Sustainable Concrete Quality Management

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The development of a concrete mixture design process for high-quality concrete production with sustainable values is a complex process because of the multiple required properties at the green/hardened state of concrete and the interdependency of concrete mixture parameters. A new multi-criteria decision making (MCDM) technique based on Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) methodology is applied to a fuzzy setting for the selection of concrete mix factors and concrete mixture design methods with the aim towards sustainable concrete quality management. Three objective properties for sustainable quality concrete are adopted as criteria in the proposed MCDM model. The seven most dominant concrete mixture parameters with consideration to sustainable concrete quality issues, i.e., environmental (density, durability) and socioeconomic criteria (cost, optimum mixture ingredients ratios), are proposed as sub-criteria. Three mixture design techniques that have potentiality to include sustainable aspects in their design procedure, two advanced and one conventional concrete mixture design method, are taken as alternatives in the MCDM model. The proposed selection support framework may be utilized in updating concrete design methods for sustainability and in deciding the most dominant concrete mix factors that can provide sustainable quality management in concrete production as well as in concrete construction. The concrete mix factors found to be most influential to produce sustainable concrete quality include the water/cement ratio and density. The outcomes of the proposed MCDM model of fuzzy TOPSIS are consistent with the published literature and theory. TheDOE method was found to be more suitable in sustainable concrete quality management considering its applicable objective quality properties and concrete mix factors.

Sustainable Quality Management | Concrete Mixture Parameters | Mixture Design Method | Fuzzy TOPSIS | Multi-Criteria Decision Making

1. Introduction

Concrete is a workable plastic mixture of cement, water, fine aggregates, and coarse aggregates in controlled proportions, for use in the construction industry [1]. The concrete mixture parameters and water/cement (w/c) ratio affect the workability, strength, and durability, while the concrete mixture factors, namely, ratio of fine aggregate to cement (FA/c) and ratio of fine aggregate to total aggregate (FA/T) have an impact on concrete quality. There are other numerous concrete mixture factors such as cement type; minimum and maximum cement content; strength of cement; types, shape, and size of aggregates; aggregates grading; ratio of coarse aggregate and cement (CA/c); characteristics of concrete in green or hardened state; cost of concrete, etc., that influence the overall quality of concrete.

There are numerous methods to design the concrete mixture. The present study has considered three mixture design techniques, viz., the American Concrete Institute (ACI), Department of Energy (DOE), and Fineness Modulus (FM) mix design methods that have potentiality to include sustainable aspects in their design procedure; two advanced and one conventional concrete mixture design method are taken as alternatives in the MCDM model. The American Concrete Institute (ACI) mix design method considers workability, consistency, strength, and durability. The main principles of the ACI method are that the w/c ratio is inversely proportional to the design strength, the bulk volume of coarse aggregate per unit volume of concrete depends on the aggregate maximum size, and fine aggregate grading. The basic assumption made by the Department of Energy (DOE) mix design method is that the strength of the concrete is governed by the water/cement ratio. The other principles of the DOE method are that fine aggregate proportion varies with aggregate maximum size and water/cement ratio. The Fineness Modulus (FM) method for concrete mix design is based on the principle that the strength of the concrete depends on the water/cement ratio and the relative proportions of fine and coarse aggregate, such that the combined aggregate needs the least amount of cement paste for full compaction. This mixture method has not directly dealt with sustainability, though it takes care about environment aspects in its design approach.

2. Sustainable Concrete Manufacturing

The proper proportioning of constituents of concrete with sustainable qualitative performance can make concrete manufacturing sustainable. To prepare a concrete mixture with sustainable criteria, a proper mix design method, the most acceptable concrete mixture parameters, and optimum proportions of concrete ingredients are needed. The requirements of the concrete mixture may change due to material product characteristics having social, economic, and environmental constraints. The socioeconomic characteristics of sustainable criteria in the context of concrete include improvement to quality of life and cost reduction through high quality concrete properties and additional quality control personnel, optimum materials, and long life of produced concrete.

The environmental characteristics of sustainable criteria in the context of concrete include lower CO_2 emission and natural resources consumption through optimum cement and water use in concrete production. Concrete mixture factors such as water/cement (w/c) ratio, density, ratio of fine aggregate to cement (FA/c), ratio of coarse aggregate and cement (CA/c), and cost of concrete may be used to satisfy the socioeconomic indicators of sustainable concrete. Concrete mixture factors such as water/cement (w/c) ratio, density, ratio of fine aggregate and total aggregate (FA/T), ratio of total aggregate to cement (T/c), and ratio of fine aggregate to cement (FA/c) can be used to satisfy the environmental indicators of sustainable concrete. Proper concrete proportioning along with optimum ratios of ingredients results in high durability of structures [2] and helps to resolve the environment and socioeconomic issues.

Alam et al. [3] identified the factors concerning the quality of concrete production and pointed out that a proper concrete mix is one of the key factors which affects the quality of concrete. Ahmad [4] studied concrete mixture proportion from the quality of concrete point of view and suggested that there exists an optimum ratio of fine aggregate and total aggregate (FA/T) and cement/fine aggregate (c/FA) ratio for improved quality. Zavadskas et al. [5] emphasized that the application of Multicriteria Decision-Making (MCDM) techniques have great potential and sustainable decision-making in structural engineering, design, and building technology. An extensive body of literature is available in which MCDM approaches are used to tackle the selection of the right stackholder, the best practice or option, an optimum measure of right materials in concrete construction project management, and sustainable construction engineering. Zavadskas et al. [6] present a summary of published research related to the application of basic decision-making frameworks and processes, along with advanced MCDM techniques for sustainability in the construction engineering discipline. A broader review of MCDM approaches and their applications in civil engineering are due to Kabir et al. [7].

Stojcic et al. [8] discussed the application of MCDM for sustainability in the engineering field. Monghasemi et al. [9] introduced a new MCDM model to optimize the construction time, construction cost, and construction quality of projects. Alhumaidi [10] proposed an MCDM technique considering a multi-attribute fuzzy weighted average approach for project contractor selection. Taylon et al. [11] used a hybrid fuzzy Analytic Hierarchy Process (fuzzy-AHP) and fuzzy TOPSIS MCDM technique for assessing the selection criteria and risk criteria of construction projects. Hamdia et al. [12] develop the reinforced cement concrete (RCC) building damage assessment criteria using the fuzzy analytic hierarchy process. The application of the MCDM technique to structural retrofitting procedures for buildings and bridges repairs is due to Caterino et al. [13] and Rashidi et al. [14]. They conclude that technique for order preference by similarity to ideal solution (TOPSIS) and the methodology of VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje in Serbian) are more suitable for selecting retrofit procedures. Zhao et al. [15] propose a coupled MCDM method, intervalued trapezoidal intuitionistic fuzzy number (IVTIFN), and a TOPSIS method to support the selection of pipe materials in building projects. The Fuzzy extended analytical hierarchy process (FEAHP) technique is proposed by Akadiri et al. [16] for ranking building materials. Falqi et al. [17] apply a TOPSIS method in a fuzzy environment for siliceous material management for sustainable concrete construction. Ahmed et al. [18] propose a hybrid MCDM approach to select a concrete mixture design method for the production of high-performance concrete. Bera et al. [19] suggested multi-attribute decision-making (MADM) to choose an appropriate proportion of silty sand and artificial clay for soil stabilization based on a mixing design approach.

It is clear from the literature review that a number of applications of MCDM techniques in construction industries for the incorporation of sustainability in various construction engineering processes and management are available.

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