CIVIL ENGINEERING JOURNAL

Article no. 16

THE CIVIL ENGINEERING JOURNAL 2-2023

THE EFFECT OF RECYCLED RUBBER AGGREGATES AND DUNE SAND OF EL-OUED REGION ON THE COMPRESSIVE STRENGTH OF CEMENTITIOUS MORTAR: OPTIMIZATION USING TAGUCHI METHOD

Kaab Mohamed Zohaïr[1], Khelaifa Hamad[1], Athamnia Brahim[2],

Djedid Tarek[3] and Hima Abdelkader[4]

1. *University of El-Oued, Faculty of Technology, Department of Hydraulics and Civil Engineering, BP 789, El-Oued 39000, Algeria; kaab-mohamed-zohair@univ-eloued.dz, khelaifahamad@gmail.com*
2. *University of Tebessa, Faculty of Sciences and Technology, Department of Civil Engineering,Tebessa 12002, Algeria; brahim.athamnia@univ-tebessa.dz*
3. *Laboratory of exploitation and valorisation of Saharan energy resources " LEVRES " University of El-Oued, Faculty of Technology, Department of Hydraulics and Civil Engineering, BP 789, El-Oued 39000, Algeria; tarek-djedid@univ-eloued.dz*
4. *University of El-Oued, Faculty of Technology, Department of Electrical Engineering, BP 789, El-Oued 39000, Algeria; Abdelkader-hima@univ-eloued.dz*

ABSTRACT

This study optimizes the effect of recycled rubber aggregates and dune sand of El-Oued's region by maximizing the compressive strength of cementitious mortar using Taguchi's design experiments. The experiments were designed using an L9 orthogonal array to see the different relationships between the factors targeted in our research, namely: water/cement (W/C) ratio, rubber aggregates (RA) content, and dune sand (SD) content, with the levels of each factor in the mortar mixture. The samples were tested at 28 days in each of the nine trial conditions for two responses: compressive strength and ultrasonic pulse velocity. The results of the analysis of variation (ANOVA) show that RA content is the factor that has the largest effect on the two tests, and the second factor affecting the two tests is the W/C ratio. Then, the analysis shows that the SD content has no significant effect on the mechanical resistance of the mortar for the two tests. And from the mathematical models investigated in this study, we conclude that the factors RA content and W/C ratio have a negative influence on the responses of the compression test and the ultrasonic test together.

KEYWORDS

Rubber aggregates, Dune sand, Mortar, Compressive strength, Taguchi method

INTRODUCTION

The Algerian Sahara has a large supply of dunes sand, particularly in the El-Oued region, where there is a growing shortage of river sand for the production of cement mortar. Added to this is the factor of the remoteness of the Saharan regions from the supply points for aggregates, which makes the value of construction materials more expensive. From these facts, using local materials such as dune sand and recycled materials such as rubber granules from used tires could present an economic advantage to manufacturing sustainable building materials.

DOI 10.14311/CEJ.2023.02.0016

Over the past two decades, dune sand has become the subject of many studies in different countries [1-5]. In this context, several research projects have been established in Algeria for the solution to the problem of the depletion of natural resources by the valorization of dune sand in the field of construction [6-11], which presented this material as the material of the future.

The evolution of increasingly restrictive requirements regarding environmental protection as well as revision of economic standards inspired by sustainable development means that recycling and recovery of industrial by-products have become very important from an environmental and economic point of view [12-15]. All over the world, when it comes to the automotive industry, the use of rubber tires is increasing every year [13, 16, 17].

Experimental studies have been carried out by Liu et al. [18] to assess the behavior of concrete with recycled tire rubber particles. In addition, Kardos and Durham [19] conducted several studies to determine how recycled rubber particles affect the mechanical and environmental performance of rubber concrete, which showed that a substitution level up to 30% of fine aggregates using crumb rubber is acceptable. These results are consistent with those obtained by certain authors, concerning concretes and/or mortars based on rubber particles [20, 21], which show a clear lack of adhesion and a more extensive transition halo between the cementitious matrix and the rubber aggregates. Therefore, it is recommended to minimize the dosage of these to keep the mechanical resistance within an acceptable range. However, these results did not clarify the degree of contribution of each material to the mechanical and environmental properties. Consequently, to solve this issue and the valorization of dunes sand in the El-Oued region, the authors suggest using statistical analysis with the Taguchi method to find the best values for these materials, which affect the mechanical strength of mortar and as well as getting the significance level of each material through the analysis of variation (ANOVA) [22-25].

The studies reviewed above centered on assessing the usefulness of recycled tire rubber aggregates (RTRA) in improving the performance of mortar and concrete. The mechanical performances of recycled rubber aggregates mixed with dune sand in the mortar have rarely been examined, and the best percentages of these components, which give the best mechanical properties of the mortar, have not been defined. To this end, this study attempts to illustrate the best values and the effect level of the recycled rubber aggregates mixed with the dune sand of El-Oued's region on the mechanical behavior of rubber mortar by statistical analysis with the Taguchi method.

TAGUCHI'S METHOD

The design of experiments by Taguchi's method is an original procedure based on a statistical analysis of experimental results. This approach uses a robust experimental design derived from a few orthogonal arrays to find the most significant factors and predict the optimum responses in a short time and with fewer experiments [26, 27]. According to the characteristics of the response to be optimized, signal-to-noise (S/N) ratios could be selected for three goals, namely: larger is better if the maximum is the best with equation (1); smaller is better if the minimum value is the best with equation (2); and nominal is better if the nominal value is the best with equation (3), respectively [25, 28-30]. However, for this study, we calculate the optimum values on the basis that "larger is better."

Larger is better: $$S/N = -10\log\left[\frac{1}{n}\sum Y^2\right] \tag{1}$$

Smaller is better: $$S/N = -10\log\left[\frac{1}{n}\sum 1/Y^2\right] \tag{2}$$

Nominal is better: $$S/N = 10\log\left[\frac{\overline{Y}^2}{S_Y^2}\right] \tag{3}$$

Where:

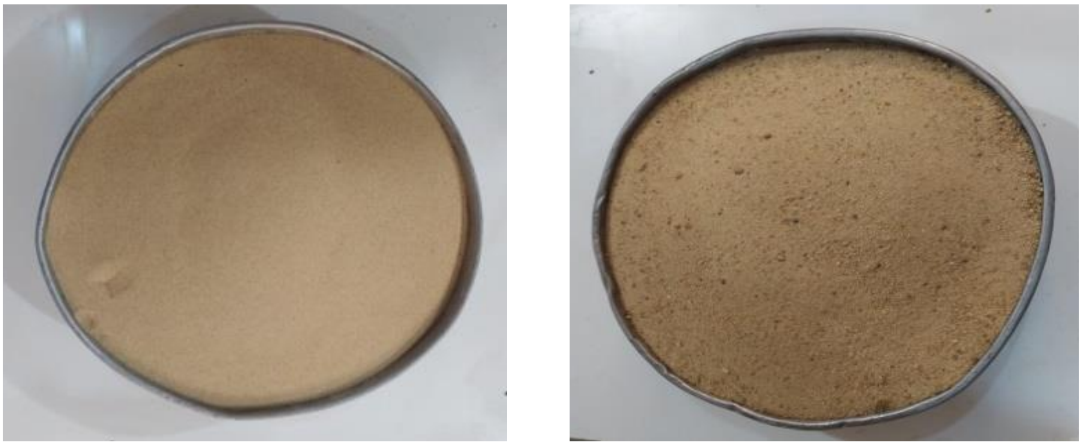
n and Y are the number of experimental tests and the experimental value, respectively.

$\overline{Y}$ and S_Y^2 are the average of data and the variation of data, respectively.

EXPERIMENTAL WORK

Materials

This study used two types of sand: dune and alluvial sand. The dune sand (SD) comes from the region of El-Oued (Figure1a) and the alluvial sand (SA) comes from the Djamaa sand pit, in the El-Oued Province (Figure1b). The physical properties of the sands are grouped in Table 1.



(a) Dune sand SD (b) Alluvial sand SA

Fig. 1 –Types of sand used

In addition, the rubber granules used in our study are obtained from the mechanical crushing of waste tires (RTRA) and come from a rubber tire crushing plant located in Setif, Algeria. After the elimination of their metallic and textile parts, they are crushed mechanically to obtain the desired fineness (Figure 2). The granular class of the recycled rubber aggregates (RA) used in our composites is from 0 to 4 mm, and the physical characteristics of these are summarized in Table 1. Furthermore, the particle size distribution curves of sands and rubber aggregates are presented in Figure 3.

DOI 10.14311/CEJ.2023.02.0016

Fig. 2 – Rubber aggregates (0-4mm)

Tab. 1 - Physical properties of sands and rubber aggregates.

	SA*	SD**	RA***
Apparent density (g/cm³)	1.64	1.56	-
Absolute density (g/cm³)	2.70	2.64	0.94
Fineness modulus	1.87	1.20	-
Sand Equivalent (%)	80	85	-
Water absorption (%)	2.60	1.62	0.30
Granulometry (mm)	-	-	0-4

(*) Alluvial sand ; (**) Dune sand ; (***) Rubber aggregates.

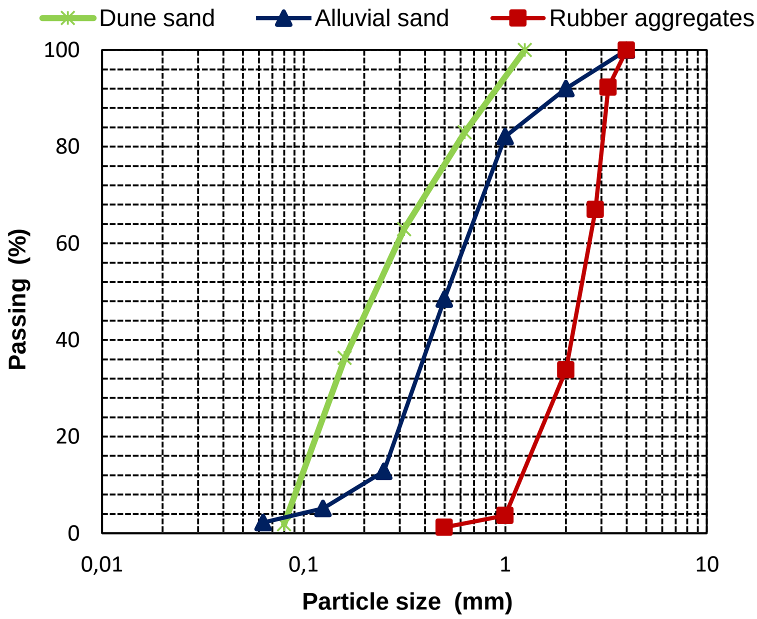


Fig. 3 – Particle size distribution curves of sands and rubber aggregates.

DOI 10.14311/CEJ.2023.02.0016

The cement used in all the experimental tests is a CEM II / B-L 42.5 N compound portland cement, it was manufactured at the LAFARGE cement plant in Algeria, and its physical and chemical properties are given in Table 2.

Tab. 2 - Physico-chemical properties of cement

Physical properties	Value	Chemical properties	Value
Specific gravity (g/cm^3)	3.08	Loss on ignition	8.0 ± 2.0
Blaine fineness (cm²/g)	3700 - 5200	Insolube residue	1.35 ± 0.65
Normal consistency (%)	26.5 ± 2.0	Sulphate content SO_3 (%)	2.5 ± 0.5
Expansion (mm)	≤ 3.0	Magnesium oxide content MgO (%)	1.7 ± 0.5
Shrinkage at 28 days (µm/m)	< 1000	Chloride content (%)	0.02 - 0.05
Initial setting time (min)	150 ± 30	C_3S	60 ± 3.0
Final setting time (min)	230 ± 50	C_2S	15 ± 3.0
Compressive strength at 2 days (MPa)	≥ 10	C_3A	7.5 ± 1.0
Compressive strength at 28 days (MPa)	≥ 42.5	C_4AF	11 ± 1.0

Design of mixtures

For statistical analysis, we applied Taguchi's method to model the effect of target factors in our research, namely: water/cement (W/C) ratio, rubber aggregates RA content, and dune sand SD content. wherein the levels of each factor were selected as shown in Table 3, based on a bibliographic search.

With a matrix of three factors at three levels, the experiments were designed using an L9 (3^3) orthogonal array as shown in Table 4.

Tab. 3 - The factors and levels targeted

Factor	Level		
	1	2	3
W/C ratio	0.55	0.60	0.65
RA content (%)	0	08	16
SD content (%)	0	10	20

Tab. 4 - Experimental design of the L9(3^3) orthogonal array

Trial	W/C ratio	RA content (%)	SD content (%)
01	0.55	0	0
02	0.55	8	10
03	0.55	16	20
04	0.60	0	10
05	0.60	8	20
06	0.60	16	0
07	0.65	0	20
08	0.65	8	0
09	0.65	16	10

Preparation of mixtures

We used a dosage of cement and sand corresponding to the dosage of the natural mortar according to EN 196-1. That is, one part of cement and three parts of sand. Then, the mortar formation used in our experimental study was carried out using RA and SD in two stages (Figure 4). In the first stage, we combined the rubber aggregates (0–4 mm) from recycled used tires in the volumetric replacement of alluvial sand SA with 0, 8, and 16% volume substitution. Whereas in the second stage, we incorporated the dune sand SD in substitution for alluvial sand SA volume with 0, 10, and 20% volume substitutions. In addition, we changed the W/C ratio for three cases: 0.55, 0.60, and 0.65.

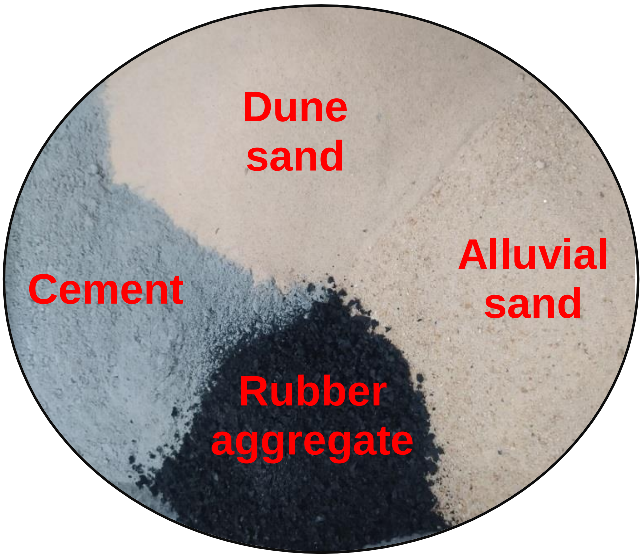


Fig. 4 –Preparation of mortar.

From these formulas, inspired by the design of the experimental (DOE), we launched the mortar formulations campaign incorporating the rubber aggregates and dune sand that we present in the following (Table 5). Knowing that the specimens produced in this study are prismatic in shape with dimensions of 40 x 40 x 160 mm according to EN 196-1. They were all put in a curing room in water at 20°C for 28 days before being submitted to compression and ultrasonic tests. It should be noted that for the different mortar mixtures, three specimens from each mixture were used to perform each test.

Tab. 5 - Composition of mortars used (kg/m^3)

Trial	Mixture designation	Cement (kg)	Alluvial sand (kg)	Rubber aggregates (kg)	Dune sand (kg)	Water (L)	W/C ratio
01	RA0 SD0	483.07	1449.22	/	/	265.69	0.55
02	RA8 SD10	483.07	1188.36	39.73	140.28	265.69	0.55
03	RA16 SD20	483.07	927.49	80.60	283.76	265.69	0.55
04	RA0 SD10	471.17	1272.15	/	136.83	282.70	0.60
05	RA8 SD20	471.17	1017.72	38.76	276.76	282.70	0.60
06	RA16 SD0	471.17	1187.35	78.61	/	282.70	0.60
07	RA0 SD20	460.03	1104.08	/	270.22	299.02	0.65
08	RA8 SD0	460.03	1269.69	37.83	/	299.02	0.65
09	RA16 SD10	460.03	1021.27	76.75	133.59	299.02	0.65

Testing

Compression test

The samples of the hardened mortar studied are subjected to an increasing load until failure, where the breaking load is the maximum load recorded during the test. The value of the resistance considered constitutes the average of the crushing stress of three specimens.

The compressive strengths were evaluated at 28 days (S_{28}) using a hydraulic compression testing machine equipped with a compression device for mortar molds.

Ultrasonic test

The ultrasonic velocity is a parameter that allows obtaining qualitative information on the materials. The speed of the ultrasonic waves results from the time taken by the waves to cross the prismatic specimens of hardened mortar, which depends enormously on the modulus of elasticity of the aggregates and their quantity in the mortar. In this study, the ultrasonic pulse velocity was evaluated at 28 days (U_{28}).

ANALYZE AND DISCUSS RESULTS

In the two tests performed in this study, the experiments were laid out using an L9 (3^3) array, and three samples were tested in each of the nine trial conditions. The results of the average of the three samples for each test are shown in Table 6.

Tab. 6 - Results of compressive strength and ultrasonic pulse velocity tests.

Trial	Mixture designation	Compressive strength (MPa)	Ultrasonic pulse velocity (m/s)
01	RA0 SD0	36.50	3587
02	RA8 SD10	33.12	3519
03	RA16 SD20	31.37	3448
04	RA0 SD10	34.62	3699
05	RA8 SD20	31.06	3477
06	RA16 SD0	27.75	3275
07	RA0 SD20	30.90	3600
08	RA8 SD0	32.25	3325
09	RA16 SD10	25.56	3125

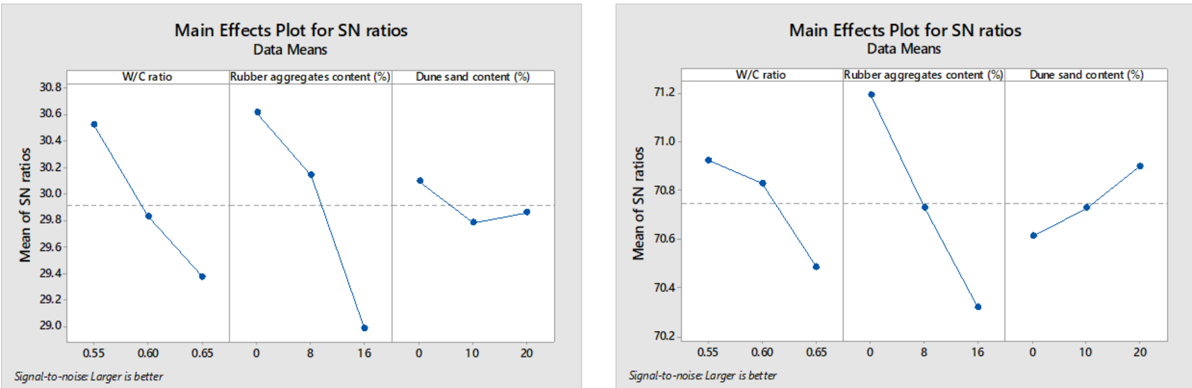
Optimum values

The results of the analysis for S/N ratios are shown in Table 7 and Figure 5. Where determine the optimum levels for each factor and the best combination of factor levels. Consequently, from the results of the main effects for the S/N ratios, we find that the optimum results for each factor to give the optimum values for mechanical compressive strength are the following: W/C ratio 0.55, rubber aggregates content 0%, and dune sand content 0%. In addition, we find that the optimum results for each factor to give the optimum values for ultrasonic pulse velocity are the following: W/C ratio 0.55, rubber aggregates content 0%, and 20% from dune sand content.

Tab. 7 - Response table for signal-to-noise ratios

	W/C ratio	RA content	SD content
Level	Compressive strength		
1	30.53*	30.61*	30.09*
2	29.83	30.14	29.78
3	29.37	28.98	29.86
Level	Ultrasonic pulse velocity		
1	70.92*	71.19*	70.61
2	70.83	70.73	70.73
3	70.49	70.32	70.90*

(*) Optimum levels for each factor.



(a) Compressive strength *(b) Ultrasonic pulse velocity*

Fig. 5 –Response plots for S/N ratios.

Analysis of variation (ANOVA)

The main objective of ANOVA is to show the factors that have the most effect on the responses of the experiments. The analysis is performed for a significance level α = 0.05, i.e., for a confidence level of 95%.

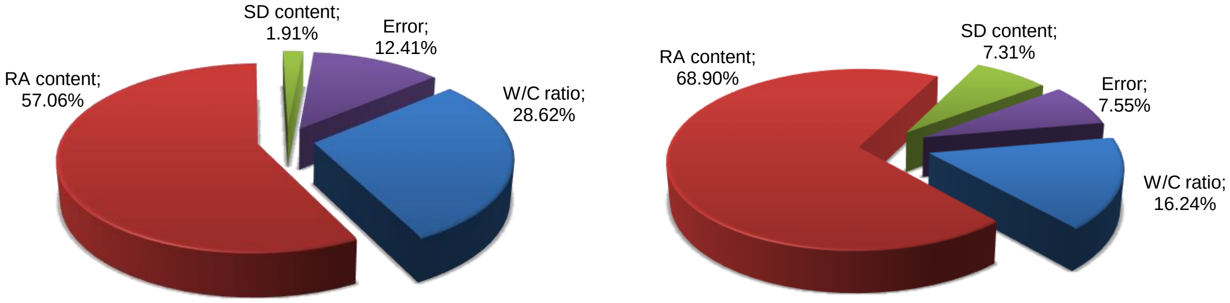
The ANOVA results of the two tests investigated are given in Table 8 and Figure 6. In this statistical technique, it is worth noting that a low probability (i.e., P-Value ≤ 0.05) indicates the statistical significance of the factor on the corresponding response, and the values of the contribution give the degree of influence of each factor on the response studied.

In the tests examined (Figure 6), analysis of contrast results showed that RA content is the factor that has the largest effect on the total variation of the two tests, which explains 57.06% of the contribution to compressive strength and 68.90% of the contribution to ultrasonic pulse velocity; the second factor affecting the two tests is the W/C ratio, with a 28.62% contribution to compressive strength and a 16.24% contribution to ultrasonic pulse velocity. Then, the analysis shows that the SD content has no significant effect on the overall variance of compressive strength and ultrasonic pulse velocity together. As a result, this statistical technique shows that the incorporation of the dune sand as a volume substitution for alluvial sand up to 20% has no effect on the mechanical resistance of the mortar. The thing that encourages the valorization of dune sand in the construction field and particularly in mortar preparation.

DOI 10.14311/CEJ.2023.02.0016

Tab. 8 - Analysis of variation results for the two tests.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	P-Value	Contribution (%)	Remarks
Compressive strength							
Regression	3	76.92	25.64	11.76	0.011	/	/
W/C ratio	1	25.133	25.133	11.53	0.019	28.62	Significant
RA content	1	50.113	50.113	22.98	0.005	57.06	Significant
SD content	1	1.675	1.675	0.77	0.421	1.91	Insignificant
Error	5	10.902	2.180	/	/	12.41	/
Total	8	87.823	/	/	/	100.00	/
Ultrasonic pulse velocity							
Regression	3	240951	80317	20.40	0.003	/	/
W/C ratio	1	42336	42336	10.75	0.022	16.24	Significant
RA content	1	179574	179574	45.61	0.001	68.90	Significant
SD content	1	19041	19041	4.84	0.079	7.31	Insignificant
Error	5	19686	3937	/	/	7.55	/
Total	8	260636	/	/	/	100.00	/



(a) Compressive strength *(b) Ultrasonic pulse velocity*

Fig. 6 –Contribution of each factor used in the experimental tests.

Mathematical models

In order to understand the effects of factors on the responses investigated. Regression analysis was used to develop the linear regression model. The mathematical models of the tests studied are the following:

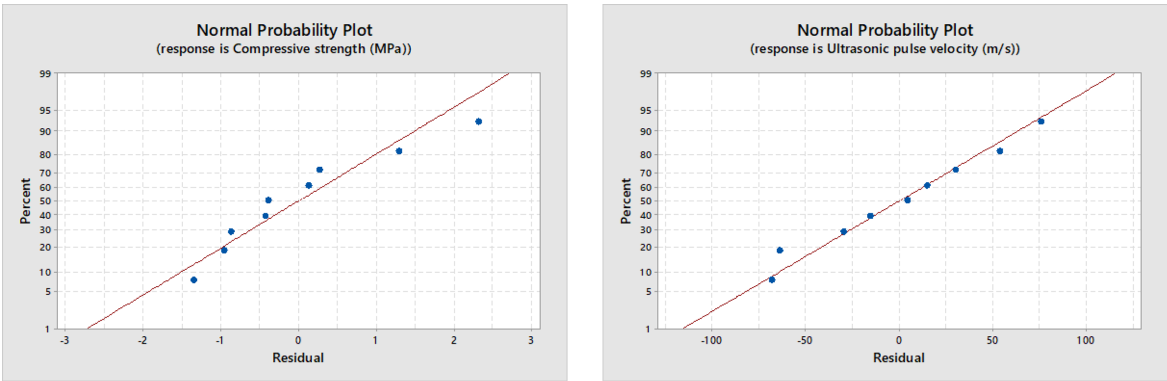
$$S_{28} = 59.44 - 40.9\, W/C - 0.3612\, RA - 0.0528\, SD \quad (4)$$

$$U_{28} = 4575 - 1680\, W/C - 21.62\, RA + 5.63\, SD \quad (5)$$

Figure 7 presents the normal probability plots of the residuals of the models developed in this study. It is seen that the residuals fit in a straight line. In addition, the coefficient of determination (R^2) for the two models approaches unity, as shown in Table 9. As a result, we can conclude that the errors have a normal distribution and that the models developed are significant.

Tab. 9 - Coefficient of determination table.

Test	R^2 (%)
Compressive strength	87.59
Ultrasonic pulse velocity	92.45



(a) Compressive strength *(b) Ultrasonic pulse velocity*

Fig. 7 –Normal probability plots.

For the two mathematical models represented by equations (4) and (5), it was observed that the minus sign (–) indicates that the factors negatively affect the answers to the two tests. On the other hand, the plus sign (+) indicates that factors positively influence responses. Thus, we conclude that the factors W/C ratio and RA content have a negative influence on the responses of the compression test and the ultrasonic test together.

In addition, the reduction in the W/C ratio implies less water in the mixture, which results in an increase in the compressive strength and ultrasonic pulse velocity together. However, an increased percentage of RA content translates to the need for the mixture to contain a large amount of water. Consequently, this results in a reduction in mechanical resistance for the mortar.

CONCLUSION

The experimental and numerical work presented is part of the application of statistical analysis in the field of materials in civil engineering. More specifically, the object of the work is to apply Taguchi's design of experiments to see the different relationships between the factors targeted in our research (W/C ratio, RA content, and SD content) with the levels of each factor.

The Taguchi method uses a robust design that provides the most important factors in controlling the consistency of mortar quality with just a few experiments.

Predictive mathematical models are developed according to the tests carried out, which allowed us to understand the effect of the factors used in our work on the compressive strength and ultrasonic pulse velocity at 28 days. In order to determine the optimal values for each factor to give the best results for each response.

The optimal values for our mortar composite are as follows:

• Compressive strength at 28 days: 0.55 of W/C ratio at level1, 0% of RA content at level1, and 0% SD content at level1.

• Ultrasonic pulse velocity at 28 days: 0.55 of W/C ratio at level1, 0% of RA content at level1, and 20% SD content at level3.

Then, the results of the ANOVA analysis used in our work for each response allowed us to conclude that the RA content is the factor that has the largest effect of the two tests, which explains 57.06% of the contribution to compressive strength and 68.90% of the contribution to ultrasonic pulse velocity; the second factor is the W/C ratio, with a 28.62% contribution to compressive strength and a 16.24% contribution to ultrasonic pulse velocity. In addition, from the mathematical models, we conclude that the factors RA content and W/C ratio have a negative influence on the responses of the compression test and the ultrasonic test together. On the other hand, the ANOVA analysis shows that the SD content has no significant effect on the mechanical resistance of the mortar for the two tests.

REFERENCES

[1] Abu Seif E.-S. S., Sonbul A. R., Hakami B. A. H, El-Sawy E., 2016. Experimental study on the utilization of dune sands as a construction material in the area between Jeddah and Mecca, Western Saudi Arabia. Bulletin of Engineering Geology and the Environment, vol. 75: 1007-1022. doi: 10.1007/s10064-016-0855-9

[2] Chuah S., Duan W., Pan Z., Hunter E., Korayem A. H., Zhao X.-L., Collins F., Sanjayan J. G., 2016. The properties of fly ash based geopolymer mortars made with dune sand. Materials & Design, vol. 92: 571-578. doi: 10.1016/j.matdes.2015.12.070

[3] Hadjoudja M., Khenfer M., Mesbah H. A., Yahia A., 2014. Statistical models to optimize fiber-reinforced dune sand concrete. Arabian Journal for Science and Engineering, vol. 39: 2721-2731. doi: 10.1007/s13369-013-0774-z

[4] Haifeng L., Jurong M., Yiying W., Jianguo N., 2017. Influence of desert sand on the mechanical properties of concrete subjected to impact loading. Acta Mechanica Solida Sinica, vol. 30: 583-595. doi: 10.1016/j.camss.2017.10.007

[5] Liu Y., Li Y., Jiang G., 2020. Orthogonal experiment on performance of mortar made with dune sand. Construction and Building Materials, vol. 264: 120254. doi: 10.1016/j.conbuildmat.2020.120254

[6] Abadou Y., Mitiche-Kettab R., Ghrieb A., 2016. Ceramic waste influence on dune sand mortar performance. Construction and Building Materials, vol. 125: 703-713. doi: 10.1016/j.conbuildmat.2016.08.083

[7] Amel C. L., Kadri E.-H., Sebaibi Y. S, Soualhi H., 2017. Dune sand and pumice impact on mechanical and thermal lightweight concrete properties. Construction and Building Materials, vol. 133: 209-218. doi: 10.1016/j.conbuildmat.2016.12.043

[8] Djeridane M., Zaidi A., Lakhdari M. F., Krobba B., 2021. Theoretical and Experimental Flexural Behavior of Steel Bars-Reinforced Concrete Beams Strengthened with Cementitious Mortars Based on Dune Sands. International Journal of Civil Engineering, vol. 19: 623-634. doi: 10.1007/s40999-020-00591-8

[9] Lakhdari M. F., Zaidi A., Bouhicha M., Krobba B., 2021. Sulfate Resistance of Cementitious Mortar Based on Dune and Alluvial Sands in Hot Region. Iranian Journal of Science and Technology, Transactions of Civil Engineering, vol. 45: 697-706. doi: 10.1007/s40996-021-00632-9

[10] Mani M., Bouali M. F., Kriker A., Hima A., 2021. Experimental characterization of a new sustainable sand concrete in an aggressive environment. Frattura ed Integrità Strutturale, vol. 15: 50-64. doi: 10.3221/igf-esis.55.04

[11] Mokhtari A., Kriker A., Guemmoula Y., Boukrioua A., Khenfer M., 2015. Formulation and characterization of date palm fibers mortar by addition of crushed dune sand. Energy Procedia, vol. 74: 344-350. doi: 10.1016/j.egypro.2015.07.624

[12] Aiello M. A., Leuzzi F., Centonze G., Maffezzoli A., 2009. Use of steel fibres recovered from waste tyres as reinforcement in concrete: Pull-out behaviour, compressive and flexural strength. Waste management, vol. 29: 1960-1970. doi: 10.1016/j.wasman.2008.12.002

[13] Eisa A. S., Elshazli M. T., Nawar M. T., 2020. Experimental investigation on the effect of using crumb rubber and steel fibers on the structural behavior of reinforced concrete beams. Construction and Building Materials, vol. 252: 119078. doi: 10.1016/j.conbuildmat.2020.119078

[14] Medina N. F., Medina D. F., Hernández-Olivares F., Navacerrada M., 2017. Mechanical and thermal properties of concrete incorporating rubber and fibres from tyre recycling. Construction and Building Materials, vol. 144: 563-573. doi: 10.1016/j.conbuildmat.2017.03.196

[15] Shahjalal M., Islam K., Rahman J., Ahmed K. S., Karim M. R., Billah A. M., 2021. Flexural response of fiber reinforced concrete beams with waste tires rubber and recycled aggregate. Journal of Cleaner Production, vol. 278: 123842. doi: 10.1016/j.jclepro.2020.123842

[16] Girskas G., Nagrockienė D., 2017. Crushed rubber waste impact of concrete basic properties. Construction and Building Materials, vol. 140: 36-42. doi: 10.1016/j.conbuildmat.2017.02.107

[17] Si R., Wang J., Guo S., Dai Q., Han S., 2018. Evaluation of laboratory performance of self-consolidating concrete with recycled tire rubber. Journal of Cleaner Production, vol. 180: 823-831. doi: 10.1016/j.jclepro.2018.01.180

[18] Liu F., Zheng W., Li L., Feng W., Ning G., 2013. Mechanical and fatigue performance of rubber concrete. Construction and Building Materials, vol. 47: 711-719. doi: 10.1016/j.conbuildmat.2013.05.055

[19] Kardos A. J., Durham S. A., 2015. Strength, durability, and environmental properties of concrete utilizing recycled tire particles for pavement applications. Construction and Building Materials, vol. 98: 832-845. doi: 10.1016/j.conbuildmat.2015.08.065

[20] Baghban S., Mo K. H., Ibrahim Z., Radwan M. K., and Shah S. N., 2022. Effect of basalt and polypropylene fibers on crumb rubber mortar with Portland cement and calcium aluminate cement binders: Strength and artificial neural network prediction model. Progress in Rubber, Plastics and Recycling Technology, vol. 38: 99-124. doi: 10.1177/14777606211062912

[21] Zaouai S., Tafraoui A., Makani A., and Benmerioul F., 2020. Hardened and transfer properties of self-compacting concretes containing pre-coated rubber aggregates with crushed dune sand. Journal of Rubber Research, vol. 23: 5-12. doi: 10.1007/s42464-019-00030-x

[22] Tanyıldızı H., 2014. Post-fire behavior of structural lightweight concrete designed by Taguchi method. Construction and Building Materials, vol. 68: 565-571. doi: 10.1016/j.conbuildmat.2014.07.021

[23] Tanyildizi H., Şahin M., 2015. Application of Taguchi method for optimization of concrete strengthened with polymer after high temperature. Construction and Building Materials, vol. 79: 97-103. doi: 10.1016/j.conbuildmat.2015.01.039

[24] Boumaaza M., Belaadi A., Bourchak M., 2021. The effect of alkaline treatment on mechanical performance of natural fibers-reinforced plaster: Optimization using RSM. Journal of Natural Fibers, vol. 18: 2220-2240. doi: 10.1080/15440478.2020.1724236

[25] Aeshah M. N. A. A., Kaplan G., 2022. Mechanical durability and microstructural properties of sustainable high strength mortars ıncorporated basalt fiber and copper slag: Taguchi optimization. Construction and Building Materials, vol. 339: 127815. doi: 10.1016/j.conbuildmat.2022.127815

[26] Karthik K., Rajamani D., Manimaran A., Prakash J. U., 2020. Wear behaviour of hybrid polymer matrix composites using Taguchi technique. Materials Today: Proceedings, vol. 33: 3186-3190. doi: 10.1016/j.matpr.2020.04.133

[27] Shaladi R. J., Johari M. A. M., Ahmad Z. A., Mijarsh M., 2022. The engineering properties and pozzolanic reaction kinetics of quaternary blended binder high strength mortars optimized by the Taguchi method. Journal of Building Engineering, vol. 54: 104582. doi: 10.1016/j.jobe.2022.104582

[28] P. Vasanthi and S. S. Selvan, 2020. Optimization of mixing parameters in nanosilica toughened cement mortar using Taguchi-grey relational analysis. Silicon: 1-7. doi: 10.1007/s12633-020-00791-w

[29] Arıcı E., Çelik E., Keleştemur O., 2021. A performance evaluation of polypropylene fiber-reinforced mortars containing corn cob ash exposed to high temperature using the Taguchi and Taguchi-based Grey Relational Analysis methods. Construction and Building Materials, vol. 297: 123792. doi: 10.1016/j.conbuildmat.2021.123792

[30] Nasir M., Johari M. A. M., Adesina A., Maslehuddin M., Yusuf M. O., Mijarsh M., Ibrahim M., Najamuddin S. K., 2021. Evolution of room-cured alkali-activated silicomanganese fume-based green mortar designed using Taguchi method. Construction and Building Materials, vol. 307: 124970. doi: 10.1016/j.conbuildmat.2021.124970