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# Evaluating the Durability of Green Cement Mortar Using Ultrasonic Pulse Velocity

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**Abstract.** Various experimental studies have highlighted the negative consequences of Portland cement on health and the environment, such as toxic emissions and alkaline sewage. The development of environmentally acceptable substitutes for cement is thus one of the objectives of current investigations. The proposed environmental alternatives to cement, nevertheless, might have detrimental impacts on the concrete's characteristics. This investigation intends to study the suitability as alternatives to cement in cement mortar, using industrial wastes like silica fume and cement kiln dust. As a replacement for cement, the cement mortars developed in this research continue from 0% to 60% silica fume and cement kiln dust. Ultrasonic pulse velocity tests at 1 to 4 weeks of age were conducted on hardened specimens. The findings showed that a low reduction in the pulse velocity resulted from high proportions of silica fume and cement kiln dust replacements, whereas an improvement in the characteristics of the mortars with low replacement ratios. Using low kiln dust and silica fume of 20 to 40%, the durability of mortars may increase.

**Keywords:** Green mortar, by-products, Silica fume, mechanical properties.

## 1. Introduction

Concrete is of fundamental element in the building sector in our age; the essential element in the concrete mix is Portland Cement (PC) [1, 2]. Although its essential importance for preserving civilization and the financial system, its function in environmental damage is well established [3, 4]. The findings suggest that cement manufacturers release 6 to 8 percent carbon dioxide in the air [5, 6], resulting in catastrophic environmental impacts such as climate change [7, 8]. Climate change has led to enormous changes in water use [9, 10] and contamination of freshwater sources [9, 11]. Furthermore, the disposal of sewer water from concrete factories and moulding operations is of extremely fundamental importance owing to the chemical composition of PC [12, 13], which has devastating consequences for the quality of water supply and mass killing in that species of living organisms [14, 15]. Several contaminants have been detected in concrete plant sewage like phenols [16, 17], turbidity [18, 19], Phosphate [20, 21], nitrates [22, 23] and metals [24-26]. These pollutants that resulted from the cement industries played a significant role in the global warming phenomenon [27-29] that threatens the existence of human beings due to the severe water shortage [30-32]. Therefore, various types of technologies and strategies have been designed to eliminate the effects of this industry on the environment, such as recycling of by-products in cement or concrete [33] and treatment of the effluents using different methods, including but limited to electrocoagulation reactors [34-38], electro-chemical units [39-42], filtration methods [43-47] and combined methods [48-51].



These approaches remain unable to manage the entire anticipated concrete production pollution [52, 53]. Concrete manufacturing has become an increasing problem because of considerable greenhouse gases and sewage emitted from concrete production activities to atmospheric and aquatic bodies. Thus, researchers suggested that developing (cementitious material) substitutes that substitute for cement, like silica fume (SF) and kiln dust (KD) are the sustainable answer to the cement industry difficulties [54]. The use of SF and KD has negative impacts on concrete mortar, although it is also recognized that these ingredients can increase their performance. In general, when the ratio of KD to cement increases, the working ability of fresh mixes decreases. Furthermore, the mortar mechanical properties similarly decrease by raising the KD [54, 55]. The pozzolanic substances, like SF, are highly reactive and extensively used in concrete because of the large surface area and the high silica oxide content. The materials are ultrafine powdered. It is observed that SF is suitable for substituting the PC with about 0.25 to 0.33 (weight proportions) while maintaining the performance [56].

An in situ, non-destructive test method for measuring the quality of concrete buildings is the ultrasonic pulse velocity test (UPVT). In this approach, concrete strengths and characteristics are measured by measuring the speed of the pulse transmitted through concrete [52, 57]. The effectiveness of SF and KD (in varied proportions) as PC substitutes was evaluated in this study. The main objective of the study is to assess the impacts of the usage of these components for cement mortar durability at various treatment ages between 7 days and 28 days with the use of the UPVT.

## 2. Experimentation

Several experiments to evaluate the ultrasonic pulse velocities of the concrete mortar by part replacement of the KD and the SF were undertaken in these experimental studies. Mix proportions and KD and SF proportions employed in this study are subsequently discussed.

### 2.1. Test Constituents

The KD is a cement industry's by-product, where it is disposed of through waste disposal. The KD is a finely powdered substance that includes active Calcium oxide, and its primary characteristics rely on the collecting system's locations, the kind of works, the dust collecting plant, and the sorts of fuel used during the manufacturing process. KD comprises raw, partly calcinated feed, clinch dust, free calcareous residue, and salt alkaline, halide, and other volatile chemicals. KD contains unresponsive raw feed. The resulting mortar might suffer a decrease in workability, setting time, and strengths due to the high alkalis content if only KD is used as cementitious materials.

SF is a by-product in the manufacture of silicon alloys. It is frequently used as a material additive in concrete since its physical and chemical characteristics encourage cement reactions. The strength of the SF is significantly increased when added to concrete, and the lifespan of the concrete can be improved. The smoke released from burners is gathered as SF in the silicon and alloys industries rather than disposed of in sites of slurry. The SF nanoparticles with a mean size of approximately 1/1000th of the typical cement particle sizes are very fine. Hence, it is a particularly reactive cementitious material because of its micro-sizes, substantial surface, and silica oxides concentration.

Due to the strong adhesive qualities that link it with other elements in the mix, the ordinary Portland cement was selected as the primary binding material for this research. The BS EN 196-2:2013 was followed to test the characteristics of the concrete.

Table 1 shows the chemical characteristics of the used cementitious materials (PC and SF). The characteristics of these materials comply with BS-EN-450-1(2012), and BS-EN-197-1(2011).

Local river sands (<5 mm) have been employed as fine aggregates in this investigation. The characteristics of the fine aggregate (particle size distribution, chloride, and sulfate content) were measured in accordance with the BS EN 12620:2002+A1 (2008). freshwater free of organic particles has also been used to mix and cure concrete.

**Table 1.** PC, KD, and SF chemicals components.

Component (%)	Sample		
	PC	KD	SF
Al <sub>2</sub> O <sub>3</sub>	14.92	2.31	0.37
CaO	62.81	45.32	0.31
Cl	0.02	7.98	0.04
Fe <sub>2</sub> O <sub>3</sub>	5.18	3.69	1.5
K <sub>2</sub> O	1.7	5.7	0.6
L.O.I	0.31	17.4	1.59
MgO	3.39	1.51	0.42
Na <sub>2</sub> O	0.2	0.29	0.39
SiO <sub>2</sub>	20.58	12.29	93.81
SO <sub>3</sub>	2.09	2.62	0.22

### 2.2. Mixture Design

The design method in this experimental investigation covers the casting of concrete mixtures by selecting the quantity of cement, moisture, aggregates, and material additive ingredients. The fine aggregates were chosen to fit the conventional gradation curve. For all mixtures, 0.4 is chosen for the water to binder ratio (Cement + CKD +SF) while the sand-to-binding ratio was between one part and 2.5 parts of sand. Table 2 shows the quantity of every element and the percentage of the design of the mixture.

**Table 2.** Experimental mixture design.

Mixture No.	PC (%)	KD (%)	SF (%)
1	100	0	0
2	60	20	20
3	50	25	25
4	40	30	30

The UPVT is started by delivering an ultrasonic pulse through the specimen and by estimating the time necessary to pierce the sample by the pulse. High speed means high concrete sample quality, whereas slower speed suggests a bad concrete sample quality. The pump generator, the transducer for the transformation of the electronic pulses into a mechanical pulse with a range of 40 to 50 kHz, together with the pulse receiver, comprises UPVT equipment/tools. The speeds of the pulse are determined accordingly:

$$UPV = \frac{\text{Sample thickness}}{\text{Travel time}} \quad (1)$$

### 2.3. Test approaches

For each case, three prisms (160x40x40mm) were prepared to investigate the impact of KD and SF substitution on the strength of the mortar mixture. In these instances, materials are tested exclusively using cement mortar. The items examined are then constructed with three KD and SF ratios. All specimens were maintained and demoulded and put in water for cure after one day of casting. Ultrasonic testing was done at 7, 14, and 28 days in accordance with BS EN 12504-4:2004 on hardened specimens.

## 3. Results

Table 3 lists the findings of experiments carried out with respect to the controlled cement mortar and specimens with partially replacing PC of varying KD and SF percentages at various curing times.

**Table 3.** The outcome of UVPT at 7, 14, and 28 days old.

Mixture No.	PC (%)	KD (%)	SF (%)	UPVT m/s		
				7 days	14 days	28 days
1	100	0	0	3798	3891	3974
2	60	20	20	3818	3952	4100
3	50	25	25	3458	3668	3789
4	40	30	30	3028	3281	3441

The results revealed that a minor drop of the pulse velocity of cement mortar typically results in a cement substitution of KD and SF in mixtures. It is nonetheless clear that contrasted with others including the second mixture exhibits an increase in UPVT. For instance, the variation in UPVT values of the three mixtures was +3%, -6%, and -14% for the first mixture, at 28 days of curing as shown in Figures 1. This explains why the small quantity of cemented materials may fill the gap in the mortar and improve its mechanical characteristics.

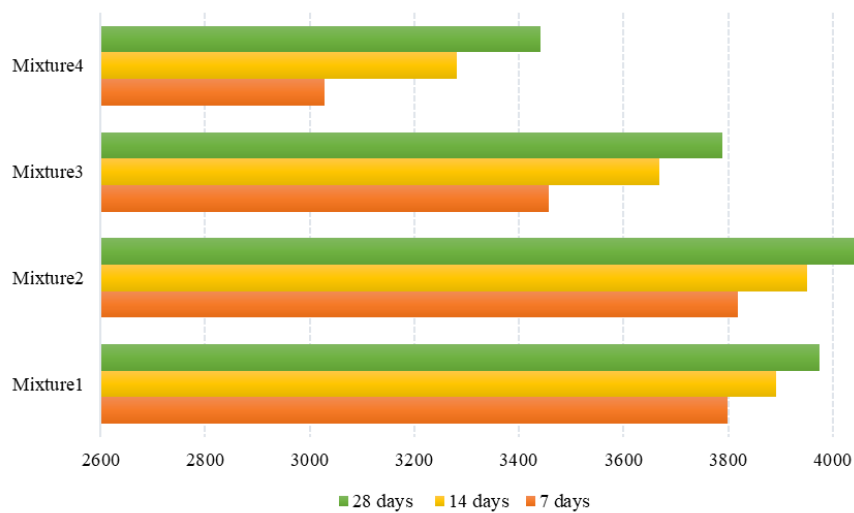


Figure 1: The UPVTs at ages 7,14 and 28 days for all mixtures

However, it can be shown that the pulse velocity of mortar falls by about 20% at a time of seven days when 60% of the parts replaced component is used. But on the other hand, the KD and SF inactive material in the early years was 11 percent lower at 28 curing times, and it took time to interact with the cement components. To summarise, approximately 20 percent can be replaced partially by KD and SF to achieve good sustainability and reduce the environment's pollution. This could be because cementitious materials decrease the cementitious mortar compression capacity, which represents a major factor in mortar manufacturing gel. Due to these effects, Ca(OH)<sub>2</sub> activates and initiates hydration of KD and SF after hydration of the cement.

The findings for specimens indicated greater pulse velocities that cured for 28 days. This may also be supported by the fact that the curing ages impact the gain and growth of the gel, which in turn increases the density of the concrete and the toughness of the mixes by lowering the volume of interior voids or permeability of the mortar construction. To illustrate, 7% and 14% increased pulse velocity values for 14 and 28 days for mixture 4, compared to 7 days for the identical samples.

It was noticed that the mechanical properties of the prepared mortar were checked here using ultrasonic pulse velocity method that could have some drawbacks; therefore, it is noteworthy to mention that there are new technologies are currently in use (but in limited scales) to measure the mechanical properties of the concrete and cracking process, such as the embedded sensors [58, 59], surface sensors [59-61], and even wireless methods [62, 63]. These methods could be used in future studies. Also, the treatment plant has been modified in some studies to achieve cost-effectiveness [64, 65].

#### 4. Conclusions

Depending on the outcomes of this investigation, the combined PC-KD and -SF substitution in mortars reduces pulse speed and, in turn, the durability of the mortars as the proportion increases. The durability of the samples, however, is somewhat improved in small volume fractions. Whenever the cement is replaced with more materials in the mixture, an increase in the treatment time will provide greater pulse velocity values. 20 percent can be considered appropriate as supplementary cementitious material; when this increases, the pulse velocity of the mortar slightly decreases.

For future studies, new technologies, such as the embedded sensors, surface sensors, and even wireless methods, are recommended to evaluate the mechanical properties of concrete or mortar. Also, the treatment plant could be modified (such as using baffle plates) to achieve cost-effectiveness.

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