Hindawi
Journal of Nanomaterials
Volume 2022, Article ID 4620687, 8 pages
https://doi.org/10.1155/2022/4620687

Research Article

Optimization of River Sand with Spent Garnet Sand in Concrete Using RSM and R Programming Packages

Jayaraju Raja Murugadoss,[1] **Nachimuthu Balasubramaniam**,[2] **Ravindiran Gokulan**,[3] **Kanta Naga Rajesh**,[3] **Gurusamy Pandian Sreelal**,[4] **Pupalwad Arti Sudam**,[5] **Dhaleelur Rahman Zunaithur Rahman**,[6] **and Razack Nasar Ali**[7]

[1]*Department of Civil Engineering, Nadimpalli Satyanarayana Raju Institute of Technology, Visakhapatnam, Andhra Pradesh 531173, India*
[2]*Department of Civil Engineering, Jansons Institute of Technology, Coimbatore 641659, India*
[3]*Department of Civil Engineeirng, GMR Institute of Technology, Rajam, Andhra Pradesh 532127, India*
[4]*Department of Civil Engineering, K.Ramakrishnan College of Technology, Trichy, Tamil Nadu 621112, India*
[5]*Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana 500090, India*
[6]*Department of Civil Engineering, Aalim Muhammed Salegh College of Engineering, Chennai 600 055, India*
[7]*Department of Civil Engineering, College of Engineering and Technology, Samara University, Afar 7240, Ethiopia*

Correspondence should be addressed to Razack Nasar Ali; nasar.ali01@su.edu.et

Received 21 April 2022; Revised 13 May 2022; Accepted 2 June 2022; Published 13 June 2022

Academic Editor: Samson Jerold Samuel Chelladurai

The main ingredients of concrete are derived from natural resources such as cement, sand, and coarse aggregate. Rapid urbanization leads to the high demand for concrete causing depletion of natural deposits of sand. In this study, the optimized quantities of sand with spent garnet sand are compared in Design Expert's Response Surface Method and R Programming's RStudio packages in terms of predicted and actual compressive and flexural strength at 28 days of curing. Optimization of sand with spent garnet sand at various percentages such as 20, 40, 60, and 80 is proposed. The findings revealed that the correlation coefficient (R^2) of 28 days compressive strength is 0.976 and 28 days flexural strength is 0.969 in both software. It indicates that both software can effectively predict and optimize.

1. Introduction

Concrete is used as a main source of material in the construction field. It consists of cement, fine aggregate, coarse aggregate, water, and admixtures if required. In general, concrete consists of 60-75% of all in aggregates [1, 2]. Fine aggregate is a natural deposit depleting at faster rates than its reclamation. There is a huge demand for its suitable alternative meeting the requirements of fine aggregate as per Indian Standards [3–5]. On the other hand, some of the promising fine aggregates used in the research community are marble dust, crushed coconut shell, used foundry sand, spent garnet sand, etc. [6–8]. The use of by-products of marble, garnet, and foundry industries in any form of concrete production reduces erosion, landslides, and other environmental hazards. Garnet is mostly acquired by digging tiny shallow pits, except in a few locations in Tamil Nadu where it is retrieved from the seashore. Mining is done by hand using pick axes and spades. Drilling and blasting are not required since garnet is extracted from soft worn rocks. Fine abrasive garnet is collected during the processing of beach sands. Dredging, both dry and wet, is used to mine beach sand. Individual minerals, including garnet, are separated in heavy upgradation plants and mineral separation plants. At TGI plan, sands containing 26% garnet are advanced to 80%-88% garnet rich concentrate, which is further upgraded to 98%-99% pure product. Garnet is used in a variety of applications, including abrasives, sandblasting, water filtration materials, abrasive blasting media, and water-jet cutting. Because of the occupational health problems associated with silica sandblasting media, garnet is projected to continue replacing it. Furthermore, garnet is less harmful to the environment and less expensive to dispose of after recycling. As a result, global demand for garnet is likely to rise, particularly for waterjet cutting and abrasive blasting media. China and India are anticipated to steadily improve garnet output and become major garnet suppliers to other nations [9]. As per the USGS 2022 survey, global production of industrial-grade garnet is estimated at 1.1 billion tonne, whereas in India 0.13 billion tonne [10]. The garnet sand after repeated use is disposed of as a landfill, embankment fill, etc and is termed as used or waste or spent garnet sand (SGS). Ab Kadir et al. reported that the use of 40% SGS as a partial replacement of fine aggregate in concrete was considered optimum in terms of compression, flexural, and split tensile strengths [11]. Some authors reported that river sand when partially replaced with 25% SGS in fly ash and granulated blast furnace slag-based alkali-activated mortars yielded enhanced flowable and strength properties [8]. Concrete with 40% SGS, 20% used foundry sand, and 40% river sand yielded on par compression and split tensile strength properties compared to control [7]. Concrete with SGS was thermally stable compared to river sand concrete at elevated temperatures [11]. The SGS was well graded in fallen in zone-II, and the leaching properties were within acceptable limits [12].

This research investigates the value of combining two unique computational modelling methodologies, viz., Response Surface Method (RSM) of Design Expert and R Programming's RStudio packages in terms of prediction with measured actual compressive and flexural strength at 28 days of curing. In this work, river sand is replaced at various percentages with SGS in concrete production. The effect of replacement on compression and flexural properties is compared with measured and predicted respective strengths in both modelling packages. The findings revealed that the correlation coefficient (R^2) of 28 days compressive strength is 0.976 and 28 days flexural strength is 0.969 in both software packages. It indicates that both software can effectively predict and optimize.

2. Materials

Cement: In all the mix proportions ordinary Portland cement of 53 grade supplied by Nagarjuna cements with 3.07 specific gravity was used [13].

Coarse Aggregate: In all the mix proportions, crushed coarse aggregates of size 20 mm, 2.66 specific gravity was used [3–5].

River Sand: the river sand in all the mix proportions confirms to IS 2720 (Part 3-1980); IS 2386 (Part 1 and 3-1963), a specific gravity of 2.69 and grain size analysis as shown in Figure 1.

Spent Garnet Sand (SGS): SGS in the nonconventional mix used as a replacement for river sand at various proportions conforming to Indian Standards [3–5], 3.72 specific gravity, 2.62 fineness modulus, 6% optimum moisture content, 20% maximum bulking volume and grain size analysis as shown in Figure 1.

2.1. Mathematical Modelling: Methodology. Concrete strength estimation is a particularly interesting challenge. Concrete performance varies widely due to a large range of materials that interact in complicated ways, despite the fact that it is utilized in practically every construction project. As a result, predicting the strength of the finished product is challenging. A model that could estimate concrete strength consistently given a list of the input materials composition might lead to safer building practices. Now a days, mathematical models are successfully applied due to their greatest advantage in reducing the time, money, number of trail mixes, etc. Hence, in this study, Design Expert software's Response Surface Method and RStudio were applied.

2.2. Response Surface Method (RSM). Design Expert software's RSM model is a mathematical tool with a statistical method used for developing, improving, optimizing, and predicting the responses based on the multiple factors [14, 15]. A face centered Central Composite Design (CCD) was used to find the functional relation between the factors and their responses. Two factors with each having variation at 2 levels and $\alpha = 1.414$ were considered as shown in Table 1. With suggested 13 experimental runs of RSM, 2 responses were considered for each factor variation to assess their influence, interaction, and significance through ANOVA. The factors are considered significant only if $p < 0.05$ which is a 95% confidence level; otherwise, insignificant. The diagnostic tab provides a report of the residual for actual and predicted values of responses. The predicted responses were considered desirable only if the correlation coefficient value is $R^2 \geq 0.85$. The higher the R^2, the better the prediction [16]. The optimization of mix proportions was achieved for target response at 28 days of curing for compression and flexural strength tests. Later, the optimized mix was validated through an experimental test and was found to be in good fit with RSM.

2.3. RStudio-Program. RStudio is a virtual integrated environment of R language to develop a code for statistical computation's regression analysis and plotting [17, 18]. The RSM's 13 data sets and 2 responses for each data set were considered, as shown in Table 2. The data sets were split into 85% training and 15% testing to analyze the correlation of actual and predicted for both the responses.

3. Results and Discussion

The first response which is compressive strength at 28 days for 13 runs was compared and analyzed for the compatibility of the software that is Design Expert and RStudio based on the correlation coefficient. Similarly, the second response which is flexural strength at 28 days was compared and analyzed.

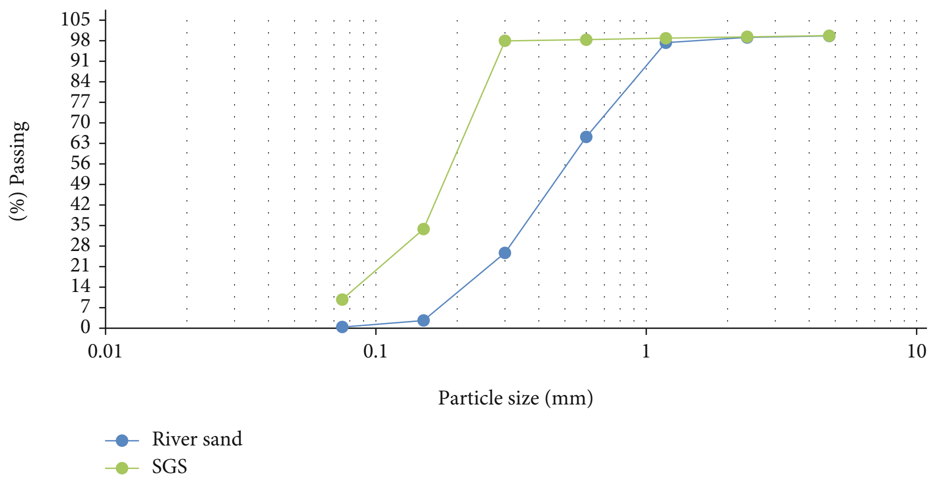

Figure 1: Grain size analysis of river sand and SGS.

Table 1: Factors and their levels of variation.

Factor	Code	Levels of variation (%) Low	High
River sand (kg/m^3)	A	20	80
Spent garnet sand (kg/m^3)	B	20	80

3.1. Response 1: Compressive Strength. As shown in Figure 2, it was observed that mixes M1 and M2 have shown overall higher strengths compared to mixes M3 and M4 which are 7.5% and 15.3%, respectively, lesser than M1. It is the pore structure of concrete mixes, and M1 and M2 were dense because the micropores are filled with river sand and SGS that made the pores in the mixes densely packed. It was inferred that river sand was replaced with SGS of 20% and 40% by wt., showing an overall higher strength. It was understood that mix M3 due to higher replacement of river sand that is 60% by wt. resulted in strength equal to the M20 grade target strength, which is 26.6 N/mm^2 and was proposed in this study. It was also noticed that mix M4, wherein 80% by wt. river sand replaced with SGS showed higher than M20 grade characteristic strength (20 N/mm^2) which is 22.7% but lesser than M1 and M3 which is 15.35% and 8.5%, respectively. The higher fineness of SGS and its poor gradation lead to improper filling of pores in the matrix thereby resulting in decreased strength in M3 and M4 and is in decent agreement with the studies conducted by Huseien et al. and Muttashar et al. [8, 19]. The strength variations of mixes M5, M6, M9, M10, and M13 followed in similar lines of M1 or M2 and mixes M7 and M8, in similar with M3, and M11 and M12 followed M4 as explained above.

3.2. ANOVA Analysis of Response 1: Compressive Strength. Based on the Design Expert and RStudio's ANOVA results as shown in Tables 3 and 4, respectively, it was understood that statistically response 1 model and the linear term A (that is river sand) were very significant $p = 0.001$ ($p < 0.05$), whereas other linear term B (that is spent garnet sand) is statistically not significant as $p > 0.05$. However, the linear term B is having its influence in the real practical mix design, especially in mixes 20%, 40%, and 60% of it and nominal influence in the mix with 80% of it. It was also inferred that the interactive term (AB) is also most significant as $p = 0.001$ ($p < 0.05$), in good agreement with the real practical mix, the same has shown higher strengths due to dense particle packing. But the square terms (A^2 and B^2) are statistically insignificant ($p > 0.05$). Using the Design Expert's coded equation (1), a response 1 that is compressive strength at 28 days can be computed. Based on the polynomial regression equation (1), the linear term "B", square terms "A," and "B" are ignored due to their lack of fit, $p > 0.05$, that is insignificant and whereas the linear term "A" interaction term "AB" and constant are considered as the most significant ($p = 0.0001$). Equation (1) is considered as most desirable for the prediction of response 1 due to the regression coefficients adjusted $R^2 = 0.976$ and predicted $R^2 = 0.971$ with a difference of less than 0.2 and very much less than 10% [14, 20]. The same regression values are observed in RStudio. Based on this, it can be concluded that Design Expert and RStudio can be efficiently applied in the concrete compressive strength prediction and its variation.

$$CS_{28} = 28.08 + 2.13A + 1.53AB, \quad (1)$$

3.3. Surface Plot of Response 1: Compressive Strength. From Figure 3 of Design Expert, the variation of 28 days compressive strength that is response 1 with respect to the factors that is "A" (river sand) and "B" (SGS) can be observed. It was inferred that with the decrease in the percentage replacement of factors "A" and "B," consequent decrease in strength is observed. With factor "A" minimum replacement (20%) and factor "B" maximum replacement (80%) yield a strength of nearly 26 N/mm^2 and when factor "A" replacement varies from 20% to 45% and factor "B" replacement varies from 80% to 20%, a yielding strength of nearly 27 N/mm^2 was attained. When the maximum replacement of factors "A and B" that is 80% replacement is done, a

Table 2: RSM 13 runs: mix proportions and responses.

Experimental run	Mix Id	Cement (kg/m^3)	Factors: River sand (%)	River sand (kg/m^3)	Spent garnet sand (SGS) (%)	Spent garnet sand (SGS) (kg/m^3)	Coarse aggregate (kg/m^3)	Responses at 28 days (N/mm^2): Compressive strength (CS28)	Flexural strength (FS28)
1	M1	413.3	80	569.87	20	142.47	1101.75	28.58	9.08
2	M2	413.3	60	427.40	40	284.94	1101.75	28.99	6.55
3	M3	413.3	40	284.94	60	427.40	1101.75	26.82	5.98
4	M4	413.3	20	142.47	80	569.87	1101.75	24.54	4.62
5	M5	413.3	80	569.87	20	142.47	1101.75	28.58	9.08
6	M6	413.3	60	427.40	40	284.94	1101.75	28.99	6.55
7	M7	413.3	40	284.94	60	427.40	1101.75	26.82	5.98
8	M8	413.3	20	142.47	80	569.87	1101.75	24.54	4.62
9	M9	413.3	80	569.87	20	142.47	1101.75	28.58	9.08
10	M10	413.3	60	427.40	40	284.94	1101.75	28.99	6.55
11	M11	413.3	40	284.94	60	427.40	1101.75	26.82	5.98
12	M12	413.3	20	142.47	80	569.87	1101.75	24.54	4.62
13	M13	413.3	80	569.87	20	142.47	1101.75	28.58	9.08

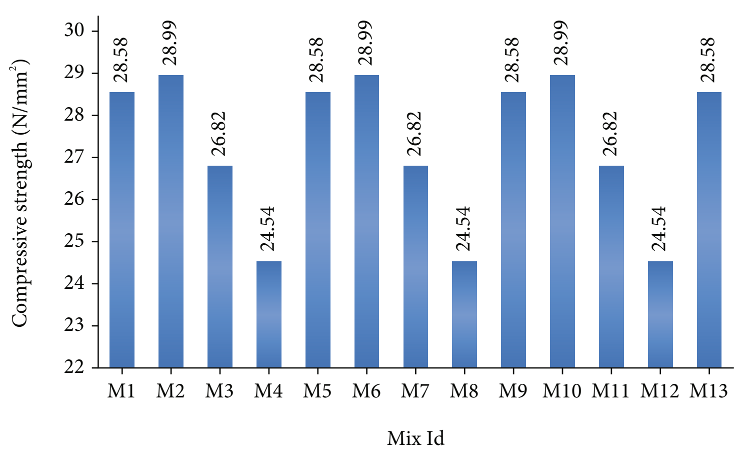

Figure 2: Response 1: 28 days compressive strength (N/mm^2).

Table 3: ANOVA response 1: compressive strength at 28 days (Design Expert).

Source	Sum of squares	df	Mean square	*F* value	*p* value	Remarks
Model	37.72	2	18.86	203.5	<0.0001	Significant
A- river sand	34.12	1	34.12	368.14	<0.0001	Significant
B- spent garnet sand	0.0000	0				Insignificant
AB	5.93	1	5.93	63.98	<0.0001	Significant
A^2	0.0000	0				Insignificant
B^2	0.0000	0				Insignificant
Residual	0.9267	10	0.0927			—
Lack of fit	0.9267	1	0.9267			—
Pure error	0.0000	9	0.0000			—
Correlation total	38.65	12				—

Table 4: ANOVA response 1: compressive strength at 28 days (RStudio).

	Estimate	Std. error	*T* value	Pr (>|t|)	Remarks
(Intercept)	2.027e+01	4.848e-01	41.822	1.46e-12	Significant
A	7.098e-02	3.699e-03	19.187	3.22e-09	Significant
B	NA	NA	NA	NA	Insignificant
AB	1.701e-03	2.126e-04	7.999	1.18e-05	Significant

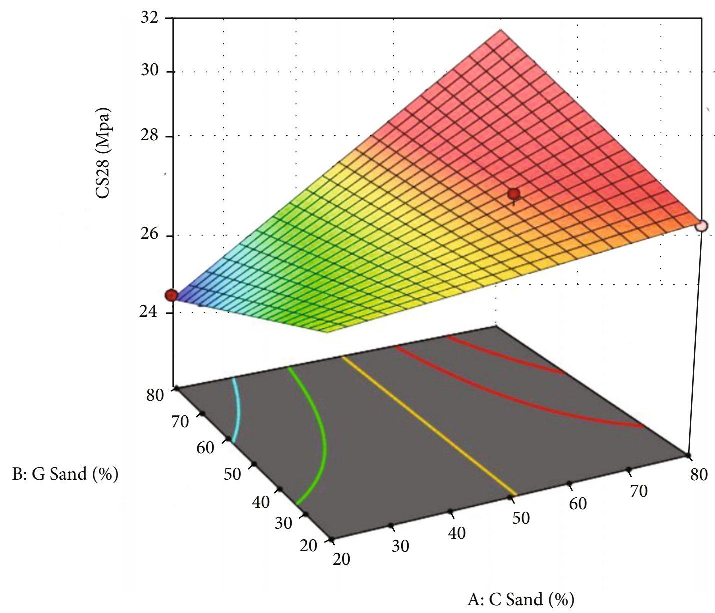

Figure 3: Surface plot of response 1: 28 days compressive strength (N/mm^2).

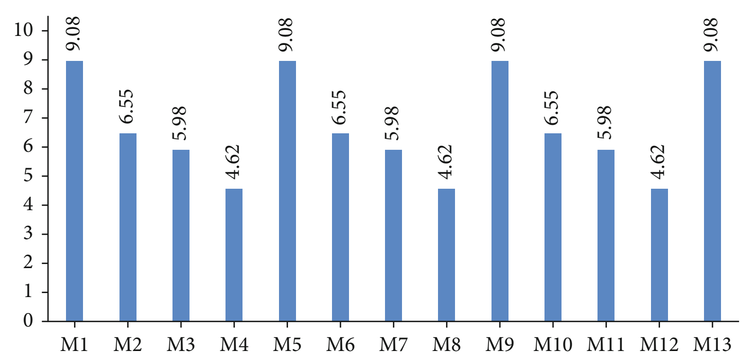

Figure 4: Response 2: 28 days flexural strength (N/mm^2).

maximum yield strength of more than 30 N/mm^2 was attained and that is practically not possible. At any point in the mix, the total combination of both factors "A and B" should not be more that 100%.

3.4. Response 2: Flexural Strength. The flexural strength of concrete is a measure of indirect tensile strength, and also, its strength can be used for evaluating the roadway and structural applications [21]. The mix M1 consisting of 80% river sand and 20% SGS resulted in overall 28 days higher flexural strength. Mixes M2, M3, and M4 exhibited strengths that are 27.86%, 34.14%, and 49.12%, respectively, lesser than M1. It indicates that the increase in substitution of SGS that is from 20% to 80% at 20% increments showed decreased strength. The increased fineness of SGS due to higher replacement of river sand resulted in poor bonding with alkali-activated binder and also due to lower ratio of river sand to SGS recorded decreased strengths as shown in Figure 4 and in line with the studies conducted by Huseien et al. and Muttashar et al. [8, 19]. The rest of the mixes followed the trend of compressive strength.

3.5. ANOVA Analysis of Response 2: Flexural Strength. From Tables 5 and 6, statistically, it was observed that the linear

Table 5: ANOVA response 2: flexural strength at 28 days (Design Expert).

Source	Sum of squares	df	Mean square	*F* value	*4* value	Remarks
Model	36.08	2	18.04	157.03	<0.0001	Significant
A - river sand	33.44	1	33.44	291.09	<0.0001	Significant
B - spent garnet sand	0.0000	0	—	—	—	Insignificant
AB	1.16	1	1.16	10.12	0.0098	Significant
A^2	0.0000	0	—	—	—	Insignificant
B^2	0.0000	0	—	—	—	Insignificant
Residual	1.15	10	0.1149	—	—	
Lack of fit	1.15	1	1.15	—	—	
Pure error	0.0000	9	0.0000	—	—	
Cor total	37.22	12	—	—	—	

Table 6: ANOVA response 1: compressive strength at 28 days (RStudio).

	Estimate	Std. error	*T* value	Pr (>|t|)	Remarks
(Intercept)	4.5586076	0.5397254	8.446	7.30e-06***	Significant
A	0.0702722	0.0041188	17.061	1.01e-08***	Significant
B	NA	NA	NA	NA	Insignificant
AB	-0.0007530	0.0002367	-3.181	0.00981**	Significant

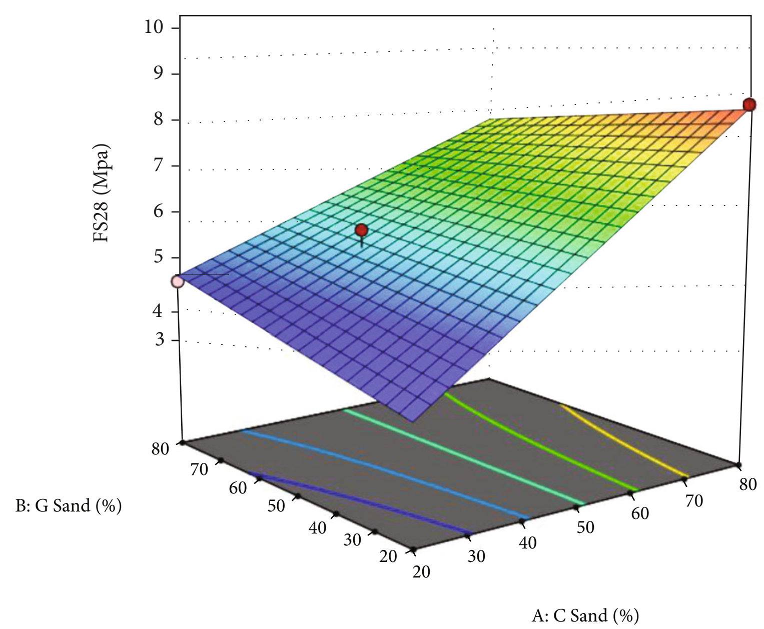

Figure 5: Surface plot of response 2: 28 days flexural strength (N/mm^2).

term A is very significant that is $p < 0.0001$ ($p < 0.05$) in both Design Expert and RStudio indicating its influence in the mix is very high both as a main ingredient and as a strength parameter. The other linear term B is statistically insignificant indicating not having any influence on the mix and strength. The cross term AB is statistically significant, which is$p = 0.0098$($p < 0.05$), indicating that the combination of river sand (A) and SGS (B) used in the mix as ingredients moderately influences the mix and strength of the studied concrete. On the other hand, square terms of A and B are statistically insignificant, indicating no influence on the mix and strength of the studied concrete. From these results, it was observed that the statistical variation of flexural strength has followed the pattern of compressive strength. The coded polynomial regression Equation (2) of Design Expert is used for the prediction of 28 days flexural strength, wherein it was observed that in Equation (2), insignificant terms such as the linear term "B" and square terms "A" and "B" are not considered for predicting the strength due to their lack of fit. The regression coefficient adjusted R^2

Table 7: Criteria for optimization of target variables (CS28 and FS28).

Name	Goal	Lower limit (%)	Upper limit (%)	Importance
A: River sand	Is in range	20	80	3
B: SGS	Is in range	20	80	3
CS28	Is target = 28.9	24.54	28.99	3
FS28	Is in range	4.62	9.08	3

Table 8: Desirability of optimized target variables (CS28 and FS28).

River sand (%)	SGS (%)	CS28 (N/mm^2)	FS28 (N/mm^2)	Desirability
58.64	41.36	28.9	6.703	1

Table 9: Validation of factors and responses with experiment.

Optimized factor	Response 1: compressive strength at 28 days (N/mm^2)				Response 2: flexural strength at 28 days (N/mm^2)			
	Design expert predicted	R program predicted	Experiment - measured	Error percent	Design expert predicted	R program predicted	Experiment - measured	Error percent
River sand = 58.64% SGS = 41.36%	28.9	28.9	27.23	5.78	6.703	6.703	6.54	2.43

and predicted R^2 were 0.963 and 0.9526, respectively, with a difference of less than 0.2 and very much less than 10% [14, 20]. Interestingly, in RStudio, same regression values are observed indicating that Design Expert and RStudio can be effectively utilized in the model analysis and its strength prediction.

$$\mathrm{FS}_{28} = 6.19 + 2.11A - 0.68AB, \quad (2)$$

3.6. Surface Plot of Response 2: Flexural Strength. From Figure 5, it is evident that factor "A" varying from 20% to 30% and factor "B" from 60%-20% resulted in a strength of 3 N/mm^2 in Design Expert. Similarly, factor "A" at 50% and factor "B" varying from 80% to 20% recorded a strength of 6 N/mm^2. It was also observed from the same figure that factor "A" from 70% to 80% and factor "B" from 70% to 20% recorded an overall higher strength of nearly 9 N/mm^2. It was inferred that maximum replacement of factor "A" and minimum replacement of factor "B" attained an overall higher strength due to dense gradation of pore structure with fine aggregate. The variation trend of flexural strength at 28 days is similar to compressive strength at 28 days.

3.7. Optimization of Factors. The optimization technique is used in the utilization of resources effectively. It helps to reduce time, cost, consumption of materials, etc. In Design Expert, using the optimization technique river sand quantity is optimized with SGS in the concrete mix. The factors "A and B" are both set at lower and upper limits of 20% and 80%, respectively, and for 28 days fixed target compressive strength at 28.9 N/mm^2 and flexural strength set in range, as shown in Table 7. For the set values, factor "A and B" is 58.6% and 41.4%, respectively, with desirability 1 indicating highly recommended as shown in Table 8. Further, it is inferred that with yielded factor percentage values, maximum compressive strength and flexural strength as predicted by the Design Expert are 28.9 and 6.703 N/mm^2, respectively, as indicated in Table 8.

3.8. Validation. Based on the optimization model, the factors $A = 58.64\%$ and $B = 41.36\%$ of the concrete mix were validated by conducting the laboratory experiment, and the results are shown in Table 9. It was inferred from the table that the error percent is less than 10% for compression and flexural strengths, indicating that the R Program and RSM of Design Expert are highly reliable for optimization of quantities, resources, time, etc.

4. Conclusion

In the optimization of river sand with spent garnet sand in the concrete mix, the model of experiments was analyzed and performed using Design Expert's RSM and RStudio's Program. Based on the results, it was concluded as follows:

The compressive strength of mixes M1 (SGS 20%) and M2 (SGS 40%) has shown overall higher strengths compared to mixes M3 (SGS 60%) and M4 (SGS 80%) which are 7.5% and 15.3%, respectively, lesser than M1. It may be due to the pore structure of concrete mixes M1 and M2 being dense because the micropores are filled with river sand and SGS that made the pores in the mixes densely packed.

The Design Expert's RSM and RStudio package were considered most desirable for the prediction of compressive strength due to their regression coefficient adjusted $R^2 = 0.976$ and predicted $R^2 = 0.971$ with a difference less than 0.2 and very much less than 10%.

The mix M1 consisting of 80% river sand and 20% SGS resulted in an overall 28-day higher flexural strength. Mixes M2, M3, and M4 exhibited strengths that are 27.86%, 34.14%, and 49.12%, respectively, lesser than M1. It indicates that the increase in substitution of SGS showed a decreased strength.

The optimized values of spent garnet sand and river sand for the target compressive value of 28.9 N/mm^2 were 58.64% and 41.36% with desirability as 1.

The validation error percent was less than 10% for compression, and flexural strengths indicated that the R Program and RSM of Design Expert are highly reliable for optimization of quantities, resources, time, etc.

Data Availability

The data used to support the findings of this study are included in the article.

Disclosure

This study was performed as a part of the employment of Samara University, Ethiopia.

Conflicts of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

Acknowledgments

The authors appreciate the support from the Samara University, Ethiopia. The authors thank Nadimpalli Satyanarayana Raju Institute of Technology, Visakhapatnam and GMR Institute of Technology, and Rajam and for the technical assistance to complete this experimental work.

References

[1] S. H. Kosmatka and M. L. Wilson, *Design and Control of Concrete Mixtures – The Guide to Applications*, Methods and Materials, Portland Cement Association, 2011.

[2] Portland Cement Association, *Cement & Concrete. In: cement*, Portland Cement Association, 2019.

[3] Indian Standard 2720 Part-3/Sec-2, *Methods of Test for Soils, Part 3: Determination of Specific Gravity, Section 2: Fine, Medium and Coarse Grained Soils, (R) 2002*, Bureau of Indian Standards, New Delhi, 1980.

[4] Indian Standard 2386 Part-3, *Methods of Test for Aggregates for Concrete, Part 3: Specific Gravity, Density, Voids, Absorption and Bulking, (R) 2002*, Bureau of Indian Standards, New Delhi, 1963.

[5] Indian Standard 2386 Part-1, *Methods of Test for Aggregates for Concrete, Part I: Particle Size and Shape, (R) 2002*, Bureau of Indian Standards, New Delhi, 1963.

[6] R. Siddique and G. Singh, "Utilization of waste foundry sand (WFS) in concrete manufacturing," *Resources, Conservation and Recycling*, vol. 55, no. 11, pp. 885–892, 2011.

[7] N. R. Kanta and M. R. Ponnada, "Performance of spent garnet sand and used foundry sand as fine aggregate in concrete," *World Journal of Engineering*, 2021.

[8] G. F. Huseien, A. R. M. Sam, K. W. Shah, A. M. A. Budiea, and J. Mirza, "Utilizing spend garnets as sand replacement in alkali-activated mortars containing fly ash and GBFS," *Construction and Building Materials*, vol. 225, pp. 132–145, 2019.

[9] Indian Bureau of Mines, *Indian Minerals Yearbook 2018-Garnet*, ENVIS Centre on Environmental Problems of Mining, Nagpur, 57th ed edition, 2019.

[10] US Geological Survey, *Mineral Commodity Summaries*, US Geological Survey, Virginia, 2022.

[11] M. A. Ab Kadir, M. I. Khiyon, A. R. Abdul et al., "Performance of spent garnet as a sand replacement in high-strength concrete exposed to high temperature," *Journal of Structural Fire Engineering*, vol. 10, no. 4, pp. 468–481, 2019.

[12] H. L. Muttashar, N. B. Ali, M. A. Mohd Ariffin, and M. W. Hussin, "Microstructures and physical properties of waste garnets as a promising construction materials," *Case Studies in Construction Materials*, vol. 8, pp. 87–96, 2018.

[13] Indian Standard 12269, *Ordinary Portland Cement , 53 grade-specification*, Bureau of Indian Standards, 2013.

[14] L. Zhang and J. Zhai, "Application of response surface methodology to optimize alkali-activated slag mortar with limestone powder and glass powder," *Structural Concrete*, vol. 22, no. S1, pp. E430–E441, 2021.

[15] K. Khaleel, A. Mousa, and A. Qashlaq, "Using design of experiment to predict concert compressive strength using fly ash and GGBFS as cement alternative," in *Proceedings of the international conference on industrial engineering and operations management*, pp. 741–749, Rabat, Morocco, 2017.

[16] I. C. Yeh, "Modeling of strength of high-performance concrete using artificial neural networks," *Cement and Concrete Research*, vol. 28, no. 12, pp. 1797–1808, 1998.

[17] RStudio Team, *RStudio: Integrated Development for R*, RStudio, Inc., Boston, MA, 2015, http://www.rstudio.com/.

[18] R Development Core Team, "R Core Team (2020)," in *R: A language and environment for statistical computing*, R Foundation for Statistical Computing, Vienna, Austria, 2019, https://www.R-project.org/.

[19] H. L. Muttashar, M. W. Hussin, M. A. M. Arriffion, J. Mirza, N. Hasanah, and A. U. Shettima, "Mechanical properties of self-compacting geopolymer concrete containing spent garnet as replacement for fine aggregate," *Jurnal Teknologi*, vol. 79, no. 3, pp. 23–29, 2017.

[20] G. Cibilakshmi and J. Jegan, "A DOE approach to optimize the strength properties of concrete incorporated with different ratios of PVA fibre and nano-Fe_2O_3," *Advanced Composites Letters*, vol. 29, article 2633366X2091388, 2020.

[21] A. M. Neville, *Properties of Concrete*, Pearson Education India, India, 5th ed edition, 2012.