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Effect of Recycled Aggregate Use on the Fresh State Properties of Limestone Calcined Clay Cement (LC3) Mortars

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Abstract **-** Recently, issues such as the global climate crisis, environmental sustainability, and resource efficiency have become important issues in the construction industry. This situation requires reviewing the environmental impacts of the production and use of construction materials and developing more sustainable alternatives. Accordingly, using recycled concrete aggregate from construction and demolition waste is an environmentally friendly and energy-saving solution. The literature contains studies on using recycled aggregate in standard cement systems. However, its use in alternative cement systems is a new topic. Limestone calcined clay cement (LC3) is a promising cement type for reducing harmful greenhouse gas emissions from cement production. It is an environmentally friendly solution, especially in mixtures that consume intensive cement, such as 3D printable concrete. In this context, the aim of the study was to use recycled aggregate by replacing it with fine aggregate in 3D printable mortar mixtures prepared using LC3 and to investigate the effect of recycled concrete aggregate on fresh state properties. For this purpose, the recycled aggregate was replaced with fine aggregate at rates ranging from 12.5% to 37.5%, and its effect on the slump and slump flow diameter values of fresh mortars and, accordingly, its suitability for the consistency parameters required for 3D printing were evaluated.

Keywords**:** Fresh State Properties, Limestone Calcined Clay Cement, Recycled Aggregate

1. Introduction

Limestone calcined clay cement (LC3) combines calcined clay, limestone, cement clinker, and gypsum. Unlike diminishing supplementary cementitious materials (SCMs) like blast furnace slag and fly ash, LC3 is a sustainable alternative [1]. It offers a 40% reduction in CO_2 emissions compared to ordinary Portland cement without compromising performance [2].

The 3D concrete printing method saves costs and labor compared to traditional techniques, increases architectural flexibility by eliminating molds, and shortens construction time. Yet, the significant CO_2 released during Portland cement production makes this technology unsustainable. Using lower carbon cement, like LC3, in 3D concrete manufacturing can address these sustainability issues.

Today, issues such as the global climate crisis, environmental sustainability, and resource efficiency have become significant concerns in the construction sector. This situation requires us to review the environmental impacts of the production and use of construction materials and to explore more sustainable alternatives. In this context, using recycled concrete aggregates from construction and demolition waste stands out as an environmentally friendly and energy-saving solution in the construction industry.

According to the Turkish National Waste Management and Action Plan 2023, approximately 300 million tons of excavated soil and construction and demolition waste are expected to be generated in 2023 [3]. In addition, urban transformation activities will significantly increase the construction and demolition waste resulting from construction activities throughout the country. Using recycled aggregates obtained from concrete waste can protect natural aggregate resources, reduce environmental pollution caused by waste concrete, and contribute to sustainability.

Limestone calcined clay cement is a promising cement type for reducing harmful greenhouse gas emissions from cement production. It is considered an environmentally friendly solution, especially in mixtures that consume intensive cement, such as 3D printable concrete. Another advantage of LC3 cement is that it improves the pore structure [4], [5]. It is thought that this advantage can be a suitable solution to prevent the problems caused by the use of recycled aggregates. In this context, the aim of this study is to understand the interaction between limestone calcined clay cement and recycled concrete aggregate in the preparation of 3D printable concrete mixtures and investigate their effects on the fresh state properties of mortars. The study conducted by [6], which defined the consistency properties for 3D printability, will be used as the basis for evaluating the results of mortar mixtures in terms of 3D printability.

2. Materials and Methods

2.1. Preparation of the Recycled Aggregate

In the first stage of the study, concrete wastes were ground into recycled concrete aggregates. For this purpose, concrete wastes in the Construction Materials Laboratory of Eskişehir Technical University Civil Engineering Department were used, and thus, the wastes in the laboratory were recycled. The wastes were first broken into small pieces with the help of a crusher and then ground to appropriate sizes. The maximum aggregate size was set to be 2 mm in order to be similar to the CEN standard sand planned to be used as reference aggregate. After the aggregates were ground, the grain distribution of the ground recycled aggregates was determined. Then, these ground aggregates were sieved, and the granulometry of the aggregates was adjusted to obtain a distribution similar to that of CEN standard sand. The granulometry curves of the recycled sand and CEN Standard sand are given in Fig. 1.

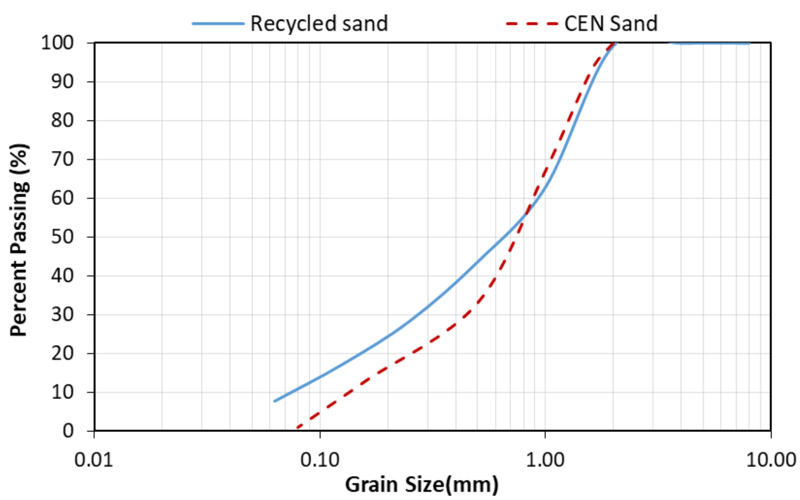

Fig. 1: The granulometry curves of the recycled sand and CEN Standard sand

2.2. Preparation of Limestone Calcined Clay (LC3) Cement

The LC3 cement prepared within the scope of the study consists of CEM I 42.5R Portland Cement, calcined clay, and limestone. The calcined clay/limestone ratio was kept constant at 2:1 during cement production. One of the LC3 cement compositions widely used in the literature - a composition of 55% CEM I 42.5R Portland cement, 30% calcined clay, and 15% limestone - was used.

2.3. Preparation of Mortar Mixtures

Within the scope of the study, in order to examine the interaction of LC3 cement and recycled aggregate, mixtures were prepared by replacing CEN standard sand with 12.5%, 25.0%, and 37.5% recycled concrete aggregate. The use of superplasticizing admixture was essential to provide the consistency properties required for 3D printable mixtures. For each mortar mix, the superplasticizer ratio was optimized to obtain a 3D printable mixture. Trial mixtures were prepared to achieve the finalized version of the mixture compositions.

2.4. Determination of the Fresh State Properties

The fresh state behavior of mixtures containing limestone calcined clay cement and recycled aggregate was characterized using slump and flow table tests, and the experiments were repeated with reference mixtures that did not contain recycled aggregate. The test was carried out in accordance with the ASTM C1437 standard [7]. For the slump test, the mold was filled with mixtures prepared in two layers, and both layers were compacted 20 times by a tamping rod. After removing the excess mix on the upper surface of the mold and smoothing the surface, the mold was removed, and the resulting slump value was recorded. In order to determine the flow diameter, the mixtures were similarly filled into the mold and compacted. Then, the mold was removed, and 25 drops were applied to the flow table. Then, the diameter of the mixture was measured from 3 different points, and the average was recorded as the slump flow diameter value.

3. Results and Discussion

According to a comprehensive study conducted by Tay et al., 2019, it was stated that mixtures that can be 3D printed should have a slump value ranging from 2 mm to 12 mm and a slump flow diameter ranging from 130 mm to 210 mm. It was also revealed that in this defined region, better surface finishability and better constructability could be achieved with mixtures with a slump between 4 mm and 8 mm and a spreading diameter between 150 mm and 190 mm. According to this referenced study, many trial mixtures were prepared to obtain the final mixture compositions. It was determined that using a superplasticizer additive at a rate of 0.8% of the binder amount in order to regulate the consistency of the mixtures was suitable for reference mixtures and mixtures containing 12.5% and 25% recycled aggregate. In addition, it was determined that the superplasticizer additive amount should be adjusted to 1% of the binder amount to reach the desired consistency values at a replacement ratio of 37.5%. The optimized mixture compositions to be suitable for 3D printability and the compliance of the mixtures prepared with these ratios with the limits recommended by Tay et al., 2019 are given in Table 1 and Figure 2, respectively.

Table 1: The optimized mixture compositions

Replacement Ratio (%) / kg/m^3	0% (REF)	12.5%	25%	37.5%
Sand	750	656.25	562.5	468.75
Recycled Sand	0	93.75	187.5	281.25
Cement	275	275	275	275
Calcined Clay	150	150	150	150
Limestone	75	75	75	75
Water	175	175	175	175
Superplasticizer (%wt of binder)	0.8	0.8	0.8	1

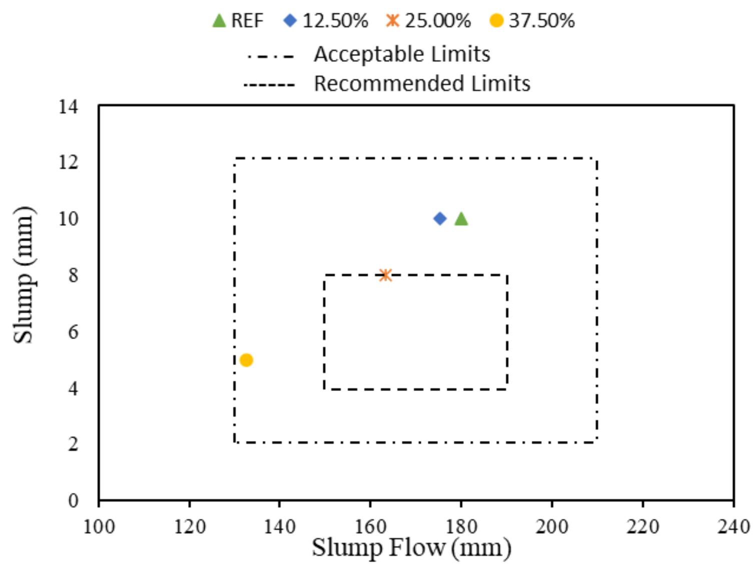

Fig. 2: The 3D printability compliance of the mixtures prepared due to the limits recommended by Tay et al., [6].

According to the results, the LC3 cement mortar with 25% recycled sand remained within the recommended limits for enhanced buildability stated by Tay et al.,2019. LC3 cement mortars with 12.5% and 37.5% recycled sand replacement ratios also remained within the acceptable region. The LC3 mortar with 37.5% recycled sand was still stiff despite the higher amount of superplasticizer. Therefore, the limit for the recycled sand replacement ratio in terms of 3D printability was suggested to be 25%.

4. Conclusion

In conclusion, for the LC3 mortars prepared within the study's scope, it was recommended that the limit for the recycled sand replacement ratio in terms of 3D printability be set at 25%, as higher ratios can lead to workability issues.

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