RESEARCH PAPER

Investigation On Blending Of Returned Concrete With Fresh Concrete In Different Dosage Of Metakaolin Powder, Polypropylene Fibers And Superplasticizer Using Descriptive Statistics

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ABSTRACT:
This abstract describes research Returned concrete generated in ready-mix concrete (RMC) plants is a major source of material waste and environmental concern. This study investigates the feasibility of blending returned concrete with fresh concrete using different dosages of metakaolin (MK) powder, polypropylene (PP) fibers, and superplasticizers for returned concrete aged from 0 to 5 hours. The objective was to evaluate the influence of these materials on the fresh, mechanical, and durability properties of blended concrete and to identify optimum combinations capable of mitigating the adverse effects of concrete ageing. Descriptive statistical methods, including mean, standard deviation, were employed to analyze the experimental data and compare the performance of different mixtures. The results indicated that increasing the ageing period of returned concrete reduced workability and strength characteristics. However, the incorporation of metakaolin significantly improved compressive strength and durability due to its pozzolanic activity, polypropylene fibers enhanced crack resistance and flexural performance, and superplasticizers effectively restored workability and improved mix consistency. In conclusion, the blending of returned concrete offers a viable strategy for achieving sustainable concrete production by reducing reliance on natural resources and minimizing landfill disposal, while still meeting the technical requirements for various construction applications. The present study includes the effectof partial replacement of cement with metakaolin by variousercentages (0%,10%,15%,20%)on the properties of M-25 grade of concrete using Polypropylene fibers as additives in various percentages (0.25%, 0.50%,0. 75%). The test result revealed that 15% replacement of OPC by metakaolin powder and 0.50% addition of Polypropylene fiber by volume of concrete increases the strength of concrete.

Keywords: Returned Concrete,Fresh Concrete Blending,,Metakaolin Powder, Polypropylene Fibers, Superplasticizers Dosage, UPV, Descriptive Statistics.
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INTRODUCTION:

Concrete is recognized as one of the most widely used materials, indispensably contributing to the civil engineering sector. Its application spans across various infrastructural developments such as buildings, roads, bridges, and more. The increasing demand for concrete has led to large-scale production in ready-mix concrete plants. During transportation and placement, some quantity of concrete often remains unused and returns to the batching plant. This unused material is termed returned concrete. Returned concrete disposal poses environmental and economic challenges. Conventional disposal methods include dumping in landfills or hardening and crushing for recycling. These methods involve material wastage and disposal costs. Therefore, reuse of returned concrete by blending with fresh concrete is considered a sustainable approach.

The workability and strength of returned concrete decrease with ageing due to hydration of cement. To overcome these issues, supplementary cementitious materials and admixtures can be added. Metakaolin is a highly reactive pozzolanic material thaimproves strength and durability. Polypropylene fibres enhance crack resistance and toughness, while superplasticizers improve workability without increasing water content. These fibers have been proven to enhance concrete's crack resistance behavior, ductility, tensile strength, and bending capacity significantly. MK, which is obtained from calcined kaolinite, is a highly active pozzolanic material that can enhance the mechanical strength, corrosion resistance, and impermeability of OPC-based concrete. Furthermore, calcined clay is the primary raw ingredient in the increasingly popular calcined clay limestone cements (LC^3). This is owing to thefactthatitsrawmaterial, clay, hasadiverse variety of sources, particularly in many developing countries. Metakaolin is produced by calcining kaolin at high temperatures and typically contains 40–45 % aluminum oxide (Al_2O_3) and 50–55 % silicon dioxide (SiO_2). The byproduct of cement hydration, CH, negatively impacts the mechanical and durability properties of concrete and does not significantly enhance the desired strength. The SiO_2 and Al_2O_3 present in MK can react with CH in the presence of water to form C-S-H, calcium aluminates hydrates (CAH), and

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calcium alumino silicate hydrates (CASH). The dehydration of kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) at an adequate temperature (600-900◦C) can produce metakaolin, an anhydrous aluminum silicate ($Al_2O_3 \cdot 2SiO_2$) that has a particular silicon source and is hence a viable material that may replaces cement. In addition to mineral admixtures, several other factors affect the development of the compressive strength of concrete. These factors are the ratio of water to cementitious content (w/c), age, cement content, coarse aggregate to total aggregate ratio (w/c), age, cement content, coarse aggregate to total aggregate ratio(CA/TA). Therefore, it is essential to examine the properties and performance of concrete before using it in real projects.

The present research work discusses the production of economical and cost effective concrete after adding Polypropylene Fibers (PPF) to reduce harmful effects of untreated waste plastic on environment and to improve the strength properties, with addition of Metakaolin as a supplementary cementicious material. All researchers reported that adding fiber from waste materials into concrete mixes reduces theworkability of the concrete. However, most researchers state that adding fiber can increase concrete's mechanical strength, especially its tensile strength. However, a researcher also reportsadecreaseinconcrete'scompressiveand tensile strength due to the addition of waste fiber, especially when utilizing waste metal materials. The addition of plastic waste fibers into the concrete mixtures reduced the workability of the concrete, slightly increased its compressive strength, significantly increased its tensile strength, and reduced its thermal conductivity. The addition of Polypropylene fiber to the concrete mixture even reported as possible to be carried out up to 1% based on the volumetric ratio. Therefore mentioned works discussed the effect of PP Fiber on strength properties of concrete. The current study discusses the combined effect of pozzolanic materials (cement and Metakaolin) and Polypropylene fibers on fresh and hardened properties of concrete, also discusses these effects when freshly prepared concrete blended with site leftover concrete for the duration of 1 hour, 2 hours, 3 hours, 4 hours and 5 hours. MK is incorporated at 5 %, 10 %, 15% and 20 % as a partial replacement to cement by weight. The test results showed that the presence of Polypropylene fiber in the mix decreased its flowability. However, whenadded up to 0.75%the mixes still meets the flawability requirements of fresh-state concrete. In addition, investigators have suggested using some stabilizing additives to help returned concrete stay fresh for a longer time and allow for reusing it, with the addition of a super-stabilizer based on concrete hydration control. This stabilizer turns the concrete into a plastic concrete, which lasts up to 72 hrs.

Descriptive statistical analysis was employed to systematically summarize and interpret the experimental data. Statistical parameters such as mean, standard deviation, were used to evaluate the influence of different material dosages and returned concrete ageing periods on concrete properties. The application of descriptive statistics enabled the identification of trends, variability, and performance patterns within the experimental results, facilitating a comprehensive understanding of the effects of metakaolin, polypropylene fibers, and superplasticizers on blended concrete.

The primary objective of this investigation is to assess the feasibility of reusing returned concrete through blending with fresh concrete while maintaining acceptable levels of workability, strength, and durability.The study also aims to establish an optimum combination of metakaolin powder,polypropylene fibers, and superplasticizers that can effectively mitigate the adverse effects of concrete ageing. The findings are expected to contribute toward sustainable concrete production practices, reduction of construction waste, conservation of natural resources, and improved resource efficiency in the ready-mix concrete industry.

LITERATURE REVIEWS:

[1] **Mostafa M. et. al (2025):**

This research investigates the effects of using metakaolin powder, prepared in a concrete mix, on the workability and compressive strength of concrete containing MK in different ratios. MK was incorporated at 5 %, 10 %, and 20 % as either a partial replacement or additive to cement by weight. The compressive strength increased by 13%, 11%, and— 5% at 7, 28, and 365 days, respectively, with no MK and the use of MW.

[2] **Meena, Vishwakarma and Khichad (2025)**

In this study the effect of metakaolin and polypropylene fibers on concrete pavement properties using statistical optimization techniques. The researchers reported that metakaolin enhanced compressive strength and durability, while polypropylene fibers improved flexural strength and crack resistance. Statistical tools were used to identify optimum dosages, demonstrating the usefulness of descriptive and optimization methods in concrete mix design.

[3] **Slamet Widodo, et. al (2023):**

This study aims to utilize fly ash and waste PET bottles for producing more sustainable self-compacting concrete with better mechanical strength. Fly ash is utilized as a supplementary cement material and waste PET bottles as fiber reinforcement to improve its flexural strength and achieve the targeted compressive strength. The two variants are added with PET fiber based on the volume fractions of 0%, 0.25%, 0.50%, and 0.75%.

[4] **Aktham H. Alania, et. al. (2022):**
The effects of adding recycled waste plastic bottles in the form Polyethylene Terephthalate (PET) fiber on the flexural and tensile behavior of Ultra-High Performance PET Fiber Reinforced Green Concrete containing different volumes of Ultra-fine palm oil fuel ash and Silica Fume have been investigated. The results showed that the addition of PET fibers modulates the stiff and brittle behavior of Ultra High-Performance Green Concrete (UHPGC).

[5] **Yousef R. Alharbi[a], et. al. (2021):**
This paper studies the impact of using metakaoline (MK) as an available alternative pozzolanas to replace silica fume(SF) in the development of Reactive Powder Concrete (RPC) in Egypt. he results showed that the blended SF and MK enhanced the strength and the durability of the RPC.Reza Noroozi[a], et. al. (2019):
To enhance the performance of RCCP, the mixtures were also modified by using pozzolanic Metakaolin (MK) as a partial substitute for cement and adding steel fibers obtained from the recycling of worn vehicle tyres. The optimal mix design obtained from the statistical model involves replacing 25 vol% of fine aggregate with PET, replacing 20 wt% of cement with MK powder, and adding 1.9 wt% SRSF to the mixture.

[6] **Khatib and Hibbert (2005)**
Investigated the influence of metakaolin as a supplementary cementitious material on the mechanical and durability properties of concrete. Cement was partially replaced with metakaolin at different percentages, and compressive strength, permeability, and durability characteristics were evaluated. Descriptive statistical analysis of the results showed that the mean compressive strength increased with metakaolin content up to an optimum replacement level of approximately 15%. The study concluded that metakaolin significantly improved concrete quality by refining pore structure and reducing permeability

1. MATERIALS AND METHODS:

All other raw materials used in the laboratory and in the production conditions by the RMC (cement, additives, and regular aggregates) were kept constant in the study. The main materials used in the
preparation of laboratory specimens were fine-grained and coarse-grained crushed aggregates, Type II Ordinary Portland Cement, and tap water. In the specimens, cement is partially replaced with MK powder from 5% to 20%. And polypropylene fibers are added with 0.25%, 0.50% and 0.75% by volume of concrete and super plasticizers are added with 1%, 2% and 3%.

1.1 Cement:

In this study, OPC grade 53 was used for preparing concrete cubes. The specific gravity was 3.15.90-95% of OPC 53-grade particles are able to pass through a 45 μm finer sieve, which emphasises its exceptional fineness. It is 225 m^2/kg.

1.2 Fine Aggregates:

The High Quality Natural Sand which is required for this project work is sourcefrom riverbeds. The composition of this High-quality natural sand is clean and free from impurities like silt, clay, shells, and organic matter, as these can reduce the strength and durability of the concrete. These sand particles having a smooth, rounded shape with specific gravity
2.45. This texture contributes to good workability, making the concrete mix easier to apply and providing smooth finishes for applications like plastering. This natural sand with particles smaller than 4.75 mm that pass through a 4.75 mm sieve. It is used in construction to fill gaps between larger aggregates, increasing the density and workability of concrete and mortar.

1.3 Coarse Aggregates:

Angular and rough-textured coarse aggregates of size 200mm with the specific gravity 2.67 are used for the project work. These types of aggregates generally provide better strength and durability due to enhancedinterlocking with the cement matrix, because proper grading (particle size distribution) is vital for achieving optimal density, which impacts the strength and workability of the concrete mix. They are strong enough to withstand crushing and impact forces.These selected aggregates having low water absorption property, because theaggregates with low water absorption help maintain the intended water-cement ratio, which is crucial for controlling concrete strength.

Properties	FA	CA
Fineness Modulus	2.34	4.73
Specific Gravity	2.62	2.68
Absorption (%)	1.52	0.81
Bulk Density (kg/m^3)	1785	1634

Table No.2:Physical properties of the aggregate.

1.4 Metakaolin Powder:

Metakaolin is often white, which lightens the color of concrete for architectural applications. Its fine particles fill voids and improve the mix's rheology, resulting in a smoother, less sticky, and more cohesive mix that is easier to finish and less prone to efflorescence. It densifies the concrete's microstructure, reducing permeability to water, chlorides, and sulfates. This improves resistance to chemical attacks, freeze-thaw cycles, and general degradation, making it ideal for infrastructure projects like bridges and marine structures.Optimal cement replacement levels typically range from 10% to 15% by weight, leading to increased compressive and flexural strength. MK tends to reduce the workability (slump) of the fresh mix due to its high surface area and water absorption properties. The specific Gravity of MK is 2.34.

1.5 Polypropylene Fiber:

These are synthetic reinforcement fibers of size 12mm added to concrete to improve its performance, primarily by increasing crack resistance, toughness, and durability, not for primary structural support. They are effective against shrinkage and cracking, enhance impact and abrasion resistance, and prevent spalling. PP fibers are lightweight, corrosion-resistant, and do not break down in the alkaline environment of concrete, unlike some other synthetic fibers like fiberglass. Optimal fiber content is often found around 0.5% to 1.0% by volume; higher percentages can lead to fiber clumping and reduced workability. They provide secondary reinforcement to the concrete, helping to prevent the formation of micro-cracks caused by plastic shrinkage during curing. As a synthetic material, PP fibers are not susceptible to rust and are resistant to chemical and thermal degradation, unlike steel fibers. By preventing cracks, PP fibers lead to lower maintenance costs over the life of the structure.

1.6 Super plasticizers:

Returned concrete aggregates differ from natural aggregates, primarily due to adhered old mortar, which results in higher water absorption and a more complex, rougher surface structure. This necessitates a super plasticizer with strong dispersion capabilities and good compatibility to manage the workability and strength properties effectively. For blending returned concrete with fresh concrete, **Poly Carboxylate Ether (PCE)** based super plasticizers are the most effective and widely used.PCEs work through a combination of electrostatic repulsion and a strong stericxxxxxhindrance effect due to their comb-like molecular structure with long side chains. This mechanism is highly effective at dispersing the diverse and irregular particles found in recycled aggregate mixes, leading to high flowability and reduced water content without segregation. They offer high water reduction rates (up to 40%) and superior slump retention over longer periods compared to other types, which is crucial for the transport and placement of ready-mix concrete, especially when blending returned material.

1.7 Water:

Generally, water that is fit for drinking (potable) is considered suitable for concrete. It must be reasonably clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials, or other substances that could be detrimental to the concrete or cause corrosion of reinforcing steel.

CONCRETE SPECIMEN PREPARATIONS:

There are 6 concrete mixes prepared for this research work. The concrete cubes of size 150mm × 150mm × 150mm size were cast with varying percentages of Metakaolin Powder and Polypropylene fibers. The concrete cubes are prepared as the blending of site leftover concrete and fresh concrete with different ratios of Metakaolin powder and polypropylene fibers with the time duration of up to 5 hours. This time duration of returned concrete is taken into consideration for attaining desired compressive strength. So, each specimen for 1 hour leftover concrete, hours leftover concrete, 3 hours leftover concrete, 4 hours leftover concrete and5 hours leftover concrete are prepared and blended with fresh concrete with varying percentages of Metakaolin Powder and Polypropylene Fibers The specimens were de-

oulded after 24 hrs and tested for compressive strength after 28 days of curing as per IS 456:2000. Specimens stored in water were tested immediately on removal from the water, while they are still in the wet condition. Surface water and grit were wiped off the specimens. The results showing variation in the compressive strength i.e. average of three test values are considered.

1. Freshly prepared concrete mixing procedure:

In first case of concrete mix, i. e. freshly prepared concrete mix, there are total 9 cubes are casted in three sets. In first set of cubes, 3 cubes of freshly prepared concrete are casted. In second set of cubes, 3 cubes of concrete with Metakaolin Powder as Supplementary Cementicious Materials are casted. In third set of cubes, 3 cubes of concrete with Metakaolin Powder and Polypropylene fibers are casted. All these cubes are tested for compressive strength at the age of 28 days. The average of 3 cubes of each set is taken into consideration.

2 Returned concrete and fresh concrete mixing procedure:

In this stage, the fresh concrete with Metakaolin Powder and Polypropylene fibers is used and mixed with the returned concrete. This returned concrete we are using for the research work is 1 hour old, 2 hours old, 3 hours old, 4 hours old and five hours old with varying

RESULTS AND DISCUSSIONS:

percentages of fresh concrete. For blending of fresh concrete with old concrete, we are varying the percent use of old concrete and new concrete. Three cubes of each blend with all durations are taken into consideration and tested for the same.

- First specimen sample is, 90% fresh concrete is mixed with 10% returned concrete,
- The second specimen sample is of 80% fresh concrete mixed with 20% returned concrete,
- The third specimen sample is of 70% fresh concrete is mixed with 30% returned concrete,
- Then fourth specimen sample is of 60% fresh concrete is blended with 40% returned concrete and
- The fifth one specimen sample is of 50% fresh concrete blended with 50% returned concrete. Similarly, we are blending this way for 2 hours old concrete, 3 hours old concrete, 4 hours old concrete and 5 hours old concrete.
- Also, for each time duration and each varying percentage of this blend, we are varying the dosage of Metakaolin powder and Polypropylene fibers. The metakaolin powder dosage is varying from 5%, 10% and 15% and the Polypropylene fiber dosage is from 0.25%, 0.50% and 0.75%. The added retarding plasticizers are also varying from 1%, 2% and 3%.

ULTRASONIC PULSE VELOCITY TEST:

Sr. No.	Percentage of Concrete (%)		Materials Used (%)			Mixing No.	UPV Values for given Timeline(Hours) in km/s					
	Fresh	Old	MK Powder	PP Fiber	SP		0	1	2	3	4	5
1	100	0	0	0	0	C1	4.6	4.6	4.6	4.6	4.6	4.6
			5	0	0	C2	4.9	4.9	4.9	4.9	4.9	4.9
			10	0	0	C3	4.95	4.95	4.95	4.95	4.95	4.95
			15	0	0	C4	5	5	5	5	5	5
			20	0	0	C5	5.05	5.05	5.05	5.05	5.05	5.05
			5	0.25	0	C6	4.93	4.93	4.93	4.93	4.93	4.93
			10	0.25	0	C7	4.98	4.98	4.98	4.98	4.98	4.98
			15	0.25	0	C8	5.03	5.03	5.03	5.03	5.03	5.03
			20	0.25	0	C9	5.08	5.08	5.08	5.08	5.08	5.08
			5	0.5	0	C10	4.94	4.94	4.94	4.94	4.94	4.94
			10	0.5	0	C11	4.99	4.99	4.99	4.99	4.99	4.99
			15	0.5	0	C12	5.04	5.04	5.04	5.04	5.04	5.04
			20	0.5	0	C13	5.09	5.09	5.09	5.09	5.09	5.09
			5	0.75	0	C14	4.95	4.95	4.95	4.95	4.95	4.95
			10	0.75	0	C15	5	5	5	5	5	5
			15	0.75	0	C16	5.05	5.05	5.05	5.05	5.05	5.05
			20	0.75	0	C17	5.1	5.1	5.1	5.1	5.1	5.1
			5	0.25	1	C18	4.96	4.96	4.96	4.96	4.96	4.96
			10	0.25	1	C19	5	5	5	5	5	5
			15	0.25	1	C20	5.05	5.05	5.05	5.05	5.05	5.05
			20	0.25	1	C21	5.08	5.08	5.08	5.08	5.08	5.08
			5	0.5	2	C22	4.96	4.96	4.96	4.96	4.96	4.96
			10	0.5	2	C23	5.01	5.01	5.01	5.01	5.01	5.01
			15	0.5	2	C24	5.06	5.06	5.06	5.06	5.06	5.06
			20	0.5	2	C25	5.11	5.11	5.11	5.11	5.11	5.11
			5	0.75	3	C26	4.97	4.97	4.97	4.97	4.97	4.97

			10	0.75	3	C27	5.02	5.02	5.02	5.02	5.02	5.02
			15	0.75	3	C28	5.07	5.07	5.07	5.07	5.07	5.07
			20	0.75	3	C29	5.13	5.13	5.13	5.13	5.13	5.13
2	90	10	0	0	0	C1	4.6	4.58	4.56	4.54	4.52	4.5
			5	0	0	C2	4.9	4.87	4.84	4.81	4.78	4.75
			10	0	0	C3	4.95	4.92	4.89	4.86	4.83	4.8
			15	0	0	C4	5	4.97	4.94	4.91	4.88	4.85
			20	0	0	C5	5.05	5.02	4.99	4.96	4.93	4.9
			5	0.25	0	C6	4.93	4.9	4.87	4.84	4.81	4.78
			10	0.25	0	C7	4.98	4.95	4.92	4.89	4.86	4.83
			15	0.25	0	C8	5.03	5	4.97	4.94	4.91	4.88
			20	0.25	0	C9	5.08	5.05	5.02	4.99	4.96	4.93
			5	0.5	0	C10	4.94	4.91	4.88	4.85	4.82	4.79
			10	0.5	0	C11	4.99	4.96	4.93	4.9	4.87	4.84
			15	0.5	0	C12	5.04	5.01	4.98	4.95	4.92	4.89
			20	0.5	0	C13	5.09	5.06	5.03	5	4.97	4.94
			5	0.75	0	C14	4.95	4.92	4.89	4.86	4.83	4.8
			10	0.75	0	C15	5	4.97	4.94	4.91	4.88	4.85
			15	0.75	0	C16	5.05	5.02	4.99	4.96	4.93	4.9
			20	0.75	0	C17	5.1	5.07	5.04	5.01	4.98	4.95
			5	0.25	1	C18	4.96	4.93	4.9	4.87	4.84	4.81
			10	0.25	1	C19	5	4.97	4.94	4.91	4.88	4.85
			15	0.25	1	C20	5.05	5.02	4.99	4.96	4.93	4.9
			20	0.25	1	C21	5.08	5.05	5.02	4.99	4.96	4.93
			5	0.5	2	C22	4.96	4.93	4.9	4.87	4.84	4.81
			10	0.5	2	C23	5.01	4.98	4.95	4.92	4.89	4.86
			15	0.5	2	C24	5.06	5.03	5	4.97	4.94	4.91
			20	0.5	2	C25	5.11	5.08	5.05	5.02	4.99	4.96
			5	0.75	3	C26	4.97	4.94	4.91	4.88	4.85	4.82
			10	0.75	3	C27	5.02	4.99	4.96	4.93	4.9	4.87
			15	0.75	3	C28	5.07	5.04	5.01	4.98	4.95	4.92
			20	0.75	3	C29	5.13	5.1	5.07	5.04	5.01	4.98
3	80	20	0	0	0	C1	4.6	4.57	4.54	4.51	4.48	4.45
			5	0	0	C2	4.9	4.86	4.82	4.78	4.74	4.7
			10	0	0	C3	4.95	4.91	4.87	4.83	4.79	4.75
			15	0	0	C4	5	4.96	4.92	4.88	4.84	4.8
			20	0	0	C5	5.05	5.01	4.97	4.93	4.89	4.85
			5	0.25	0	C6	4.93	4.89	4.85	4.81	4.77	4.73
			10	0.25	0	C7	4.98	4.94	4.9	4.86	4.82	4.78
			15	0.25	0	C8	5.03	4.99	4.95	4.91	4.87	4.83

			20	0.25	0	C9	5.08	5.04	5	4.96	4.92	4.88
			5	0.5	0	C10	4.94	4.9	4.86	4.82	4.78	4.74
			10	0.5	0	C11	4.99	4.95	4.91	4.87	4.83	4.79
			15	0.5	0	C12	5.04	5	4.96	4.92	4.88	4.84
			20	0.5	0	C13	5.09	5.05	5.01	4.97	4.93	4.89
			5	0.75	0	C14	4.95	4.91	4.87	4.83	4.79	4.75
			10	0.75	0	C15	5	4.96	4.92	4.88	4.84	4.8
			15	0.75	0	C16	5.05	5.01	4.97	4.93	4.89	4.85
			20	0.75	0	C17	5.1	5.06	5.02	4.98	4.94	4.9
			5	0.25	1	C18	4.96	4.92	4.88	4.84	4.8	4.76
			10	0.25	1	C19	5	4.96	4.92	4.88	4.84	4.8
			15	0.25	1	C20	5.05	5.01	4.97	4.93	4.89	4.85
			20	0.25	1	C21	5.08	5.04	5	4.96	4.92	4.88
			5	0.5	2	C22	4.96	4.92	4.88	4.84	4.8	4.76
			10	0.5	2	C23	5.01	4.97	4.93	4.89	4.85	4.81
			15	0.5	2	C24	5.06	5.02	4.98	4.94	4.9	4.86
			20	0.5	2	C25	5.11	5.07	5.03	4.99	4.95	4.91
			5	0.75	3	C26	4.97	4.93	4.89	4.85	4.81	4.77
			10	0.75	3	C27	5.02	4.98	4.94	4.9	4.86	4.82
			15	0.75	3	C28	5.07	5.03	4.99	4.95	4.91	4.87
			20	0.75	3	C29	5.13	5.09	5.05	5.01	4.97	4.93
4	70	30	0	0	0	C1	4.6	4.56	4.52	4.48	4.44	4.4
			5	0	0	C2	4.9	4.85	4.8	4.75	4.7	4.65
			10	0	0	C3	4.95	4.9	4.85	4.8	4.75	4.7
			15	0	0	C4	5	4.95	4.9	4.85	4.8	4.75
			20	0	0	C5	5.05	5	4.95	4.9	4.85	4.8
			5	0.25	0	C6	4.93	4.88	4.83	4.78	4.73	4.68
			10	0.25	0	C7	4.98	4.93	4.88	4.83	4.78	4.73
			15	0.25	0	C8	5.03	4.98	4.93	4.88	4.83	4.78
			20	0.25	0	C9	5.08	5.03	4.98	4.93	4.88	4.83
			5	0.5	0	C10	4.94	4.89	4.84	4.79	4.74	4.69
			10	0.5	0	C11	4.99	4.94	4.89	4.84	4.79	4.74
			15	0.5	0	C12	5.04	4.99	4.94	4.89	4.84	4.79
			20	0.5	0	C13	5.09	5.04	4.99	4.94	4.89	4.84
			5	0.75	0	C14	4.95	4.9	4.85	4.8	4.75	4.7
			10	0.75	0	C15	5	4.95	4.9	4.85	4.8	4.75
			15	0.75	0	C16	5.05	5	4.95	4.9	4.85	4.8
			20	0.75	0	C17	5.1	5.05	5	4.95	4.9	4.85
			5	0.25	1	C18	4.96	4.91	4.86	4.81	4.76	4.71
			10	0.25	1	C19	5	4.95	4.9	4.85	4.8	4.75
			15	0.25	1	C20	5.05	5	4.95	4.9	4.85	4.8
			20	0.25	1	C21	5.08	5.03	4.98	4.93	4.88	4.83
			5	0.5	2	C22	4.96	4.91	4.86	4.81	4.76	4.71
			10	0.5	2	C23	5.01	4.96	4.91	4.86	4.81	4.76
			15	0.5	2	C24	5.06	5.01	4.96	4.91	4.86	4.81
			20	0.5	2	C25	5.11	5.06	5.01	4.96	4.91	4.86
			5	0.75	3	C26	4.97	4.92	4.87	4.82	4.77	4.72
			10	0.75	3	C27	5.02	4.97	4.92	4.87	4.82	4.77

			15	0.75	3	C28	5.07	5.02	4.97	4.92	4.87	4.82
			20	0.75	3	C29	5.13	5.08	5.03	4.98	4.93	4.88
5	60	40	0	0	0	C1	4.6	4.55	4.5	4.45	4.4	4.35
			5	0	0	C2	4.9	4.84	4.78	4.72	4.66	4.6
			10	0	0	C3	4.95	4.89	4.83	4.77	4.71	4.65
			15	0	0	C4	5	4.94	4.88	4.82	4.76	4.7
			20	0	0	C5	5.05	4.99	4.93	4.87	4.81	4.75
			5	0.25	0	C6	4.93	4.87	4.81	4.75	4.69	4.63
			10	0.25	0	C7	4.98	4.92	4.86	4.8	4.74	4.68
			15	0.25	0	C8	5.03	4.97	4.91	4.85	4.79	4.73
			20	0.25	0	C9	5.08	5.02	4.96	4.9	4.84	4.78
			5	0.5	0	C10	4.94	4.88	4.82	4.76	4.7	4.64
			10	0.5	0	C11	4.99	4.93	4.87	4.81	4.75	4.69
			15	0.5	0	C12	5.04	4.98	4.92	4.86	4.8	4.74
			20	0.5	0	C13	5.09	5.03	4.97	4.91	4.85	4.79
			5	0.75	0	C14	4.95	4.89	4.83	4.77	4.71	4.65
			10	0.75	0	C15	5	4.94	4.88	4.82	4.76	4.7
			15	0.75	0	C16	5.05	4.99	4.93	4.87	4.81	4.75
			20	0.75	0	C17	5.1	5.04	4.98	4.92	4.86	4.8
			5	0.25	1	C18	4.96	4.9	4.84	4.78	4.72	4.66
			10	0.25	1	C19	5	4.94	4.88	4.82	4.76	4.7
			15	0.25	1	C20	5.05	4.99	4.93	4.87	4.81	4.75
			20	0.25	1	C21	5.08	5.02	4.96	4.9	4.84	4.78
			5	0.5	2	C22	4.96	4.9	4.84	4.78	4.72	4.66
			10	0.5	2	C23	5.01	4.95	4.89	4.83	4.77	4.71
			15	0.5	2	C24	5.06	5	4.94	4.88	4.82	4.76
			20	0.5	2	C25	5.11	5.05	4.99	4.93	4.87	4.81
			5	0.75	3	C26	4.97	4.91	4.85	4.79	4.73	4.67
			10	0.75	3	C27	5.02	4.96	4.9	4.84	4.78	4.72
			15	0.75	3	C28	5.07	5.01	4.95	4.89	4.83	4.77
			20	0.75	3	C29	5.13	5.07	5.01	4.95	4.89	4.83
6	50	50	0	0	0	C1	4.6	4.54	4.48	4.42	4.36	4.3
			5	0	0	C2	4.9	4.83	4.76	4.69	4.62	4.55
			10	0	0	C3	4.95	4.88	4.81	4.74	4.67	4.6
			15	0	0	C4	5	4.93	4.86	4.79	4.72	4.65
			20	0	0	C5	5.05	4.98	4.91	4.84	4.77	4.7
	5	0.25	0	C6	4.93	4.86		4.79	4.72	4.65		4.58
	10	0.25	0	C7	4.98	4.91		4.84	4.77	4.7		4.63
	15	0.25	0	C8	5.03	4.96		4.89	4.82	4.75		4.68
	20	0.25	0	C9	5.08	5.01		4.94	4.87	4.8		4.73
	5	0.5	0	C10	4.94	4.87		4.8	4.73	4.66		4.59

10	0.5	0	C11	4.99	4.92	4.85	4.78	4.71	4.64
15	0.5	0	C12	5.04	4.97	4.9	4.83	4.76	4.69
20	0.5	0	C13	5.09	5.02	4.95	4.88	4.81	4.74
5	0.75	0	C14	4.95	4.88	4.81	4.74	4.67	4.6
10	0.75	0	C15	5	4.93	4.86	4.79	4.72	4.65
15	0.75	0	C16	5.05	4.98	4.91	4.84	4.77	4.7
20	0.75	0	C17	5.1	5.03	4.96	4.89	4.82	4.75
5	0.25	1	C18	4.96	4.89	4.82	4.75	4.68	4.61
10	0.25	1	C19	5	4.93	4.86	4.79	4.72	4.65
15	0.25	1	C20	5.05	4.98	4.91	4.84	4.77	4.7
20	0.25	1	C21	5.08	5.01	4.94	4.87	4.8	4.73
5	0.5	2	C22	4.96	4.89	4.82	4.75	4.68	4.61
10	0.5	2	C23	5.01	4.94	4.87	4.8	4.73	4.66
15	0.5	2	C24	5.06	4.99	4.92	4.85	4.78	4.71
20	0.5	2	C25	5.11	5.04	4.97	4.9	4.83	4.76
5	0.75	3	C26	4.97	4.9	4.83	4.76	4.69	4.62
10	0.75	3	C27	5.02	4.95	4.88	4.81	4.74	4.67
15	0.75	3	C28	5.07	5	4.93	4.86	4.79	4.72
20	0.75	3	C29	5.13	5.06	4.99	4.92	4.85	4.78

Formulae for Descriptive Statistics

Let the observed values be represented as:

1. Arithmetic Mean

The mean represents the average value of the test results.

$$x=\frac{\sum xi}{n}$$

- x = arithmetic mean,
- xi = individual measurement,
- n = number of observations.
- Σ= sum of observation

2. Standard Deviation

Standard deviation indicates the consistency of the test results.

$$s=\frac{\sqrt{\Sigma(xi-x)2}}{n-1}$$

where:

- s = standard deviation.
- $\Sigma = sum\ of\ all\ values$
- xi = individual measurement
- $x = average$

Lower values indicate better consistency among specimens.

2. Application in the Present Study

These descriptive statistical parameters were used to evaluate the influence of:

- Returned concrete ageing: **0–5 ho;'[urs**,
- Metakaolin dosage: **5–20%**,
- Polypropylene fiber dosage: **0.25–0.75%**,
- Superplasticizer dosage: **1–3%**,

on the fresh and hardened properties of blended concrete, including slump, compaction factor, initial setting time, final setting time, compressive strength, flexural strength, ultrasonic pulse velocity, drying shrinkage, and water permeability. The statistical analysis enabled comparison of mix performance, assessment of data variability, and identification of optimum material combinations for sustainable utilization of returned concrete

DESCRIPTIVE STATISTICS RESULT FOR UPV TEST:

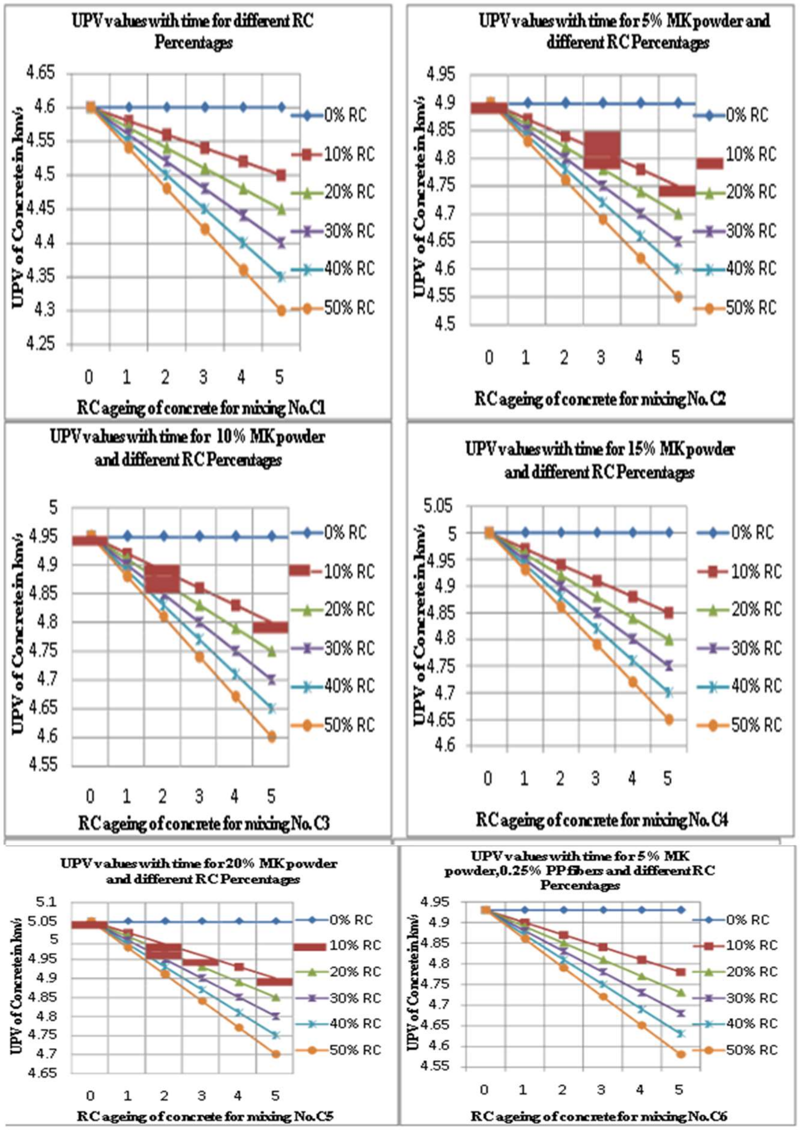
% of concrete blended			Mean	Standard Deviation				Mean	Standard Deviation
fresh	returned	Mix No.			fresh	returned	Mix No.		
100	0	C1	4.6	9.72951E-16	90	10	C1	4.55	0.037416574

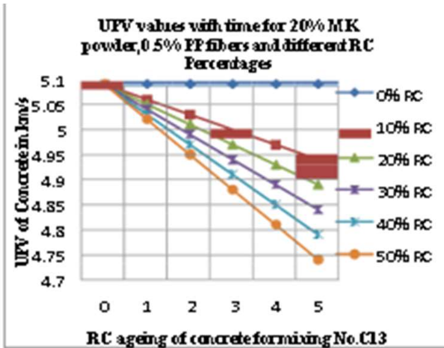
		C2	4.9	9.72951E-16			C2	4.825	0.056124861
		C3	4.95	0			C3	4.875	0.056124861
		C4	5	0			C4	4.925	0.056124861
		C5	5.05	0			C5	4.975	0.056124861
		C6	4.93	0			C6	4.855	0.056124861
		C7	4.98	0			C7	4.905	0.056124861
		C8	5.03	0			C8	4.955	0.056124861
		C9	5.08	9.72951E-16			C9	5.005	0.056124861
		C10	4.94	0			C10	4.865	0.056124861
		C11	4.99	9.72951E-16			C11	4.915	0.056124861
		C12	5.04	0			C12	4.965	0.056124861
		C13	5.09	0			C13	5.015	0.056124861
		C14	4.95	0			C14	4.875	0.056124861
		C15	5	0			C15	4.925	0.056124861
		C16	5.05	0			C16	4.975	0.056124861
		C17	5.1	9.72951E-16			C17	5.025	0.056124861
		C18	4.96	0			C18	4.885	0.056124861
		C19	5	0			C19	4.925	0.056124861
		C20	5.05	0			C20	4.975	0.056124861
		C21	5.08	9.72951E-16			C21	5.005	0.056124861
		C22	4.96	0			C22	4.885	0.056124861
		C23	5.01	9.72951E-16			C23	4.935	0.056124861
		C24	5.06	0			C24	4.985	0.056124861
		C25	5.11	0			C25	5.035	0.056124861
		C26	4.97	0			C26	4.895	0.056124861
		C27	5.02	0			C27	4.945	0.056124861
		C28	5.07	0			C28	4.995	0.056124861
		C29	5.13	0			C29	5.055	0.056124861

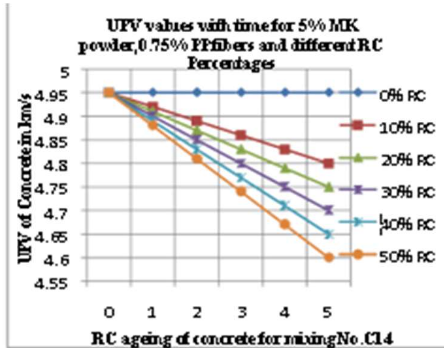
% of concrete blended			Mean	Standard Deviation	% of concrete blended			Mean	Standard Deviation
fresh	returned	Mix No.			fresh	returned	Mix No.		
80	20	C1	4.525	0.056124861	70	30	C1	4.5	0.074833148
		C2	4.8	0.074833148			C2	4.775	0.093541435
		C3	4.85	0.074833148			C3	4.825	0.093541435
		C4	4.9	0.074833148			C4	4.875	0.093541435
		C5	4.95	0.074833148			C5	4.925	0.093541435
		C6	4.83	0.074833148			C6	4.805	0.093541435
		C7	4.88	0.074833148			C7	4.855	0.093541435
		C8	4.93	0.074833148			C8	4.905	0.093541435
		C9	4.98	0.074833148			C9	4.955	0.093541435
		C10	4.84	0.074833148			C10	4.815	0.093541435
		C11	4.89	0.074833148			C11	4.865	0.093541435
		C12	4.94	0.074833148			C12	4.915	0.093541435
		C13	4.99	0.074833148			C13	4.965	0.093541435
		C14	4.85	0.074833148			C14	4.825	0.093541435
		C15	4.9	0.074833148			C15	4.875	0.093541435
		C16	4.95	0.074833148			C16	4.925	0.093541435
		C17	5	0.074833148			C17	4.975	0.093541435
		C18	4.86	0.074833148			C18	4.835	0.093541435
		C19	4.9	0.074833148			C19	4.875	0.093541435
		C20	4.95	0.074833148			C20	4.925	0.093541435

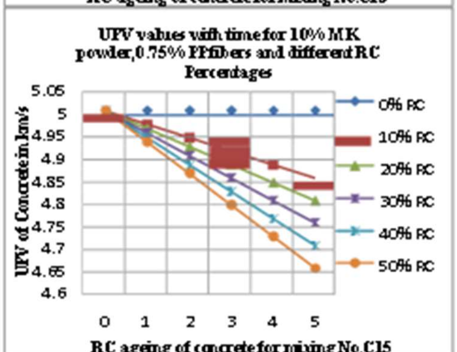
		C21	4.98	0.074833148			C21	4.955	0.093541435
		C22	4.86	0.074833148			C22	4.835	0.093541435
		C23	4.91	0.074833148			C23	4.885	0.093541435
		C24	4.96	0.074833148			C24	4.935	0.093541435
		C25	5.01	0.074833148			C25	4.985	0.093541435
		C26	4.87	0.074833148			C26	4.845	0.093541435
		C27	4.92	0.074833148			C27	4.895	0.093541435
		C28	4.97	0.074833148			C28	4.945	0.093541435
		C29	5.03	0.074833148			C29	5.005	0.093541435

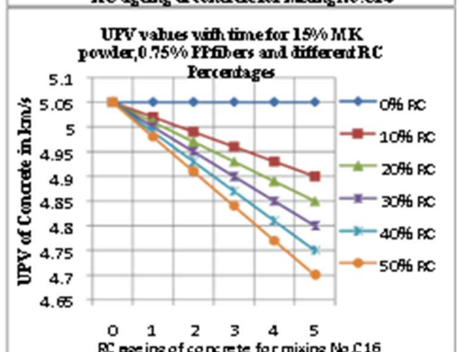
% of concrete blended			Mean	Standard Deviation	% of concrete blended			Mean	Standard Deviation
fresh	returned	Mix No.			fresh	returned	Mix No.		
60	40	C1	4.475	0.093541435	50	50	C1	4.45	0.112249722
		C2	4.75	0.112249722			C2	4.725	0.130958009
		C3	4.8	0.112249722			C3	4.775	0.130958009
		C4	4.85	0.112249722			C4	4.825	0.130958009
		C5	4.9	0.112249722			C5	4.875	0.130958009
		C6	4.78	0.112249722			C6	4.755	0.130958009
		C7	4.83	0.112249722			C7	4.805	0.130958009
		C8	4.88	0.112249722			C8	4.855	0.130958009
		C9	4.93	0.112249722			C9	4.905	0.130958009
		C10	4.79	0.112249722			C10	4.765	0.130958009
		C11	4.84	0.112249722			C11	4.815	0.130958009
		C12	4.89	0.112249722			C12	4.865	0.130958009
		C13	4.94	0.112249722			C13	4.915	0.130958009
		C14	4.8	0.112249722			C14	4.775	0.130958009
		C15	4.85	0.112249722			C15	4.825	0.130958009
		C16	4.9	0.112249722			C16	4.875	0.130958009
		C17	4.95	0.112249722			C17	4.925	0.130958009
		C18	4.81	0.112249722			C18	4.785	0.130958009
		C19	4.85	0.112249722			C19	4.825	0.130958009
		C20	4.9	0.112249722			C20	4.875	0.130958009
		C21	4.93	0.112249722			C21	4.905	0.130958009
		C22	4.81	0.112249722			C22	4.785	0.130958009
		C23	4.86	0.112249722			C23	4.835	0.130958009
		C24	4.91	0.112249722			C24	4.885	0.130958009
		C25	4.96	0.112249722			C25	4.935	0.130958009
		C26	4.82	0.112249722			C26	4.795	0.130958009
		C27	4.87	0.112249722			C27	4.845	0.130958009
		C28	4.92	0.112249722			C28	4.895	0.130958009
		C29	4.98	0.112249722			C29	4.955	0.130958009

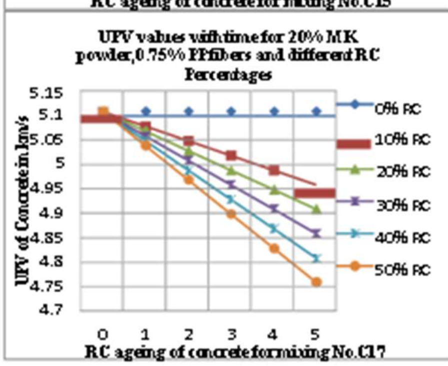

UPV values with time for different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No. C1
UPV values with time for 5% MK powder and different RC Percentages
RC ageing of concrete for mixing No. C2
UPV values with time for 10% MK powder and different RC Percentages
RC ageing of concrete for mixing No. C3
UPV values with time for 15% MK powder and different RC Percentages
RC ageing of concrete for mixing No. C4
UPV values with time for 20% MK powder and different RC Percentages
RC ageing of concrete for mixing No. C5
UPV values with time for 5% MK powder,0.25% PP fibers and different RC Percentages
RC ageing of concrete for mixing No. C6
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

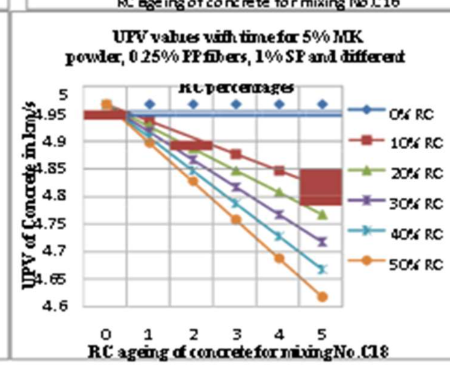

UPV values with time for 20% MK powder,0.5% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C13
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

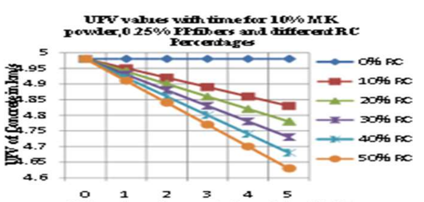

UPV values with time for 5% MK powder,0.75% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C14
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

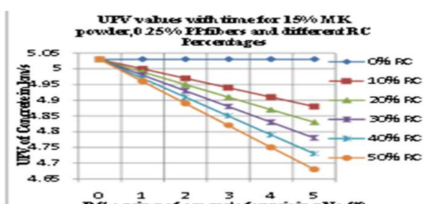

UPV values with time for 10% MK powder,0.75% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C15
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

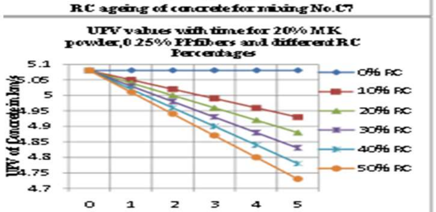

UPV values with time for 15% MK powder,0.75% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C16
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

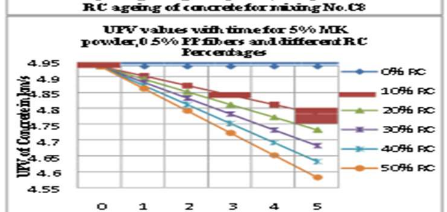

UPV values with time for 20% MK powder,0.75% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C17
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

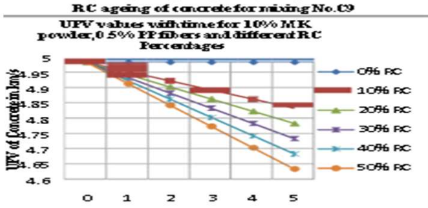

UPV values with time for 5% MK powder, 0.25% PP fibers, 1% SP and different RC percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C18
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

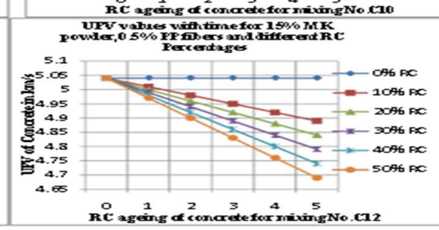

UPV values with time for 10% MK powder,0.25% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C7
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

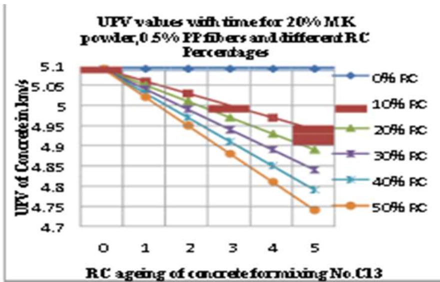

UPV values with time for 15% MK powder,0.25% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C8
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

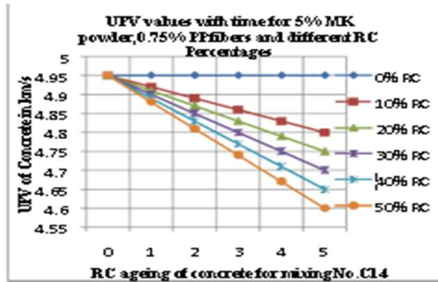

UPV values with time for 20% MK powder,0.25% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C9
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

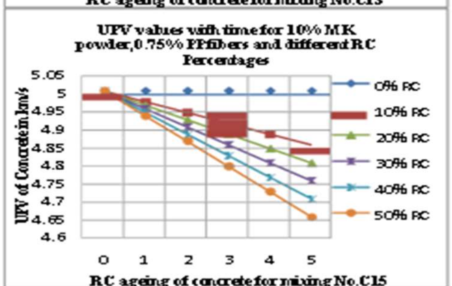

UPV values with time for 5% MK powder,0.5% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C10
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

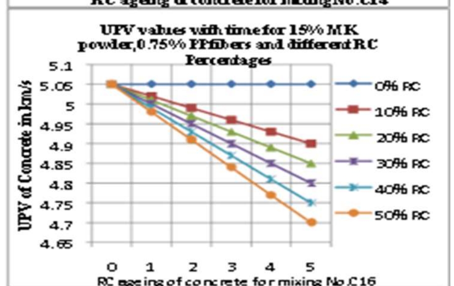

UPV values with time for 10% MK powder,0.5% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C11
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

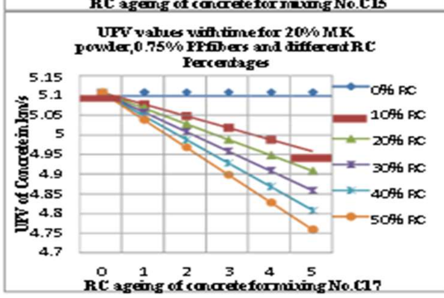

UPV values with time for 15% MK powder,0.5% PP fibers and different RC Percentages
UPV of Concrete in km/s
RC ageing of concrete for mixing No.C12
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC

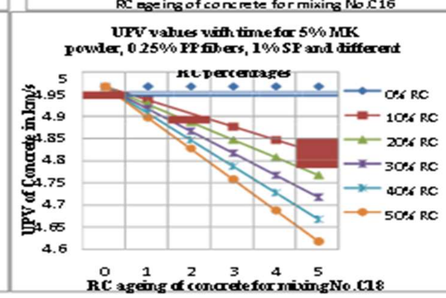

UPV values with time for 20% MK powder,0.5% PP fibers and different RC Percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C13

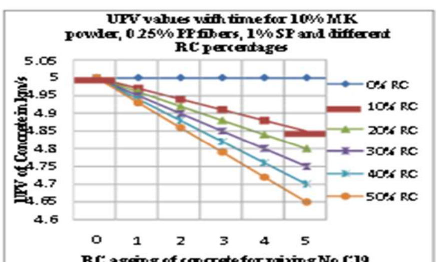

UPV values with time for 5% MK powder,0.75% PP fibers and different RC Percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C14

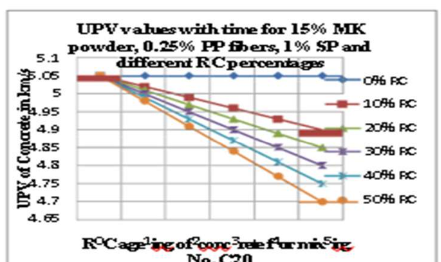

UPV values with time for 10% MK powder,0.75% PP fibers and different RC Percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C15

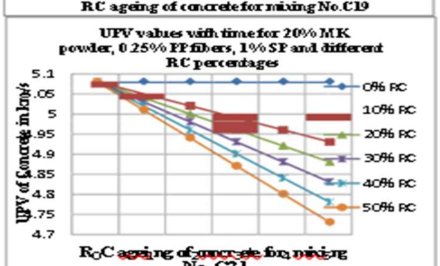

UPV values with time for 15% MK powder,0.75% PP fibers and different RC Percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C16

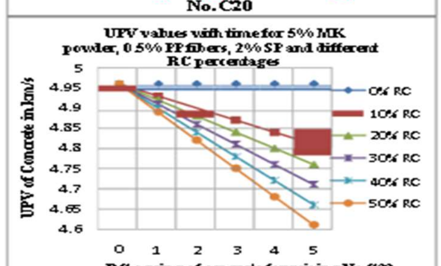

UPV values with time for 20% MK powder,0.75% PP fibers and different RC Percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C17

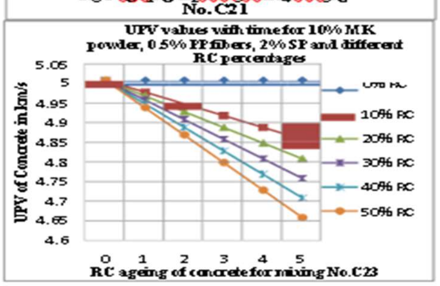

UPV values with time for 5% MK powder, 0.25% PP fibers, 1% SP and different RC percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C18

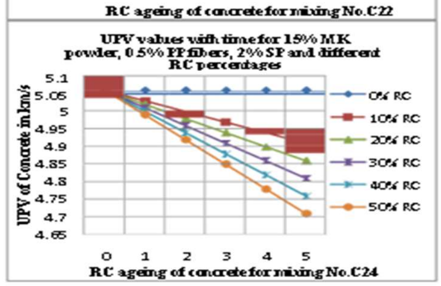

UPV values with time for 10% MK powder, 0.25% PP fibers, 1% SP and different RC percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C19

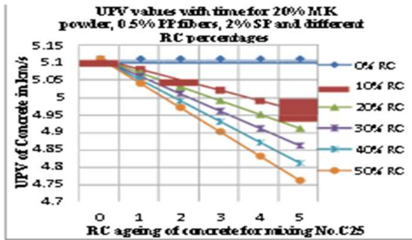

UPV values with time for 15% MK powder, 0.25% PP fibers, 1% SP and different RC percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
No. C20

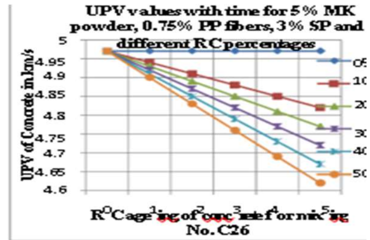

UPV values with time for 20% MK powder, 0.25% PP fibers, 1% SP and different RC percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
No. C21

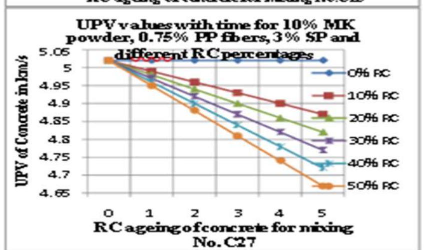

UPV values with time for 5% MK powder, 0.5% PP fibers, 2% SP and different RC percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C22

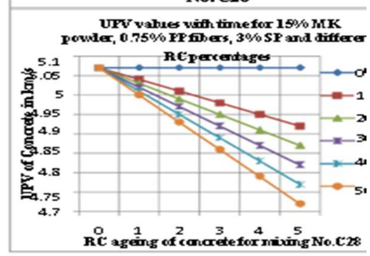

UPV values with time for 10% MK powder, 0.5% PP fibers, 2% SP and different RC percentages
UPV of Concrete in km/s
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C23

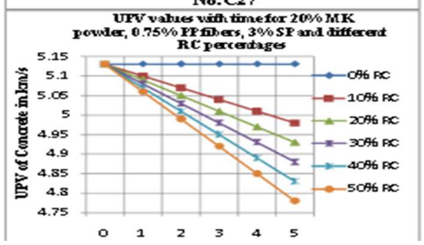

UPV values with time for 15% MK powder, 0.5% PP fibers, 2% SP and different RC percentages
UPV of Concrete in km/s
0% RC
10% RC
20% RC
30% RC
40% RC
50% RC
RC ageing of concrete for mixing No.C24











The incorporation of metakaolin significantly improved UPV values due to its pozzolanic activity and filler effect. As the MKcontent increased to 15%–20%, UPV values generally remained high due to continued pore refinement. At 0.25% fiber dosage, a slight increase in UPV was observed due to improved crack resistance. At 0.5%, the fibers effectively bridged microcracks and enhanced structural continuity, leading to higher pulse velocity values. At 0.75%, further improvements in crack control were achieved; however, excessive fiber content occasionally caused fiber clustering and reduced workability. These effects could create localized discontinuities, resulting in only marginal gains or slight reductions in UPV compared to the optimum fiber dosage.

At approximately 2% dosage, the concrete exhibited improved particle packing and reduced porosity, facilitating faster transmission of ultrasonic waves through the hardened matrix. Lower dosages may not have provided sufficient workability for mixes containing MK and fibers, while higher dosages (above 2%–3%) could lead to segregation or bleeding, creating localized defects that slightly reduced UPV values. At 0–1 hour ageing, the returned concrete retained adequate workability and hydration potential, allowing effective blending with fresh concrete. The resulting matrix was relatively homogeneous and dense, producing higher UPV values. As ageing increased from 2 to 5 hours, the hydration process progressed, reducing workability and the ability of the returned concrete to integrate effectively with fresh concrete. The highest UPV values were generally observed for mixes containing: MK: 5%–10% , PP fibers: 0.5%, Superplasticizer: 2%, Returned concrete ageing: 0–2 hours.

CONCLUSION

Descriptive statistical methods were employed to evaluate the central tendency, variability, and distribution of the results obtained ultrasonic pulse velocity (UPV). Statistical measures showed reduced dispersion of UPV values for optimized mixes, indicating a uniform microstructure with fewer internal defects. The decline in mean UPV values with increasing ageing duration reflected the formation of weaker interfacial transition zones and increased porosity. The incorporation of metakaolin significantly improved UPV values due to its pozzolanic activity and filler effect. As the MK content increased to 15%–20%, UPV values generally remained high due to continued pore refinement. At 0.25% fiber dosage, a slight increase in UPV was observed due to improved crack resistance. At 0.5%, the fibers effectively bridged microcracks and enhanced structural continuity, leading to higher pulse velocity values. At 0.75%, further improvements in crack control were achieved; however, excessive fiber content occasionally caused fiber clustering and reduced workability. These effects could create localized discontinuities, resulting in only marginalgains or slight reductions in UPV compared to the optimum fiber dosage.At approximately 2% dosage, the concrete exhibited improved particle packing and reduced porosity, facilitating faster transmission of ultrasonic waves through the hardened matrix. Lower dosages may not have provided sufficient workability for mixes containing MK and fibers, while higher dosages (above 2%–3%) could lead to segregation or bleeding, creating localized defects that slightly reduced UPV values. At 0–1 hour ageing, the returned concrete retained adequate

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