Use of Cement Kiln Dust and Silica Fume as partial replacement for cement in concrete

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Abstract. Cement is amongst the most polluting materials utilized in the building sector, contributing to a variety of hazardous pollutants, including greenhouse gas emissions. This raises health impacts related to the manufacture of cement. As a result, a substitute substance for conventional cement with low environmental effects and better building characteristics is required. The purpose of the study would be to look at the consequences of using supplementary cementitious materials (SCMS) to substitute cement in a concrete mix partially. This study employed silica fume (SF) and cement kiln dust (CKD) as supplementary cementitious materials. Several concrete mixtures were created by substituting cement by a combination of SF and CKD in three proportions which that 25%, 35%, and 45% within curing periods of (one week and four weeks); the concrete mixtures were tested. The ultrasonic pulse velocity (UPV) test has been used to investigate the concrete mixture's strength in this study. The findings show that the optimal proportion of SF replacement cement and CKD involvement ranged from 25% to 35%. The pulse velocity of specimens improves when the proportion of CKD and SF increases to the optimal percentage, while the larger amounts of these by-products begin to lower the pulse velocity of specimens.

1. Introduction
Cement is an essential part of several forms of the construction industry and is needed in large quantities to create new buildings [1, 2]. Despite the fact that cement has a vital role in the upkeep of civilization and the global financial system, its role in environmental deterioration is well-known [3-5]. Cement factories are estimated to emit 7 to 10% of total carbon dioxide in the air, leading to catastrophic environmental effects such as weather change [6-10]. Therefore, the pollution and consumption of water have risen substantially. The released effluents from concrete plants and casting activities are highly particular due to the chemical composition of conventional concrete [11, 12]. Also, the production of solid waste from the cement industry had resin remarkably, especially from demolishing old concrete structures in the cities (municipal areas) [13-15]. As a result, devastating impacts on the overall quality of water and the degradation of living beings have occurred [16, 17]. Different treatments techniques have been developed to remove many pollutants found in cement plant effluent and other industrial wastewaters [18-20], including filtrations [21-24], coagulation [25-29], electrocoagulation [30-32], sonication-assisted [33, 34], electro-chemical [35-38], electro-physical [39-42], and hybridised methods [43-46]. However, recent studies show an increase in water pollution [47] and freshwater consumption [48-50]. Additionally, these techniques are inadequate to control all anticipated pollutants from cement factories. Because of the huge volumes of carbon dioxide released into the air from the operations related to conventional cement, which is responsible for climate change [51, 52] and global warming [53, 54], as well as contaminants discharged into water bodies, cement manufacture has become a growing subject of attention [1, 55]. As a consequence, reviews show that the development of replacements for cement components, such as silica fume (SF) and cement kiln dust (CKD), is the most viable solution to minimize cement production [9].
Although the utilization of SF and CKD can improve the properties of concrete, Previous studies have proven that the use of these materials also has detrimental effects on the characteristics of concrete. As the percentage of CKD to cement increased, the workability of fresh mixes dropped. Furthermore, as the percentage of CKD increases, the strength of concrete lowers. SCMS materials like SF and CKD are extremely effective and widely employed as cementitious materials because they have large surface surfaces and considerable silica oxides. Earlier research has shown that replacing cement with SF at a proportion of (0.22-.30) is an effective way to maintain the strength of concrete. The ultrasonic pulse velocity (UPV) is a non-destructive testing method used to assess the quality of concrete buildings. This technique, which involves measuring the velocity of the ultrasonic pulse velocity travelling through concrete members, is used to analyze several attributes of concrete, such as quality and strength [56, 57].

This research assessed the effectiveness of SF and CKD as cement substitutes. The main goal of this study is to investigate if these chemicals impact cement characteristics like strength at different curing periods using an ultrasonic pulse velocity test (one and 4) weeks. The ultrasonic pulse technology was used in this study because it is cheap and accurate [58-61], and also it could be used on the surface of the concrete sample or by embedding it in the body of the concrete and connect it to the receiver using wireless technologies [62-66].

2. Experimentation curriculum
In a number of lab tests, the ultrasonic pulse velocity of the concrete mix produced by partially substituting cement with SF and CKD was measured.

2.1. Materials
Cement kiln dust (CKD) is a by-product of the cement industry. It's a finely powdered substance that looks like Portland cement. Usually, CKD is made up of micron-sized grains recovered by combustion processes during the cement clinker manufacturing process [4, 9]. Cement kiln dust CKD is a fine powdery substance that ranges in hue from grey to brown and is relatively homogeneous in dimension. The manufacturing process, dust collecting technique, chemical properties of CKD, and alkali concentration all influence the gradation of CKD. With fly ash and GGBS in various percentages up to 16%, this product could be used as a cementitious substance. If CKD is utilized separately, the resultant combination may have decreased workability, weight, and setting time due to the high alkali concentration [9, 56].

Silica fume is regarded as a by-product of the silicon and ferrosilicon alloy manufacturing industries, and it is produced at extreme temps from quartz reduction. Because of its properties that promote the cementitious reaction, silica fume is widely utilized as a cementitious material in concrete. It is an ultrafine powder consist of 84-96 non-crystalline silica and about 76 percent silicon [4]. The quantity of Silicon dioxide in silica fume is proportional to the kind of alloy generated in the manufacturing facility.

SF partials are extremely tiny and round, roughly 100 times finer than ordinary cement particles. Previous researches show that the SF concrete has reduced bleeding, porosity, and permeability. Because SF oxides react with and consume Calcium hydroxide, which is CH generated during cement hydration. The main binding ingredient in this experiment was Portland Cement, which has strong mechanical characteristics that help the combination to remain coherent. The cement properties used in this study were measured according to BS EN 196-2:2013.

Diagrams 1, 2 and 3 show the chemical composition of SF, CKD, and Portland cement. These features meet the requirements of the BS-EN-197-1(2011) and BS-EN-450-1 standards (2012). The particle size of the grains, and even the chloride and sulfate concentrations, were checked using the BS EN 12620:2002+A1 standard (2008).

Concrete was prepared and treated using impure and organic-free portable water.
Figure 1: The chemical structure of silica fume.

Figure 2: The chemical structure of CKD.

Figure 3: The chemical structure of Portland cement.
2.2. Testing Techniques
For every mix, three prisms (160x40x40 mm) were cast to see how substituting cement with CKD and SF affected the quality of the mortar mixture. These tests are limited to examining items poured from cement mortar. The investigated specimens are then built up of cement in three different concentrations of CKD and SF. Upon completion of the initial setting time of the mixtures, all samples were maintained in good condition, moulded, and placed in water for the cure. BS EN 12504-4:2004 was used to conduct ultrasonic tests on hardening specimens at one week and 4 weeks.

2.3. Design of Mixture
In this study, part of the design process includes determining the proportions of fine aggregate, water, cement, and materials additive ingredients for the control concrete mixes. To match conventional rating curves, fine aggregates have been utilized in the mixture design. The water to binder ratio was 0.4 in all of the mixes. The ratio of sand to a binder that used in this study was 2.4 in all of the mixes. The percentage of each component of the mix is shown in figure (4).

![Figure 4: The Mix design.](image)

The ultrasonic pulses are sent through the sample to be examined, and the time required for the pulse to permeate the specimen is measured. A high speed implies that the examined structure is of top condition, whereas a low velocity suggests that the examined structure is of bad condition. Pulse producers, a transducer for converting electronic pulses into mechanical pulses with vibrations of 40 to 50 kHz, and a pulses detector are all used in UPV assessment. The velocities of pulses are determined as follows:

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\text{Pulse velocity} = \frac{\text{The specimen's thickness}}{\text{The required time for the pulse to penetrate the sample}}
\] (1)

3. Results
The results of examining a control concrete mix with substitute material of cement with varying quantities of SF and CKD at different curing periods are explained in Table 1 and Figure 5.
Table 1. One week and 4 weeks ultrasonic pulse velocity testing.

| Number of tests | Cement (%) | SF (%) | CKD (%) | UPV test (m/s) |
|-----------------|------------|--------|---------|---------------|
| MIX1            | 100        | 0      | 0       | 3828          | 4008 |
| MIX2            | 75         | 12.5   | 12.5    | 3850          | 4102 |
| MIX3            | 65         | 17.5   | 17.5    | 3785          | 4055 |
| MIX4            | 55         | 22.5   | 22.5    | 3578          | 3863 |

The main conclusions that may be drawn from the findings of this study are listed below:
The use of a partial replacement of SF and CKD in mixes has been demonstrated to lower concrete pulse velocity values by a tiny portion. In comparison to the control mixture, the pulse velocity of mixtures two and three have been enhanced by 2.3% and 11% after 4 weeks of curing, respectively. Whereas mixture number four decrease the velocity by 3.6 %. This would be based on the view that just a little amount of cementitious materials is required to fill empty fields in the mortar, therefore improving its mechanical properties. Previous studies showed that CKD and SF are ineffectual substances at first and require time to connect with cement components. Therefore, it can be noted that After one week of curing, using 45 percent of a partial substitute decreases the pulse velocity measurements of the mix by around 6.5 percent. At the same time, this value fell to 3.6 after curing for 4 weeks. This is because extra cementitious ingredients reduce concrete compressive strength, which is a key component of the manufacture gel (C-S-H) in concrete. After sitting time, they interact and utilize the moisture components, Ca (OH)2, to allow and initiate hydration of silica fume and cement kiln dust.

Figure 5. Ultrasonic Pulse Velocity Monitoring with one week and 4 weeks curing day mixtures.

According to the observations, specimens that were treated for four weeks had greater pulse velocity readings. That was based on the fact that the curing time improves C-S-H, which leads to a decline in the number of interior gaps or porosity in the conventional concrete, which impacts the properties of concrete and enhances its capacity to withstand compressive stresses.
The Ultrasonic Pulse Velocity method, a non-destructive test methodology, was used in this investigation. As a result, more sophisticated procedures for verifying concrete properties are now accessible. Sensors were used to monitor microcracks, concrete humidity, and other applications in the past. Additional research might utilize the same approach.
4. Conclusions
According to the results of the analysis, it could be stated that as the fraction of cement substituted by silica fume and CKD in concrete increases, the pulse velocity values decrease. The material quality, on the other hand, shows a little improvement with a restricted replacement rate. Whenever the cement in a combination is replaced with extra material, a longer curing period results in a higher-quality specimen.

The use of 25 ~ 35 percent additional cementitious material as a cement substitution for cement could be appropriate proportions, with an increment in this ratio resulting in a slight improvement in quality assessment. Moreover, the used strategy in this research was Ultrasonic Pulse Velocity, which is a traditional instrument; consequently, more current approaches, such as Laser Scanners, are recommended to evaluate the mechanical properties of concrete.

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