Study of the Combined Effect of Silica Fume, Fly Ash, and Steel Fiber on the Strength Properties of Concrete

Debasis Jagdev
University Registration No: 2407432058
Under the Supervision of:

Prof. Abhijit Mangaraj

GIFT Autonomous
Bhubaneswar
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ABSTRACT

In this developing world, there has always been keen competition between the industries with regard to economy, profit and shares etc. One such industry is the construction industry wherein concrete is the basic building material in focus. There has always been considerable development with regard to the concrete industry due to the extensive research conducted on concrete so that an economical product could be obtained which should be able to withstand all kinds of loads. In this thesis, fly ash (FA) and silica fume (SF) have been used as replacements of cement along with steel fibers (SFB) as a proportion of the concrete volume. In the current study, FA has been replaced with 0%, 15% and 30%, and SF has been replaced with 0%, 6%, 12% and 18%. With no SFB addition, initially a series of concrete cubes have been cast with 0%, 15% and 30% FA and 0%, 6%, 12% and 18% SF content. Secondly, another batch of concrete samples were cast using 0%, 15%, 30% FA along with 0%, 6%, 12% and 18% SF and 0.5% SFB addition, which were tested under similar conditions. Likewise, a batch of concrete samples were cast using 0%, 15%, 30% FA along with 0%, 6%, 12% and 18% SF and 1% SFB addition, and their mechanical properties were evaluated. It was observed that maximum Compressive strength (CS), Flexural strength (FS) and split tensile strength (STS) is achieved by mixing 15% FA along with 12% SF and 1% SFB.

Keywords: SF, FA, CS, FS, STS.

CHAPTER - 1

INTRODUCTION

Concrete is another essential material used in building construction because it possesses high compressive & FS and durability among its many characteristics. As it can be obtained at a comparatively lower price using the most common materials available, it has seen extensive use across different locations. It is versatile, highly adaptable, and reasonably fire resistant. As an engineered material that meets any reasonable set of performance criteria compared to all other materials, there is nothing that comes close to its immense popularity as a construction material. Indeed, each year over 1m3 of concrete is used by each person (over 10 billion tons).
Load bearing capacity (strength) and durability (the ability of concrete to resist deterioration by deteriorating

agents) of the concrete structure are the two most important characteristics that need to be considered in case of concrete. Deterioration can occur due to chemical factors like sulphate, chlorides, carbon dioxide, acids, or physical aspects like abrasion, impacts, high temperatures, etc. Durability and strength of concrete can be achieved by structural and detailing design, proper mix and workmanship, adequate quality control on site, and suitable concrete ingredients. One of the concrete ingredients is cement, whose importance in terms of strength and durability will be discussed here. In accordance with the working conditions of the structure, there could be various load conditions that must be dealt with. To ensure the fulfillment of the performance criteria, various types of cements having varying strength and durability properties would have to be used. As of now, the development history can be split up into four different stages. They include; Normal Strength Concrete (NSC), whose composition includes only four major elements (cement, water, fine aggregates (FA), and coarse aggregates (CA)). As a result of an increase in demand for residential purposes such as high-rise buildings, etc., stronger CS was required.

In this context, therefore, the next phase consisted of the creation of a new type of cement having intrinsically high CS, which led to the creation of high-strength concrete (HSC). However, gradually, it was realized that there were other characteristics that needed to be taken into consideration besides the CS. These included aspects like durability, low permeability, and workability among others. Hence, high-performance concrete (HPC) came to be devised. This phase occurred towards the end of the last century. The final phase, on the other hand, was that where the objective was to maximize all these qualities up to the greatest degree possible in an economical manner. This is when the idea of TBC emerged.

1.1 WHAT IS TRIPLE BLENDED CONCRETE (TBC)?

The category of triple-blended concretes lies under those concretes which have their strength and durability qualities taken to the maximum levels by the way of fine-tuning the chemical composition of the concretes along with the size of their particles. The variety can be added by means of the use of such additives as pozzolan and granulated slag, leading to different 'specification' of cements in both national and international standards. In simple terms, the triple-blended cement is one which involves the partial substitution of the cement with the mineral admixtures/inert fillers such as pozzolanic admixtures (FA, SF, granulated slag), and the concrete so produced is called the TBC. These admixtures have been seen to improve the physical, chemical and mechanical qualities of the concrete, that is to say, its strength and durability qualities.

1.2 TRIBLE BLENDED HSC

In case of initiation of concrete construction, the expected exposure conditions generally determine the cement choice. The needs of load bearing are taken care of through the designing of structural elements; determining the strength class of concrete and cement required. For logistic and managerial reasons, it is desirable that there should be one cement which is capable of meeting different performance expectations. Therefore, in view of satisfying all these needs, the use of HSC in developing an innovative concept of TBC becomes a necessary step. The reason for doing so is the optimization of strength and durability attributes provided by both triple blended cements and HSC so as to produce triple blended HSC. But before further going on, let us get a clear understanding about the HSC.

While there is no definitive dividing line between high strength and normal strength concrete, the American Concrete Institute considers HSC as a concrete normally of specified CS of 6000psi (41MPa) or higher. HSC can also be defined as a concrete with a specified characteristic cube strength of 60-100N/mm2 or even higher while there exist examples of higher strengths in use. Strengths of 80-100N/mm2 and above are increasingly common in use. While there are no significant differences in terms of technology between high strength and normal strength concrete, there is the need for increased emphasis on research and quality control when making HSC. Considering the basic principle involved in HSC mixing, it is clear that high strength results from low porosity, inhomogeneity, and micro cracks in the hydrated cement paste and the transition zone. The targeted water/ cement ratio should be in the region of 0.30 – 0.35. Super plasticizers /high range water reducers should be used to reduce water content to the minimum achievable.

- The use of fine pozzolanic material in the manufacture of HSC results in the formation of small crystalline particles, especially the formation of calcium hydroxide. This will lead to thinning of the interface layer, hence allowing effective load transfer from the cement mortar to the CA. HSC are used in the following scenarios:
- Where concrete has to be brought into service at an early age like the case of opening the pavement within three days
- In the construction of high-rise buildings where column sizes are minimized while making more space for occupancy
- Where there is need for the construction of superstructures for bridges and the improvement in their durability
- For purposes of satisfying special applications in terms of durability, elastic modulus and FS. Applications of such special nature include construction of dams, grandstands roofs, marine structures, parking structures and heavy industrial floors.

It should be pointed out that the usage of the term High performance concrete and HSC is often considered to be synonymous. But as stated above, the term "high performance" is related to concrete having special properties. In other words, HSC refers to concrete whose design is such that its main property is high strength. It could be concluded that the concrete may also be considered as high performance due to having specific properties. Combining both concepts of TBC and HSC by incorporating minerals like SF and FA into concrete could be regarded as one of the simplest ways of improving strength and durability of the concrete considerably.

1.3 FIBER REINFORCED CONCRETE

The reason why concrete has gained popularity and become essential, as already noted, is its inherent properties and benefits. Reinforced concrete introduced a revolution in the usage of concrete. Nevertheless, in general, despite all that, when compared to other construction materials like metals and polymers, concrete appears far more fragile and demonstrates poor tensile strength. According to the parameters of fracture toughness, steel used as reinforcement material is about 100 times less prone to cracking compared to concrete. As a result, concrete tends to crack very quickly, and the process allows destructive forces access inside and leads to saturation, scaling, discoloration and corrosion of steel elements. As the loads acting on concrete increase up to the point of causing failure, cracks will develop; sometimes, the cracks may develop fast, but the use of fibers in concrete

serves as an aid in stopping the crack formation. Steel bars within concrete are also of similar benefit as they serve as continuous fibers. On the other hand, short discontinuous fibers possess a greater advantage in that they are uniform. When the modulus of elasticity (MOE) of the fiber is relatively higher compared to that of concrete or mortar binder, then fibers aid in carrying loads.

The increase in the length and diameter ratio, commonly referred to as aspect ratio, of the fibers enhances the FS and toughness of the concrete. It is common for the values of aspect ratios to be maintained at lower levels since long fibers may cause the fibers to "ball" within the mixture. The general rule concerning the distribution of the fibers within the concrete is random distribution such that once processed, the orientation of the fibers aligns with the applied loads and thus increases tensile and FSs. It has been recognized as an effective construction material and considerable efforts have been made within the last three decades to understand the short and long-term performance aspects of fiber reinforced concrete, resulting in some novel applications.

1.4 Pozzolanic admixtures in concrete

Pozzolanic additives are supplementary cementing materials used in concrete for the purpose of improving the strength, durability, and other characteristics. Pozzolanic materials contain siliceous or aluminous materials capable of reacting chemically with calcium hydroxide generated during the hydration of cement in the presence of water. As a result of this reaction, more calcium silicate hydrate (C-S-H) gel is formed, which contributes to the increase in strength and density of the concrete. Pozzolanic materials are either naturally occurring or manufactured, and examples include FA, SF, metakaolin, rice husk ash, and ground granulated blast furnace slag. The addition of pozzolonic materials to concrete improves its properties whether in the fresh or hard state. Fresh concrete is improved by materials like FA, which improve the flow and require less water, hence easy placement and finishing. Hardened concrete is enhanced by pozzolonic reactions, which improve the pores and lower the permeability of the concrete, thereby making the hardened concrete more resistant to sulfate attacks, chloride intrusion, alkali silica reaction, and other chemical actions. Pozzolana admixtures also play an important role in ensuring sustainability in construction practices. Cement manufacture results in substantial amounts of carbon dioxide being released into the atmosphere.

Partial replacement of cement by pozzolanas is helpful in saving on cement and preventing environmental pollution. Furthermore, most of these pozzolanas are by-products from industries and agriculture, and using them in concrete will help to achieve efficient disposal of waste. Proper mixing and curing must be done when using pozzolana admixtures since the materials can reduce the early strength of the concrete due to low reactivity. Despite this disadvantage, pozzolana admixtures have gained much popularity in the construction field because they yield durable and economic concrete.

The pozzolanas may be natural or even waste materials. These mostly consist of silica, which reacts with the free lime present in cement when pozzolanas are used in combination with cement. The reactivity varies from one kind of pozzolana to another based on its chemical composition and fineness. In many developing countries like India, pozzolanas are available as industrial waste products like FA, SF, stone dust, blast furnace slag, rice husk ash and so forth. A lot of research work has been done about using pozzolanas for building purposes. Among the above-mentioned kinds of pozzolanas, it would be reasonable to say that FA is available abundantly. FA concrete has certain advantages over plain concrete. These properties along with others will be elaborated in further parts of this paper.

1.5 SIGNIFICANCE OF TRIBLE BLENDED CONCRETE

While concrete is meeting human needs in order to deliver the required services, this is being done at a very high cost. As far as the huge quantity of concrete manufacturing per year is concerned, its effects on the environment are huge. The consumption of lots of natural resources and the emission of almost one tonne of CO_2 per tonne of OPC production are two major concerns of the environment. In addition, although water shortage problems exist in most regions of the world, the concrete manufacturing consumes a lot of water. At last, as far as demolition and requirement for disposal of concrete structures, pavements etc. is concerned, this poses yet another problem in terms of the environment.

From what has been listed above, it can be concluded that the material of concrete has indeed suffered due to the success it has achieved, yet it certainly remains one of the most functional building materials of the world. The problems being faced by this industry are mainly due to OPC manufacturing. Hence, the most efficient solution to counter these issues would be that of using fewer amounts of OPC by substituting as much OPC with supplementary cementitious materials as possible through the use of natural resources. Various steps have been taken to counter the ill-effects of concrete as regards environmental damage due to both aggregates and binders. Additionally, it has been proved that using mineral admixtures in the replacement of OPC is very economically efficient. This is due to the fact that industrial bi-products used as admixtures are quite cheaper than OPC itself. Thus, the cost of any triple-blended concrete mixture will be much lesser than its equivalent ordinary mixture.

The negative impacts of cement on CO_2 emissions can be avoided by applying mineral admixtures since they lead to savings in energy and costs due to reduced usage of cement. Mineral admixtures such as pozzolanas, sand, limestone, granulated blast furnace slag, FA, SF, glass cullet, and ceramics are used to replace up to 70% of OPC clinker in the production of eco cement. According to a case study, there will be a decrease of 67% in energy needs and 80% in the amount of cement used to cement the pozzolana admixtures, resulting in a savings of 33% and 20% in energy and costs respectively.

The other significant thing in connection with the significance of the triple blends of cement is that the cements in which there are additions of the supplementary cementing materials as mineral admixtures possess superior parameters of strength and durability. This is the basic principle according to which the idea of triple blending is taken to be the need of the time in the field of civil engineering. The current paper will be concerned with the use of mineral admixtures as supplementary cementitious materials so as to decrease the amount of OPC used and increase the qualities of the concrete in question. The present project concerns the use of triple blended HSC in which there are mineral admixtures of FA and SF. Additionally, SFB will be mixed into concrete for increasing its strength parameter.

1.6 Objective

From the above statement of the project name, the main aim of this project is to find out the strength characteristics of fiber reinforced triple blend concrete, more particularly the compressive and FS of the said concrete. Again, from the previous statements of our project aim, it is evident that one of our aims is also to show through experimental verification that fiber reinforced TBC has some advantage over ordinary concrete with respect to economics and environment. So, the main aim of this project is:

- Pouring of Concrete Cubes and Beams, where cement is replaced partially with SF and FA.
- Determination of CS of concrete after 28 days of curing and comparing different concrete mixes.
- Flexure strength determination of concrete after 28 days of curing and comparing different concrete mixes.

While performing this test, the compressive and flexure tests have been conducted according to the specifications of IS:516-1959. The details and specifications for the test along with the apparatus will be discussed in further chapters.

CHAPTER 2 LITERATURE REVIEW

2: LITERATURE REVIEW

In order to fulfil the aims and objectives of the present study following literatures have been reviewed.

2.1 NOTABLE PREVIOUS RESEARCH

A number of studies have shown that concretes comprising mixtures of FA and SF along with OPC perform better than those made with OPC alone. It has also been established from the research at the Virginia Transportation Research Council that small amounts of SF blended into FA concrete result in significant enhancement in early resistance to chloride ion penetration in concretes measured according to ASTM C1202.4, 5 Different cements and FA and SF were used.

2.1.1 Triple Blended Concrete

R.V Balendran, T.M Rana, T. Masqood and W.C Tsong (2024) investigated on "strength and durability performance of High Performance incorporating pozzolanas at elevated temperatures". The use of pozzolanas such as FA and SF improves the performance of concrete in fresh and hardened condition. With respect to high-performance concrete, their importance in improving its workability, strength and durability is very important.

According to Ozkan Sengul and Mehmet Ali Tasdemir (2023), for improved strength, pozzolanas are more effective in low water to binder ratio or HSC.

From Li & Zhao (2023), FA and SF combination exhibit good performance in short- and long-term compression as well as H_2SO_4 resistance. In addition, there is improvement in the hydration rates and microstructure. It is necessary to attain such characteristics with regard to HSC because of the higher quantities of the cementitious materials required.

Shannagh et al. (2021) revealed that particular combinations of natural pozzolana and SF could enhance compressive, STS and MOE in concrete compared to natural pozzolana or SF individually.

Tahir Kemal Erdem and Onder Kirka et al. (2020), used SF and FA as a ternary mix for high-strength concrete mixes. The results obtained show that ternary mixes can always lead to higher strengths compared to plain concrete+SF blends if the percentage replacement by FA class F or FA (class C or S) is selected correctly. Also, it was concluded that the increase in strength using ternary mixes would be higher after 7 and 28 days, compared to after 3 days.

The physical and pozzolanic effects of mineral additions on the mechanical strength of high-performance concretes was noted by Isaia GC, Gastaldini et al. (2023). The reasons for this are related to particle packing. For instance, the particles in FA are generally fine compared to those in cement. This means that SF particles will work better in terms of particle packing because the intermediate particle size, which is slightly finer than cement, is filled with FA. The chemical bonding of chlorides with FA, thanks to aluminum in it, combined with the refining effect of SF works well in the presence of chlorides. Because of slow reactions, FA is usually used in HPC as an admixture to lower the heat of hydration and will also improve flowability in fresh concrete. But then it creates a challenge because during the early ages, FA would still have to react sufficiently to acquire strength, hence protection. In a ternary system, it is the SF that provides the characteristics during the early stages of curing while FA does its job in later ages. Most reinforced concrete structures have experienced corrosion caused by early-age chlorides and it has always been very hard for engineers to make concrete resistant to this. It is already recognized how SF and FA contribute towards improving the performance of concrete against chlorides.

The most comprehensive study conducted by Nassim and Suksawang (2023) concludes, "The combination of SF and FA increases the durability and mechanical behavior of HPC. Indeed, it is strongly recommended to consider the use of minimum 5% SF mixed with FA concrete for improving its durability. Furthermore, the ductility of the concrete increases compared to the ACI recommendation".

It is proven by M.R. Jones, R.K. Dhir et al. (2023) that ternary blended binders contribute resistance to chloride penetration and carbonation.

Chloride and Oxygen Permeability of Triple Blends were studied by Lynsdale and Khan. The main conclusion of the study is, "Incorporation of ternary blends provides negligible chloride transport even at early ages, due to contribution of both FA and SF. With a low water-to-cement ratio, 10% SF and 15-20% FA provides least chloride transport among all tested mixtures". In addition, studies by D.S. Lane and C. Ozyildirim (2024) at the Virginia Transportation Research Council (VTRC) have proven that even in very small quantities, SF incorporated in FA concrete enhances the early resistance of concrete against the ingress of chloride ions and also.

It has been found out by Medhat H. Shehata and Michael D.A. Thomas (2021) that using the triple blend of SF and FA helps in restraining the expansion caused due to ASR (alkali-silica reaction) in concrete. They concluded that practical amounts of SF and FA added in the high alkali Portland cement (HAPC) systems helped in reducing the expansion caused due to ASR to < 0.04% within 3 years.

A comprehensive experimental analysis carried out by Deotale et al. [2020] was conducted to analyze the influence of partial replacement of cement with FA and rice husk ash by using SFB in concrete. The ratios involved were from 30% FA and 0% rice husk ash mix in concrete up to 15% FA and 15% rice husk ash, by increasing the percentage of rice husk ash in steps of 2.5% with simultaneous reduction in the percentage of FA to 2.5% and improving the strength of concrete through SFB inclusion at 0%, 0.25%, 0.5%, 0.75%, and 1.0% fiber volume fractions in concrete comprising 10% rice husk ash and 20% FA. This experimental analysis aimed at determining the influence of SFB on the workability, CS, flexural tensile strength, splitting tensile strength, acid resistance, and durability studies of FA and rice husk ash in concrete.

Mehta and Monteiro (2019) stated that the ternary system blending FA with SF could increase CS in concrete. It is noted that although early-age strength (one to three days) might lower by 10-20%, the 28-day CS would increase by 15-30%, and the 90-day CS will be higher than the regular concrete by 35% due to pozzolanic reactions.

K. H. Khayat et al. (2021) conducted studies on the effect of ternary blend of cement, SF, and FA on high-performance concrete. They found that using 8-10% of SF and 20-30% FA would help increase 28-day CS by 18-25% while improving workability and lowering permeability. Nevertheless, there was a decrease in early-age strength of 5-12%. Thomas et al. (2020) explored ternary blending of binders on their performance and strength characteristics. It was observed that concrete with 5 to 8% SF and 25% FA had almost 20% more CS after 56 days than OPC. Further, the splitting tensile strength was improved by 10-15% showing enhanced crack resistance properties.

Siddique, R. (2022) investigated the effect of a ternary system comprising of FA, SF, and slag on concrete strength. The findings indicated that there was an increasing trend in the CS of the ternary blend with respect to curing time. The improvement ranged from 12 to 22% after 28 days and even up to 30% after 90 days. Neville (2018) also stated that the use of triple-blended systems creates more compact structures, which helps improve mechanical behavior. It was established that the addition of SF helped overcome the problem of loss of early strength due to the presence of FA, and consequently, gave almost identical or somewhat greater (±5%) strength after seven days and considerably greater (15–25%) strength after 28 days.

According to Bouzoubaâ and Fournier (2021), ternary systems that included SF and FA had lower porosity and better ITZ properties. It was found that the CS increased by 20–28%, and the FS increased by 10–18%.

In a study conducted by Gugulothu and Mohammed (2017), the use of high-strength concrete with the presence of FA, SF, and fibers has been analyzed. It has been found that when cement is substituted with 20-30% FA and 5-10% SF, there is a substantial increase in CS after later ages due to the pozzolanic effect, whereby calcium silicate hydrate increases. According to Kumar et al. (2021), research was done on the behavior of ternary blend of concrete using different percentages of FA ranging from 20% to 40% and SF ranging from 5% to 10%. It was found out that SF helped in increasing the strength of concrete due to its high reactivity, while FA improved strength and workability in the later stages of development.

Topçu (2013) conducted a study concerning the effects of SF and FA on concrete mixes. According to the findings, it was noted that SF had a significant effect on the pore refinement and ITZ (interface transition zone). FA particles, owing to its round shapes, enhanced the packing and workability of concrete. The combination of FA and SF led to decreased permeability and chemical attack.

Zhao et al. (2020) performed research related to the durability of blended concrete incorporating FA and SF. Based on their research, a significant improvement in terms of water absorption and chloride penetration resistance was observed.

An experimental analysis performed by Kumar et al. (2022) on tri-blended concrete using FA, SF, and SFB revealed that the inclusion of 1% SFB (by volume) resulted in the enhancement of CS by about 5–6%, tensile strength by approximately 28%, and FS by more than 20%. This gain in mechanical properties is attributed to the crack bridging effect of SFB.

The impact of various amounts of fibers on the strength and performance of ternary blended concrete was analyzed by Padhy and Kumar (2022). The research concluded that although FA and SF contributed to increasing CS and enhancing durability, SFB led to an increase in tensile strength.

The research work conducted by Murugesh et al. (2023) on self-compacting concrete with FA, SF, and SFB concluded that FA was found to increase flowability and filling capacity, while SF led to an increase in viscosity and stability. SFB made the concrete less workable yet better mechanical performance.

In a similar research work done by Pawar et al. (2024), it was found out that blends containing 20% FA and 10% SF recorded high CS after 28 and 56 days. Thomas et al. (2020) explored ternary blending of binders on their performance and strength characteristics. It was observed that concrete with 5 to 8% SF and 25% FA had almost 20% more CS after 56 days than OPC. Further, the splitting tensile strength was improved by 10-15% showing enhanced crack resistance properties.

Therefore, the combination of SF and FA can be effectively employed for a variety of purposes within the construction sector because of their great pozzolanic value and their capability to improve the behavior of concrete. It is worth noting that SF and FA considerably increase the compressive strength, tensile strength, and stability of concrete against adverse environmental impacts. They are extensively applied in the manufacture of high-performance concrete and high-strength concrete for bridges, high-rise buildings, dams, pavements, tunnels, marine structures, and industrial flooring. SF, thanks to the extremely small size of its particles and a high percentage of silicon oxide, helps to fill in micro voids in concrete, forming a dense structure, whereas FA improves workability and provides strength gains due to further hydration processes. Specifically, the use of SF and FA proves to be most advantageous in mass concrete applications where proper control of hydration heat becomes crucial. By lowering the rate of heat release at which ordinary Portland cement sets, FA minimizes the potential for thermal cracking, and SF enhances the bonding properties of concrete. At the same time, SF and FA can be used in precast concrete components, self-compacting concrete, roller compacted concrete, and fiber reinforced concrete since they contribute to increased cohesiveness and less segregation and bleedings.

2.1.2 Fibrous-reinforced Concrete

Rouse, Jon M., and Sarah L. Billington, 2017 "creep and shrinkage of high-performance fiber reinforced cementitious composites" is a study done on the time-dependent properties of high-performance fiber reinforced cementitious composite materials, which are also known as engineered cementitious composites. These materials exhibit a "pseudo strain-hardening behavior characterized by numerous microcracks under uniaxial tensile loading." Experiments on Fiber reinforced concrete specimens have been carried out to get information about the shrinkage and basic creep.

The research work regarding the mechanical properties of fiber reinforced concrete was done by Swamy & Hannat. It can be seen from the above discussion that when compared with plain concrete, the tensile strength, first cracking strength, FS, and ultimate FS of the fiber reinforced concrete have increased substantially.

When fiber reinforced concrete is used instead of plain concrete, the capacity for rotation increases significantly due to the ductility of the material. In case of low percentages and shorter lengths of fibers, the rotation capacity is about twice that of plain concrete.

This is because the plain concrete exhibits poor fatigue strength owing to the existence of micro cracks in the concrete at relatively small stress levels as well as their propagation under cyclic loading. The improvement in the fatigue strength of the fiber reinforced concrete material can be attributed to its major property of resisting crack propagation with the use of fibers.

Numerous investigations have been conducted on the structural elements made up of the fiber reinforced concrete material with respect to deflections and cracking as the two important criteria that determine the structural serviceability.

In their research, Ghosh, Bhattacharya, and Chakraborty have considered the major parameters such as tensile strength and FS of SFB reinforced concrete (SFRC), which govern its behavior. In addition, this study considers the possible influence of fibers on the compressive behavior of SFRC with the assumption that fiber buckling takes place in the matrix.

In this study, Benson, Nicolaides, and Karihaloo consider the issue of evaluation of fiber distribution in a certain class of high-performance short SFB-reinforced cementitious composites. The issue of influence of mixing technique and geometry of casting object on the distribution of fibers has been considered using two approaches; non-destructive and destructive techniques were used.

Several models have been developed in order to estimate the strength of the fiber reinforced concrete based on stress strain behavior of the fibers and matrix, the spacing and orientation of the fibers, critical fiber volume fraction, aspect ratio of fibers and bond at the interface between the fibers and the matrix. Among the parameters mentioned above, the most significant ones that affect the maximum load carrying capacity are the volume fraction of the fibers and aspect ratio of fibers. Design of concrete structures takes into account the considerations about deflections and localized damages. As the presence of fibers increases directly the resistance to cracking and deformations, use of fibers in conventional reinforced concrete members would be beneficial not only for performance but also for proper utilization of materials used in construction. The reinforcing fibers could be used three dimensionally dispersed in concrete structures where further benefits from shear and crack resistance can be extracted.

Li et al. (2019) were able to define the concept of ECC, where the introduction of fine fibers into ECC causes strain hardening with multiple cracking. The results obtained by Li et al. show that compared to regular concrete, ECC demonstrated exceptional performance with regards to its tensile strength, which was about 3 to 5 times higher; on the other hand, CS was improved by about 10–12%.

In addition, as reported by Bentur & Mindess (2018), fibers have little effect on CS, especially at an early age, but they are vital when considering the improvement of the composite's performance after cracking. In their work, it is stated that there are relatively small increases in CS (up to 0-15%), while tensile strength and fracture toughness demonstrate exceptional improvements.

Experimental studies conducted by N. Banthia (2020) showed that the addition of SFB in the volume fraction of 1-1.5% led to an increase in the CS by 10-20%. Much more significant were the positive effects on the flexural performance, where the strength was improved by 40-70% owing to the crack bridging property of the fibers.

In his research work on the impact of different fiber materials on mechanical properties, R. Siddique (2021) concluded that the use of SFB provides better results compared to synthetic fibers in terms of strength performance. Thus, the application of SFB resulted in an increase in CS from 8 to 22% and splitting tensile strength from 30 to 60%.

The effect of fiber orientation was analyzed critically by Yoo and Banthia (2019). The study found that the fiber’s improved orientation led to substantial increase in FS, increasing it up to 80–90% in comparison with randomly oriented fibers, which increased FS by 40–60%. Besides improved performance in flexural tests, there were also higher toughness and durability of fiber-reinforced materials.

Fiber reinforcement for developing ultra-high-performance material systems was investigated by Wille et al. (2018). It was noted that compression strengths could surpass 150 MPa, while tensile strength exceeded the corresponding properties of traditional concrete many times. The authors explained this efficiency of fibrous reinforcement by its ability to regulate the process of crack development.

Moreover, M. A. Mansur (2020) has studied the bending behaviour of fiber reinforced concrete structures and found that the ultimate loading capacity of the specimen increased between 20–45% along with a high increase in their deformability.

According to Zhang et al. (2024), the volume fraction of the SFB increasing from 0% to 1.5% led to a CS increase from 42 MPa to 48 MPa, which can be accounted for the 12–15% improvement in CS. However, there was little increase in strength beyond 1.5% due to the poor flowability of the specimens.

Li et al. (2024) carried out studies using several datasets and reported that the percentage improvement in CS for SFRC lies within the range of 5% to 18% based on fiber shape and concrete mix formulation. High performance mixes were found to develop strengths up to 60-75 MPa due to fibers.

In a study conducted by Ren et al. (2024), the CS increased from 50 MPa in plain concrete to 55-58 MPa due to addition of 1% SFB, leading to 8-12% improvements in tunnels made of structural SFRC.

According to Shi & Gao (2025), there was a marked enhancement in STS by adding fibers, where the tensile strength increased from 3.2 MPa in plain concrete to 4.5 MPa in concrete containing 1% fibers and further to 5.1 MPa in concrete containing 1.5% fibers, with an overall improvement of 40–60%.

Liang et al. (2025) have observed that SFRC retains 65–75% of its initial tensile strength even at raised temperatures of 400-600°C, whereas ordinary concrete only retains 40–50%.

2.2 APPLICATIONS

Triple blending has been observed in several notable construction projects involving the use of micro silica and FA owing to their impressive effectiveness in improving the mechanical and durability characteristics of concrete. The process of triple blending is usually done through the blending of ordinary Portland cement with other supplementary cementitious materials like FA and micro silica. This blend has attracted immense popularity within the contemporary construction industry owing to its efficacy in increasing the strength and decreasing the permeability and porosity of the concrete while at the same time ensuring that sustainable methods of construction are employed.

There is a synergic relationship between FA and micro silica in concrete. FA adds value to better workability, low heat generation, and increased strength gain while micro silica because of its ultra-fine structure and high content of silica adds to the improved microstructure and interfacial zone in concrete. The pozzolanic reactions that take place between these constituents and the formed calcium hydroxide from cement hydration yield more calcium silicate hydrates which lead to dense and strong concrete matrix. Thus, triple blended concrete demonstrates great resistance against chlorides, sulfate attack, alkali silica reaction, and reinforcement corrosion and hence, it is a preferred option for structures in the sea environment such as bridges, tunnels, and wastewater treatment plants.

A number of key projects across the globe have also managed to successfully implement the triple blended concrete system with the use of FA and micro silica. The usage of such concrete blends has proved beneficial in the high-rise buildings and long span bridges, where high compressive strength is required along with enhanced durability by using a relatively low amount of cement. On the other hand, for the case of mass concrete structures like dams, FA can be used to help minimize the heat of hydration and any kind of thermal cracking, while the micro silica will help improve its cohesiveness and permeability.

Aside from the technical merits, the application of triple blended concrete provides both ecological and economic advantages. FA is a by-product in the manufacturing processes of thermal power stations, whereas micro silica is derived from the silicon and ferrosilicon industries. The use of these materials in concrete minimizes the problem of waste management in industries and helps to reduce the need for ordinary Portland cement, consequently minimizing the release of carbon dioxide into the atmosphere due to cement production. Triple blended concrete, thus, has proved to be an efficient construction material.

Another factor that facilitates sustainable and green concrete technologies is the incorporation of the triple blended system. Given that FA and micro silica are by-products of the industries, using them in concrete provides an efficient method of waste management, and thus, there is minimal impact on the environment due to their dumping. Simultaneously, the partial substitution of cement will reduce energy use and carbon dioxide emissions that occur during cement production. The decrease in carbon footprint will help towards sustainable development of infrastructure worldwide. In summary, the use of the triple blended system involving the use of FA and micro silica in concrete will be advantageous from several perspectives – improved engineering properties, economy, conservation of resources, and the environment.

CHAPTER 3
MATERIALS AND METHODOLOGY

3: MATERIALS AND METHODOLOGY

3.1 MATERIALS

3.1.1 CEMENT:

OPC is a key constituent of concrete whose characteristic includes adhesion and cohesion enabling the various other components such as sand and gravel to form a homogenous paste. In this experiment, OPC of grade 53 is used.

Test on Cement:

Following are the tests to be led to judge the nature of cement.

1. FINENESS
2. SOUNDNESS
3. CONSISTENCY
4. INITIAL AND FINAL SETTING TIME

The various properties of cement which is used are as follows.

Table 1: CHEMICAL PROPERTIES OF OPC

CaO	60-69%
SiO_2	15-26%
Al_2O_3	4-9%
Fe_2O_3	0.6-7%
MgO	0.2-5%
SO_3	2-4%

Table 2
PHYSICAL PROPERTIES OF OPC 53 GRADE

S .No	PROPERTY	TEST RESULTS
1.	Standard Paste Consistency	30%
2.	Specific gravity (SG)	2.94
3.	Time of Initial Set Time of Final Set	45 min 180 min
4.	Soundness (expansion) lechatlier Method	3 min
5.	Cement Fineness	3080
6.	CS of cement mortar cubes a) 7 days b) 28 days	 34 N/mm^2 53 N/mm^2

3.1.2 FINE AGGREGATE:

Local sand is used as FA in the current study. The sand does not contain any clay, salts, or organic matter. The sand has been tested for several physical properties such as SG and bulk density, as per the requirements mentioned in IS 2386-1963(28). It can be observed from the grain size distribution of sand that it falls in zone 1 of IS 383-1970(29). Physical characteristics of sand are given in table 3. Details of sieve analysis are given in table 4.

Table- 3

PROPERTIES OF FA

S.No	Property	FA
1.	SG	2.68
2.	Density	1640 kg/m³
3.	Fineness Modulus	2.78

Table- 4

SIEVE ANALYSIS FOR FA SAMPLE- 2000gms

Sl. No.	Standard Sieve Size	Mass Retained (g)	Percentage Retained (%)	Cumulative Retained (%)	Percentage Passing (%)
1	80 mm	–	–	–	–
2	40 mm	–	–	–	–
3	20 mm	–	–	–	–
4	10 mm	–	–	–	–
5	4.75 mm	36.00	1.80	1.80	98.20
6	2.36 mm	52.00	2.60	4.40	95.60
7	1.18 mm	310.00	15.50	19.90	80.10
8	600 µm	790.00	39.50	59.40	40.60
9	300 µm	690.00	34.50	93.90	6.10
10	150 µm	112.00	5.60	99.50	0.50
	Total	**2000.00**			

Fineness modulus =2.78

3.1.3 COARSE AGGREGATE:

The CA is used in order to increase the volume of concrete, improve the hardness of concrete. CA chosen is angular crushed and the size of aggregate is 20 mm. As per IS 2386-1963 Part 3, fineness modulus test, SG test, and bulk density test were conducted.

Table- 5

PROPERTIES OF CA

S.No	Property	CA
1.	SG	2.64
2.	Density	1700kg/m³
3.	Fineness Modulus	7.14

Table- 6

SIEVE ANALYSIS FOR CA SAMPLE- 5000 gms

Sl. No.	Standard Sieve Size	Mass Retained (g)	Percentage Retained (%)	Cumulative Retained (%)	Percentage Passing (%)
1	80 mm	–	–	–	–
2	40 mm	–	–	–	–
3	20 mm	1040.00	20.80	20.80	79.20
4	10 mm	3560.00	71.20	92.00	8.00
5	4.75 mm	400.00	8.00	100.00	–
6	2.36 mm	–	–	100.00	–
7	1.18 mm	–	–	100.00	–
8	600 µm	–	–	100.00	–
9	300 µm	–	–	100.00	–
10	150 µm	–	–	100.00	–
	Total	**5000.00**			

Fineness modulus =7.14

3.1.4 FLY ASH

Fly ash is one of the most prominent waste products generated from the thermal power plants during burning of coal. FA is divided into two main types, namely Class C and Class F. The former type is known as high calcium FA which contains less than 2% carbon, while latter is referred to as low calcium FA containing 5-10% of carbon. Here we have taken Class C FA for our study.

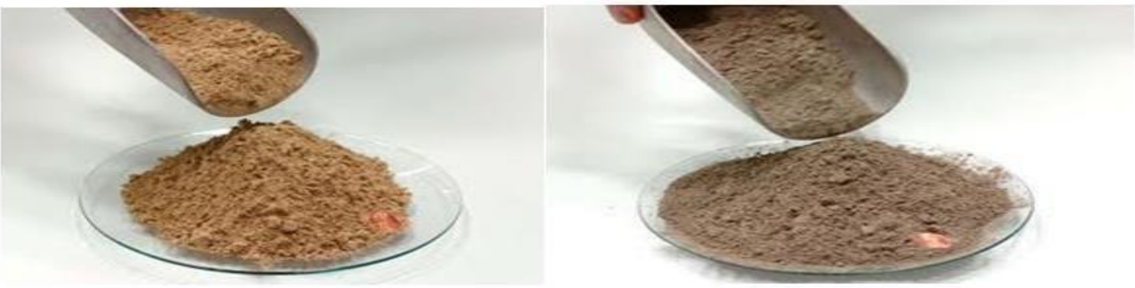


FIG 1: FLYASH POWDER

Table- 7

CHEMICAL PROPERTIES OF FLYASH

COMPOSITION	VALUE
SiO_2	51.63 %
Al_2O_3	22.42 %
CaO	4.72 %
Fe_2O_3	14.93 %
K_2O	Nil
Na_2O	Nil
SO_3	0.99 %
MgO	1.78 %

Table- 8

PHYSICAL PROPERTIES OF FLYASH

SG	2.20
Bulk density	1250 g/cm^3
Specific surface area	390 m^2/kg

3.1.5 SILICA FUME

Fumed silica, which is referred to as condensed SF and sometimes referred to as micro silica, is a dry powder that, once added to the cement, will lead to an increase in the hardness and strength of the concrete, in addition to lowering its permeability.

Fig.2: Condensed SF (CSF)

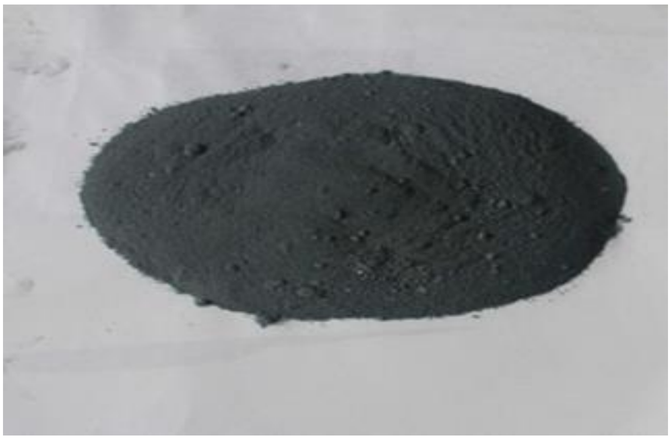
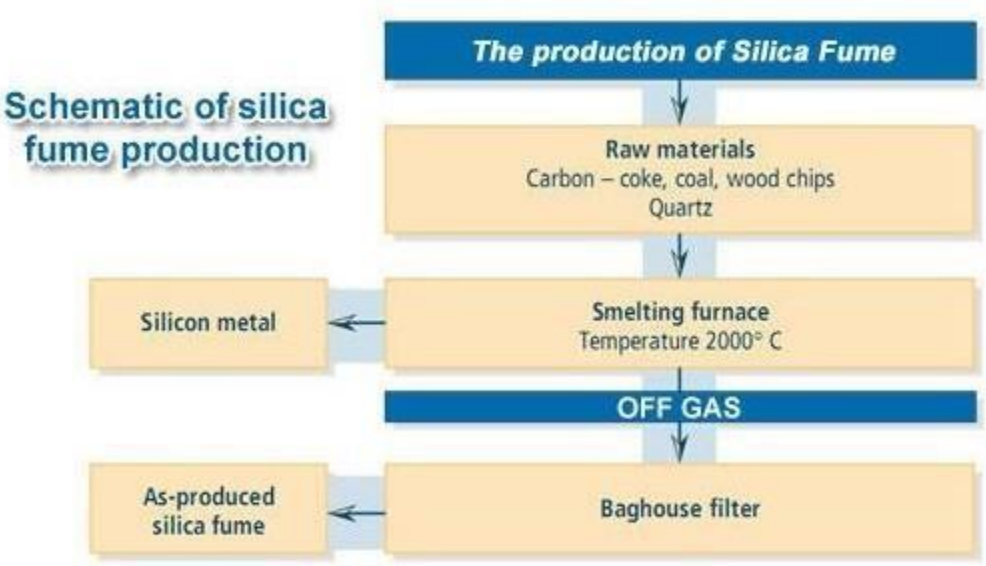


Fig .3: Schematic diagram of SF production



3.1.5.1 SF and its sources:

Silica is a highly pozzolanic material obtained from amorphous silica formed as a byproduct of silica or Ferro-silicon alloy formation in electric arc furnaces. Highly pure Quartz is subjected to heat treatment at a temperature of 2000°C in the presence of wood chips or coal/cokes as fuel and the electric arc is used for the separation of the materials. During the process, the quartz undergoes reduction reaction, giving off silicon oxide fumes. The silicon oxide vapor is then combined with oxygen and oxidized to form amorphous silicon dioxide in the form of microscopic spheres. Fumes are separated using a pre collector and cyclone to collect larger particles of wood or carbon before being passed into filter bags.

3.1.5.2 Characteristics:

SF, upon collection, is usually an ultra-fine powder that exhibits the following characteristics:

1. A minimum content of 85% $SiO2$
2. A mean particle size of 0.1 – 0.2 microns
3. The minimum specific surface area being 15,000m²/kg
4. Spherical particle shape

This powder has a greyish appearance although this may change depending on its source.

Table 9: CHEMICAL COMPOSITION OF SF

COMPOSITION	VALUE
SiO_2	85 %
Al_2O_3	1.09 %
CaO	0.45 %
Fe_2O_3	1.58 %
K_2O	0.6 %
Na_2O	0.9 %
SO_3	0.70 %
MgO	0.64 %

Table 10: PHYSICAL PROPERTIES OF SF

SG	2.25
Bulk density	570 kg/m^3
Specific surface area	150000 cm^2/g

3.1.6 STEEL FIBERS:

Fibers of steel are used to improve the tensile and bending strength of concrete. In this case, fibers of steel with diameter 0.5mm and length 60mm are used.

Fig.4: SFB

Table 11: PROPERTIES OF SFB

Ultimate tensile strength	650 N/mm^2
Young's modulus	205 N/mm^2
Aspect ratio	120

3.1.7 WATER:

Potable water has been used in the experiment for mixing and curing.

3.1.8 SUPER PLASTICIZER:

Superplasticizer used in this particular experiment is SP430. It is available through Fosroc. Superplasticizers belong to an entirely new group of substances whose addition in concrete leads to improvement in its workability. Superplasticizers are generally naphthalene or melamine sulphonates, often produced in the presence of formaldehyde. Superplasticized concrete refers to normal concrete which has been mixed with superplasticizing agents in order to improve the state of workability without affecting the water-cement ratio of concrete. The application of superplasticizers in concrete and ready-mixed concrete has made the deterioration of concrete on account of its density and appearance less likely. On the other hand, it makes concrete placements cheaper.

3.1.9 MIX DESIGN

The process of choosing appropriate materials along with their correct quantities is done by means of a method called concrete mix design. There exist several procedures for mix proportioning of concrete; but in the current experiment, the mixing was done according to the Bureau of Indian Standards codes as described in IS 10262 and IS 456. The procedure of concrete mix proportioning is mentioned in the IS 10262 code while IS 456 deals with the strength, durability, and workability aspects of concrete for different exposures. The main reason for concrete mixture design is to determine the best possible quantity of each ingredient including cement, water, fine aggregates (FA), coarse aggregates (CA), and any other additional ingredients needed to form the concrete mixture with the aim of producing concrete mixture having the desired compressive strength, workability, durability, and economy. Cohesion and stability characteristics should also be imparted to the concrete mixture to avoid segregation and bleeding.

For the current experiment, the mix proportions were formulated using the detailed procedure described in IS 10262:2019 based on the target mean strength, water-cement ratio, workability, exposure conditions, and material properties. The criteria related to durability, including minimum cement content, maximum water-cement ratio, and classification of exposures, were selected based on the guidelines provided in IS 456:2000. Before designing the mixes, the physical properties of cement, fine aggregates, coarse aggregates, and other supplementary cementitious materials were examined.

The water content and aggregate percentage have been decided according to the slump requirement and properties of the aggregates to ensure uniformity and workability of the concrete. Different trial mixes were designed and tested for obtaining the necessary properties of fresh and hardened concrete. Required changes have been made in the mix proportions until proper strength and workability were obtained. The chosen mix design procedure ensured the preparation of concrete with good consistency and sufficient durability.

Moreover, the Indian Standard method for mix design is quite popular in India because of its simplicity, reliability, and adaptability to modified mixes of concrete, incorporating supplementary cementing materials and fibers. Thus, this mix design procedure was selected for the current study.

3.2 METHODOLOGY

The M80 grade concrete mix design was performed based on the guidelines provided in Bureau of Indian Standards, IS 10262:2009 and IS 456:2000. Ordinary Portland Cement (OPC) grade 53 was used as the binding agent. The angular crushed coarse aggregates with the maximum nominal size of 20 mm and fine aggregate belonging to Zone-I gradation were selected for the mix design process. The concrete was to be prepared considering the moderate environment exposure with the targeted slump of 75 mm. Specific gravities for cement, coarse aggregate, fine aggregate and chemical admixture were taken as 2.98, 2.64, 2.78, and 1.10, respectively. The water absorption of the coarse and fine aggregates was considered to be 0.6% and 0.8%, respectively.
The target mean compressive strength of concrete was determined using the expression:

$$f_m = f_{ck} + 1.65S$$

On substituting the values, the target mean strength value was calculated as 88.25 N/mm² for the M80 concrete grade. Taking into consideration the recommendation of IS 456:2000 for moderate exposure conditions and the target strength value, the water-cement ratio of 0.31 was selected. From Table 2 of IS 10262:2009, the water content value for a nominal size of 20 mm aggregates with a slump value of 75 mm was considered as 195 kg/m³. The amount of cement was calculated based on the chosen water-cement ratio and the water content. Thus, the required cement value was computed as 629.03 kg/m³, which fulfilled the minimum cement content value required considering durability concerns. Assuming the total density of fresh concrete to be 2400 kg/m³, the aggregate content was computed by deducting the volume of cement and water from the total density of the concrete. Hence, the total aggregate content was evaluated to be about 1575.97 kg/m³.
Additionally, taking into account the properties of the aggregates in terms of their grading as well as the required workability, the amount of fine aggregate is determined as 38% of the total amount of aggregates. Thus, the volume of fine aggregate is determined as 598.86 kg/m³, and the remaining volume is allocated to coarse aggregate in the amount of 977.28 kg/m³. In the end, the mix proportions for M80 grade concrete are found as follows: cement – 629.03 kg/m³, fine aggregate – 598.86 kg/m³, coarse aggregate – 977.28 kg/m³, and water – 195 kg/m³. In other words, the resulting proportion of concrete is 1 : 0.95 : 1.55, with the water-cement ratio equal to 0.31.

3.3. CASTING OF SPECIMENS

In the present thesis work, a detailed experimental study was performed in order to analyze the properties of concrete incorporating various amounts of FA, SF, and SFB. The main objective of the present work was to assess the effects of such additives and fibers on the performance of concrete. In order to accomplish this task, three main categories of concrete samples were considered. The experimental study mainly involved the measurement of CS, FS, and STS of concrete specimens. Concrete cubes were used to measure compressive strength, while beams were employed to determine the flexural strength of concrete. Cylindrical specimens were considered for STS determination of concrete. FA and SF in various replacement percentages as well as SFB blends in different dosages were taken into account during the experiment.

The use of FA and SF was done as partial substitution of cement in order to improve the properties of concrete. FA is pozzolonic waste produced from the thermal power plants, which not only makes the concrete more workable but also helps develop strength along with lowering down the heat of hydration of the concrete mixture. On the other hand, SF is fine-grained material containing high amounts of silica, which plays an important role in the densification of concrete. By using these two materials, secondary hydration occurs, resulting in the formation of more calcium silicate hydrate gel in the concrete, thus making the concrete strong and durable. For the current study, the following replacement ratios for FA and SF were adopted: FA at 0%, 15%, and 30%; SF at 0%, 6%, 12%, and 18% by weight of cement.

Apart from mineral admixtures, SFB was added in the concrete mix to improve the properties of concrete such as resistance against cracks, ductility, toughness, and post-crack behavior of concrete. Normal concrete is very brittle and has low tensile strength; hence the addition of fibers will help in restraining cracks and also increase the ability of the concrete to absorb energy. SFB was added to the concrete mix in amounts of 0%, 0.5%, and 1% by volume of concrete. The SFB were properly blended in the concrete matrix so that proper bonding took place during loading.

In the experimental work, different mixes of concrete were developed by mixing the chosen percent ratios of FA, SF, and SFB. To begin with, the materials used for concrete production that comprised cement, fine aggregate, coarse aggregate, FA, SF, SFB, water, and chemical admixtures were accurately weighed in accordance with the designed mix ratios. Dry materials were uniformly mixed, and then water and super plasticizer were added. Workability of the concrete produced was tested using the slump test method. Concrete was filled in molds of desired sizes for cubes, cylinders, and beams. Vibration method was applied for compacting the concrete to remove air bubbles and make concrete specimens homogeneous.

The aim of the present experiment was to find out the most appropriate proportioning for FA, SF, and SFB, which will provide us with high-performance concrete with better mechanical and durability properties. In other words, the main aim of the research was to improve concrete performance through the inclusion of supplementary cementitious material and fibers in optimum amounts. Another key aim of the experiment was to promote industrial wastes usage in concrete production, as it can not only help to solve environmental pollution issues but will also decrease reliance on OPC.

The addition of FA and SF helped improve the microstructure, density, and durability of concrete, and the addition of SFB improved the ability to resist cracking, enhance ductility, and provide good post-cracking characteristics. The use of these materials together facilitated the production of concrete which possessed high strength, toughness, and environmental stability.
In addition to this, the experiments conducted focused on promoting sustainable construction methods and efficient utilization of waste products from industries in making concrete. Reduced cement usage also ensured reduced carbon emission due to cement production.

The results of this experiment have made significant contributions toward developing high-performance fiber-reinforced sustainable concrete that is highly efficient, durable, and sustainable. In addition, the results have clearly shown that the utilization of FA, SF, and SFB together can be considered a highly effective alternative means	BEAMS	CYLINDERS	CEMENT (%)	FA (%)	SF (%)	SFB (%)

of manufacturing advanced concrete material. CUBES						
M1	B1	C1	100	0	0	0
M2	B2	C2	85	15	0	0
M3	B3	C3	70	30	0	0
M4	B4	C4	94	0	6	0
M5	B5	C5	79	15	6	0
M6	B6	C6	64	30	6	0
M7	B7	C7	88	0	12	0
M8	B8	C8	73	15	12	0
M9	B9	C9	58	30	12	0
M10	B10	C10	82	0	18	0
M11	B11	C11	67	15	18	0
M12	B12	C12	52	30	18	0
M13	B13	C13	100	0	0	0.5
M14	B14	C14	85	15	0	0.5
M15	B15	C15	70	30	0	0.5
M16	B16	C16	94	0	6	0.5
M17	B17	C17	79	15	6	0.5
M18	B18	C18	64	30	6	0.5
M19	B19	C19	88	0	12	0.5
M20	B20	C20	73	15	12	0.5
M21	B21	C21	58	30	12	0.5
M22	B22	C22	88	0	18	0.5
M23	B23	C23	67	15	18	0.5
M24	B24	C24	52	30	18	0.5
M25	B25	C25	100	0	0	1
M26	B26	C26	85	15	0	1
M27	B27	C27	70	30	0	1
M28	B28	C28	94	0	6	1
M29	B29	C29	79	15	6	1
M30	B30	C30	64	30	6	1
M31	B31	C31	88	0	12	1
M32	B32	C32	73	15	12	1

M33	B33	C33	58	30	12	1
M34	B34	C34	82	0	18	1
M35	B35	C35	67	15	18	1
M36	B36	C36	52	30	18	1

Where, **P** STANDS FOR CUBES
Q STANDS FOR BEAMS
R STANDS FOR CYLINDERS

<u>NUMBER OF SPECIMENS CASTED</u>

Number of substitutions = 36
Number of samples per substitution = 9 (3 cubes, 3 beams & 3 cylinders) Total number of specimens = 36x9
= 324

3.4. PROCEDURE FOR CASTING

3.4.1 Sampling of materials

Representative samples of the concrete material to be used were collected through proper sampling techniques. The test sample of the cement consisted of a selected amount from several bags available at the construction site. The test samples of aggregates were collected by quartering and sieving.

3.4.2 Preparation of Materials

All materials were allowed to attain room temperature, i.e., 27 + 3oC, prior to conducting the experiments. The samples of cement were mixed thoroughly, while still in its dry form, by hand, thus ensuring proper blending of the material. Foreign matter was avoided during mixing of the cement. The samples of cement were kept in a dry atmosphere.

Samples of aggregates for each mixture of concrete were of the required grading and were air dried. Normally, the aggregates were divided into coarse and FA in such a manner as to ensure that the required grading is obtained for each concrete sample. Normally IS Sieve 480 was used for separating the fine and CA.

3.4.3 Proportioning

The proportions of the materials, taking into account the presence of water in the mixes, used to find out if the materials were suitable for use in construction, were similar in all aspects to those to be used in construction.

3.4.4 Weighing

The amounts of cement, aggregate of each size and water for each mix were calculated using a scale to an accuracy of 0.1%.

3.4.5 Mixing of concrete

The mix designations of some mixes were done manually while others were done using a batch laboratory mixer. The strength of this method is that there is a certain accuracy which will be attained through the mixing since the losses of water and other ingredients would be minimalized. Nevertheless, in order to determine the differences between the mixes, hand mixing method has also been used for a couple of mixes. The volume of each concrete mix was adequate to ensure 10% surplus was left after making the test samples.

3.4.5.1 Machine mixing

In the case where the mixing drum was filled by the power loader, it is noteworthy that all the mixture was poured into the drum prior to solid materials, with half the amount of CA being placed on top of the skip. In instances where the mixing drum was manually loaded, the drum was charged with dry materials in a similar way and the water added before the drum was turned. The mixing time was about two minutes before getting uniformly colored concrete. In the use of pan mixers, concrete was piled up before sampling..

3.4.5.2 Hand mixing

3.4.5.3

- The concrete was prepared on a water-proof surface using a shovel or any other similar implement in accordance with the following methodology
- The cement, FA, SF, and the FA were mixed together without any water being added, and until a uniformly colored mix was achieved.
- Then, the CA was added to the above mixture and well-mixed until the aggregate was evenly distributed in the mixture. This step was then followed by adding fibers to the mixture and mixing them uniformly.
- Lastly, the water and the super-plasticizer solution were added, and then mixed well until homogenous mix was attained.

3.4.6 Workability

The workability of each batch of concrete mix was tested immediately after its preparation by compaction factor test as mentioned in IS : 1199 – 1959. Neither water nor any other substance was lost during the procedure. The concrete mix for testing workability was again mixed with the remaining part of the batch prior to the preparation of concrete samples. The remixing time was kept minimum but long enough to achieve a uniform mixture. The fresh concrete mix is subjected to workability test by
compaction factor apparatus.

3.4.6.1 Compaction Factor test

Compaction Factor test is an indirect method of workability measurement based upon the extent of compaction obtained due to work applied to it for a standard height fall.

For performing Compaction factor test, the specimen concrete will be filled into the top hopper to its full capacity. The trap door is opened, enabling the concrete to fall into the bottom hopper. Further, trap door of the bottom hopper is opened to enable the concrete to fall into the cylinder. In case of dry concrete, there might be chances that concrete may not fall with the opening of trap door.

In that case, a minor poking of the rod would be sufficient enough to put the concrete into action. After that, the extra concrete lying on top of the cylinder would be removed using plain blades provided along with the machine. The surface of the cylinder would be cleaned and the weight of the partially compacted concrete would be taken out up to an accuracy of 10 grams.

Afterwards, the cylinder would be again cleaned and filled with the concrete specimen in layers of each around 5 cms thickness. The layering would be followed with a heavy ramming process or preferably vibration so as to get the maximum possible compaction. The top surface of the compacted concrete would then be neatly cut and the weight of the completely compacted concrete would be measured up to an accuracy of 10 grams.

Compaction Factor:

Weight of partly compacted concrete / Weight of completely compacted concrete

Compaction factor is determined for different percentage of FA concretes and also different ordinary concretes, at a constant water cement ratio.

3.4.7 Size of the test specimens

3.4.7.1 For compression test

Since the maximum size of aggregate was more than 2 cm, the size of the test specimen prepared was taken as 100 x 100 x 100 mm cubic as suggested by the IS Code..

3.4.7.2 For flexure test

Since the maximum nominal size of aggregate was less than 19mm, the test specimen size prepared was 100 x 100 x 500 mm.

3.4.8 Casting of specimen

The metal molds made up of the C.I are being used for casting the samples. All the metal molds have been cleaned from dust particles and then been coated with mineral oil. Then the concrete mixture is filled in the mold.

3.4.9 Compaction by vibration

Each individual layer of concrete is vibrated by the use of vibrating machine until the required condition is reached, which ensures that the void spaces within the mold are properly filled up.

3.4.10 Curing

The test specimens after the process of casting and placing the specimens in a dry environment for 24 hours were placed in an environment free from vibrations, in moisture-filled air having at least 90% relative humidity and at a temperature of 27o + 2oC for 24 hours + ½ hour, starting from the moment water was added to the dry mixture. After that period, specimens were labeled and removed from molds and immersed into fresh and clean water. This procedure was followed until just before carrying out the tests. Water used to immerse the specimens was changed after seven days and the water maintained at room temperature.

3.5 TESTING OF SPECIMENS

3.5.1 CS test

Testing Machine

The compressive testing machine which has been employed in our experiment is reliable in its construction and adequate in its capacity for the tests. Permissible error for the machine does not exceed + 2 percent of the maximum load. The machine has two steel bearing platens whose faces are hardened. One of the platens (which will act against the upper surface of the specimen) has a ball seating which is cut out of some portion of a sphere, where the centre of this sphere coincides with the central point of the platen face. The second compression platen is a rigid flat bearing block. The bearing faces of these platens have dimensions larger than the nominal dimension of the specimen acted upon by the load. These faces of the platens depart from the plane of their position by less than 0.01mm in all points and they maintain the permissible variation of 0.02mm between each other. The moveable part of the compression platen with ball seating remains on its spherical seat, however, in such a way that the bearing face can be rotated freely in any direction.

Fig.5: Compressive testing machine that was used to test the strength of the cubes **Age at test**

The test is carried out at the standard ages for the age of the specimen, the most common being 7 and 28 days. Ages will be counted from the time water is added to the dry constituents. In our project, the curing age has been taken as 28 days..

Test Procedure

The test was performed on samples that were immediately immersed in water after removal from water. The surface water was wiped off, and the fins were removed. For the specimens treated with dry heat, immersion in water was made for 24 hours prior to the test..

Placing the specimen in the testing machine

The surfaces of the testing machine were cleaned while removing loose sand or other materials from the specimen to be tested in the machine. Since the test specimens were in the shape of cubes, they were loaded in the testing machine in such a way that the load was applied to the opposite sides of the cubes in their original condition, that is, not to the top and bottom of cubes. The axes of the specimen were aligned with the center of the load of the spherically seated platen. No packing was provided between the faces of the test specimen and the steel platen of the test machine as per the requirements of the IS Code. With the loading of the specimen through the spherically seated platen, the movable portion of the machine was turned slowly by hand for uniform seating of the specimen in the platen. The load was applied without shock and increased gradually at the rate of 140kg/sq.cm/minute till the resistance offered by the specimen to the increase in load collapsed. The maximum load applied to the specimen was recorded while noting the nature of the specimen and mode of failure.

Calculation

The CS value of the specimen was calculated as the ratio of the maximum load applied to the specimen to the cross-section area of the specimen derived from its mean dimensions. The average of the measured values has been considered representative of the batch, provided that there is no individual variation of more than + 15% compared to the average value.

The cube specimens cured according to the specified procedure were subjected to tests according to standard procedures after removing them from the curing tank and drying them in the shade. The test of cube specimens was performed using a digital compression testing machine with a load capacity of 2000 KN. These results have been included in table number 4.1. In order to conduct a CS test of the cube specimen, the cube specimen was fixed such that the cast face of the cube specimen is perpendicular to its position during casting. As per standard specifications, the load was applied until the cube specimen failed.

Casting procedure is based on weighing of materials, mixing, casting, compacting, and curing.

All these processes are carried out strictly in accordance with the provisions of IS : 516 – 1959 that include specification of all these processes of casting as well as testing.

IS code also contains a clause describing the method of fabrication and curing of compression test specimen of concrete in the laboratory, in which the amount of materials used can be controlled accurately and in which the maximum nominal size of aggregates shall not exceed 38 mm. This method is especially suitable for carrying out preliminary compression tests for determining suitability of materials or appropriate mix proportions.

3.5.2 Flexure test Apparatus

The testing machine is a dependable one of adequate capacity for the tests and able to apply the load at the prescribed rate. The permissible errors will be no more than + 0.5% of the designated load if a high level of accuracy is needed and no more than +1.5% of the applied load in case of commercial usage of the testing machine. The base of the testing machine is equipped with two steel rollers of 38 mm in diameter on which the specimen is placed and such rollers are arranged in such a way that the distance between their centres is 60 cm for specimens of 15 cm in length and 40 cm for specimens of 10 cm in length. The loading load is transferred through two other steel rollers mounted at the third point of the span; that is, there is a spacing of 20 or 13.3 cm between their centres.

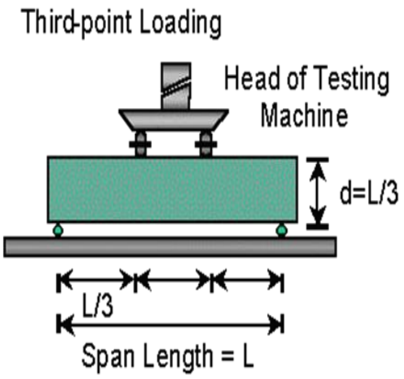


Fig.8: Third point loading arrangement

<u>Placing the specimen in the testing machine</u>

The bearing surfaces of the supporting and loading rollers are cleaned from sand or other material lying loose on them. The specimen will be put in the machine in such a way that the load will act upon the top surface of the specimen as cast in the mould on two parallel lines, 20 cm or 13.3 cm apart respectively. It is essential to see that the axis of the specimen should be aligned with the axis of the loading mechanism. Packing will not be done between the bearing surfaces of the specimen and the rollers. Loading will be without any shock, but will be continuous and will be increased at a rate such that the extreme fiber stress increases at the rate of 7 kg/sq. cm per minute, i.e., at a rate of 400 kg per minute for the 15 cm specimens and at a rate of 180 kg per minute for the 10 cm specimens. The loading will go on until the specimen fails. Maximum loading on the specimen shall be recorded.

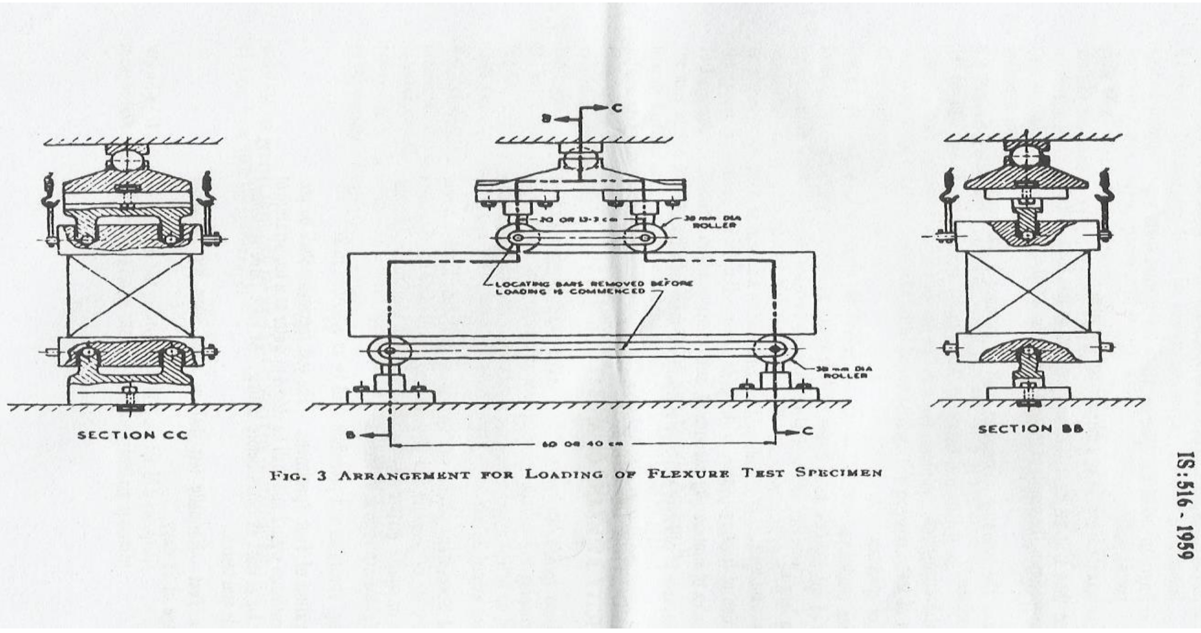


Fig.6: Arrangement for loading of flexure test specimens as per IS : 516 - 1959

<u>Calculations</u>

The FS of the test piece is defined as the Modulus of Rupture fb, where if ‘a’ is the distance of the line of fracture from the nearest support, measured along the centre line of the tension surface of the test piece, in centimeters, then the formula for calculating the same is given by:

***Case 1*:** when ‘a’ is greater than 20 cm for 15 cm specimen or greater than 13.3 cm for a 10 cm specimen:

$$f_b = \underline{p \times l}$$

$6 \times d^2$

***Case 2*:** When 'a' is less than 20 cm but greater than 17 cm for 15 cm specimen or less than 13.3 cm but greater than 11 cm for a 10 cm specimen:

$$f_b = \frac{3p \times a}{b \times d^2}$$

Where,

b = measured width in cm of the specimen

d = measured depth in cm of the specimen at the point of failure

l = length in cm, of the span on which the specimen was supported p= maximum load in kg applied to the specimen.

Case 3: *If 'a ' is less than 17 cm for a 15 cm specimen, or less than 11 cm for a 10 cm specimen*:

The results of the test shall be discarded.

Fig.7: Sampling and preparation of materials

Fig.8: Mixing of materials by machine mixing

Fig.9: Dried concrete mixture before addition of water and super-plasticiser

Fig.10: Fixing of moulds

Fig.11: De-moulded samples

Fig.12: Placing dried samples in the curing tank

CHAPTER 4 RESULTS AND DISCUSSION

4: RESULTS AND DISCUSSION

Tests on CS, FS, and STS were carried out on the different sets of concrete cubes, concrete beam, and concrete cylinders to study the mechanical properties of concrete when FA is used to replace the cement content at percentages of 0%, 15%, and 30%, and SF is added at the percentage of 0%, 6%, 12%, and 18%.

4.1 CS RESULTS

Table 13: CS values for various replacements of FA, SF with 0% SFB by volume of concrete for 28 days curing

S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	0	77.93	77.86	76.95	77.58
2	0	6	0	78.98	79.23	77.95	78.72
3	0	12	0	78.95	79.89	79.96	79.60
4	0	18	0	79.96	79.68	78.96	79.53
5	15	0	0	78.63	78.95	77.94	78.51
6	15	6	0	79.96	80.12	78.62	79.57
7	15	12	0	79.84	79.76	80.12	79.90
8	15	18	0	79.86	80.21	78.94	79.67
9	30	0	0	77.66	77.92	76.96	77.51
10	30	6	0	79.96	80.23	78.56	79.58
11	30	12	0	80.36	79.85	78.63	79.61
12	30	18	0	79.96	79.86	78.92	79.58

Table 14: CS values for various replacements of FA, SF with 0.5% SFB by volume of concrete for 28 days curing

S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	0.5	77.42	77.52	77.63	77.52
2	0	6	0.5	77.81	78.82	78.93	78.52
3	0	12	0.5	78.63	79.92	79.56	79.37
4	0	18	0.5	79.21	79.45	79.56	79.41
5	15	0	0.5	78.63	78.54	77.92	78.36
6	15	6	0.5	79.54	79.46	78.91	79.30
7	15	12	0.5	80.79	80.96	80.66	80.80
8	15	18	0.5	80.84	80.92	79.96	80.57
9	30	0	0.5	77.97	78.92	78.85	78.58
10	30	6	0.5	79.86	79.96	77.95	79.26
11	30	12	0.5	79.98	80.56	80.99	80.51
12	30	18	0.5	78.98	79.95	79.86	79.60

Table 15: CS values for various replacements of FA, SF with 1% SFB by volume of concrete for 28 days curing

S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	1	80.56	80.36	79.98	80.30
2	0	6	1	81.46	81.57	80.92	81.32
3	0	12	1	81.78	81.86	80.98	81.54
4	0	18	1	80.97	81.36	81.84	81.39
5	15	0	1	81.67	81.74	80.99	81.47
6	15	6	1	82.23	81.63	80.24	81.37
7	15	12	1	83.21	82.36	81.54	82.37
8	15	18	1	81.72	81.59	80.95	81.42
9	30	0	1	80.46	80.75	79.98	80.40
10	30	6	1	82.36	81.42	80.34	81.37
11	30	12	1	81.46	82.12	80.27	81.28

12	30	18	1	81.86	81.72	80.94	81.51

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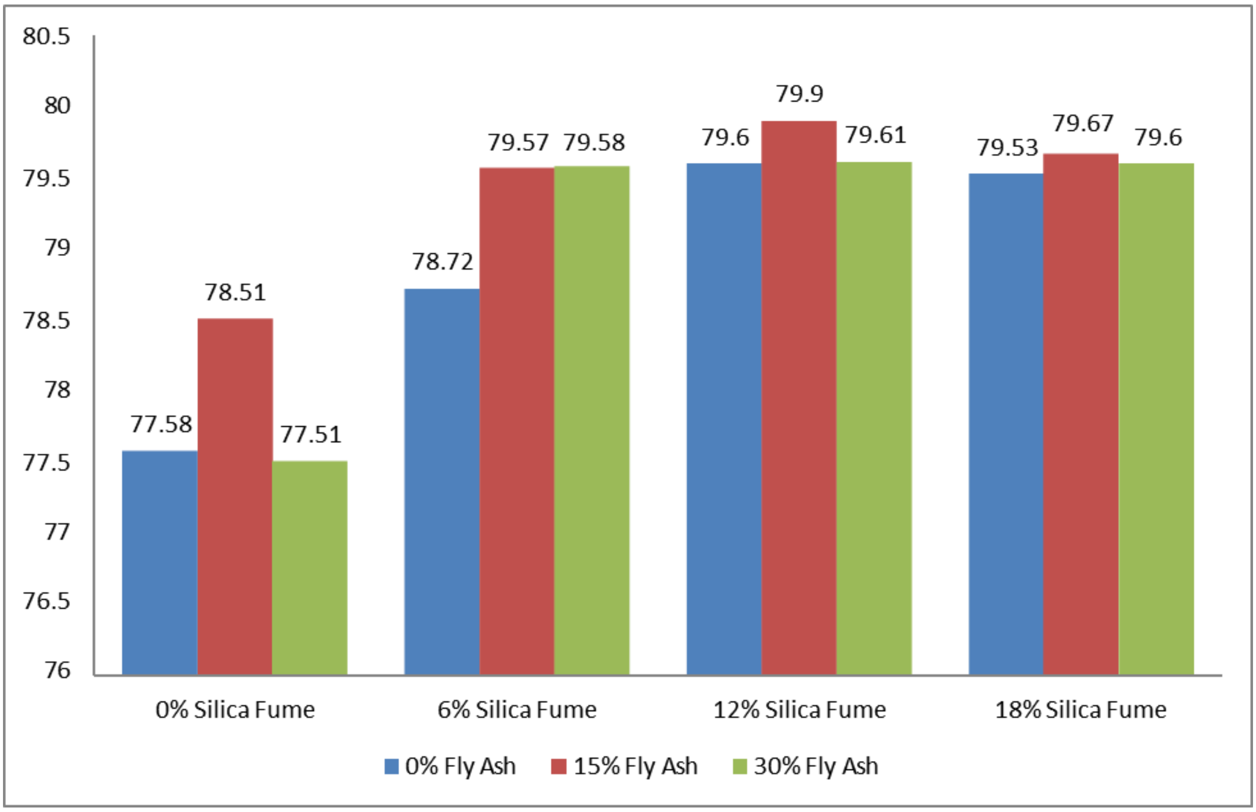
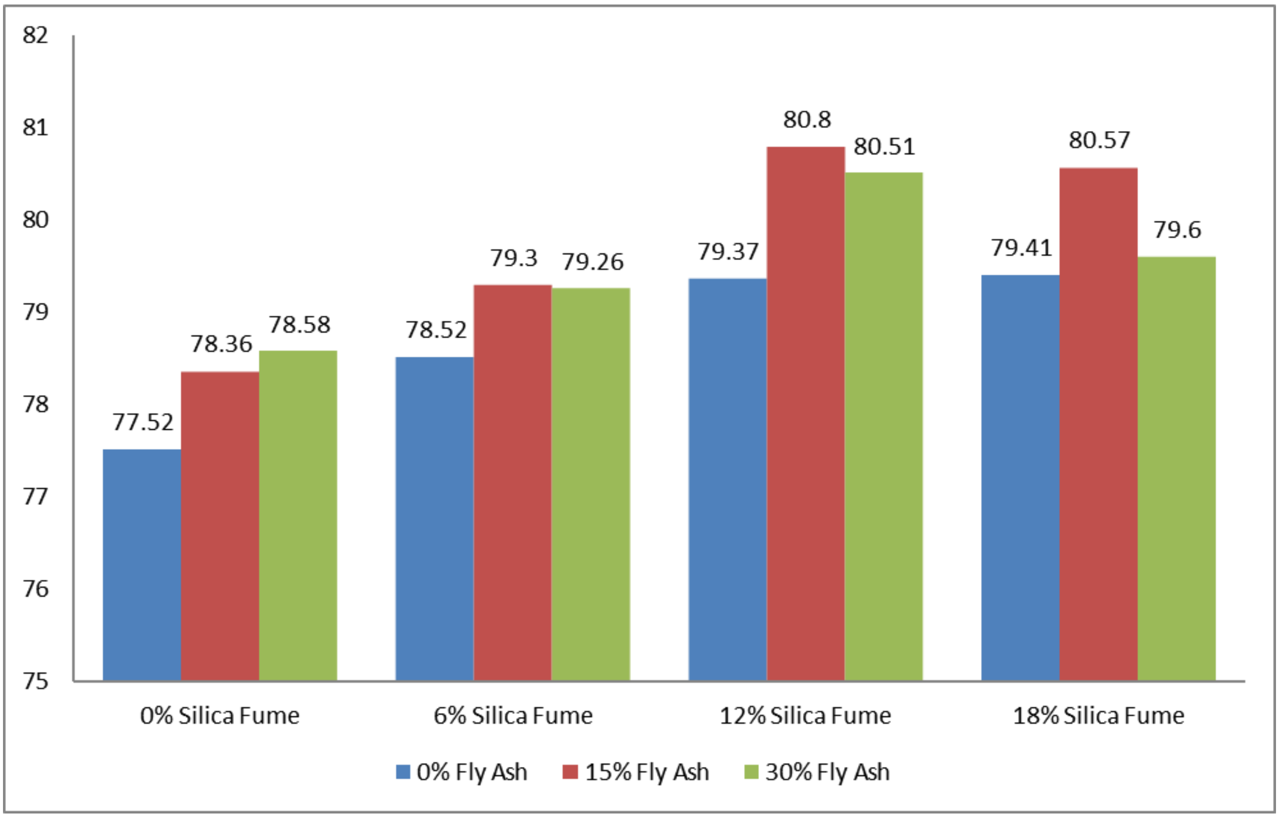
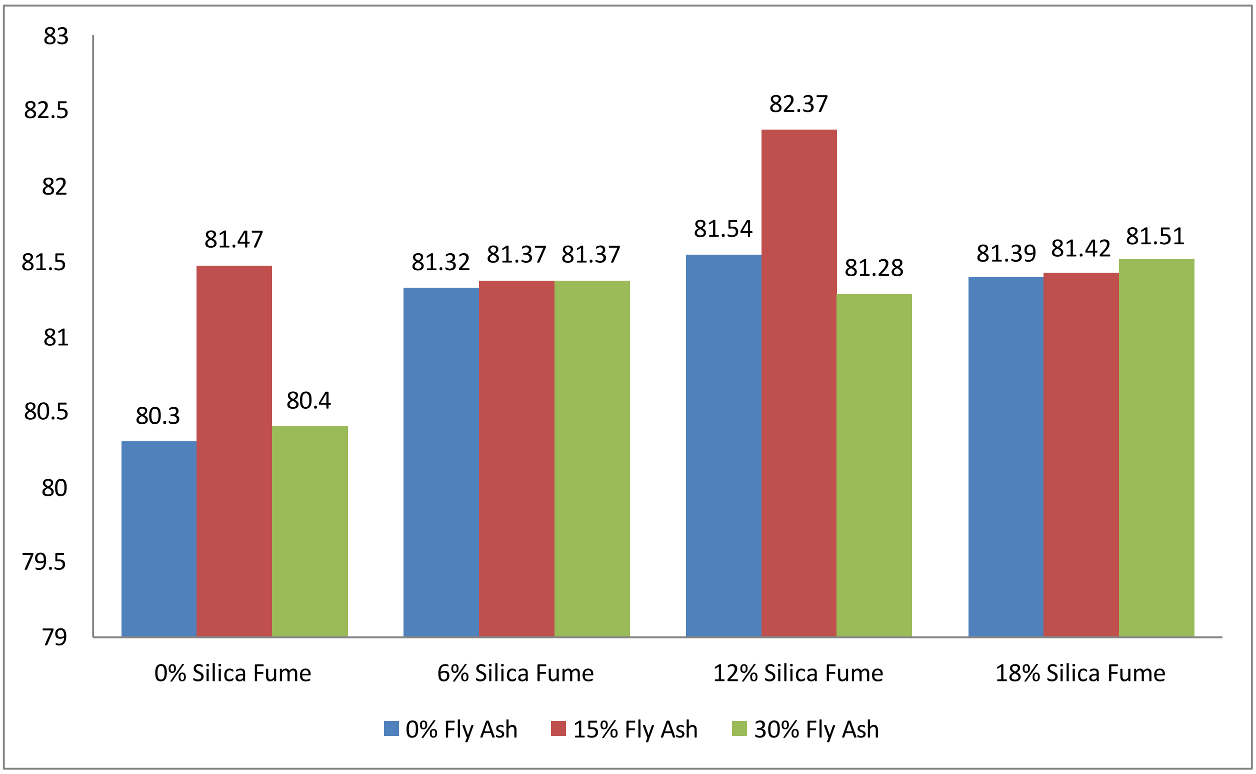
Graph 1: CS of cubes for various replacements of FA & SF with 0% SFB



Graph 2: CS of cubes for various replacements of FA & SF with 0.5% SFB



Graph 3: CS of cubes for various replacements of FA & SF with 1% SFB



Discussions:

Tests were carried out to obtain the results for CSs for various replacement proportions. First set of tests was carried out on ordinary concrete cubes without the use of FA, SF, and SFB. Second set of tests was carried out on concrete cubes where FA percentage was 15% and 30%, while that of SF was 6%, 12% and 18% with no addition of SFB and with maximum CS 79.90 N/mm^2 at 15% FA and 12% SF. Third set of tests was performed for the concrete cubes with 15%, 30% FA and 6%, 12% and 18% SF with an addition of 0.5% SFB and highest CS of 80.80 N/mm^2 at 15% FA and 12% SF. Fourth set of tests was performed on cubes with 15%, 30% FA, 6%, 12% and 18% SF with 1% SFB and maximum CS 82.37 N/mm^2 for 15% FA and 12% SF. Hence, the comparative highest CS obtained from all the above sets of tests was for 15% FA and 12% SF with 1% SFB.

FS RESULTS:

Table 16: FS values for various replacements of FA, SF with 0% SFB by volume of concrete for 28 days curing

S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	0	7.56	7.86	6.94	7.45
2	0	6	0	7.84	7.46	6.86	7.39
3	0	12	0	8.74	8.57	7.92	8.41
4	0	18	0	7.81	7.94	6.93	7.56
5	15	0	0	7.56	7.62	7.46	7.55
6	15	6	0	8.69	8.56	8.42	8.55
7	15	12	0	8.61	8.67	8.65	8.64

8	15	18	0	8.84	8.59	7.98	8.47
9	30	0	0	7.96	7.85	6.98	7.60
10	30	6	0	8.56	8.95	7.86	8.46
11	30	12	0	8.36	8.47	8.58	8.47
12	30	18	0	8.94	8.56	8.26	8.59

Table 17: FS values for various replacements of FA, SF with 0.5% SFB by volume of concrete for 28 days curing

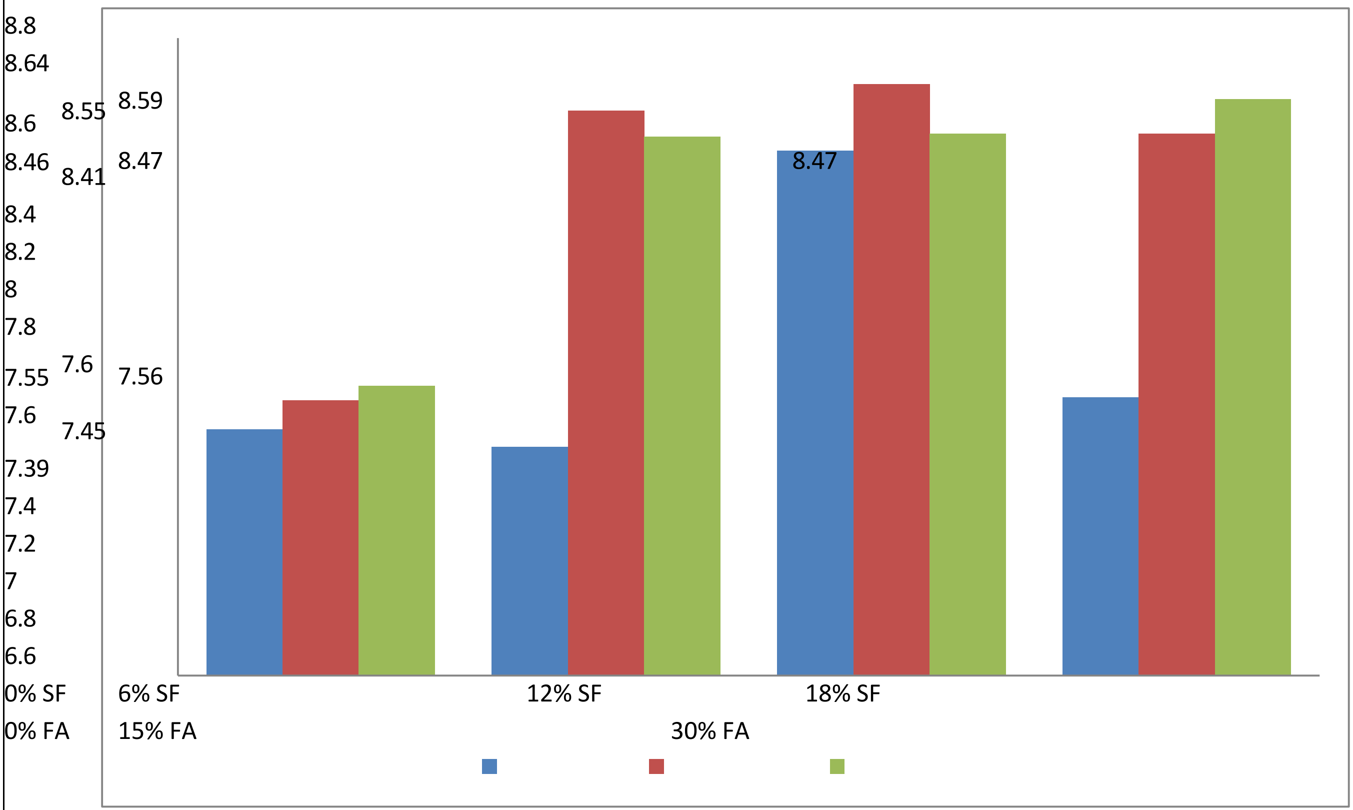
S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	0.5	8.36	8.24	8.19	8.26
2	0	6	0.5	8.82	8.85	8.75	8.81
3	0	12	0.5	7.98	8.85	8.83	8.55
4	0	18	0.5	8.95	8.86	7.95	8.59
5	15	0	0.5	8.76	8.79	8.62	8.72
6	15	6	0.5	8.67	8.76	8.95	8.79
7	15	12	0.5	8.76	8.92	8.83	8.83
8	15	18	0.5	8.81	8.64	8.75	8.73
9	30	0	0.5	8.57	8.46	8.37	8.47
10	30	6	0.5	7.96	8.18	8.21	8.12
11	30	12	0.5	8.82	8.71	8.68	8.74
12	30	18	0.5	8.36	8.49	8.58	8.48

Table 18: FS values for various replacements of FA, SF with 1% SFB by volume of concrete for 28 days curing

S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	1	7.61	7.52	7.48	7.54
2	0	6	1	7.95	7.81	7.74	7.83
3	0	12	1	8.02	8.24	8.12	8.13
4	0	18	1	7.95	8.12	8.04	8.04
5	15	0	1	7.84	7.62	7.75	7.74

6	15	6	1	8.10	7.94	8.05	8.03
7	15	12	1	8.96	9.04	8.92	8.97
8	15	18	1	8.36	8.27	8.19	8.27
9	30	0	1	7.64	7.57	7.72	7.64
10	30	6	1	8.05	7.94	7.86	7.95
11	30	12	1	8.12	8.24	8.31	8.22
12	30	18	1	8.26	8.14	8.07	8.16

Graph 4: FS of beams for various replacements of FA & SF with 0% SFB



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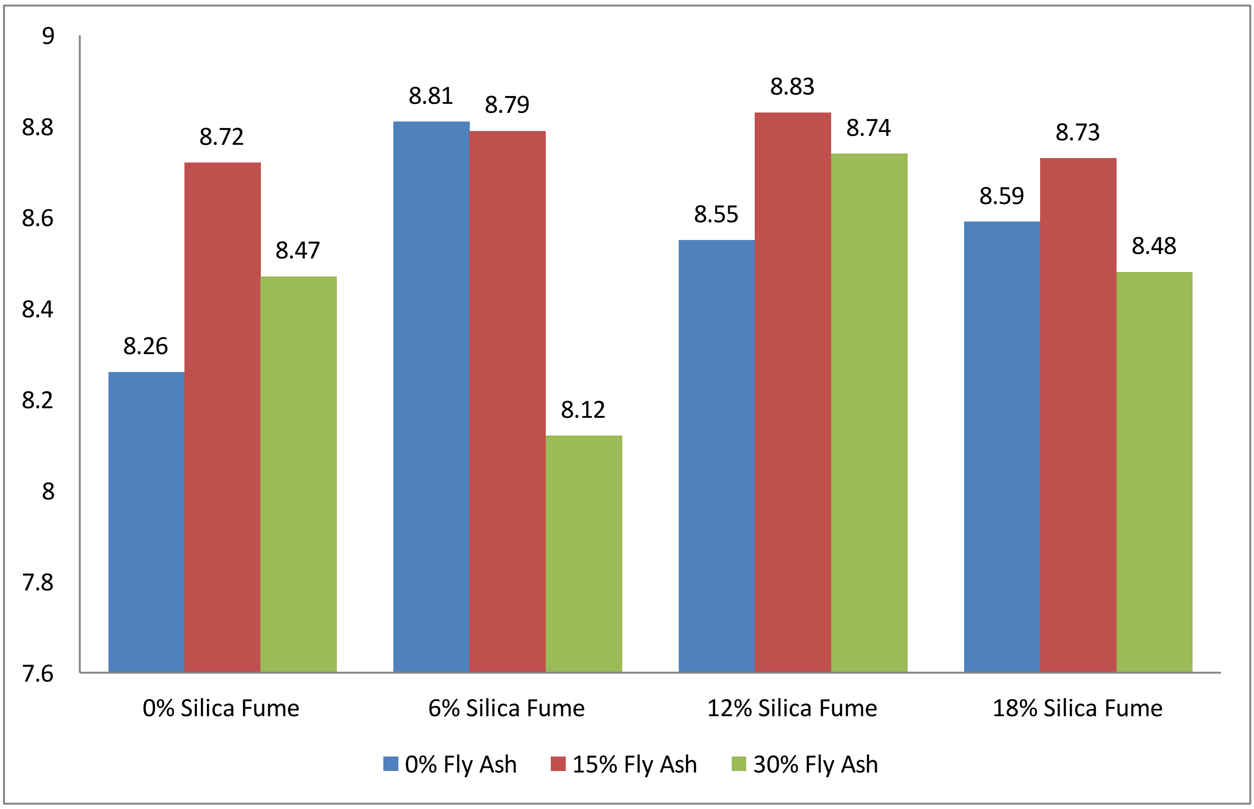
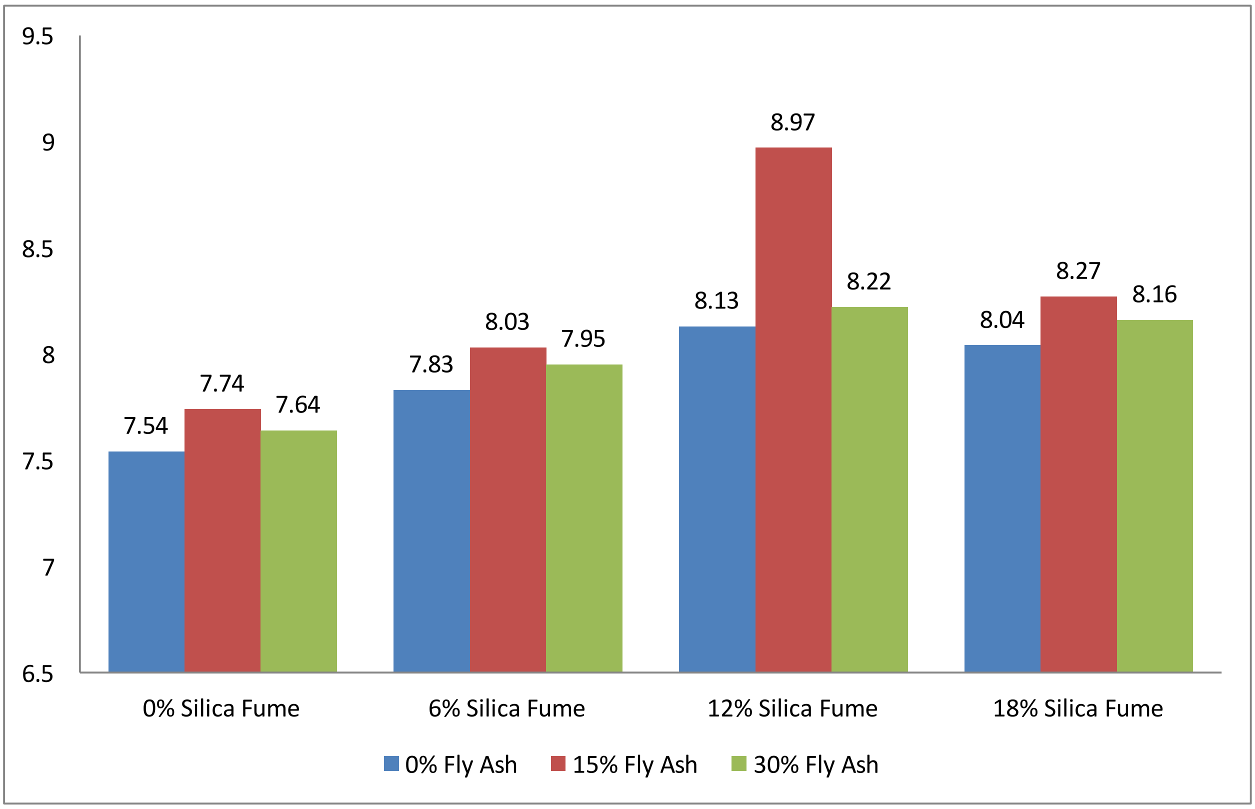
Graph 5: FS of beams for various replacements of FA & SF with 0.5% SFB



Graph 6: FS of beams for various replacements of FA & SF with 1% SFB



Discussions:

The results of testing were taken into account. First, some tests were performed for ordinary concrete beams without the presence of any FA, SF, and SFB. Further, there was a series of tests performed for concrete beams containing various combinations of percentages of 15%, 30% FA, and percentages of 6%, 12%, and 18% SF replaced by cement with no addition of SFB and a maximum FS of 8.64 N/mm^2 was achieved with 15% FA and 12% SF combination. Then, thirdly, testing was done for concrete beams mixed with percentages of 15%, 30% FA and percentages of 6%, 12%, and 18% SF with an addition of 0.5% SFB where maximum FS of 8.83 N/mm^2 was achieved with the same 15% FA and 12% SF combination. Another series of tests were also performed for concrete beams made up of percentages of 15%, 30% FA and percentages of 6%, 12%, and 18% SF with an addition of 1% SFB where highest FS of 8.97 N/mm^2 was achieved with same combination of percentages of FA and SF.

STS RESULTS

Table 19: STS values for various replacements of FA, SF with 0% SFB by volume of concrete for 28 days curing

S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	0	6.38	6.15	6.37	6.30
2	0	6	0	6.37	6.28	6.42	6.36
3	0	12	0	6.36	6.48	6.52	6.45
4	0	18	0	6.54	6.63	6.74	6.64
5	15	0	0	6.44	6.56	6.68	6.56
6	15	6	0	7.64	7.58	7.75	7.66
7	15	12	0	7.73	7.65	7.84	7.74
8	15	18	0	7.43	7.38	7.58	7.46
9	30	0	0	6.57	6.47	6.62	6.55
10	30	6	0	7.38	7.42	7.56	7.45
11	30	12	0	7.54	7.63	7.74	7.64
12	30	18	0	7.38	7.45	7.53	7.45

Table 20: STS values for various replacements of FA, SF with 0.5% SFB by volume of concrete for 28 days curing

S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	0.5	7.24	7.32	7.17	7.24
2	0	6	0.5	7.48	7.52	7.64	7.55
3	0	12	0.5	7.42	7.53	7.61	7.52
4	0	18	0.5	7.73	7.61	7.58	7.64
5	15	0	0.5	7.62	7.74	7.81	7.72
6	15	6	0.5	7.73	7.81	7.67	7.74
7	15	12	0.5	7.81	7.86	7.91	7.86
8	15	18	0.5	7.73	7.64	7.84	7.74
9	30	0	0.5	7.32	7.41	7.56	7.43
10	30	6	0.5	7.04	7.16	7.23	7.14
11	30	12	0	7.62	7.73	7.81	7.72
12	30	18	0	7.36	7.42	7.54	7.44

Table 21: STS values for various replacements of FA, SF with 1% SFB by volume of concrete for 28 days curing

S.NO	% FA	% SF	% SFB	CS IN MPA FOR 28 DAYS			
				SAMPLE-I	SAMPLE-II	SAMPLE-III	AVERAGE
1	0	0	1	6.52	6.41	6.67	6.53
2	0	6	1	6.82	6.73	6.91	6.82
3	0	12	1	7.04	7.12	7.24	7.13
4	0	18	1	6.96	7.06	7.14	7.05
5	15	0	1	6.71	6.64	6.53	6.63
6	15	6	1	7.92	7.04	7.18	7.38
7	15	12	1	7.92	7.96	7.99	7.95
8	15	18	1	7.14	7.26	7.34	7.25

9	30	0	1	6.53	6.67	6.72	6.64
10	30	6	1	6.84	6.92	7.03	6.93
11	30	12	1	7.13	7.26	7.34	7.24
12	30	18	1	7.06	7.14	7.21	7.14

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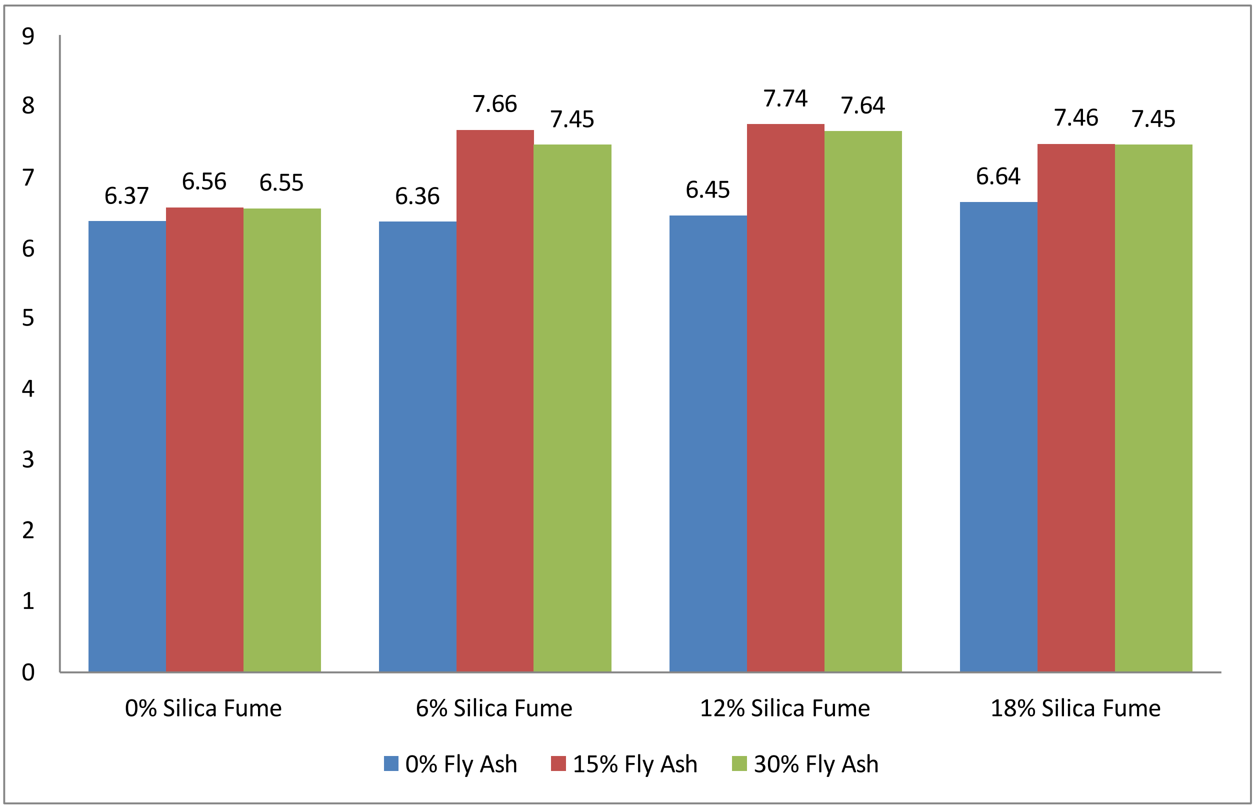
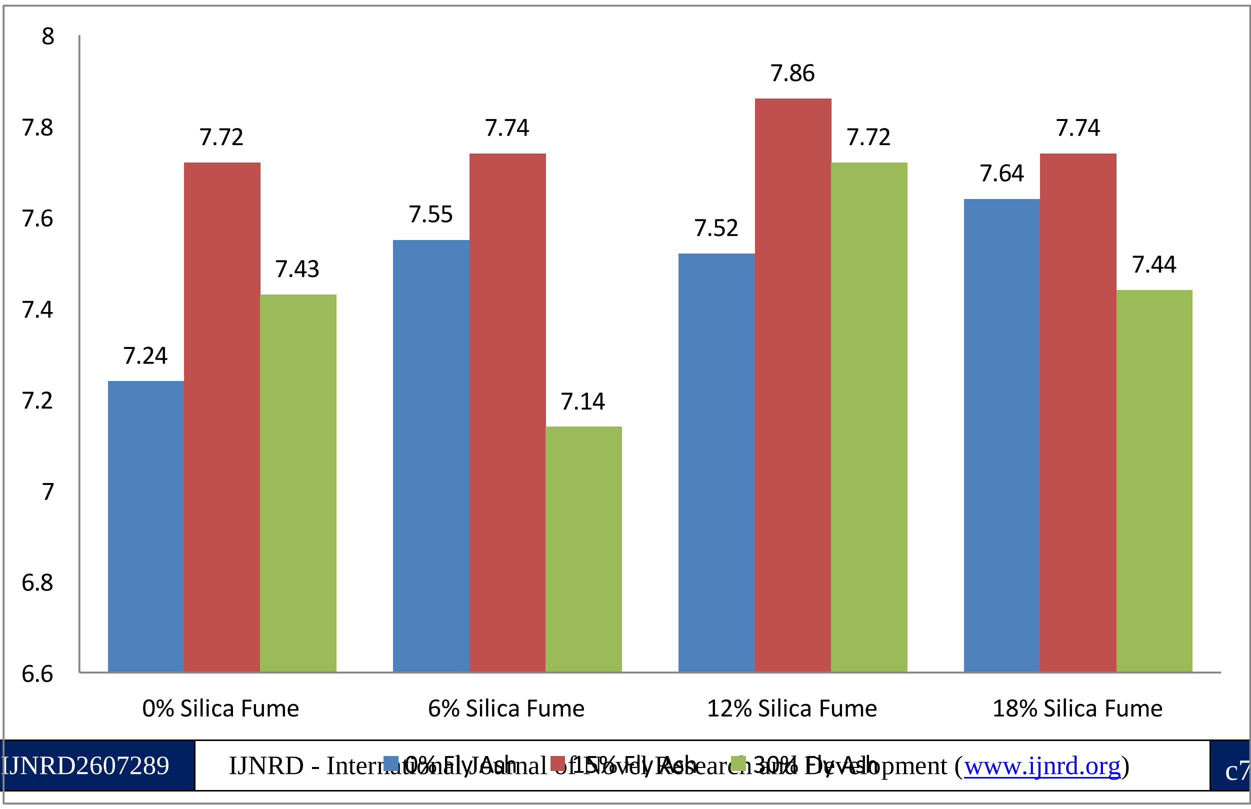
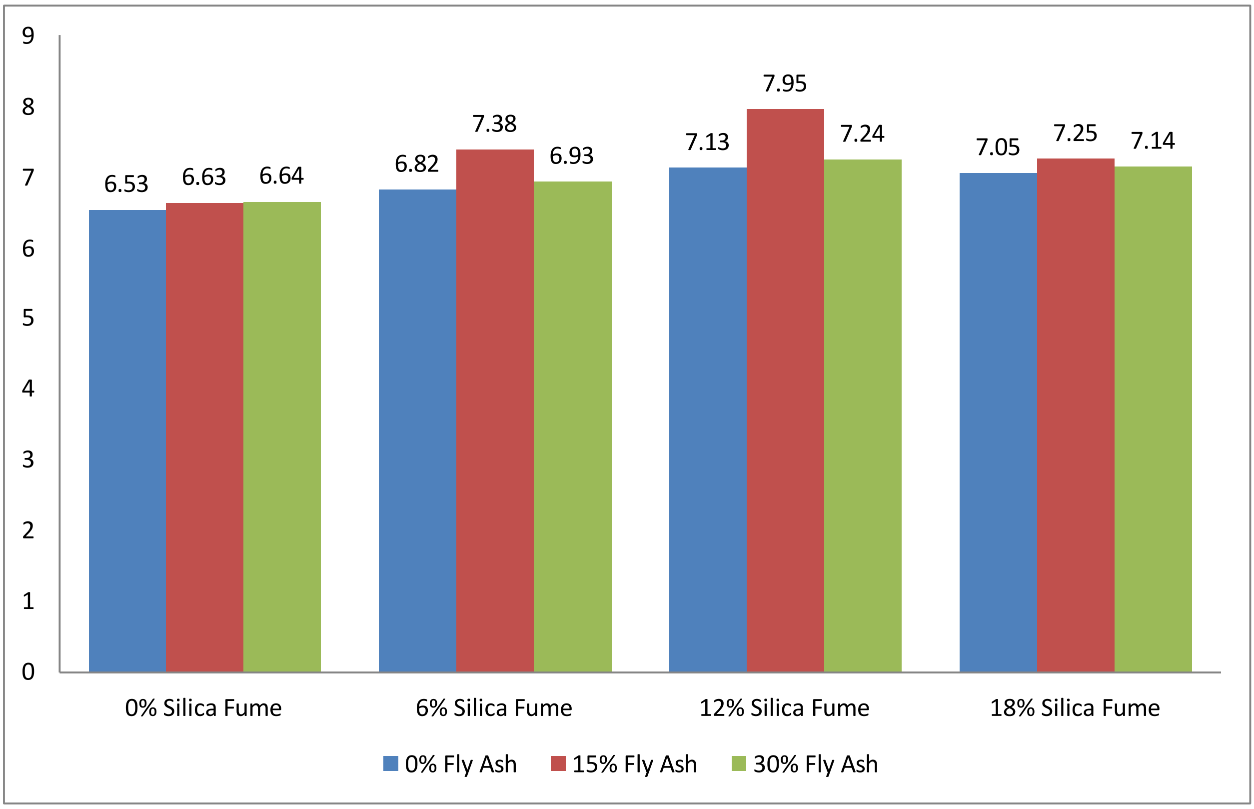
Graph 7: STS of cylinders for various replacements of FA & SF with 0% SFB



Graph 8: STS of cylinders for various replacements of FA & SF with 0.5% SFB



raph 9: STS of cylinders for various replacements of FA & SF with 1% SFB



Discussions:

Similarly tensile strength tests have been conducted and the following results have been achieved. Initially tests were conducted on ordinary concrete cylinders without adding FA, SF, and SFB. Then secondly sets of tests were carried out for concrete cylinders containing 15%, 30% FA and SF 6%, 12%, 18% respectively, while there was no percentage addition of SFB and maximum STS attained in this case was 7.74 N/mm^2 at 15% FA and 12% SF mix. Then third set of tests were conducted where there was a combination of 15%, 30% FA and SF 6%, 12%, 18% respectively but in this case, 0.5% of SFB were added and maximum STS attained was 7.86 N/mm^2 which was again the same percentage as 15% FA and 12% SF mix. Lastly another set of tests were performed for concrete cylinders containing 15%, 30% FA and SF 6%, 12%, 18% respectively but 1% SFB were added in this case and maximum STS obtained was 7.95 N/mm^2.

CHAPTER-5
CONCLUSIONS

. CONCLUSIONS

The following conclusions were drawn from the results obtained from the experiments:

1. From the above experiment, it can be seen that the CS for all mixes of concrete has not reached beyond the mean strength required, but the CS of all mixes of concrete having FA, SF, and SFB has exceeded the CS of control concrete for curing period of 28 days.
2. It is examined that highest CS of 81.37 N/mm^2 is attained for a mix of concrete having 15% FA and 12% SF with 1% SFB when compared to other concrete mixes.
3. As can be seen from the experimental results, it was observed that concrete samples containing FA, SF and SFB showed higher values of FS compared to the FS obtained by plain concrete samples in a curing period of 28 days.
4. Maximum FS of 8.97 N/mm^2 is observed at a replacement of 15% FA and 12% SF with 1% SFB when compared to other concrete mixes.
5. STS values of concrete mixes containing FA, SF, and SFB are higher than STS values of ordinary concrete mixes without FA, SF, and SFB after 28 days of curing.
6. Highest STS of 7.95 N/mm^2 is observed at a replacement of 15% FA and 12% SF with 1% SFB when compared to other concrete mixes.

CHAPTER-6
FUTURE SCOPE

6. FUTURE SCOPE

This study proves that there are positive effects associated with the use of FA, SF, and SFB on the mechanical properties of concrete. Nevertheless, more elaborate studies need to be conducted to fully understand the long-term performance of composite materials. A thorough examination of durability characteristics will determine whether triple blended fiber reinforced concrete is durable enough when exposed to extreme environmental conditions. Future research studies will need to focus on resistance of such materials to sulphate, chloride ion, and acid attack, since these factors significantly affect the long-term performance of concrete in marine, industrial, and sewage applications. Properties such as mass loss, residual strength, permeability, and ion diffusion coefficients will need to be examined through extended exposure durations. Advanced structural analysis will also be needed to determine the reasons behind improved concrete properties. Such examinations can be performed using techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD), and energy dispersive spectroscopy (EDS). Such tests will enable researchers to conduct an examination of ITZ, hydration products, and fiber-matrix bonding. Such research will shed light on the effect of pore refinement, crack-bridging techniques, and SCMs on the formation of microstructure. Also, it will be important to conduct an investigation of pore size distribution, total porosity, and pore connectivity using Mercury Intrusion Porosimetry (MIP). In addition, this will facilitate correlation between microstructural characteristics and mechanical behavior. Longevity of the proposed concrete mixture can be evaluated using life cycle assessment (LCA). Life cycle assessment is necessary for measuring the environmental effect, energy usage, and CO2 emissions during the use of by-products in concrete manufacture. Life cycle assessment will help in identifying the environmental advantages of the concrete and encourage its application in green construction practices. Finally, there may be future research on the optimal fiber content, combinations of different fibers, and various types of SCMs for improved concrete performance. Also, field testing and applications to structures may be considered in future studies.

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