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Application of Multi Criteria Decision Making tools in Selection of Concrete Mix

Uzair Khan[1], Rajat Verma[1], Binod Kumar Singh[2] and Vikash Yadav[1]*
[1]ABES Engineering College, Ghaziabad, Uttar Pradesh, India
[2]Ajay Kumar Garg Engineering College, Ghaziabad, Uttar Pradesh, India

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Now a day decision making plays a major role in deciding the execution of any task. Two key tools are available to serve the purpose of decision-making. These include AHP as well as TOPSIS, both falls under Multi Criteria Decision Making (MCDM) tools. These techniques are now also brought in the field of civil engineering. MCDM techniques are used in various applications of civil engineering. This paper presents comparison of AHP and TOPSIS for making final decisions for the best concrete mix with fibres of steel and basalt available with different proportions. The comparison is made on the tests of split tensile strength, compressive strength and flexure results. Results of the experiment are used to validate results of AHP and TOPSIS. Optimum hybrid mixes for mechanical properties is M-S0.5-B0 at 28 days.

Keywords: AHP, Basalt fibres, Comparative Data Study, Steel fibres, TOPSIS

Introduction

The execution of task always depends on the decision making and recognizing and selection of the best possible alternative among all. This brought to the development of advanced tool called as Multi Criteria Decision Making tools. This tool after becoming popular has brought a shift in trends of civil engineering. The tool has ensured its user to analyse the performance based on the grounds of technology, all constraints related to the economic factors and impact on the conditions of environment. The most widely tools of MCDM includes AHP and TOPSIS. This will present ideas about all facts and insights correlated with selection of alternatives available for decision-making.[1]

The purpose of bringing MCDM tool in civil engineering is to bring the aspects of sustainable approach in designing the materials of construction industry. The studies of this branch of engineering basically deals with the construction of structures and analysing their functional approach as well the durability and strength of the structure.[2]

The tools find more appropriate place in deciding the mix of concrete. Concrete is one of the most important construction materials available to the construction industry. Concrete is prepared by mixing various building materials like cement, aggregates and water. Concrete mix basically follows various design standards. Their final performance helps to make decision in the selection of best possible mix available for use. MCDM technique evolves around analysing the design of concrete mix and then grading the mix as per the results obtained. Consequently, all works related to MCDM basically revolve around construction field.[3]

The various methods of MCDM deals with different types of inputs and then making the final decision on the basis of alternatives available for use.[4]

The procedural steps of MCDM basically involved the following pattern :[5, 6]

(1) Know the problems and find possible solutions for the same.
(2) Decide final goal.
(3) Try to initiate all possible options.
(4) Decide best decision-making tool.
(5) Make a final decision for the problem.

The first tool of the MCDM technique is Analytical Hierarchy Process (AHP). It is the most widely used tool of mathematics that is helpful in making the decision for complex problems. The tool was first developed in 1980.(7) The tools help its user to analyse the priorities between all the alternatives available. Further it is helpful in making the best decision in all available alternatives. It follows the hierarchical order by doing required arrangement of criteria as per the standard pattern available. It works in the manner by putting problems into various hierarchy levels with the objective on its top. In the middle criteria are assigned and at bottom level all

*Author for Correspondence
E-mail: vikash.yadav@abes.ac.in

different available alternatives are kept. One of the best uses of AHP is the ability to rank the alternatives in order while meeting the goals when conflicts arise.[8] AHP has been kept under category of broader approach of MCDM method called as additive weighing techniques.

The second tool of MCDM technique involves Technique for Order Preference by Similarity to Ideal Solution, popularly called as TOPSIS. This model has been brought up in 1981.[(9)] It is a method that helps in making the appropriate decision. It also helps in putting comparison with all alternative decision available from different choices. The most optimum results of TOPSIS depend on PIS and NIS.[10] The central theme of TOPSIS is to select that alternative which has smallest distance in context to positive solution and is far from the negative value, both in ideal case. Thus, it revolves around the technique of selecting and ranking the alternatives available, with the concept of distance measures. Thus, it is used to verify the result obtained from the technique of AHP. TOPSIS allows the assessment on the basis of both quantitative and qualitative criteria. So, there will be a proper balance of both good and bad results in different criterion available for choice.

Both methods are widely used in analysing the results of concrete mix. Detailed information was given related to the use of recycle tyre aggregate in concrete mix.[11] The work has given complete idea that how TOPSIS and AHP plays major role in deciding the best alternative so to get the most sustainable concrete. Important thing to note is that the balance is made between both the factors of performance based on mechanical and environmental ground.

So, both these tools of MCDM technique have become an important factor in deciding the most suitable design mix. AHP and TOPSIS tools thus gain popularity in all trends of civil engineer field. They are considered to be a tool to serve following needs.[12]

(1) Everyone understands both the tools easily.

(2) The idea of ranking is obtained from both the tools.

(3) While TOPSIS compare for the available ideal solution, AHP uses hierarchical structure to give solution as per the assigned criteria of objective.

(4) Both the tools are available to everyone.

Using these tools, the results from experiments will be verified from mathematical tools. This will help to deal with the problems of sustainability. These tools help the user to provide consistency in decision-making process. These tools provide following advantages to the user.[13]

(1) It reduces the chance of biased decision making for available choices, as results obtained are cross-verified with practical experiments.

(2) The technique deals with all economic constraints and has easy approach for computation.

(3) These techniques deal with real life problems and provide best solution from all the alternatives available.

The paper finds application in construction industry while selecting the design mix of concrete as per suitable testing results. These methods can be applied to find the optimum percentage of fibres for the best concrete design mix for desired workability and mechanical properties.

The prime objective is to use two analytical methods AHP and TOPSIS to evaluate a sustainable hybrid fibre reinforced self-compacting concrete containing steel and basalt fibres in Fig. 1. Mechanical properties of hybrid fibre reinforced self-compacting concrete are shown in Table1.

Analytical selection of sustainable hybrid fibre reinforced self-compacting concrete

Proportions of steel and basalt fibres are taken in samples as 0%, 0.25%, and 0.5 % by volume. To identify the best mechanical properties out of seven mix of concrete AHP and TOPSIS methods are employed. Similarly, worst mix is identified using `same statistical methods i.e. AHP and TOPSIS. For notations, M is used for concrete mix, S is used for steel and B is used for the basalt fibre. Finally, results are obtained from AHP and TOPSIS method and were compared.

Results and Discussions

Selection by analytical hierarchy process

The first step is to generate the pair-wise matrix by doing normalization of all available for each criterion

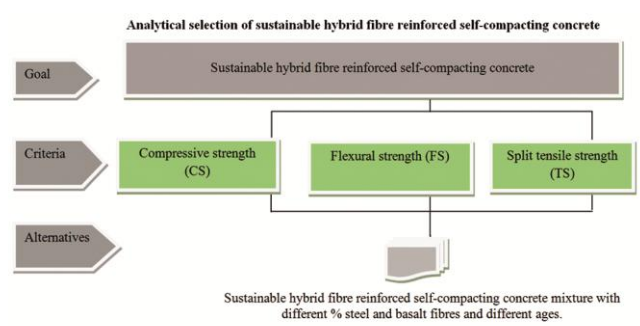

Fig. 1 — Schematic diagram for AHP analysis to select the sustainable hybrid fibre reinforced self-compacting concrete

as shown in Tables 2–4. In Table 2, pairwise matrix is generated for compressive strength as criterion for all available alternatives. In Table 3, pairwise matrix is generated for flexural strength as criterion for all available alternatives. Similarly, in Table 4, pairwise matrix is generated for split tensile strength as criterion for all available alternatives. The determination of complete Eigen Value is done for all

Table 1 — Mechanical Properties of hybrid fibre reinforced self-compacting concrete containing steel and basalt fibres [15]

Sr. No	Mix	CS at 7 days	CS at 28 days	FS at 7 days	FS at 28 days	TS at 7 days	TS at 28 days
1	M-S0-B0	30.01	39.4	5.69	7.77	2.43	3.31
2	M-S0.25-B0	30.45	39.85	5.95	7.82	2.48	3.45
3	M-S0.25-B0.25	32.67	41.92	5.96	7.9	2.5	3.48
4	M-S0.25-B0.5	37.85	49.82	6.34	8.31	2.6	3.53
5	M-S0.5-B0	35.11	47.4	7.53	9.61	3.14	4.07
6	M-S0.5-B0.25	37.11	48.85	6.69	8.34	3.12	4.02
7	M-S0.5-B0.5	32.74	42.81	6.1	8.13	3.02	3.98

Compressive strength (CS) Flexural strength (FS) Split tensile strength (TS) — measured in (N/mm^2)

Table 2 — Pair-wise comparison for all alternatives with respect to criteria for compressive strength

Compressive Strength		7 days							28 days						
		M-S0-B0	M-S0.25-B0	M-S0.25-B0.25	M-S0.25-B0.5	M-S0.5-B0	M-S0.5-B0.25	M-S0.5-B0.5	M-S0-B0	M-S0.25-B0	M-S0.25-B0.25	M-S0.25-B0.5	M-S0.5-B0	M-S0.5-B0.25	M-S0.5-B0.5
7 days	M-S0-B0	1.00	0.99	0.92	0.79	0.85	0.81	0.92	0.76	0.75	0.72	0.60	0.63	0.61	0.70
	M-S0.25-B0	1.01	1.00	0.93	0.80	0.87	0.82	0.93	0.77	0.76	0.73	0.61	0.64	0.62	0.71
	M-S0.25-B0.25	1.09	1.07	1.00	0.86	0.93	0.88	1.00	0.83	0.82	0.78	0.66	0.69	0.67	0.76
	M-S0.25-B0.5	1.26	1.24	1.16	1.00	1.08	1.02	1.16	0.96	0.95	0.90	0.76	0.80	0.77	0.88
	M-S0.5-B0	1.17	1.15	1.07	0.93	1.00	0.95	1.07	0.89	0.88	0.84	0.70	0.74	0.72	0.82
	M-S0.5-B0.25	1.24	1.22	1.14	0.98	1.06	1.00	1.13	0.94	0.93	0.89	0.74	0.78	0.76	0.87
	M-S0.5-B0.5	1.09	1.08	1.00	0.86	0.93	0.88	1.00	0.83	0.82	0.78	0.66	0.69	0.67	0.76
28 days	M-S0-B0-28	1.31	1.29	1.21	1.04	1.12	1.06	1.20	1.00	0.99	0.94	0.79	0.83	0.81	0.92
	M-S0.25-B0	1.33	1.31	1.22	1.05	1.14	1.07	1.22	1.01	1.00	0.95	0.80	0.84	0.82	0.93
	M-S0.25-B0.25	1.40	1.38	1.28	1.11	1.19	1.13	1.28	1.06	1.05	1.00	0.84	0.88	0.86	0.98
	M-S0.25-B0.5	1.66	1.64	1.52	1.32	1.42	1.34	1.52	1.26	1.25	1.19	1.00	1.05	1.02	1.16
	M-S0.5-B0	1.58	1.56	1.45	1.25	1.35	1.28	1.45	1.20	1.19	1.13	0.95	1.00	0.97	1.11
	M-S0.5-B0.25	1.63	1.60	1.50	1.29	1.39	1.32	1.49	1.24	1.23	1.17	0.98	1.03	1.00	1.14
	M-S0.5-B0.5	1.43	1.41	1.31	1.13	1.22	1.15	1.31	1.09	1.07	1.02	0.86	0.90	0.88	1.00

Table 3 — Pair-wise comparison for all alternatives with respect to criteria for flexural strength

Flexural Strength		7 days							28 days						
		M-S0-B0	M-S0.25-B0	M-S0.25-B0.25	M-S0.25-B0.5	M-S0.5-B0	M-S0.5-B0.25	M-S0.5-B0.5	M-S0-B0	M-S0.25-B0	M-S0.25-B0.25	M-S0.25-B0.5	M-S0.5-B0	M-S0.5-B0.25	M-S0.5-B0.5
7 days	M-S0-B0	1.00	0.96	0.95	0.90	0.76	0.85	0.93	0.73	0.73	0.72	0.68	0.59	0.68	0.70
	M-S0.25-B0	1.05	1.00	1.00	0.94	0.79	0.89	0.98	0.77	0.76	0.75	0.72	0.62	0.71	0.73
	M-S0.25-B0.25	1.05	1.00	1.00	0.94	0.79	0.89	0.98	0.77	0.76	0.75	0.72	0.62	0.71	0.73
	M-S0.25-B0.5	1.11	1.07	1.06	1.00	0.84	0.95	1.04	0.82	0.81	0.80	0.76	0.66	0.76	0.78
	M-S0.5-B0	1.32	1.27	1.26	1.19	1.00	1.13	1.23	0.97	0.96	0.95	0.91	0.78	0.90	0.93
	M-S0.5-B0.25	1.18	1.12	1.12	1.06	0.89	1.00	1.10	0.86	0.86	0.85	0.81	0.70	0.80	0.82
	M-S0.5-B0.5	1.07	1.03	1.02	0.96	0.81	0.91	1.00	0.79	0.78	0.77	0.73	0.63	0.73	0.75
28 days	M-S0-B0-28	1.37	1.31	1.30	1.23	1.03	1.16	1.27	1.00	0.99	0.98	0.94	0.81	0.93	0.96
	M-S0.25-B0	1.37	1.31	1.31	1.23	1.04	1.17	1.28	1.01	1.00	0.99	0.94	0.81	0.94	0.96
	M-S0.25-B0.25	1.39	1.33	1.33	1.25	1.05	1.18	1.30	1.02	1.01	1.00	0.95	0.82	0.95	0.97
	M-S0.25-B0.5	1.46	1.40	1.39	1.31	1.10	1.24	1.36	1.07	1.06	1.05	1.00	0.86	1.00	1.02
	M-S0.5-B0	1.69	1.62	1.61	1.52	1.28	1.44	1.58	1.24	1.23	1.22	1.16	1.00	1.15	1.18
	M-S0.5-B0.25	1.47	1.40	1.40	1.32	1.11	1.25	1.37	1.07	1.07	1.06	1.00	0.87	1.00	1.03
	M-S0.5-B0.5	1.43	1.37	1.36	1.28	1.08	1.22	1.33	1.05	1.04	1.03	0.98	0.85	0.97	1.00

Table 4 — Pair-wise comparison for all alternatives with respect to criteria for split tensile strength

Split tensile strength		7 days							28 days						
		M-S0-B0	M-S0.25-B0	M-S0.25-B0.25	M-S0.25-B0.5	M-S0.5-B0	M-S0.5-B0.25	M-S0.5-B0.5	M-S0-B0	M-S0.25-B0	M-S0.25-B0.25	M-S0.25-B0.5	M-S0.5-B0	M-S0.5-B0.25	M-S0.5-B0.5
7 days	M-S0-B0	1.00	0.98	0.97	0.93	0.77	0.78	0.80	0.73	0.70	0.70	0.69	0.60	0.60	0.61
	M-S0.25-B0	1.02	1.00	0.99	0.95	0.79	0.79	0.82	0.75	0.72	0.71	0.70	0.61	0.62	0.62
	M-S0.25-B0.25	1.03	1.01	1.00	0.96	0.80	0.80	0.83	0.76	0.72	0.72	0.71	0.61	0.62	0.63
	M-S0.25-B0.5	1.07	1.05	1.04	1.00	0.83	0.83	0.86	0.79	0.75	0.75	0.74	0.64	0.65	0.65
	M-S0.5-B0	1.29	1.27	1.26	1.21	1.00	1.01	1.04	0.95	0.91	0.90	0.89	0.77	0.78	0.79
	M-S0.5-B0.25	1.28	1.26	1.25	1.20	0.99	1.00	1.03	0.94	0.90	0.90	0.88	0.77	0.78	0.78
	M-S0.5-B0.5	1.24	1.22	1.21	1.16	0.96	0.97	1.00	0.91	0.88	0.87	0.86	0.74	0.75	0.76
28 days	M-S0-B0-28	1.36	1.33	1.32	1.27	1.05	1.06	1.10	1.00	0.96	0.95	0.94	0.81	0.82	0.83
	M-S0.25-B0	1.42	1.39	1.38	1.33	1.10	1.11	1.14	1.04	1.00	0.99	0.98	0.85	0.86	0.87
	M-S0.25-B0.25	1.43	1.40	1.39	1.34	1.11	1.12	1.15	1.05	1.01	1.00	0.99	0.86	0.87	0.87
	M-S0.25-B0.5	1.45	1.42	1.41	1.36	1.12	1.13	1.17	1.07	1.02	1.01	1.00	0.87	0.88	0.89
	M-S0.5-B0	1.67	1.64	1.63	1.57	1.30	1.30	1.35	1.23	1.18	1.17	1.15	1.00	1.01	1.02
	M-S0.5-B0.25	1.65	1.62	1.61	1.55	1.28	1.29	1.33	1.21	1.17	1.16	1.14	0.99	1.00	1.01
	M-S0.5-B0.5	1.64	1.60	1.59	1.53	1.27	1.28	1.32	1.20	1.15	1.14	1.13	0.98	0.99	1.00

Table 5 — Normalized priority vector for fourteen hybrid fibre reinforced self-compacting concrete options and their summation

Alternatives		Criteria			
		CS	FS	TS	Sum
7 days	Eigen Value	14.035	14.000	13.989	–
	M-S0-B0	0.055	0.056	0.054	0.165
	M-S0.25-B0	0.056	0.058	0.055	0.169
	M-S0.25-B0.25	0.060	0.058	0.055	0.173
	M-S0.25-B0.5	0.069	0.062	0.058	0.189
	M-S0.5-B0	0.064	0.074	0.070	0.208
	M-S0.5-B0.25	0.068	0.065	0.069	0.202
	M-S0.5-B0.5	0.060	0.060	0.067	0.187
28 days	M-S0-B0	0.072	0.076	0.073	0.221
	M-S0.25-B0	0.073	0.077	0.076	0.226
	M-S0.25-B0.25	0.077	0.077	0.077	0.231
	M-S0.25-B0.5	0.091	0.081	0.078	0.250
	M-S0.5-B0	0.087	0.094	0.090	0.271
	M-S0.5-B0.25	0.086	0.082	0.089	0.257
	M-S0.5-B0.5	0.078	0.080	0.088	0.246

matrixes. The calculation of both CR and CI is done with the help of all available corresponding values. The priority vector is generated after this for each criterion. The summation of this vector decides the priority to alternatives. The normalized priority vector for all alternatives of hybrid reinforced self-compacting concrete mixes and their summation is represented in the Table5.

Seven alternatives are tested at 7 days of curing and remaining seven alternatives at 28 days. Results of AHP technique clearly show that M-S0.5-B0 is the best alternative at the age of 28 days and M-S0-B0 is the worst alternative at the age of 7 days. When results are compared without fibre ingredients, worst alternative is M-S0.25-B0 at 7 days. It is clearly inferred from experimental results and statistical analysis the optimum amount of fibre is 0.5% steel by volume. Fig. 2 clearly shows that highest sum value for priority vector is obtained for M-S0.25-B0 mix at 28 days.

$$V^{+} = [0.337, 0.348, 0.333] V^{-} = [0.203, 0.206, 0.199]$$

$$H^{+} = \begin{bmatrix} 0.237 \\ 0.227 \\ 0.218 \\ 0.187 \\ 0.146 \\ 0.157 \\ 0.192 \\ 0.115 \\ 0.106 \\ 0.095 \\ 0.065 \\ 0.016 \\ 0.047 \\ 0.072 \end{bmatrix} H^{-} = \begin{bmatrix} 0 \\ 0.011 \\ 0.021 \\ 0.030 \\ 0.095 \\ 0.082 \\ 0.054 \\ 0.122 \\ 0.132 \\ 0.142 \\ 0.187 \\ 0.228 \\ 0.206 \\ 0.177 \end{bmatrix}$$

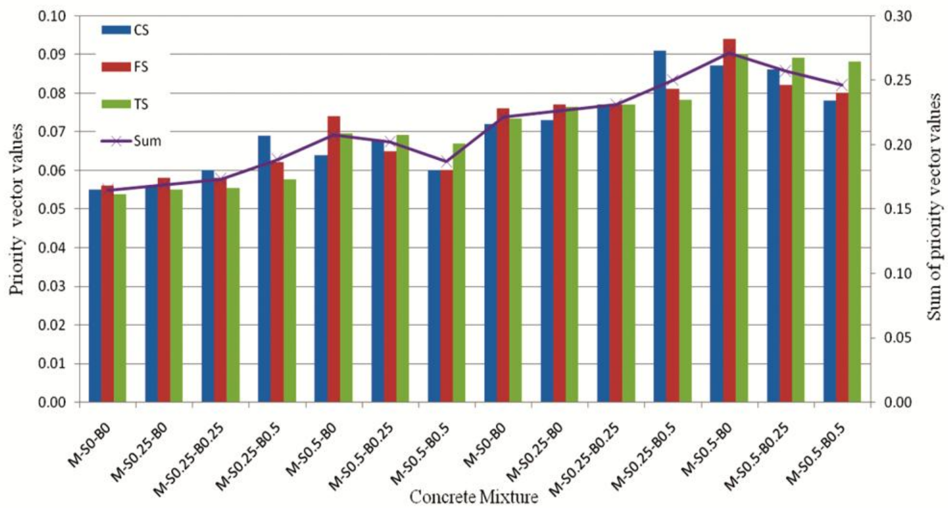

Fig. 2 — Priority vector values of all alternatives by AHP

Table 6 — Normalized values of evaluation matrix

	Alternatives	Criteria		
		CS	FS	TS
7 days	M-S0-B0	0.203	0.206	0.199
	M-S0.25-B0	0.206	0.215	0.203
	M-S0.25-B0.25	0.221	0.216	0.204
	M-S0.25-B0.5	0.256	0.229	0.212
	M-S0.5-B0	0.237	0.273	0.257
	M-S0.5-B0.25	0.251	0.242	0.255
	M-S0.5-B0.5	0.221	0.221	0.247
28 days	M-S0-B0	0.267	0.281	0.270
	M-S0.25-B0	0.270	0.283	0.282
	M-S0.25-B0.25	0.284	0.286	0.284
	M-S0.25-B0.5	0.337	0.301	0.288
	M-S0.5-B0	0.321	0.348	0.333
	M-S0.5-B0.25	0.330	0.302	0.328
	M-S0.5-B0.5	0.290	0.294	0.325

Selection by Technique for Order Preference by Similarity to Ideal Solution

The second analytical technique of multi criteria decision making is TOPSIS. Firstly, normalized values for evaluation matrix is calculated as shown in Table 6. It is used in calculating relative closeness coefficient (RCC).The results obtained for the entire relative closeness coefficient (RCC) of available alternatives are presented in Fig. 3.

Comparison of AHP and TOPSIS

The comparison of results for both techniques is shown in Fig. 4. For mechanical properties, M-S0.5-B0 at the age of 28 days comes out to be the best possible outcome. The little difference is observed due to the difference in procedural steps. AHP is more sensitive to small changes with comparison to TOPSIS analysis. Though procedure is different for AHP and TOPSIS method results are showing almost identical trend.

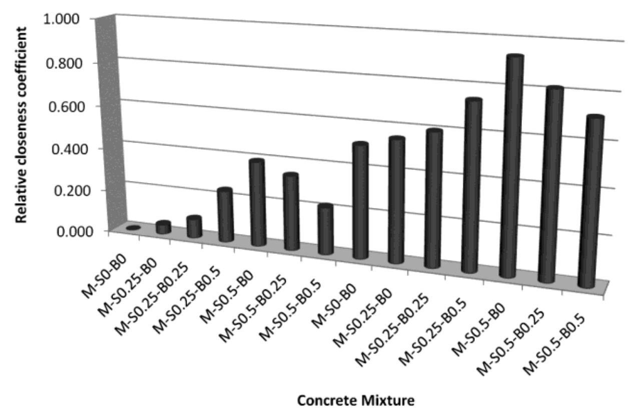

Fig. 3 — RCC of all alternatives by TOPSIS

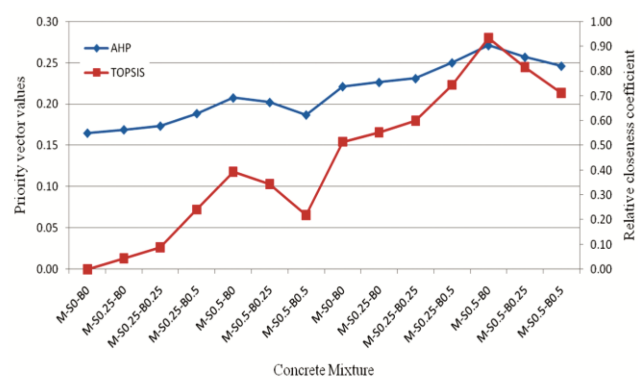

Fig. 4 — Summary of both types of technique

Conclusions

From the present study of both the techniques of multi criteria decision making, the following conclusions can be inferred.

1. Most suitable hybrid mix for mechanical properties is M-S0.5-B0 at the age of 28 days
2. M-S0-B0 is the worst alternative at the age of 7 days.
3. Though methodology of AHP and TOPSIS is different final results are most identical by both methods.
4. These tools will help in selecting the most sustainable concrete mix in the construction industry. This will also help in distinguishing the best and worst concrete mix. Therefore, MCDM techniques play vital role in decision making process and can now be widely used in civil engineering.
5. This study will also provide economical and technical advantages as decision making is quite easy and it can be validated through different tests.
6. This work will also help in deciding the sustainability and durability of the proposed mixture for longer periods of time.

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