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EFFECT OF RISE IN TEMPERATURE (250°C) ON THE PHYSICO-MECHANICAL PROPERTIES OF RUBBER MORTARS

ABSTRACT

The recovery and use of waste in the field of civil engineering, particularly in construction materials, is one of the most prominent solutions for preserving the environment. In order to evaluate the results obtained, it is necessary to study the evolution of the properties of these new materials in the different environments where they can live or be exposed, and why not develop an effective method of treatment of such materials for the possibility of their use even in the field of precast concrete. The objective of this work is to study the effect of the increase in temperature as a living environment or as a treatment on the physico-mechanical properties of a crumbled mortar, a potential source of many environmental and economic problems. Hence the screening and the possibility of using these new mortars with sufficient physico-mechanical properties for masonry and why not for prefabrication. The formulation of the mixtures based on the substitution of dune sand by crumb rubber, at different weight contents 10, 20 and 30%. Consequently, prismatic specimens (4x4x16) cm^3 subjected to the temperature (250°C), with a speed of 2°C/min followed by a one-hour plateau at the target temperature then cooling to the ambient temperature. The results obtained show that the maximum mass loss is 5% for 30% substitution and that for 10% substitution the absorption by total immersion decreased by more than two thirds and the porosity accessible to water decreased by more than half. The compressive strength increases by 8.9% for 10% substitution and the minimum decrease in tensile strength by bending is at the same substitution of an order of 26.9%. Using the analysis of variance, the influence of the substitution of dune sand by rubber crumbs and of the rise in temperature to 250°C on the behavior of the mortar acquired. Patterns developed by response surface methodology were significant for all p-value substitutions <5%. The results of the numerical optimization showed that the best mixture could obtained by replacing 30% of dune sand with rubber crumb and subjecting the hardened mortar obtained from this mixture to the temperature of 135°C.

Keywords: *Thermal treatment; Rubber powder, Physical properties, Prefabrication, Response surface*

INTRODUCTION

The overwhelming urbanization worldwide has posed challenges for the construction industry to meet the demands for construction materials while ensuring sustainable development [1]. Waste, whether domestic, agricultural or industrial, represents one of the biggest problems of the 21st century. Indeed, the increasing world population and its concentration in the cities, as well as the development of industrial equipment's and

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consumer goods are actually generating astronomical quantities of residues. In addition, traditional building materials of natural origin eventually exposed to scarcity and even depletion. It is therefore important to think about developing new composite materials based on artificial or recycled light aggregates from industrial and agricultural waste [2].

Concrete is the most commonly used construction material, requiring a considerable amount of natural resources. The continued extraction and use of natural aggregates not only harms the environment but also depletes the remaining resources. Therefore, in recent years, there has been a growing interest in using waste materials to replace conventional concrete components. In order to develop environment friendly concrete that minimizes the use of natural resources [3]. The use of vehicles generates a large amount of rubber waste tires.

The accumulation of rubber wastes in landfills pollutes the environment and natural resources. The valorization of rubber wastes in cement-based materials such as construction aggregates neutralize their harmful effects on the environment. Nevertheless, their sensitivity to temperature effect, constitute a major obstacle for reuse in cement-based materials exposed to temperature effect [4]. Utilizing scrap tire rubber by incorporating it into concrete is a valuable option. Many researchers are interested in using rubber tire waste in concrete. The possible uses of rubber tires in concrete, however, are dispersed and unclear. Therefore, a compressive analysis is necessary to identify the benefits and drawbacks of rubber tires for concrete performance. For examination, the important areas of concrete freshness, durability, and strength properties considered [5]. The use of precast concrete commonly considered an economical, durable, quality and architecturally versatile way to build [6].

There have also been a number of research studies, which have based on the pre-treatment of the waste before its use, therefore before its incorporation into the building material, whether mortar or concrete, or others. For example for rubber pretreatment, Abdelrahman Swilam et al. [7] quoted that: Tian et al. [8] pretreatment of calcium chloride with inorganic salt ($CaCl_2$), Huang et al. [9] as well as Dong et al. [10] pretreatment with a silane coupling agent followed by embedding in cement paste, Abdulla and Ahmed [11] pretreatment with sulfuric acid (H_2SO_4). All these pretreatment methods and even others have improved certain properties, mainly mechanical, but with a negative impact on other properties. As for the thermal pretreatment, we can cite that Abd-Elaal et al. [12], investigated the influence of heat treatment of four different sizes of rubber particles on the characteristics of rubberized concrete, in the improvement of mechanical characteristics was observed for small rubber particles thermally pretreated. In addition, Abdelrahman Swilam et al. [7] concluded that the heat treatment at 200°C for 2 hours of the rubber could recover the losses of the compressive strength recorded in the case of the use of untreated rubber. Of a value of almost 15% for a percentage of 40% in substitution of sand and even an improvement in impact resistance.

The role that prefabrication could play in the medium and long term, since its potential in contributing to an effective reduction in overall building impacts and costs discussed. With more environmentally sustainable policies, it will be possible to ensure more energy-efficient and carbon-reduced buildings. The main benefits are the type of use of materials, waste reduction, cost and construction time reduction, the increase in the safety and quality of products, greater efficiency in quality control, the growth of productivity, and the improvement of the performance of buildings [13]. To minimize the environmental impact and energy consumption of buildings, the performance of coating mortars can improved by incorporating sustainable and innovative insulating and lightweight materials, such as recycled aggregates and/or nanostructured materials [14]. With the continued growth of

urban populations and the construction of skyscrapers and industrial structures, building fires have increased in frequency and the resulting damage has increased in severity. Cement mortar is the most common mortar, but its resistance to high temperatures is insufficient [15]. A high temperature can cause alterations in concrete materials by destroying the constituents of cement paste. This destruction involves the weakening by degradation of the mechanical properties of the material such as rigidity and resistance. Following this destruction, a weakening of the material can occur [16].

There are only a few studies on with fire resistance. It was observed that the residues the mechanical properties of rubberized concrete are noticeably more affected than those of normal concrete, especially for high temperatures, this reduction does not prevent its use in structural applications. Recent studies have reported a reduction in compressive and tensile strength post-fire resistance of rubberized concrete. Despite this reduction, the incorporation of rubber particles in the concrete reduce the risk of explosive bursting of concrete at high temperature [17].

In recent years, the response surface optimization (RSM) method has been widely used in several scientific and industrial fields [18]. There are methods dealing with the effect of several characteristics on the lab-based target variable. One of them is to use the Response Surface Methodology (RSM), which uses the multivariate nonlinear regression method and strives to obtain optimal experimental conditions. Being one of most widely used experimental design methods; RSM uses the method of Box – Behnken to assess the link between autonomic factors and responses [19].

The objective of this experimental work presented in this article is to evaluate the impact of the replacement of sand dunes by rubber crumbs at progressive rates (0%, 10%, 20% and 30% by weight) on the physical and mechanical behavior of the mortar obtained at room temperature and at high temperature (250°C). As well as the possibility of adapting, these mortars, which contain dune sand and rubber, waste for application in construction and why not in prefabrication. To carry out this work, the preparation of the test specimens was according to the percentages of substitutions chosen (0%, 10%, 20% and 30%), and the treatment cycles followed (20°C and 250°C). of course the conservation of the specimens was in water until 28 days, then the physico-mechanical characterization at 20°C and after 250°C. As well as the optimization of the percentage of the substitution of dune sands by rubber crumbs, and at what temperature can this mortar be subjected to have the maximum resistance to compression and to tensile bending, with properties physical (absorption, porosity) target.

EXPERIMENTAL

The materials used for the preparation of the mixtures and the making of the various mortars are of local origin, their chemical compositions and their physical properties are shown in Table 1 and Table 2 respectively.

Cement

The cement used is a composite cement of the CPJ-CEM II / A 42.5 MPa type from the "Hajar-Assoud of Skikda" cement plant.

Dune sand

The sand used for the manufacture of the mortars studied is a very clean dune sand (SD) of class 0/1, very fine with a very tight appearance, its apparent and absolute densities are respectively (1.46; 2.11) g /cm^3.

Rubber crumb

The rubber crumb used comes from a recycling company in Serif. The dimension maximum of rubber crumbs is 4.0 mm; as well as their densities absolute and apparent are 0.94 and 0.40 g/cm3 respectively.

Table 1. *Chemical compositions of cement and dune sand*

	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	LoI*
Cement	58.6	24.92	6.58	3.65	1.21	0.85	0.08	2.17	1.7
Dune	1.63	90.46	1.38	1.92	0.39	0.22	0.00	0.2	2.56

* Loss on Ignition

Table 2. *General material properties*

	Unit	Dune	Cement	RC
Finess modulus	(%)	1.837	-	3.92
Sand equivalent	(%)	99.56	-	-
Sand equivalent	(%)	85.97	-	-
Apparent density	(g/cm^3)	1.46	1.09	0.40
Absolute density	(g/cm^3)	2.11	3.11	0.94
SSB	(cm^2/g)	-	3371	-

Studied mixtures

A control mortar of dune sand (SD) and three mortars composed in a way to replace (SD) by different percentages of (PC) crumbs of rubber (10%, 20% and 30%), Table 3.

Table 3. *Composition of mortars studied*

Rubber content (%)	0	10	20	30
S_{dune} (g)	1350	1215	1080	945
C (g)	450	450	450	450
W (g)	450	450	450	450
RP (g)	0	60.14	120.28	180.42
W/C	1	1	1	1

Test procedures and apparatus

The tests concerned the determination of some physico-mechanical properties of the mortars (porosity, absorption, a loss of mass, compressive strength, and tensile strength). All the tests carried out on prismatic specimens (4 x 4 x 16) cm^3. These residual properties were determined after subjecting the specimens to the study temperature of 250°C and cooling them to the environment. A temperature rise rate of 2°C/min used to reach the target temperature followed by a 1-hour plateau for homogenization of the temperature in the

specimen, and these properties were determined on the part before the ambient temperature. The physical characterization carried out at the level of the educational laboratory of the department of civil engineering and hydraulics of the University May 8, 1945 of Guelma, and that mechanical carried out within the research laboratory (LGCH) of the same university.

The compression test is carried out by a press of 2000 kN capacity with a speed of 0.5 MPa/s and the tensile test (by three-point bending) is carried out by a universal digital CONTROLS brand mechanical resistance testing machine with a capacity of 50 kN, with controlled load and displacement. The measurements of the physical properties carried out by a hydrostatic Balance of precision 0.01 g.

RESULTS

Physical properties

Absorption by total immersion

The absorption by total immersion at 20°C and at 250°C and the ratio between the two temperatures illustrated in Figure 1.

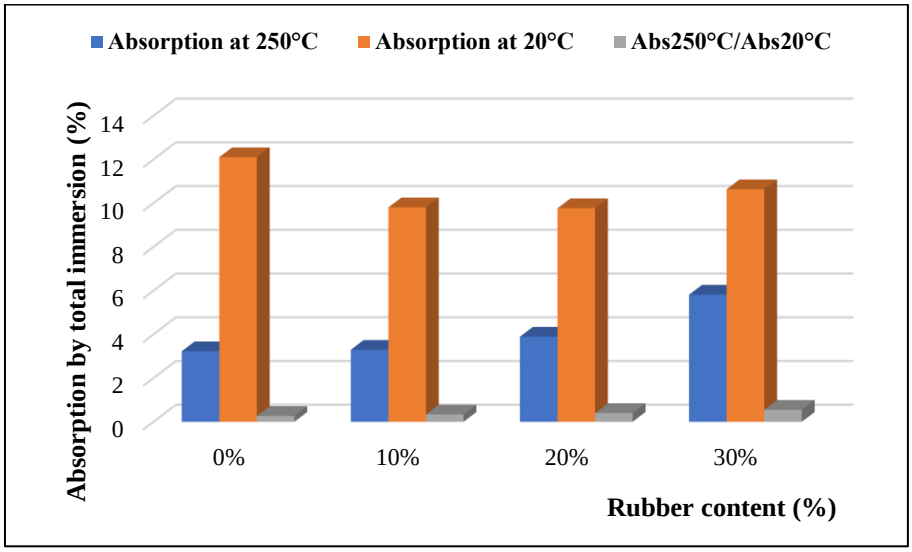


Fig. 1. Evolution of the absorption by total immersion of the mortars studied at 20°C and 250°C according to the rubber content, and absorption ratio at 250°C

At 20°C, the absorption by total immersion decreases by about 18.92%, 19.25% for mortars respectively with (10%, 20%) RP substitution compared to control mortar, in accordance with the findings of several authors for the incorporation of rubber aggregates in cementitious matrices and the zero absorption of rubbers [20, 21] cited by [22]. This is surely due to the probable decrease in the porosity of these mortars [23]. On the other hand, there was a return in the decrease in absorption of the order of 7.18% for the mortar with 30% RP substitution, differently to the result found by [22] for this percentage of substitutions. Our result could related to the pores generated by this amount of PCs due to their non-polar natures and their smaller size compared to RGs, which tend to trap air on the surface. The air trapped in this mortar makes the mortar more porous, therefore more permeable and more water absorbent.

So the most remarkable thing is after 250°C, the absorption by total immersion of the four mortars has decreased in the order of (3.75%, 3%, 2.51% and 1.83%) for the mortars respectively at (0%, 10%, 20% and 30%) of RP substitution compared to that labeled at 20° C., which is favorable for this physical property. By articulating on [24] concerning the melting point of certain rubber which is (161-165) °C, we can say that the fused rubber to occupy a high percentage of the voids which resulted in these results.

Porosity accessible to water

The porosity accessible to water at 20°C and at 250°C and the ratio between the two temperatures illustrated in Figure 2.

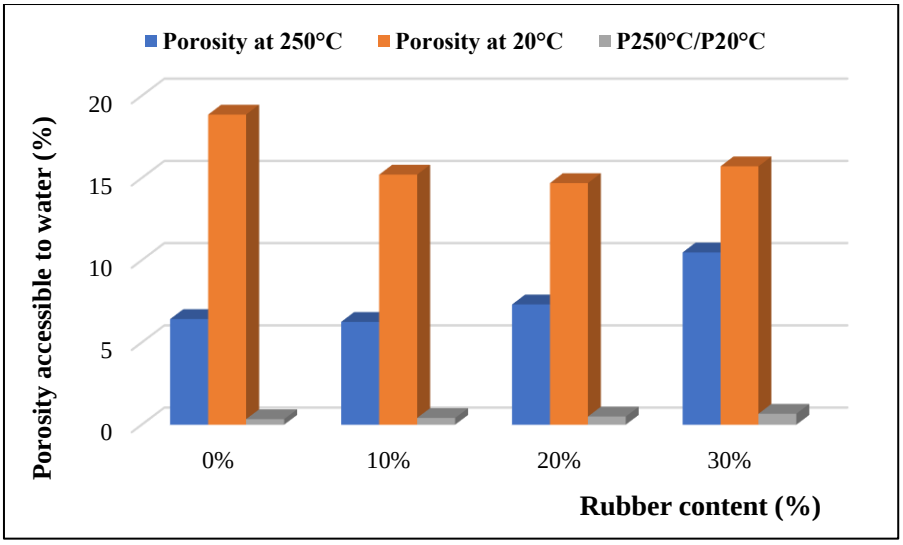


Fig. 2. Evolution of the porosity accessible to water of the mortars studied at 20°C and 250°C as a function of the rubber content, and ratio of the porosity at 250°C

At 20°C, the decrease in porosity reached 19.35% and 22.11% respectively for sand mortars with 10% and 20% substitutions of DS by RP, which confirms the observations noted above concerning the possibility of a decrease in porosity, especially at 10% substitutions. Contrary to the results of other authors who indicate that the occluded air entrained by the RGs during mixing is a factor favoring the increase in porosity [25, 26, 27]. While at 30% of DS, substitutions by RP the return is also noticed (5.42%). Note that other authors [28, 29] suggest that the hydrophobic nature of GR is responsible for trapping air bubbles, which contributes to the weight reduction of GR composites.

In fact at 250°C and coordination with the findings of absorption by total immersion. The decrease in the porosity accessible to water of the four mortars is of the order of (2.94%, 2.43%, 2.01% and 1.50%) for the mortars respectively at (0%, 10%, 20% and 30%) substitution of RP compared to that labeled at 20°C, which is in the favorable direction. With a minimum porosity at 250°C of 6.25% for the 10% substitution mortar.

A loss of mass

The loss of mass at 20°C and at 250°C and the ratio between the two temperatures illustrated in Figure 3.

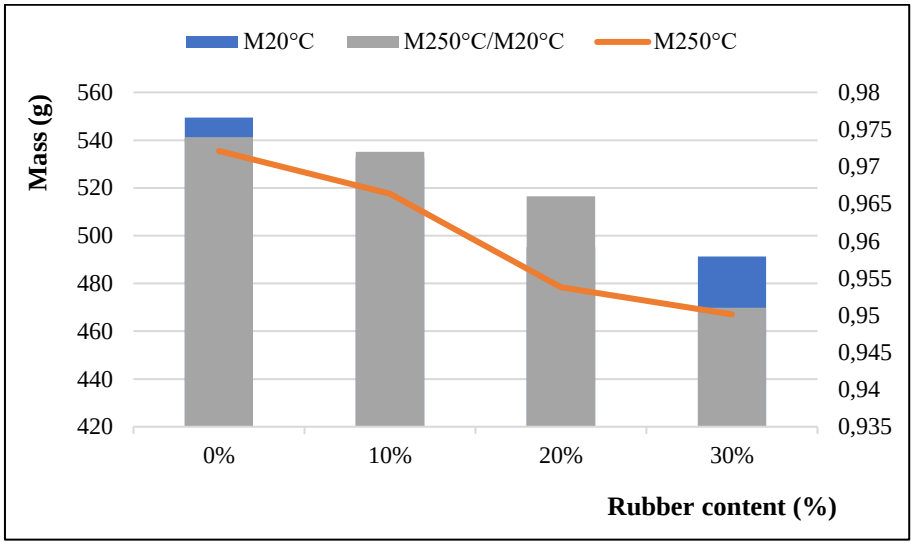


Fig. 3. Mass loss of mortars studied as a function of rubber content

At 20°C, the decrease in mass as a function of the rubber content reached 3.05%, 9.88% and 10.58% respectively for the sand mortars with (10%, 20% and 30%) substitutions compared to the control mortar. While at 250°C this reduction reached, 3.35%, 10.65% and 12.78% respectively for the sand mortars with (10%, 20% and 30%) substitutions compared to the control mortar. Which, is remarkable that the reduction at 10% substitution is almost identical to that found by Guelmine et al [4] for a 9% substitution at (200°C) but with a temperature rise rate different from 2°C/min, which indicates that the mass loss not influenced by the rate of temperature rise. While for 20% and 30% of substitutions, the losses are three and 4 times respectively compared to the first substitution, which confirms the start of the relief. In addition, the loss of mass is of the order of (2.6%, 2.8%, 3.4% and 4.9%) respectively for sand mortars at (0%, 10%, 20% and 30%) which indicates that the mass loss is proportional to the rubber content. The mass losses recorded by [30, 31] at (200°C) are less than 5% for concretes with a maximum of substitutions of (24%), this finding confirms that the presence of gravel in the cementitious matrix reduces the loss of mass.

Mechanical properties

Compressive and tensile strength

The compressive and tensile strength at 20°C and at 250°C and the ratio between the two temperatures illustrated in Figure 4.

We first notice that at 20°C, the substitution of SD by PC reduces the two resistances. While the decrease in tensile strength is slight in the range of (9.51%, 13.89%) to (10%, 20%) substitution respectively, and very remarkable for 30% substitution (38.57%). On the other hand, for the resistance to compression the reductions are more than 30% for the three substitutions (10%, 20% and 30%) of the order of (30.44%, 34.63% and 47.15%) respectively, in accordance with those found by [32] for a rubberized concrete. This loss of mechanical performance according to [32] mainly linked to the weak adhesion of the rubber particles to the cementitious matrix. The most remarkable is the decreases of the two mechanical resistances at 30% of substitution, which can lead us to limit the percentage of substitution to less than 30%. However, in spite of that this loss remains less than that found by [22].

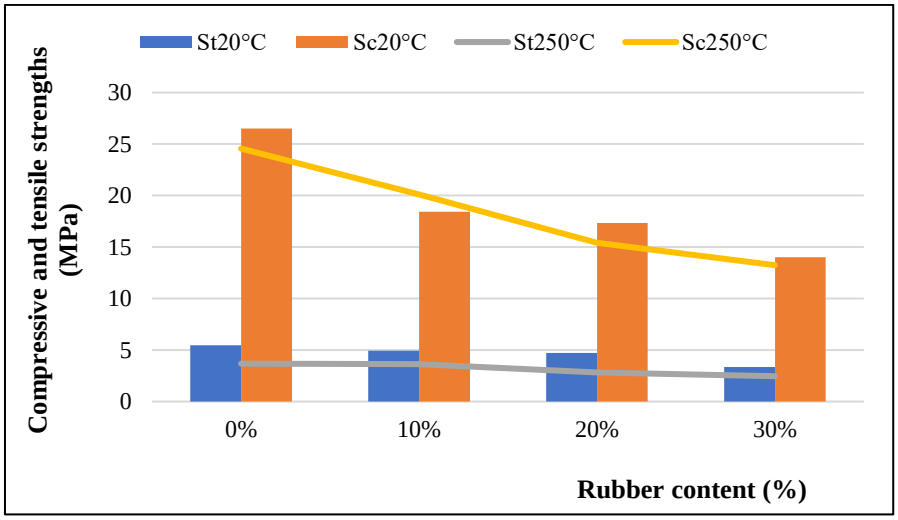


Fig. 4. Evolution of the compressive and tensile strengths of the mortars studied at 20°C and 250°C as a function of the rubber content, and ratio of the porosity at 250°C

Most remarkable that at 250°C the loss of tensile strength is acceptable (30.5%, 26.2%, 36.6% and 24.6%) for the four substitutions (0%, 10%, 20% and 30%) respectively, slightly higher than that found by [16] for ordinary concretes. However, what really caught my attention is the gain in resistance for the mortar at 10% substitutions, of an order of 8.9% contrary to the results found by [32]. Which indicates that the gain was for the sample at 0% substitution at 100°C, of rise in temperature because of the favoring of the continuation of the process of hydration of the cement by the temperature, and therefore the filling of the pores, and even for [32]. Which indicated that the decreases reached at (300°C) almost 40% to 30% substitution. But which supports our observation is that even for the other mortars the loss is very slight in comparison with those of [17] of an order of (7%, 11.1% and 5.3%) for the substitution mortars (0%, 20% and 30%) respectively, which confirms the findings above (absorption and porosity). The gain in compressive strength was also observed by [33] for rubber mortars exposed to a temperature of (200°C) for 4 hours.

Application of RSM using the Box–Behnken design approach

Factors affecting mixture design investigated using the Box–Behnken design approach. This experimental design technique programmed using Design-Expert. In the interactions between the independent and dependent variables are analyzed by establishing mathematical models of the second order (quadratic model). The ranges and levels as well as the desired goal of the three factors (dune sand, rubber crumb, and temperature) and the five responses (porosity, absorption, mass loss, compressive strength, and flexural tensile strength) shown in Table 4.

Table 4. *Levels and purpose of factors and responses*

Name	Goal	Lower Limit	Upper Limit
A:DS (%)	is target = 85	70	100
B:RW (%)	is target = 30	0	30
C:T (°C)	is target = 135	20	250
Rc (MPa)	maximize	13.24	26.51
Rt/f (MPa)	maximize	2.46	5.47
W (%)	is target = 3.22	3.22	12.1
P (%)	is target = 6.26	6.26	18.86
M (g)	is target = 508.255	467.05	549.46

Analysis ANOVA

The F-value of the model used for the five responses is greater than Fisher's F-value, which implies that the model is significant and that the variables retained for the modeling have a significant effect.

The majority of the probability values for the five responses are less than 0.0500, indicating that most terms in the model are significant under each response.

The statistical adjustment of the five responses gives R^2 close to 1 (0.9644, 0.9625, 0.9914, 0.9898, 0.943), and differences between adjusted R^2 and predicted R^2 less than 0.2, as well as signal to noise ratios greater than 4 which is desirable. This indicates that the signal is adequate and the model can used to navigate the design space.

The equation in terms of coded factors can used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded +1 and the low levels are coded -1. The regression equations for each response grouped in Table 5.

Table 5. *The regression equation for each response as a function of the factors*

Response	Regression Equations
Rc (MPa)	Rc = 17.11+ 5.89 DS - 0.6121 T - 2.60 DS x RW + 0.2582 DS x T
Rt/f (MPa)	Rt/f = 3.94 + 0.8239 DS - 0.7921 T + 0.1961 DS x RW - 0.0964 DS x T
W (%)	W = 6.83 - 0.4564 DS - 3.07 T - 1.11 DS x RW - 1.01 DS x T
P (%)	P = 11.14 - 0.4682 DS - 3.97 T - 1.75 DS x RW - 1.86 DS x T
M (g)	M = 501.35 + 35.93 DS - 10.63 T - 10.39 DS x RW + 3.11 DS x T

Optimization and graphical representation

Optimization consists in having, after a numerical analysis, adequate solutions to the problem posed, for this; we have specified the purpose of each factor and each response according to the objective of the work as shown in Table 4. Moreover, we have left with four solutions (mixtures, see Table 6) of desirability 0.710 and the evolution of the different responses are schematized in 3D in Figure 5.The factors, which strongly influence all the answers, are that of the percentage of dune sand and the temperature as well as the dune sand and the crumb of rubber together. The contributions of each factor grouped in Table 7, and the influence of each shown in Figure 6. In it clearly noticed that the two responses (compressive strength and mass loss) strongly influenced by the percentage of dune sand, while the two responses (absorption and porosity) are strongly influenced by the degree of temperature. On the other hand, the tensile strength by bending influenced by the two factors (percentage of dune sand and degree of temperature).

Table 6. *The four solutions chosen at the same desirability*

N°	DS	RW	T	Rc	Rt/f	W	P	M	Desirability	
1	89.057	30	135.001	18.000	4.218	6.406	10.544	508.256	0.710	Selected
2	89.196	30	135.000	18.030	4.227	6.391	10.524	508.493	0.710	
3	89.113	30	136.139	18.007	4.214	6.367	10.491	508.256	0.710	
4	89.426	30	135.004	18.081	4.243	6.367	10.490	508.885	0.710	

Table 7. *Percentage contribution of each factor for each response*

Contribution	Rc	Rt/f	W	P	M
DS (%)	88.39	30.89	0.9	0.54	76.52
T (%)	2.15	64.28	92.04	87.45	15.07
DSxRW (%)	5.74	0.58	1.8	2.5	2.13
DSxT (%)	0.17	0.42	4.4	8.49	0.47

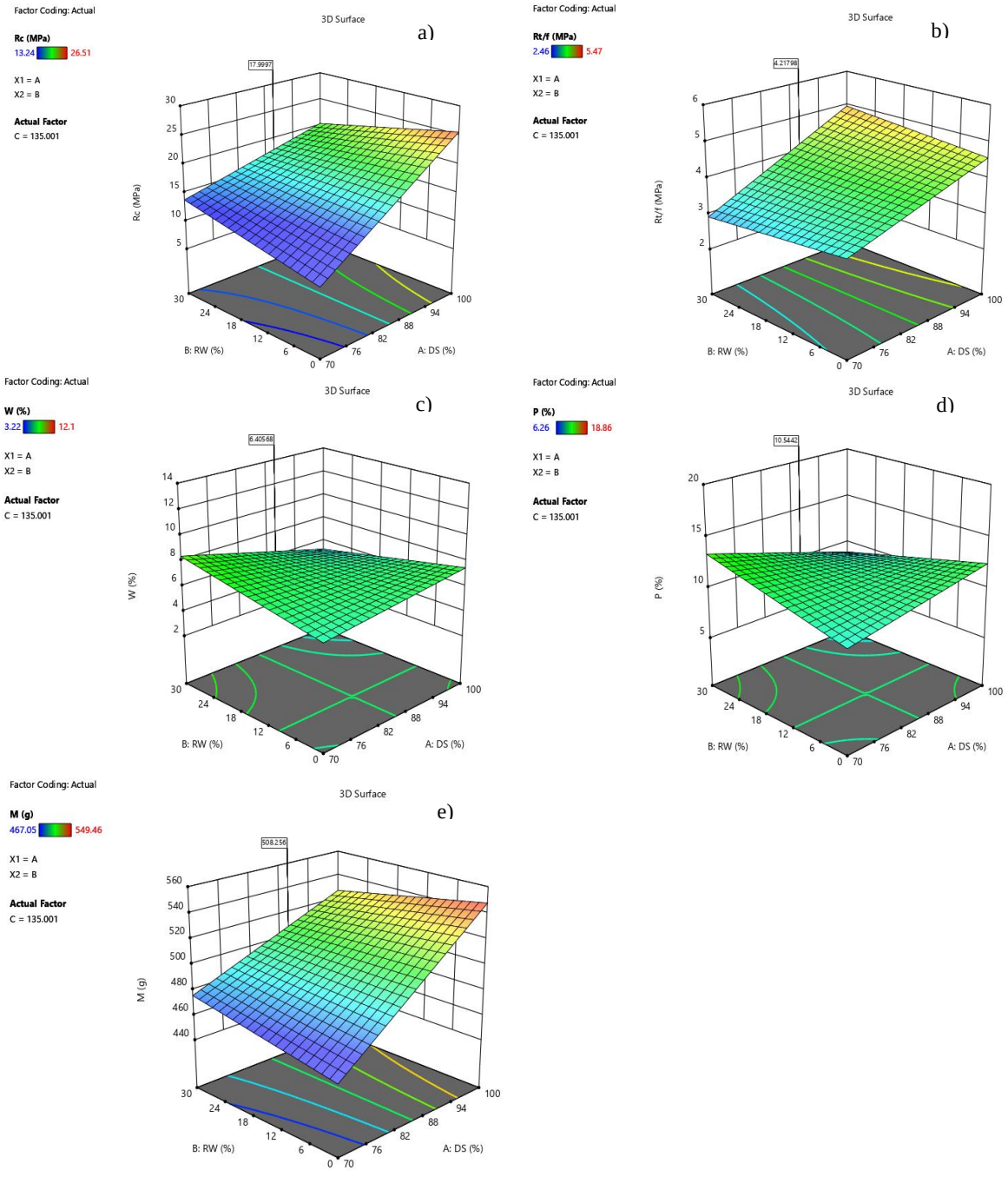


Fig. 5. 3D surface of the evolution of the different responses. a) Compressive strength, b) Flexion tensile strength, c) Absorption by total immersion, d) Porosity accessible to water and e) Mass

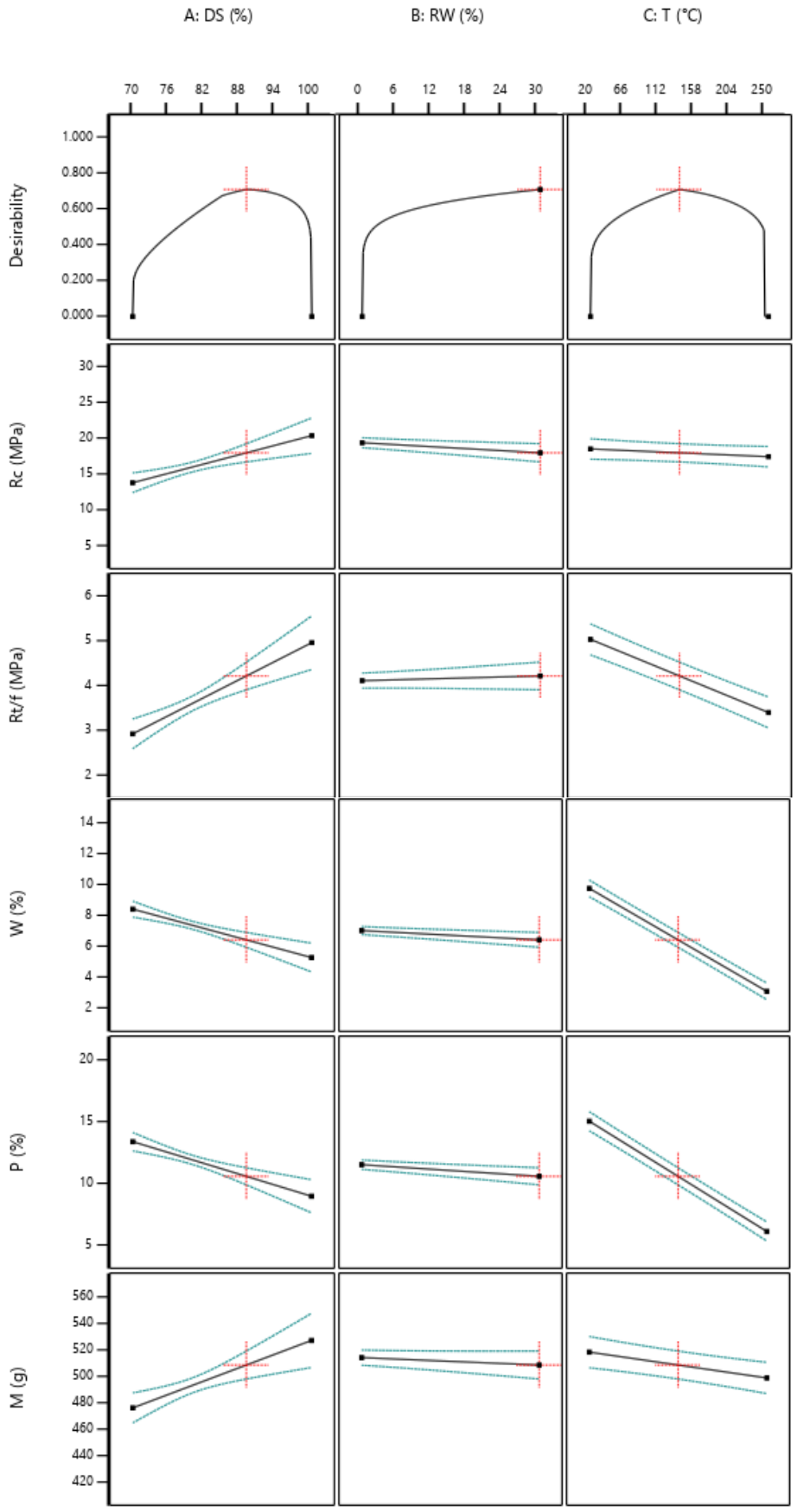


Fig. 6. Influence of each factor on each response

CONCLUSIONS

Based on the results discussed above, it can concluded that:

- At 20°C A positive, effect for absorption by total immersion up to 20% substitution of DS by RP. On the other hand, at 30% of substitutions, the absorption returns has increased. The effect of the substitution of DS by RP on the porosity of mortars is the same as that of absorption with different values (decrease up to 20% substitution and an increase to 30% substitution). The percentage of substitution of DS by RP can be limited to less than 30% because of its harmful effect on the two mechanical resistances.
- The effect of raising the temperature (or heat treatment) up to 250°C clearly improved the physical properties of the three mortars with substitutions and even the control mortar (very remarkable decrease in absorption by total immersion and the porosity accessible to water compared to those at 20°C). The mass losses are almost identical for the two temperatures (20°C and 250°C) except for the 30% substitution mortar.
- The effect of raising the temperature (or heat treatment) up to 250°C has reduced the mechanical properties as usual, especially the tensile strength, while the reduction in the compressive strengths is clearly improved and even it marked a very interesting increase for the mortar at 10% substitutions.
- In the end, rubberized mortar with 10% substitutions can chose as the solution for the recovery of this type of waste either in the field of construction (use in situations of temperature rise up to that studied). On the other hand, in the field of prefabrication (as heat treatment for improving prefabricated elements).
- The use of the Box – Behnken design approach through RSM, has allowed us to have optimal results with the maximum valuation of the rubber crumb by applying the quadratic model, which has been adapted to navigate in the design space.
- Optimization by RSM has extended the threshold of the percentage of rubber waste to 30% substitution. The influence of DS and temperature clearly noticed.

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