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PRODUCTION OF REINFORCED CONCRETE MEMBERS BY SPRAYED CONCRETE CONTAINING WASTE PLASTICS

A Thesis

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بَسمِ الله الرَحمن الرحيم

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Committee Certification

We certify as an Examining Committee, that we have read this thesis titled "**Production of reinforced concrete members by sprayed concrete containing waste plastics**" and examined the student **"Amer Mohammed Enad**" in its content and what related to it and found it adequate for the standard of a thesis for the degree of **Master of Science** in **Civil Engineering**.

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Abstract

Wet-mix shotcrete is commonly utilized as a placement method in tunneling and ground support. In terms of productivity gains, using a set accelerating admixture offers significant benefits. Little is known about effects of Waste Plastic Fiber (WPF) in wet-mix shotcrete mixtures. Shotcrete concrete containing WPF is used in fabrication of structural members which is innovative in this work.

To be able to produce shotcrete concrete, a shotcrete machine was manufactured and modified to be able to shoot the specific shotcrete concrete that incorporates with WPF.

Extensive research was done in this project to generate wet-mix shotcrete combinations using locally sourced waste materials like beverage bottles. The qualities of WPF shotcrete concrete (SC) were investigated in terms of fresh, hardened, mechanical, and bending behavior. Five SC formulations (0.25, 0.5, 0.75, 1.0, and 1.25) percent WPF content, as well as the control shotcrete (SC0.00), were used in this study. In addition, the flexural behavior of SC beams manufactured from the produced shotcrete incorporated with the same waste materials was studied.

The initial component of the experiment was measuring the fresh properties of SC (750, 780, 790, 880, 750, and 690) seconds for slump flow, (0, 0.5, 1, 1, 1, and 1) seconds for T500, and (15.1, 13.4, 11.2, 9.6, 9.1, and 8.3) seconds for sieve segregation, for (0.00, 0.25, 0.5, 0.75, 1.0, and 1.25) % respectively, to see how different amounts of WPF affected SC. The harder properties of SC mixes, including as dry density were (2364, 2368, 2377, 2373, 2358, and 2355) kg/m^3, water absorption (0.67, 1.08, 1.48, 1.68, 1.75, and 1.85) %, voids content (0.80, 1.27, 1.87, 1.95, 2.19, and 2.62) %,

and ultrasonic pulse velocity tests (4.46, 4.38, 4.37, 4.29, 4.26, 4.14) km/sec. for (0.00, 0.25, 0.5, 0.75, 1.0, and 1.25) % respectively, were covered in the second section. The mechanical properties of SC mixes, such as compressive strength (40.2, 36.0, 31.3, 30.3, 25.3, and 24.4) Mpa, splitting tensile strength 3.2, 3.4, 3.8, 3.9, 4.1, and 4.4) Mpa, and modulus of elasticity (21.45, 19.86, 17.39, 16.51, 15.93, and 15.12) Gpa, were discussed in the third section for (0.00, 0.25, 0.5, 0.75, 1.0, and 1.25) % respectively.

The results showed that addition of WPF improves the splitting tensile strength of SC. The final part of the experiment was examining the structural performance of reinforced concrete beams with various WPF (12.8, 13.8, 13.3, 12.8, 13.3, and 14.84) mm as ultimate deflection for (0.00, 0.25, 0.5, 0.75, 1.0, and 1.25) % respectively. The results showed similar flexural behavior in term of formation of crack patterns and width in addition to ductility index (2.03, 2.29, 2.02, 1.94, 2.16, and 1.99), and stiffness (5.50, 4.59, 4.48, 5.01, 4.81, 1.31) for (0.00, 0.25, 0.5, 0.75, 1.0, and 1.25) % respectively, of all SC beams. SC beams showed lower post-cracking flexural resistance. Ultimate deflection of SC beams decreased with the increasing amount of WPF till 0.75%.

Finally, the study showed that the SC produced with waste materials increase the density of the shotcrete mixes when WPF reach 0.5%. The analysis of mechanical properties of SC specimens revealed that there was not much improvement except splitting tensile strength. While SC with 0.75% WPF replacement provides the best flexural performance in term of ultimate deflection, ductility, and stiffness. Waste materials such as WPF should be limited in shotcrete because of their low values of hardened properties

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Abbreviations

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
EFNARC	European Federation of National Associations Representing for Concrete
FRC	Fiber Reinforced Concrete
FRS	Fiber Reinforced Shotcrete
FRSC	Fiber Reinforced Spray Concrete
I.Q.S	Iraqi Standard Specification
OPC	Ordinary Portland Cement
PET	Polyethylene Terephthalate
PPF	Polypropylene Fibers
PSI	Pounds Per Square Inch
SCM’s	Supplementary Cementing Materials
UPV	Ultrasonic Pulse Velocity
VSI	Visual Stability Index
WPF	Waste Plastic Fiber
WPFRC	Waste Plastic Fibers Reinforced Concrete
LSF	Lime Saturation Factor

SM	Silica Modulus/Ratio
AM	alumina modulus/Ratio
C3S	Tricalcium Silicate
C2S	Dicalcium Silicate
C3A	Tricalcium Aluminate

Notation

cm	Centimeter
cm^3	Cubic centimeter
Kg	Kilo Grams
kN	Kilo Newton
m	Meter
m^3	Cubic meter
mm	Millmeter
Mpa	Mega Pascal
Pu	Ultimate Load
Pu/Δu	Stiffness
SC	Shotcrete
SI	Segregation Index
SP	Superplasticizer
SR	Segregation Resistance
U	Ductility Index
Δu	Ultimate Deflection

CHAPTER ONE

Introduction

1.1 General

Shotcrete is a Portland cement-based mortar or concrete that is set in situ by projecting a high-velocity mix onto a surface pneumatically. Shotcrete is a structurally strong and long-lasting building material that bonds well to existing concrete, rock, and a variety of other materials. It may also have high strength, low absorption, strong weathering resistance, and resistance to a variety of chemical assaults. Shotcrete may have physical qualities that are equivalent to or better than traditional concrete or mortar of the same composition when correctly placed [1].

Shotcrete is frequently employed in the repair sector, subsurface support, slope stabilization, and in regions where traditional concrete is difficult to access [2–7]. When formwork is prohibitively expensive or impracticable, and forms may be minimized or removed, shotcrete provides benefits over traditional concrete. It's particularly useful when working in a difficult-to-reach region or when a thin layer or changeable thickness is necessary. Additional savings are typically attainable as compared to the fabrication and installation of traditional concrete since shotcrete only requires a small and portable facility. As a result, shotcreting operations may frequently be carried out in regions with restricted access to conduct structural repairs [1].

1.1 Dry and Wet-Mix Shotcrete

The dry-mix and wet-mix shotcrete application procedures are two separate shotcrete application processes. The cementitious material and aggregate are entirely blended in dry-mix shotcrete and then either bagged or mixed and supplied straight to the shotcrete cannon. A water ring is installed in the inside of the nozzle, which sprays water evenly into the mixture as it exits the nozzle. The cementitious material, aggregate, water, and admixtures are fully combined in wet-mix shotcrete the same way in traditional concrete. The combined material is then fed into a concrete pump, which utilizes compressed air to push it through the delivery line and out the nozzle [8].

The dry mix shotcrete is beneficial in repair applications when it is necessary to stop and adjust frequently. However, dust will be higher when using the dry ingredients. It is not applicable where the shotcrete quantity is applied more frequently. In contrast, wet-mix shotcrete has less rebound (shotcrete falls down due to paucity in setting), less dust compared to dry-mix shotcrete, and larger volume can be placed in lesser time. However, a highly skilled operator is needed in spraying, and water/cement, pressure and accelerator dosage have to be unambiguous [9].

The choice of the dry-mix or wet-mix process may depend on the equipment cost, maintenance requirements, operational features, placement characteristics and product quality. Generally, bond strengths to existing materials are higher with dry-mix shotcrete than with wet-mix shotcrete. Rebound is a common problem, in which the shotcrete material bounds off the shooting surface when shotcreting. Wet-mix process is somewhat better than dry-mix process in this aspect. [10]. In this research, due to the concern of rebound and fiber dispersion, the wet-mix process has been chosen for all experiments

1.2 Polyethylene Terephthalate (PET)

Polyethylene Terephthalate (PET) is a chemical compound which belongs to the polymer category. It is characteristically suitable for packaging but also has several industrial applications. It comes in various shapes such as fibers, plates, or beverage containers. It has a good stability in regular conditions; it is also light and transparent and can be easily colored [11,12].

PET is non-toxic and always presents the same chemical form of fibers, film, liquid or solid. It has a melting point of 265°C (538 K) irrespective of storage condition. The tensile strength of PET is (86-105) MPa. The first design of a PET bottle was reported in 1975 by Nathaniel C. Wyeth. The PET bottle is mainly advantageous as a relatively small volume of material which can give a container of maximum volume. PET took over from glass in the United States market after only two years of its productions. Initially, it was produced from petrochemicals, in contrast to other plastics that are mainly sourced from coal [13,14].

Despite of the varieties of plastics produced, PET is the most relevant , it is currently versions about 7% of the total plastic waste [15]. The use of PET plastics in the packaging and presentation of several goods has contributed to its huge generation as most of the PET plastics are discarded into the environment soon after being produced. For instance, PET water and soda containers are discarded after consuming their content, thereby, generating a huge volume of plastic post-consumer waste.; In fact, the estimated annual production of PET waste has been predicted to be doubles each decade [16]. Many organizations and institutes try to study the recycle PET within clear environmental and standards. The management of PET waste is still not completely sustainable [17,18].

Polypropylene fibers (PPF) are a type of synthetic fiber, which commonly used on concrete mix designs. PPF is used to increase tensile strength of concrete members therefore widely used to improve concrete tensile stresses [19]. They are also used to reduce overall cracking in a concrete member and reduce overall crack width and area [20]. In shotcrete, Polypropylene fibers have a role comparable to its role in conventional concrete.

The inclusion of PET fibers in concrete mixtures might increase their mechanical characteristics in term of enhancing the splitting tensile strength [11,21,22]. The length of fiber had a significant effect in fiber-reinforced concrete, since increasing the embedding length of fibers enhanced interlocking behavior and binding energy between fibers and concrete matrix [23].

1.3 Problem Statement

The main problems of shotcrete in general can be considered in this study are low compressive strength, tensile strength, and segregation. Also, there are no studies consider the strength of reinforced shotcrete beams through using waste plastic. The statistics about number of PET bottles production in Iraq, are not clear but is estimated more than million bottles. Most of these bottles are discarded due to negative impact on the environment. One of method to treat the waste plastic is recycled with construction application.

1.4 Aim and Objectives of the Study

The aim of this research is production of reinforced concrete member casting by sprayed waste plastic fiber (WPF). In order to achieve that, the following objectives have been considered:

1. Manufacture and develop wet-mix shotcrete machine that could produce special shotcrete concrete.
2. Investigate fresh shotcrete concrete properties with various WPF percentages (0.25, 0.5, 0.75, 1.0 and 1.25) % through testing slump flow and segregation resistance with fixed length over dimeter ratio (l/d).
3. Investigate hardened mechanical properties of shotcrete concrete containing different percentage of WPF (0.25, 0.5, 0.75, 1.0 and 1.25) % such as compressive strength, splitting tensile strength, modulus of elasticity, dry density, air voids, water absorption, and ultrasonic pulse velocity tests.
4. Study strength of reinforced shotcrete concrete beams behaviour, which casting by shotcrete concrete containing different percentage of WPF.

1.5 Novelty of Research

A thorough assessment of the literature revealed that, to the best of the author's knowledge, the outcome provided in this thesis tackles (at a minimum) the following topics:

1) Only a few prior researches have looked at the performance of WPF shotcrete mixes.
2) It is difficult to locate research that has looked into the influence of WPF content on the fresh and hardening qualities of wet-shotcrete.
3) Examine the strength of reinforced shotcrete beams containing WPF. This study is the first to employ sprayed WPF shotcrete to create a reinforced beam for such quantification.

1.6 Thesis Outline

Chapter One introduces overview of shotcrete concrete, dry and wet mix shotcrete, Polyethylene Terephthalate, the effect of plastic waste on environment, and the backgrounds of each one. It also presents the problem of the study, the aim and objectives, as well as the thesis outline.

Chapter Two covers a detailed review of the existing literature on reinforced concrete member casting by sprayed waste plastic fiber, in addition to the structural behavior of reinforced shotcrete member containing WPF in flexure.

Chapter Three presents the experimental design, covering the properties, dimensions, and geometric of the materials, mixing, casting, and curing of samples, test set-up, testing and instrumentation.

Chapter Four presents the results, along with an analysis on the effects of WPF on various properties (fresh, hardened, and mechanical) of shotcrete concrete and reinforced shotcrete member mixtures.

Chapter Five presents a summary of the research findings, as well as some guidelines for future study.

CHAPTER TWO

Literature Review

2.1 Introduction

Shotcrete is commonly used for the repair and rehabilitation of structures. It is widely employed for the protection of soil and rock slopes. In addition, in common use in tunnels and substructures. Conventionally, to control shrinkage cracking of the shotcrete layer, steel meshes are placed before shotcreting is carried out. A more effective technique, however, is to incorporate short fibers into the shotcrete mix. With large surface area per volume, fibers are very effective for crack control. Also, by removing the procedure of steel mesh laying, construction efficiency is improved [24].

Properties for fiber reinforced concrete (FRC) of different compositions are widely available. Despite a fiber of reinforced shotcrete (FRS) properties are, more difficult to find. Within the same mix proportion, the properties of FRC and FRS are expected to be different, since the compaction process in the two cases are not the same. The difference in properties between FRC and FRS has never been systematically studied [25,26].

2.2 History of Shotcrete Concrete

Carl Akeley, (1907) [27] created a Gunite (old name) , Sprayed or shotcrete concrete by using a dry aggregate and cementitious material out of a hose with compressed air and applying water at the nozzle. Shotcrete has greatly advanced in its machinery use, producing better and more efficient shooters, pumps and nozzles for the job. The first double-chambered cement shooter was created in 1910 which spearhead shotcrete into mainstream construction. At the time, shotcrete had rapidly gained in popularity due to having better strengths than conventional placed concrete due to the lack of information on the consolidation of general concrete and poor techniques [28].

It was not until the 1950's that wet-mix shotcrete was produced, however still required improvement. ACI committee 506 was also created as demand for shotcrete became more pronounced, so did the demand for research and regulation on the product [29]. The 1970's appeared ideas that allowed for greater advancements in the material and machine, as silica fume was introduced to concrete mix designs, reducing rebound and increasing bond strength of shotcrete, and a wet-mix shotcrete pump was created to more effectively push the heavier aggregate due to the addition of water [30].

Sprayed (Gunite) would later be renamed to dry-mix shotcrete as wet-mix shotcrete became popular in the 1970s by use of a concrete pump and more improved techniques. Shotcrete is continuously used around the world whenever the production of formwork becomes an issue. Shotcrete (2017) defined in ACI 506r-16 as "A method of applying concrete projected at high velocity primarily on to a vertical or overhead surface" [31]. Figure 2-1 shows a historic photograph for the process of using shotcrete in tunnel lining in 1920.

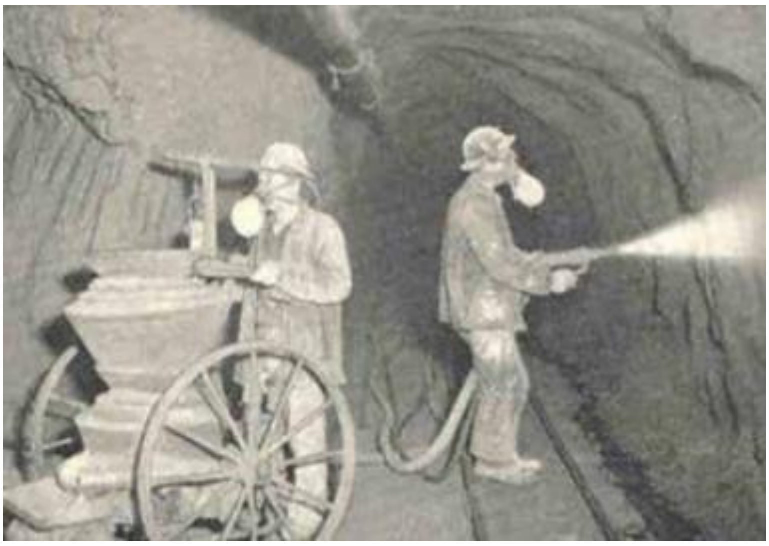


Figure 2-1 Lining a tunnel with Gunite using a double-chamber gun during the 1920s [32]

Because shotcrete is a matter of machinery rather than material, as it is exactly like conventional concrete, it has gained great popularity around the world, reported to be an $8.3-billion-dollar market by 2021 with underground construction as its greatest application. Europe currently holds the highest market share for shotcrete where there is a large demand for underground transportation [33].

2.3 Types of Shotcrete Equipment’s

As stated before, shotcrete is concrete sprayed at a high velocity. There are currently two major types of mixes.

- Dry-Mix: Aggregate is batched and pumped to the nozzle dry where water is introduced only at the nozzle.
- Wet-Mix: Aggregate is batched similarly to conventional concrete, then pumped using a wet-mix pump to the nozzle.

Generally, dry-mix shotcrete is used for smaller projects and provides more control of the water-cement ratio in the concrete mix to better suit the location being sprayed. Because dry-mix does not have any fresh concrete properties that can be appropriately measured due to the variable water content at the nozzle, conventional concrete testing methods cannot be used [34].

Wet-mix shotcrete is used for a much higher volume requirement and projects that allow for transit mixers to be transferred on site and constantly mixed. Although the water-cement ratio cannot be changed instantly to better match the variable conditions, the mix is more consistent with its water content. Because the wet-mix is batched and mixed the same way as conventional concrete, it can be tested in a similar fashion with regards to fresh properties [33].

There are variety of equipment that are used for a general shotcreting job. The main pieces include an air compressor, shooter or pump, hose, nozzle, and blowpipes. There are extra considerations depending on the job which may include remote shotcrete gun, fiber feeders, admixture dispensers, and air movers.

2.3.1 Dry-Mix Equipment

The nozzle-carrier is the brain of shotcreting, and the equipment is the heart. Behind every successful job using shotcrete are well maintained guns, air compressors, hoses, manifolds, etc. For dry-mix shotcrete, the main equipment used is the gun and the air compressor. Batch and double-chamber guns are used effectively by using a rotary feed wheel to meter the flow of the batched material being expelled from its pressurized lower chamber. This allows for a constant flow by way of the material being supplied to the top chamber which is then moved to the pressurized chamber. Dry-mix guns are continuous-feed guns or Rotary guns and are by far the most popular gun to use for dry-mix shotcrete. Rotary guns use a rotating airlock that allows for the material to be pressurized while continuously fed through the chamber. Figure 2-2 represents the rotary shooter of shotcrete [28].

Figure 2-2 Rotary gun [28]

Compressed air is placed in the lower chamber in order to push out the material at the necessary velocity. The air come from an air compressor which is to meet the specified requirements of the shotcrete mix type, and the inside diameter of the hose being used. Dry-mix shotcrete requires a more powerful air compressor [28]. Table 2-1 represents the capacity of dry-mix compressor.

Table 2-1 Dry-mix compressor capacity based on inside diameter of hose [28]

Interior Diameter of Hose (mm)	**Compressor Capacity (m^3/minute)**
25	10
32	12.5
38	17.0
51	22
64	29

The flow rate is considered at a pressure of 689.47 Kpa, however it is important to note that the operating air pressure may change depending on the length of the hose in use. This is because the outlet of the hose must obtain a certain pressure in order to achieve the velocity needed to push out the shotcrete material. The longer the hose, the more material that must be pushed through in order to reach the outlet, thus the pressure may need to be increased [34].

Shotcrete nozzle are specialized for each mix. Dry-mix shotcrete nozzles usually contain a nozzle tip, control valve, water ring, and water body and is generally a hydro-mix nozzle which mixes the water through the nozzle body. The nozzle body is separate from the nozzle tip, unlike other nozzles. It acts as a presetting system to wet the dry-mix shotcrete that is being pumped into it so that the shotcrete is wet before leaving the nozzle rather than mixing the water as it is leaving. This provides as even a material property as possible. It's important to note that the nozzle body doesn't help push the shotcrete mix through the hose [35]. Figure 2-3 shows the details of dry-mix nozzle.

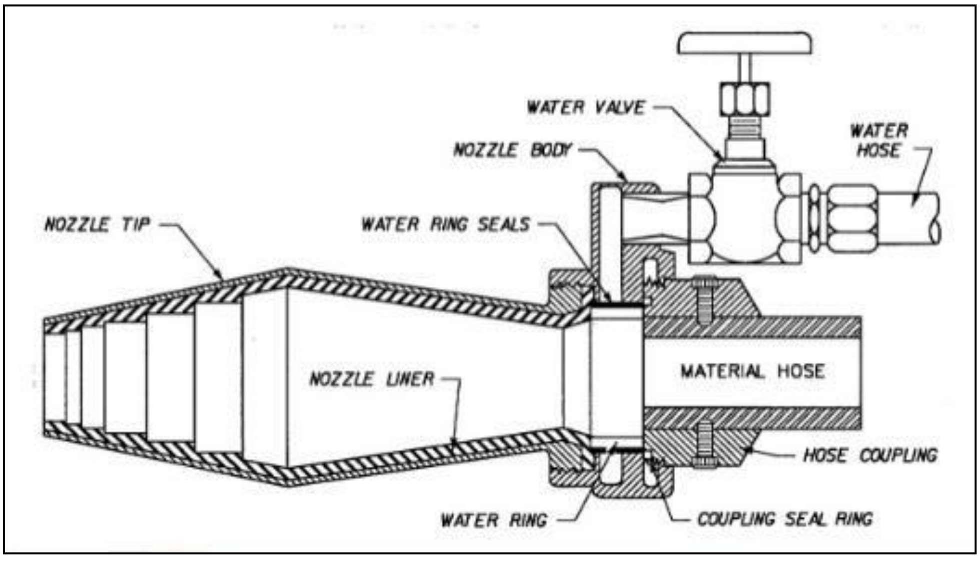


Figure 2-3 Dry-mix nozzle [28]

2.3.2 Wet-Mix Equipment

Wet-mix pumps concrete already mixed with water, meaning the concrete being pumped weighs more and has higher workability. A wet-mix pump injects the concrete through a tube into the delivery hose hydraulically, usually using piston pumps. Larger jobs require stronger pumps, as the time needed to for shotcrete to shoot is consistent from job to job. Therefore, large jobs can require shotcreting rates of 6 m^3/hr to as much as 23 m^3/hr in order to finish the project. These pumps have larger outlet diameters and pistons [36].

In the case of retrofitting, a generally smaller job category, smaller pistons, outlet diameter, and is applied at a slower rate. This is usually defined for a total mix size of 1.15 to 2.3 m^3 of total concrete and are shot at a rate of around 1.5 m^3/hr. With regards to compressed air, it is applied at the nozzle [28].

A wet-mix nozzle includes a rubber nozzle tip, housing, air injection ring, and a control valve. There is no need for extra manifolds for potential admixtures, as the mix already includes both liquid and powdered admixtures. Wet-mix nozzles are much easier to use in that the hose easier to maneuver and rotate while shooting [37]. Figure 2-4 shows the details of wet-mix nozzle.

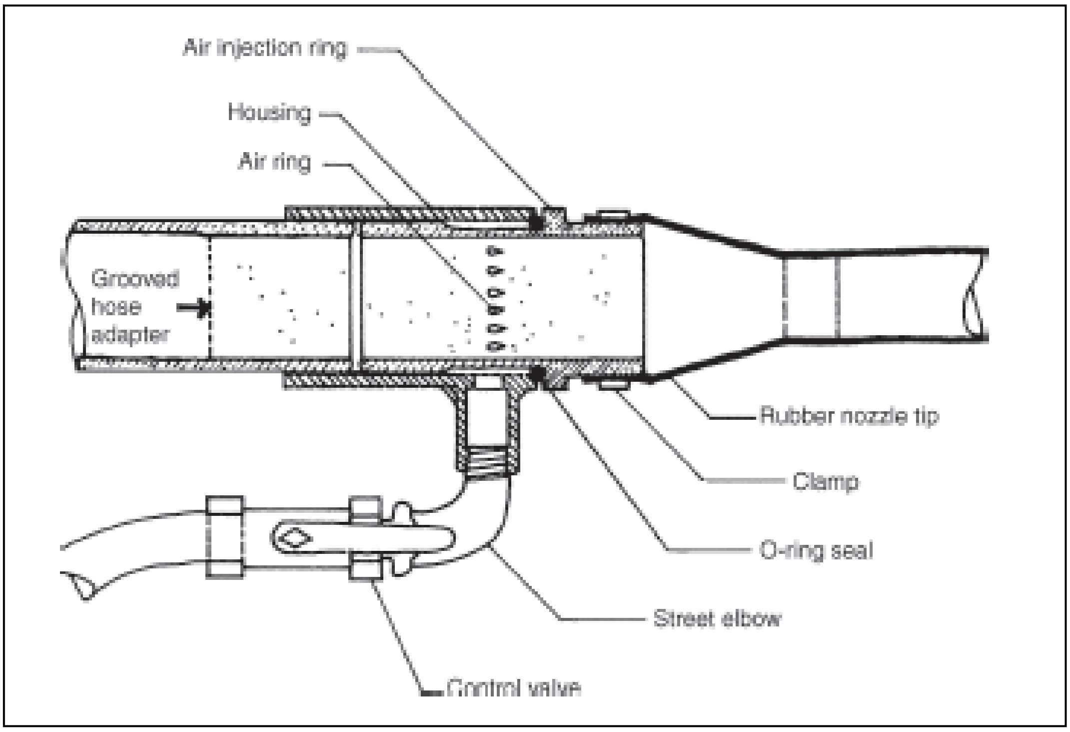


Figure 2-4 Wet-mix nozzle cut-away [28]

2.4 Shotcrete Concrete Technique

The most important aspect of the shotcrete is its application technique, therefore the person who use the nozzle (nozzle carrier), must be experienced. ACI standard put limitation for person that work as nozzleman and there are certified for the specific mix, wet or dry [35].

A nozzleman must think about are rebound, overspray, angle of application, and encasement as shown in Figure (2-5). Rebound is an unavoidable by product of shooting aggregate that has not been fully encased by cementitious material at a high velocity onto a hard surface. The aggregate will reflect and possible cause a buildup at a point, which will have an excess of aggregate causing a weak point. Rebound can be contained based on the nozzle angle, amount of accelerator, distance of the nozzle to the applied substrate, and area of application [38].

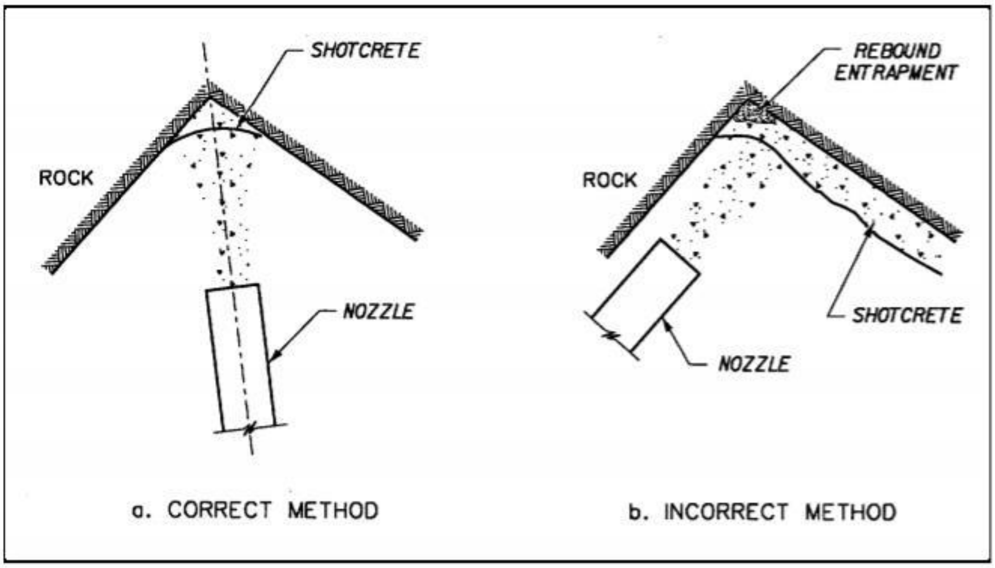


Figure 2-5 Shotcreting interior corners [38]

Overspray is similar to rebound, however, it is used to describe when small or fine materials bounce off a surface and stick to adjacent areas that the nozzle is not directly spraying as seen in Figure 2-6. This causes a layer with too little coarse aggregate and affects the overall effectiveness of a shotcrete layer [38].

The angle of application is important when attempting to reduce overspray and rebound, and make sure there is a strong bond between the shotcrete and the substrate as shown in Figure 2-7. It is defined by the posture and position of the nozzleman, and where he points the nozzle [28].

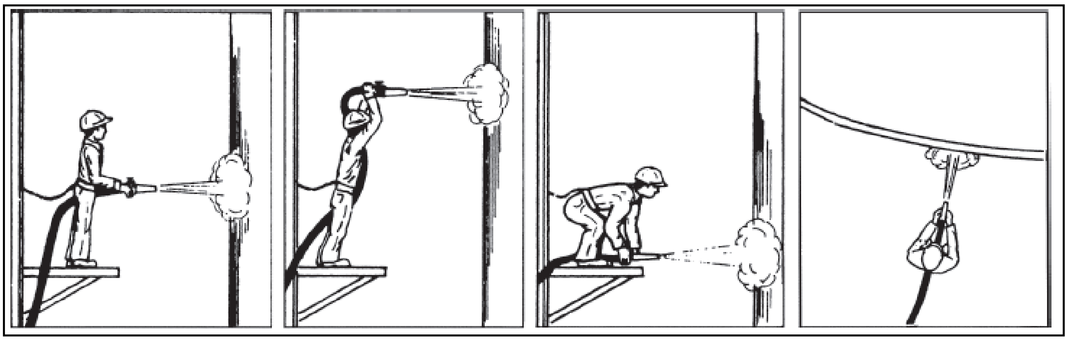


Figure 2-6 Correct shooting positions [28]

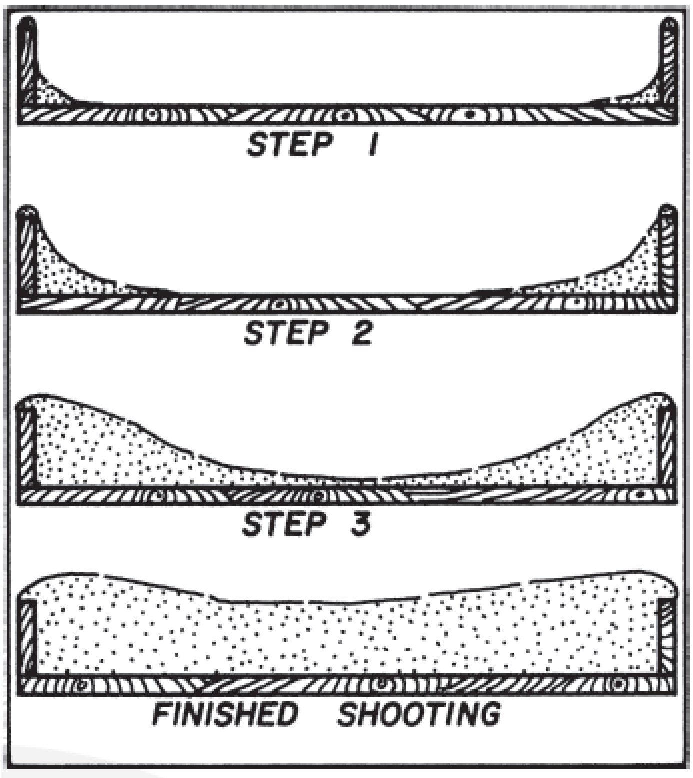


Figure 2-7 Proper procedure for shooting horizontal surface [28]

Encasement is what is used to describe the degree at which various protruding elements, such as rebar and a steel mesh, are covered by the shotcrete. Good encasement means that there are no voids along the item, bad encasement implies many or large air voids that usually show up directly behind the element as seen in Figure 2-8 [28].

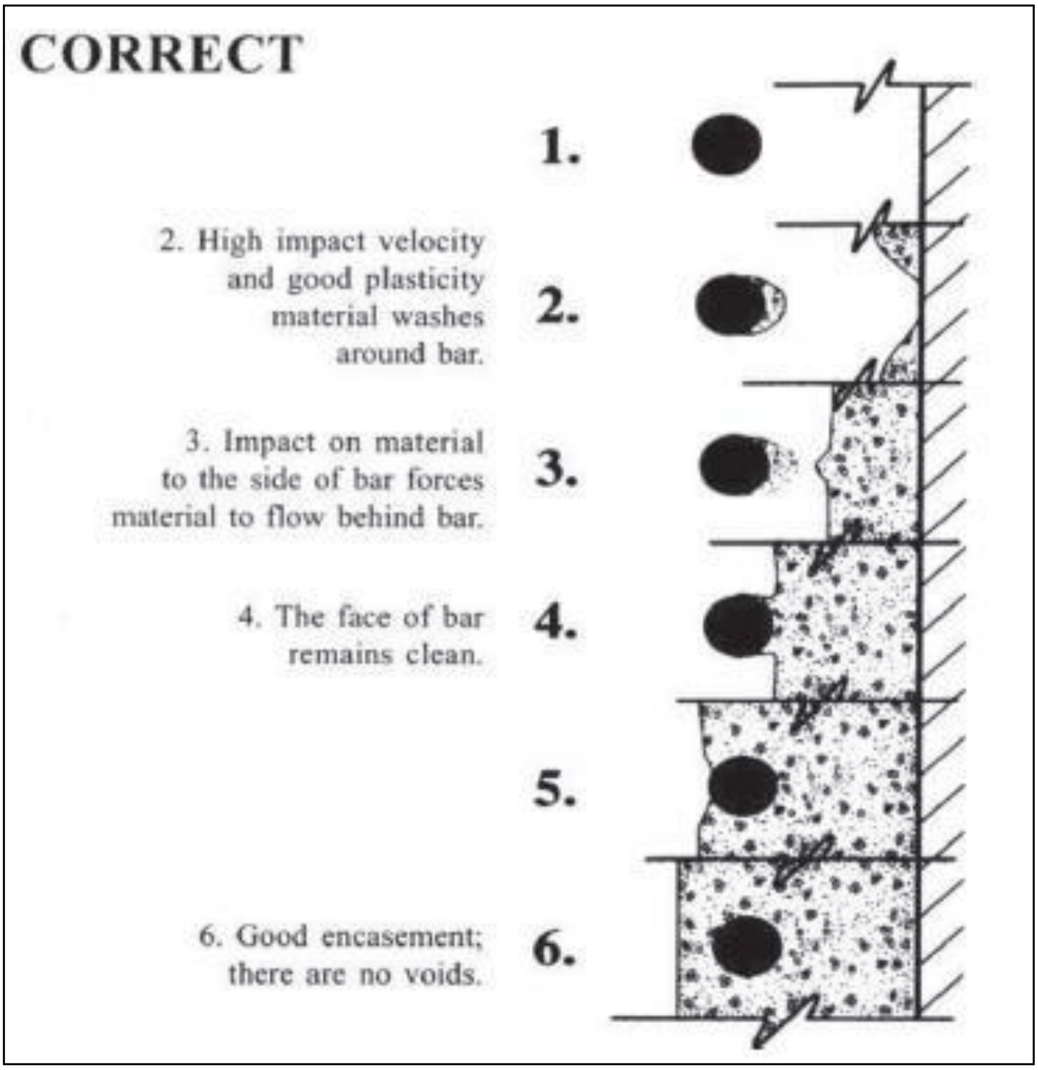


Figure 2-8 Illustration of correct steps of steel encasement [28]

2.5 Fiber Reinforced Shotcrete (FRS)

In the 1960s, fiber reinforced concrete (FRC) introduced new ways of increasing the structural dependency of concrete. In terms of mechanical performance, fibers have been observed to increase structural strength, reduce permeability, reduce shrinkage and expansion, and increase overall durability [39]. The two most common fibers used for enhancing concrete are polypropylene and steel fibers [25].

Fibers have been used to enhance shotcrete since the early 1970s. Because conventional concrete is so close to shotcrete save for application, fiber reinforced shotcrete caught on relatively quickly. Fiber reinforced shotcrete (FRS) is "mortar or concrete containing discontinuous discrete fibers that is pneumatically projected at high velocity onto a surface." Steel, glass, and synthetic fibers are used in shotcrete while steel being the most popular [40].

The processes by which FRSC (Fiber Reinforced Spray Concrete) regulates deformations and absorbs energy are complicated, including both spray concrete process technicalities and fiber qualities. The fundamental prerequisite for FRSC as a ground support is toughness. However, an appropriate design and combination of concrete strength, fiber anchoring, and placement technique are required for the FRSC to have the maximum strength and toughness. As a result, the fiber type and content must be appropriate for the ground conditions in a given region as well as the projected concrete mixture design. For the design of FRSC for ground support, there is no universally acknowledged design process. There are general design guidelines, but no specific/complete design guide is allowed for FRSC. Flexural strength, residual flexural strength after cracking, moment-normal force (M-N) behavior, and energy absorption (toughness) were among the performance criteria investigated [41].

The spraying at high velocity, the unique rheology of the mixture, the qualities of the concrete and the fibers, and the resultant combination must all be considered while building a discussion on FRS. In reality, factors like shotcrete rebound may have a major impact on FRS performance, often in unexpected ways. In dry-mix FRS, for example, a greater compressive strength does not always imply a better flexural toughness since a stiffer consistency enhances the rebound phenomena and lowers the fiber dose in situ [42].

Shotcrete has been criticized for not being able to prevent violent internal voids occurrences [43]. FRS, on the other hand, has been demonstrated to absorb as much as, if not more, energy than certain standard ground support systems [44]. FRS functions effectively in severe situations when combined with anchor bolts [45]; It has a higher energy absorption capacity than steel mesh alone or in a shotcrete layer. As a result of the requirement for effective countermeasures for dynamic occurrences in deep subterranean places, the development of novel high-performance FRS mix designs is critical for industrial safety and development.

Cheng et al. [12] demonstrated the development of a sustainable lightweight wet-mix shotcrete by substituting a byproduct for natural coarse gravel (walnut). To enhance the qualities of the lightweight wet-mix shotcrete, fibers derived from discarded polyethylene terephthalate (PET) bottles were added in. The compressive and splitting tensile strength of casting concrete declined as the walnut shell content increased, but slump and pressure drop decreased marginally. Furthermore, adding walnut shell to new concrete with a low rebound rate and a big build-up thickness may increase shootability.

Fiber reinforced concrete is widely-used for reinforcing concrete structures [46]. Even though shotcrete has widespread use both in mining and tunneling in general, its load bearing capacity has not yet been documented and presented in a satisfactory way. Therefore, it is considered fair to assume that many of these underground reinforcement solutions are heavily oversized [46,47].

2.6 Fiber Reinforced Concrete (FRC)

Several studies have investigated the influence of recycling PET on the concrete properties [48–50]. The recycled fibers of comfortably blend in concrete, allowing new characteristics of the materials [51].

Soroushian et al. (1995) [52] reported that the usage of polypropylene as synthetic fibers can improve the concrete toughness. Foti (2011) [53] investigated using waste fibers from PET bottles for reinforced concrete, it was observed that the addition of PET bottles can pose a greater effect on the post-cracking outcome of simple concrete elements. In addition, these fibers increase the plasticity and toughness of the concrete.

Pereira de Oliveira et al. (2011) [54] utilized fibers generated from recycled PET bottles to produce reinforced mortar. They observed that there was a significant increment in the toughness, compressive and flexural strength of mortars using PET fibers. A study conducted by Foti (2013) [11] investigated the prospect of reprocessing PET fibers procured from waste bottles of varied shapes. The results reflected that the presence of PET fibers in concrete can improve its ductility.

Meddah and Bencheikh (2009) [55] investigated the effect of length and volume of polypropylene and polypropylene waste fibers on the toughness, flexural, and compressive strengths of fibers reinforced concretes. The outcomes of the study revealed that polypropylene fibers declined the compressive strength mostly when utilizing lengthy fibers that had elevated volume fraction. A gradual decline in the compressive strength was seen in the composites comprising over 2% metallic waste fibers. Nevertheless, the hybrid and polypropylene fibers improve the flexural strength of reinforced concretes.

Mazaheripour et al. (2011) [56] studied the influence of introducing polypropylene fibers in hardened and fresh characteristics of lightweight self-compacting concrete (density between 1700–2000 kg/m^3). The obtained results indicated that polypropylene fibers do not affect the elastic modulus and compressive strength, nevertheless, using a higher portion of volume improved the flexural strength by 10.7% and tensile strength by 14.4% through splitting tensile strength analysis.

Kim et al. (2010) [57] studied the fundamental properties of materials and shrinkage drying resistance of concrete reinforced using reprocessed PET fibers. The results involving the comparisons with samples comprising of polypropylene fibers reinforcement showed that concrete reinforced using PET fiber reflected a gradual decline in elastic modulus and compressive strength with increasing the fiber volume fraction. In addition, the recycled polypropylene and PET fiber-reinforced samples reflected a declined in compressive strength of approximately 1–10% and 1–9%, in relation to samples that do not contain fiber reinforcement.

Al-Hadithi A.I. (2013) [58] studied the influence of joining the chips obtained from cutting beverage plastic bottles using hands (mostly utilize in Iraqi markets) as compact fibers mixed with the gap-graded concrete. Then, the fibers were mixed at varying proportions (1.5, 1 and 0.5%) of concrete volumes. A control concrete mix was provided for comparison purposes. The outcomes showed that the addition of plastic waste fibers in these proportions resulted in enhancement of splitting tensile strength of concretes. However, there was more enhancement in the splitting tensile strength. Low-velocity impact resistance showed a noticeable increment in every waste plastic fibers reinforced concrete (WPFRC) mixes as compared to that of control. The outcomes reflected that WPFRC of 1.5% showed the optimum impact resistance as compared to others which were 328.6%. In the cases of

1 and 0.5%, the results were 128.6 and 200%, respectively. Cracks in concrete were prevented by Synthetic-fiber reinforcement, synthetic fibers of small diameter (nylon, glass, steel or polypropylene) reducing shrinkage cracking by more than 80% according to independent lab tests [58].

2.7 Mixture Design: Pumpability and Workability

Workability of shotcrete depends on several combinations of parameters. The fresh concrete must remain stable during pumping, without segregation or pump blockage events [37]. The shotcrete also needs to be properly placed with the lowest slump as possible, in order to obtain a thicker layer without fallouts. These somewhat opposite requirements often lead to the use of superplasticizer admixture for a highly workable mix for pumping and the addition of set accelerating admixture at the nozzle to stiffen the in-place mix during spraying [36].

During the pumping process, concrete is subjected to high pressures, especially through hose diameter reduction, creating stringent requirements for the shotcrete mix design. Passing through the reducer requires constant reorganization of the aggregates without segregation or bleeding and an adequate volume of cement paste which lubricates the aggregates to ensure its stability within the mixture [59]. An appropriate aggregate distribution is of the utmost importance in reducing void space and increasing the volume of available cement paste to work as a lubricant [37].

Several well-known researchers have studied concrete pumping behaviour [60,61] and all have a focus on aggregate size distribution, viscosity and yield strength of concrete to predict the concrete pumpability. If the fresh concrete is too firm, aggregates do not rearrange well during pumping, creating pumping blockage. If the fresh concrete is too liquid, it lacks stability and during the pumping movement, the cement paste will filter through the aggregates, also creating pumping blockage.

In order to increase the stability of the fresh concrete, the use of supplementary cementing materials (SCM's) is a common solution, increasing the volume of binder paste and reducing slump of fresh concrete [8]. These two characteristics improve pumping and result in a more stable concrete during spraying, also reducing rebound and improving built-up thickness. Overall improvement of durability is also well documented [62,63], showing improved resistance to freeze-thaw and improvement in reducing chloride ingress.

2.8 Failure Modes of Shotcrete

There are two basic types of failures; the first one is fallouts of only shotcrete, which indicates poor adhesion against the rock surface or other surfaces [64]. The second mode is fallouts of shotcrete and surface, which indicates that the surface has failed. These two main types of failures can also be subdivided into six categories with more precise descriptions of the actual failure modes, see Figure 2-12.

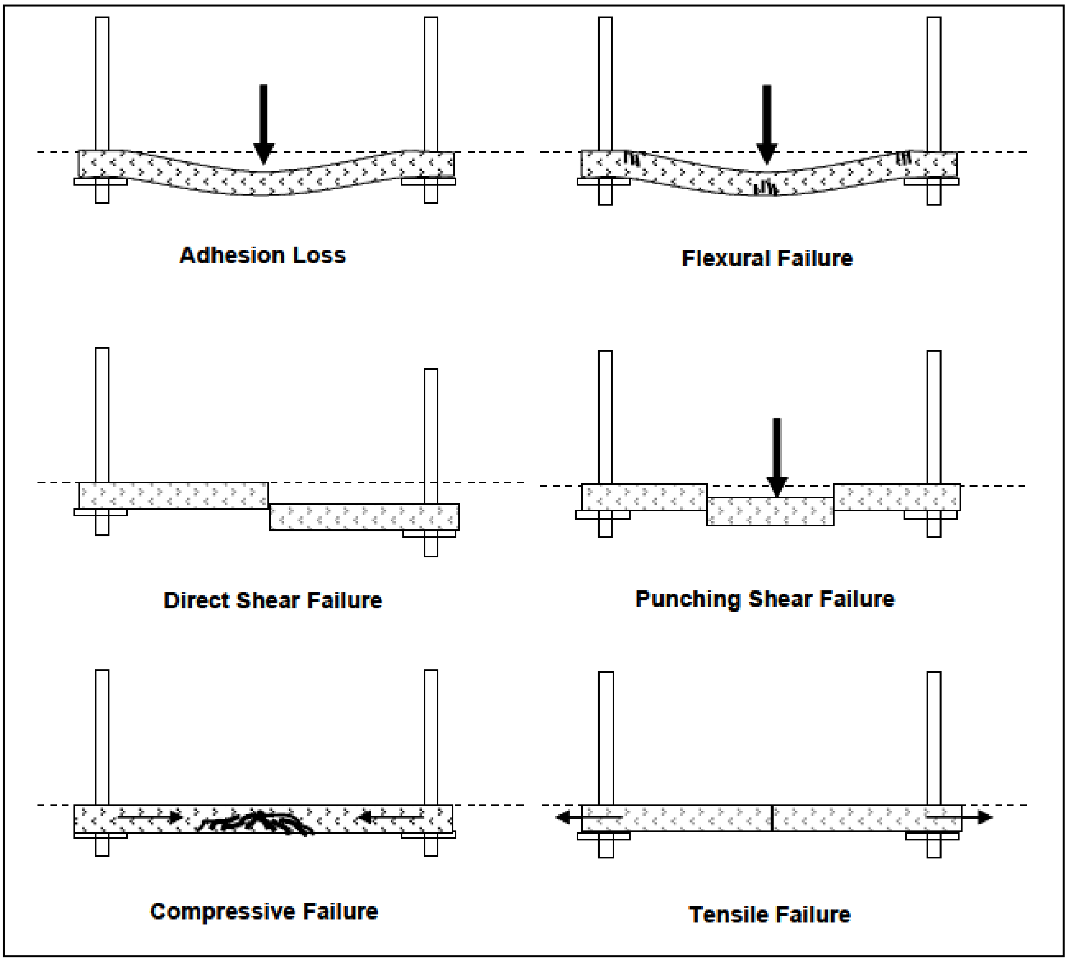


Figure 2-9 Failure modes of shotcrete [65]

- Adhesive failure: adhesive failures occur when the bond between the shotcrete and the substrate simply is not strong enough. Seymour (2010) explains that this causes an air bubble to form between the surface and the shotcrete, which might fail and result in falling shotcrete [64]. This failure mode can however be partially prevented by carefully washing the surface prior to spraying [47].
- Flexural failure: if the adhesion is lost due to peeling off the shotcrete from surface or slabbing within the substrate, then and only then does the flexural failure mechanism become possible [65]. Flexural failures can be derived from beam theory, where the shotcrete layer is represented by a constrained beam that is being loaded with the weight

of loose surface material. This causes the shotcrete to fail in tension in planes that are perpendicular to the shotcrete layer [47].

- Direct shear failure: if the adhesion is strong and loss of adhesion does not occur failure of the shotcrete layer might occur in direct shear, if the load exceeds the shear strength of the shotcrete [65].
- Punching shear failure: once the adhesion is lost punching shear failure may occur close to the surface bolts that is spanning the shotcrete, where the shear forces have the largest magnitude [47]. The failure occurs in an inclined plane of approximately 45^o with respect to the horizontal plane, therefore being perpendicular to the tensile stresses that are imposed on the shotcrete layer [47].
- Compressive and tensile failure: these failures occurs if the induced compressive or tensile stress caused by stress changes in the surface results in fracturing or spalling of the shotcrete layer [65].

2.9 Fresh Properties of Shotcrete Mixtures

The rheological evaluation of concrete is used to replace the conventional slump test [66]. Slump is an old way of measuring fresh concrete's workability. A fall, on the other hand, may lead to blunder. The slump test alone, according to Roussel et al., isn't adequate to evaluate pumpability since fresh concrete with the same slump value might have different pumping performance [67]. Good concrete pumping performance does not necessarily indicate slump, and vice versa. It has been shown that rheological characteristics collected using a rheometer may properly determine the workability of fresh concrete. Some of the most often used metrics for defining rheological qualities of new concrete are yield stress, plastic viscosity, and thixotropy [68,69]. Rheology research in the area of fresh concrete has made great progress in the past few years in terms of applying rheology to enhance the behavior of construction materials [70]. According to the data, Feys et al. [71] found a relationship between concrete rheological features and pressure loss in terms of pumpability (i.e. pressure loss, blockage, or not). The study also showed that the relationship between flow rate and pressure loss in pipes is similar to the rheological behavior of new concrete, with nonlinear rheological properties leading to nonlinear "press loss-flow rate" curves. Secrieru et al. focused on numerous rheology-based methodologies for assessing fresh concrete pumpability [72]. The pumping pressure is determined not only by the properties of the boundary layer between the pipe and the concrete mass, but also by the rheological parameters of the concrete, according to Mai et al. [73]. Measuring the rheological parameters of new concrete is challenging because to early hydration and thixotropy, and they alter with shear history and time [74].

2.10 Mechanical Properties of Shotcrete

As indicated in the literature studies [21,75], incorporating PET fibers into concrete mixes may improve their mechanical properties. Foti [11] looked into the impact of lamellar and ring-shaped PET fibers on concrete ductility and discovered that the distinctive ring shape helped to hold the concrete together on both sides of a cracked region. A small number of ring-shaped PET fibers might have a big influence on the hardness of concrete mixtures this way. PET fibers in concrete improved the splitting tensile strength and compressive strength, according to Irwan et al. [21]. According to Fadhil and Yaseen, as compared to plain concrete, the rupture strength and impact resistance of concrete panels mixed with PET fibers increased by 34.27 percent and 157.14 percent, respectively [22]. The length of fiber has a substantial influence on fiber-reinforced concrete, according to Juhasz et al. Increased fiber embedding length improved pullout strength, according to the researchers. Pullout strength was also affected by surface friction and interfacial binding energy between fibers and the concrete matrix [23].

2.11 Shotcrete Application in Structural Member

The ability of Fiber Reinforced Shotcrete (FRS) to resist load when broken is the reason for its extensive application in construction. So far, the most common use has been in the fabrication of civil tunnel linings. It has risen in prominence as a result of gains in both economic competitiveness and structural performance over the previous 25 years, to the point that it is currently used for at least a component of practically every tunnel recently built [76].

Experimentation with mix compositions and research into the mechanical behavior of fibers in a cured concrete matrix have improved FRS structural performance. Shotcrete design standards have shifted from prescriptive to performance-based, which has resulted in this breakthrough. It was commonly considered in the early days of FRS that all fibers functioned equally in the post-crack region and that fiber dosage was the most significant determinant of post-crack performance [76]. These premises have now been shown to be erroneous through experience. FRC structural standards are currently based on performance utilizing either beam or panel specimens, mainly in the fractured condition [77]. The ASTM C-1018 test for beams is a commonly used test [78].

Fiber reinforcement produces a concrete liner that differs from mesh reinforced concrete in many ways. Most economically viable FRS mix formulations incorporate post-crack strain softening in flexure, although mesh reinforced concrete is typically plastic (at least up to moderate crack widths). The degree of strain softening that happens is governed by a variety of factors, including fiber type and dosage, and varies greatly amongst concretes used for different purposes. Due to the complexity of post-crack material behavior, efforts to develop a rational lining design approach using FRS have been frustrated, leading to the usage of arbitrary performance measures. It's predictable that there's a lot of debate over which kind of test offers the greatest measure of performance for discriminating between competing FRS mixes in this puzzling situation [77].

2.12 Concluding Remarks

Fiber reinforced shotcrete has a lot of potential for usage in value-added applications to optimize economic and environmental advantages. Converting PET into useable resources in the manufacturing of sprayed concrete may result in significant cost savings. Several research have examined the qualities of PET and FRC in order to better understand the impact of FRS physical properties on fresh and mechanical concrete properties. The following are the important remarks that may be summarized from the examined studies:

1. Waste plastic fibers applications in term of FRC and FRS have been explained thoroughly in this chapter.
2. There are two methods to produce sprayed concrete: dry-mix and wet-mix methods.
3. The cost of equipment, maintenance needs, operating features, placement characteristics, and product quality may all influence whether a dry-mix or wet-mix procedure is used.
4. Generally, bond strengths to existing materials are higher with dry-mix shotcrete than with wet-mix shotcrete.
5. Despite the varieties of plastics produced, PET is the most relevant as it currently accounts for about 7% of the total plastic waste.

6. Using shotcrete to repair specific structural members has been in use lately.
7. Workability of shotcrete depends on several combinations of parameters.
8. The shotcrete also needs to be properly placed with the lowest slump as possible, in order to obtain a thicker layer without fallouts.
9. There are two basic types of shotcrete failures; the first one is fallouts of only shotcrete, which indicates poor adhesion against the surface, the second mode is fallouts of shotcrete, which indicates that the surface has failed.
10. There is lack of studies in evaluating shotcrete incorporated with WPF at various contents in order to study the structural behaviour of casted reinforced concrete members.

CHAPTER THREE

Materials and Experimental Program

3.1 Introduction

Features of shotcrete materials' components have a significant impact on their behavior (fiber, concrete material and additive). As a result, analyzing the qualities of these components will give useful information for designing and optimizing the mix for these composites. This chapter covers the material selection, characterisation, and mixture design approach used for reference and WPF shotcrete mixes, as well as various mix design-related parameters including density, splitting, and compressive strength. From December 1, 2020, to July 1, 2021, the experimental work was carried out at Anbar University's civil engineering department laboratory. Figure 3-1 is a flow chart that describes the experimental program.

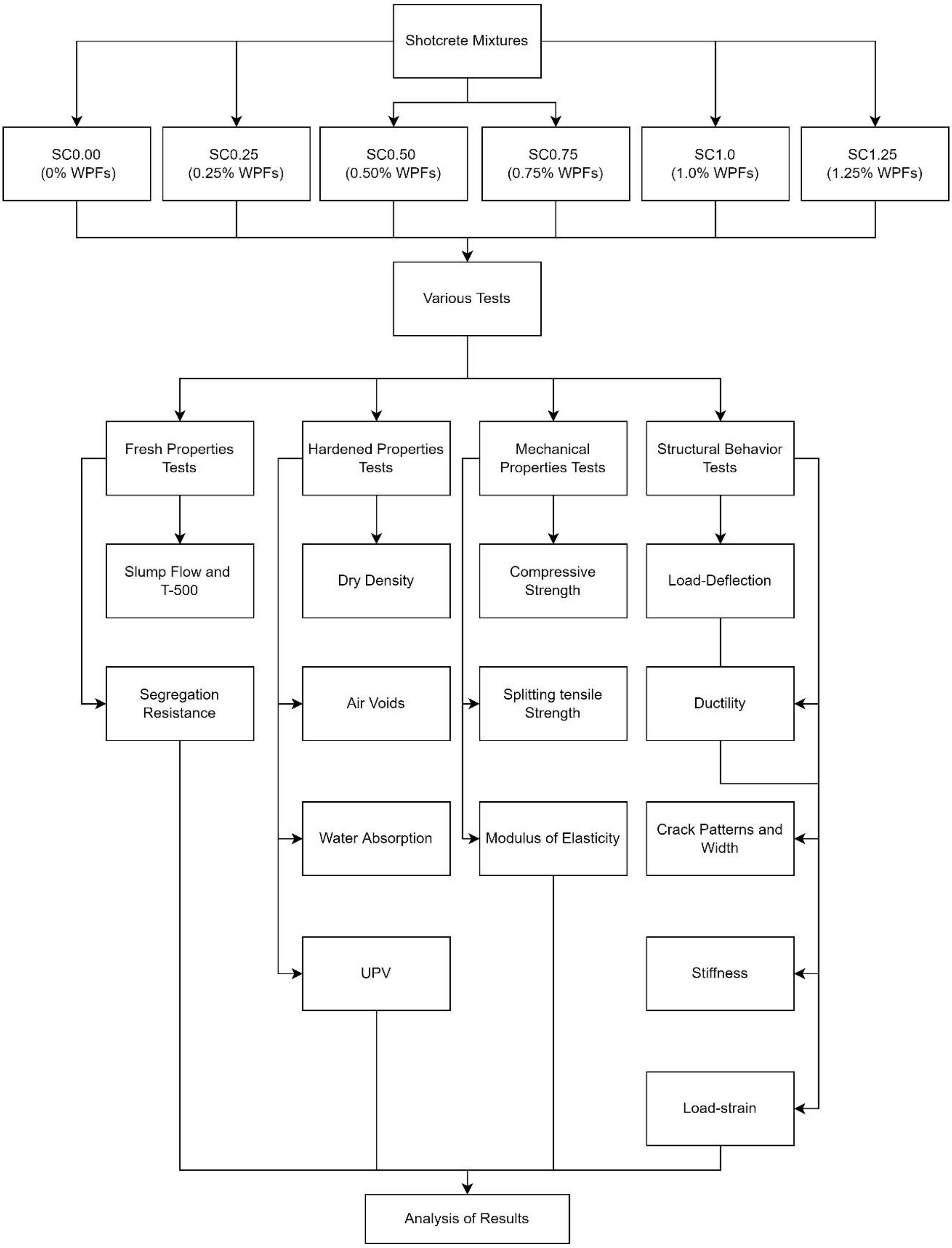


Figure 3-1 Flow chart of the experimental work

3.2 Materials

The materials used for the shotcrete mixes are complied with universal and local standards.

3.2.1 Cement

In this investigation, Al-Mass Ordinary Portland Cement (OPC) with a specific gravity of 3.15 was employed. In Iraq, this is the kind of preferred cement. Table 3-1 shows its physical and chemical attributes.

Table 3-1 Physical properties and chemical compositions of cement

Physical Properties		
Test Type	**Content**	**Iraqi standard No. 5/1984 Limits**
Fineness (cm^2/kg)	361.0	≥230
Initial Setting (min) Final Setting (min)	195 315	≥45 ≤600
Compressive strength for cement mortar cube		
3 Days (MPa)	20	≥15
7 Days (MPa)	27	≥23
Chemical Compositions		
Oxide composition	**Content (%)**	**Iraqi standard No. 5/2019 Limits**
SiO_2	20.3	-
CaO	62.7	-
MgO	2.7	5 % Max.
Al_2O_3	4.5	-
SO_3	2.5	2.8 % Max.
Fe_2O_3	3.9	-
Loss on ignition	3.0	4 % Max.
Insoluble residue	0.4	1.5 % Max.
Phases		
LSF	0.94	-
SM	2.42	-
AM	1.15	-
C_3S	56.8	-
C_2S	15.3	-
C_3A	5.3	-

* Full test results are shown in Appendix A

3.2.2 Water

All specimens were cast and cured using tap water throughout the study.

3.2.3 Coarse Aggregate

Crushed aggregate with a nominal maximum size of 10 mm was procured from the Al-Nabaee quarry in Iraq for this investigation. According to Iraqi standard specification (I.Q.S.) No.45/ 1984, this was gathered, dried, and kept in various depots [79] as shown in Table 3-2, The analysis of coarse aggregate utilized is shown in Figure 3-2. The coarse aggregate has a dry density of 1650 kg/m^3. The coarse aggregate is shown in Table 3-2.

Table 3-2 The Gradient properties of coarse aggregate

Sieve Size	**Passing %**	**Limits of Iraqi specification No.45**
12.5	100	100
9.5	99.07	85-100
4.75	1.27	0-25
2.36	0.00	0-5
Deleterious Substance		
≤ 75 μm	1.1	≤ 3.0
SO_3 (%)	0.043	≤ 0.1

* Full test results are shown in Appendix A

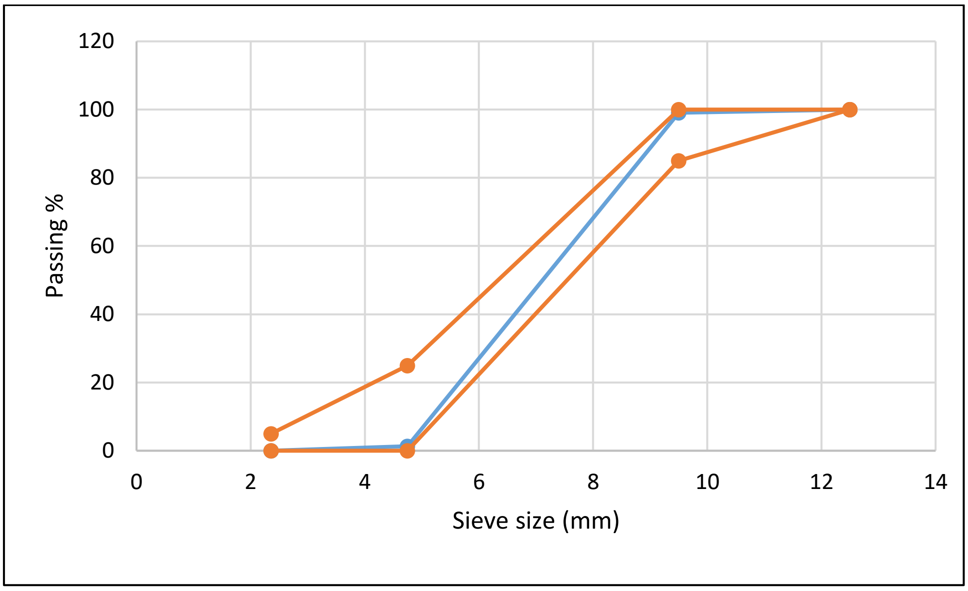


Figure 3-2 Sieve analysis of coarse aggregate

3.2.4 Fine Aggregate

From locally regions (ASSELLA), Natural sand was utilized in this study, as shown in Figure 3-4. It had rounded shape and smooth texture with maximum size 4.75 mm. Before testing and using, the sand was washed to remove mud and any defective particles. Table 3-3 and Figure 3-3 present the sieve analysis and physical characteristics of fine aggregate. The finding showed that, the sand grading, sulfate content and passing from 0.075% were sufficient to the Iraqi specification (I.Q.S.) No.45/ 1984 [79].

Table 3-3 Sieve analysis for fine aggregate (sand)

Sieve Size	Passing %	Limits of Iraqi specification No.45
4.75	99.53	90-100
2.36	87.13	75 - 100
1.18	67.93	55 - 90
600 µm	40.00	35 - 55
300 µm	9.53	8 - 30
150 µm	1.00	0 - 10
Deleterious substance		
≤ 75 µm	1.4	≤ 5.0
SO_3 (%)	0.34	≤ 0.5

* Full test results are shown in Appendix A

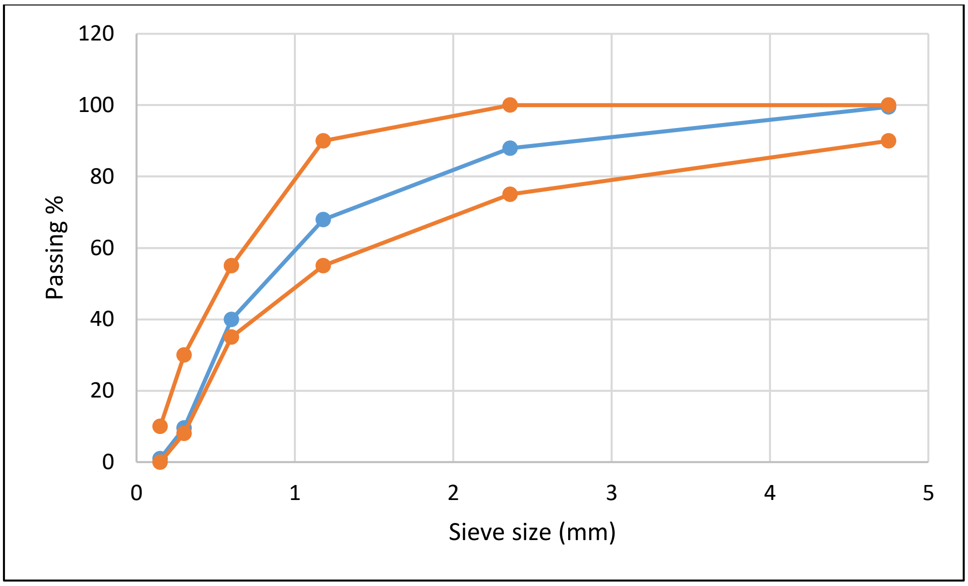


Figure 3-3 Sieve analysis of fine aggregate

3.2.5 Superplasticizer (SP)

MasterGlenium® 51 is a new generation water-reducing superplasticizer concrete additive designed for ready-mix concrete and precast industries that need high early and final strengths and durability. According to ASTM C 494 Type F, the physical parameters of superplasticizer are as follows: Concrete Admixture Standards with a High Range Water Reducing/Super Plasticizer [80]. Appendix A shows the full data sheet of the superplasticizer.

Table 3-4 Physical properties of MasterGlenium® 51 superplasticizer*

Technical data	**Results**
Form	Viscous Liquid
Color	Light Brown
Relative density	1.1 @ 20°C
pH	6.6
Viscosity	128 +/ - 30 cps @ 20°C

*The physical properties were considered according to company (see Appendix A)

3.2.6 Accelerator

To accelerate hardening of shotcrete concrete, the SikaRabid ®-1 was used according to ASTMC1240-15 [81], The specific gravity of accelerator was 1.17 while the other properties could be seen at Appendix A.

3.2.7 Waste Plastic Fibers (WPF)

The fibers were obtained by cutting WPF, gathered directly from disposed drinking bottles in trash sites. Figure 3-5 shows the used WPF. The fibers were made into piece for one aspect ratio by using shredder. 27, 4, 0.29 mm were the length, width and thickness of the fiber, respectively. The aspect ratio of fibers (22) was adopted in this work according to calculation below. The dimensions and physical properties WPF are given in Table 3-5.

$$\frac{\pi D^2}{4} = 4 \times 0.29 \rightarrow D = \sqrt{\frac{4 \times 4 \times 0.29}{\pi}} = \sqrt{1.477} = 1.215 \qquad (3\text{-}1)$$

$$\frac{l}{D} = \frac{27}{1.214} = 22.24 \ (aspect\ ratio) \qquad (3\text{-}2)$$

Table 3-5 Dimensions and Physical properties of WPF

Fiber's type	PET
Length (mm)	27
Width (mm)	4
Thickness (mm)	0.29
Aspect Ratio	22
Water absorption	nill

Figure 3-5 Waste plastic fiber

3.2.8 Steel Reinforcement Bars

All of the reinforced bars employed in this research were distorted. The longitudinal orientation of the beams was strengthened with 10 mm diameter reinforcements at the bottom and top as shown in Figure 3-6. Stirrups with an 8 mm diameter were used in the shear reinforcement. The ASTM A615 standard was used to test the reinforced steel bars [82], to evaluate the yield stress, ultimate strength and elongation. The tests were carried out at the civil engineering department's laboratory at Anbar University. Table (3-6) shows the mechanical characteristics of reinforced bars. Keep in mind that the nominal diameter in Table (3-6) comes from the manufacturer, but the actual area of the cross-sectional bars was obtained by dividing the weight of samples by the measured lengths and steel density for each of the three bars and averaging the results.

Table 3-6 Mechanical properties of steel bars

Diameter	**Nominal area (mm^2)**	**Actual area (mm^2)**	**Yield Strength (MPa)**	**Ultimate Load (MPa)**	**Elongation (%)**
8 mm	50.265	49.016	551	714	11.5
10 mm	78.540	75.429	29	800	11.1

Figure 3-6 Steel reinforcement bars

3.2.9 Wooden Mold

Six molds were made from the plywood. The interior dimensions of all molds are (100) mm width, (150) mm height and (1200) mm length. Figure 3-7 shows the wooden molds of reinforced concrete beams.

Figure 3-7 Wooden mold

3.3 Shotcrete Machine

Shotcrete machines are used for wet concrete spraying process. The job must be automated because of the high spray outputs and wide cross-sections. Working with wet mixtures necessitates the use of concrete spraying systems with pumps. Unlike traditional concrete pumps, these systems must also offer a concrete flow that is as consistent as possible, and therefore continuous, in order to ensure uniform spray application [83].

A wet shotcrete machine was manufactured from materials available in the local market. This machine works with the mechanism of hydraulic pressure and speed control of compressed air in order to shoot the wet concrete to different distances. The required shootable distance of wet concrete is controlled by both the hydraulic pressure and the velocity of the compressed air. Manufacturing Shotcrete to pump shotcrete to repair and reinforce broken concrete sections locally to save a lot of money, effort, and time, as well as acquire expertise throughout the manufacturing process. Appendix B has more comprehensive images of shotcrete machine production.

The detail of the machine is summarized below as shown in Figure 3-8 and listed in Table 3-7:

1) Steel structure.

2) Electric pump with 20 hp capacity.

3) Hydraulic pump with 400 bar capacity.

4) Pistons with speed regulator.

5) Hooper

6) Air Compressor electric motor.

7) Electrical control panel.

8) Cooling system.

9) Hose and tube.

Table 3-7 Details of manufactured shotcrete machine

Hooper size (m^3)	Hose size (in)	Air compressor capacity (Kpa)	Maximum output (m^3/hr)
0.0864	2	1240	2.6

(a) Pistons (b) Mixer

(c) Shotcrete body (d) Control Panel

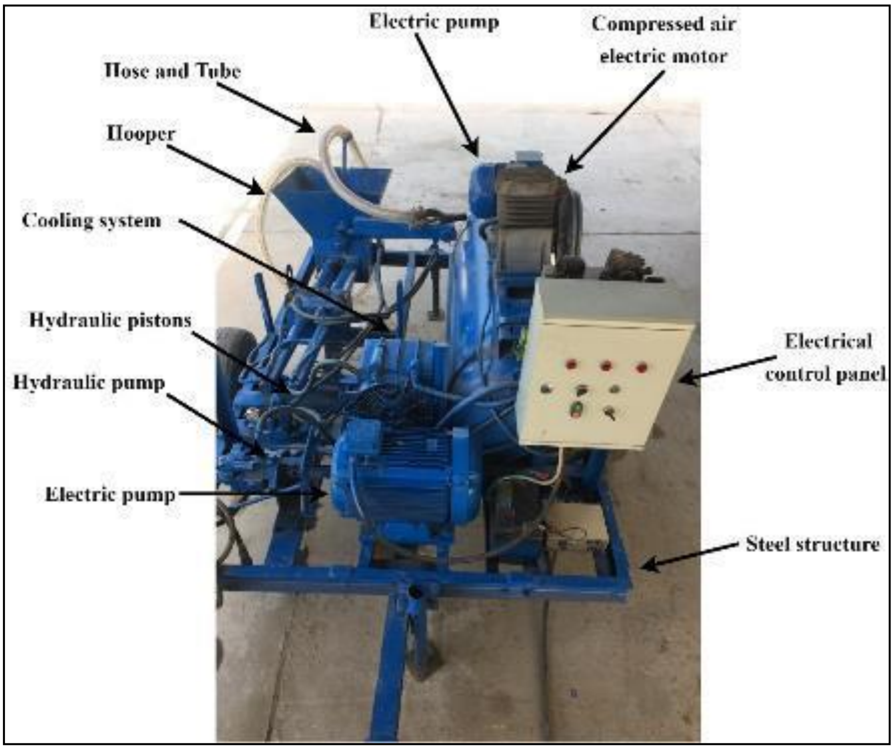


Figure 3-8 Main parts of shotcrete machine

3.4 Mixing, Casting and Curing Procedure

3.4.1 Mix Design

The shotcrete mix proportion considered in this study was cement, water, coarse aggregate, fine aggregates, and additives. The content of PET fibers was 0.25%, 0.5%, 0.75%, 1.0% and 1.25 % as a replacement of shotcrete volume. Table 3-8 lists the mix proportion of wet-mix shotcrete. The mixture proportions applied based on practical experiments and previous studies [12, 13, 54, 55].

The six shotcrete mixtures presented in Table 3-8 were developed according to ACI PRC-506-16 [84] using many trials mixes which doing for the references mix without WPF in order to obtain optimum shotcrete mix. The objective was to have optimum compressive strength. The control concrete specimens without WPF underwent the same tests as to compare the results with that of the specimens with WPF. Table 3-8 states that the amount of WPF in concrete mixes were 0.25, 0.5, 0.75, 1.0 and 1.25%. The selection of the amount of WPF for each concrete was mostly based on previous studies that stated the minimum and maximum amount of WPF in concrete. Superplasticizer was added to reduce the water. Thus, the w/c ratio was decreased from 0.45 to 0.414. In addition, Accelerator was used to make the mixture more hardened after been threw out from the machine.

Table 3-8 Shotcrete mixtures proportion ratios

Mix Code	C. kg/m^3	G. kg/m^3	S. kg/m^3	W. kg/m^3	Acc. kg/m^3	S.P kg/m^3	WPF kg/m^3
SC0.00	497.0	738.4	880.0	206.0	22.00	3.10	0
SC0.25	495.8	736.5	877.8	205.5	21.95	3.10	3.44
SC0.50	494.5	734.7	875.6	205.0	21.98	3.09	6.88
SC0.75	493.3	732.9	873.4	204.5	21.84	3.08	10.31
SC1.00	492.0	731.0	871.2	203.9	21.78	3.07	13.75
SC1.25	490.8	729.2	869.0	203.4	21.73	3.07	17.19

C = Cement, G = Gravel, S = Sand, W = Water, Acc.= Accelerator, S.P = Superplasticizer, and WPF = Waste Plastic Fibers

3.4.2 Mixing Procedure

The procedure, which adopted to mixing the compounds of shotcrete concrete could be summarized in the following:

1. The coarse and fine aggregate were wished by water to get rid from any clay particles and dust from the surface.
2. All materials were weighted according to design proportion using digital balance and putted in clean bags to store in dry place until casting day.
3. All standard molds cylinders and beams were cleaned and lubricated the inside surface by brush to prevent concrete cohesion on the molds before casting days. The reinforcement mesh was placed in molds after the spacers were fixed to achieve the required covers at each side.

4. Shotcrete contents were mixed including water in separated mixer than poured in shotcrete mixer in order to process through shotcrete machine and sprayed after mixed with water.
5. Shotcrete were propped up at an angle while the nozzleman shot the concrete perpendicular to the mold to reduce rebound and improve encapsulation as shown in Figure 3-9.
6. Finally, the concrete surface was levelled by hand trowel and using nylon sheets for covering the specimens to avoid water evaporation of concrete.

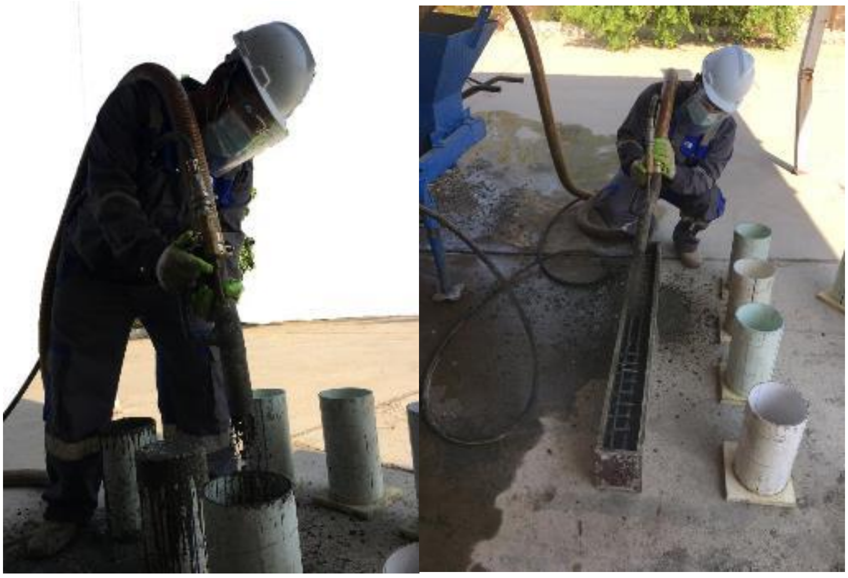


Figure 3-9 Shotcrete casting for hardened properties

Although the testing methods between wet mix shotcrete and conventional concrete are similar, there are some major differences with how it is set up. Typically, shotcrete is tested by coring samples from the machine that has been shot by the nozzleman using the same mix being used on site. This is examined by shooting normal 150x300 mm cylinders with the shotcrete and comparing to a shot slab with the same mix [42].

3.4.3 Curing Process

After the concrete was reached to hardened stage, all specimens extracted from molds and prepared to place in water tank for curing process for 28 days, relatively at constant temperature (25±3°C). The curing process is essentially at early hardened stage to prevent water, that sharing in cement hydration, from evaporation and to gain subsequently high strength. It should be mentioned that an electrical water heater was used to balance the temperature at 25°C until the end of curing period (ASTM C192/C192M-18) [85], see Figure 3-10. After 28 days curing, the specimens would take off for testing.

Figure 3-3 Curing process of shotcrete samples

3.5 Tested Properties of Shotcrete Concrete

3.5.1 Slump Flow Test and T-500

The slump flow test for all the shotcrete mixtures were conducted using standards and procedure of ASTM C1611/C1611M-18 [86]. This test determines the flow of the shotcrete mixture after it has been mixed. This is an important test to conduct since there is a higher risk of segregation of aggregate and bleeding of the mix [87,88]. Figure 3-11 shows the test setup for this test.

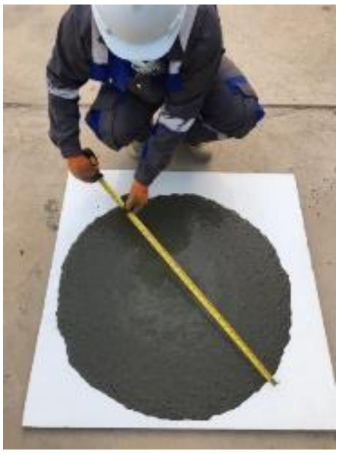


Figure 3-4 Slump flow test setup

The set up for this test is shown in Figure 3-11 and a summary of the procedure of this test is as follows; a reference diameter of 500 mm has been drawn out on the flat surface. Then the slump cone which was placed on a flat surface in the center of the reference diameter had been filled with the concrete mix till it reached the top of the cone. After the excess concrete at the top of the cone had been removed using a bar. The mold was then removed and once the cone was lifted off the surface a timer had started to measure the time it took for the concrete mix to reach 500 mm. This time is known as the variable T500. Once the mix had stop spreading, a visual inspection was made to see that no segregation or bleeding around the diameter was present. Two diameter measurements were recorded, and the slump flow was calculated by taking the average of the two measurements. The visual inspection of the fresh concrete for each mix has been classified into a Visual Stability Index (VSI) value. Table 3-9 is a summary of the VSI values [86].

Table 3-9 Visual Stability Index (VSI) [86]

VSI Value	Criteria
Highly Stable	No evidence of segregation or bleeding
Stable	No segregation and slight bleeding as a sheen
Unstable	Slight mortar halo ≤ 10 mm and/or aggregate piled in the center of the concrete mass
Highly Unstable	Segregated, large mortar halo > 10 mm and/ or large aggregate pile in the center of the concrete mass

3.5.2 Segregation Test

In order to determine the concretes resistance to segregation, segregation index (SI) test was conducted where each mix was visually inspected during slump-flow test according to EFNARC [89]. A segregation index (SI = 0) is assigned to a certain SC mixture when there is no visible segregation of coarse particle/mortar at the center of the concrete spread and there is no water flowing freely around its perimeter which means this particular concrete is free of segregation. On the other hand, if there is slight accumulation of coarse aggregate particles/mortar at the center of the concrete spread or there is water flowing freely around its perimeter then this particular concrete is assigned SI=1, which means it has adequate resistance to segregation. This test has been carried out by determining SI using Equation. 3-3.

$$SI = \frac{M_{ps}}{M_t} \times 100 \qquad (3\text{-}3)$$

Where *SI* is segregated index, M_{ps} is mass of passed materials (gm) and M_t is initial mass of placed on to the sieve (5mm) (gm).

3.6 Hardened Properties of Shotcrete Mixtures

3.6.1 Dry Density

The density values were determined according to the requirements of ASTM C642-6 [90], for shotcrete with 28 days of age, using a 300 mm cylindrical specimens. Three specimens were cast for each concrete mix developed. This test was performed at the Laboratory of the Civil Engineering Department in University Of Anbar, following the steps below:

a) The specimens were then dried in an oven at 80 °C for not less than 24 hours and, the specimens were cooled to room temperature for subsequent determination of the dry mass (A)
b) For 24 hours, the specimens were submerged in water. The wet surface of all specimens was then dried with a towel to determine the density of the specimens in a saturated state (B).
c) The specimens were then dried in an oven at 80°C for at least 24 hours before being cooled to room temperature for further dry mass determination (C).
d) After immersion and boiling, suspend the specimen by a wire and assess the apparent mass in water to record this apparent mass (D).

After obtaining the masses mentioned above, it was possible to calculate the density of the specimens by means of the following equation:

$$Dry\ Density\ \% = \frac{A}{B-D} \times 100 \qquad (3\text{-}4)$$

3.6.2 Voids

The voids test was carried out on 300 mm cylindrical specimens, according to ASTM C642-13 [90]. The average voids of each mix were the average of three cylinders by using equation (3-5).

$$\text{Voids } \% = \frac{C-A}{C-D} \times 100 \tag{3-5}$$

3.6.3 Water Absorption

ASTM C642-6 [90] guidelines were followed in this test. Water Absorption test carried out on 300 mm cylindrical specimens. Average value of three specimens was adopted as result. Water Absorption is measured by using following equation.

$$Water\ Absorption\ \% = \frac{C-A}{A} \times 100 \tag{3-6}$$

3.6.4 Ultrasonic Pulse Velocity

Ultrasonic methods have been employed in the geotechnical area and mining research for some years. According to ASTM C597-16, this test was performed on 150*300 mm cylindrical specimens [91] Using the Ultrasonic Nondestructive Digital Indicating Tester on the Go (pundit). The transit time was measured in microseconds using a 54 kHz transducer configured to enable direct transmission. The UPV was used to measure the micro-cracking, homogeneity, and solidity/compactness of cement-based mixes as a non-destructive test technique. The quality of concrete is classified by ultrasonic digital tests based on longitudinal pulse velocity, as shown in Table 3-10 [91].

Table 3-10 Quality of concrete as revealed by ultrasonic velocity [91]

Velocity (km/sec.)	**Quality of concrete**
≥ 4.5	Excellent
3.66 - 4.57	Good
3.05 – 3.66	Fair
2.14 – 3.05	Weak
≤ 2.14	Very Weak

The surface of the samples was cleaned using polishing paper and oiled with grease in order to fully transmit the pulse produced by the transducer to the concrete. Ultrasonic velocity is used to (i) determine the dynamic poisons ratio and modulus of elasticity of concrete, (ii) evaluate the uniformity of concrete in or between members, (iii) assess the quality of concrete, and (iv) identify the alterations in properties of the hardened concrete with time. Equations (3-7 and 3-8) are used to determine the ultrasonic pulse velocity and strength in this test [92].

$$V = \frac{L}{T} \tag{3-7}$$

$$Ultrasound\ Strength = 2.8 \times e^{(0.53V)} \tag{3-8}$$

Where V is ultrasonic pulse velocity in km per sec., L is path length in mm. T is transit time in μ second.

Figure 3-5 UPV test setup

3.7 Mechanical Properties of Shotcrete Mixtures

3.7.1 Compressive Strength

ASTM C39 / C39M-21 was used to assess the compressive strength of the shotcrete mixtures [93]. For all combinations, the test was performed on 150 X 300 mm cylindrical test specimens at the ages of 7, 14, and 28 days. To execute all mechanical tests according to ASTM criteria, a cylindrical shape was used as a test specimen in compressive strength. Until the test day, all cylinders were wet cured in the curing chamber at 23 °C and 90% humidity. In this test, a universal hydraulic digital compression testing equipment was employed. Figure 3-14 shows a BESMAK with a capacity of 2000 KN and a loading rate of 5.3 kN/s.

Figure 3-6 Compressive strength test setup

3.7.2 Splitting Tensile Strength

At 7, 14, and 28 days, the splitting tensile strength of 150*300 mm concrete cylinders was tested. The test was carried out in accordance with ASTM C496/C496M-17 as shown in Figure 3-15 [94]. Concrete cylinders were water-cured in the curing chamber until the test day, at a temperature of 23 °C and a humidity of 90%. Before one hour had passed since the test, the concrete cylinders were taken from the curing chamber, dried, and placed on the loading machine. The concrete specimen was put on top of a plywood strip that ran along the center of the loading machine's bottom bearing block. On top of the concrete specimen, a comparable plywood strip was centered over the bottom strip. The load was applied continuously at a steady rate within the range of 2.1 kN/s until the specimen failed. The equation (3-7) was used to compute the tensile strength of concrete.

$$T = \frac{2P}{\pi LD} \tag{3-7}$$

T is the tensile strength of the splitting tensile in N/mm. The maximum load in N is 2P. The length and diameter of the concrete sample in millimeters are L and D. The arrangement of the tensile strength test is shown in Figure 3-15.

Figure 3-7 Splitting tensile strength test setup

3.7.3 Modulus of Elasticity (Young's Modulus)

The modulus of elasticity test was performed using standard cylinders with a diameter of 150 mm and a height of 300 mm, as specified by ASTM C469-14 [95]. For normal hardened concrete cylinder specimens of any age and curing circumstances, this test may produce a "stress to strain" ratio result (from the stress-strain curve). For each blend, the average test result of three specimens was used. The cylinder specimen and the apparatus utilized in this test are shown on Figure 3-15. The equation (3-8) was used to compute the static modulus of elasticity (Ec):

$$E_c = \frac{S_2 - S_1}{\varepsilon_2 - 0.00005} \quad (3\text{-}8)$$

Where:

S_2: the stress corresponding to 40% of ultimate load (MPa)

S_1: the stress corresponding to a longitudinal strain 0.00005 (MPa)

ε_2: The longitudinal strain produced by stress S_2

Figure 3-8 Modulus of elasticity test setup

3.8 Bending Behavior of Shotcrete Reinforced Beams

3.8.1 Flexural Beams

The tests in this work were undertaken to assess the flexural behavior of shotcrete beams and to calculate their ultimate flexural capacity. Six flexural beams with suitable shear reinforcement were cast and tested for the investigation. All of the beams were designed as under-reinforced tensile.

The parameters of all the beams were: width = 100 mm, depth = 150 mm, and length = 1200 mm. As previously stated, one arrangement was chosen for flexural reinforcement. A transparent cover of 20 mm was applied to all beams, and shear reinforcement was given by bar strips (8 mm) at 50 mm c/c. The cross-sections and reinforcing arrangement of the flexural beams were shown in Table 3-11 and Figure 3-16. Appendix C shows the calculation for the steel reinforcement ratio (ρ).

Table 3-11 Geometry & reinforcement configuration of the flexural beams

Beam No.	**Beam Width (mm)**	**Beam Depth (mm)**	**Beam Length (mm)**	**Bottom Flexural Rein.**	**Comp. Rein.**	**Rein. Ratio**	**Fiber Content %**
SC0.00	100	150	1200	2, Ø10 mm	2, Ø8 mm	0.0135	0
SC0.25							0.25
SC0.50							0.5
SC0.75							0.75
SC1.00							1
SC1.25							1.25

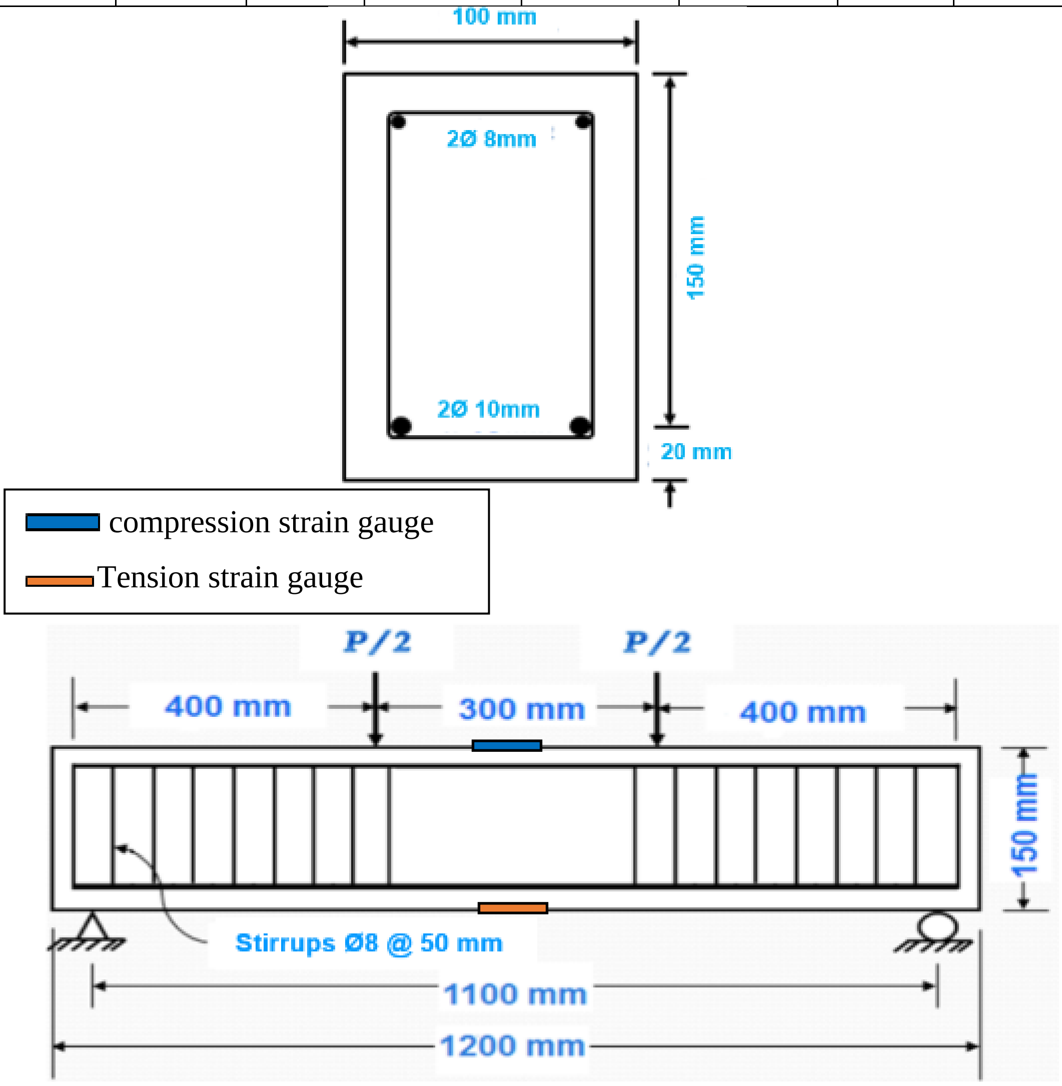


Figure 3-9 Detailed dimensions of tested beam instrumentation

3.8.2 Experimental Setup and Instrumentation

The specimens were simply evaluated as supported beams under four-point loading. Digital gauges were used to measure the deflections at the mid span and loading point. Figure 3-18 depicts the experimental setup and placement of the digital gauges for measuring strain in shotcrete concrete.

Figure 3-10 Experimental setup for flexural beams

The force was applied progressively from a hydraulic jack at 5 kN for each increment, and the load was held steady for some time at each step to watch the crack pattern. During the test, the start and growth of shear and flexural cracks were observed and recorded at different stages. During the testing to failure, the load–deformation reaction was observed and recorded by 28 Mega-pixel digital camera. The test also showed the beam's overall behavior, including fracture formation, crack patterns, failure modes, and weight transmission mechanism.

In this work, the measuring strain for compression, for all beams by using the strain gauge and data logger. In this study, two strain gauges were used at the critical positions; attached on concrete surface (tension and compression zone), for measurement the strain behavior during applying load. It should be cleaning a surface of concrete before fix the strain gauge by special epoxy. The type of data logger was TML (Tokyo Sokki Kenkyujo) and the CSW-5A 5-channel automatic switching box such as shown in Figure 3-18. Before the test, the gauge factor must be entered to the data logger to ensure the accuracy of the results.

Figure 3-11 Data logger series

CHAPTER FOUR

Results and Discussion

4.1 General

In this chapter, the results are presented into three different sections. The first section shows fresh shotcrete samples test results incorporated with WPF. The second section considered the hardened shotcrete characteristics incorporated with WPF test results. Finally, the strength behavior of shotcrete with WPF and without WPF in shape of reinforced concrete beam are presented and compared in term of different contents of WPF.

4.2 Fresh Properties of Shotcrete Mixtures

As explained in Chapter three, Slump flow, T_{500} and Sieve Segregation tests were conducted on WPF shotcrete. The main results of tests can be summarized as follow:

4.2.1 Slump Flow and T_{500}

The obtained results of slump flow and T_{500} of shotcrete mixtures are shown in Table 4-1 and Figures 4-1 and 4-2. The results showed an increase in slump while increasing the WPF till 0.75%. After that, the slump decreased when adding WPF more than this percent. Such behavior could describe as two parts: first, adding superplasticizer with WPF may increase slump test values, while increasing surface area by adding more WPF will decrease the slump. Those concepts approved by many researchers [25, 28 and 91]. The T_{500} results showed the same reason of slump test results. In Fact, the workability of fresh shotcrete affected by many reasons such types and quantity of superplasticizer and pressures of air concrete shooter. The slump value of 880 mm considered maximum slump value after many try and error. Therefore, the slump flow for 0.75% WPF replacement (SC0.075) showed an increase in slump.

Table 4-1 Slump flow and T500 tests results for all mixtures

Mix Code	Slump Flow (mm)	T500 (sec.)
SC0.00 (Ref.)	750	0.3
SC0.25	780	0.5
SC0.50	790	1
SC0.75	880	1
SC1.00	750	1
SC1.25	690	1

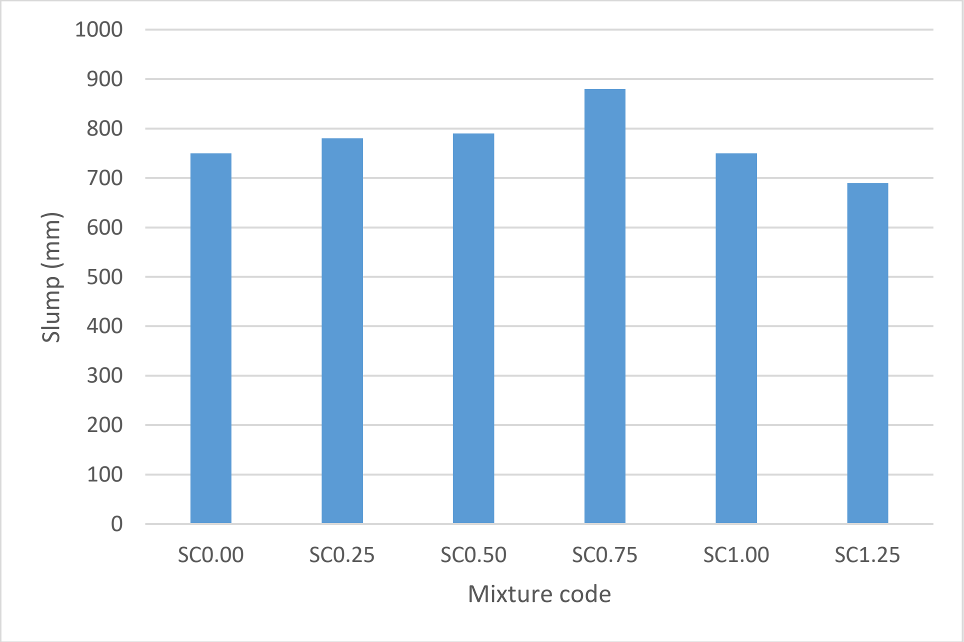


Figure 4-1 Slump flow tests results for all mixtures

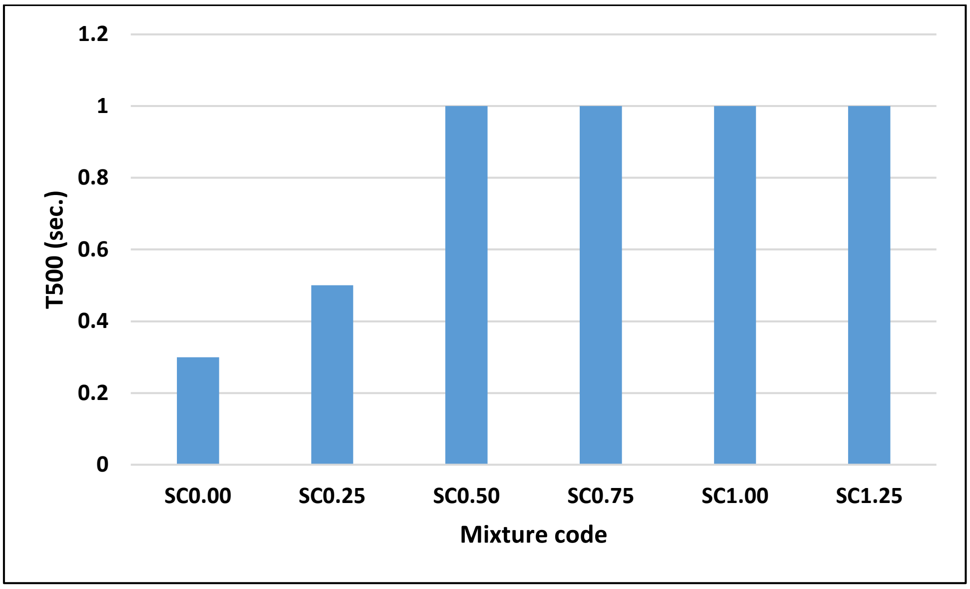


Figure 4-2 T_{500} tests results for all mixtures

4.2.2 Sieve Segregation

Table 4-2 and Figure 4-3 explain the results of sieve segregation test. The results exhibited a good resistance to segregation according to EFNARC limitations. The SI% values index were between 8 to 13, which are less than standard value (15%).

Table 4-2 Segregation Index (SR%) test results for all mixtures

Mix Codes	Segregation Index (SI%)
SC0.00 (Ref.)	14.8
SC0.25	13.4
SC0.50	11.2
SC0.75	9.6
SC1.00	9.1
SC1.25	8.3

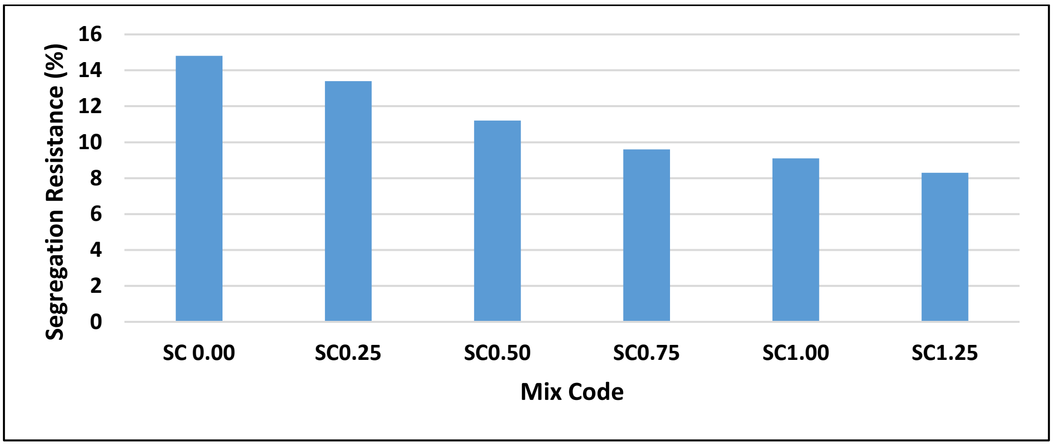


Figure 4-3 Segregation Index (SI%) test results for all mixtures

The sieve segregation test revealed that mixes with a larger proportion of WPF had a higher packing density and less void between aggregate particles, allowing for more paste in shotcrete and improved flow and segregation resistance till certain amount [96]. The increased angularity and surface roughness at a higher WPF content contributed to increase the cohesiveness, thus leading to lower segregation index.

4.3 Hardened Properties of Shotcrete Mixtures

4.3.1 Dry Density

Shotcrete dry density was measured in hardened phase only. Dry density results were measured at age of 28-day and shown in Table 4-3.

Table 4-3 Dry density test results for all mixtures

Mix Code	Dry Density (kg/m^3)	Difference (%)
SC0.00	2364	-
SC0.25	2368	0.16
SC0.50	2377	0.52
SC0.75	2373	0.36
SC1.00	2358	-0.27
SC1.25	2355	-0.41

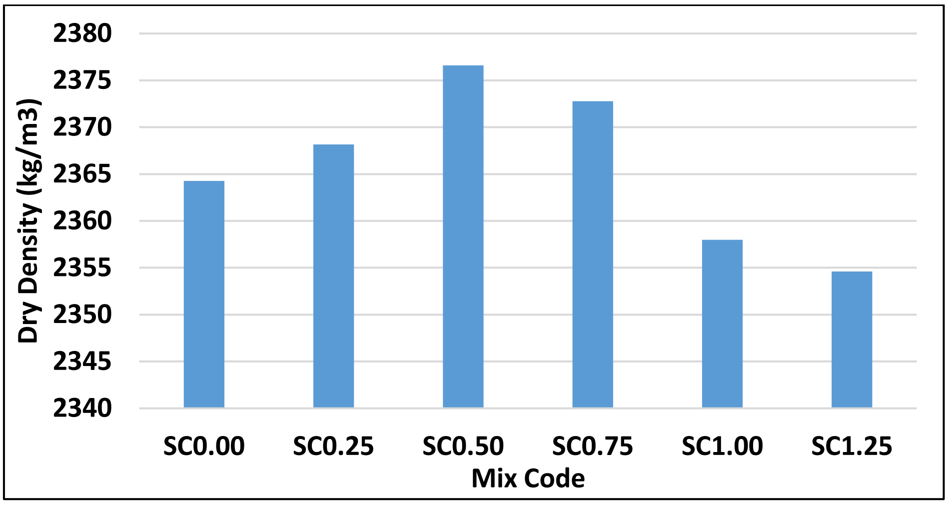


Figure 4-4 Dry density test results for all mixtures

Figure 4-4 shows dry densities for all mixes. Table 4-3 indicated that the density of SC0.75 decreased with the increase of fiber content. Moreover, SC0.25, SC0.50, and SC0.75 have higher densities compared to the control specimen (SC0.00). more cement ratio plays important rule in compared with WPF for describing the increasing density. The same results found by previous researchers [22,25,97]. The control specimen (SC0.00) had heavier density than SC1.00 and SC1.25 with 1.00 and 1.25 % of WPF, respectively.

4.3.2 Air Voids (%)

Table 4-4 represents the results of air voids percentage of shotcrete specimens incorporated with WPF.

Table 4-4 Air voids test results for all mixtures

Mix Code	Air Voids (%)	Increase (%)
SC0.00	0.80	-
SC0.25	1.27	58
SC0.50	1.87	132
SC0.75	1.95	142
SC1.00	2.19	172
SC1.25	2.62	224

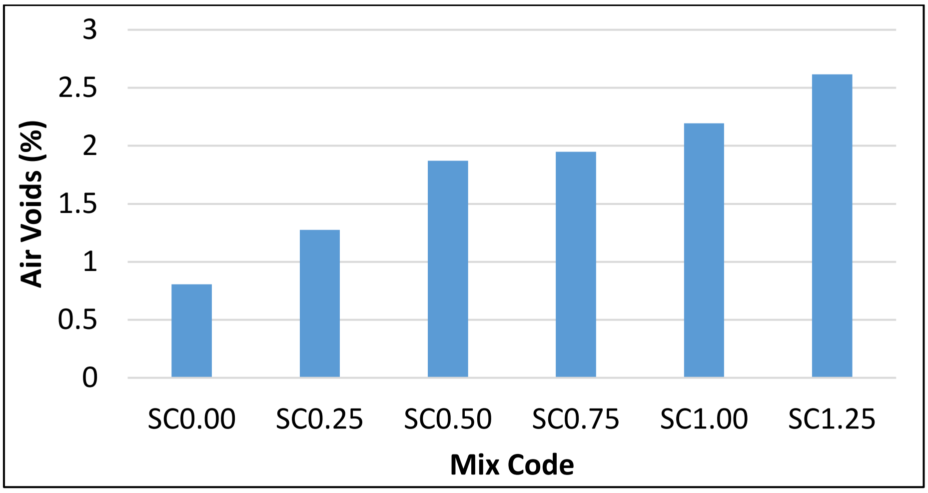


Figure 4-5 Air voids test results for all mixtures

When air entrained concrete is made, bubbles are purposely created. The bubbles generate huge voids in the cemented concrete. The presence of these voids will effect the fresh material's workability, consistency, bleeding, and yield, as well as the density, strength, and, most importantly, the hardened concrete's longevity [93].

In this study, it had been noted that the control specimen (SC0.00) had lower air voids ratio in compered with WPF specimens. The air voids of shotcrete reduce the surface tension of water, allowing more and smaller bubbles to form and stabilize during mixing. In addition, the mechanism of cohesion WPF with cement allow to generate more voids.

Doukakis 2013 [98] found through an experimental work in the self-compacting lightweight concrete, the fiber could have caused larger air avoids occurring which reduced the density of the mixture.

4.3.3 Water Absorption

According to earlier research, new specimens of concrete with WPF have a higher water absorption capacity owing to air entrapment and the development of air gaps that enable water to enter the concrete matrix more readily [99]. The experimental work showed that there are somehow linear relation in the water absorption with WPF as explain in Table 4-5 and Figure 4-6.

Table 4-5 Water Absorption test results for all mixtures

Mix Code	Water Absorption (%)	Increase (%)
SC0.00	0.67	-
SC0.25	1.08	61
SC0.50	1.48	120
SC0.75	1.68	150
SC1.00	1.75	160
SC1.25	1.85	176

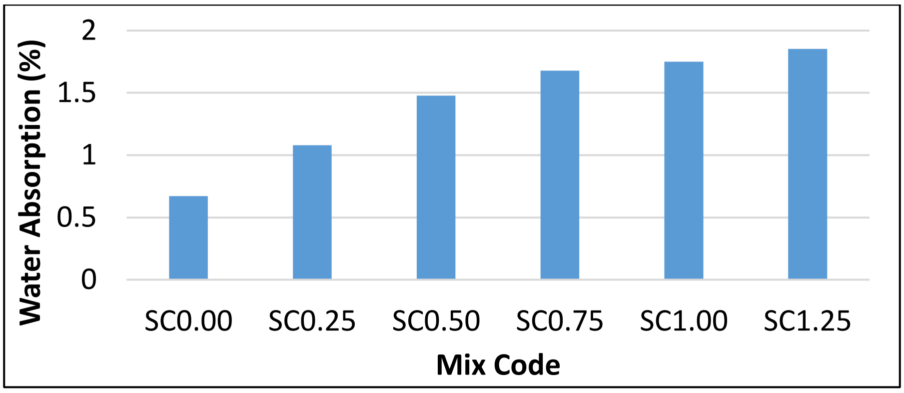


Figure 4-6 Water Absorption test results for all mixtures

4.3.4 Ultrasonic Pulse Velocity (UPV)

The results of ultrasonic pulse velocity test of all mixtures are given in Table 4-6 and Figure 4-7.

Table 4-6 Ultrasonic pulse velocity (UPV) test results for all mixtures

Mix Code	Time (μ sec.)	Length (mm)	UPV (km/sec.)	Ultrasound Strength (Mpa)	Mark
SC0.00	67.3	300	4.46	29.73	Good
SC0.25	68.5	300	4.38	28.53	Good
SC0.50	68.7	300	4.37	28.33	Good
SC0.75	70	300	4.29	27.14	Good
SC1.00	70.5	300	4.26	26.71	Good
SC1.25	72.5	300	4.14	25.10	Good

Figure 4-7 Ultrasonic pulse velocity (UPV) test results for all mixtures

It can be observed from results shown in Figure 4-7 that the maximum UPV was for SC0.00. The adding of WPF decreased the UPV because the possible effect of WPF in decreasing density.

The decrease in UPV value caused by WPF integration might be ascribed to a reduction in material interlocking and, as a result, contact efficiency. The WPF most likely decreased the amount of interactions between natural aggregate particles, which influenced ultrasonic wave transmission. In addition, a WPF with more elasticity may be able to absorb some of the wave energy.

Another reason could be that the availability of voids in the mixes with fibers is greater than the voids in the control mix SC0.00, which might reduce the time required for the ultrasonic wave to pass, resulting in increased mechanical properties of shotcrete mixtures in a directly proportional manner. Tests of hardened shotcrete were conducted to characterize as best as possible for all mixtures with different five selected WPF contents.

4.3.5 Compressive Strength

The results of the compressive strength tests for all mixes are summarized in Table 4-7. The compressive strengths are shown at ages 7, 14, and 28 days after water curing. The compressive strength values are calculated as the averages of three specimens made from each mix.

Table 4-7 Compressive strength test results for all mixtures at 7, 14, 28-day

Mix Code	Compressive Strength (MPa)					
	7-day	Reduction (%)	14-day	Reduction (%)	28-day	Reduction (%)
SC0.00	27.6	-	32.4	-	40.2	-
SC0.25	24.3	11.8	30.5	5.8	36.0	10.4
SC0.50	20.5	25.5	30.0	7.3	31.3	22.2
SC0.75	21.4	22.4	28.8	11.2	30.3	24.7
SC1.00	20.7	24.9	24.9	23.3	25.3	36.9
SC1.25	19.2	30.4	23.3	28.0	24.4	44.3

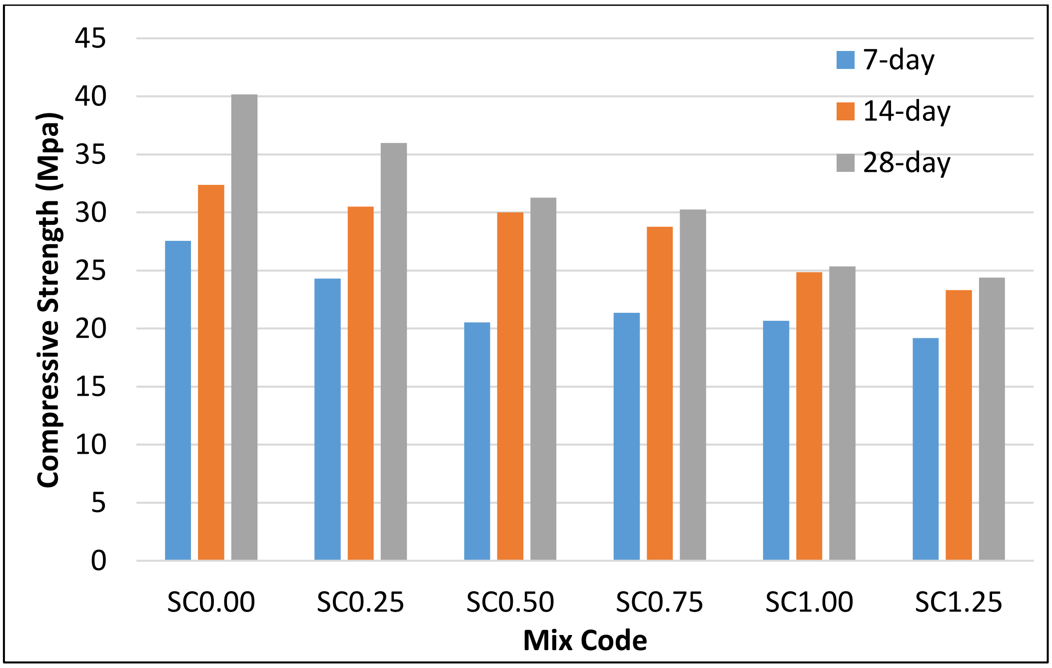


Figure 4-8 Compressive strength test results of all mixtures for 7, 14, and 28-day

As shown in Figure 4-8, the use of WPF has no effect on the compressive strength of shotcrete. When the WPF content was raised, the compressive strength of SC0.25, SC0.50, SC0.75, SC1.00, and SC1.25 specimens did not improve.

The weak binding force between the surface of the plastic waste and cement paste, as well as the plastic particles that do not absorb water by nature, may be linked to the steady decline in compressive strength values with increasing plastic waste fiber proportions [100–102].

A relationship can be established in this study between the results of non-destructive testing (UPV) and compressive strength. These values were plotted in graphs in Figure 4-9.

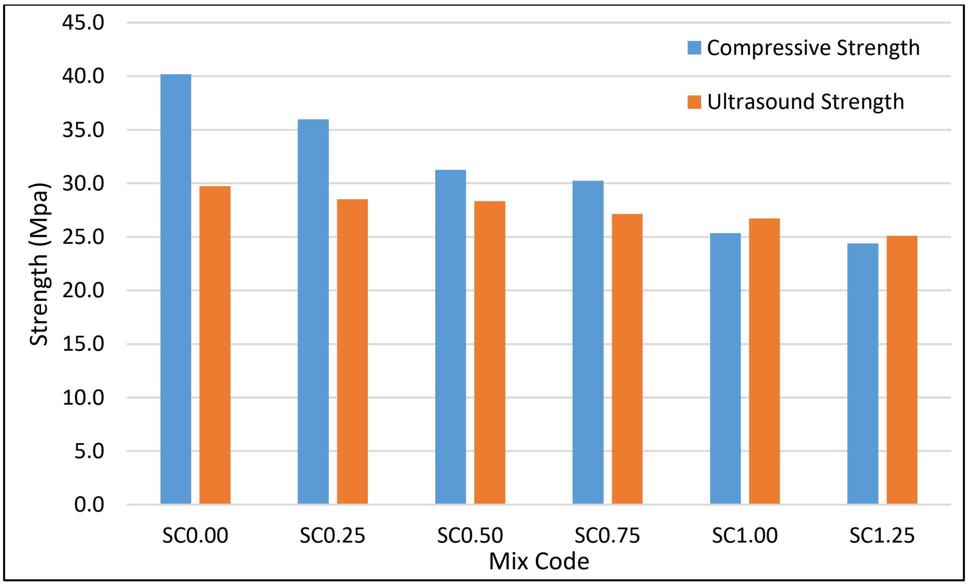


Figure 4-9 Comparison of compressive strength (28-days) with ultrasound strength results

It was found from Figure 4-9 that WPF effect on compressive strength and ultrasound strength at the same rhythm. Meaning that there is a gradual decrease in strength when WPF increases.

4.3.6 Splitting Tensile Strength

Due to the inclusion of WPF, the splitting tensile strength resulted in slight increase. The resistance to indirect stress was influenced by waste plastic fibers. The test results for splitting tensile strength are shown in Figure 4-10.

As seen in Table 4-8, the tensile strength of specimen rises as the amount of WPF in the specimen increases. This increase in tensile strength is subsequent to the addition of WPF which can be attributed to the strong bond between the WPF and the matrix.

Table 4-8 Splitting tensile strength test results for all mixtures at 7, 14, 28-day

Mix Code	Splitting Tensile Strength (MPa)					
	7-day	Increase (%)	14-day	Increase (%)	28-day	Increase (%)
SC0.00	2.6	-	3.1	-	3.2	-
SC0.25	3.2	23.1	3.3	6.5	3.4	6.2
SC0.50	3.4	30.8	3.6	16.1	3.8	18.8
SC0.75	3.2	23.1	3.5	12.9	3.9	21.9
SC1.00	3.3	26.9	3.7	19.4	4.1	28.1
SC1.25	3.4	30.8	3.8	22.6	4.4	37.5

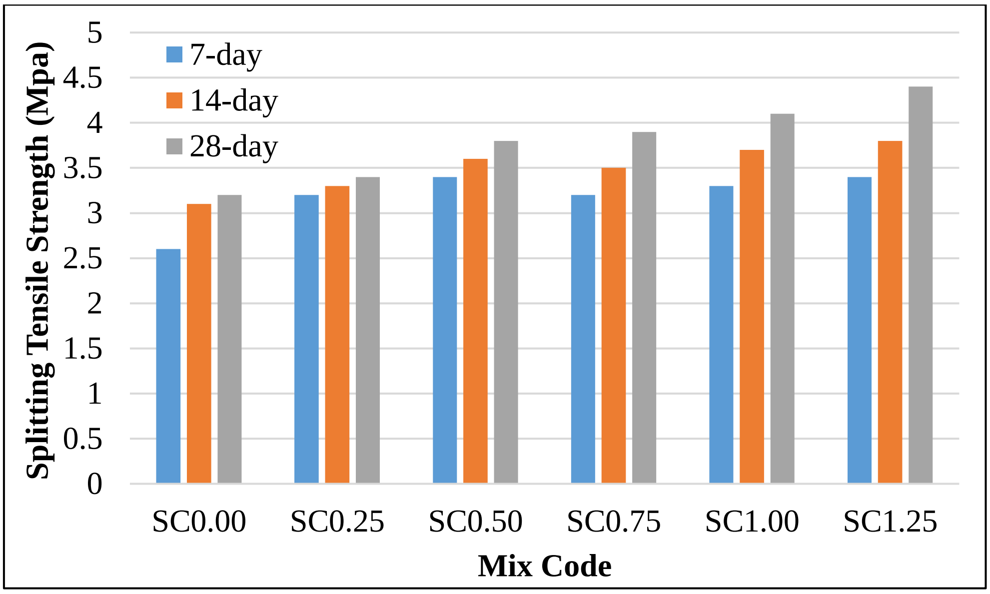


Figure 4-10 Splitting tensile strength test results of all mixtures for 7, 14, and 28-day

For 7, 14, and 28 days, the splitting strength increased by 23–31 percent, 7–23 percent, and 6–38 percent, respectively. For 7 and 28 days, the

1.25 percent WPF contents showed a notable increase in strength of 30.8 percent and 37.5 percent, respectively.

4.4 Modulus of Elasticity (Young's Modulus)

Table 4-9 shows the elastic modulus results for the shotcrete incorporated with WPF cylinders at 28-day.

Table 4-9 Modulus of Elasticity test results of all mixtures for 28-day

Mix Code	Modulus of Elasticity (GPa)
SC0.00	21.45
SC0.25	19.86
SC0.50	17.39
SC0.75	16.51
SC1.00	15.93
SC1.25	15.12

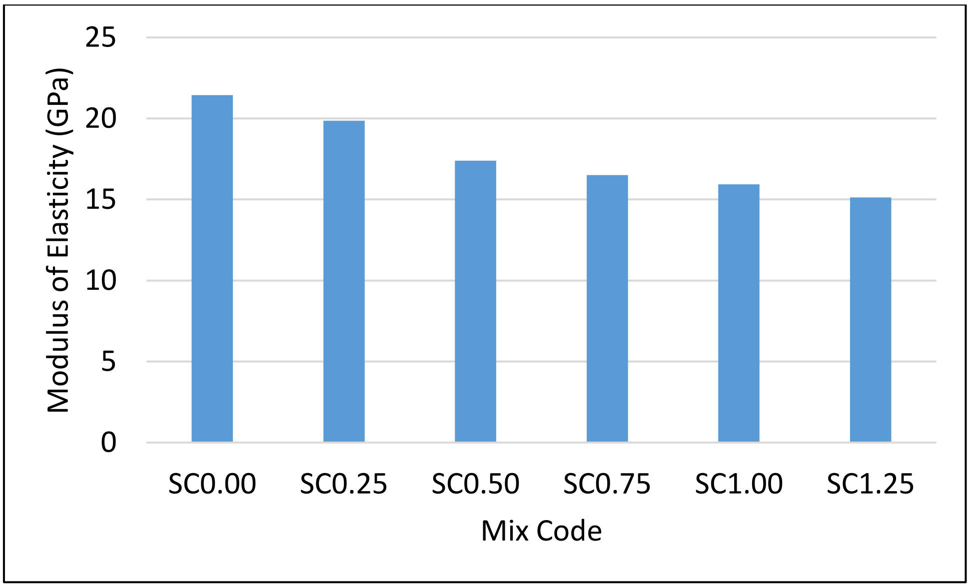


Figure 4-11 Modulus of Elasticity test results of all mixtures for 28-day

Figure 4-11 shows the modulus of elasticity of shotcrete incorporated with WPF. The modulus of elasticity value of the control specimens (SC0.00) at 28-day was 21.45 GPa while the modulus of elasticity values at 28-day for WPF shotcrete specimens were 19.86, 17.39, 16.51, 15.93, and

15.12 GPa for 0.25, 0.5, 0.75, 1.0, and 1.25%, respectively. The reduction in modulus of elasticity results might be linked to the same reasons that observed for compressive strength results.

4.5 Bending Behaviour of Shotcrete Beams

4.5.1 Load-Deflection Relationship

All beams that include control beams, beams with different WPF had tested under four-point load. The loads – deflection curves at mid span for each beam were shown in Figure 4-12. The experimental setup test results are summarized up in Table (4.10).

Table 4-10 Ultimate load and deflection test results for selected beams

Beam Mark	WPF Replacement (%)	First Crack Load (kN)	Ultimate Load (kN)	Maximum Crack width (mm)	Ultimate Deflection at mid-span (mm)
SC0.00	0	10	70.4	1.7	12.8
SC0.25	0.25	12	63.35	1.2	13.8
SC0.50	0.50	13	59.53	0.9	13.3
SC0.75	0.75	14	64.18	0.6	12.8
SC1.00	1.0	11	64.0	1.8	13.3
SC1.25	1.25	9	19.45	2.1	14.84

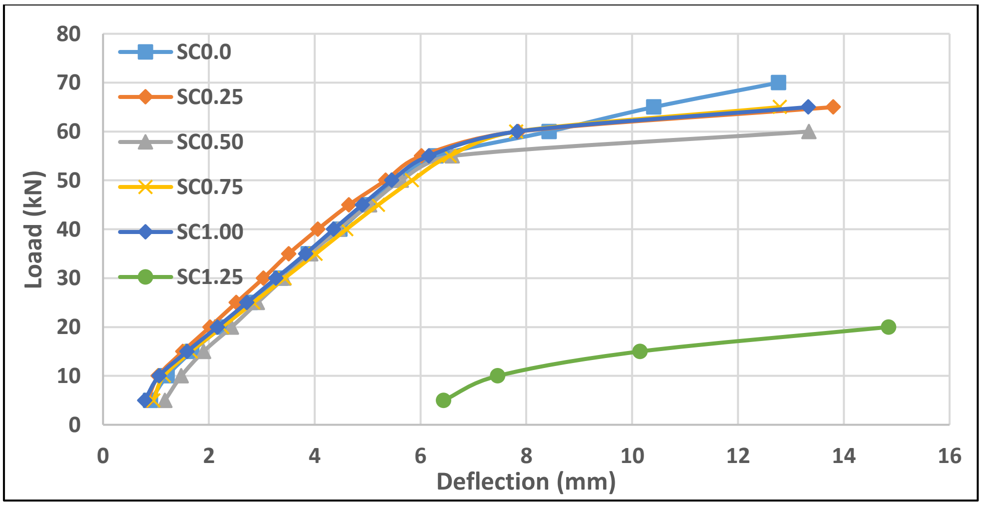


Figure 4-12 Deflection vs. load graph for all selected beams

As shown in Figure 4-12, the following observations have been found:

- Beam (SC0.00) with (0% WPF) exhibited a deflection value of 3.88 mm at first crack load with crack load of 10kN. The ultimate load of SC0.00 beam was giving 70.4kN at 12.8 mm deflection.
- Beam (SC0.25) with (0.25% WPF) exhibited a deflection value of 4.12 mm at first crack load with crack load of 12kN. The ultimate load of SC0.25 beam was giving 63.35kN at 13.8 mm deflection.
- Beam (SC0.50) with (0.50% WPF) exhibited a deflection value of 5.04 mm at first crack load with crack load of 13kN. The ultimate load of SC0.50 beam was giving 59.53kN at 13.3 mm deflection.
- Beam (SC0.75) with (0.75% WPF) exhibited a deflection value of 2.9 mm at first crack load with crack load of 14kN. The ultimate load of SC0.75 beam was giving 64.18kN at 12.8 mm deflection.
- Beam (SC1.00) with (1.00% WPF) exhibited a deflection value of 2.9 mm at first crack load with crack load of 11kN. The ultimate load of SC1.00 beam was giving 64.18kN at 12.8 mm deflection.
- Beam (SC1.25) with (1.25% WPF) exhibited a deflection value of 7.72 mm at first crack load with crack load of 9kN. The ultimate load of SC1.25 beam was giving 19.45kN at 14.48 mm deflection.

4.5.2 Ductility Index

A ductility is defined as the ratio of absolute maximum deflection (u) to matching yield deflection (y). Ductility is an important attribute of structural members because it guarantees that substantial deflections occur due to overload conditions before the structure fails [103].

The ductility index, (u), can be calculated using the load-deflection relationship as presented in Equation (4-1). It is based on a beam's mid-span deflection calculation. Table 4-11 and Figures (4-13 to 4-18) show the deflection ductility index (u) for beams evaluated experimentally in this work.

$$\mu = \frac{\Delta u}{\Delta y} \qquad \text{Eq. (4-1)}$$

Where Δu is the deflection of the beam at the ultimate load, and Δy is the deflection of the beam at the yield load.

Table 4-11 Ductility results for all tested beams

Beam Mark	**Δu**	**Δy**	**Ductility Index (μ)**
SC0.00	12.77	6.3	2.03
SC0.25	13.8	6.02	2.29
SC0.50	13.34	6.6	2.02
SC0.75	12.79	6.6	1.94
SC1.00	13.33	6.16	2.16
SC1.25	14.85	7.46	1.99

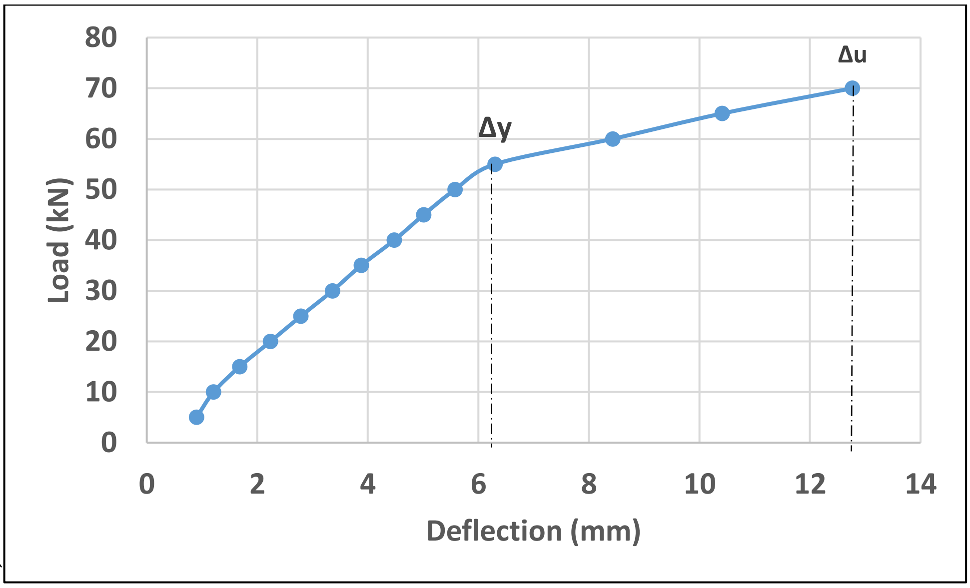


Figure 4-13 Deflection vs. load graph for SC0.00 beam

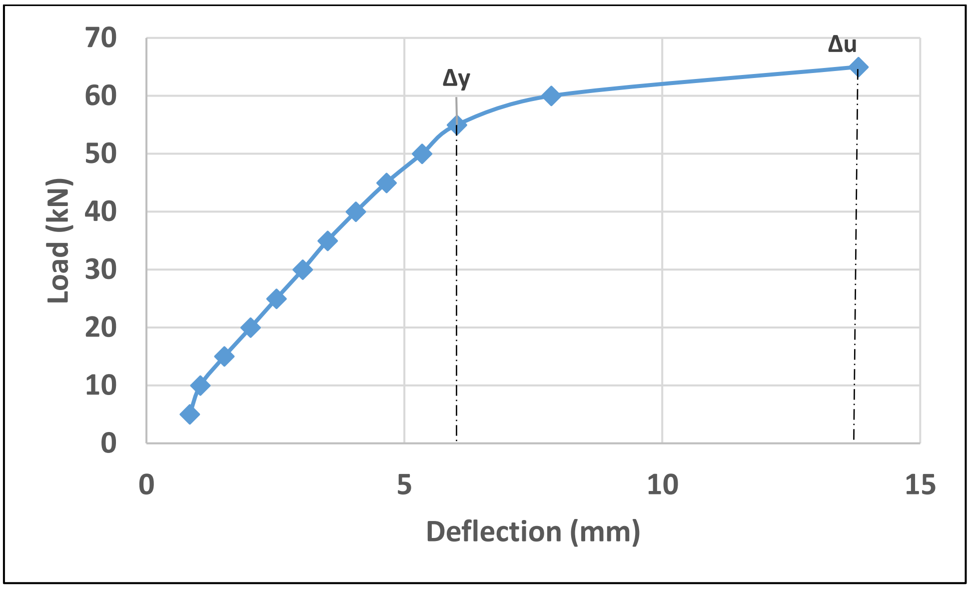


Figure 4-14 Deflection vs. load graph for SC0.25 beam

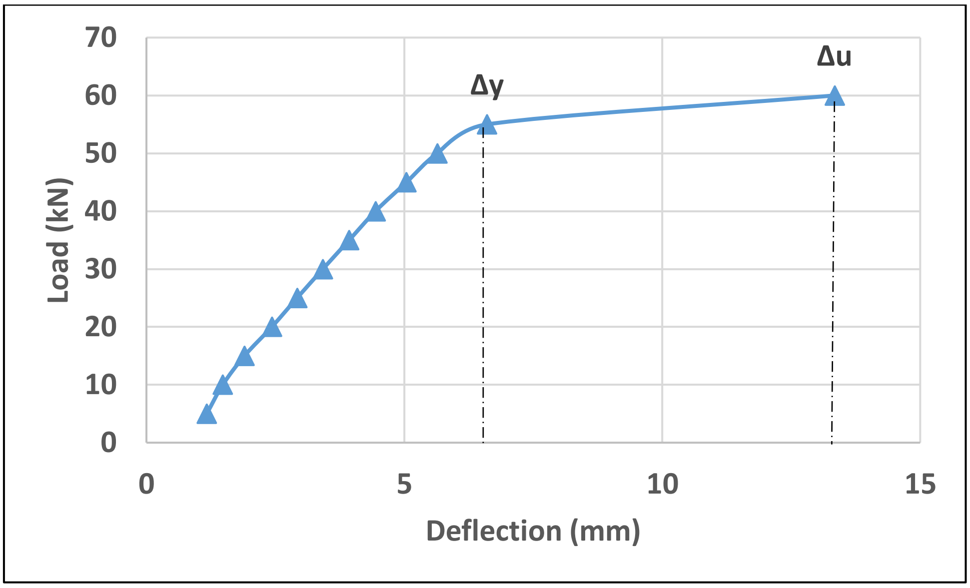


Figure 4-15 Deflection vs. load graph for SC0.50 beam

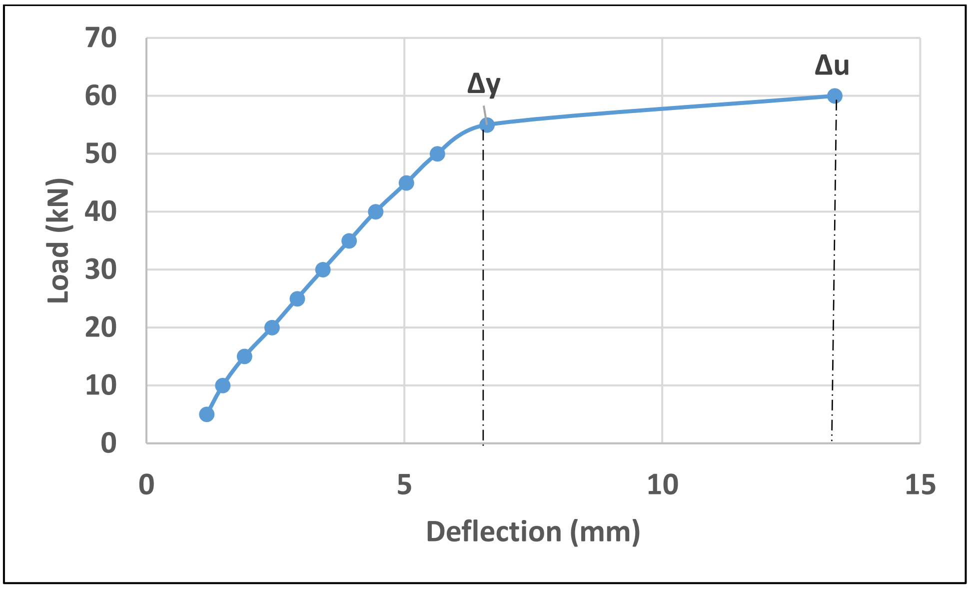


Figure 4-16 Deflection vs. load graph for SC0.75 beam

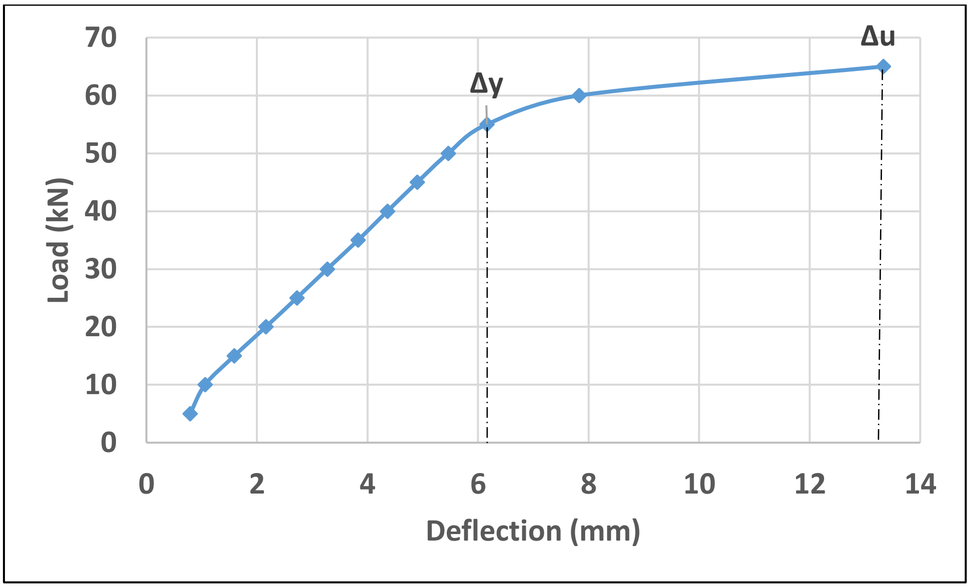


Figure 4-17 Deflection vs. load graph for SC1.00 beam

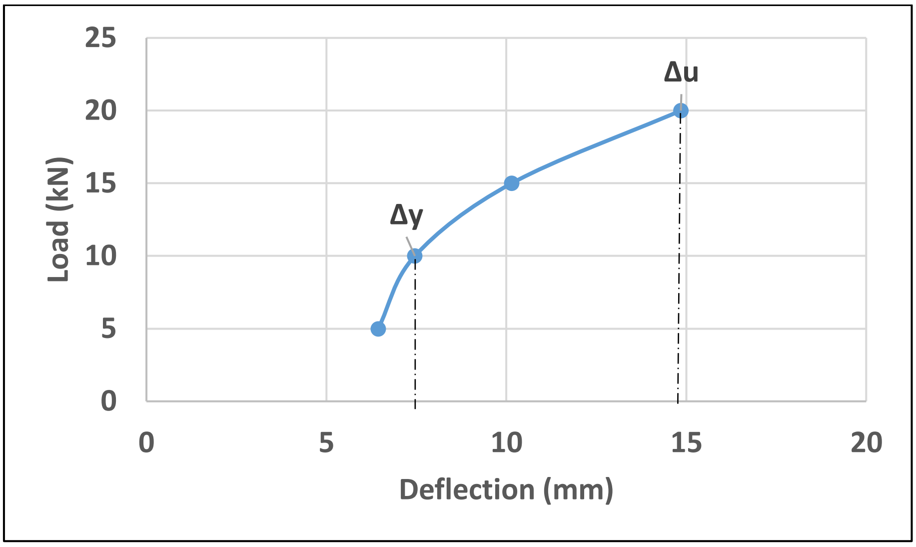


Figure 4-18 Deflection vs. load graph for SC1.25 beam

According to reference, the ductility index varies from 1.94 to 2.29 in Table 4-11, indicating substantial agreement [97]. All beams have a ductility index of less than 3.0. A high ductility index, in general, suggests that a structural part can withstand considerable deformations before failing. It is regarded essential for suitable ductility for beams with a ductility index in the range of 3 to 5, notably in the fields of seismic design and moment redistribution [104–106]. Beams having a ductility index of just 1.99 had insufficient ductility and were unable to redistribute moment [57].

4.5.3 Crack Width

The crack width of reinforced concrete beam was estimated to inspect the limit state of serviceability; Maximum crack width values were calculated for ultimate load and presented in Table 4-10 and shown in Figure 4-19. The crack width of beam SC1.25 considered maximum value up to 2.1 mm compared with others beams. While smaller value recorded of crack width was 0.6 mm belongs to beam SC0.75.

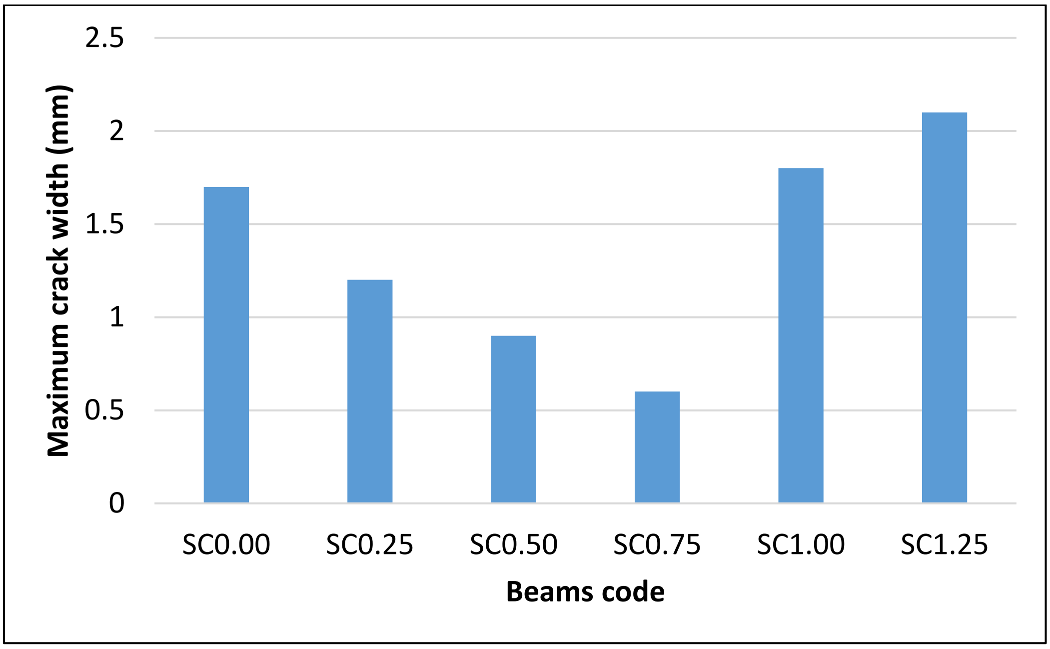


Figure 4-19 Maximum crack width for all selected beams

Through the test result of all selected beams for ultimate load, SC1.25 beam showed an increase of crack width more than SC0.75 beam due to minimum of shear reinforcement in the bending moment region. Depending on the amount of longitudinal reinforcement. It can be seen from test results that the presence of WPF accelerated appearance first crack load and influenced wider of the crack width. From test results of deflection, higher or raise of deflection showed wider crack, therefore the increase of crack width may effect on the aesthetic of structure.

4.5.4 Crack Pattern

In general, crack propagation was diverse across tested beams, as shown by crack patterns in the shear zone and bending area. The first hairline vertical flexural fractures appeared in the beams' mid-span, with the first vertical flexural crack occurring at roughly 14 to 46 percent of the ultimate load. These findings show that the first crack appears at a lower ultimate load percentage. Furthermore, the quantity of transverse reinforcement had an impact on the crack angle. Figures 4-20 to 4-25 show the final cracking patterns of the shotcrete beams that were tested. When compared to reference shotcrete beams, all of the shotcrete with WPF beams exhibited more severe cracking with tighter spacing. Within the shear zones, many inclined fractures occurred at increasing stresses. These inclined fractures also have a sharper slope to the horizontal axis.

Figure 4-20 Crack patterns of beam SC0.00

Figure 4-21 Crack patterns of beam SC0.25

Figure 4-22 Crack patterns of beam SC0.50

Figure 4-23 Crack patterns of beam SC0.75

Figure 4-24 Crack patterns of beam SC1.00

Figure 4-25 Crack patterns of beam SC1.25

4.5.5 Stiffness

The results listed in the Table 4-12 and Figure 4-26 refer to all tested beams. Beam SC0.00 recorded the highest stiffness result to (5.50 kN/mm), while beam SC1.25 recorded the lowest result (1.31 kN/mm). It is noticed that the beams which achieved the highest ductility recorded the lowest stiffness.

Table 4-12 Stiffness results for all tested beams

Beam Mark	Ultimate Load (Pu) (kN)	Ultimate Deflection (Δu) (mm)	Stiffness (Pu/Δu) (kN/mm)
SC0.00	70.4	12.8	5.50
SC0.25	63.35	13.8	4.59
SC0.50	59.53	13.3	4.48
SC0.75	64.18	12.8	5.01
SC1.00	64	13.3	4.81
SC1.25	19.45	14.84	1.31

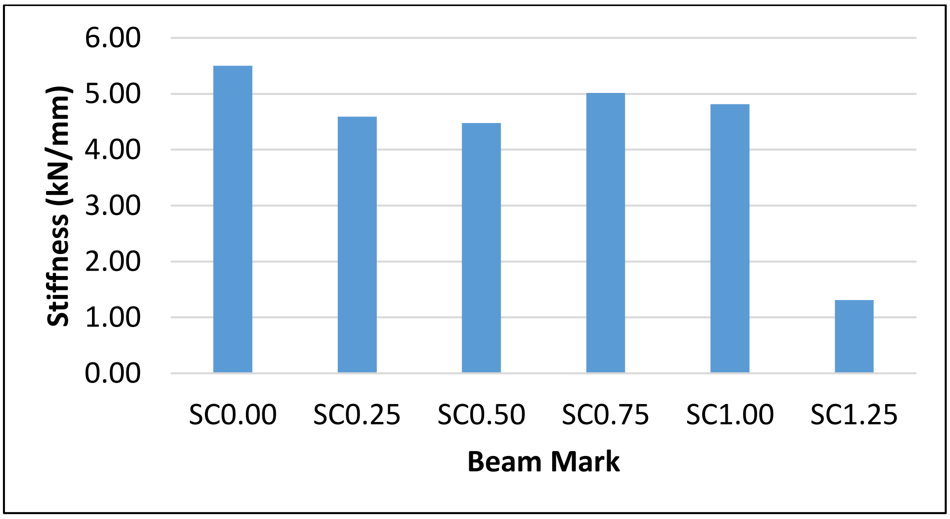


Figure 4-26 Stiffness results for all tested beams

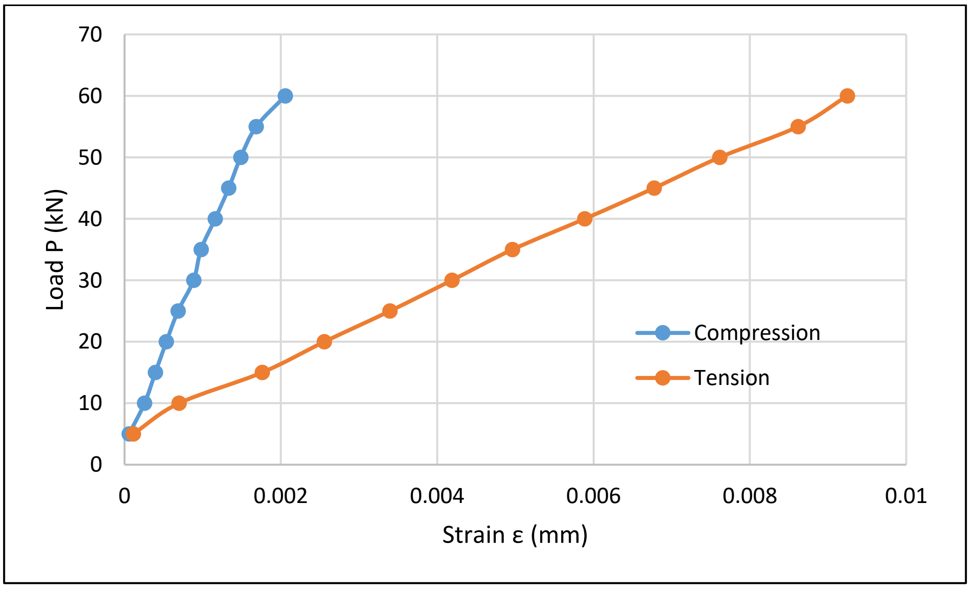
4.5.6 Stress-Strain Responses of Shotcrete

The minimum and maximum strain values for all beams are shown in Table 4-13, and the stress-strain curves for shotcrete are shown in Figure 4-27.

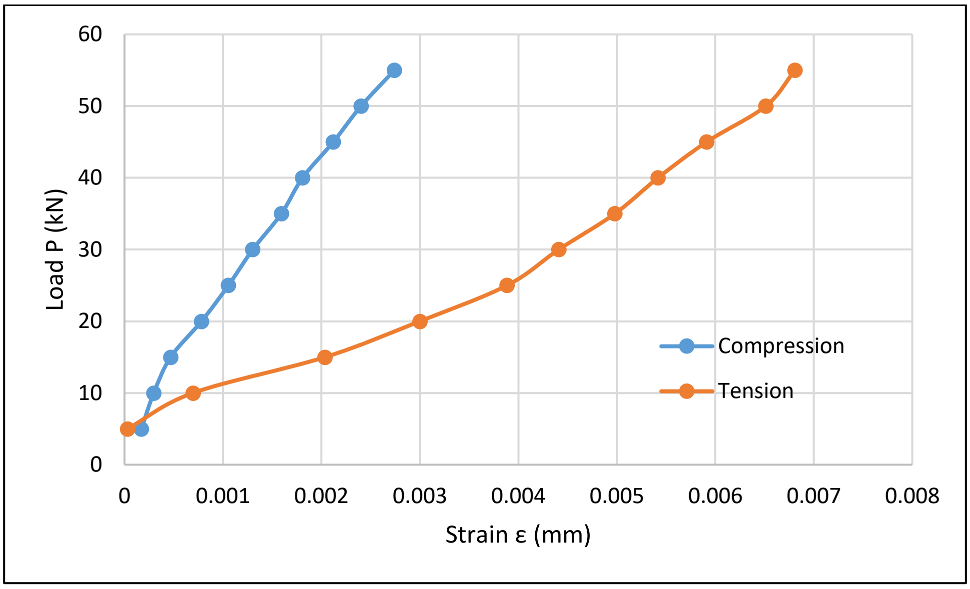
Because of concrete cracking, the slopes of the curves dropped (P70 kN for SC0.00); after that, the stress-strain curves developed linearly, and the peak strains were distant from reaching the yielding strain. Furthermore, there was a clear distinction between the specimens with various WPF compositions.

Table 4-13 Strain gauge results for shotcrete beams

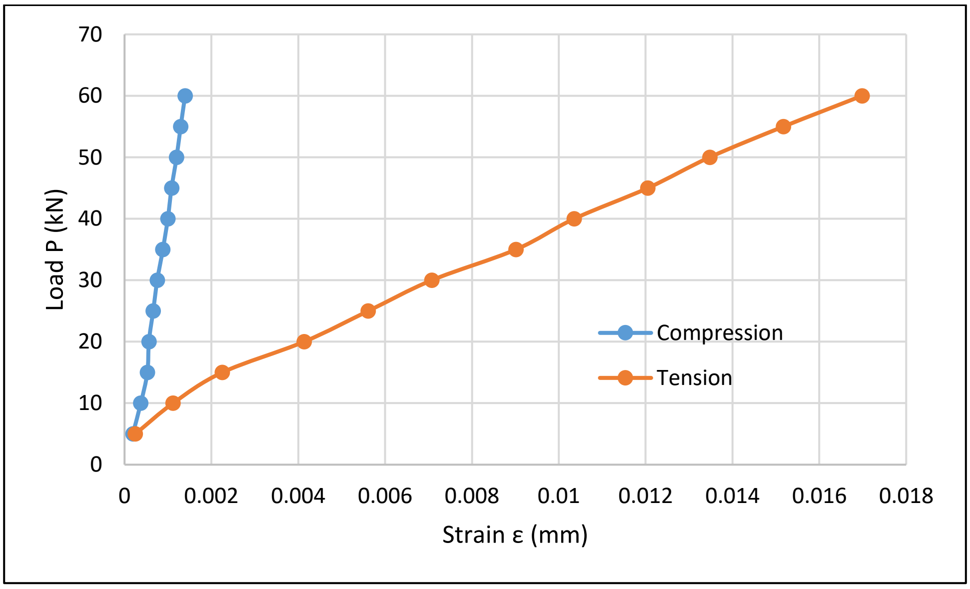
Beam Mark	**Strain ε (mm)**			
	Top strain gauge		**Bottom strain gauge**	
	Min.	**Max.**	**Min.**	**Max.**
SC0.00	0.000198	0.001897	0.000006	0.000331
SC0.25	0.000058	0.002438	0.000110	0.009245
SC0.50	0.000171	0.002741	0.000029	0.006808
SC0.75	0.000191	0.001394	0.000248	0.016981
SC1.00	0.000125	0.003771	0.000272	0.012352
SC1.25	0.002165	0.003280	0.011400	0.036053



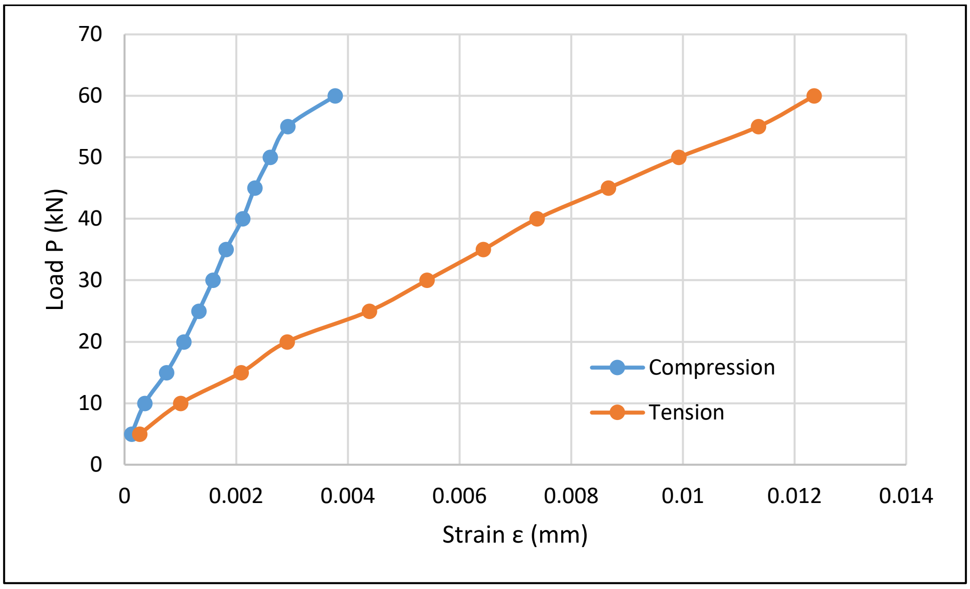
(a) SC0.25 (0.25% WPF)



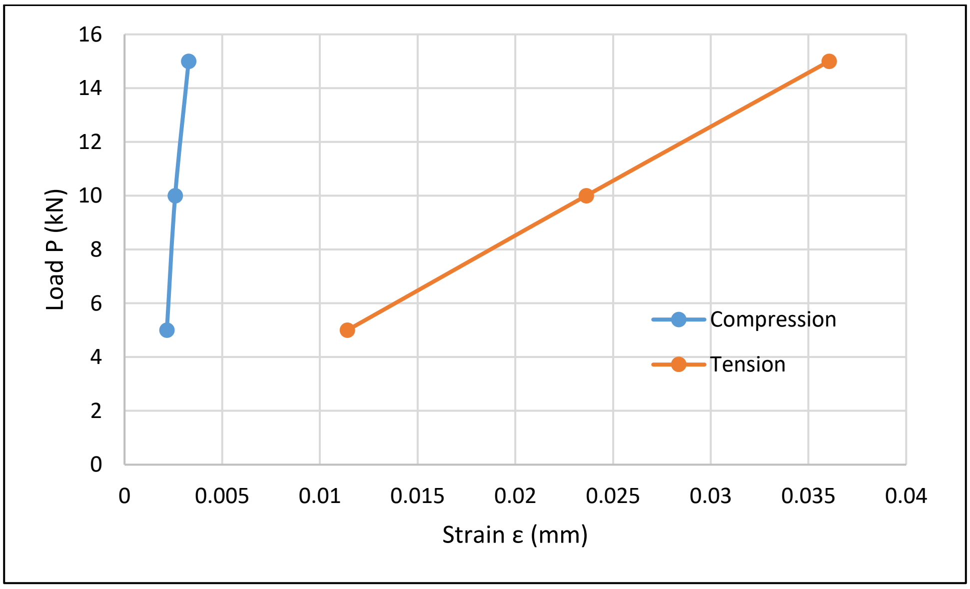
(b) SC0.50 (0.50% WPF)



(c) SC0.75 (0.75% WPF)



(d) SC1.00 (1.00% WPF)



(e) SC1.25 (1.25% WPF)

Figure 4-27 Load-strain curves

The load-strain curves of shotcrete incorporating varied WPF contents showed the same increase pattern until the yield point (9246, 6808, 16981, 12352, 36053) μmm strain for (0.25, 0.50, 0.75, 1.00, and 1.25) percent WPF, as shown in Figure 4-26. Following that, the shotcrete strain curves increased linearly, indicating that the flexural capabilities were resisted.

CHAPTER FIVE

Conclusions and Recommendations

5.1 Introduction

This thesis investigates various WPF replacement percentages in wet-shotcrete mixtures by first manufacturing wet-mix shotcrete machine in order to study the properties of producing wet-mix shotcrete. In addition, load deflection behaviors were investigated for WPF shotcrete reinforcement beams.

5.2 Conclusions

The main conclusions are summarized as follows:

1. There is an ability in developing wet-mix shotcrete through using local manufacturing and made machine in order to study the wet-mix shotcrete, containing WPF.
2. Increasing WPF till 0.75% lead to increase the slump to (88 cm) and T_{500} to (1 seconds). Increasing WPF contents further than 0.75% decreased the workability.
3. The sieve segregation test revealed that shotcrete mixes with higher percentage of WPF results in less segregation index (SI%).
4. Because of incorporating WPF, more water was absorbed resulted in increasing the voids, which decreased the dry density of the mixtures. The mixture that provided highest dry density were made of 0.50% WPF

with dry density, air voids and water absorption percentage values of 2377 kg/m^3, 1.87%, and 1.48% respectively.

5. It can be seen from the results obtained in this study that the increase of WPF contents, compressive strength at 28-day was lower compared to the reference specimen (0% WPF content). These decreases were (10.4, 22.2, 24.7, 36.9, and 44.3) % for (0.25, 0.50, 0.75, 1.00, and 1.25) % WPF contents respectively.
6. The WPF shotcrete specimens are ‘‘good’’ in terms of its UPV values, and it generally achieves 4.46, 4.38, 4.37, 4.29, 4.26, and 4.14 km/s for (0.25, 0.50, 0.75, 1.00, 1.25) % WPF content respectively.
7. It can be seen from the results obtained in this study that the increase of WPF contents increased splitting tensile strength at 28-day as compared to the reference specimen (0% WPF content). These increases were (6.2, 18.8, 21.9, 28.1, 37.5) % for (0.25, 0.50, 0.75, 1.00, and 1.25) % WPF content respectively.
8. It can be seen from the results obtained in this study that the increase of WPF contents decreased modulus of elasticity at 28-day as compared to the reference specimen (0% WPF content). These decreases were (7.4, 18.9, 23.0, 25.7, 29.5) % for (0.25, 0.50, 0.75, 1.00, and 1.25) % WPF content respectively.
9. The results of flexural SC beams for all WPF percentages tested to failure under four-point loading were presented and discussed, together with the prediction of cracking & ultimate moment resistances. From the results of this study, the following conclusions were made:

a. All the specimens exhibited multiple cracking behaviour under two-point bending load and uniaxial flexural load. The load-deflection capacity for the five mixtures prepared with different WPF contents ranged from 12.8 to 14.83 mm.

b. In term of crack width, SC0.75 recorded small crack width that showed failure mode as a flexural failure with 0.6 mm, while SC1.25 registered higher crack width that demonstrated crack pattern as flexural failure with 2.1 mm.
c. No huge difference in cracking patterns was observed between the different contents of WPF of shotcretes.
d. The highest stiffness result was (5.50 kN/mm) to SC0.00, while beam SC1.25 recorded the lowest result (1.31 kN/mm). It is noticed that the beams which achieved the highest ductility recorded the lowest stiffness.

5.3 Recommendations

Number of recommendations are listed below:

1. Waste materials such as WPF should be limited in shotcrete because of low values of hardened properties of WPF.
2. WPF should be limited to 0.75% in shotcrete to achieve a durable mixture with it. While 1.25% WPF contents should be avoided in future research due to its major disadvantages.
3. In design of shotcrete mixtures with a specified WPF contents (0.25, 0.50, 0.75, 1.0, and 1.25), it is recommended for improve of both the workability, the stability of fresh concrete and the hardened properties of shotcrete.
4. For production of shotcrete, the wet-mix method is often selected based on its benefits to achieve specified strength and unit weight of concrete.
5. Develop the smart system in shotcrete machine can control the shoot of light shotcrete concrete.
6. Investigate shear behaviour of reinforced shotcrete concrete beam containing waste plastic.

7. Investigate strength of reinforced concrete slab casting by waste plastic shotcrete concrete.
8. Using the manufactured machine for retrofitting and strengthening purposes.

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Appendix A

Table **A- 1**: Physical test results of cement

REPUBLIC OF IRAQ
MINISTRY OF HIGHER EDUCATION & SCIENTIFIC RESEARCH
UNIVERSITY OF ANBAR
COLLEGE OF ENGINEERING
ENGINEERING CONSULTING BUREAU

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة الانبار
كلية الهندسة
المكتب الاستشاري الهندسي

E.C.B 1993

تقرير الفحص

اسم الفحص المطلوب	نوع الاسمنت	كتاب طلب الفحص		اسم الجهة طالبة الفحص
		الرقم	التاريخ	
الفحص الفيزيائي للاسمنت	(سمنت عادي ماس)	بلا	2021/3/24	طالب الدراسات العليا (المهندس عامر محمد عناد) كلية الهندسة / جامعة الانبار

ت	اسم الفحص	نوع الأسمنت	النتيجة	حدود المواصفة
1	التجمد الابتدائي (دقيقة)	الاسمنت (نوع ماس)	195	دقيقة 45 لا يقل عن
2	التجمد النهائي (دقيقة)		315	دقيقة600لايزيد عن
3	مقاومة الانضغاط (3) يوم N/mm^2		20	15 N/mm^2كحد ادنى
4	مقاومة الانضغاط (7) يوم N/mm^2		27	23 N/mm^2كحد ادنى

الملاحظات:-
- النتائج تمثل النموذج الذي تم جلبه من قبل مخولكم .
- النموذج مطابق لمتطلبات المواصفة القياسية العراقية (م.ق.ع 5/1984)
المختبر غير مسؤول عن النمذجة .

د/ الاستشاري
د. غسان صبحي جميل

الفاحص
المهندس ايمن حميد فياض

1st branch: Iraq-Anbar-Ramadi-Opposite to Al-Anbar Passport Directorate
الفرع الاول: العراق – الانبار – رمادي – مقابل مديرية جوازات الانبار
2nd branch: Iraq-Fallujah- Street 60 - Opposite to Al- Sabtain Police Center
الفرع الثاني: العراق – الانبار – فلوجة – شارع 60 – مقابل مركز شرطة السبطين
Mobile: +964 780 282 5481 / +964 781 547 0993 / +964 772 961 3560 / +964 783 555 0652
البريد الالكتروني: eng.con.bureau@uoanbar.edu.iq & engburanbar@gmail.com

Table **A-2**: Chemical test results of cement

REPUBLIC OF IRAQ
MINISTRY OF HIGHER EDUCATION & SCIENTIFIC RESEARCH
UNIVERSITY OF ANBAR
COLLEGE OF ENGINEERING
ENGINEERING CONSULTING BUREAU

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة الانبار
كلية الهندسة
المكتب الاستشاري الهندسي

E.C.B
1993

تقرير الفحص

اسم الفحص المطلوب	نوع الاسمنت	كتاب طلب الفحص		اسم الجهة طالبة الفحص
		الرقم	التاريخ	
الفحص الكيميائي للأسمنت	(سمنت عادي ماس)	بلا	2021/3/24	طالب الدراسات العليا (المهندس عامر محمد عناد) كلية الهندسة / جامعة الانبار

Chemical Properties	Wt %	Iraqi Standard Requirements
Calcium oxide (Cao)	62.7	-
Silicon Dioxide (Sio2)	20.3	-
Aluminum oxide (Al2O3)	4.5	-
Blaine	3610	Not thos than 2500 m^2/g
Ferric Oxide (Fe2O3)	3.9	-
Sulfur Trioxide (So3)	2.5	2.8 %
Magnesium Oxide (MgO)	2.7	5 % Max
Loss on ignition	3.0	4 % Max
Insoluble residue	0.4	1.5 %Max
Phases		
LSF	0,94	-
SM	2.42	-
AM	1.15	-
C3S	56,8	-
C2S	15.3	-
C3A	5.5	-

د/ الاستشاري

د. غسان صبحي جميل

الفاحص

المهندس ايمن حميد فياض

1[st] branch: Iraq-Anbar-Ramadi-Opposite to Al-Anbar Passport Directorate
2[nd] branch: Iraq-Fallujah- Street 60 - Opposite to Al- Sabtain Police Center

الفرع الاول: العراق – الانبار – رمادي – مقابل مديرية جوازات الانبار
الفرع الثاني: العراق – الانبار – الفلوجة – شارع 60 – مقابل مركز شرطة السبطين

Mobile: +964 780 282 5481 / +964 781 547 0993 / +964 772 961 3560 / +964 783 555 0662

eng.con.bureau@uoanbar.edu.iq & engburanbar@gmail.com :البريد الالكتروني

Table **A-3**: Physical and chemical test results of coarse aggregates

ENGINEERING CONSULTINCY GROUP BUREAU

مكتب المجموعة الاستشارية الهندسية

التاريخ: ٢٢ / ٣ / ٢٠٢١

العدد: ٦٧١

الى/ المهندس عامر محمد عناد المحترم

م/ تقرير فحص نموذج حصى مكسر

Test Results and Specification Limits:

Sample lab No.		GR 51			
Test type		Test Results	Specification Limits		
	Sieve Size (mm)	Passing (%)	(40-5) mm	(20-5) mm	(14-5) mm
Grading	75.0	100	100	Not limited	Not limited
	63.0	100	Not limited	Not limited	Not limited
	37.5	100	95-100	100	Not limited
	20.0	100	35-70	95-100	100
	14.0	100	Not limited	Not limited	90-100
	10.0	81	10-40	30-60	50-85
	5.0	1.27	0-5	0-10	0-10
	2.36	0.0	Not limited	Not limited	Not limited
Deleterious substances	Finer than 0.075mm (%)	1.1	Max. 3		
	SO_3 content (%)	0.043	Max.0.1		

الملاحظات:

1- العلامة (*) ان وجدت تعني وجود انحراف عن حدود المواصفة القياسية.
2- تم إجراء الفحص الفيزياوي بموجب المواصفة القياسية العراقية رقم (30) لسنة 1984 والدليل الاسترشادي المرجعي /500 لسنة 1994.
3- تم إجراء الفحص الكيمياوي بموجب الدليل الاسترشادي المرجعي /500 لسنة 1994.
4- تم جلب النموذج من قبل الطالب عامر محمد عناد.

التوصيات: - النتائج مطابقة للمواصفة القياسية م.ق.ع. (1984/45) ضمن تدرج (5-14) ملم.

المهندس الاستشاري
د. إبراهيم عبد الله عيدان
رئيس مكتب المجموعة الاستشارية الهندسية

نسخه منه:
- الاضبارة للحفظ.

تم تأسيس المكتب بموجب شهادة التأسيس المرقمة 649 استنادا لقرار مجلس نقابة المهندسين العراقية المؤرخ في 14 /2005/8
العنوان: العراق – بغداد – حي الخضراء /شارع البصرة هاتف: 009647700025931 , 009647736383837 , 009647826524963
Email: ecg.baghdad@gmail.com

Table **A-4**: Physical and chemical test results of fine aggregates

ENGINEERING CONSULTINCY GROUP BUREAU

التاريخ: ٢٢/ ٣/ ٢٠٢١

مكتب
المجموعة الاستشارية الهندسية

العدد: ٦٧٢

الى/ المهندس عامر محمد عناد المحترم

م/ تقرير فحص نموذج رمل احمر

Test Results and Specification Limits:

Sample lab No.		**SA 67**				
Test type		**Test Results**	**Specification Limits**			
	Sieve Size (mm)	**Passing (%)**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
Grading	10	100	100	100	100	100
	4.75	99.53	90-100	90-100	90-100	95-100
	2.36	87.13	60-95	75-100	85-100	95-100
	1.18	67.93	30-70	55-90	75-100	90-100
	0.6	40.0	15-34	35-59	60-79	80-100
	0.3	9.53	5-20	8-30	12-40	15-50
	0.15	1.00	0-10	0-10	0-10	0-15
Deleterious substances	**Finer than 0.075mm (%)**	1.4	Max. 5			
	SO_3 Content (%)	0.34	Max.0.5			

الملاحظات:

1- العلامة (*) ان وجدت تعني وجود انحراف عن حدود المواصفة القياسية.
2- تم إجراء الفحص الفيزياوي بموجب المواصفة القياسية العراقية رقم (30) لسنة 1984 والدليل الاسترشادي المرجعي /500 لسنة 1994.
3- تم إجراء الفحص الكيمياوي بموجب الدليل الاسترشادي المرجعي /500 لسنة 1994.
4- تم جلب النموذج من قبل الطالب عامر محمد عناد.

التوصيات:

1- **النتائج مطابقة لحدود المواصفة القياسية العراقية .ق.ع. (1984/45) ضمن تدرج صنف (2).**
2- **نسبة المواد الضارة العابرة من منخل 200 ضمن حدود المواصفة القياسية العراقية م.ق.ع. (1984/45).**
3- **نتائج الأملاح الكبريتية مطابقة لحدود المواصفة القياسية العراقية م.ق.ع. (1984/45).**

Engineering Consultancy Group
المجموعة الاستشارية الهندسية

المهندس الاستشاري
د. إبراهيم عبد الله عيدان
رئيس مكتب المجموعة الاستشارية الهندسية

نسخه منه:

- الاضبارة للحفظ.

تم تأسيس المكتب بموجب شهادة التأسيس المرقمة 649 استناداً لقرار مجلس نقابة المهندسين العراقية المؤرخ في 2005/8/14
العنوان: العراق – بغداد – حي الخضراء / شارع البصرة م/641 ز/51 د/18 هاتف: 009647700025931 , 009647736383837 , 009647826524963
Email: ecg.baghdad@gmail.com

Data sheet of the Superplasticizer

BASF
The Chemical Company

MasterGlenium® 51

(Formerly known as Glenium 51)

A high performance concrete superplasticiser based on modified polycarboxylic ether

DESCRIPTION

MasterGlenium 51 has been primarily developed for applications in the ready mixed and precast concrete industries where the highest durability and performance is required.
MasterGlenium 51 is free from chlorides and complies with ASTM C494 Types A and F.
MasterGlenium 51 is compatible with all Portland cements that meet recognised international standards.

CHEMISTRY AND MECHANISM OF ACTION OF MasterGlenium 51

Conventional superplasticisers, such as those based on sulphonated melamine and naphthalene formaldehyde condensates, at the time of mixing, become absorbed onto the surface of the cement particles. This absorption takes place at a very early stage in the hydration process. The sulphonic groups of the polymer chains increase the negative charge on the surface of the cement particle and dispersion of the cement occurs by electrostatic repulsion

MasterGlenium 51 is differentiated from conventional superplasticisers in that it is based on a unique carboxylic ether polymer with long lateral chains. This greatly improves cement dispersion. At the start of the mixing process the same electrostatic dispersion occurs as described previously but the presence of the lateral chains, linked to the polymer backbone, generate a steric hindrance which stabilises the cement particles capacity to separate and disperse.

This mechanism provides flowable concrete with greatly reduced water demand

TYPICAL APPLICATIONS

The excellent dispersion properties of **MasterGlenium 51** make it the ideal admixture for precast and readymixed concrete where low water cement ratios are required. This property allows the production of very high early and high ultimate strength concrete with minimal voids and therefore optimum density. Due to the strength development characteristics the elimination or reduction of steam curing in precast works may be considered as an economical option

MasterGlenium 51 can be used to produce very highearly strength floor screeds. For screed mix designs consult BASF Technical Services.

- High workability without segregation or bleeding
- less vibration required
- can be placed and compacted in congested reinforcement
- reduced labour requirement
- improved surface finish

PACKAGING

MasterGlenium 51 is available in 208 litre drums and in bulk tanks upon request

TYPICAL PROPARITIES

Properties listed are only for guidance and are not a guarantee of performance

Form	Viscous Liquid
Colour	Light Brown
Relative density	1.1 @ 20°C
pH	6.6
Viscosity	128 +/ - 30 cps @ 20°C
Transport	Not classified as dangerous
Labelling	No hazard label required

EFFECT ON HARDENED CONCRETE PROPERTIES

- increased early and ultimate compressive strengths
- increased flexural strength
- higher E modulus
- improved adhesion to reinforcing and stressing steel
- better resistance to carbonation
- lower permeability
- better resistance to aggressive atmospheric conditions
- reduced shrinkage and creep
- increased durability

MASTER® BUILDERS SOLUTIONS

BASF

The Chemical Company

MasterGlenium® 51

(Formerly known as Glenium 51)

COMPATABILITY OF MasterGlenium 51

MasterGlenium 51 must not be used in conjunction with any other admixture unless prior approval is received form BASF Technical Services.

MasterGlenium 51 is suitable for mixes containing:

- microsilica
- pulverised fuel ash
- ground granulated blast furnace slag cement

DOSAGE

The normal dosage for **MasterGlenium 51** is between 0.5 and 1.6 litres per 100 kg of cement (cementitious material). Dosages outside this range are permissible subject to trial mixes.

DIRECTIONS FOR USE

MasterGlenium 51 is a ready to use admixture that is added to the concrete at the time of batching.

The maximum effect is achieved when the **MasterGlenium 51** is added after the addition of 50 to 70 % of the water. MasterGlenium 51 must not be added to the dry materials.

Thorough mixing is essential and a minimum mixing cycle, after the addition of the MasterGlenium 51 of 60 seconds for forced action mixers is recommended.

STORAGE

MasterGlenium 51 should be stored in original containers and at above 5 Centigrade. If frozen gradually thaw and agitate until completely reconstituted.

Failure to comply with the recommended storage conditions may result in premature deterioration of the product or packaging. For specific storage advice consult BASF's Technical Services Department.

SAFETY PRECAUTIONS

MasterGlenium 51 contains no hazardous substances requiring labelling. For further information refer to the Material Safety Data Sheet.

NOTE

Field service, where provided, does not constitute supervisory responsibility.

For additional information contact your local BASF representative.

BASF reserves the right to have the true cause of any difficulty determined by accepted test methods

QUALITY STATEMENT

This statement is made under condition that the material and usage thereof conform to the terms of our published literature and recognized good workmanship

BASF JO 03/2014

® = Registered trademark of the BASF-Group in many countries

BASF Construction Chemicals – Jordan

P.O. Box 752, 11118, Amman, Jordan

Tel +962-6 5521673

Fax +962 6 5523148

http://www.basf-cc.com.jo/

Appendix A

Data sheet of the Hardening Accelerator

Product Data Sheet
Edition 01.22.2017
Sika® Rapid-1

Sika® Rapid-1

Strength/Hardening Accelerating Admixture

Concrete

Description	Sika® Rapid-1 is a non-chloride strength/hardening accelerator formulated to increase the early strength of concrete without affecting the initial workability. Sika® Rapid-1 meets the requirements of ASTM C-494, Type C accelerating admixture.

Benefits

High Early Strength Concrete: Sika® Rapid-1 delivers excellent results in normal and hot weather conditions where very high early strengths are required.

Benefits

- Early stripping and re-use of forms.
- Faster finishing operations on flatwork surfaces.
- Earlier post-tensioning.
- Effective with Type I/II/III cements.

Precast Concrete: Sika® Rapid-1 delivers excellent results for precast concrete when high early strengths are required. Curing times are significantly reduced while concrete quality is improved.

Benefits

- Use as a replacement for steam curing to save energy costs.
- Increase early strengths and allow faster rotation of molds to increase production per day.
- Use as a replacement for Type III cement.

Cold weather concreting: Sika® Rapid-1 is an effective hardening accelerator where high early strength concrete is desired and the use of calcium chloride is prohibited.

Benefits

- Insulation and heating costs for curing time can be reduced.
- Earlier stripping and reuse of forms increases labor productivity.
- Accelerated strength gain allows earlier structural use and speeds completion time.

Sika® Rapid-1 does not contain calcium chloride or any other intentionally added chlorides and will not initiate or promote the corrosion of reinforcing steel present in the concrete.

Placing concrete in freezing conditions: When used at Sika recommended dosage rates, Sika® Rapid-1 may reduce the need for cold weather concreting practices as specified in ACI 306-Standard Specification for Cold Weather Concreting. Field evaluations should be carried out when concrete is to be placed in freezing conditions to determine the minimum ambient and concrete temperatures required, and the optimum dosage for the desired setting time and strength performance. Sika strongly recommends that appropriate sound curing practices be used to protect fresh concrete from excessive heat loss in extreme weather conditions.

Sika®

Concrete

How to Use

Dosage	To promote high early strength Sika® Rapid-1 may be used at the rate of 8-48 fl.oz. per 100 lbs. (520-1950 ml/100 kg) cement. When used to protect concrete from freezing, dosage will vary with different brands of cement and ambient temperatures and higher dosages may be necessary. Adjust water content accordingly when used at dosage of 16 fl.oz/100 (1040 ml/100 kg) cementitious or higher. Sika recommends that trial mixes be performed to determine the most efficient dosage. Please contact your local Sika regional office or Sika technical service department at 1-800-933-7452 for further information and assistance.
Mixing	Add correct amount of Sika® Rapid-1 at the concrete plant or into ready mix truck at the job site. The admixture may be added manually or by automated dispenser directly into the sand or into the water line at the batch plant. When used in combination with other admixtures care must be taken to dispense each admixture separately into the mix. Do not mix with dry cement.
	Use With Other Admixtures: Sika® Rapid-1 performs well in combination with other admixtures such as non-retarding water reducers, high range water reducers and air entraining agents. Do not mix Sika® Rapid-1 with expansion agents or shrinkage compensating agents.
Packaging	Sika® Rapid-1 is available in 55 gallon drums (208 liters), 275 gallon totes (1040 liters) and bulk delivery.
Storage and Shelf Life	Sika® Rapid-1 should be stored at above 40°F (5°C). If frozen, thaw and agitate thoroughly to return to normal state.
	Shelf life when stored in dry warehouse conditions between 50°F and 80°F (10°C-27°C) is 1 year.

Typical Data

Appearance	Reddish/Violet liquid. Color may change upon continuous exposure to UV light.
Specific Gravity	Approx. 1.17

KEEP CONTAINER TIGHTLY CLOSED • KEEP OUT OF REACH OF CHILDREN • NOT FOR INTERNAL CONSUMPTION • FOR INDUSTRIAL USE ONLY • FOR PROFESSIONAL USE ONLY

Sika Corporation
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PRIOR TO EACH USE OF ANY SIKA PRODUCT, THE USER MUST ALWAYS READ AND FOLLOW THE WARNINGS AND INSTRUCTIONS ON THE PRODUCT'S MOST CURRENT PRODUCT DATA SHEET, PRODUCT LABEL AND SAFETY DATA SHEET WHICH ARE AVAILABLE ONLINE AT HTTP://USA.SIKA.COM/ OR BY CALLING SIKA'S TECHNICAL SERVICE DEPARTMENT AT 800-933-7452. NOTHING CONTAINED IN ANY SIKA MATERIALS RELIEVES THE USER OF THE OBLIGATION TO READ AND FOLLOW THE WARNINGS AND INSTRUCTION FOR EACH SIKA PRODUCT AS SET FORTH IN THE CURRENT PRODUCT DATA SHEET, PRODUCT LABEL AND SAFETY DATA SHEET PRIOR TO PRODUCT USE.

Appendix B

DETAILED PICTURES OF SHOTCRETE MACHINE MANUFACTURING




Appendix C

CALCULATION FOR P

$$\rho = \frac{As}{bd}$$

$$\rho_{min} = \frac{\sqrt{fc'}}{4fy} \; for\; fc' > 30\; MPa$$

$$\rho_{max} = 0.85\beta \frac{fc'}{fy} . \frac{\varepsilon_u}{\varepsilon_u + \varepsilon_t} \qquad use\; \varepsilon_u = 0.003, \varepsilon_t = 0.004$$

$$\beta = 0.85 - 0.05(fc' - 28)/7 \qquad for\; 28 \le fc' \le 55\; MPa$$

$$\rho_t = 0.85\beta \frac{fc'}{fy} . \frac{\varepsilon_u}{\varepsilon_u + \varepsilon_t} \qquad use\; \varepsilon_t = 0.005, \varepsilon_u = 0.003$$

$$Mu = \emptyset \rho b d^2 fy (1 - 0.59\rho \frac{fy}{fc'})$$

Flexural Design:

Area of steel Ø10mm = 79 mm^2

Area of steel Ø8mm = 50 mm^2

$$fc' = 40\; Mpa\,, \;\; fy\, \emptyset 10mm = 629\;\; MPa$$

$$fy\, \emptyset 8mm = 551\;\; MPa$$

d = 150 – (20+8+5) = 117 mm

$$\rho = \frac{79 * 2}{117 * 100} = 0.0135$$

$$\rho_{min} = \frac{\sqrt{40}}{4 * 629} = 0.00251$$

$$\beta = 0.85 - \frac{0.05(40-28)}{7} = 0.76428$$

$$\rho_{max} = 0.85 * 0.76428 * \frac{40}{629} . \frac{0.003}{0.003+0.004} = 0.01770$$

$$\rho_{min} < \rho < \rho_{max} \qquad \therefore OK$$

Shear Design:

$$\rho_t = 0.85 * 0.76428 * \frac{40}{629} . \frac{0.003}{0.003+0.005} = 0.01549$$

$$\rho < \rho_t \qquad \therefore \emptyset = 0.9$$

$$Mu = 0.9 * 0.01350 * 100 * 117^2 * 629 \left(1 - 0.590.01350 \frac{629}{40}\right) * 10^{-6}$$

$$Mu = 9.15129 \, MPa$$

$$\sum fy = 0$$

R = P/2 $\sum M(c) = 0 \quad + \circlearrowleft$

9.15129 = 0.15P/2 – 0.55P/2 = 0

P = 45.756 kN

Vu = P/2 = 22.878 kN

$$\phi Vc = \frac{0.75}{6}\sqrt{fc'}bd = \frac{0.75}{6}\sqrt{40} * 100 * 117 * 10^{-3} = 9.2496 \, kN$$

$$Vu > \phi Vc$$

$$u \, \phi Vc = 4 * 9.2496 = 36.99 \, kN$$

$$\phi Vs = Vu - \phi Vc$$

$$\phi Vs = 22.878 - \phi 9.2496 = 13.6284 \, kN$$

$$\phi Vs < 4\ \phi Vc$$

$$2\ \phi Vc = 18.495\ kN$$

$$\phi Vs < 2\ \phi Vc$$

$$S_{max} \leq \begin{cases} \frac{d}{2} = 58.5\ mm \\ 600\ mm \\ \frac{3Avfyt}{b} = \frac{3 * 2 * 50 * 551}{100} = 1653\ mm \\ \frac{16Avfyt}{\sqrt{40}b} = \frac{16 * 2 * 50 * 551}{\sqrt{40} * 100} = 4408\ mm \end{cases}$$

$$\therefore use\ S = 50\ mm$$

الخلاصة

يتم استخدام الخرسانة المقذوفة ذات المزيج الرطب بشكل واسع لطريقة الصب لدعم الجدران في الانفاق والتدعيم تحت الأرض. يمكن الحصول على مكاسب كثيرة من استخدام هذا النوع ومع ذلك فأن المعلومات المتوفرة عنها قليلة. وخاصة لتلك التي تحوي على الالياف البلاستيكية. تم اعداد هذه البحث لغرض دراسة انتاج هذا النوع من الخرسانة بالإضافة الى دراسة خواصه و التصرف الانشائي باستخدام ماكنة قذف مصنعة محلياً. لتكون قادرًا على إنتاج الخرسانة المقذوفة، تم تصنيع آلة رش الخرسانة المقذوفة من اجل إطلاق الخرسانة المقذوفة والتي تتضمن نفايات الألياف البلاستيكية.

تم إجراء دراسة مكثفة في هذا البحث لتوليد مزيج من الخرسانة المقذوفة باستخدام مواد نفايات محلية مثل زجاجات المشروبات. حيث تم فحص صفات الخرسانة المقذوفة الحاوية على نفايات الألياف البلاستيكية من حيث السلوك الطري والصلب والميكانيكي واخيرا الانحناء مع تحليل النتائج كاملاً. تم استخدام خمس خلطات (0.25 ، 0.5 ، 0.75 ، 1.0 ، و 1.25) في المائة من محتوى نفايات الألياف البلاستيكية، بالإضافة إلى الخرسانة المقذوفة المرجعية (SC0.00) في هذه الدراسة. بالإضافة إلى ذلك، تمت دراسة سلوك الانحناء للعتبات المصنوعة من نفس مواد النفايات.

اعتمد الجزء الأول على قياس الخصائص الجديدة، مثل فحص الركود للخرسانة الطرية (750 ، 780 ، 790 ، 880 ، 750 ، 690) ثانية ، و T500 (0 ، 0.5 ، 1 ، 1 ، 1 ، 1) ثانية ، وفصل الغربال (15.1 ، 13.4 ، 11.2 ، 9.6 ، 9.1 ، و 8.3) ثانية، لمعرفة كيف أثرت كميات مختلفة من نفايات الألياف البلاستيكية على الخرسانة المقذوفة. تمت تغطية الخصائص الأكثر صلابة للخلطات، في القسم الثاني، تمت مناقشة الكثافة الجافة (2364 ، 2368 ، 2377 ، 2373 ، 2358 ، و 2355) كجم / م 3 وامتصاص الماء (0.67 ، 1.08 ، 1.48 ، 1.68 ، 1.75 ، و 1.85)٪ ومحتوى الفراغات (0.80 ، 1.27 ، 1.87 ، 1.95 ، 2.19 ، و 2.62)٪ (4.46 ، 4.38 ، 4.37 ، 4.29 ، 4.26 ، 4.14) كم / ثانية واختبارات سرعة الموجات فوق الصوتية (4.46, 4.38, 4.37, 4.29, 4.26, 4.14) كم/ثا في القسم الثاني. في القسم الثالث، تمت مناقشة الخصائص الميكانيكية للخلطات، مثل مقاومة الانضغاط (40.2 ، 36.0 ، 31.3 ، 30.3 ، 25.3 ، و 24.4) ميجا باسكال وقوة الشد (3.2 ، 3.4 ، 3.8 ، 3.9 ، 4.1 ، 4.4) ميجا باسكال ومعامل المرونة (45.21 ، 19.86 ، 17.39 ، 16.51 ، 15.93 ، و 15.12) كيكا باسكال.

أظهرت النتائج أن إضافة نفايات الألياف البلاستيكية يحسن قوة شد في الخرسانة المقذوفة. بينما كان الجزء الأخير من البحث هو فحص الأداء الهيكلي للعتبات الخرسانية المقذوفة المسلحة مع نسب مختلفة من نفايات الألياف البلاستيكية (12.8 ، 13.8 ، 13.3 ، 12.8 ، 13.3 ، 14.84) ملم كإنحراف نهائي للنسب (0.00 ، 0.25 ، 0.5 ، 0.75 ، 1.0 ، 1.25) ٪ على التوالى. أظهرت النتائج سلوك انثناء متشابه مقارنة بتكوين أنماط الشقوق وعرضها بالإضافة إلى مؤشر الليونة (2.03 ، 2.29 ، 2.02 ، 1.94 ، 2.16 ، 1.99) والصلابة (5.50 ، 4.59 ، 4.48 ، 5.01 ، 4.81 ، 1.31) لجميع العتبات الخرسانية للنسب (0.00 ، 0.25 ، 0.5 ، 0.75 ، 1.0 ، 1.25) ٪ على التوالى. أظهرت العتبات الخرسانية مقاومة للثني بعد تسليط القوة. وانخفض الانحراف النهائي للعتبات الخرسانية مع زيادة كمية نفايات الألياف البلاستيكية حتى 0.75٪.

أخيرًا ، أوضحت الدراسة أن الخرسانة المقذوفة الممزوجة مع هذه النفايات بنسبة 0.5% زادت من كثافة الخليط الخرساني المقذوفة. و أظهر تحليل الخواص الميكانيكية للعتبات الخرسانية أنه لم يكن هناك تحسن كبير باستثناء مقاومة الشد. بينما تبين العتبات الخرسانية الممزوجة مع 0.75% من نفايات الالياف البلاستيكية أفضل أداء للثني من حيث الانحراف والليونة والصلابة لها.

وزارة التعليم العالي والبحث العلمي

جامعة الانبار

كلية الهندسة

إنتاج الاعضاء الخرسانية المسلحة من خلال قذف الخرسانة التي تحتوي على نفايات بلاستيكية

رسالة مقدمة

الى كلية الهندسة / جامعة الانبار

كجزء من متطلبات نيل شهادة ماجستير علوم

في

الهندسة المدنية

من قبل

عامر محمد عناد

(بكالوريوس علوم في الهندسة المدنية 2005)

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شعبان 1443 هـ

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