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# Effects of the Cement Kiln Dust on the Ultrasonic Wave Velocity in the cement mortar

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**Abstract:** The mixture of the traditional cement mortar is mainly made from three components; ordinary Portland cement (OPC), sand and water. However, the OPC has many proven adverse effects on the environment and economy, such as harmful emissions and depletion of natural sources. Therefore, some studies try to minimise the use of OPC in cement mortar by providing and testing some alternatives, such as Cement Kiln Dust (CKD). The available studies confirm the applicability of CKD as a promising alternative to OPC in cement mortar. This study will explore the effects of different percentages of CKD (10-30% of OPC amount) on the Ultrasonic Pulse Velocity (UPV) in the cement mortar's properties. This study showed that adding CKD as a partial replacement for OPC decreases the UPV compared to the reference sample.

**Keywords:** UPV, CKD, cement mortar, compressive strength.

## 1. Introduction

The use of cement-based products in the infrastructures of the cities is a major concern due to the serious effects of cement on the environment and health; it is proven the cement industry is a major source of carbon monoxide and Carbone dioxide in the atmosphere (Hasanbeigi et al., 2012), for example, the production of one tone of Ordinary Portland Cement (OPC) generates a tone of the carbon dioxide (Al-Faluji et al., 2021). This high production of CO2 gas represents about 5–7% of the total CO2 in the atmosphere (Hasanbeigi et al., 2012). Additionally, the cement industry produces high amounts of nitrogen and sulphur oxides and particulates, which seriously damages the air quality (Madsen et al., 2004).

The production of greenhouse gases from the cement industry contributes to climate change nowadays, such as the increase the in the weather temperatures, change in the precipitations, and lack of water (Emetere and Dania, 2019, Chen et al., 2015). Additionally, the emissions of the cement industry cause global warming, losing the ozone layer, acidic rains, and minimising crop productivity (Pariyar et al., 2013). Regarding the economy, the cement industry consumes huge amounts of non-renewable resources like raw materials and fossil fuels.

These gases affect not only the air quality but also serious health; for example, the gases produced by the cement industry cause chest and eye infections, tuberculosis and asthma (Emetere and Dania, 2019).

Therefore, minimising the use of the OPC in the infrastructure is the aim of many studies nowadays. For example, Duan et al. (2013) used two industrial by-products, which are ground granulated blast furnace slags (GGBS) and metakaolins (MK), as a replacement for OPC in concrete and studied their effects on the mechanical and physical properties of concrete. Additionally, their effects on the pores structures and microhardness and morphology of the interfacial transition zones (ITZ) were studied. The results proved that GGBS and MK positively impacted concrete pores refinement and ITZ. Torkaman et al. (2014) partially replaced the OPC in concrete with three wastes, wood fibre wastes (WFW), ashes of rice husk (RHA), and limestone powder wastes (LPW), to produce light-weight concrete blocks. The changes in the mechanical and physical properties of the concrete were studied, and it was found that using WFW, RHA, and LPW as a replacement for OPC minimised the compressive strength of the concrete. Nevertheless, adding these wastes with a ratio of 25 wt% of OPC improved the energy absorption of the concrete. It was found that adding the three wastes with a ratio of not more than 5% of the OPC did not decrease the mechanical and physical properties. Kabay et al. (2015) used two materials, pumice powders (PP) and fly ashes (FA), to partially replace the cement in the concrete. The effects of the PP and FA on the mechanical and physical properties of concrete were studied, and it was found that the compressive strength of the concrete was not encouraging at the early ages. Still, it was improved at late ages. Furthermore, the PP and FA minimised the concrete's water adsorption and porosity and improved the concrete's resistivity to magnesium sulphate.

The cement industry around the world hugely produces cement kiln dust (CKD), and because of its chemical properties and its huge production, it encouraged researchers to search for possible ways to recycle and reuse it in different applications. For example, Shoaei et al. (2017) used CKD as a partial replacement for OPC to produce light-weight concrete. They investigated the effects of CKD on the physical and mechanical of light-weight concrete. It was found that adding the CKD to the concrete minimises the workability and elasticity of the concrete compared to the reference sample, but it improved the compressive strength when a reasonable amount of CKD was used. It was found replacing 10% of OPC with CKD does impact the properties of concrete seriously. The effects of CKD on the properties of concrete were also studied by Alharthi et al. (2021) . This study

investigated the effects of replacing the OPC with CKD (on the compressive and tensile strength and voids ratio). The results proved a decrease in the compressive and tensile strengths because of the CKD and an increase in the voids ratio. It was found that the best replacement ratio was 5%.

The results of the studies in this introduction showed using limited ratios of CKD as a replacement for OPC in concrete is useful. This study will explore the effects of different percentages of CKD (10-30% of OPC amount) on the Ultrasonic Pulse Velocity (UPV) in the cement mortar's properties.

## 2. Materials and Methods

Reference cement mortar samples (S1) were prepared by mixing OPC with sand and water; the used percentage of water 40% of the cement weight (0.4 Water/Cement), while the used ratio of sand was 250% of the cement weight (2.5 Sand/Cement). The used OPC used in this study complies with BS EN 197-1.


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The reference samples were cast in the moulds (10 cm X 10 cm X 10cm) and left in the laboratory for 24 hours to gain the required hardness. After that, the reference samples were de-moulded and submerged in clean water for 28 days to be tested for UPV at different ages, 1, 3, 7, 14, 21 and 28 days.

Then, the OPC was replaced by the CKD at three different ratios, as shown in Table 1, using the same ratios of sand and water (0.4 Water/Cement and 2.5 Sand/Cement). The Ultrasonic Pulse Velocity test was performed according to the standard methods BS EN 1881-203.

**Table 1.** Mix design for the cement mortar samples.

| Samples | Ratios | | | |
|---|---|---|---|---|
| | OPC | CKD | Water/cement | Sand/Cement |
| S1 samples (Reference) | 100 | 0 | 0.4 | 2.5 |
| S2 samples | 90 | 10 | 0.4 | 2.5 |
| S3 samples | 80 | 20 | 0.4 | 2.5 |
| S4 samples | 70 | 30 | 0.4 | 2.5 |

The test was carried out using a UPV device (U200, 5~500KHz); the transducers of the UPV device were placed firmly on parallel faces of the concrete samples, as shown in Figure 1. Samples were taken out from the curing tank at the desired age (1, 3, 7, 14, 21 and 28 days) and dried with a towel to remove the extra moisture from their surfaces before the UPV test.

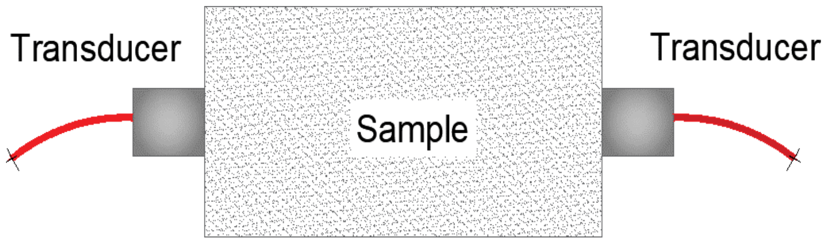


**Figure 1.** UPV testing setup.

## 3. Results

Three samples of concrete of each mix (reference and CKD samples) were taken out from the curing tank at the desired age (1, 3, 7, 14, 21 and 28 days) and tested using the UPV device according to the procedures stated in the materials and methods.

The results of these tests are shown in Figure 2. It can be observed from the figure below that the velocity of the ultrasonic waves decreases with the increase of the used replacement ratio of the CKD; for example, the UPV at the age of 28 days was 4300 m/sec in the reference


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samples, but it decreased to the vicinity of 4200, 4100, and 3800 m/sec when 10, 20 and 30% of the OPC were replaced with CKD. The decrease in the UPV with the increase in the added percentage of CKD is related to the ability of the CKD to increase the air voids in the cement mortar or concrete, which causes a decrease in the velocity of the ultrasonic wave.

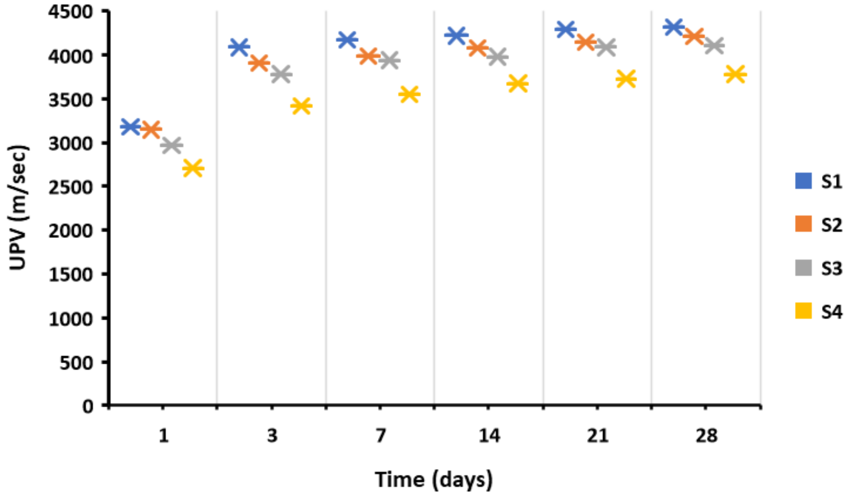


**Figure 2.** The progress in the UPV with the percentages of CKD.

The increase in the air voids indicates good thermal and sonic insulation efficiency. Therefore, it can be concluded from the results of this work that the addition of the CKD is not only useful for the improvement of the environment and cost-effectiveness of the cement mortar, but it also improves some important properties of the cement-based products, such as the thermal and sonic insulation efficiency. Also, it can be concluded that the UPV test could be of good application in investigating thermal and sonic efficiency.

## 1. Conclusions

The current study aimed to investigate the effects of replacing OPC with CKD on the velocity of the ultrasonic waves in the cement mortar. The results of this study showed:

1. The OPC cement mortar samples have the highest efficiency in transmitting ultrasonic waves.
2. Replacing the OPC in the cement mortar samples with different percentages of CKD decreased the velocity of the ultrasonic waves.
3. Adding CKD to the cement mortar improved the thermal and sonic insulation efficiency.
4. UPV is a good tool for examining the air voids within the cement mortar samples.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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