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MECHANICAL AND FRACTURE PROPERTIES OF SELF-COMPACTING CONCRETES INCORPORATING WASTE PVC POWDER

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BY

MAHAMMED ALHASSAN

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Mechanical and fracture Properties of Self Compacting Concretes incorporating waste PVC powder.

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Supervisor:

Assoc. Prof. Dr. Mehmet GESOGLU

by

Mahammed ALHASSAN

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Name of the student: Mahammed ALHASSAN

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Approval of the Graduate School of Natural and Applied Sciences:

Prof. Dr. Metin BEDİR
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Abdulkadir ÇEVİK
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assoc. Prof. Dr. Mehmet GESOĞLU
Supervisor

Examining Committee Members:	Signature
Assoc. Prof. Dr. Mehmet GESOĞLU	....
Assoc. Prof. Dr. Erhan GÜNEYİSİ	....
Assist. Prof. Dr. Kasım MERMERDAŞ	....

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Mahammed ALHASSAN

ABSTRACT

MECHANICAL AND FRACTURE PROPERTIES OF SELF-COMPACTING CONCRETES INCORPORATING WASTE PVC POWDER

ALHASSAN, Mahammed

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Supervisor: Assoc. Prof. Dr. Mehmet GESOGLU

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For sustainability, civil engineering industry seeks to execute projects in harmony with nature. This is achieved to some extent by judicious use of natural resources in construction practices. When the plastic waste materials used in daily life complete their lifetime or lost their necessary, they are continuously added to the waste materials in the landfills all over the world and their disposal needs a viable and environmental friendly solution. This has encouraged the use of waste plastic in concrete production, which not only allows for a more efficient life cycle of natural resources but also contributes to environmental protection leading to sustainable development. In this thesis, an experimental study was carried out to investigate the quality of concrete and hardened characteristic of the self-compacting concretes (SCC) made with PVC. A laboratory investigation with a total 6(six) set of mixtures were proportioned having constant water–cementinous material (w/b) ratio of 0.35 and total binder content of 520 kg/m^3. Class F fly ash was used as a 20% of total binder content in all mixtures. Polyvinyl-chloride (PVC) powder was employed to replace cement contents of 5, 10, 15, 20 and 25% by volume.

Keywords: Self-Compacting Concrete (SCC), Plastic Waste, PVC Powder, Mechanical Properties, Compressive Strength

ÖZET

ATIK PVC TOZU ICEREN ÖZ SIKISTIRMA KENDİLİĞİNDEN YERLEŞEN BETONUN MEKANIK ÖZELLİKLERİNE

ALHASSAN, Mahammed

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İnşaat mühendisliği sanayi doğa ile uyum içinde projeleri yürütmek istiyor. Bu yapı uygulamalarında doğal kaynakların akıllıca kullanımı ile bir dereceye kadar elde edilir. günlük hayatta kullanılan plastik atık maddeler kendi ömrünü tamamlamak ya da gerekli kaybetti, onlar sürekli tüm dünyada çöplüklere atık maddelerin ilave edilir ve bunların bertaraf uygulanabilir ve çevre dostu bir çözüm gerekiyor. Atık plastik malzemeler nedeniyle hafifliği, elastikiyet, enerji emilimi, ses ve ısı yalıtım özelliklerine inşaat sektöründe gelecek vaat eden bir malzemedir. Bu doğal kaynakların daha verimli bir yaşam döngüsü sağlayan sadece beton üretiminde, atık plastik kullanımını teşvik değil, aynı zamanda sürdürülebilir gelişimine yol açan çevre korunmasına katkıda olmuştur. Bu tezde, deneysel bir çalışma PVC ile yapılan kendiliğinden yerleşen betonlar (SCC) beton kalitesi ve sertleşmiş karakteristiğini incelemek amacıyla gerçekleştirilmiştir. bunların karışımları, toplam altı (6) seti ile bir laboratuvar araştırması sabit bir su-çimento materyali olan biçimli ağ / 0.35 oranında ve / m3 520 kg toplam bağlayıcı içeriği, b. F sınıfı kül tüm karışımlarda toplam bağlayıcı içeriği% 20 olarak kullanıldı uçar. Polivinil klorür (PVC) 5 hacim, 10, 15, 20 ve% 25 çimento içeriğini değiştirmek için kullanılmıştır.

Anahtar Kelimeler: Kendiliğinden yerleşen beton (SCC), PVC Tozu, Mekanik özellikleri, Basınç dayanımı

To God is the Glory.

My family they should receive my greatest appreciation for their enormous love. They always respect what I want to do, and also give me their full support and encouragement over the years.

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LIST OF SYMBOLS/ABBREVIATIONS

SCC	Self Compacting Concrete
HRWRA	High Range Water Reducing Admixture
PVC	Polyvinyl Chloride
PET	Polyethylene Terephthalate
HPC	High Performance Concrete
CFT	Concrete Filled Tubes
VMA	Viscosity Modifying Agent
SP	Superplasticizer
NVC	Normal Vibration concrete
SF	Silica Fume
FA	Fly Ash
GF	Fracture Energy
LVDT	Linear Variable Displacement Transducer

CHAPTER 1

INTRODUCTION

1.1 Background of Self-Compacting Concrete

Self-compacting concrete (SCC) comes as a result of efforts by scientists and Engineers in the quest for advanced construction materials that fulfill requirements of better compaction and lower segregation with very high performance. The properties that made SCC attractive as a concrete are its filling-ability, passing-ability and segregation resistance and also its ability to flow under its own weight and it does not require vibration for its compaction Domone, P. L. (2007).

The Japanese first developed the SCC in the 1980s and used it in construction where there was the need for congestion in reinforced structures especially in seismic regions for building structures that can stand earthquakes Persson, B. (2001).

The development of SCC was driven by a need of durable concrete structures in Japan where an adequate compaction by skilled laborers was required to obtain durable concrete structures. These needs gave birth to the development of SCC and it was first reported by Zhu W, Bartos PJM (2003).

SCCs have fluidity and segregation resistance which ensures its excellent homogeneity, with little or no concrete voids and guaranteed concrete strength, giving rise to potential for a superb grade of finish and durability to the structure.

Self compacting concrete (SCC) is a special kind of concrete with a high flow ability and passing ability. In addition, SCC has superb segregation resistance and deformability. It's specific cement-based material which was obtained at the end of eighties by Japan. SCC has high fluidity which provides spreading and compacting under its own weight. It can easily fill small gaps of molds without vibration and easily pumped through long distances Khayat KH, Bickley J, (2000). Labor condition in construction site and environment has been improved by utilization of SCC EFNARC (2005).

In manufacturing phase of SCC, the coarse aggregate amount and size is limited and usually mineral and chemical admixtures are used with the low water-binder ratios Persson, B. (2001). For obtaining acceptable fluidity in self compacting concrete and to prevent the segregation effect proper amount of Portland cement (PC), superplasticizer and admixtures generally used Domone, P. L. (2007). The use of fly ash and ground granulated blast furnace slag admixtures reduced dosage of superplasticizer and improved the workability of concretes but they slow down the setting time and lowered the early strength . From the literature it can be noticed that there are a number of researches report the utilization of different kinds of admixtures improves the selfcompactibility and mechanical properties of the SCC Sonebi, M. (2004).

Hannawi K, Kamali-Bernard S, (2010) investigated the unreinforced and reinforced polymer concrete using an unsaturated polyester resin based on recycle polyethylene terephthalate (PET) plastic waste. Frigione M. (2010) researched the impact of PET bottles in concrete properties. It lowered the weight by 2–6%. Furthermore, 33%

decrease in the compressive property was observed. Kan A, Demirboga R. (2009) used plastic material particles as aggregate in concrete and get different properties of concrete such as chemical, physical, and mechanical properties. As the result, the fractions <10% in volume inside of cement matrix does not significantly effect mechanical properties of concrete. Frigione M. (2010) claimed that polypropylene can be utilized as synthetic fibers for enhancing the toughness of concrete. Choi YW, Moon DJ, Lachemi M. (2009) explored the probability of using varied plastic wastes including high density polyethylene (HDPE) as additives to asphalt concrete, as the result it was observed that the waste of polyethylene provides better endurance against continuous deformations because of their high stability. In other investigation, utilize sodium polystyrenesulfonate (NaPSS) as mixture in concrete.

The obtained results showed that polystyrenesulfonate can be utilized as plasticizer or as an admixture in order to reduce water in concrete production. Additionally, enhancement in concrete slump flow observed up to 300% with 0.3% content of NaPSS. Hannawi K, Kamali-Bernard S, (2010) in their study investigated the plastic bottle waste utilized as replacement aggregate in concrete mixture materials. The investigation indicated that shredding the plastic bottles into small PET particles can be utilized as concrete admixture which is a low-cost material with compatible properties. Frigione M. (2010) studied PET aggregates which are made from unwashed PET bottle wastes.

The substitution of 5% of fine aggregate with the same weight of PET bottle waste results show that unwashed PET with the 300 kg/m^3–400 kg/m^3 cement content and 0.45–0.55 water to cement (w/c) ratios had almost the same slump which was identical to the ordinary fresh concrete. Moreover, compressive and tensile strength are slightly lowered than the reference mixture, and it had smaller modulus of elasticity which means higher plasticity. Ismail ZZ, AL-Hashmi EA (2008) investigated substitution of sand with PET aggregates.

They declare that a decrease in concrete unit weight and an increase in water absorption occurred. As the substitution percentage increased, the flow value increased as well. Due to the round and slippery surface of PET aggregates friction between the mortar and the aggregates decreases and compressive strength is reduced. Al-Manaseer AA, (1997) investigated the behavior of the PET waste particles. PET particle size were observed as 0.26 cm and 1.14 cm. According to the investigation there were some reduction in mechanical properties of the concrete. Additionally, according to non-destructive tests, adding PET particles to the concrete mixture results the reduction of slump, increase of water absorptions, and also reduction in propagation rate of ultrasonic pulse which decreases the concrete rigidity.

This concrete has been widely adopted in so many countries for different construction purposes and structural configurations. Construction productivity was enhanced and overall cost was significantly reduced by the adoption of SCC substantially.

Some of the benefits of SCC are enumerated below:

i) Faster construction,

ii) Reduction in manpower required for a particular project,

iii) Ease in placement,

iv) Uniform and complete compaction,

v) Better surface finishes,

vi) Improvement in durability,

vii) Increased bond strength,

The basic characteristics required of SCC are: high deformability, restrained flowing-ability and a high resistance to segregation Sekino, (2003). High deformability is refers to the ability of the concrete to deform and freely spread in order to fill all the spaces in a formwork.

This usually depends on the form, size, and the quantity of the aggregates, and the friction between the solid particles, which can be assured by adding a high range water-reducing admixture (HRWRA) to the mixture. SCCs exhibit very excellent performance in compression and can assure other construction needs because during its production, Okamura, H (1999) almost all the requirements in the structural design must have been considered.

1.2 Plastic Waste – Polyvinyl Chloride (PVC)

Plastics are considered as one of the greatest inventions of the 20th century, and this has brought with it huge benefits to humanity. Almost all Societies have found one use of this product or the other and as a result, huge plastic wastes have been created over the years. Marzouk, O.Y., Dheilly R.M (2007). These wastes come in large amount and are having serious impact on the environment owing to its very low biodegradability.

A significant growth in the consumption of plastic is observed all over the world in recent years, furthermore the production of plastic-related waste also increased. Nowadays the plastic waste is environmental threat to modern civilization. Plastic is formed from several toxic chemicals which pollutes soil, air and water. Disposal of plastic waste in nature is taken into account as a huge problem as the result of its very low biodegradability and large amount. The acceptable decision is utilizing waste materials in other industries in order to lessen the unfavorable effect Albano C, Camacho N. (2009). Lately, major investigations have been done for application probability of plastic wastes in concrete.

The huge quantity of plastic waste can be utilized if there were a possibility to mix the plastic without remarkable impact of properties with concrete. It therefore becomes necessary to develop innovative ways of disposing the waste in a sustainable way and economically too with a view to giving a deserved protection of the environment.

A wide work has already been done on the application of plastic waste such as polyethylene terephthalate (PET) bottle Y.W Choi D. J. Moon, J. S (2005) , poly vinyl chloride (PVC) pipe , poly-propylene fiber as an aggregate or a fiber in concrete mixture. But some important properties such as fresh properties, durability and workability performance of cement mortar and concrete containing PVC powder as aggregate were not discussed before due to shortage of information. Information were provided only for several properties, where plastic was used as fiber in concrete mixture thus the amount consumed was very small in comparison to its use as aggregate in concrete production. However, concrete takes an important part in the advantageous usage of these types of materials in construction sector. Some materials can be effectively integrated into concrete mixture but some not suitable for using them as concrete binder or admixtures so it is crucial to examine this issue before application K. S. Rebeiz (1996). As every material, concrete also composed of plenty of deficiencies and micro-cracks. The speedy spread of micro-cracks under the applied load is because of low tensile strength of concrete.

It can be supposed that the tensile strength of concrete can be quietly increased by adding PVC powder as an aggregate. Generally plastic as the waste material is becoming a considerable investigation subject for using them in concrete, especially in SCC type of concrete.

Polyvinyl chloride (known simply as PVC) is a thermoplastic material that is used almost daily by humans in shopping and luxury etc., from bags to electronics, healthcare and construction etc. and of course in so many other areas not mentioned here. So many reviews of the physical and mechanical properties of PVC with the focused mainly on the possibilities of using it as construction material especially in the areas of concrete technology have been carried out L. Pezzi P. De Luca, D.(2006).

Recycling plastic wastes have been identified as one of the ways for use as construction materials. It has been discovered that recycled plastic waste like polyvinyl chloride (PVC) can be used in producing unsaturated polyester resin for polymer concrete or mortare, for it has been determined that concretes produced from such material have shown better performance than the concrete or mortar made of Portland cement. To reduce the cost of producing polymer concrete or mortar, The use of polyvinyl chloride have been proposed instead, this can also ensure environmental protection and energy savings. So many viewpoints about the importance of recycling of wastes have been presented across the globe highlighting some specific ones like; decrease in pollution, sustenance of natural resources and provision of jobs among others K. S. Rebeiz (1996).

Industrial by-products wastes are considered as potentially valuable resources simply awaiting suitable management and application. These wastes is plastic and have very long period before it becomes biodegradable and this property makes it among the most seriously harmful to the environment of these wastes. Consequently, the way to reduce this effect is to collect and apply this plastic in other areas of human life. The use of this plastic as a construction material could be one of such areas of application, especially in the production of SCC Asokan P, (2010).

However, it has been experimentally observed that; the properties of SCC (both mechanical and physical including durability) are altered by the inclusion of PVC due mainly to the weak compatibility between plastic particles and cement paste. Measurements conducted for the modulus' of elasticity and strengths of PVC based concretes are found to be lower than those recorded of a reference concrete containing normal density natural aggregate only, further, these properties were observed to be decreasing with increased plastic waste content in concrete Al-Manaseer AA, (1997).

Concrete containing plastic waste can enable the elimination of the propagation of micro cracks, and more so an improvement of concrete toughness was also recorded and found to be true. These properties are very significant in the production of high quality concrete. The use of plastic waste as a natural aggregate substitute in concrete is a relatively novel recent concept. Other benefit of the use of plastic wastes found in the reviews was reduction in cost.

Additionally, use of PVC in concrete production reduces the need of natural aggregates. Current investigation aims to research the combined effects of PVC powder as aggregate admixture on the mechanical properties of the SCC. So six SCC series were designed with PVC powder contents of 0%, 5%, 10%, 15%, 20% and 25%. Moreover, PC was replaced with PVC powder by weight. Moreover, fly ash was used as 20% of total binder content by weight to improve the workability of SCCs. Totally, 6 SCC mixtures containing different PVC powder ratio were created with a total binder content of 550 kg/m^3 and w/b ratio of 0.35. The study has as its main objective the investigation of the strength properties of SCC after partially substituting fine aggregate with plastic.

1.3 Research Objectives

The following are the main objectives of carrying out this study.

- To experimentally investigate the effect of polyvinyl chloride (PVC) on the mechanical properties of self-compacting concrete.
- To find the best mix design for substituting natural aggregates with PVC without altering the functional requirements of SCC.
- To provide recommendations for the best way and manner of using the plastic waste in concrete production.

1.4 Importance of the thesis:

It is expected that some useful information will come out of the study that can contribute to education, economy, society, health of people, and save the environment etc.

This thesis work seeks to encourage the use of PVC in production of SCC thereby removing plastic wastes from the environment.

1.5 Outline of the thesis

Chapter 1 gives an introduction, aim(s) and objectives of the thesis and highlighted possible areas of contribution.

Chapter 2 provides a literature review conducted on the historical evolution of self-compacting concretes, its properties and the use of polyvinyl chloride (PVC) for the production of self-compacting concretes.

In chapter 3, presents all the experimental works conducted throughout this study. Properties of cement, PVC, aggregates, enhancers (admixtures etc) that have been selected and used in the production of the PVC-based self-compacting concrete have been evaluated experimentally.

Chapter 4 consists of the discussion of the results of the experimental evaluation of the PVC-based self-compacting concrete proposed.

Chapter 5 Conclusions.

CHAPTER 2

LITERATURE REVIEW

2.1 Development of Self Compacting Concrete

Advancements in concrete studies have led us to achieving concretes of high performance among which is the Self-compacting concrete (SCC). The late 1980's saw the Japanese researchers disturbed about durability of concretes especially the concretes cast in a congested reinforced structures. The challenges faced during casting of concretes in these kinds of construction works necessitated the search for a better type of concretes, hence the Japanese' efforts yielded the SCC Şahmaran, M. (2006). These challenges included the quality control of the concretes cast especially honeycombing and or segregation, another one is finding the skillful workforce to ensure the adequate compaction of the concretes Sonebi, M. (2004) The adoption of SCC is ideal for construction works in particularly seismic regions like Japan and Turkey etc. where construction works in such regions require very large number of reinforcement structures for a particular civil engineering work. Self- Compacting concrete (SCC) is a concrete that flows easily and achieve its compaction due to its weight, as a result, efficiency of work is improved and hence, safety is assured on-site Okamura, H. (1999).

The idea of a concrete mixture that can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibration, was first considered in 1983 in Japan, when concrete durability, constructability and productivity became a major topic of interest in the country. During this period, there was a shortage of number of skilled workers in Japan which directly affected the quality of the concrete Domone, P. L. (2007).

To produce durable concretes, sufficient compaction of the paste during casting is required and this can only be possible by employing skillful workforce to work the paste in to acceptable compaction level.

However, these skillful workforce required has been declining and the dearth of this category of workers in the construction industry has had a serious impact also on the quality of civil engineering construction. The use of self-compacting concrete can mitigate this problem because SCC can quickly flow and take the shape of the formwork it is placed in without necessarily requiring any manual compaction by skillful worker or the use of automated systems like vibrating machines in order to achieve the desired compaction EFNARC (2005).

2.2 Basic Principles and Requirements of SCC

SCC is made of the same components as conventionally vibrated normal concrete, which are; cement, aggregates, water, additives and admixtures. However, super plasticizers for reduction of the liquid limit are required in high volume for better workability; the high powder content serves as "lubricant" for the coarse aggregates, including the use of viscosity-agents to increase the viscosity of the concrete should be considered for a better SCC Okamura, H (1999).

2.3 Hardened properties of self-compacting concrete

The pore system in concrete is very critical because some important properties of the concrete including but not limited to its strength, changes in dimension, durability and others depend on it. The total surface area, volume, size of the pore, its connectivity and distribution are very good characteristic features Persson, B. (2001). Concrete has a pore system whose size varies and changes over time. Some published papers have reported the following as the hardened properties of SCC; the modulus of elasticity, the fracture Energy, Tensile and the compressive strength just like other normal concretes.

2.3.1 Advantages of self-compacting concrete

1. Improving the quality of concrete:

- Homogeneous concrete is achieved even when construction work is limited by access difficulty and jammed reinforcement structures especially in seismic regions.
- SCC can easily fill up any formwork without any difficulty and can fill around all reinforcements.
- SCC is extremely suited in challenging structures works where compaction is highly critical, e.g. tunnel linings casting, closed space works etc.
- Only minor variation in properties is observed on-site.
- Construction of high rise buildings require in most cases the use of special concrete called concrete filled tubes where SCC is employed.

2. Impact on Environmental and Human Health Protection:

- Lesser noise and sound during production at site, the pre-cast factory and neighborhood.
- Eliminates and removes problems with blood circulation in which it leads to ‘white fingers’ normally associated with operations of concrete compacting

machines, hence, the tagging of a “healthy concrete”.

- Shortens the process of construction, ensuring increased productivity, efficiency and speed, more so in pre-cast industry.

3. SCC is Economical:

- The ease with which Placement of concrete is achieved; thereby reducing cost of equipment and labour, and attaining increased productivity.
- Wearing and tearing of forms is reduced to minimal, as a result, the life in service of the equipment is extended.
- Man hours required for the same job is decreased by about 70%,
- High fluidity of the concrete ensures that vibrating it is unnecessary, and hence, energy savings and cost remain high with the use of this SCC.
- Reduction of expenses and manpower needed for patching finished precast elements.
- Consistency in production is achieved with low manpower working in a particular plant.

4. The final shape of the concrete is not affected the shape of the reinforcement bars structure arrangement.

5. Construction with SCC decreases the possibility of accident by decreasing number of equipment required for operations and a decrease in the cost of insurance and compensations.

2.3.2 Disadvantages of self-compacting concrete

- Increased costs of material, especially for cementations materials and admixtures.
- Increased costs of formwork due probably to higher formwork performance expected.
- Increased technical expertise required to develop and control mixtures.
- Increased variability in properties, especially workability.
- Increased quality control requirements.
- Decreased hardened properties including modulus of elasticity and dimensional stability-due to factor such as high paste volumes or low coarse aggregates contents.
- Delayed setting time in some situation due to the usage of admixtures.
- Increased risk and uncertainty because SCC has not been around for quite long, so, opinion over its use is not very strong, i.e. there is still some skepticism about SCC being it not a very old trusted concrete.

2.4 Applications of self-compacting concrete

Examined the application of SCC as an overhead repair material. Three types of repair materials: normal concrete, SCC and shotcrete were tested. Three concrete blocks were repaired at a depth of about 40 mm on one surface of every block. The SCC used in the experimentation involved a Viscosity- Modifying Agent (VMA) to decrease bleeding and segregation in the mixture Khayat KH, (2000).

After seven days from the repairs, explanations were made for each repair method. Results showed that the normal concrete did not have suitable mechanical properties and filling capacity to be used as an overhead repair material. It also developed large segregation and large air pockets.

This method required skilled labour and was expensive. SCC performed well as a repair material making a good bond and demonstrated good rheological properties important for a quality repair material.

But unfortunately, SCC was costly due to the use of chemical admixtures. Furthermore, labour was not a main reason in the placement of the SCC as it consolidated under its own weight. Shotcrete bond to old concrete was practically perfect, but skilled labour was required to achieve the work and the cost of using it is increased significantly. The investigation also recommended the need for more researches to develop cost-effective SCC in order to increase its use as a repair material.

Additional applications for SCC as a repair material were defined by. SCC was used to repair a chloride-induced deteriorated cast-in-place bridge constructed in the 1960‘s in the Swiss Alps.

The concrete structure had lost a significant quantity of concrete and steel reinforcement on its underside. Formwork and placement of concrete followed the replacement of the steel reinforcement below the deck. The only poured concrete available to accommodate the job at hand was SCC, and it was pumped in the formwork through the underside. Air holes were drilled at the top of the deck to permit the release of pressure generated when concrete is pumped in the formwork. SCC allowed the project to be completed on time while keeping the required concrete quality throughout the entire project Fraj AB, (2010).

Persson, B. (2010) Studied projects in Canada where SCC was used. These contained within the rehabilitation of the Webster parking garage in Sherbrooke, the repair works of the Beauhamois Dam close to Montreal, the casting of residential basement walls for experimental purpose,

and the construction of a reaction wall at the Universite de Sherbrooke. The use of SCC in the projects portrays SCC to be an effective material for the rehabilitation of damaged structural parts. Also, reliability and durability of newly constructed concrete walls have been improved as a result of the use of SCC in the repair works.

The employment of SCC in the construction of the anchorages of Akashi-Kaikyo Bridge in Japan has shown one of the most important use of SCC. and of course the in the construction of the longest suspension bridge in the world – approximately 1991 meters (Figure 2.1). The two anchorages had consumed about 290000m^3 by volume. A New construction system, which made full use of the performance of SCC, was introduced for this. The concrete was mixed at the batching plant on the site and was pumped out of the plant. It was transported 200 meters through pipes to the casting site, where the pipes were arranged in rows of 3 to 5 meters a part. The concrete was cast from gate valves located at 5-meter intervals along the pipes. To preserve a surface level of the cast concrete, automatically controlled valves were employed. A construction period reduction of 20% was recorded because of the use of SCC.

Figure 2.1Akashi-Kaikyo Bridge with its two anchorages. Quiroga PN, (2003).

Sonebi, M. (2004) Discussed the use of SCC in Japan and the advantage gained by the firms when producing their own. For example, the Kiba-Park Large Bridge, a 151-m concrete bridge, required two workers only to pour 650 m^3 of SCC within nine(9) months. The difficulty and high labour cost of placing normal concrete in heavily reinforced concrete structures drives the needs for applying SCC. The second was a 70-storey building, the tallest high-rise in Japan, that used 885 m^3 of SCC pumped into steel tubular columns. The concrete was pumped in from the bottom at a maximum filling height of 40 m.

2.5 Mixture proportioning of self-compacting concrete

SCC generally has a higher content of finer particles and better flow characteristics than normal vibrated concrete. It has three basic characteristics at fresh level, i.e. passing ability, segregation resistance, and filling ability. However, its mixture constituents are same to other concretes. SCC comprises of cement, water, and aggregates (fine and coarse), and admixtures.

The SCC may be influenced by the physical properties of these elements and the mixture quantities. The mixture ratio is governed by the need of the SCC to flow accordingly with very low W/cm ratio. The Homogeneity of the mix is maintained through the use of High-range water-reducing admixture (HRWRA) combined with other admixtures for instance VMA to confirm Sakata S. (1996).

2.5.1 Admixtures

Superplasticizer: Super Plasticizer (SP) is essential in ensuring improved workability. Superplasticizer also well known as a high range waters reducer is a chemical admixture required where well-dispersed particle suspension is necessary. This polymer used as dispersants in order to refrain segregation. Additionally, to enhance the flow property of fresh conditions of varied types of concrete. The amount of water (w/c) added to concrete mixture is reduced by addition of superplasticizers and enables the production of self-compacting concretes

The following are some of the properties of admixtures:

(i) high dispersing effect for low water/powder ratio (less than 1 by volume)

(ii) maintenance of the dispersing effect for at least two hours after mixing, and

(iii) less sensitivity to temperature changes .

Superplasticizer use ensures flowing concrete having very high slump that is to be used in heavily reinforced structures and in places where adequate consolidation by vibration cannot be readily achieved.

Superplasticizer is applied in the production of high-strength concrete at w/c's ranging from 0.3 to 0.4.

The ability of a super plasticizer to increase the slump of concrete depends on factors like, dosage, and time of addition, w/c and the type or amount of cement. It has been observed that for most types of cement, a superplasticizer improves the workability of concretes.

Benefits of a superplasticizer include:

1. Guaranteed attaining of the expected strength of the concrete when the workability is greater or better than the standard.

2. Placing of concrete is faster and costs of labor and machinery/equipment is reduced.

3. Plasticizer enhances the durability of concrete by making it impermeable.

Benefits of high-range water reducer (HRWR):

1. With the same amount of cement, the strength of the concrete can be improved at standard workability.

2. As its name implies, water reduction agent in concrete primarily reduces the water of the concrete and hence, 'bleeding' drastically reduces.

3. At high slump, a strong and effective concrete is attained

4. Water reducing agents reduces striking times

Some areas of applications of a superplasticizer are and uses:

1. Increase in workability to a level of up to self-leveling state etc.

2. Plasticizer is used in a construction involving profoundly reinforced sections,

3. Is employed when compaction and consolidation in deep sections promises to be difficult

4. Smooth finishes on the surfaces of the concrete when formwork is removed.

5. Plasticizer is employed when concrete is to be pumped through long pipe

6. Plasticizer harmoniously combines well with all PC and sulfate-resistant cement etc.

2.6 Properties of materials of SCC

Most materials suitable for normal vibrated concrete can be use to produce SCC, but they produce more influences on the fresh characteristics of SCC than on those of NVC.

The characteristics of the constituents of SCC and their effects on the fresh and hardened properties are summarized in this section.

2.6.1 Cement

Portland cement is considered as energy-intensive. Also some drawbacks regarding that the concrete's properties which have reduced those negative impacts, the possible requirements of powder content has been explored as the contents of cement, which exceeded an identified value. To could be increased in SCC regularly met by use of basic additions. Portland cement is the most common material and the main basic component of concrete composite types around the world that is grey in color.

It is developed in England in the half of nineteenth century and generally depended on limestone rocks. It is manufactured by heating limestone materials in a kiln to procedure clinker, grinding the clinker, then adding a small amount of clay. Furthermore, the availability and low cost of the limestone and other naturally materials utilized in cement makes it widely used and the cheapest material over the last century. Accordingly, multiples essential studies were empirically achieved through the use of diverse additions for particular cement‟s replacement in SCC or self-compacted mortar such as slag, basalt powder, fly ash, silica fume, and limestone powder. Type I-Portland cements is compatible to ASTM C150 (2002) in the current study, the materials of cement used which ordinary Portland cements (CEM-I-42.5) compatible to ASTM C150 (2002). As stated by the European guidelines for SCC, all cements that are conformed to EN 197-1 can be used.

2.6.2 Cement materials

High proportion of powder is typically needed for SCC. If only cement is used, SCC has a high cost and vulnerable to attack and thermal cracking, therefore, it is necessary to substitute some of the cement with additives such as fly ash, silica fume, GGBS or limestone filler. Additives are extremely fine materials used in concrete to enhance certain characteristics or properties. A summary of the effects of additives on fresh and hardened characteristics of SCC is presented below:

Silica Fume (SF): an extremely fine but expensive powder. It enhances shear stress and plastic viscosity, thereby significantly reducing the slump flow and segregation of the concrete Tattersall GH. (2003). SF ensures decreased in the ionic strength of the pore solution Improved in durability is recorded with the use of SF, and the hardened properties enhancement were also observed. Quantities of up to 5% have been used in SCC.

Fly Ash (FA): an effective additive which ensures increased in cohesion and filling ability of concrete because of its spherical particle shape; However, FA leads to low early strength (The Concrete Society and BRE, 2005). Fly ash is a side product of the coal burnout, that has ability to react with $Ca(OH)_2$ at 23 °C. The pozzolanic activity of fly ash depends on the presence of SiO_2 and Al_2O_3 in the amorphous condition Baker, M. (1984). Utilization of fly ash in concrete technology dates back 1930s. It is estimated that about 450 million tons of fly ash is produced worldwide annually, but only 6% of the total available is used as pozzolan in in concrete mixtures. In Turkey, there are twelve active coal-burning power plants with annual fly ash production of about 15 millions tons. According to ASTM C 618 [70] fly ash can be classified into two classes as F and C. This classification is mainly based on if the fly ash in question carries only pozzolanic (Class F) or pozzolanic and cementitious (Class C) properties. The former is normally generated due to combustion of anthracite or bituminous coal whereas the latter is manufactured by means of flaming the brown or sub-bituminous coal. From a physical point of view, fly ash can also be very different from one another.Various fineness of FA has been used. An ultra-pulverized fly ash can lead to an increase in the viscosity a decrease in the possibility of segregation, with satisfactorily lower powder content Asokan P. (2010). FA contributes to the strength at later age due to its pozzolanic nature.

2.7 Properties of self-compacting concrete

2.7.1 Workabiltiy

The workability of SCC is normally explained in terms of its following properties: Passing ability, filling ability and Segregation resistance.

2.7.2 Filling ability

The ability of concrete to flow under its own mass and completely fill formwork. This makes concrete to consolidate (compacted) adequately.

2.7.3 Passing ability

The property of concrete to flow through narrow openings between reinforcing bars and formwork etc. increasing this property is directly proportional to increasing the passing ability of the concrete but the reverse case is not guaranteed.

2.7.4 Segregation resistance

Is a desired concrete paste property of remaining unchanged and unvarying in composition from placement until setting. Segregation resistance comprises dynamic and static stability. Segregation resistance during mixing and placement and that when concrete is fully at rest (after casting) is called dynamic stability and Static stability respectively.

2.7.5 Factors influencing workability of a concrete are:

- Duration and method of transport.
- Characteristics and Quantity of cement materials.
- Slump

- Grading shape and surface texture of fine and coarse aggregates.
- Entrained air.
- Water content.
- Concrete and ambient air temperatures.
- Admixtures.

A uniform distribution of aggregate particles and the presence of entrained air significantly help to control segregation and improve workability.

2.8 Plastic Waste

2.8.1 Polyvinyl Chloride (PVC)

Our world is faces serious waste dumping crunch today, notably this waste is constituted of plastic known as polyvinyl chloride (PVC), generally called vinyl. PVC has been a chief reason of dioxin discharge from incinerators when burnt. The more we use and dump PVC products, the more we are faced with disposal issue of this same product.

Civil Engineering construction and demolition activities also substantially contribute to the amount of PVC wastes around us. Interestingly, the construction industry can take back these wastes through its use as a construction material. The need for a social awareness in the industry about the use of recycled PVC waste cannot therefor be over emphasized. Substituting aggregates (sand and gravel) by recycled PVC waste in concrete production is going to be an environmentally sustainable method of recycling wastes considering the very high demand of concrete the world over, and more so in developing economies.

The potential use of recycled plastic waste as a substitute for aggregates in concrete and other construction materials has been of interest to many professionals in the industry.

Numerous studies on largely the effects of integration of PVC granules to substitute aggregates in concrete production and its effects on the properties of concrete have been widely investigated. At large, adding plastic waste as aggregates in concrete production leads to decrease in unit weight of the concrete. It follows that the modulus of elasticity of the composite concrete also decreases, additionally; samples collected from experiments gives increased ductile behaviour on increased quantity of plastic aggregate.

Plastics which is also named as synthetic resins separated into two classes which are thermosetting and thermoplastic resins. The thermosetting resins are phenolic and melamine resin. These resins hardened with heating activity and they will not soften anymore. However, thermoplastic resins are PVC, PE, PS and PP which have ability to become soft with thermal activity. PVC resin is more often supplied in powder or that have capability to be kept for a long time because of it's durability against oxidation. PVC products consist of different additives and pigments. For example, PVC contains 57% chlorine and 43% carbon.

Furthermore, a reduction, though not very significant in proportion in the compressive strength, flexural tensile strength, and splitting tensile strength of cement-based composites has also been observed. However, increase in water absorption is recorded as a result of addition of the plastic aggregate.

2.8.2 PVC Production.

The desirable and attractive properties of PVC have made it popular as candidate for construction material especially because of its low cost and versatility. It starts as a powder that is derivative of salt and fossil fuel. The ability to influence its features through selection of the suitable manufacturing and fabrication procedures, and use of applicable additives and plasticizers for ductile products, is unequaled by several other thermoplastic material.

Other products comprise copolymers that include materials, such as vinyl acetate and vinylidine chloride, in order to enhance the desirable mechanical and other properties.

2.8.3 Benefits of PVC

Strong and lightweight PVC's have good abrasion resistance and lightweight, good mechanical strength and toughness. These properties give it a technical age over other materials for use in building and construction purposes especially in concretes (SCC).

Durability: PVCs have lifetime exceeding 40 years and continue to be in service for up to 100 years or more and they can withstand weathering, chemical rotting, corrosion, shock and abrasion. Resistance to oxidation is the most significant influencing factor of durability. The structure of PVC is molecular, thus have high resistance against the oxidation. Furthermore, it preserves performance for long period.

PVC composed of carbon and hydrogen molecules which are sensitive to corruption by oxidation in lengthy utilization circumstances. It is a product choice in many different long-life and open-air products.

PVC has been employed in both medium and long-term applications production of construction materials and other important products in the building industry.

Cost-effective**:** PVC has been very competitive when it comes to price per unit weight compared with its performance.

2.8.4 Waste plastic aggregate: Background

Concrete is a combination of cement, aggregates and water. Aggregates constitute about 70% by weight of the concrete. There is a great demand for natural aggregates as the construction actions are increasing every day. As the natural resources are decreasing, some alternate materials that will help the purpose of the natural aggregates should be presented Naik TR, (1996). Because of the chemical stability of PVC small change occurs in mechanical strengths. But, this types of materials are viscoelastic so creep deformation may occur. However, the PVC has small creep deformation compared with other types of plastics.

The modern life style along with the new technologies produced more waste materials productions for which the disposing problem takes place. Majority of the waste materials are non-disposal and remain for a long periods of time in the environment. These non-recyclable wastes along with population development have caused environmental disasters around the globe.

Many of them are bloated in the dump place or they are outpoured in the wastebaskets illegally.

2.9 Effect of plastic waste (PVC) on mechanical properties of SCC

The use of plastic waste particles in concrete production has recently received attention of most researchers. In all their studies, it was remarked that the size, surface texture and volume of the plastic waste particles have a great effect in the mechanical characteristics of the modified concrete. They stated that the samples had significant load bearing capability after rupture and offered significant displacements without complete separation. These displacements and deformations were reversible after load releasing.

The strength properties and modulus of elasticity of concrete including different types of plastic wastes are always lower than those of a reference concrete having normal density natural aggregate only, and they further reduce with increasing plastic waste content in concrete Madandoust R, (2012). However, it has been requested that the incorporation of waste plastic-aggregate up to a certain level does not affect the compressive and flexural strengths of cement mortar. Frigione M. (2010) when coarse recycled aggregate of good quality is used, the total substitution of the natural coarse aggregate by recycled aggregate from demolition of concrete structures has a minimal influence on the compressive and tensile strength reduction. The authors found a reduction of 9% for compressive strength and 13% for tensile strength, at 28 days.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this thesis work, an experimental study was conceived and conducted to examine the effect(s) of polyvinyl chloride (PVC) on the mechanical properties of self-compacting concretes. During the experimental effort, concrete samples with varying concrete mix designs were considered. The mechanical properties of the self-compacting concrete produced from these concrete mixes were studied by some tests to determine the Compressive strength, Splitting tensile strength, Modulus of elasticity and Fracture parameters.

3.2 Materials used

The materials used in the experiment are stated below:

3.2.1 Cement

Ordinary Portland cement (CEM I 42.5R) of specific gravity 3.15 g/cm^3 and Blaine fineness of 326 m^2/kg was employed in this study.

3.2.2 Class F fly ash (FA)

according to ASTM C 618 having a specific gravity of 2.25 g/cm^3 and Blaine fineness of 379 m^2/kg was employed in the production of the SCCs.

3.2.3 Pvc powder

The specific gravities and the specific surface of PVC powder used are 1.53 and 16 m^2/kg was employed in this study.

Table 3. 1 Chemical compositions of Portland cement, Fly ash and PVC powder

Analysis Report (%)	Cement	Fly ash	PVC powder
CaO	62.58	4.24	-
SiO_2	20.25	56.20	-
Al_2O_3	5.31	20.17	-
Fe_2O_3	4.04	6.69	-
MgO	2.82	1.92	-
SO_3	2.73	0.49	-
K_2O	0.92	1.89	-
Na_2O	0.22	0.58	-
Ignition loss	3.02	1.78	$\leq$1.00
Specific surface area (m^2/kg)	326	379	16
Specific gravity	3.15	2.25	1.53

Figure 3.1 Photographic views of FA, PVC powder and PC used in production of SPC

3.2.4 Aggregates

A river gravel of a nominal size of 16 mm square and a fine aggregate of natural river sand and crushed limestone of maximum size 4 mm square were selected for the work. River sand, crushed sand, and river gravel had specific gravities of 2.65, 2.43, and 2.71, respectively.

3.2.5 Superplasticizer

These was a water-reducing admixture that employed to significantly enhance the flowing ability of the proposed concrete with a very low effect on its viscosity.

The table below shows the properties of superplasticizers.

Table 3.2 Superplasticizer

Properties	Superplasticizer
Name	Glenium 51
Color tone	Dark brown
State	Liquid
Specific gravity (kg/l)	1.07
Chemical description	Polycarboxylic-ether
Recommended dosage	%1-2 (binder content

3.3 Mix design and proportion

Self-compacting concrete (SCC) mixtures were designed to have a constant w/b ratio of 0.35 and total binder content of 520 kg/m^3. Class F fly ash was used as a 20% of total binder content in all mixtures. Polyvinyl chloride (PVC) substitutes cement contents by 5, 10, 15, 20 and 25% by volume. Six (6) different sample mixtures were designed with only one sample being the control mix having no PVC. A slump flow diameter of 600 ± 30 mm was achieved using the super plasticizer at varying amounts for the concrete mixtures design.

3.3.1 Details of the mix design are as shown below:

Table 3.3 Mix Design

Mix code	Cement	Fly Ash	PVC	Water	NCA 16-8 mm	NCA 8-4 mm	NFA	SP
M1	440	110	0	192.5	404.9	403.4	785.5	105
M2	418	110	22	192.5	400.0	398.5	776.0	95
M3	396	110	44	192.5	395.1	393.6	766.4	85
M4	374	110	66	192.5	390.2	388.7	756.9	80
M5	352	110	88	192.5	385.3	383.8	747.4	75
M6	330	110	110	192.5	380.3	378.9	737.8	70

3.4 Concrete casting and procedures

Concrete mix batching and mixing procedure proposed by Khayat KH. (2000) was adopted to ensure that homogeneity and uniformity of all SCC mixtures considering that mixing sequence and duration are important in the production of self-compacting concrete. The following procedure was used during the mixing; fine and coarse aggregates, followed by cement, fly ash, PVC, superplasticizer were mixed in a revolving pan mixer evenly for a period of half a minute (30 seconds), then, half of the mixing water was added into the mixer and the mixing continued for one more minute (60 seconds).

The aggregates were left to soak the water in the mixer for 1 minute (60 seconds). The mixer was started again for another minute.

Finally, super plasticizers with outstanding water were poured into mixer, and the concrete was mixed for 3 min and then left for a 2 min rest. Further, the concrete was mixed for additional 2 minutes and tests to determine the workability and passing ability of the SCC were conducted and the results were recorded. The concrete casting was followed by protecting the specimens with plastic sheets and these were left in the casting room for a day (24 hours) at 20 ± 2 °C and then the specimens were demoulded and tested after 56-day water curing period.

3.4.1 Specimen description

72 numbers of cubes of concrete of 150 *150 *150 mm were molded for compressive strength, and modulus of elasticity tests. 48 numbers of cylinders of concrete of 200*100 mm were molded for splitting tensile test and other prisms of concrete were molded for the fracture test.

3.5 Mechanical properties

Tests on hardened concrete have been performed to determine compressive strength, splitting tensile strength and fracture modulus of elasticity. The strength of the concrete was evaluated after 56days.

3.5.1 Compressive Strength Test

For compressive strength measurement of SCRC, cubical specimens of 150 mm were tested with respect to ASTM C 39 (2012) by means of 3000 KN capacity testing machine. The test was conducted on three samples from each SCRC mix at 56 days.

Figure 3.2 When conducting compressive strength test.

Figure 3.3 The shape of the concrete cube after conducted the compressive strength test.

The compressive strength was measured by averaging the results from the three tested specimens at each age of testing.

3.5.2 Splitting Tensile Strength Test

According to ASTM 496 (2011), splitting tensile strength of the concretes was determined by using the cylindrical samples of Ø100x200 mm at 56 days.

Figure 3.4 When conducting the splitting tensile test

Figure 3.5 The shape of the concrete cylinder after conducting the splitting tensile strength concrete

The splitting tensile strength was obtained by averaging the results from the three tested cylindrical samples.

3.5.3 Modulus of Elasticity Test

Concrete cube with a dimension of 150x150 were tested for determining the static modulus of elasticity according to ASTM C469. Each of the specimens was fitted with a compressometer containing a dial gage capable of measuring deformation to

0.002mm and then loaded three times to 40% of the ultimate load of companion Cube. The first set of reading of each cylinder was discarded and the modulus was reported as the second setting of readings.

Figure 3.6 Concrete specimen setting for elastic modulus measurement.

3.5.4 Fracture Energy and net flexural strength

In order to calculate the fracture energy (GF) of SCCs, the test was carried out according to RILEM 50-FMC (1985). The measurement of displacement was observed simultaneously via linear variable displacement transducer (LVDT) at midpoint of span.

A testing machine (Instron 5590R) having a highest performance of 250 kN for applying to load was used

The beams having a 500 mm length and cross-section of 100x100 mm were cast to calculate fracture energy test. The opening notch was done by reducing the effective cross section to 60x100 mm via a sawing so as to locate aggregates in more denseness. Thus, the notch versus depth ratio (a/D) of beams was 0.4. However, the distance between supports of the specimens was 400 mm. After obtaining the curve of load versus deflection at the midpoint of span for each beam, the area under this load versus displacement at midpoint of span. For SCRCs determination of fracture energy is dependent on the area under the whole load versus deflection at midpoint of span curve as much as a limited displacement 1.5 mm displacement chosen as cut-off point. The beam specimens were loaded at a constant rate of 0.02 mm/min.

The notched specimens were used to calculate the net flexural strength, assuming no notch sensitivity, where Pmax is the ultimate load.

$$f_{flex} = \frac{3P_{max}S}{2B(W-a)^2}$$

By the following expression, the brittleness of materials can be determined in terms of characteristic length (Hillerborg, 1985):

$$l_{ch} = \frac{EG_F}{f_{st}^2}$$

$$G_F = 41.771\, f_c^{\;0.31}$$

$$f_{st} = 0.108\, f_c - 1.64$$

Where, fst, E, and G_F are the splitting tensile strength, static elastic modulus, and fracture energy, respectively. In this study, splitting tensile strength was used instead of direct tensile strength.

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Figure 3.7 Photographic view of testing devices and three-point flexural testing fixture.

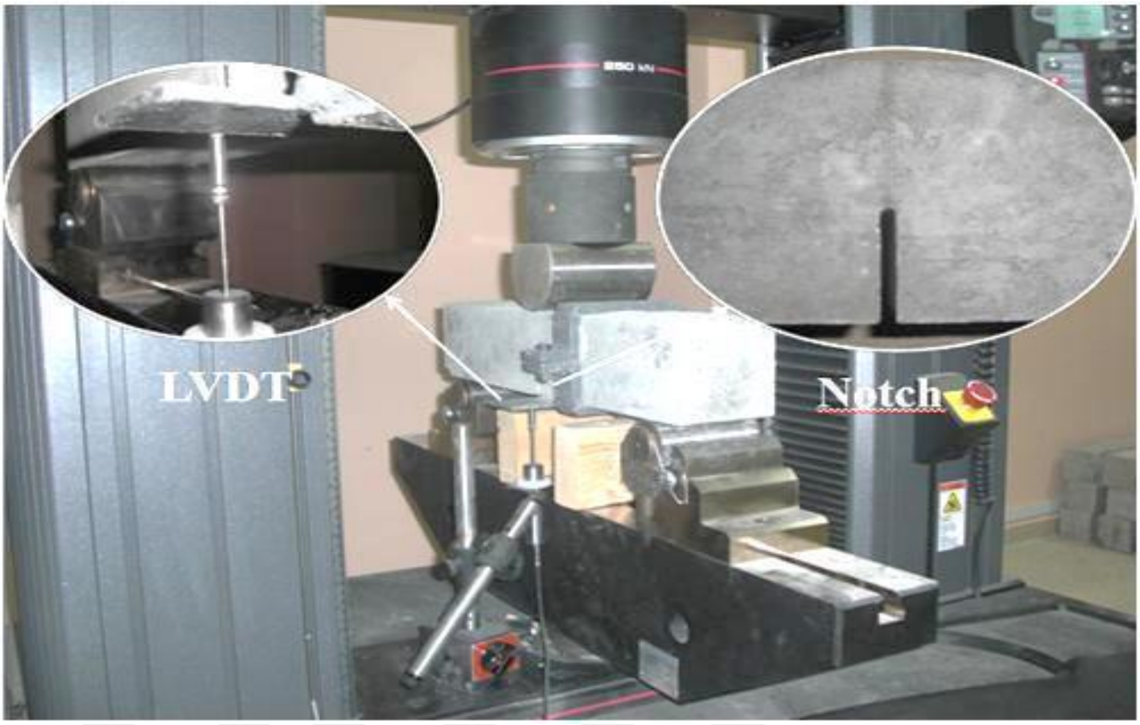

Figure 3.8 Photographic view of notched beam specimen

Figure 3.9 The shape of the concrete cube after conducting the facture energy test.

CHAPTER 4

TEST RESULTS AND DISCUSSIONS

4.1. Compressive Strength

The effect of PVC powder 56 day compressive strength of the self compacting concrete mixtures is illustrated in Figure 4.1 and tabulated in Table 4.1. The results showed that the addition of PVC powder to mixtures has resulted in the reduction of the compressive strength at 56 days. However, from observation made in this investigation the decrease in the compressive strength of the mixtures containing PVC was more than the concrete mixture without PVC. The 56-days compressive strength for Mixes 2, 3, 4, 5 and 6 were less than that of Mix 1 (control mix) by about 5, 8, 12, 23, and 25% respectively.

The reason for this behavior is attributed to the non- cementitious nature of the PVC powder. Since it has no cementitious value, it lessened the compressive strength when replaced with the cement. It was also found that there was no filling ability of the PVC powder to compensate the strength loss.

Table 4.1 Compressive Strength Results

Mix No.	Compressive Strength (MPa)	% Reduction
Mix 1 (control mix)	60.40 MPa	0%
Mix 2	57.27 MPa	5%
Mix 3	55.54 MPa	8%
Mix 4	53.45 MPa	12%
Mix 5	46.74 MPa	23%
Mix 6	45.54 MPa	25%

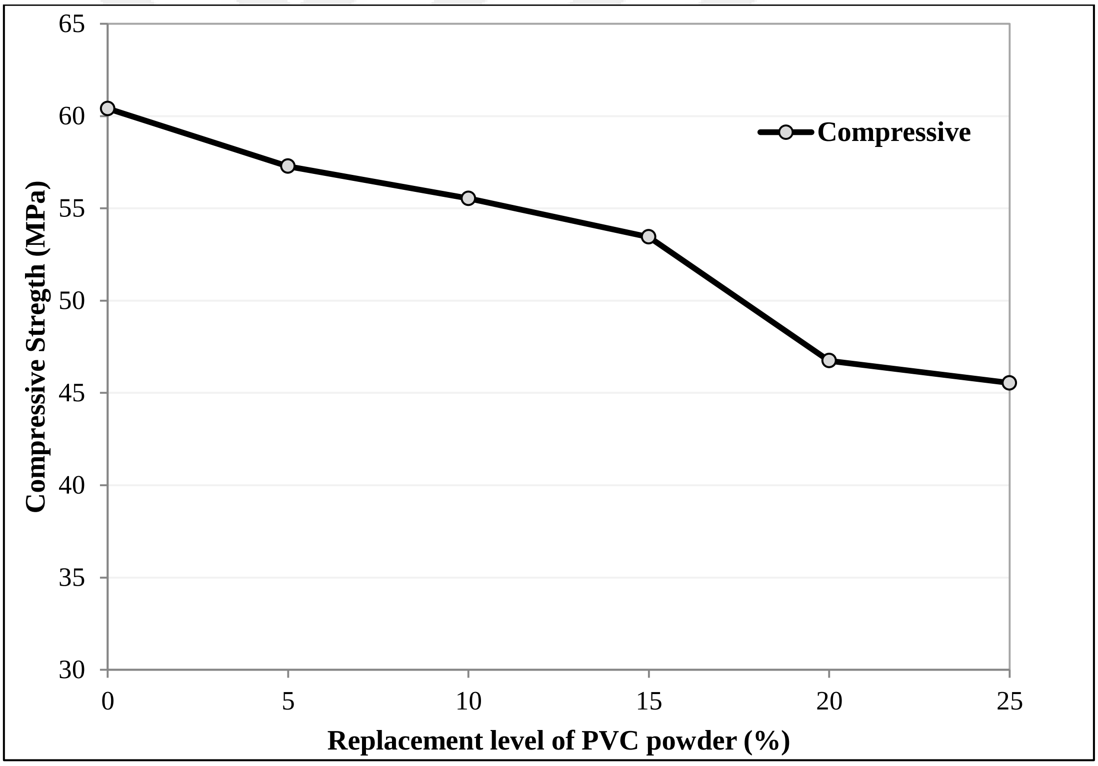

Figure 4.1 Variation of 56 days compressive strength with various percentage of PVC powder

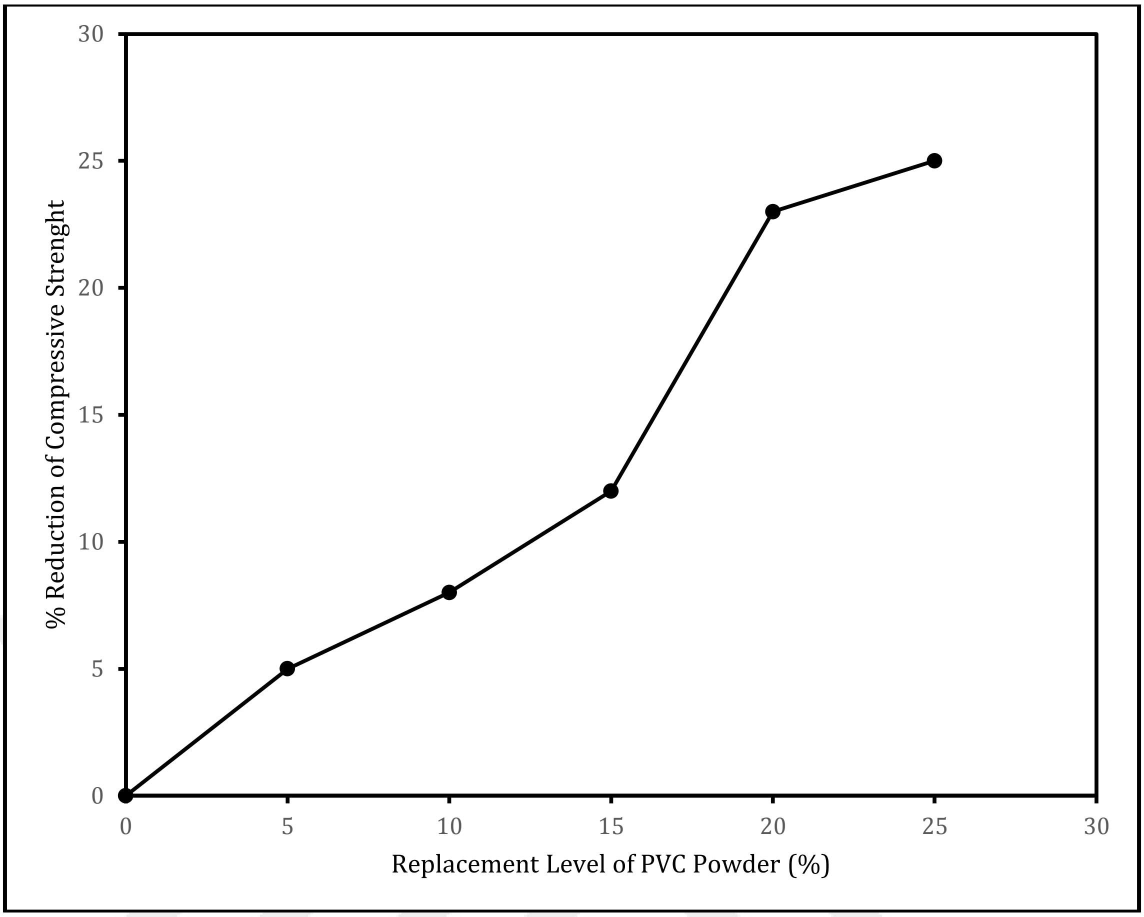

Figure 4.2 % Reduction of compressive strength with various percentage of PVC powder

Therefore, the increasing the waste plastic (PVC) content resulted in a systematic decrease in compressive strength summarizes the effect of PCV replacing by cement content 5, 10, 15, 20 and 25PVC% with different percentages on the compressive strength. The results indicated that the compressive strength of higher than 60 MPa was achieved only in mix 1 (control mix) and also It is clear from the results that as the percentage of PVC increases, the compressive strength decreases for all different mix design.

4.2 Splitting Tensile strength

The 56 day splitting tensile strength of the concretes are presented in Table 4.2 and graphically shown in Fig.4.2. The strength reduction pattern for the splitting tensile strength is similar to that of the compressive strength. Moreover, systematical decreasing in splitting tensile strength was also observed with increasing the PVC content The lowest splitting tensile strength value of 3.287 MPa which corresponds to (mix 6) with the highest PVC percentages that's mix 6, and whereas the maximum value of 4.99 MPa which corresponds to the control mixture (Mix 1) with 0% PVC, was determined.

Table 4.2 Splitting tensile strength Results

Mix No.	**Splitting tensile strength (MPa)**	**% Reduction**
Mix 1 (control mix)	4.99 MPa	0%
Mix 2	4.89 MPa	2%
Mix 3	4.21 MPa	16%
Mix 4	4.01 MPa	20%
Mix 5	3.54 MPa	29%
Mix 6	3.28 MPa	34%

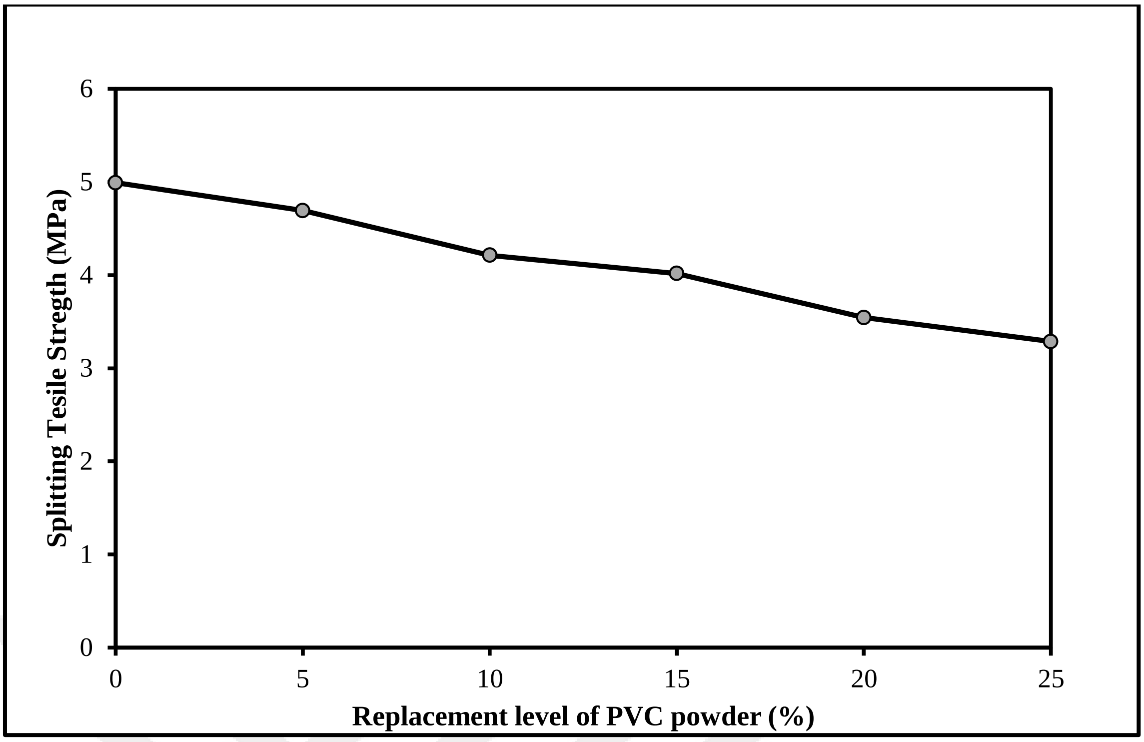

Figure 4.3 Variation of 56 days splitting tensile strength with various percentage of PVC

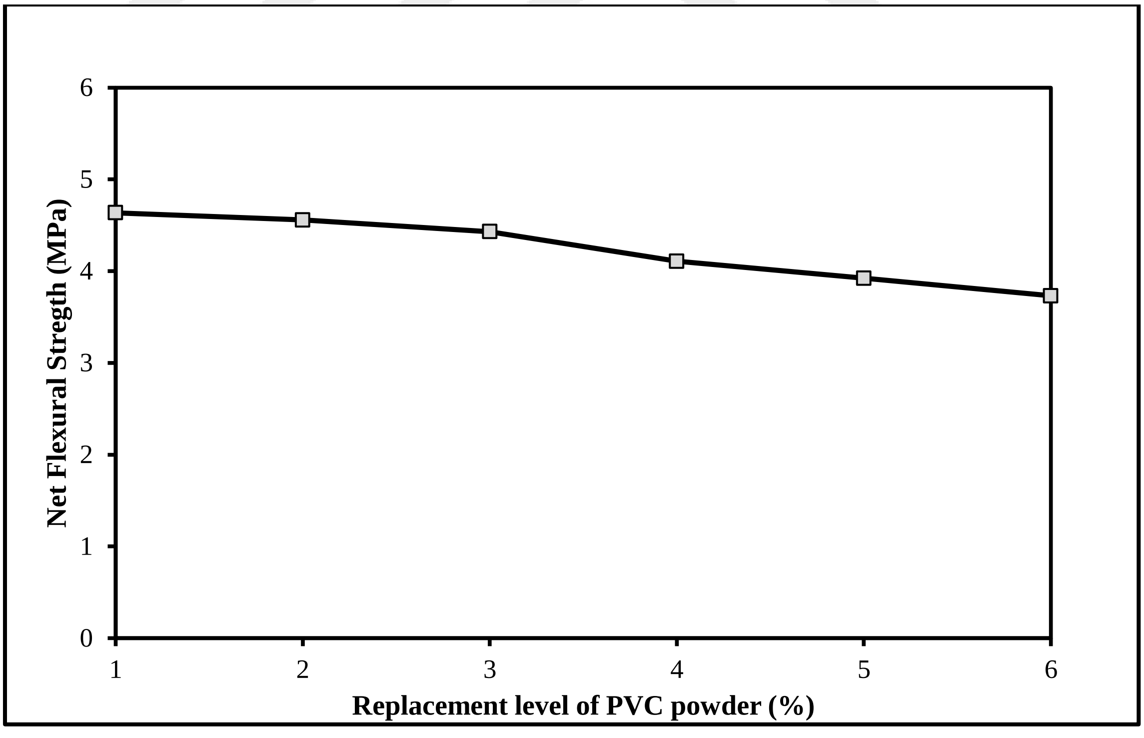

Figure 4.4 Variation of 56 days Net Flexural strength with various percentage of PVC

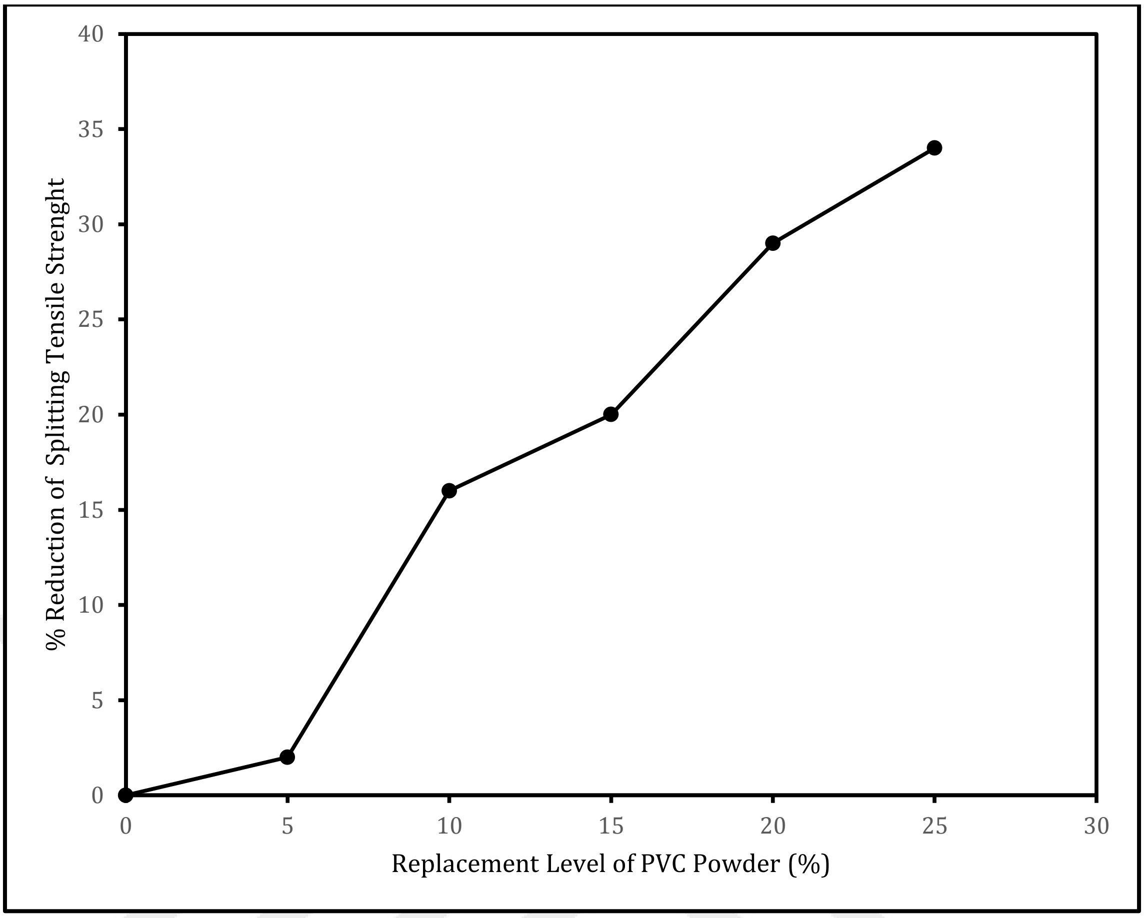

Figure 4.5 % Reduction of splitting tensile strength with various percentage of PVC

The reduction in splitting tensile strength with increasing PVC content is attributed to the same factors which affect the compressive strength of specimens. In general, it is observed that the tensile strength of SCC mixture is around 10-15% of compressive strength.

ACI-318 (2011) provides a relationship between the tensile and compressive strength of conventional concrete and proposed that the tensile strength is proportional to the square root of the compressive strength (ACI equation 9-10).

4.3 Modulus of elasticity

The 56 day modulus of elasticity test results as a function of PVC contents are presented in Fig. 4.3 and tabulated in Table 4.3. The modulus of elasticity values ranging between 17.95 and 24.93 GPa were achieved in this study. The highest modulus of elasticity values were determined in the concretes produced without PVC content in mix 1 (control mix).

Table 4.3 Modulus of Elasticity Results

Mix No.	**Modulus of Elasticity (GPa)**	**% Reduction**
Mix 1 (control mix)	24.9 GPa	0%
Mix 2	24.4 GPa	2%
Mix 3	23.3 GPa	6%
Mix 4	20.3 GPa	18%
Mix 5	19.7 GPa	21%
Mix 6	17.9 GPa	28%

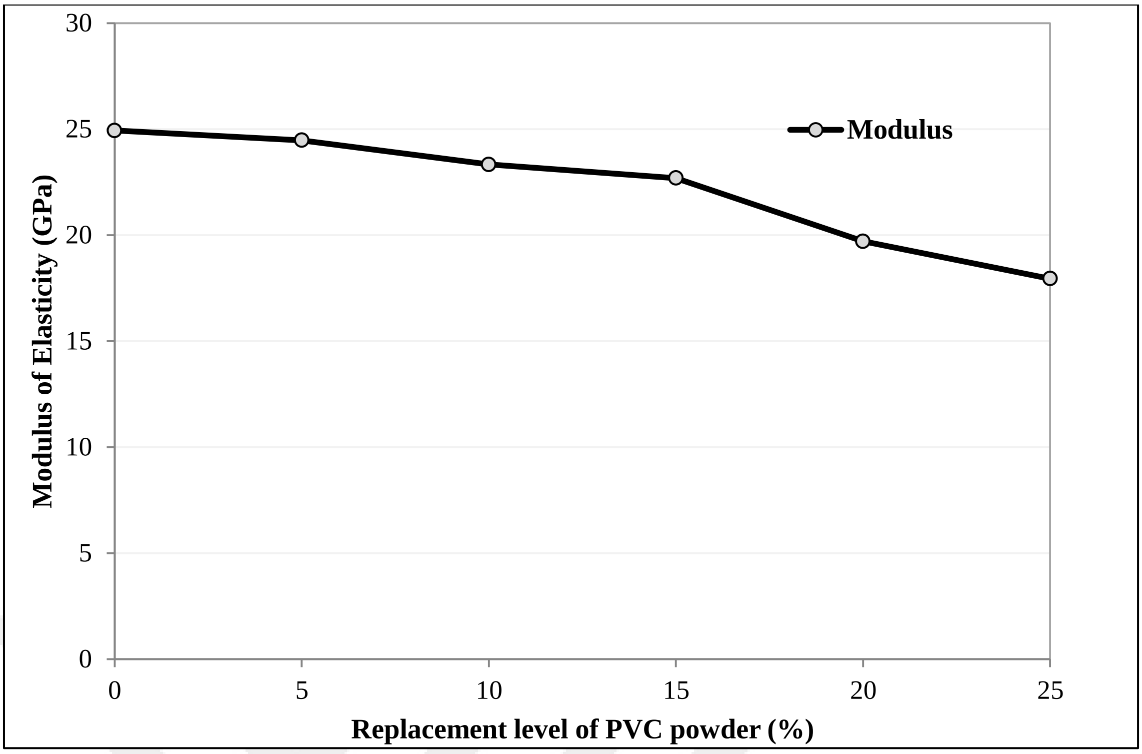

Figure 4.6 Variation of 56 days Modulus of Elasticiy with various percentage of PVC powder (%)

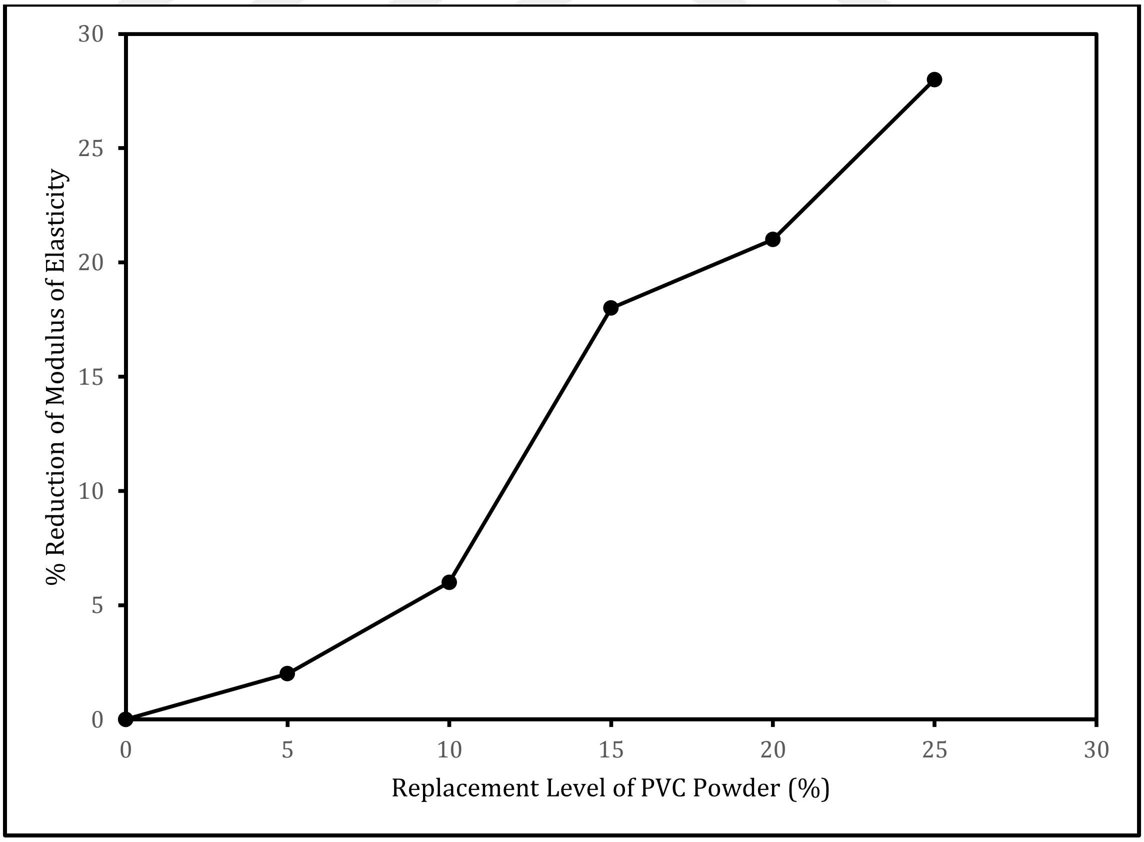

Figure 4.7 % Reduction of modulus of elasticity with various percentage of PVC

However, the lowest value of the modulus of elasticity is mix 6 with 17.92 GPa with regard to PVC content all mixtures results measured in Fig.4.4 demonstrated that modulus of elasticity reduced with increasing PVC content in a similar manner to that observed in compressive strength and splitting tensile strength.

4.4 Fracture energy and characteristic length

The calculation of fracture energy consists of two parts; energy supplied by the actuator and by the own weight of the beam. The area under the load versus displacement curve is used in the calculation of fracture energy as the energy supplied by the actuator, and the weight of the beam is used in the calculation as the energy supplied by own weight of the beam. The final displacement of the specimens is used in the calculation of energy supplied by it own weight.

In effect, adding plastic powder in SCCs significantly affected the pre-peak stiffness of load-displacement curve. For example, mix CPVC25 recorded 2239 N compared with 2782 N for CTR mix. Hence, it could be estimated that the peak load noticeably depended on the plastic powder content inside the mixture. Moreover, the slop of the curve at pre-peak region and early post-peak region are also related to the presence of PVC powder. Indeed, the plastic powder presence and increase in level necessarily produced less brittle than conventional concrete. In this study, the final displacement was extended for PW concrete compared with CTR mixture where the minimum value was recorded at 1.1 mm. The variation in the tail of the softening branch, observed for PW concretes, referred to higher elastic behavior than “plan” SCCs. However, a steeper gradient of the softening branch with the corresponding lower final displacement values was recorded whenever plastic content decreased.

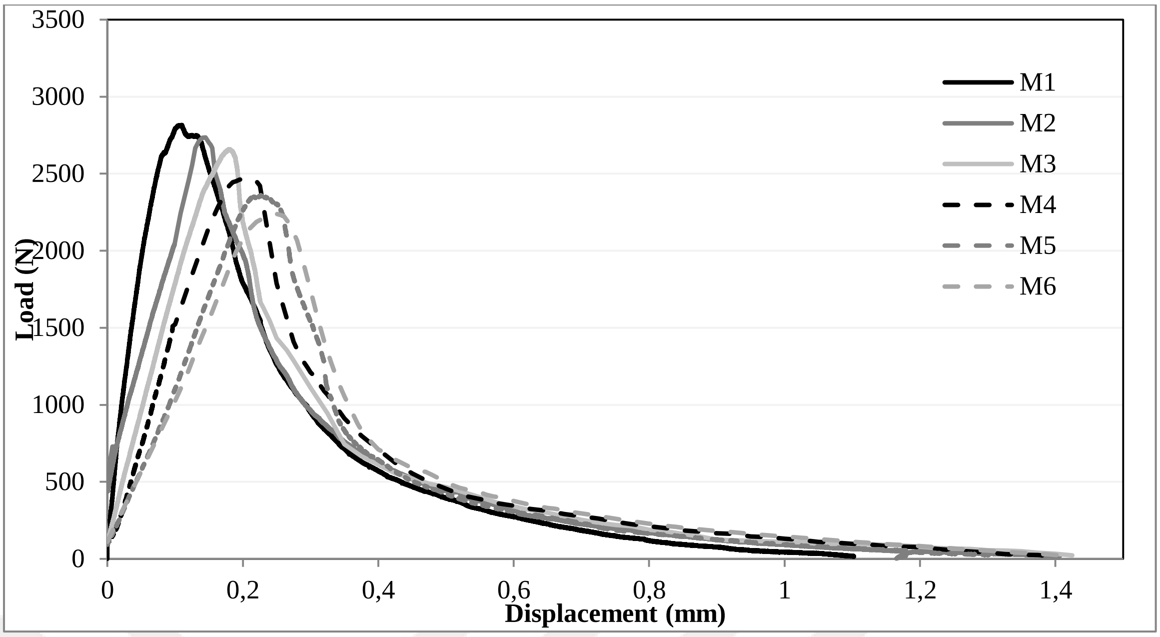

Figure 4.8 Variation of Fracture load and Displacement (mm)

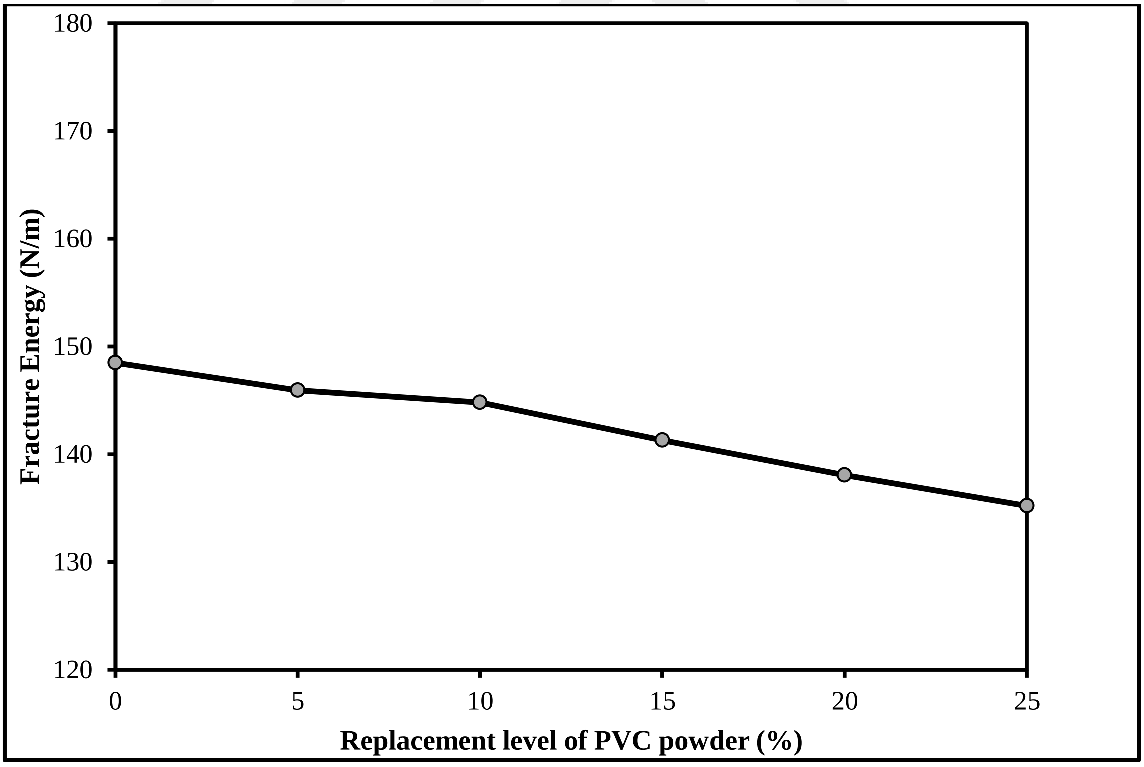

Figure 4.9 Variation of 56 days Fracture Energy with various percentage of PVC powder

These finding emphasized that PW concretes were more ductile than reference mixtures due to the fact that the use of plastic powder decreased the strength of concrete. Aforementioned, l_{ch} results were compatible with the trend reported by previous researchers. In PW concretes, the strength of cement paste and degrades due to utilizing PW, showing an increase in stress concentration around aggregates. Thereby, cracks develop through aggregates leading to contraction of fracture process zone and producing concrete with less brittle behavior. As a result, l_{ch} increases at high level of plastic content and thus the brittleness of concrete decreases. It is believed that the weakness of paste-aggregate interface and non-homogeneous microstructure in PW concrete are responsible for the reduction in the brittleness of such concretes; hence, the crack pattern will be different than in reference concrete

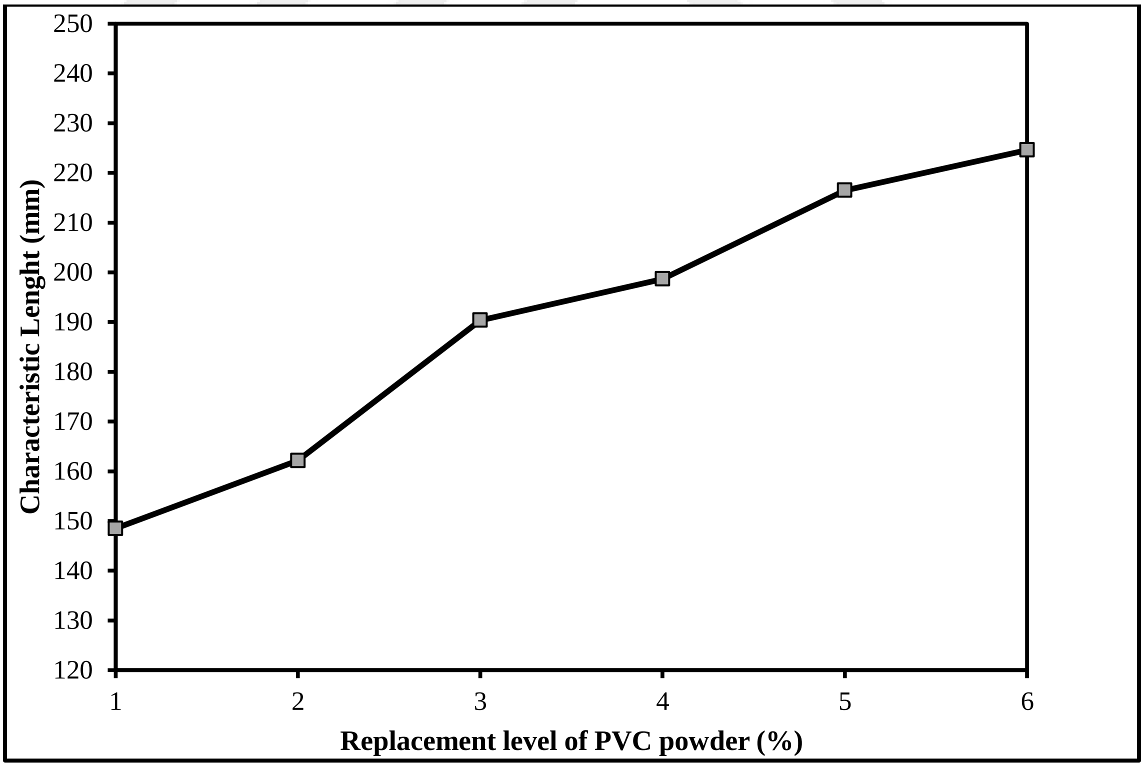

Figure 4.10 Variation of 56 days Characteristic length with various percentage of PVC powder

CHAPTER 5

CONCLUSIONS

The following conclusions can be drawn based on the findings of the experimental investigation:

- The compressive strength was significantly reduced with increasing the PVC powder, using 5, 10, 15, 20 and 25% PVC has decreased the compressive strength of all mixtures compared with the control mix for the case of 0% PVC powder content.
- The elastic modulus of SCC indicated the same trend with the compressive strength and splitting tensile strength. With increasing the PVC powder content. Apparently, the replacement by the cement content with PVC is the critical factor which affected the reduction in elastic modulus obtained in this study.
- The fracture energy of SCC was systematically increased by increasing PVC powder volume fraction. Moreover, SCC including waste plastic particles had a lower ultimate load and higher displacements under three-point bending test.
- This study investigated that the utilization of PVC powder significantly effected on the mechanical properties of SCC. Moreover, with increasing the quantity systematically of PVC caused to reducing the value of compressive strength, Splitting tensile Strength, modulus of elasticity and fracture energy

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