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Optimization of additives in cement mortar using Taguchi method.

Optimización de aditivos en morteros de cemento mediante el método Taguchi.

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ABSTRACT

Recent emerging developments in construction works have introduced many enormous and wonderful construction materials. But till now, cement based construction materials are being used in various activities e.g., masonry, lining, grouting etc. Cement, a key ingredient for various construction materials, needs to be replaced by another natural or artificial inert, due to its perilous effects in ecology. The present study has been conducted to evaluate the compressive strength, electrical resistivity, cost analysis and environment assessment of cement mortar after replacing the cement with various proportions of Kota stone powder. Calcium nitrate and triethanolamine were also added to the mortar mixes to control the parametric behaviours of the mixes. The Taguchi technique has been used to curtail the number of mix proportions for effort saving practices. Taguchi technique produces a data set of lesser experimental runs than a full factorial approach. Therefore, Taguchi method could be used to optimize the number of combinations to make the project cost-effective. The purpose of this study is to evaluate the performance of cement mortar containing calcium nitrate, triethanolamine, and Kota stone powder in various proportions with respect to various attributes. An L9 (3^3) orthogonal array containing nine mortar blends was analyzed to optimize the process parameters on the basis of the laboratory responses. Results of the study positively affirmed that the efficacy of the incorporation of Kota stone powder in mortar has yielded as economic and ecological construction material over other additives.

Keywords: Industrial waste, admixtures, mortar mixture, optimization, Taguchi method.

RESUMEN

Los recientes avances en las obras de construcción han introducido muchos materiales de construcción enormes y maravillosos. Pero hasta ahora, los materiales de construcción a base de cemento se utilizan en diversas actividades, por ejemplo, albañilería, revestimiento, lechada, etc. El cemento, un ingrediente clave para diversos materiales de construcción, necesita ser reemplazado por otro inerte natural o artificial, debido a sus peligrosos efectos en ecología. El presente estudio se realizó para evaluar la resistencia a la compresión, la resistividad eléctrica, el análisis de costos y la evaluación ambiental del mortero de cemento después de reemplazar el cemento con varias proporciones de polvo de piedra Kota. También se agregaron nitrato de calcio y trietanolamina

a las mezclas de mortero para controlar el comportamiento paramétrico de las mezclas. La técnica Taguchi se ha utilizado para reducir el número de proporciones de mezcla para prácticas que ahorran esfuerzo. La técnica de Taguchi produce un conjunto de datos de ejecuciones experimentales menores que un enfoque factorial completo. Por lo tanto, el método Taguchi podría utilizarse para optimizar el número de combinaciones para que el proyecto sea rentable. El propósito de este estudio es evaluar el desempeño del mortero de cemento que contiene nitrato de calcio, trietanolamina y polvo de piedra Kota en diversas proporciones con respecto a diversos atributos. Se analizó una matriz ortogonal L9 (3^3) que contiene nueve mezclas de mortero para optimizar los parámetros del proceso en función de las respuestas del laboratorio. Los resultados del estudio afirmaron positivamente que la eficacia de la incorporación de polvo de piedra de Kota en el mortero ha resultado como material de construcción económico y ecológico frente a otros aditivos.
Palabras clave: Residuos industriales, aditivos, mezcla de mortero, optimización, método Taguchi.

INTRODUCTION

Population growth and industrial development both are correspondent and consequently cause infrastructure requirement and production of industrial wastes. Cement play a key role in preparing the construction materials. The production of cement causes emission of greenhouse gases inthe environment to a great extent and require huge energy consumption in manufacturing. One of the possible solutions to reduce the cement consumption without compromising the quality of the cement mortar or concrete is the utilization of readily availableindustrial by-products as substitution to raw materials. The stone waste in its different forms e.g., broken pieces, dust, powder or slurry form is found on a large scale in the stone industries and have dumped into open land areas or water courses. Such disposal practices are hazardous to the ecology of the area. Therefore, safe stone waste disposal is a serious concern for the industries. Although lately, the use of industrial waste materials or by-products in mortar or concrete production is popularizing, due to their benefits in terms of reducing the final product cost and negative impact on the existing environment. This approach paved a way for an efficientwaste management as well. Therefore, the stone slurry can be utilized in producingcement mortar [1, 2]. However, the raw material consumption for the trials can be reduced up to a certain extent by optimizing the cement mortar and concrete mixture compositionwithout compromising the quality of the final product. The optimization and contribution of additive materials can be assessed through various optimization techniques and statistical analyses. The optimum content and range of additive percentage can also be evaluated through these optimization techniques e.g., Taguchi method or Robust design. This technique has been found much efficient in optimizing the replacement variations of admixtures and industrial wastes in cement mortar, obtaining good laboratory responses for the compressive strength, electrical resistivity and cost. Optimal content of additives can be obtained at minimal use of materials, time and cost by adopting this approach [3-8]. Chokkalingam et al. [2] analysed the effects of ceramic waste and granulated blast furnace slag on the mechanical and durability properties of geopolymer concrete using Taguchi method integrated withtwo approaches BWM and TOPSIS. The optimum mix was found same for both approaches. Arici and Keleştemur [5] examined the performance of mortar consisting of steel scale using Taguchi based grey relational analysis (T-GRA) approach andfound a significant improvement in the grey relational grade value.Side et al. [7] studied the optimization of mortar mixtures containing silica fume as cement substitution using Taguchi experiment design method and found the optimum mix proportions of mortar as silica fume-150 gr, cement-660 gr and sand-1400 gr in terms of compressive strength, pH and water absorption, respectively. In the present study, Taguchi-Design of experiments (DOE) was used to determine the optimum mix proportions of cement mortar with respect to various properties i.e., compressive strength, electrical resistivity, cost and environmental assessment. Analysis of variance (ANOVA) was also performed to quantify the percentage contribution of various additives in affecting the various engineering properties of the cement mortar. Taguchi orthogonal array L9 was taken to determine the optimum level of various factors i.e., calcium nitrate (CN), triethanolamine (TEA) and stone waste powder (SSP) in the cement mortar.

MATERIALS AND METHODS

Mix Proportions- Ordinary Portland cement (43 Grade) confirming to IS:8112-1989, and, coarse sand [FM-3.17, G-2.62 and ρ_b -1646 kg/m^3 (loose),1824 kg/m^3 (compacted)] confirming to IS:383-2016 were used in the mortar mixtures (Devi et al., 2019). Kota stone slurry (SSP) was procured from Kota, Rajasthan (India). It was used as cement substitution of 0%, 5% and 7.5%, after drying and minute to fine powder form, in preparing mortar mixes(Devi et al., 2018). Accelerating admixtures namely, calcium nitrate tetrahydrate purified (abbreviated as CN) [Chemical formula:Ca $(NO_3)_2.4H_2O$] was used in thecrystal form and constituted 0%, 1% and 2% in the prepared mortar mixes. Another additive, Triethanolamine LR (abbreviated as TEA) [Chemical formula: $C_6H_{15}NO_3$] was used in proportions of 0%, 0.025%, 0.05% to prepare the designed mixes. Tap water,free from allimpurities, was addedfor the preparation of the mix proportions (Devi et al., 2019).

Taguchi Technique

For Taguchi based optimization, the additives and their proportions were considered as factors (process parameters) and levels (Quality parameters) respectively and, have been given in Table 1. In the present study, a standard orthogonal array of nine experimental runs (L9-3^3) with three levels and three factors was adopted for laboratory experiments. The corresponding experimental runs withdesignation of mix proportions have been given in Table 2. Taguchi method follows three steps which comprise(i) calculation of signal (desirable response) to noise (undesirable response) ratio commonly known as SNR (ii) response graphs (SNR and mean graphs) and, (iii) analysis of variance (ANOVA). The whole optimization and analysis were done using MINITAB 22 software (Kumar and Soni, 2019a, b, Kumar and Soni, 2020, Kumar and Jain, 2023).In the present study, character P has been used for SSP,T for TEA and C for CN, to represent the optimized levels of the additives in a mix proportion for various properties of the mortar mixes. For example, P1, T2 and C3 indicate 0% SSP, 0.025% TEA and 2% CN.

Table 1 Factors and their levels

Level	Factors		
	SSP (%)	TEA (%)	CN (%)
1	0	0	0
2	5	0.025	1
3	7.5	0.05	2

Table 2 Standard orthogonal array

Input Output	Cement	Sand	Coarse aggregates	Water	CN	TEA	SSP	SP

Mix Designation	SSP (%)	TEA (%)	CN (%)
MD1	0	0	0
MD2	0	0.025	1
MD3	0	0.05	2
MD4	5	0	1
MD5	5	0.025	2
MD7	7.5	0	2
MD8	7.5	0.025	0
MD9	7.5	0.05	1
MD6	5	0.05	0

The compressive strength of mortar mixes was determined for cubes of size 70.6mm x 70.6 mm x 70.6 mm in accordance to IS: 4036-1989 (Part-6) after 7 and 28 days of water curing. The electrical resistivity of mortar cubes was measured using two-point method (Devi et al., 2020). The energy consumption and CO_2 emission were also evaluated; for those the inventory data was taken from the previous research conducted by Devi et al., 2022 and has been given in Table 3(Devi et al., 2022).

Table 3 Inventory data of raw materials

EE, MJ/kg	4.8	0.081	0.0083	0.2	0.1368	-	-	11.5
ECO_2, $kgCO_2/kg$	0.93	0.0051	0.0008	0.0008	0.481	-	-	0.6
Cost, INR/kg	6	1	1.8	0.05	430	1060	-	200

RESULTS AND DISCUSSION

On the onset, the performance of the different mortar mixes consisting SSP, TEA and CN was evaluated experimentally and then Taguchi method was employed to analyse the performance characteristics statistically in terms of compressive strength, electrical resistivity cost and environmental assessment. A thorough knowledge on Taguchi Technique can be acquired from previous researches (Kumar and Soni, 2019a, b, Kumar and Soni, 2020, Kumar and Jain, 2023).

Compressive strength-7 Day (7D-CS): The compressive strength test results (performance characteristics) of the various mortar mixes have been taken from previously published work of Devi et al., 2018. The Signal (desirable) to Noise (undesirable) Ratios (SNR) using laboratory responses have been calculated accordance to Larger-the-Better condition. The calculated SNRs for 7D-CS have been given in Table 4 and the corresponding calculated SNRs means have been given in Table 5.

TABLE 4 SNR VALUES FOR 7D-CS

Level	SSP	TEA	CN
1	28.18	29.26	29.38
2	29.51	28.98	28.86
3	28.94	28.39	28.39
Delta	1.33	0.87	0.99
Rank	1	3	2

TABLE 5 SNR MEANS FOR 7D-CS

LEVEL	SSP	TEA	CN
1	25.91	29.08	29.46
2	29.88	28.21	27.79
3	28.00	26.50	26.55
DELTA	3.97	2.58	2.91
RANK	1	3	2

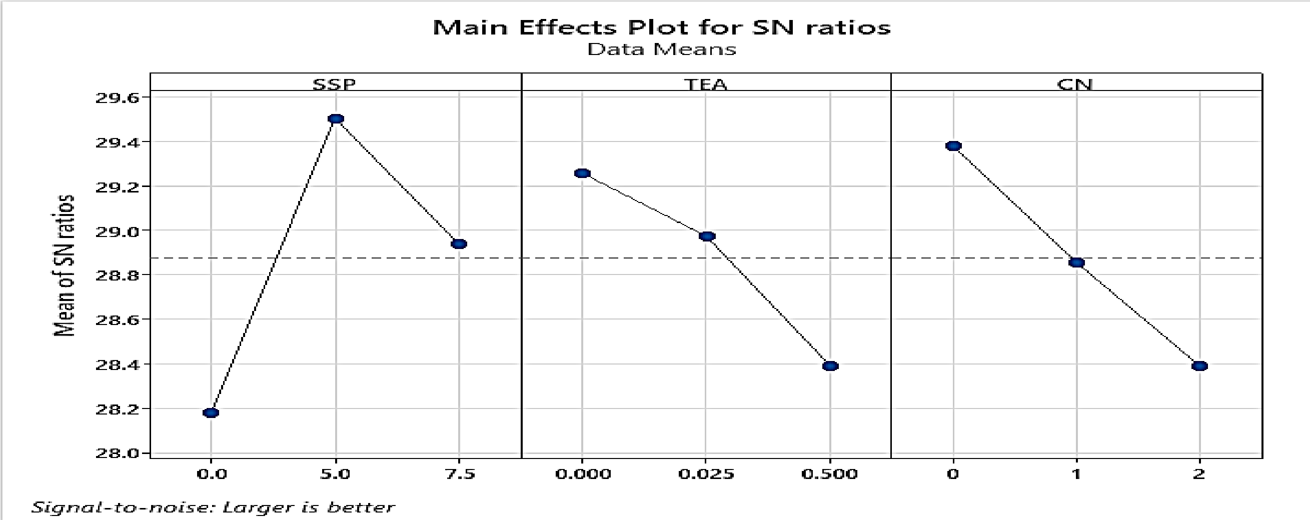
In Table 4, delta is the difference between highest and lowest SNR for a particular performance characteristic and, rank is the hierarchical order of the calculated deltas.

Analysis of variance (ANOVA) of the SNRs has also been done, using fit linear model, to quantify the performance characteristics statistically and to obtain the percent contribution of the process parameters to affect the responses. A 95% confidence level ANOVA table for 7D-CS, in extended form, has been arranged and given in Table 6.

TABLE 6 ANALYSIS OF VARIANCE OF 7 DAYS COMPRESSIVE STRENGTH

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
SSP	2	2.647	2.647	1.3233	1.15	0.465	34.94%
TEA	2	1.164	1.164	0.5822	0.51	0.664	15.37%
CN	2	1.464	1.464	0.7320	0.64	0.611	19.33%
Error	2	2.300	2.300	1.1498	-	-	30.36%
Total	8	7.575	-	-	-	-	100.00%

From Table 6, it can be interpreted that, SSP is a significant factor followed by CN and TEA, to affect the 7D-CS. The experimental results showed the increment of strength due to inclusion of SSPand CN in mortar may be because of formation of dense matrix due to pore filling effect of SSP's particles and high content of lime which formed additional hydrated-calcium-silicate gel by reacting with silica that contributed enhancement in strength(Devi et al., 2019, Devi et al., 2018). TEA reduced the strength due to its retarding effect on C_3S hydration (Devi et al., 2019). Furthermore, a high P-value of the factors also proved that the all factors have participated in affecting the performance characteristic. A high Fig, 1. SNR Graph of 7D-CS



Fig, 1. SNR Graph of 7D-CS

Error could be justified by the fact that the used standard OA contains less experimental runs therefore there was an interaction-lack between laboratory responses. Moreover, though the laboratory conditions for all the mix proportions were idol but the asymmetrical mix proportions had reacted discordantly (Kumar and Soni, 2021).

SNR graph is used to observe the optimized levels of the process parameters. An SNR graph for 7D-CS with respect to SSP, CN and TEA has been shown in Fig. 1. Optimized levels corresponds to the highest SNR therefore, from Fig. 1; S2T1C1 [SSP (5%), TEA (0%) and CN (0%)] could be observed as optimized levels for 7D-CS.

Compressive strength-28 Day (28D-CS)

The compressive strength test results of the various mortar mixes for 28D-CS have also been taken from previously published work of Devi et al., 2018. The Signal (desirable) to Noise (undesirable) Ratios (SNR) of the laboratory responses have been calculated accordance to Larger-the-Better condition as the targeted compressive strength must be high. The calculated SNRs for 28D-CS have been given in Table 7 and the corresponding calculated SNRs means have been given in Table 8. SSP was the predominant factor for the enhancement of strength followed by CN and TEA as discussed above.

TABLE 7 SNR VALUES FOR 28D-CS

Level	SSP	TEA	CN
1	30.10	31.48	32.08
2	31.87	31.48	31.08
3	31.62	30.63	30.43
Delta	1.77	0.85	1.65
Rank	1	3	2

TABLE 8 SNR MEANS FOR 28D-CS

LEVEL	SSP	TEA	CN
1	32.44	37.54	40.19
2	39.21	37.74	35.92
3	38.20	34.57	33.73
DELTA	6.77	3.17	6.46
RANK	1	3	2

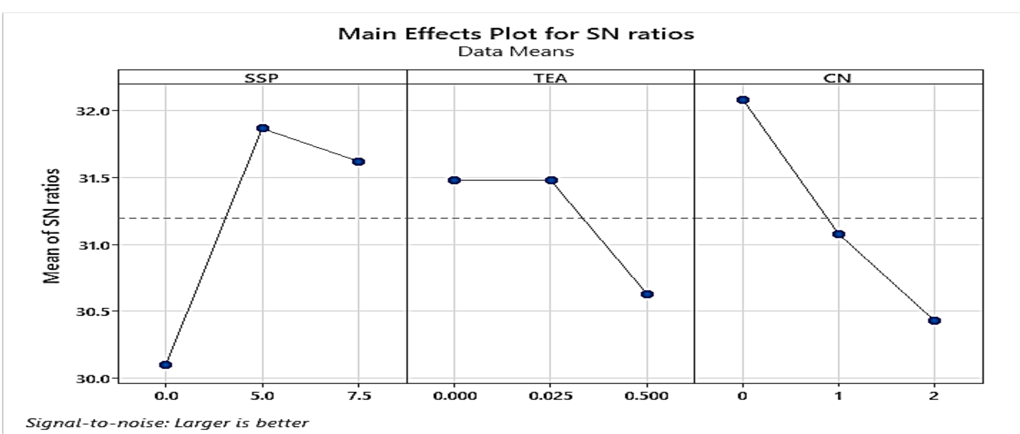
A 95% confidence level ANOVA table for 28D-CS, in extended form, has been arranged in Table IX.

TABLE 9 ANALYSIS OF VARIANCE OF 28 DAYS COMPRESSIVE STRENGTH

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
SSP	2	5.477	5.477	2.7386	3.20	0.238	42.89%
TEA	2	1.441	1.441	0.7207	0.84	0.543	11.29%
CN	2	4.141	4.141	2.0704	2.42	0.292	32.43%
Error	2	1.710	1.710	0.8550	-	-	13.39%
Total	8	12.769	-	-	-	-	100.00%

From Table 9, it can be interpreted that, SSP has found as a significant factor followed by CN and TEA, to affect the 28D-CS as discussed above. It may also be due to finest SSP particles have pore filling effect which fills the voids and produces a dense matrix(Devi et al., 2019). A high P-value of the factors also proved the significant role of all the factors in affecting the performance characteristic. The error in this case was found less than 7D-CS, which is good for fit of the responses.

SNR graph has been used to observe the optimized levels of the process parameters. An SNR graph for 28D-CS with respect to SSP, CN and TEA has been shown in Fig. 2.



Fig, 2. SNR Graph of 28D-CS

From Fig. 2; S2T1C1 [SSP (5%), TEA (0%) and CN (0%)] could be observed as optimized levels for 28D-CS which are same as for 7D-CS.

Electrical resistivity: The Signal (desirable) to Noise (undesirable) Ratios (SNR) of the test performance values have been calculated accordance to Larger-the-Better condition as ER must be high. The calculated SNRs for ER have been given in Table 10 and the corresponding calculated SNRs means have been given in Table 11.

TABLE 10 SNR VALUES FOR ER

Level	SSP	TEA	CN
1	25.60	26.14	26.72
2	26.67	26.35	25.76
3	25.99	25.77	25.78
Delta	1.07	0.58	0.96
Rank	1	3	2

TABLE 11 SNR MEANS FOR ER

LEVEL	SSP	TEA	CN
1	19.13	20.30	21.67
2	21.55	20.85	19.43
3	19.97	19.50	19.55
DELTA	2.42	1.35	2.24
RANK	1	3	2

A 95% confidence level ANOVA table for ER, in extended form, has been arranged in Table 12.

TABLE12ANALYSIS OF VARIANCE OF ER

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
SSP	2	1.7347	1.7347	0.8673	3.37	0.229	38.07%
TEA	2	0.5224	0.5224	0.2612	1.01	0.496	11.46%
CN	2	1.7848	1.7848	0.8924	3.47	0.224	39.17%
Error	2	0.5148	0.5148	0.2574	-	-	11.30%
Total	8	4.5566	-	-	-	-	100.00%

From Table 12, it can be interpreted that, CN is a significant factor followed by SSP and TEA, to affect the ER of the mortar mixes. This could be explained by the fact that better packing of particles within the matrix produced dense microstructure which restrained the ion movement within the concrete specimens and consequently increased the ER (Devi et al., 2020). Furthermore, a high P-value of factors also indicated the substantial involvement of all the factors in affecting the electrical resistivity. The error in this case was also found low which is good for fit of the responses.

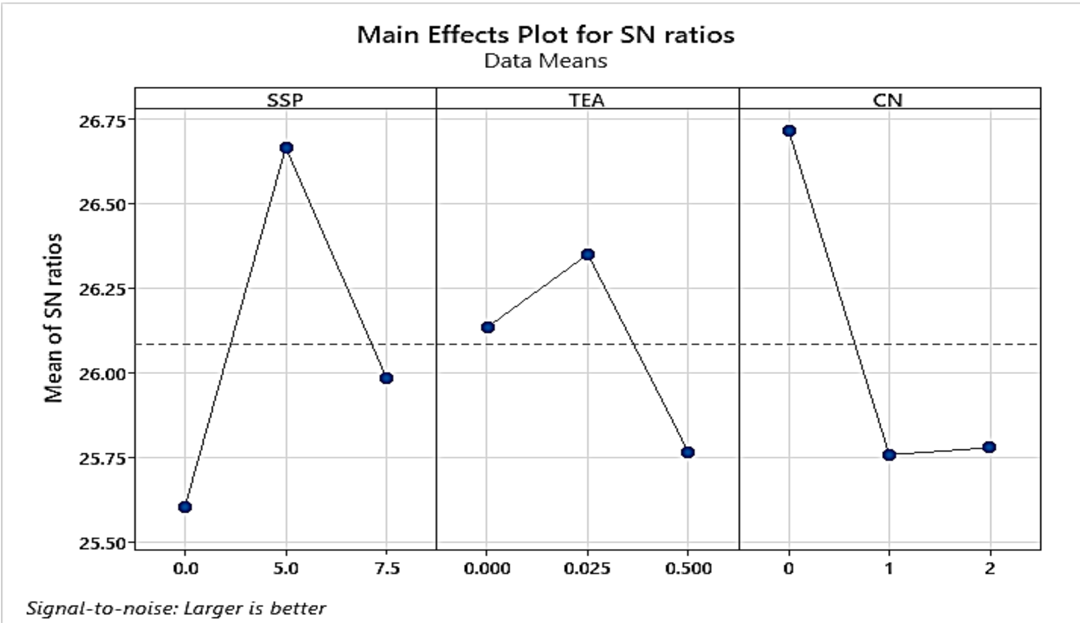


Fig. 3 SNR Graph of mortar mixes ER

Fig. 1. As usual, SNR graph has been used to observe the optimized levels of the process parameters to affect the ER in the mortar mixes. An SNR graph for ER with respect to SSP, CN and TEA has been shown in Fig. 3. From Fig. 3; S2T2C1 [SSP (5%), TEA (0.025%) and CN (0%)] have been observed as optimized levels for ER of the mortar mixes.

Cost

The cost of the final product must be as low as can, so, the Signal (desirable) to Noise (undesirable) Ratios (SNR) of the performance characteristics have been calculated accordance to Smaller-the-better condition. The calculated SNRs for product cost have been given in Table 13 and the corresponding calculated SNRs means have been given in Table 14.

TABLE13 SNR VALUES FOR PRODUCT COST

Level	SSP	TEA	CN
1	-77.83	-77.55	-75.13
2	-77.83	-77.91	-77.99
3	-77.79	-78.00	-80.34
Delta	0.04	0.46	5.21
Rank	3	2	1

TABLE 14 SNR MEANS FOR PRODUCT COST

LEVEL	SSP	TEA	CN
1	8087	7779	5713
2	8002	8084	7931
3	7959	8185	10404
DELTA	128	406	4691
RANK	3	2	1

A 95% confidence level ANOVA table for product cost, in extended form, has been arranged in Table 15.

TABLE 15 ANALYSIS OF VARIANCE OF PRODUCT COST

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
SSP	2	0.0030	0.0030	0.0015	0.04	0.960	0.01%
TEA	2	0.3481	0.3481	0.1740	4.90	0.170	0.84%
CN	2	40.8131	40.8131	20.4065	574.33	0.002	98.98%
Error	2	0.0711	0.0711	0.0355	-	-	0.17%
Total	8	41.2352	-	-	-	-	100.00%

From Table 15, it can be interpreted that, CN is a most significant factor than TEA and SSP, to affect the final product cost. Though the cost of CN is much more than SSP (based on latest price/kg) but, is very less than comparatively to TEA. So, in terms of chemicals used in the present study CN has been found dominant chemical inert to minimize the production cost (Devi et al., 2022). Furthermore, a high P-value of factors also indicated the considerable participation of all the factors in reducing the product cost. The calculated error in the product cost ANOVA was also found less which indicates a good fit of the responses. In this case also, SNR graph has been used to observe the optimized levels of the process parameters to affect the product cost of the mortar mixes. An SNR graph for product cost with respect to SSP, CN and TEA has been shown in Fig. 4.

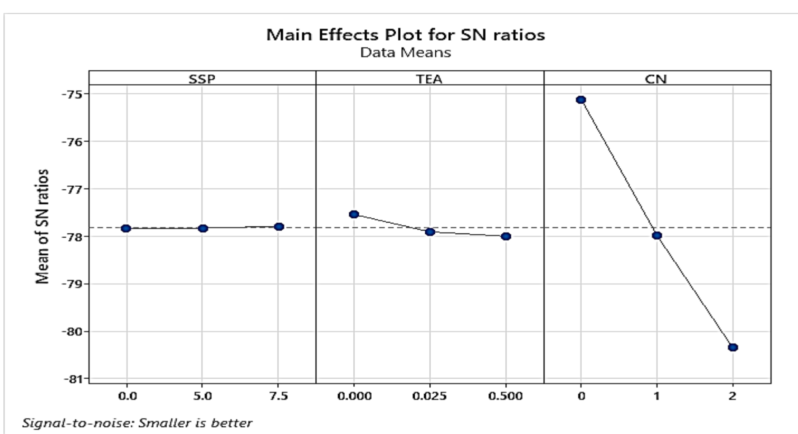


Fig. 2. SNR Graph of the cost of mortar mixes

From Fig. 4; S3T1C1 [SSP (7.5%), TEA (0 %) and CN (0%)] have been observed as optimized levels to achieve the minimum final production cost of mortar mixes.

Environmental Assessment

Embodied Energy

The consumed energy during procurement of the materials to the final product must be low so, the Signal (desirable) to Noise (undesirable) Ratios (SNR) of the performance characteristics have been calculated accordance to Smaller-the-Better condition. The calculated SNRs for embodied energy have been given in Table 16 and the corresponding calculated SNRs means have been given in Table 17.

TABLE16 SNR VALUES FOR EMBODIED ENRGY

Level	SSP	TEA	CN
1	-69.65	-69.31	-69.22
2	-69.24	-69.31	-69.31
3	-69.02	-69.31	-69.39
Delta	0.63	0.00	0.17
Rank	1	3	2

TABLE17 SNR MEANS FOR EMBODIED ENRGY

LEVEL	SSP	TEA	CN
1	3039	2920	2892
2	2897	2921	2921
3	2826	2922	2949
DELTA	213	1	57
RANK	1	3	2

A 95% confidence level ANOVA table for the embodied energy, in extended form, has been arranged in Table 18.

TABLE 18 ANALYSIS OF VARIANCE OF EMBODIED ENRGY

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
SSP	2	0.6170	0.6170	0.3085	30730.00	0.000	93.51%
TEA	2	0.0002	0.0002	0.0001	0.17	0.852	0.00%
CN	2	0.0428	0.0428	0.0214	2131.47	0.000	6.49%
Error	2	0.0002	0.0001	0.0001	-	-	0.00%
Total	8	0.6598	-	-	-	-	100.00%

From the observations of Table XVIII, it can be interpreted that, SSP is the most significant factor than CN and TEA, to affect the embodied energy during production of the mortar mixes. The error in the embodied energy of the product was found likely to zero which is quite good for fit of the responses.

SNR graph has been used to observe the optimized levels of the process parameters to affect the embodied energy in producing mortar mixes. An SNR graph for the embodied energy with respect to SSP, CN and TEA has been shown in Fig. 5.

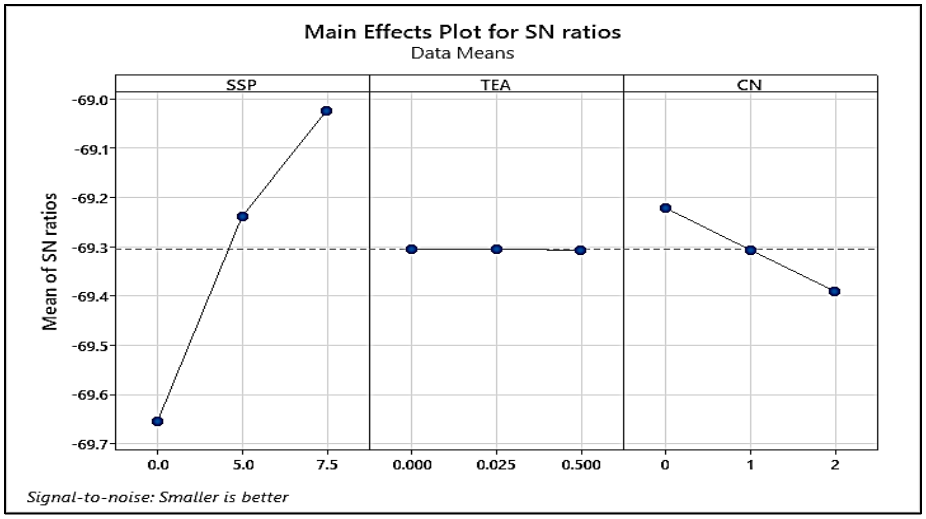


Fig. 3. SNR Graph of the embodied energy of the product

From Fig. 5; S3T3C1 [SSP (7.5%), TEA (0.5 %) and CN (0%)] have been observed as optimized levels for least embodied energy consumed during the production of the designed mortar mixes.

Embodied Carbon-Dioxide: The energy characteristics in the form of exhausted Carbon-Dioxide (CO_2)during casting of various mortar mixes. The exhausted CO_2 during procurement of the materials to the final product must also be low so, the Signal (desirable) to Noise (undesirable) Ratios (SNR) of the performance characteristics have been calculated accordance to Smaller-the-Better condition. The calculated SNRs for embodied energy have been given in Table 19 and the corresponding calculated SNRs means have been given in Table 20.

TABLE19 SNR VALUES FOR EMBODIED CO_2

Level	SSP	TEA	CN
1	-54.84	-54.48	-54.34
2	-54.41	-54.47	-54.48
3	-54.18	-54.47	-54.61
Delta	0.66	0.00	0.27
Rank	1	3	2

TABLE20 SNR MEANS FOR EMBODIED CO_2

LEVEL	SSP	TEA	CN
1	551.9	529.5	521.5
2	525.2	529.6	529.6
3	511.8	529.8	537.8
DELTA	40.1	0.3	16.2
RANK	1	3	2

A 95% confidence level ANOVA table for the embodied CO_2, in extended form, has been arranged in Table 21.

TABLE21 ANALYSIS OF VARIANCE OF EMBODIED CO_2

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution
SSP	2	0.665726	0.665726	0.332863	12530.79	0.000	86.22%
TEA	2	0.000008	0.000008	0.000004	0.16	0.866	0.00%
CN	2	0.106376	0.106376	0.053188	2002.29	0.000	13.78%
Error	2	0.000053	0.000053	0.000027	-	-	0.01%
Total	8	0.772163	-	-	-	-	100.00%

From the observations of Table 21, it can be interpreted that, SSP is the most significant factor than CN and TEA, to affect the embodied CO_2 during production of the mortar mixes. The error in the embodied CO_2 of the product was also found likely to zero which is quite good for fit of the responses.

SNR graph has been used to observe the optimized levels of the process parameters to affect the embodied CO_2 in producing the mortar mixes. An SNR graph for the embodied CO_2 with respect to SSP, CN and TEA has been shown in Fig. 6. The dominancy of SSP in reducing EE and ECO_2 could be justified by the fact that, SSP is a direct industrial by-product of stones or wastes of stone industries and can be reused directly without much processing.

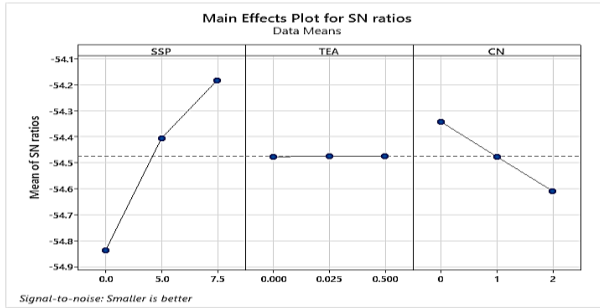


Fig. 4. SNR Graph of the embodied CO_2 of the product

From Fig. 6; S3T3C1 [SSP (7.5%), TEA (0.5 %) and CN (0%)] have been observed as optimized levels for least embodied CO_2exhausted during the production of the designed mortar mixes.

In a nutshell, optimized levels for all the studies conducted in this research article have been provide in Table 22, this could be used for the ease of reading and concluding the research work.

TABLE22 COMPARISON OF THE OPTIMIZED LEVELS

PROPERTIES STUDIED	PILOT TESTS RESULT	OPTIMIZED LEVEL	CONFIRMATORY TESTS RESULT	UNITS
7D-CS	30.82	S2T1C1	35.11	MPa
28D-CS	39.24	S2T1C1	43.19	MPa
ER	21.4	S2T2C1	23	kΩ- cm
COST	66.03	S3T1C1	62.63	INR/KG
EE	3010.04	S3T3C1	2794.14	MJ/KG
E-CO_2	543.674	S3T3C1	503.568	KGCO_2/KG

On the observation of the Table 22, it can be interpreted that SSP was varied from level 2 to level 3 and TEA varied for all levels i.e., level 1 to level 3 whereas CN has been found constant i.e., level 1 in optimized mix proportions.

It can also be observed that the confirmatory tests have better test results than the pilot tests in all terms which consequently indicate the improvement in the mechanical, electrical and environmental properties after incorporating the additives.

CONCLUSIONS

The current study is based on the determination of the optimization of various additives i.e., SSP, TEA and CN in producing more economic and ecologic mortar mixes. The conclusions derived from the current experimental investigation and statistical analysis can be summarized as follows:

- Stone powder (5%) was found significant parameter in improving the compressive strength after 7-Days and 28-days of water curing by 13.92% and 10.07% respectively due to its pore filling effect resulting formation of dense matrix.
- Absence of the CN have a good influence on the electrical resistivity of the designed mortar mixes. Almost 7.48% improvement in electrical resistivity has been reported during confirmation test of optimized mix design.
- TEA had negligible effect on the energy consumption and carbon emission due to presence of very small quantity.
- The addition of the CN in mortar mixes could lower the final product cost by combining it with SSP. The confirmation test results of optimized mix design showed 5.15% cost reduction.
- In environment assessment of the designed mortar mixes, SSP has played a key role to decline the embodied energy and embodied CO_2 by 7.17% and 7.38% respectively due to reduction in cement content and inclusion of industrial by products or waste.
- Meanwhile in most of the cases, SSP has been found a prime process parameter to influence the mortar properties and final product quality so, it would not be exaggerated that SSP could be used as an economic as well as ecologic waste for mortar production.

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