**Investigation of Properties of Waste Concrete Powder Substituted Cement-based Mortars**

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| **Abstract**  As a result of the demolition of buildings, that have reached the end of their lifespan and do not meet current needs, whether due to urban transformation activities or the damage from natural disasters, a large amount of construction and demolition waste (CDW) is generated. However, urbanization, industrialization and rapid population growth and rising construction activities continue to increase the demand for cement day by day. This study aimed to assess the properties of CDW-incorporated cement-based mortars and evaluate CDW’s potential as a substitute to cement. In this study, the properties of mortars produced by replacing cement with 10%, 20% and 30% waste concrete powder were compared with reference samples (without waste concrete powder) through workability, flexural strength, compressive strength and ultrasonic pulse velocity tests. The substitution of waste concrete powder in mortar mixtures reduced 7- and 28-day flexural and compressive strength values. However, the strength values of samples with a 10% substitution rate were close to those of the reference samples. It was observed that the ultrasonic pulse velocity measurements taken after 28 days correlated with the compressive strength values. As the strength of the samples increased, the ultrasonic pulse speeds increased. As a result, it was concluded that waste concrete powder can be used in cement-based systems and the properties of mortars prepared with varying ratios of concrete waste as a substitute for cement in concrete should be examined in greater detail. |
| Keywords: Waste concrete powder, compressive strength, flexural strength, ultrasonic pulse velocity |

1. **Introduction**

It is estimated that construction and demolition waste represents at least 30% of the total solid waste produced in the world, and therefore, the construction industry is considered one of the largest producers of solid waste worldwide [1]. Engineering studies today aim to both improve the strength and durability of concrete and minimize the negative impacts on the environment. Recycling construction and demolition waste, which occurs as a result of demolition of buildings that have completed their lifespan through urban transformation and natural disasters such as earthquakes, is very important both economically and environmentally [2,3]. The huge demand for concrete worldwide causes high greenhouse gas emissions [4]. In addition to the need for tons of aggregate to meet the current market for concrete, a large amount of fossil fuel resources are required to be used in cement furnaces. Therefore, recycling of concrete waste which is the largest portion of the construction and demolition waste generated can contribute to the gradual reduction of the utilization of fossil fuels [5]. Adding this waste into cement as substitute materials can improve the properties of concrete, reduce the pressure on natural resources [6], and positively reduce greenhouse gas emissions [7]. The large amount of concrete waste generated in recent years, which has caused negative environmental problems, makes it necessary to turn this waste into a recyclable building material [8]. This study aimed to determine the properties of construction and demolition waste and evaluate its usability as an alternative to cement use.

1. **Materials and Methods** 
   1. **Materials**

According to the TS EN 196-1 standard, cement mortars were prepared by replacing cement with 10%, 20%, and 30% waste concrete powder. The chemical compositions of the cement and waste concrete powder used in the study are given in Table 1. CEM I 42.5 R type Portland cement by TS EN 197-1 was used in the study.

The concrete rubble fragments obtained from the demolition process of the buildings in urban transformation areas were ground until reached approximately the fineness of the cement to obtain the waste concrete powder. Sand used in this study was CEN reference sand mentioned in the TS EN 196-1 standard.

**Table 1.** Chemical compositions of materials

|  |  |  |
| --- | --- | --- |
| **Chemical Composition** | **Cement (%)** | **Waste Concrete Powder (%)** |
| SiO₂ | 24.30 | 31.6 |
| Al₂O₃ | 3.96 | 4.8 |
| Fe₂O₃ | 3.34 | 3.5 |
| CaO | 59.98 | 31.5 |
| MgO | 2.01 | 5.1 |
| SO₃ | 4.20 | 0.9 |
| K₂O | 0.42 | 0.7 |
| Na₂O | 0.35 | 0.45 |
| TiO₂ | - | 0.2 |
| P₂O₅ | - | 0.1 |
| Loss on ignition | 1.43 | 21.1 |

* 1. **Preparation of Mixtures**

The material quantities of mortar samples prepared according to the TS EN 196 – 1 standard are given in Table 2. In the table, “WCP” refers to waste concrete powder, while “0, 10, 20, and 30” refer to the substitution rate.

**Table 2.** Material quantities of mortar mixtures

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sample Code** | **Cement (Gram)** | **WCP (Gram)** | **Aggregate (Gram)** | **Water (Gram)** |
| WCP0 | 450 | 0 | 1350 | 225 |
| WCP10 | 405 | 45 | 1350 | 225 |
| WCP20 | 360 | 90 | 1350 | 225 |
| WCP30 | 315 | 135 | 1350 | 225 |

* 1. **Testing of Samples**

Flow table, compressive strength, flexural strength, and ultrasonic pulse velocity tests were performed on the samples.

* + 1. **Flow Table Test**

The workability conditions of cement mortars were examined with the flow table test by ASTM C1437 standard.

* + 1. **Flexural Strength Test**

At the end of 7 and 28 days, 40×40×160 mm prism-shaped samples were subjected to a flexural load at a constant speed of 50 ± 10 N/s according to TS EN 196-1 standard.

* + 1. **Compressive Strength Test**

Compressive strength tests were performed at the end of 7 and 28 days of the curing process by TS EN 196-1 standard by applying a load at a constant speed of 2400 ± 200 N/s.

* + 1. **Ultrasonic Pulse Velocity Test**

Ultrasonic pulse velocity test was performed on at least three oven-dried prism-shaped samples of 50 x 50 x 50 mm, and the average values were determined as the result. The values obtained from the device were used for direct comparison without any processing.

1. **Results and Discussion** 
   1. **Flow Table Test**

The results obtained from the flow table test conducted to determine the workability properties of waste concrete powder substituted cement mortars are given in Figure 1. according to the flow table test results in the graph, it was observed that the initial flow values were equal and 100 mm for all samples. The highest fluidity was in the WCP0-coded cement mortar without additives, with a final flow value of 148.5 mm, while the lowest fluidity was in the WCP30-coded cement mortar, with a final flow value of 141 mm. It is thought that this situation is because the water absorption capacity of waste concrete powder is higher than that of cement.

**Figure 1**. Flow table values of mortar mixtures.

* 1. **Compressive and Flexural Strength Test**

Compressive and flexural strength tests were performed on the prepared samples at the end of the 7th and 28th days, and the results are presented in Figure 2. In some studies in the literature, it has been stated that the mechanical properties of cement-based materials, where waste concrete powder has low reactivity, will decrease as the replacement rate increases [9-10]. When the results are examined, the highest compressive strength test results were obtained from the WCP0 sample as 44.55 MPa in 7-day samples and 52.14 MPa in 28-day samples. The highest flexural strength results of the samples were obtained as 5.74 MPa for the 7th day and 6.55 MPa for the 28th day in the WCP0 sample. It is seen that the strength values at the end of 28 days are very close to the highest strength of the WCP10 sample. It is seen that the lowest strengths are in the WCP30 sample. This shows that there is a decrease in strength with the decrease in the amount of cement.

**Figure 2.** 7th and 28th day flexural and compressive strength values of mortar mixtures.

* 1. **Ultrasonic Pulse Velocity Test**

The results obtained from the ultrasonic pulse velocity test performed for 28-day-old mortar samples are given in Figure 3. The ultrasonic pulse velocity of concrete increases in systems with less porosity and a denser microstructure [11]. Based on this, when the ultrasonic pulse velocity values are examined, it can be said that the results obtained are parallel to the mechanical test results. In other words, the highest ultrasonic pulse velocity value was obtained in the WCP0 sample, which exhibited the highest mechanical performance.

**Figure 3.** Ultrasonic pulse velocity values of mortar mixtures on the 28th day.

1. **Conclusion**

In this study, waste concrete powder was substituted instead of cement at 10%, 20% and 30% rates. Fresh property evaluation, mechanical property tests, and ultrasonic pulse velocity measurements were performed on the samples. The findings obtained as a result of the study are as follows:

• Waste concrete powder substitution in mortar mixtures decreased fluidity.

• Waste concrete powder substitution in mortar mixtures decreased 7- and 28-day flexural and compressive strength values. However, the strength values of the samples with a 10% substitution rate are close to the reference samples.

• As a result of the ultrasonic pulse velocity measurements performed at the end of 28 days, it was observed that the values were parallel to the compressive strength values. The ultrasonic pulse velocities increased as the strength of the samples increased.

As a result, recycling construction and demolition waste can provide great economic and environmental benefits. Therefore, it was concluded that waste concrete powder can be used in cement-based systems, and the properties of mortars prepared with varying ratios of concrete waste as a substitute for cement in concrete should be examined in greater detail.

**References**

1. Soto-Paz J., Arroyo O., Brayan A., Torres-Guevara L.H., Parra-Orobio B.A., Casallas-Ojeda M. 2023. The circular economy in the construction and demolition waste management: A comparative analysis in emerging and developed countries, *Journal of Building Engineering*, 78,107724.
2. Kul A., Ozel B.H., Ulugol H., Ozcelikci E., Yildirim G., Gunal M.F., Sahmaran M. 2023. Characterization and life cycle assessment of geopolymer mortars with masonry units and recycled concrete aggregates assorted from construction and demolition waste, *Journal of Building Engineering*, 78, 107546.
3. Shi Y., Xu J. 2021. BIM-based information system for econo-enviro-friendly end-of-life disposal of construction and demolition waste. Automation in Construction, 125,10361.
4. Miller S.A., Moore F.C. 2020. Climate and health damages from global concrete production, *Nature Climate Change*.10,439–443.
5. Zhang C., Hu M., Meide M., Maio F.D., Yang X., Gao X., Li K., Zhao H., Li C. 2023. Life cycle assessment of material footprint in recycling: A case of concrete recycling. *Waste Management.* 155, 311–319.
6. Ashraf, M., Iqbal, M. F., Rauf, M., Ashraf, M. U., Ulhaq, A., Muhammad, H., & Liu, Q. F. (2022). Developing a sustainable concrete incorporating bentonite clay and silica fume: Mechanical and durability performance. *Journal of Cleaner Production*, *337*, 130315.
7. Knight, K. A., Cunningham, P. R., & Miller, S. A. (2023). Optimizing supplementary cementitious material replacement to minimize the environmental impacts of concrete. *Cement and Concrete Composites*, *139*, 105049.
8. Tuğla, R. K. (2020). Kendiliğinden Yerleşen Betonda Atık Beton Tozu Etkisinin İncelenmesi. *Bayburt Üniversitesi Fen Bilimleri Dergisi*, *3*(1), 53-62.
9. Xiao, J., Ma, Z., Sui, T., Akbarnezhad, A., & Duan, Z. (2018). Mechanical properties of concrete mixed with recycled powder produced from construction and demolition waste. *Journal of Cleaner Production*, *188*, 720-731.
10. Horsakulthai, V. (2021). Effect of recycled concrete powder on strength, electrical resistivity, and water absorption of self-compacting mortars. *Case Studies in Construction Materials*, *15*, e00725.
11. Hong, G., Oh, S., Choi, S., Chin, W. J., Kim, Y. J., & Song, C. (2021). Correlation between the compressive strength and ultrasonic pulse velocity of cement mortars blended with silica fume: An analysis of microstructure and hydration kinetics. *Materials*, *14*(10), 2476.

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