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Optimal Performance Assessment of Re-Recycled Concrete: Combining Water Absorption, Compressive Strength Using MOORA Technique

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This work presents water absorption and compressive strength testing of re-recycled aggregate concrete with fly ash and silica fumes. Two different types of fly ash and silica fume were used in place of ordinary Portland cement. According to test results, the selected ratios of fly ash and silica fume added to the used concrete mixtures enhanced its strength and balanced the loss in water absorption, at water-cement ratio of 0.4. The paper also thoroughly examines the full life cycle and evaluates the reuse of recycled concrete, considering seven various mixtures, using multi-criteria decision-making, namely MOORA technique. This framework is analysed by evaluating essential performance factors, namely water absorption, technical aspect (compressive strength for both short and long durations), environmental factors (effects on human health, quality of ecology, global changes in climate, and source utilization), and financial considerations (price-related). The results indicate that utilizing re-recycled concrete aggregate presents a significant environmental impact reduction (up to 39 %), and cost savings (5-10 %) compared to traditional concrete.

1. Introduction

Concrete's significant environmental impact (EI) has prompted researchers to propose alternatives, like using demolition waste in concrete to reduce EI (Akhtar et al., 2018). Much research has been carried out on the influence of alternative ingredients on concrete, investigating various aspects, such as high performance in both fresh and hardened or water absorption stages, as well as EI and economic impact (Damdelen, 2018); Experimentally, a fine content alternative, fly ash, which improves workability and minimises cracking because of the lower heating of hydration, has been put into concrete so that the dose of superplasticiser may be lowered while still meeting the flow table test requirements. Aside from fly ash, silica fume appears to be a promising alternative in fine content because its pozzolanic reaction improves the binding between paste and recycled aggregate (Leung et al., 2016).

The ideal concrete mix involves multiple factors and isn't just about low EI, long life, or cost. Using non-traditional ingredients, we can make concrete that is more affordable and environmentally friendly (supplementary cementitious materials) and recycled concrete aggregates (RCA) (Shmlls et al., 2023b).

The utilisation of re-recycled aggregate concrete (RRAC) represents a novel concrete option suitable for actual construction applications. RRAC's hard properties at different ages were evaluated by Huda and Alam (2014) using fly ash up to 20 %. The results showed that RRAC could still reach at least 25 % better strength than the traditional concrete even with complete substitution (100 %). Continuously, to establish RRAC as a more environmentally friendly option, an assessment should encompass not only its strengths but also consider economic and EI aspects. To analyse the CO_2 of various materials, such as cement and aggregate, specialized programs like clicks LCA, SimaPro, or GaBi software (Blengini, 2006) have proved necessary. These software programs make it possible to use several EI evaluation approaches in compliance with EN 15804 (2012) by integrating life cycle assessment (LCA) into any activity or production. Ultimately, the MOORA (Multi-Objective Optimisation on the basis of Ratio Analysis) technique was employed, considering all the outputs from studied aspects as factors in order to aid in choosing the optimal option from a range of alternatives. Brauers et al. (2008) used MOORA to optimise road design alternatives in the field of construction. The findings demonstrated

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that this technique is well-suited for dealing with problems that involve a substantial number of scenarios and objectives. For this goal, a panel of experts was formed to participate in all steps, ranging from the identification of the collection of choice factors to the formation of pairwise comparisons among them using a different technique. However, very engaging and other methods were presented by (Shmlls et al. 2023b), such as TOPSIS, EDAS, and VIKOR.

The connection between an original technique (MORRA) and multi-recycled aggregate concrete is the unique approach to choosing the optimal concrete mixture from seven options considering cost, water absorption, high performance, and EI. The authors included fly ash, silica fume, and two varied proportions of multi-recycled coarse aggregate, as well as RCA. In conclusion, a multitude of applications are being tested in an effort to demonstrate the dependability of the suggested approach in all conditions and applications within the emerging building industry.

2. Method

The following table (Table 1) shows each material's type, amount, and physical properties:

Table 1: Materials type, amount and physical properties

Materials	Type	Amount (kg/m^3)	Physical Properties
Cement	CEM I 52.5 N	360	3.12
Sand	Local (Danube River)	686	2.6
Water	Tap water	145	-
Superplasticizer	Sika Visco	4.32 - 5.76	1.07
Silica fume	Sika fume	43.2	2.23
Fly ash	Microsite 20	72	2.45

The specific amount of three distinct types of used aggregates for every type of concrete mixture, which is detailed in Table 2 (RF-C is a traditional concrete; RSF1 is concrete with 30 % RCA; RSF2 is concrete with 70 % RCA; RRSF1 is concrete with 30 % RRCA (RSF1, original crushed concrete); RRSF2 is concrete with 70 % RRCA (RSF1, original crushed concrete); RRSF3 is concrete with 30 % RRCA (RSF2, original crushed concrete); RRSF4 is concrete with 70 % RRCA (RSF2, original crushed concrete)).

The proper Hungarian standards (Shmlls et al., 2023 a) were strictly followed during the experiments. First, the visual inspection and flow table test, following the Hungarian standard, determines the workability of all concrete types (Figure 1). The concrete samples were stored in a water-curing tank once they were de-moulded after a day. The specimens were taken out of the curing tank the day before testing and dried in an oven for a full 24 h at 105 °C. The specimens were then kept inside the laboratory for a further 24 h period.

The water absorption of the used aggregates is 3.1 %, 5.5 %, and 5.8 % for NA, RCA, and MRCA. The specific gravity is 2.6 g/cm^3, 2.53 g/cm^3, and 2.5 g/cm^3 for NA, RCA, and MRCA.

During the second stage, one of the primary boundary conditions, which incorporates LCA, has to do with the manufacture of set concrete elements for each manufacturer. Figure 2 shows the criteria for the boundaries. The data was adjusted in accordance with the operating unit and then inserted into the software, namely Simapro LCA.

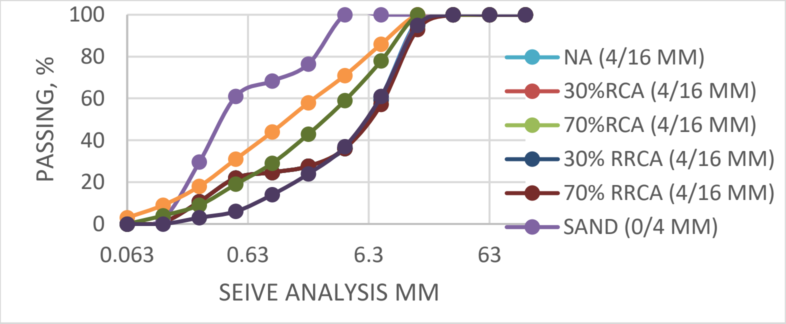

Figure 1: Sieve analysis curves

Table 2: Specific amount of three types of aggregates

Blend	Natural aggregate	CoarseBlend	Natural Coarse aggregate
RF-C	1029	-	-
RSF1	848	362	-
RSF2	363	848	-
RRSF1	362	-	847
RRSF2	847	-	362
RRSF3	362	-	847
RRSF4	847	-	362

The environmental advantages evaluated in this study are mostly based on the elimination of natural aggregate production in both the 2nd and 3rd productions of designed concrete. In addition, the replacement of cement with silica fume and fly ash played a significant role in reducing the negative effect of CO_2, in accordance with European LCA analysis guidelines (ISO 14040, 2006). The data gathered were transformed into SimaPro 9.0 by applying the mixing ratios provided in the experimental stage and adjusting it based on the unit of function. This method includes a complex list of 15 impact categories, providing a robust platform for the identification of environmental burden on both midpoint and endpoint levels. The impact categories included in the assessment are listed as follows: Aquatic acidification (AAC), Aquatic ecotoxicity (AE), Aquatic eutrophication (AEU), Carcinogens (CA), Global warming (GW), Ionizing radiation (IA), Land occupation (LO), Mineral extraction (ME), Non-carcinogens (NCA), Non-renewable energy (NRE), Ozone layer depletion (OLD), Photochemical oxidation (PO), Respiratory inorganics (RI), Terrestrial acidification/nitrification (TAN), and Terrestrial ecotoxicity (TE).

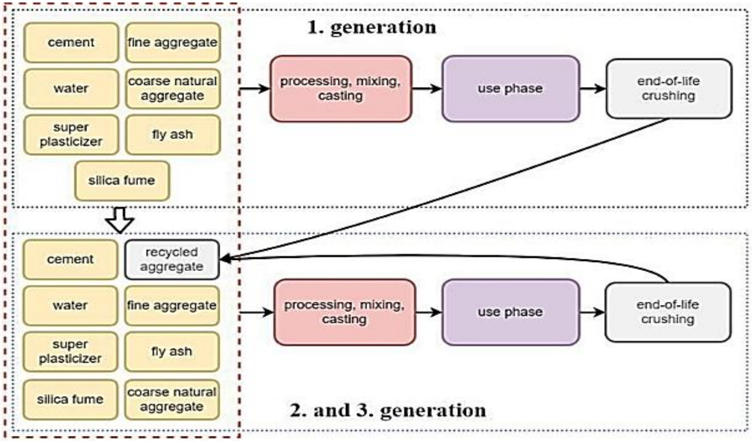

Figure 2: Seven concrete mixtures' boundary conditions

In the cost analysis, the third stage is concerned. Using RRCA in place of natural aggregate will be necessary if RRCA's actual price, carrying cost and production expenses are less than those of natural aggregate. This study focuses on comparing the actual price of used aggregates in three productions. Because RCA and RRCA were produced in the university laboratory manually, transportation was unnecessary. However, all the material prices provided by Hungarian local suppliers are based on international prices (Duna-Dráva, 2024; Meselia, 2024).

In the final phase of the study, the selection of the optimal mixture was undertaken using the MOORA technique. This optimisation process addressed a crucial challenge characterised by multiple independent objectives and a multitude of potential solutions. To meet all of these initial criteria comprehensively, MOORA, a new and innovative technique for multi-objective optimisation with recycled and multi-recycled aggregate concrete mixtures, was employed. A thorough and rigorous approach was ensured to selecting the best concrete mixture. Figure 3 illustrates the entire MORRA procedure. from the decision matrix to the assessment value calculation.

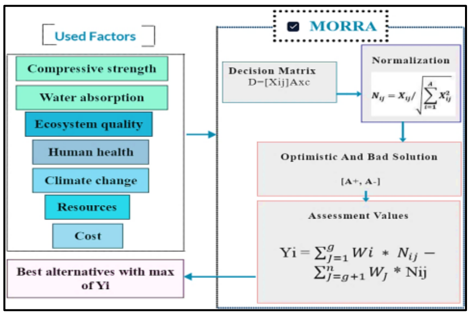

Figure 3: MOORA technique steps

3. Results and discussion

3.1 Water absorption

Water absorption tests were performed on all concrete mixtures by immersing three 150 x 150 x 150 mm cubes in water until they were fully saturated. Subsequently, the specimens were thoroughly dried in an oven at a temperature range of 105 °C. Figure 4 provides the results of the water absorption test carried out after 90 days under atmospheric pressure for all concrete mixtures. A slight variation in water absorption was noted with an increase in the proportion of RCA replacement, with a 70 % re-placement of natural aggregate by RCA. This result concurred with those in (Wang et al., 2023). Notably, the experiment also showed that the use of three productions of concrete boosted the capacity to absorb water. The mixture of RRSF1, however, showed the lowest water absorption results among all third-production mixtures, while RRSF4 obtained the highest value (25.7 % higher than RF-C), demonstrating that expanding the recycling cycle and high quantity of replacement ratio increases the concrete's ability to absorb water. Even if RRAC’s mixture values are not so high, this behaviour might be related to the right chosen ratios of both fly ash and silica fume. 20 % and 12 %, where the graded particle distribution can aid in good filling of the pores inside the concrete. Reduced water absorption is caused by fewer pores when the w/b ratio is low.

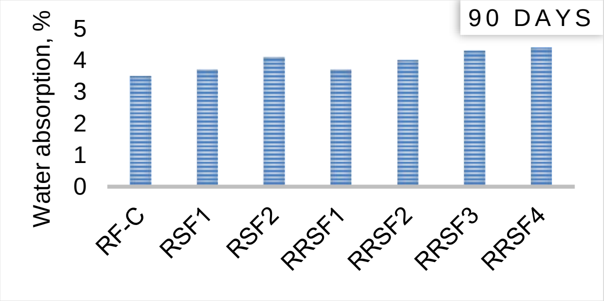

Figure 4: Water absorption results

3.2 Compressive strength

Figure 5 shows the compressive strength marginally impacted by RCA. Specifically, RSF1 (Figure. 5a) exhibited strength that was comparable to RF-C. The increased strength of recycled mixtures might be due to their increased rough surfaces. For more consistency and after analysing numerous previous studies and conducting countless concrete tests, this study illustrates the anticipation of achieving optimal outcomes through the utilisation of prescribed quantities of two additional materials instead of cement; here in this study, fly ash and silica fume were applied. Specifically, it highlights the enhancement of concrete with both of the used supplementary materials, noting that a high proportion of the used type of fly ash leads to a drop in compressive strength. Additionally, it was determined that the optimal ratio of silica fume to cement weight lies between 10 % and 15 %. Similarly, the compressive strength of RRSF1 was found to be 7.2 %, 14.3 %, and 8.77 % higher than RSF1 at three studied ages. Figure. 5b illustrates that a greater quantity of RRCA also increased the strength under compression of concrete. For instance, RRSF4's strength increased to 22 %.
These results agreed with those in (Shmlls et al., 2023a).

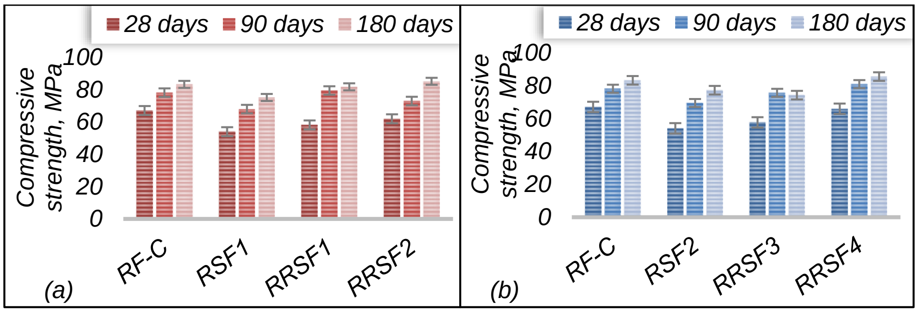

Figure 5: Compressive strength results of two aggregate replacement ratios: (a) compressive strength of concrete having 30 % substitution; (b) compressive strength of concrete having 70 % substitution.

3.3 Result of LCA

The recycling scenario employs RF-C for the 1st production, RSF2 for the 2nd production, and RRSF4 for the 3rd production. Nearly all studied midpoint categories exhibit an average reduction of 20 - 25 % based on the results from the software. When the recycled aggregate was included in the analysis. The 1st production of concrete made using natural resources, however, does not show as much of an advantage as substituting natural materials. This finding agreed with those in (Shmlls et al., 2023b). Additionally, the environmental parameters of the used scenario reveal similar variations with regard to endpoint parameters, as shown in Figure 6. The research shows that the majority of the environmental burden is caused by changing the climate, which is pursued by negative impacts on human health and natural resources. The EI of the RF-C combination is notably larger than that of the 3rd production, highlighting the benefits of utilising RRCA.

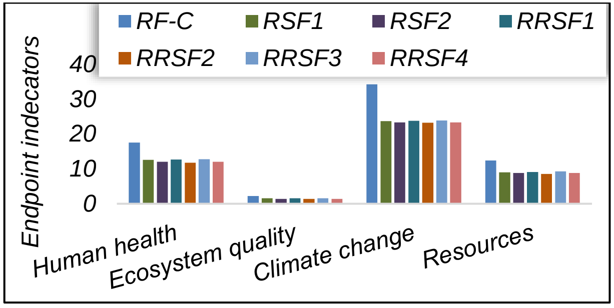

Figure 6: Environmental endpoint using Simapro 9.0

When comparing 2nd production mixtures to 3rd production mixtures, the results showed that the reduction in costs was significantly greater when silica fume and fly ash with RRCA were used in the same mixture together, RRSF4. Therefore, the mixtures from the 3rd production are the least cost; the reductions for RRSF1, RRSF2, RRSF3, and RRSF4 are 6.3 %, 9.77 %, 4.9 %, and 7 %

3.4 Results of the MOORA technique

The technique named MOORA determines which option is optimal by taking the greatest value (Yi). The assessment values for the selected weighting technique were computed and are shown in Figure 7 to determine this value for every mixture. However, before finalising the results, the normalisation matrix was calculated. Subsequently, the benefit and non-benefit factors were identified, and the results of this identification are represented by Eq.(1) and Eq.(2).

A^{+} = [0.053, 0.051, 0.05, 0.042, 0.039, 0.043, 0.042, 0.045] (1)

A^{-} = [0.043, 0.043, 0.044, 0.062, 0.065, 0.063, 0.061, 0.049] (2)

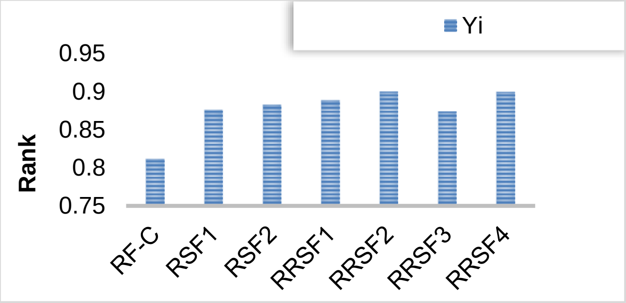

Figure 7: Assessment values (Yi) results of MOORA technique

4. Conclusions

In this paper increasing recycled coarse aggregate in concrete by up to 70 % and substituting supplementary cementitious materials for cement improved compressive strength when compared to traditional concrete. 2) Replacing 70 % of natural aggregate by RRCA obtained better results than re-placing 30 % of natural aggregate by RRCA, due to the high number of fine particles produced by the 3rd production of crushing procedures. 3) The findings show that increasing the recycling cycle of concrete increases its ability to absorb water (up to 25.7 %). However, combining a correct ratio of fly ash and silica fume in the same mixture may be able to balance this capacity. 4) Compared to traditional concrete, using RCA or RRCA results in an average savings of environmental burden of around 20-25 % in most midpoint categories. 5). The integrated framework (water absorption, compressive strength, LCA, cost) with multi-objective optimisation or complex proportional assessment serves as a robust instrument for the sustained management of resources, which can be applied in several zones.

References

Akhtar A., Sarmah A.K., 2018, Strength improvement of recycled aggregate concrete through silicon rich char derived from organic waste. Journal of Cleaner Production, 196, 411-423.

Blengini G., 2006, Life cycle assessment tools for sustainable development: case studies for mining and construction industries in Italy and Portugal. PhD Thesis in Mining Engineering, Universidade Tecnica de Lisboa, Instituto Superior Tecnico, Portugal, 283 ps.

Brauers W.K.M., Zavadskas E.K., Peldschus F., Turskis Z., 2008, Multi-Objective Optimization of Road Design Alternatives with an Application of the Moora Method. Presented at the 25th International Symposium on Automation and Robotics in Construction, Vilnius, Lithuania, DOI: https://doi.org/10.22260/ISARC20,

Damdelen O., 2018, Investigation of 30% recycled coarse aggregate content in sustainable concrete mixes. Construction and Building Materials, 184, 408-418.

Duna-Dráva, 2024. Portland cement EN 197-1 CEM I 52,5 N, Beremend. Duna-Dráva Cement <https://www.duna-drava.hu/en/portland-cement-en-1971-cem-i-525-n-beremend>, accessed 27.10.2024.

EN 15804, 2012, Sustainability of construction works - Environmental product declarations, rules for the product category of construction products. European Committee for Standardization, Brussels, Belgium.

Huda S.B., Alam M.S., 2014, Mechanical behavior of three generations of 100% repeated recycled coarse aggregate concrete, Construction and Building Materials, 65, 574-582.

ISO 14040, 2006, Environmental management, Life cycle assessment, Principles and framework. <https://www.iso.org/standard/37456.html>, accessed 27.10.2024.

Meselia, 2024, Coal fly ash - Microsit, 27.07.2022.

Leung H., Kim J., Nadeem A., Jaganathan J., Anwar M., 2016, Sorptivity of self-compacting concrete containing fly ash and silica fume. Construction and Building Materials, 113, 369-375.

Shmlls M., Bozsaky D., Horvath T., 2023a, The Analysis of Lifecycle and Multi-Criteria Decision-Making for Three-Generation High-Strength Recycled Aggregate Concrete, Chemical Engineering Transactions, 107, 229.

Shmlls M., Abed M., Fořt J., Horvath T., Bozsaky D., 2023b, Towards closed-loop concrete recycling: Life cycle assessment and multi-criteria analysis. Journal of Cleaner Production, 410, 137179.

Wang J., Che Z., Zhang K., Fan Y., Niu D., Guan X, 2023, Performance of recycled aggregate concrete with supplementary cementitious materials (fly ash, GBFS, silica fume, and metakaolin): Mechanical properties, pore structure, and water absorption. Construction and Building Materials, 368, 130455.