to the worldwide carbon dioxide emissions. The emissions of CO_2 and other harmful gases can be reduced if industrial by-goods such as fly as is used as a partial cement substitute. Fly ash proportions for cement replacement by weight were taken in the range of 0 – 20 percent. The authors also conducted tests for determining the mechanical properties of concrete. It was concluded that the addition of fly ash in concrete as a partial cement replacement enhances the durability.

2.1.3 Literature Review on Pervious Concrete:

Also called zero slump concrete and porous concrete by ACI pervious concrete is an open-graded concrete consisting of materials likes Portland cement, coarse aggregate, admixtures as per requirements, little to no fine aggregate as per mix design and water. Below is are the literature review of pervious concrete.

As mentioned by Malhotra 1976 the history of the pervious concrete is states as back as 1852. Two houses were found built using gravel, water, and cement in the UK. In the 1923 people started accepting pervious concrete construction and by the 1930s pervious concrete structures were found in most of Europe. After World War II and its devastation, pervious concrete construction picked up a new pace as there was a requirement of fast and long-lasting construction.

Compaction also affects the properties of pervious concrete deeply as over compaction reduces the ability to drain the surface water and void content whereas insufficient compaction results in surface raveling and low strength (Meininger, 1988; Schaefer et al. 2006; Sumanasooriya and Neithalath, 2011). Therefore, for permeable concrete pavements, roller compaction is needed as it consolidates near-surface aggregate resulting in stronger bond but decreases surface permeability. Troweling and floating operations are not performed on PCP as they tend to close surface area (Tennis et al., 2004; ACI, 2010; Obla, 2010). The stormwater reduction is the primary purpose of pervious concrete, therefore, it must contain minimal fine aggregate as well as uniformly sized CA creating more void space in the matrix for transporting and holding water (Zouachi et al, 2000).

The aggregate size of pervious concrete is generally in the range of 9.5 to 19 mm that can be singly sized or narrowly graded (ACI 2010). As compared to uniformly graded singly sized aggregate produces larger pores and improves permeability but decreases the infiltration rate and porosity (Schaefer et al., 2006). The addition of fine aggregate is most often excluded but have an affirmative effect on pervious concrete as the addition of fine aggregate in a small amount (up to 7% wt. coarse aggregate) not only increases flexural strength and compressive strength but also improves density and freeze-thaw durability maintaining the permeability rate as well. (Wang et al., 2006; Schaefer et al., 2006; Kevern et al., 2008; Henderson and Tighe, 2012). The aggregate shape also impacts the concrete mix round-shaped aggregate such as gravel increases the compressive strength and demonstrates lower void content whereas angular aggregate which is oriented in one direction during compaction negate bonding and contact area therefore flaky and elongated aggregates are averted in pervious mix (Tennis et al., 2004; Kevern et al., 2010; Lian and Zhuge, 2010). Aggregate to cement ratio is inversely proportional to compressive strength but directly proportional to permeability as less cement paste binds aggregate particle (Ghafoori and Dutta, 1995). According to ACI 2010, a/c ratio of the pervious concrete must be in a typical range of 4 to 4.5. Aggregate moisture content also must be taken in count as dry aggregate reduces the workability for compaction and placing whereas the wet aggregate contributes to pastedown, potentially clogging the concrete (ACI, 2010).

2.2 Review on Compressive Strength

The primary drawback for pervious concrete is its low compressive strength and with the use of recycled aggregate, it is going to decrease furthermore. As the bond between aggregate and concrete is very weak it cannot provide sufficient strength to pervious mix as compared to its conventional counterpart. Therefore, the traditional choice was to use pervious concrete where high strength is not required such as pavements. The compressive strength of pervious concrete depends on various factors such as water-cement ratio, aggregate size, and type of aggregate used. Meininger, McCain, and Dewoolkar in their studies reported that the optimal range for the use of water-cement ration is (0.35-0.45) as in this range there is better workability, bonding also improves significantly transforming a high strength mix.

According to a study conducted by Schaefer et al., 2006 suggested that compressive strength not only depends upon aggregates, w/c cement, and compaction but also depends on interface between aggregate and paste, the strength of the paste, as well as thickness of paste coating the aggregate, therefore, smaller coarse aggregate with mineral admixtures, provide better results as compared to their counterparts.

A study by Wang at al. 2006, concentrates on increasing the compressive strength of pervious concrete without compromising permeability. Some positive results were achieved by adding small amounts of fines, fibers, and latex. The most success was realized in samples with 7% of fine sand, which increased the compressive strength on average by 46% while still maintaining adequate permeability. The finesse modulus of the river sand fines used was 2.9, the specific gravity was 2.62, and the absorption was 1.1%.

It is agreed that achieving the balance between porosity (voids) and compressive strength is the single biggest challenge with mixing pervious concrete. Inconveniently, the compressive strength decreases as the porosity increases. Same as the compressive strength, the unit weight increases with compaction efforts while porosity and permeability decrease. (Chopra et al. 2007)

According to Crouch et al 2006 and ACI, 2010 minimum design strength of pervious pavements not exposed to vehicular moments should be 13.8 MPa. On the other hand, pavements exposed to vehicular moments must have a design strength of 20.7 MPa subjected to low-speed accountability (Hager 2009).

Table 2.1- Literature review on the basis of the finding of different authors

Authors	**Research Overview**	**Conclusions**
Meininger et al. 1988	Effect of w/c ratio on pervious concrete	An optimal range of water-cement ratio (0.35-0.45) which results in better workability, good bonding between aggregate and cement paste therefore providing high compressive strength required
Ghafoori and Dutta et al. 1995	They studied the relationship between compressive strength with compaction energy having no fine aggregate and by varying the a/c ratio	The relation between compaction energy and compressive strength is non-linear; with greater incremental increases in compressive strength at low compaction energies and almost no incremental increase at compaction energies above 5,000 lbs/ft3
Kevern *et al.* 2006	They conducted research on Placements of pervious hardened materials. Slab samples were placed in the laboratory using different field-based methods.	Rolling number increases when a light roller is used which densified the surface layer whereas more some passes with a heavy roller produce more uniform compaction. The graph between porosity vs density for a particular mix found to be linear in nature.
Wang *et al.* 2006	The effect of size of aggregate with shape and gradation along with admixtures dosage were studied using freeze-thaw durability as a principal criterion	Strength and durability were increased dramatically at the same time by using 7% fine aggregate by weight of coarse aggregate Under a criterion of compressive strength greater than 20MPa, less than 5% mass loss at 300 cycles using the ASTM C666A method and permeability greater than 0.1 cm/s.
Suleiman *et al.* 2006	The impact of different materials was studied using different compaction energies.	Specimens having the same mixed proportions have different strengths, different energy, and different permeability. Low compaction mix observes much higher freeze-thaw deterioration
Schaefer and Kevern 2007	Effect of stormwater on pervious concrete mix was studied by constructing a real-time payment	Favorable results were not obtained as sensor installation was not properly set up as well as aggregate layer delayed the frost formation
Kevern *et al.* 2008b	Freeze and thaw property of various concrete mix were studied with regard to water-cement ratio, replacement percentage, admixture used and concentration applied	Compaction procedure, as well as compaction method significantly, improves the durability. Increasing water concentration improves the durability of specimens without sand. Application of latex has defect effect on workability and durability.

Table 2.2 – Recommended A/C (aggregate to cement ratio) and W/C (water to cement ratio) reviewed in the literature

Source	Aggregate size	A/C	W/C
Meiningener 1998		NA	0.35 to 0.45
Ghafoorie and dutta 1995 a	20 mm to 10 mm	4:1 by weight	0.37
		4.5:1 by weight	0.38
		5:1 by weight	0.39
		6:1 by weight	0.42
Montes and haselbach 2006	16 to 10 mm	4:1 by weight	0.25 to 0.26
Crouch et al 2007	20 mm to 10 mm	4.47:1 to 5.64 by weight	0.3
chopra et al 2007	10 mm limestone	4:1 to 7:1 by volume	0.33 to 0.52
Kervern et al 2009		4 to 10	0.24 to 0.30
Bassuoni & Sonebi 2010		4 to 6	0.28 to 0.40
Nguyen et al 2013		4.9	0.30
Yahia & Kabagire 2014		NA	0.30
Chandrappa et al 2016		3 to 5	0.25 to 0.35
Khankhaje et al 2016		NA	0.32

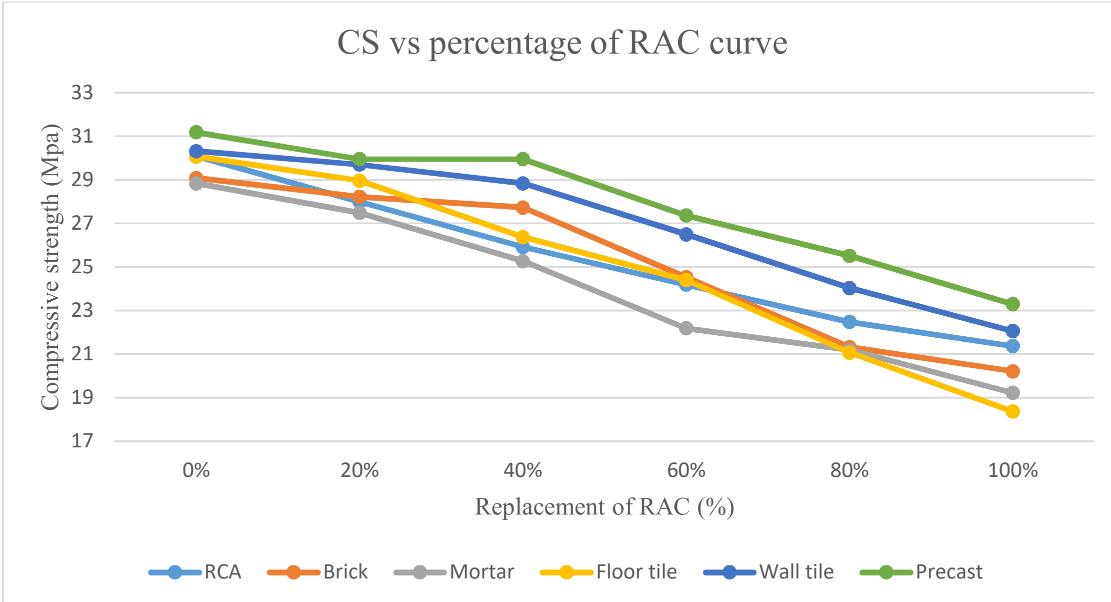

Figure 2.1- Compressive Strength of RCA using different types of recycling waste

2.3 Review on Permeability

One of the most discerned properties of pervious concrete is its high permeability, which is a measure of fluid flow with ease through the material under a pressure gradient. Permeability basically depends on pores structures that are porosity which is the number of pores present in concrete. To make concrete more pores little to no fine aggregate are mixed which has pros and cons at the same time.

Lian et al. (2010) concluded that the addition of superplasticizer constituent's silica fume in small amounts also can increase mechanical as well as permeability property of the pervious mix.

Ravindrarajah et al. (2010) studied the mechanical and durability property of pervious concrete by replacing the cement with fly ash also varying the percentage used. In his studies, he concluded that with an increase in fly ash concentration compressive strength of the mix decreases and replacement of fly ash up to 50% does not have big significance on the permeability.

Jain et al (2011) studied the permeability of pervious concrete with respect to the size of aggregate and water-cement ratio. He in his study concluded that as aggregate size increases water permeability also increases.

Ajamu et al. (2012) investigated the compressive strength and permeability of pervious concrete varying the aggregate cement ratio and aggregate sizes. Aggregate cement ratio of 6:1 reflected the highest compressive strength in comparison to 10:1 and 8:1. Specimen with higher aggregate cement ratio must be used in pavements where there is not a high requirement of strength as compared to permeability.

Rasiah et al. (2012) studied the behavior of pervious concrete partially replacing the cement with ground granulated furnance slag and concluded that as the amount of GGBFS increases the permeability of the mix decreases and compressive strength increases.

Patel et al. (2014) studied the pervious concrete behavior by substituting the cement with silica fume and fly ash. She concluded that when the water-cement ratio is increased the permeability of concrete mix decreases whereas compressive strength is increased for the mix containing 10 % silica fume and fly ash.

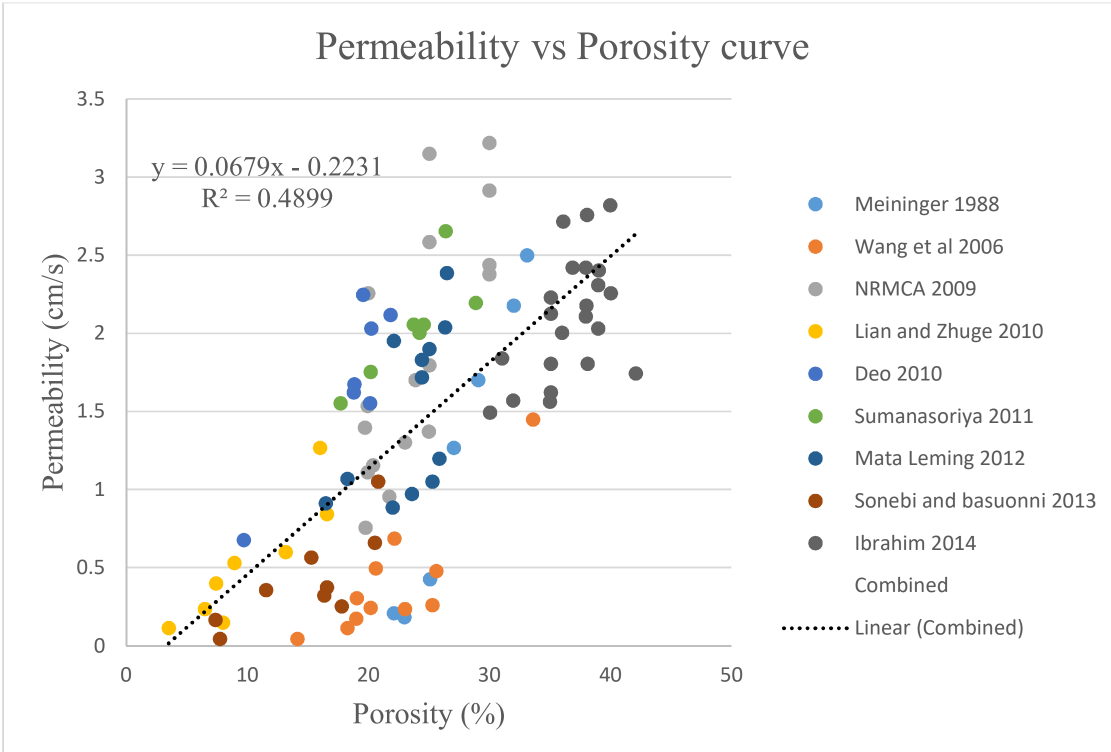

Figure 2.2- Correlation between permeability and porosity for a wide range of pervious concretes reported in the literature

CHAPTER 3

PERFORMANCE OF RECYCLED AGGREGATE ON MECHANICAL AND DURABILITY PROPERTIES OF PERVIOUS CONCRETE

3.1 General

Fly ash is waste generated at thermal power stations. Flushing is a powder, fine, soft and glassy material that is collected from a corrosive case by a bag filter. It is an environmentally friendly solution that meets performance specifications. It gives better strength from the different age. It's positive to think that if we add extra 20% -30% of fly ash in concrete replaced by cement then it will give better results for different curing ages. According to the various research and experimental studies conducted in the available literature and the current study, the fly and silica sand was found to be highly suitable for construction work as it solves the problem of deposition or dumping of less useful products of the industry and also a good quality material for construction.

Past studies indicate that no detailed structural behavior of the cylinder specimen using silica sand and fly ash with partial replacement of coarse aggregate by the recycled aggregate in pervious concrete has not been investigated. To bridge the research gap, this study investigated the structural behavior of reinforced concrete (RC) cylinders using recycled aggregate as coarse aggregate. This chapter describes an experimental investigation on the performance of reinforced concrete cylinders by using recycled concrete aggregates (RCA) as a partial replacement for coarse natural aggregates. The US body for sustainable construction and practices mostly focuses on the replacement of cement with natural admixtures such as silica fume, fly ash, and polymers). Meanwhile, conservation of virgin aggregate has been ignored which constitutes up to 40 to 50% of the concrete mix. Partial replacement of virgin aggregate creates a new window for us as it reduces our dependability on natural admixtures, and paves way for a more sustainable mix.

3.2 Materials:

The details of the characteristics of different materials used like fly ash, ferrochrome ash, fine aggregate, coarse aggregate, recycled aggregate, water, silica sand are explained below.

3.2.1 Fly ash:

Fly ash is waste generated at thermal power stations. Flushing is a powder, fine, soft and glassy material that is collected from a corrosive case by a bag filter. It is a construction materials which can be used in the concrete mix and replaced by the Portland cement and it will make a low maintenance cost. It is an environmentally friendly solution that meets performance specifications, if we add extra 20% -30% of fly ash in concrete replaced by the cement then it will give better results for different curing ages.

Figure 3.1: Fly ash (source, Douliu, Taiwan)

Table 3.1 Chemical Composition of Fly ash (% by weight):

Sl Number	Constituent	Fly ash
1	Na_2O	1.02
2	MgO	1.41
3	Al_2O_3	25
4	SiO_2	59
5	P_2O_5	0
6	SO_3	1.5
7	Cl	0
8	K_2O	1.46
9	CaO	6.9
10	Cr_2O_3	0
11	MnO	0
12	Fe_2O_3	3.7
13	NiO	0
14	CuO	0
15	ZnO	0
16	Ga_2O_3	0
17	Br	0
18	Rb_2O	0
19	SrO	0
20	PbO	0

3.2.2 Coarse Aggregate:

Coarse Aggregate was taken from the local market has a minimum size of 10 mm and a maximum size of 20 mm. Only two types of aggregate were used.

3.2.3 Recycled aggregate:

The coarse recycled concrete aggregate (RCA) in this research was sourced from demolished structures, waste samples that were obtained from the Guitian Lab, Douliu, Taiwan. The original concrete has been cured properly with a maximum aggregate size of 40 mm. As per the procedure of ASTM C 128, the specific gravity of recycled coarse aggregate was ranged between 2.2-2.6 and the natural coarse aggregate was 2.7. The difference was mainly occurred because of the old adhered mortar attach to the RCA. Non-crushed granite of 10 mm & 20 mm size is used as a coarse natural aggregate.

Figure 3.2: Recycled Aggregate (source: Douliu, Taiwan)

3.2.4 Water:

Clean potable water as obtained from the laboratory of Green Technology department, Nanhua University, Taiwan was used for mixing and curing of concrete.

3.2.5 Silica Sand:

Silica exists in natures in many forms but out of those most important are crystalline form such as quartz, Tripoli tridymite, etc. Silica Sand is a loose granular material basically consists small grains or particle of mineral silica (ranging in between 1.18 mm to 600 microns (used in the construction industry) other than that it also includes aluminum, felspar, and iron-bearing minerals. Silica sand is a low priced product but contains a high proportion of silica nearly around 99% of SiO_2. Before the application of silica sand, it goes through many processes which include washing, sizing to remove non required sizes, cleaning of grains, and finally chemical processing to remove iron and other elements. It is generally white, pinkish, or brown color due to the presence of iron oxide. Silica Sand is generally used for making glass after the number of processes in construction industry silica sand is not widely used as it does not meet construction industry requirements of purity and physical characteristics such as grain size and distribution, grain strength, grain shape, and refractoriness. In 2016 global Silica sand production reached 280 million tons in a single year.

Figure 3.3: Silica Sand (source: Douliu, Taiwan)

3.3 Mix Design:

An absolute volume mix design method was considered in this study with & without the effect of recycled aggregate was also examined in these proportions.

In the mix design, the following preliminary data are taken into consideration:

1. Characteristics of pervious Concrete (fck) Compressive Strength = 20 MPa
2. Cure type: Cure in water tank for 24 hours and test after 28 days.
3. Aggregates bulk density: 1299.1 kg/m^3
4. Fly ash: fineness on a specific surface: 430 m^2/kg
5. Cement: bulk density 540 kg/m^3
6. Design steps

i. Calculation of volume of cylinder
a. Volume of one cylinder $V = \pi r^2 h$
R=150 mm and height= 300 mm
V= 0.0212 m^3
b. Weight of one cylinder= 0.212*2400=50.89 kg
ii. Calculation of volume of Concrete for M20 grade
a. Volume of cement for 1 m^3=1/(1+4)= 0.2 m^3
weight of cement per m^3= 0.2*1440= 288 kg
b. Volume of aggregate for 1 m^3= 0.2*4= 0.8 m^3
weight of aggregate per m^3= 0.8*1520= 1216 kg
iii. W/C ratio= 0.35
weight of water= 258.16/0.35= 737.6 kg
iv. Density of concrete = weight of (cement+aggregate+water) per m^3

$=288+1216+737.6= 2241.6$ kg/ m^3

v. weight of concrete for one cylinder= 2241.6*0.0212= 47.52 kg

On the basis of above design, other calculations can be done and the material used for making of cylindrical mold is shown appendix.

3.4 Experimental Methodology

3.4.1 Preparation of concrete specimens

The cylinder was layered by means of oil on its internal surface, in addition, to being positioned on a granite stage. The quantity of fly ash, silica sand, recycled aggregates necessary for specimens are measured. First, a dry mix is done in concrete mixer containing coarse aggregate and mineral admixtures for about 2-3 minutes then wet material like water and liquid plasticizer are added according to specified amount and mixer is allowed to rotate for 5 more minutes. After the completion of both the mix concrete is cast properly in three layers with 40 tampings associated with each layer. The wet mix is allowed to dry for one day after which is placed in a waterlogged tank.

3.4.2 Mixing procedure

Uniform mixing of concrete should be ensured to get the correct test results of the specimen. Initially, the recycled aggregate was weighed for the required quantity as per mix proportioning in a tray; the completely dry coarse aggregate was weighed and poured into another mixing tray. Fly ash or silica sand was weighed and uniformly spread over the surface of aggregates and uniform mixing was ensured. Mixed admixtures and aggregates were uniformly spread over the recycled aggregate. Then dry mixing was carried out. Later water was mixed with the dry mix and mixing was ensured up to a minimum of 5 minutes until the uniform color of concrete is seen. The color of pervious concrete based on fly ash is light black.

Figure 3.4: Concrete mixer used in the research

3.4.3 Casting of cylinders

An absolute volume mix method was used to find out the concrete mix proportions. It is an accurate method for making concrete specimen occupying unit volume using specific gravity for all the ingredients used. After suitable mixing, the concrete was pouring into the mold, cylinders, and beam immediately with 3 layers and each layer tampers 25-30 times simultaneously. After casting, the specimen was kept in a water tank for 24 hours. After one day, the specimen was kept in the curing chamber for 28 days, and then again specimen was again kept at room temperature.

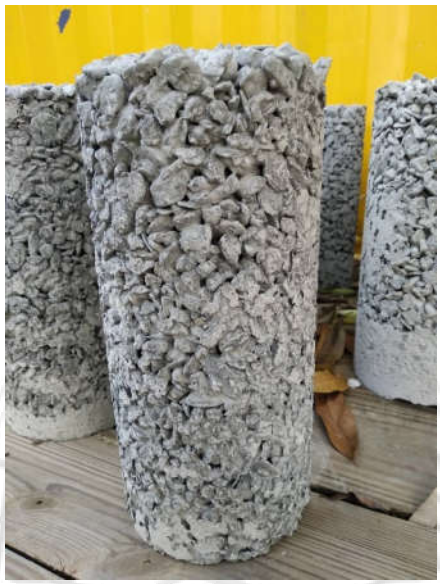

Figure 3.5: Sample specimen picture

Figure 3.6: Set of specimens sample picture

3.4.4 Curing of specimens

For pervious concrete, all materials, chemicals, and mixtures are adequately mixed and cured at room temperature. Pervious concretes based on fly ash and silica sand does not immediately set in cylinders if the room temperature is less than 30°C therefore sustainable arrangement must be done for the same. After the initial setting, they must be preserved in a waterlogged tank therefore in our study also after 24 hrs specimens were placed in the water tank as per ACI (American Concrete Institute) guidelines.

3.4.5 Compressive strength

Out of many tests applied to the concrete, this is the utmost importance property which gives an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. Strength durability and structural performance of concrete are affected by the compressive strength of concrete, therefore, becoming for the most effective behavior of the hardening of concrete. Property of RAC relies upon several factors for example w/c ratio, use of superplasticizer, mineral dust content, water absorption, curing condition. The shape and sizes of aggregate affect the compressive performance of RAC. The amount of adhered mortar is high the compactness is also high therefore to achieve a better quality of cement matrix.

Although much research has been conducted in the past on pervious concrete compressive strength but testing must still be accomplished to understand the nature of pervious concrete fusion with mineral admixture. In this research, one hundred twenty-two (122) test cylinders were created and used as a representative sample of varying mixture ratios (i.e. A/C ratio and W/C ratio). The cylinders used for testing were one-time use only. These cylinders are four inches in diameter and eight inches in height. The pervious concrete was made from 20 mm and 10 mm aggregate and Type 1 Portland Cement. The test cylinders used and the pervious concrete mixed are in accordance with CNS 1232. Characteristic details of the specimens are given in the table placed in the appendix.

3.4.6 Permeability

One of the most important features of pervious concrete is its ability to allow percolation of water through the matrix. The percolation rate of pervious concrete is directly related to the air void content. The Polyvinyl chloride (PVC) pipe was placed on the pervious concrete specimen and was properly sealed with the contact surface of the specimen in order to avoid leakage. The permeability test was carried out when the quantity of water allowed to flow into the specimen through the PVC pipe was such that the constant head of water could be maintained at the desired water head in the inlet pipe. The water flow rate can be controlled by means of allowing a certain amount of water to pass. The flow rate of water can be determined by measuring the volume of water collected in the water tank over time for a particular head of water. The coefficient of permeability k in $L/min/m^2$ can be expressed.

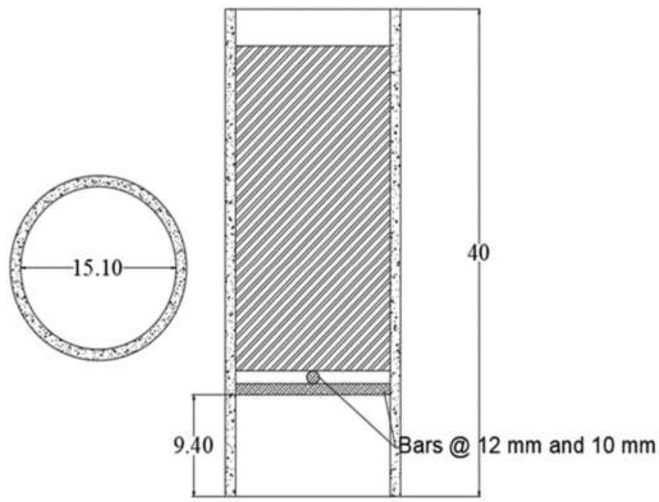

Figure 3.7: Cross sectional and side view of experimental setup (dimensions are in cm**)**

CHAPTER 4

RESULT AND DISCUSSION

This chapter will extensively discuss the results of the experiments described in the previous chapter. Comparisons will be provided of relevant relationships between water, aggregate, and cement to show the influence each has on one another. Tables indicating minimum pavement thickness levels will also be given. As mentioned above there are a total of 122 samples prepared to vary the reused aggregate content as well as by varying the admixture content of the cylindrical sample in the percentage of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60. There are a total of 3 types of admixtures used with natural and recycled aggregate namely silica sand, fly ash and combination.

For permeability calculation, a typical constant head method was used following the guidelines of ACI 522R-10. Test conducted at Nanhua University used a PVC pipe having 15.1 cm diameter and 40 cm height, two 10 mm steel rods, and a bucket as shown in the figure. In this experiment 1 liter of water was supplied to the concrete specimen for a duration of 1min, water which passes through the specimen and drained at the bottom of the bucket was then collected and measured. The same procedure is reiterated 5 times until the volume of water collected gets constant. The Cross-sectional and side view sketch of the experimental setup is shown in the figure 3.7 and figure 4.1.

Figure 4.1: Permeability experimental test setup

From the permeability test of the sample containing W/C 0.40 (10 mm), it was observed that permeability first increase and then decreases becoming nearly same as that of conventional pervious concrete when silica sand and fly ash were used silica sand showed better permeability results as compared to it has larger diameter increasing the permeability as shown in figure 4.2 and 4.3.

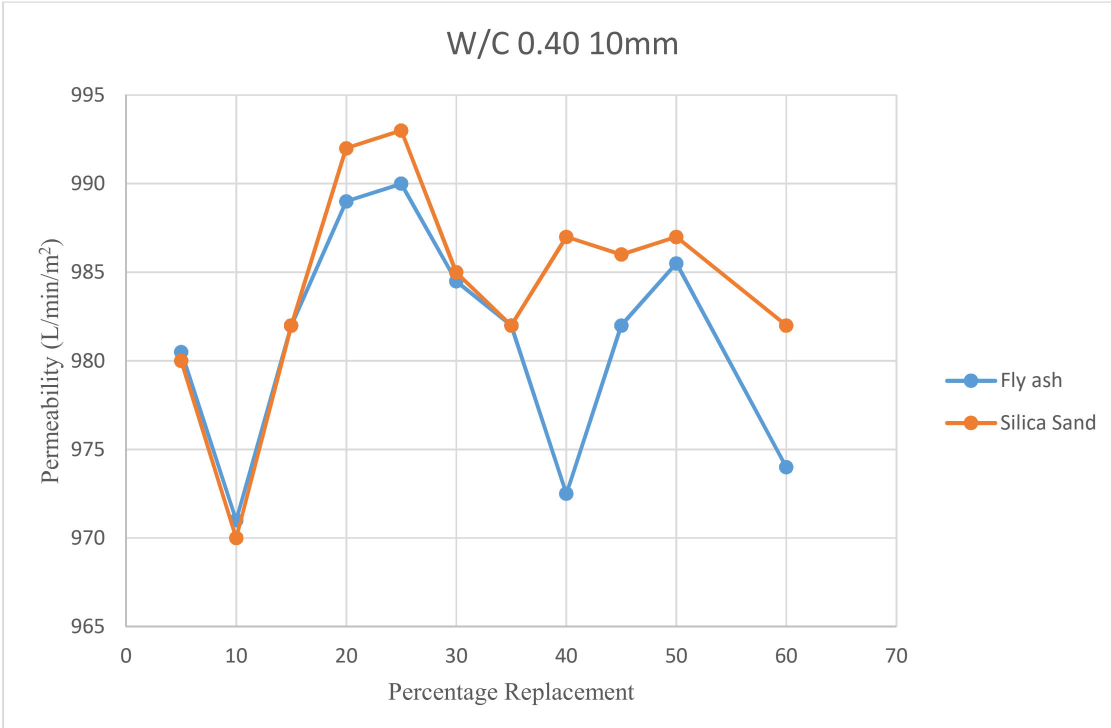

Figure 4.2: Permeability curve for W/C 0.40 (10 mm)

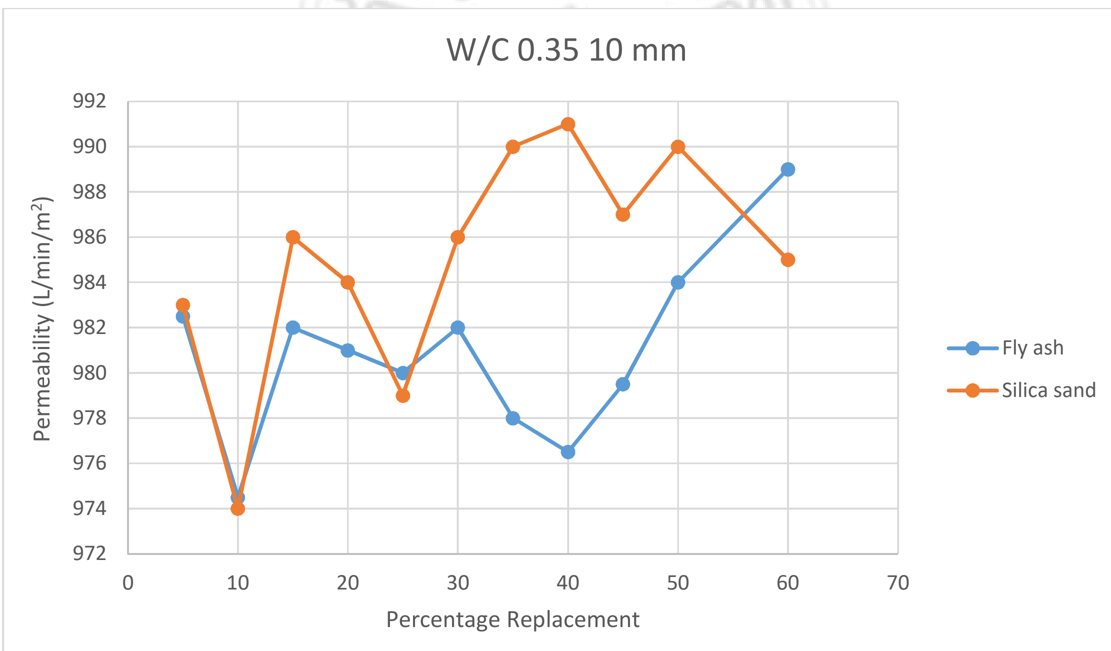

Figure 4.3: Permeability curve for W/C 0.35 10 mm

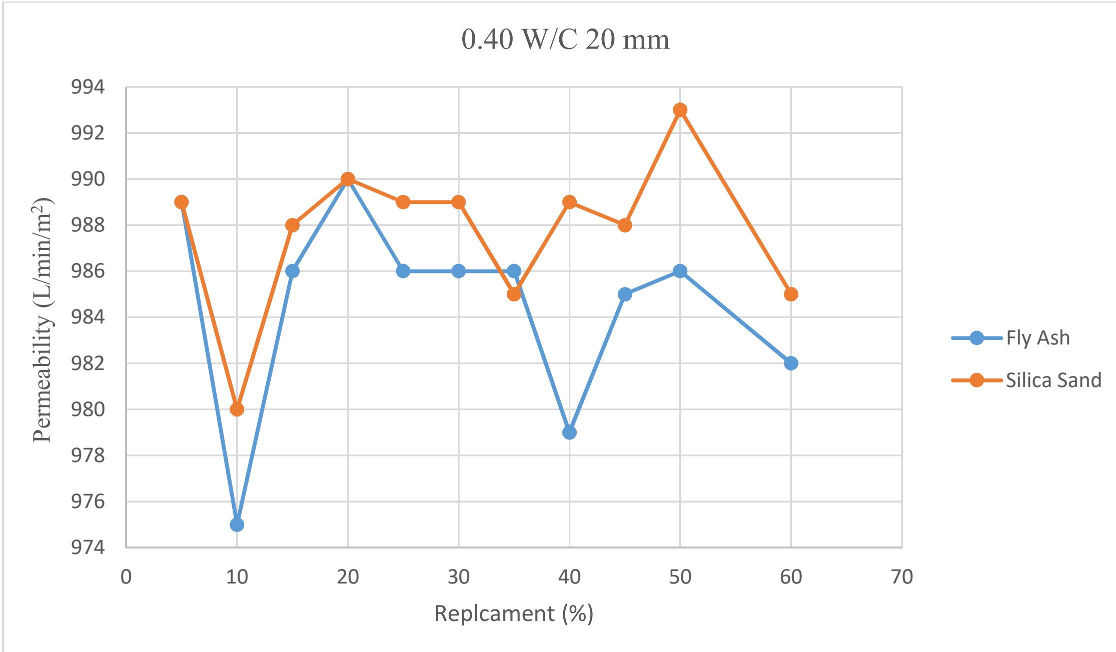

Figure 4.4: Permeability curve for W/C 0.40 20 mm

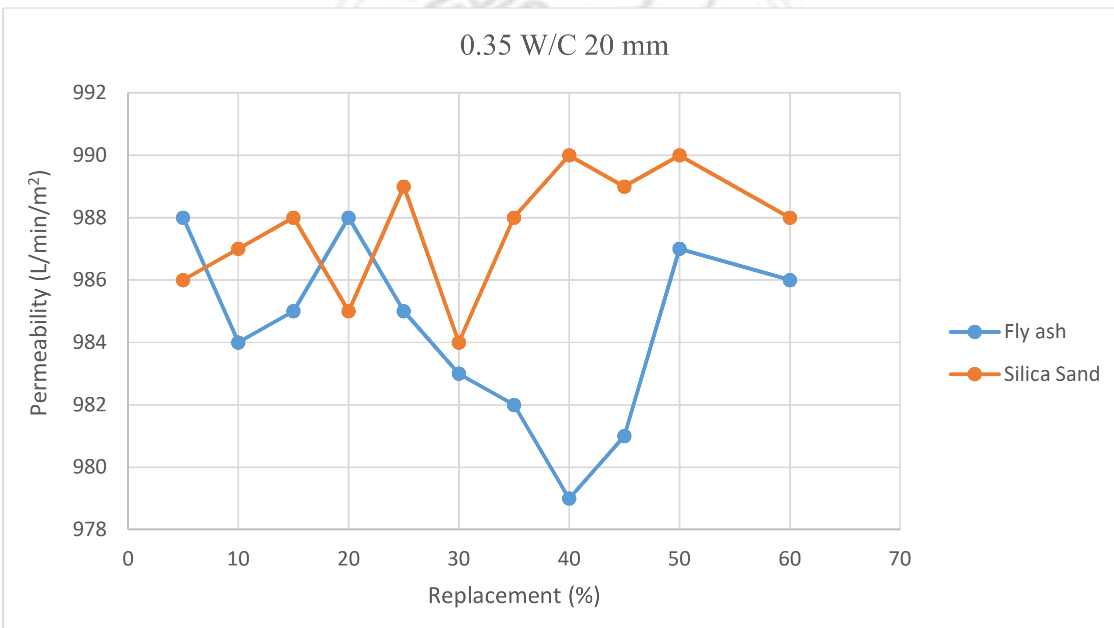

Figure 4.5: Permeability curve for W/C 0.35 20 mm

It can be observed from the permeability curve for 20 mm aggregate (figure 4.4 and figure 4.5) that it tends to decrease with increase in partial replacement of mineral admixture it can also be observed that silica sand showed better permeability as compared to fly ash due to presence of larger diametrical particle resulting in better permeability.

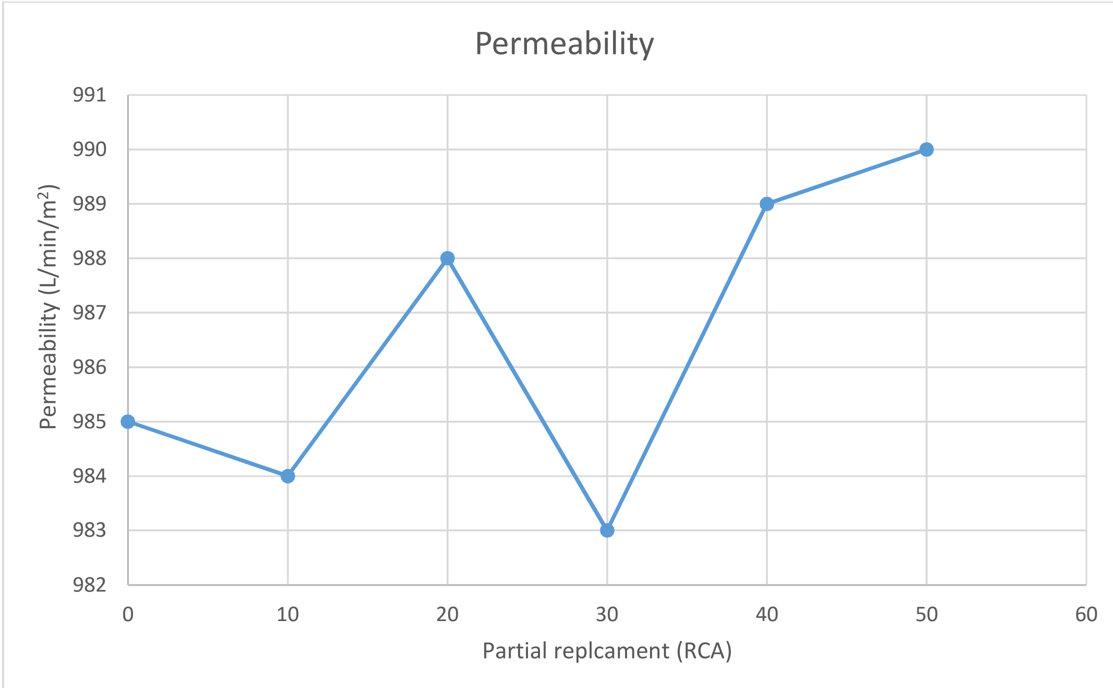

Figure 4.6: Permeability curve for Recycled aggregate concrete (RAC**)**

From the permeability experiment for the RAC, it can be observed as compared to conventional pervious mix RAC mix have better permeability which can be explained as the bigger diameter of particles were used as compared to regular pervious aggregate tends to creating bigger void ratio, therefore, increasing the permeability as shown in figure 4.6.

The performance analysis of the compression test was to obtain the compressive strength of the concrete. All the compressive strength test was done in accordance with CNS 1232. Figure 4.7, figure 4.8, and figure 4.9 depicts the compressive strength results obtained. As it can be depicted from the graph that initially compressive strength tends to increase for specimens containing mineral admixture but as a percentage of mineral admixture tends to increase more than 20% compressive strength of the mix gradually decreases which can be explained as the fly and silica sand lack binding ability as compared to cement initial increase is because of fact that there is a great bond between fly ash, cement particle and aggregate creating a perfect mix whereas when the concentration of admixtures are increased more than required specimens lose its binding ability resulting in low compressive strength.

When a 10 mm sized aggregate is used it results in a more compacted and singular mix as compared to 20 mm aggregate as creating more porosity and void resulting in a decrease in compressive strength. The compressive strength test of RAC showed that as replacement of RCA increases the compressive strength of RAC decreased significantly as shown in the figure which is a result of improper bond formation between adhered mortar, conventional aggregate, and recycled aggregate of uneven size.

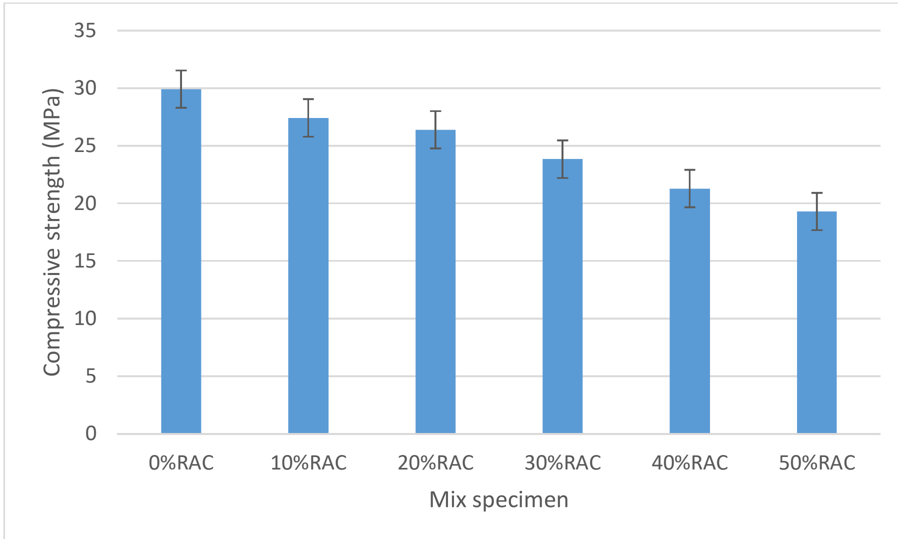

Figure 4.7: Compressive strength of various percentage of RAC

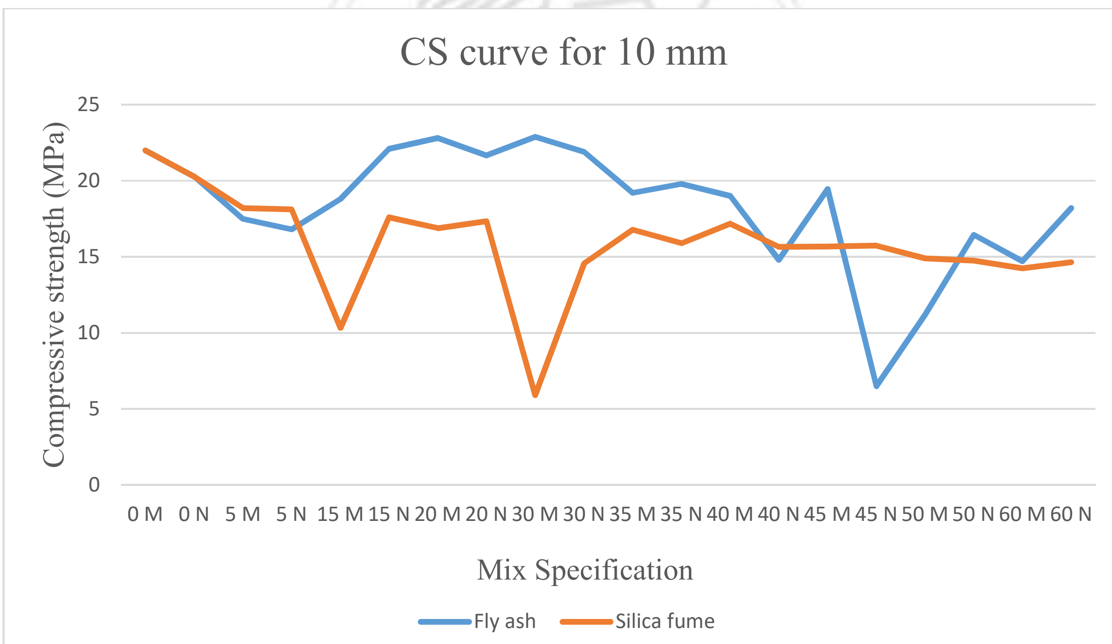

Figure 4.8: Compressive strength of various percentage of 10 mm pervious mix

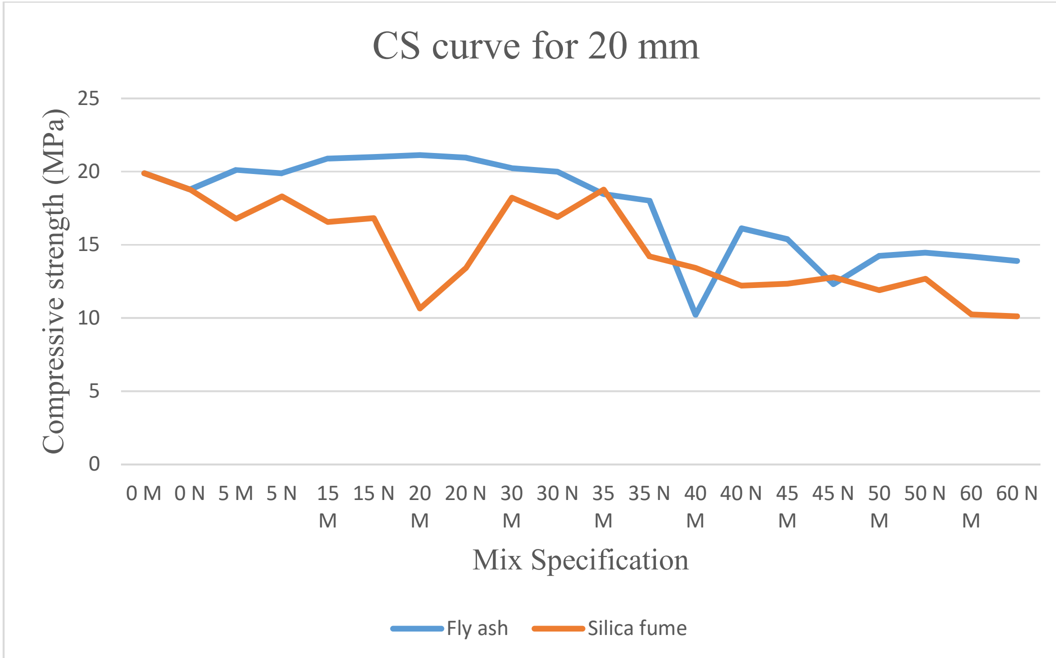

Figure 4.9: Compressive strength of various percentage of 20 mm pervious mix

CHAPTER 5

CONCLUSION

For achieving high permeability and porosity pervious concrete are favored as compared to any other concrete type. Pervious concrete has 15 to 30% more pores as compared to conventional concrete but that lowers its compressive strength many folds. Therefore, the conventional pervious concrete mix requires some modifications like the addition of admixtures like fly ash, silica sand, and recycled aggregate. A series of experiments were conducted sequentially for the determination of durability and mechanical behavior of RCA, where recycled aggregate has been replaced by natural coarse aggregate. On account of the observations and results obtained in the current research, the following outcomes can be concluded considering permeability as the main factor:

- When the water-cement ratio was decreased compressive strength was observed to be increased validating that aggregate to cement ratio is inversely proportional to the strength of previously cement. As increased cementitious property tends to increase the compressive strength.
- Permeability increased while compressive strength decreased with an increase in aggregate size.
- Permeability results for RAC specimens showed that permeability of pervious concrete increased but authors think that permeability mainly depends on the void ratio and the same is not influenced by the presence of a type of aggregate.
- Replacement of fly ash should be done up to 15% as it increases the compressive strength and doesn't alter the permeability of the mix compared to conventional pervious mix.
- When the use of recycled aggregate compressive strength of pervious was decreased furthermore any increase in recycled aggregate percentage has a detrimental effect on the compressive strength. The research also depicts that RCA as a partial replacement of NCA up to 20% is to be considered in sustainable concrete.
- The application of silica sand should be limited to 5% as it increases the compressive strength but decreases the permeability.

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Appendix

Sl no.	Aggregate size (mm)	Water cement ratio	Cement (kg/m3)	Aggregate quantity (kg/m3)	Water (kg/m3)	Admixture type	Admixture quantity	Sample Code
1	10	0.35	1930	9786	1000	Nil	0	M1
2	10	0.4	1930	9786	875	Nil	0	M2
3	20	0.35	1930	9993	1000	Nil	0	M3
4	20	0.4	1930	9993	875	Nil	0	M4
5	10	0.35	1833.5	9786	1000	Fly ash	96.5	M5
6	10	0.4	1833.5	9786	875	Fly ash	96.5	M6
7	10	0.35	1737	9786	1000	Fly ash	193	M7
8	10	0.4	1737	9786	875	Fly ash	193	M8
9	10	0.35	1640.5	9786	1000	Fly ash	289.5	M9
10	10	0.4	1640.5	9786	875	Fly ash	289.5	M10
11	10	0.35	1833.5	9786	1000	Silica Sand	96.5	M11
12	10	0.4	1833.5	9786	875	Silica Sand	96.5	M12
13	10	0.35	1737	9786	1000	Silica Sand	193	M13
14	10	0.4	1737	9786	875	Silica Sand	193	M14
15	10	0.35	1640.5	9786	1000	Silica Sand	289.5	M15
16	10	0.4	1640.5	9786	875	Silica Sand	289.5	M16
17	10	0.35	1544	9786	1000	Fly ash	386	M17
18	10	0.4	1544	9786	875	Fly ash	386	M18
19	10	0.35	1447.5	9786	1000	Fly ash	482.5	M19
20	10	0.4	1447.5	9786	875	Fly ash	482.5	M20
21	10	0.35	1351	9786	1000	Fly ash	579	M21
22	10	0.4	1351	9786	875	Fly ash	579	M22
23	10	0.35	1254.5	9786	1000	Fly ash	675.5	M23
24	10	0.4	1254.5	9786	875	Fly ash	675.5	M24
25	10	0.35	1158	9786	1000	Fly ash	772	M25
26	10	0.4	1158	9786	875	Fly ash	772	M26
27	10	0.35	1061.5	9786	1000	Fly ash	868.5	M27
28	10	0.4	1061.5	9786	875	Fly ash	868.5	M28
29	10	0.35	965	9786	1000	Fly ash	965	M29
30	10	0.4	965	9786	875	Fly ash	965	M30
31	10	0.35	772	9786	1000	Fly ash	1158	M31
32	10	0.4	772	9786	875	Fly ash	1158	M32
33	10	0.35	1833.5	9786	1000	SS and FA 2.5&2.5)	48.25 both	M33

34	10	0.4	1833.5	9786	875	SS and FA (2.5&2.5)	48.25 both	M34
35	10	0.35	1737	9786	1000	SS and FA (5&5)	96.25 both	M35
36	10	0.4	1737	9786	875	SS and FA (5&5)	96.25 both	M36
37	10	0.35	1640.5	9786	1000	SS and FA (7.5&7.5)	144.75 both	M37
38	10	0.4	1640.5	9786	875	SS and FA (7.5&7.5)	144.75 both	M38
39	10	0.35	1544	9786	1000	SS and FA (10&10)	193 both	M39
40	10	0.4	1544	9786	875	SS and FA (10&10)	194 both	M40
41	10	0.35	1447	9786	1000	SS and FA (12.5&12.5)	241.5 both	M41
42	10	0.4	1447	9786	875	SS and FA (12.5&12.5)	241.5 both	M42
43	10	0.35	1351	9786	1000	SS and FA (15&15)	289.5 both	M43
44	10	0.4	1351	9786	875	SS and FA (15&15)	289.5 both	M44
45	10	0.35	1544	9786	1000	Silica Sand	386	M45
46	10	0.4	1544	9786	875	Silica Sand	386	M46
47	10	0.35	1447.5	9786	1000	Silica Sand	482.5	M47
48	10	0.4	1447.5	9786	875	Silica Sand	482.5	M48
49	10	0.35	1351	9786	1000	Silica Sand	579	M49
50	10	0.4	1351	9786	875	Silica	579	M50

						Sand		
51	10	0.35	1254.5	9786	1000	Silica Sand	675.5	M51
52	10	0.4	1254.5	9786	875	Silica Sand	675.5	M52
53	10	0.35	1158	9786	1000	Silica Sand	772	M53
54	10	0.4	1158	9786	875	Silica Sand	772	M54
55	10	0.35	1061.5	9786	1000	Silica Sand	868.5	M55
56	10	0.4	1061.5	9786	875	Silica Sand	868.5	M56
57	10	0.35	965	9786	1000	Silica Sand	965	M57
58	10	0.4	965	9786	875	Silica Sand	965	M58
59	10	0.35	772	9786	1000	Silica Sand	1158	M59
60	10	0.4	772	9786	875	Silica Sand	1158	M60
61	20	0.35	1833.5	9993	1000	Fly ash	96.5	M61
62	20	0.4	1833.5	9993	875	Fly ash	96.5	M62
63	20	0.35	1737	9993	1000	Fly ash	193	M63
64	20	0.4	1737	9993	875	Fly ash	193	M64
65	20	0.35	1640.5	9993	1000	Fly ash	289.5	M65
66	20	0.4	1640.5	9993	875	Fly ash	289.5	M66
67	20	0.35	1833.5	9993	1000	Silica Sand	96.5	M67
68	20	0.4	1833.5	9993	875	Silica Sand	96.5	M68
69	20	0.35	1737	9993	1000	Silica Sand	193	M69
70	20	0.4	1737	9993	875	Silica Sand	193	M70
71	20	0.35	1640.5	9993	1000	Silica Sand	289.5	M71
72	20	0.4	1640.5	9993	875	Silica Sand	289.5	M72
73	20	0.35	1544	9993	1000	Fly ash	386	M73
74	20	0.4	1544	9993	875	Fly ash	386	M74
75	20	0.35	1447.5	9993	1000	Fly ash	482.5	M75
76	20	0.4	1447.5	9993	875	Fly ash	482.5	M76
77	20	0.35	1351	9993	1000	Fly ash	579	M77
78	20	0.4	1351	9993	875	Fly ash	579	M78
79	20	0.35	1254.5	9993	1000	Fly ash	675.5	M79
80	20	0.4	1254.5	9993	875	Fly ash	675.5	M80

81	20	0.35	1158	9993	1000	Fly ash	772	M81
82	20	0.4	1158	9993	875	Fly ash	772	M82
83	20	0.35	1061.5	9993	1000	Fly ash	868.5	M83
84	20	0.4	1061.5	9993	875	Fly ash	868.5	M84
85	20	0.35	965	9993	1000	Fly ash	965	M85
86	20	0.4	965	9993	875	Fly ash	965	M86
87	20	0.35	772	9993	1000	Fly ash	1158	M87
88	20	0.4	772	9993	875	Fly ash	1158	M88
89	20	0.35	1833.5	9993	1000	SS and FA (2.5&2.5)	48.25 both	M89
90	20	0.4	1833.5	9993	875	SS and FA (2.5&2.5)	48.25 both	M90
91	20	0.35	1737	9993	1000	SS and FA (5&5)	96.25 both	M91
92	20	0.4	1737	9993	875	SS and FA (5&5)	96.25 both	M92
93	20	0.35	1640.5	9993	1000	SS and FA (7.5&7.5)	144.75 both	M93
94	20	0.4	1640.5	9993	875	SS and FA (7.5&7.5)	144.75 both	M94
95	20	0.35	1544	9993	1000	SS and FA (10&10)	193 both	M95
96	20	0.4	1544	9993	875	SS and FA (10&10)	194 both	M96
97	20	0.35	1447	9993	1000	SS and FA (12.5&12.5)	241.5 both	M97
98	20	0.4	1447	9993	875	SS and FA (12.5&12.5)	241.5 both	M98
99	20	0.35	1351	9993	1000	SS and FA (15&15)	289.5 both	M99
100	20	0.4	1351	9993	875	SS and FA	289.5 both	M100

						(15&15)		
101	20	0.35	1544	9993	1000	Silica Sand	386	M101
102	20	0.4	1544	9993	875	Silica Sand	386	M102
103	20	0.35	1447.5	9993	1000	Silica Sand	482.5	M103
104	20	0.4	1447.5	9993	875	Silica Sand	482.5	M104
105	20	0.35	1351	9993	1000	Silica Sand	579	M105
106	20	0.4	1351	9993	875	Silica Sand	579	M106
107	20	0.35	1254.5	9993	1000	Silica Sand	675.5	M107
108	20	0.4	1254.5	9993	875	Silica Sand	675.5	M108
109	20	0.35	1158	9993	1000	Silica Sand	772	M109
110	20	0.4	1158	9993	875	Silica Sand	772	M110
111	20	0.35	1061.5	9993	1000	Silica Sand	868.5	M111
112	20	0.4	1061.5	9993	875	Silica Sand	868.5	M112
113	20	0.35	965	9993	1000	Silica Sand	965	M113
114	20	0.4	965	9993	875	Silica Sand	965	M114
115	20	0.35	772	9993	1000	Silica Sand	1158	M115
116	20	0.4	772	9993	875	Silica Sand	1158	M116
Sl no.	Aggregate size (mm)	Water cement ratio	Cement (kg/m3)	Aggregate quantity (kg/m3)	Water (kg/m3)	RCA quantity	Percentage material	
117	Regular	0.35	1930	9786	1000	0	0	R1
118	Regular	0.35	1930	8807.4	1000	978.6	10	R2
119	Regular	0.35	1930	7828.8	1000	1957.2	20	R3
120	Regular	0.35	1930	6850.2	1000	2935.8	30	R4
121	Regular	0.35	1930	5871.6	1000	3914.4	40	R5
122	Regular	0.35	1930	4893	1000	4893	50	R6