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Eco-friendly road construction: Harnessing fly ash and waste marble powder for sustainable road construction using a fuzzy logic assessment

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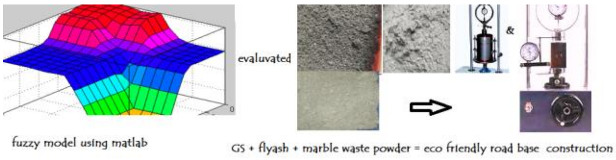
Graphical abstract



Abstract

More than seventy percent of mineral gets wasted during mining and polishing processing, and all this dumped waste threatens the aquifer. Utilizing this waste in construction works helps to reduce the environmental effects. This research aims to protect the environment by implementing mineral waste collected from neyveli lignite fly ash with waste marble waste powder in road-base construction. Accessing the different required combinations of mineral admixtures through laboratory tests poses a challenge. This study identify a suitable combination of fly ash with waste marble powder for assessing the compaction properties and compressive strength for road base construction through fuzzy logic. A fuzzy model was created by using MATLAB software. It consists of two input and four output parameters, fly ash and marble waste powder are the input parameters with four different combinations, and the output factors are dry unit weight, water content, unconfined compressive strength and CBR. The fuzzy model was evaluated with laboratory test results. The study concluded that only a minimum percentage of deviations between the predicted strength and actual results from the laboratory. In future research, this study helps to reduce the time and cost of laboratory tests for different combinations.

Keywords: Eco friendly construction, reusing flyash, marble waste, fuzzy logic

1. Introduction

The road is an important one for the infrastructure development of every country. The transmission of all loads to the sub-base and underlying soil is the primary purpose of road pavement. Road construction materials included crushed stone, sand and gravel, or flexible pavement packed with binder materials like tar, asphalt, etc. However, the failure of road pavement is unavoidable. The failure occurs due to weakness in the road's surface or the road's base or subgrade. Many researchers continuously try alternate solutions to avoid this type of failure: the recycled industrial waste and admixture in the concrete with required strength. In the last few decades, marble industries continuously dumped large amounts of construction waste in open places. The viability of using leftover marble as a coarse aggregate in concrete was determined and in comparison to control concrete, the marble aggregate mix had 14% more workability and 18% more compressive strength (Kore 2016).

Instead of coarse aggregate, marble waste was used with ground blast furnace slag (GBFS) and river sand as fine aggregate with 0.4 w/c ratios. The report concluded that mechanical properties were increased by 3 to 6% river sand with marble waste combination. The study observed that marble waste and ground granulated blast furnace slag combination durability in concrete was superior to the control concrete (Binici 2008). The Los Angeles abrasion, aggregate, impact value, freezing & thawing, Marshall Stability flow, and flakiness index tests concluded that homogenous marble and andesite quarry waste materials as medium-trafficked asphalt pavement(Akbulut 2007). The compressive strength of concrete has increased by adjusting various proportions of coarse aggregates and incorporating fly ash as an admixture in concrete(Raimon 2020). Economic and environmental consequences of various admixtures used to improve the stability of the soil. Marble waste powder, fly ash, eggshell powders, stone waste, and lime powder are the mineral admixtures that stabilize the soil(Zada *et al.* 2023). Incorporating coconut shells, regarded as agricultural waste, into concrete makes an eco-friendly alternative material. The treated coconut shell in concrete increases the compressive and split tensile strength(Maheswaran 2023). Adding marble powder to the fly ash-based geopolymer mortar enhances the dry density and compressive strength. Therefore, the research concluded that utilizing marble waste in geopolymers is feasible(Farhana Mukhtiar 2022). The combination of sand, gravel, or both sand and gravel mixes replaces 75% of marble waste with the same w/c ratio, and the study observed that the strength of the concrete increases more than conventional concrete (Hebhoub *et al.* 2011). Soil stabilization is a geotechnical process, and it consists of mechanical, chemical, or other techniques that improve the engineering characteristics of the soil, such as water absorption and compressibility of soil(Amiri *et al.* 2022; Arun Kumar 2014), adding fly ash and limestone dust as admixtures in the expansive soil improves the durability and stability of untreated soil. This combination was an outstanding expansive soil stabilizer and also cost-effective. The granular soil with marble dust and fly ash combination increases in UCS and CBR. (Zorluer and Demirbas 2013).

2. Material and method

This study determines the strength and compaction characteristics of various admixture combinations using a fuzzy model. The model is then assessed using the outcomes of laboratory tests. A fuzzy inference method with Matlab has been used to access the strength and compaction parameters of the granular soil containing a combination of fly ash and marble waste powder This research collected dust from a marble processing factory and fly ash from Neyveli Lignite Corporation, Neyveli, Tamil Nadu.

Table 1. Soil Admixture Compositions

Mix proportions	% GS	%FA	%WMP
100(GS):10(FA):5(MWP)	100	10	5
100(GS):20(FA):10(MWP)	100	20	10
100(GS):30(FA):15(MWP)	100	30	15
100(GS):40(FA):20(MWP)	100	40	20

Table 2. Different mixture compositions with their laboratory test results

Mix proportions	dry unit weight (kN/m3)	% of optimum water content	Unconfined Compressive strength (kN/m2)	Californio Bearing Ratio (kN/m3)
100(GS):10(FA):5(MWP)	2.23	2.73	3791	2543
100(GS):20(FA):10(MWP)	1.93	4.96	2561	3011
100(GS):30(FA):15(MWP)	1.90	7.85	995	2438
100(GS):40(FA):20(MWP)	1.86	9.73	743	2197

The collected fly ash belongs to class C, and the percentage of liquid limit and the shrinkage limit of the fly ash were determined as 44% and 38%, respectively. As per IS 1124-1974, the marble waste powder water absorption and specific gravity was determined as 0.4% maximum by its weight and 2.02g/cm^3. The different combinations of the mix of lignite fly ash with marble waste powder are first mix combinations containing 100% granular soil with 10% fly ash and 5% marble waste powder, the second mix combination of 100% granular soil with 20% fly ash and 10% marble waste powder and the third mix was 100%, granular soil with 30% fly ash and 15% marble waste powder and the final mixture was 100% granular soil with40% fly ash and 20% marble waste powder.

Dry unit weight, represented by the symbol γd, is the weight of soil solids per unit volume of the soil, expressed in kN/m³. A high value of dry unit weight indicates that more solids are packed in a unit volume of soil, hence a more compact soil. The water content associated with the maximum dry density is termed the optimum water content. The confined compression test with Biomomentum equipment evaluates a material's resistance to axial compressive loads without expanding perpendicularly to the force. The unconfined compressive strength was to measure the cohesive strength of the soil.

CBR, or California Bearing Ratio, is the percentage ratio of the force needed to penetrate soil with a standard 50 mm diameter circular plunger at 1.25 mm/min, compared to the force required for a similar penetration in the conventional material. The California Bearing Ratio test is a penetration test designed to assess the sub grade strength of roads and pavements. The above table 2 represent, the mixtures differ in their characteristics depending on the combinations of (GS), (FA), and (MWP). In Mix 1, there's a dry unit weight of 2.23, an optimum water content of 2.73, a compressive strength of 3791 kN/m^2, and a California Bearing Ratio (CBR) of 2543kN/m^3. In Mix 2, the dry unit weight decreases to 1.93%, the optimum water content increases to 4.96%, and the compressive strength and CBR are 2561 kN/m^2 and 3011 kN/m^3, respectively. Mix 3 displays a dry unit weight of 1.90%, an optimum water content of 7.85%, a compressive strength of 995 kN/m^2, and a CBR of 2438 kN/m^3. Finally, Mix 4, shows a dry unit weight of 1.86%, an optimum water content of 9.73%, a compressive strength of 743 kN/m^2, and a CBR of 2197kN/m^3.

3. Fuzzy logic inference system

Many academics have recently embraced the fuzzy inference system to solve their difficulties because fuzzy logic quickly analyzes the uncertainty of the variables without requiring complex statistical or mathematical answers. The Fuzzy-Analytic Hierarchy Process with Artificial Neural Networks model assesses the vulnerability of the earthquake's demographic, environmental, and physical components. Fuzzy logic with a genetic algorithm has evaluated the outcome of the model (Ahmed A Shaheen 2007; Chen *et al.* 2012). The fuzzy logic developed four different outcomes with one specimen, and fuzzy gave reliable results to identify various outcomes(Akcay 2018; Zorluer *et al.* 2010). Fuzzy logic has been regarded as a soft computing method since, rather than utilizing crisp sets, fuzzy set theory was applied, and fundamental idea was to categroize the variables into fuzzy sets using membership function The inference system of fuzzy function was to formulate the mapping of a given input to an output, and the mapping serves as the basis for making judgments. The Mamdani fuzzy inference process is divided into five steps: fuzzification, fuzzy operation, implication, aggregate the outputs, and defuzzification (Buyuközkan 2012; Zadeh 1965).

3.1. Fuzzy model in MATLAB software

Fuzzy is an effective tool for dealing with complex decision-making for the absence of any absolute measurements. In this research, there is a possibility to influence one parameter over another because of various behavior from different materials. Therefore, model has created by fuzzy logic in MATLAB software.

Mamdani and Sugeno are two fuzzy inference system methods in the MATLAB software's Fuzzy Logic Toolbox. The Mamdani fuzzy inference approach is used to develop a model in this work. The methods below demonstrate how to create a program based on the fuzzy approach using MATLAB software. The first step is to launch MATLAB and open the fuzzy toolbox. The editor in FIS (Fuzzy inference system) provides general information about the fuzzy inference system is characterized by its configuration, including the count and designations of input and output. Below Figure 1 delineates the inputs, namely fly ash and waste marble powder alongside the output variables, which encompass dry unit weight, water content, compressive strength and California Bearing Ratio (Figure 2).

Figure 1. Laboratory work has been presented

3.2. Membership function editor

- Membership functions of the fuzzy sets represent the input materials as fly ash and waste marble powder and output as strength and compaction properties information.
- The first input Membership function represents the percentage of waste marble powder.
- The second input Membership function represents the percentage of lignite fly ash.
- The output Membership functions represent the compressive strength

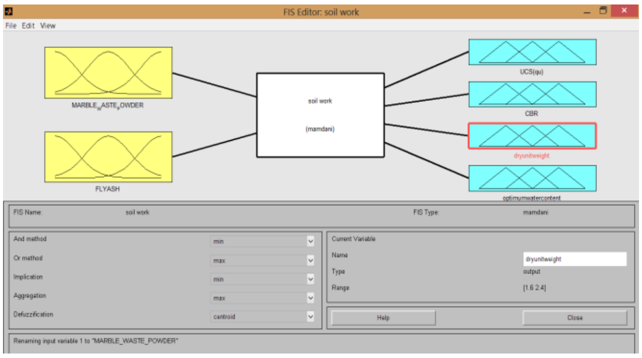


Figure 2. Fuzzy logic controller in MATLAB toolbox window

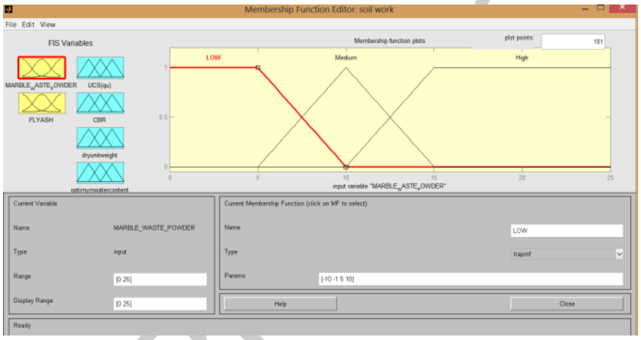


Figure 3. Membership Function Editor

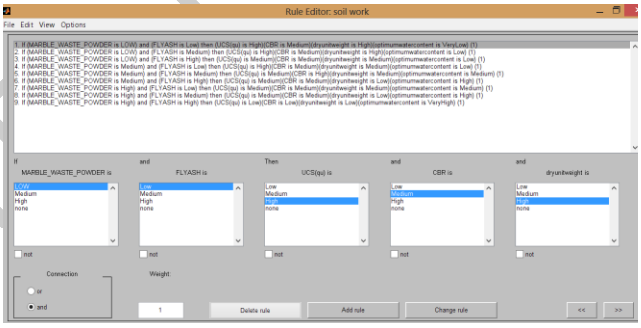


Figure 4. Rule Editor

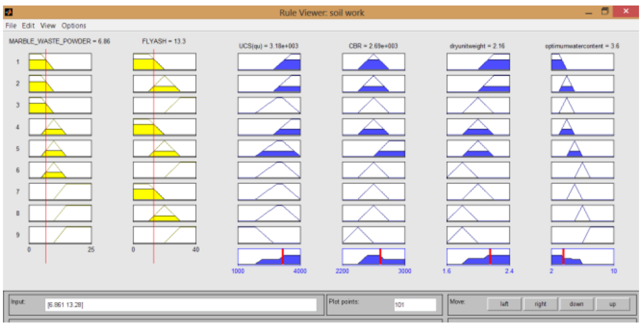


Figure 5. Rule Viewer

Figure 3 shows the rule editor for road-based work, represented by the if and then rule. The variables are thought to be independent of one another. The roadmap of the complete fuzzy inference system is displayed in the rule viewer window. Figure 4 depicts a two-dimensional surface viewer that exhibits the mapping of the UCS and CBR anticipated values.

In Figure 4, the depiction of the combined proportions of fly ash and waste marble powder provides insights into the expected outcomes for unconfined compression strength, CBR, maximum dry weight, and optimum moisture content.

The surface viewer function is used for 3D plotting surfaces, creating a surface plot and visualising 3D data. Figure 4 shows the surface viewer displays a 3D surface plot of two inputs and one output.

4. Result and discussion

Table 3 delineates a comparison between the outcomes generated by the fuzzy model and the laboratory test findings. A significant advantage of this fuzzy model is its capacity to calculate both compressive strength and compaction properties for specimens incorporating various ratios of fly ash admixture and waste marble powder. The table serves as a means to compare research outcomes with existing laboratory results, including untested intermediate data for fly ash admixture and waste marble powder (Figures 5 and 6).

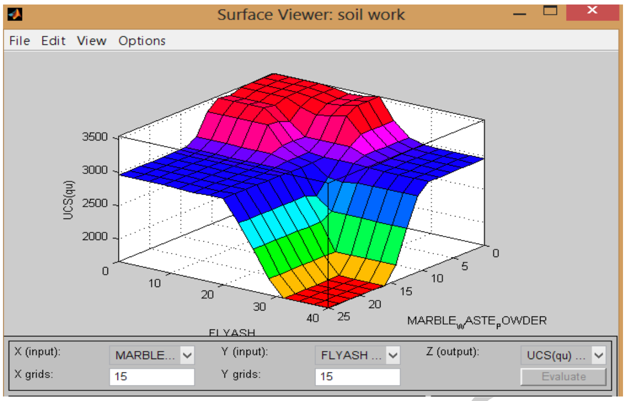


Figure 6. Surface Viewer

Table 3. Contrasting Laboratory Findings with Fuzzy Model Results

FA	MWP	ω opt (%)			dry,max (γ)			qu kN/m²			CBR kN/m³		
		Existing result	Fuzzy result	% of Deviation	Existing result	Fuzzy result	% of Deviation	Existing result	Fuzzy result	% of Diff	Existing result	Fuzzy result	% of Diff
10	5	2.73	2.76	1.1	2.23	2.25	0.9	3791	3390	10.6	2543	2630	3.4
20	10	4.96	5	0.8	1.93	2	3.6	2561	2610	1.9	3011	2850	5.3
30	15	7.85	8.26	5.2	1.9	1.8	5.3	995	879	11.7	2438	2400	1.6

In Table 3, represents the percentage of the deviation between the laboratory test results and the fuzzy model's predictions. The water content result deviated 11% from the predicted value when using a mixture of 10% FA and 5% MD. However, for the combination of 20% FA and 10% MD, the deviation was significantly lower at 0.8%. Furthermore, the fuzzy model performed well in estimating CBR strength and UCS strength, with deviations of 10%, 1.9%, and 11% compared to the lab results. The outcomes of this developed fuzzy model effectively predicted the strength of the granular soil.

5. Conclusion

In the research, a study was made on the usage of marble dust and fly ash effects in the road base construction work. Based on this study, the fuzzy model was developed from MATLAB software and evaluated the model with various laboratory tests. The result concludes only a minimum deviation between the developed model and the laboratory test. The combination of fly ash and waste marble powder increases the properties of sub-base materials, which increases the stabilization of the soil. Reusing waste materials in construction works creates economic contribution and reduces environmental pollution. In addition, the fuzzy model reduces the time and cost of the research for various combinations of mixes.

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