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ANN modelling approach for predicting SCC properties - Research considering Algerian experience. Part II. Effects of aggregates types and contents

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Abstract. The objective of this investigation is to illustrate the effect of aggregates types and contents on fresh and hardened properties of self-compacting concrete (SCC) considering Algerian experience. Based on experimental data available in the literature, Artificial neural network (ANN) models are established to illustrate the variation of aggregate types and contents (sand and gravel) in binary and ternary contour plots. Modelling results concerning the effect of sand types and proportions in binary and ternary combinations show the beneficial effect of river sand (RS) and crushed sand (CS) on slump flow. The highest L-Box ratio was obtained for mixtures composed of 50% of both RS and CS for binary and ternary mixtures. The increase in CS content enhance static stability, while the increase in RS gives higher compressive strength at 28 days. Concerning the study of aggregate sizes and contents, it was found that the increase of sand content leads to an increase in flowability and a decrease in static stability. An increase in gravel content leads to a decrease in passing ability, while a significant improvement in viscosity, static stability and mechanical strength with an increase in gravel content were observed.

Key words: SCC, ANN, aggregates types and contents, contour plots, fresh and hardened properties.

1. Introduction

Self-compacting concrete (SCC) is a highly flowable concrete which can flow and consolidate under its self-weight. Due to the complexity of its mix design, SCC might be more susceptible to any changes in components compared to conventional concrete (Ghoddousi & Salehi, 2017). SCC is very sensitive to changes in aggregate characteristics (size, grading, shape, texture, and morphology), therefore, the aggregate must be carefully chosen (Khaleel, Al-Mishhadani, & Razak, 2011). In order to enhance flowability and passing ability of SCC, many researchers suggest the reduction of the total aggregate content within the range of 40-50% of the solid content. The addition of more paste can also contribute to reduce the frequency of collision between coarse particles (Ling & Kwan, 2015). Lin (Lin, 2020) show that a higher sand to aggregate ratio (S/A) have a positive effect on flowability, while a decrease in (S/A) ratio improved the mechanical properties of SCC.

Other studies have also evaluated the effects of river, crushed and dune sand in binary and ternary combinations on the fresh and hardened properties of self compacting concretes and mortars (Rmili, Ouezdou, Added, & Ghorbel, 2009) (Benabed, Kadri, Azzouz, & Kenai, 2012) (Bouziani, 2013) (Zeghichi, Benghazi, & Baali, 2014) (Sahraoui & Bouziani, 2019b). The experimental results indicate an improvement in rheological and mechanical properties with mixtures of CS and DS with RS.

Artificial neural network (ANN) is a predictive tool of machine learning algorithms, which is of great interest to researchers in recent years. This technique allows to modeling the behavior of building materials based on experimental data available in literature (Yaman, Abd Elaty, & Taman, 2017) (Asteris, Kolovos, Douvika, & Roinos, 2016) . ANN is an effective and successful tool to learn and predict SCC properties, moreover, this efficient computing system is very useful

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to treat and combine one or more concrete mix constituents as an independent input variables (Gupta, Patel, Siddique, Sharma, & Chaudhary, 2019)(Jain, Jha, & Misra, 2008).

Design of experiments (DOE) is also a statistical tool to evaluate the factors and describe the effects of all components proportions as well as all their possible interactions on the variation of each measured responses. Response surface methodology is used to investigate the effects of two independent factors, while simplex lattice design is available for mixture models in three factors.

In this study, a simplex lattice mixture design approach was used to establish mathematical models in order to illustrate the variation of different types and proportions of three sands in ternary contour plots. On the other hand, Mathematical models are also established to illustrate the variation of aggregates size and contents using response surface methodology.

2. Methodology

The first axis of this research investigates the influence of three types of sands (RS, CS and DS) and their coupled effects on rheological and mechanical properties of SCC. A simplex-lattice mixture design was used to describe the effect of sand types (Zaitri, Bederina, Bouziani, Makhloufi, & Hadjoudja, 2014) (Bouziani, 2013)(Sahraoui & Bouziani, 2019b). This space filling design creates a triangular grid of combinations with three factors and five levels as illustrated in Figure 1. The number of experiments or combinations (c) can be calculated by the following equation:

$$C = \frac{(\mathrm{m} + q - 1)!}{m!\,(q - 1)!} \quad (1)$$

where, m and q are the levels and number of factors respectively. With five levels and three factors, the mixture design of this study comprising 21 experiments. Each mixture consisted of 450 kg/m^3 of cement, 420 kg/m^3 of both Gravel 3/8 and 8/15 (G1 and G2), total sands content was 860 kg/m^3, water to cement ratio (W/C) of 0.4 and the superplasticiser-cement (SP/C) ratios was 1% by weight of cement.

A second-degree model was used to describe the effect of sands proportions and their blends. The proposed model is expressed in Equation 2:

$$Y = b_1 \times RS + b_2 \times CS + b_3 \times DS + b_4 \times (RS \cdot CS) + b_5 \times (RS \cdot DS) + b_6 \times (CS \cdot DS) \quad (2)$$

Where:

Y is the output result of ANN-based models of predicting SCC properties mentioned in the Part I of this research (Sahraoui & Bouziani, 2019c).

bi are the model coefficients (Table 2) determined by a standard least-square fitting.

The second axis devoted to the modelling of aggregate sizes and contents in contours plots using also the ANN models of the Part I (Sahraoui & Bouziani, 2019c). The mix proportioning has been designed as follows:

- Sand and gravel contents varying from 750 to 950 kg/m^3.
- Three proportions of G1/G2 ratios (0.5, 1 and 2) were chosen.
- Cement content, W/C and SP/C content were kept constant (450 Kg/m^3, 0.4 and 1% respectively).

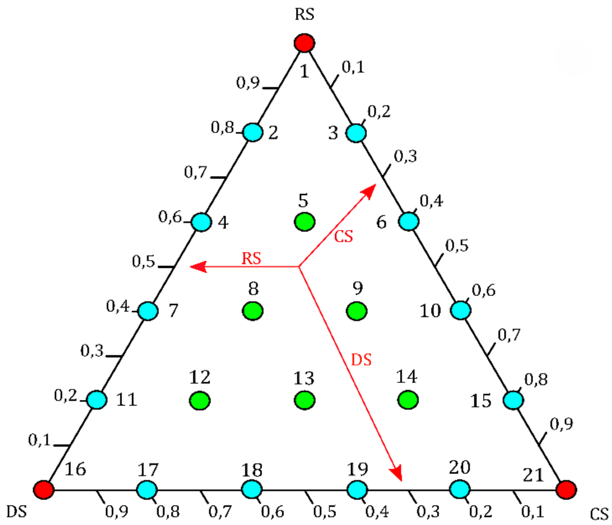

Figure 1 simplex-lattice design with 3 factors and 5 levels

3. Results and discussion

Table 1 summarizes test results of predicting fresh and hardened properties of 21 SCC mixtures issued from ANN models and experimental design of ternary systems.

Correlation coefficients (R^2), root mean square error (RMSE), p-values (P) and Coefficients of derived models (Coeff.) are shown in Table 2. This finding shows a strong correlation coefficients (R^2>80%), a lower RMSE values and P-value less than 0.05 for all studied responses which is statically significant and indicate the good prediction performance of the obtained models.

Table 1 Sands combinations and output results of ANN-based models

Mix N°	Sands combinations			Slump (cm)	V-Funnel (s)	L-Box (%)	Pi (%)	Rc28 (MPa)
	RS	CS	DS					
1	1	0	0	77,00	5,68	82,88	13,09	92,93
2	0.8	0	0.2	74,28	5,97	67,11	13,41	80,17
3	0.8	0.2	0	74,84	5,70	85,16	8,22	88,33
4	0.6	0	0.4	72,24	6,58	67,05	12,12	64,34
5	0.6	0.2	0.2	72,37	6,14	88,25	12,18	73,43
6	0.6	0.4	0	71,22	5,81	93,09	5,86	80,74
7	0.4	0	0.6	70,95	7,30	71,62	11,30	55,07
8	0.4	0.2	0.4	70,13	6,75	80,64	11,05	63,67
9	0.4	0.4	0.2	69,10	6,33	96,54	9,80	68,72
10	0.4	0.6	0	69,09	5,98	91,32	3,91	73,32
11	0.2	0	0.8	69,58	8,07	76,11	11,17	53,48
12	0.2	0.2	0.6	68,19	7,37	87,88	10,75	56,07
13	0.2	0.4	0.4	66,81	6,85	84,34	9,54	63,75
14	0.2	0.6	0.2	67,80	6,48	94,05	3,94	66,34
15	0.2	0.8	0	71,77	6,17	89,81	2,33	68,56
16	0	0	1	66,79	8,96	80,68	11,18	53,29
17	0	0.2	0.8	65,23	8,10	93,35	10,82	54,41
18	0	0.4	0.6	64,07	7,41	83,89	9,67	57,15
19	0	0.6	0.4	65,32	6,90	91,90	7,82	64,02
20	0	0.8	0.2	68,91	6,57	90,82	1,33	65,32
21	0	1	0	72,26	6,33	86,18	1,43	66,25

Table 2 Model parameters estimates of measured responses

Coefficients	Slump (cm)	V-funnel (s)	L-box (%)	Pi (%)	Rc28 (MPa)
	R^2=0.96	R^2=0.99	R^2=0.80	R^2=0.91	R^2=0.98
	RMSE=0.7892	RMSE=0.0460	RMSE=4.4570	RMSE=1.3489	RMSE=1.5574
	P<0.0001	P<0.0001	P<0.0001	P<0.0001	P<0.0001
	Coeff.	Coeff.	Coeff.	Coeff.	Coeff.
b1	77.019635	5,5989016	78,531529	12,776154	94,807684
b2	72.370621	6,3419881	84,771469	-0,124884	66,244594
b3	67.115348	8,9467554	82,700394	10,839367	51,931309
b4	-15.10044	-0,170344	52,323887	-3,696535	-13,35029
b5	0.0768441	-1,347922	-41,96906	3,2970021	-51,55611
b6	-18.97238	-1,884983	32,960541	12,166139	6,6548402

Ternary contour plots presented in Figure 2 and Figure 3 illustrate the effects of RS, DS and CS proportions on slump flow and L-Box ratio. It can be seen that the increase of RS and CS will improve flowability and the RS has the greatest effect on slump flow measurements. This is apparently caused by the well graded RS particles and the important quantity of fines in CS which resulting in a higher packing (Nécira, Guettala, & Guettala, 2017) (Sahraoui & Bouziani, 2019b).

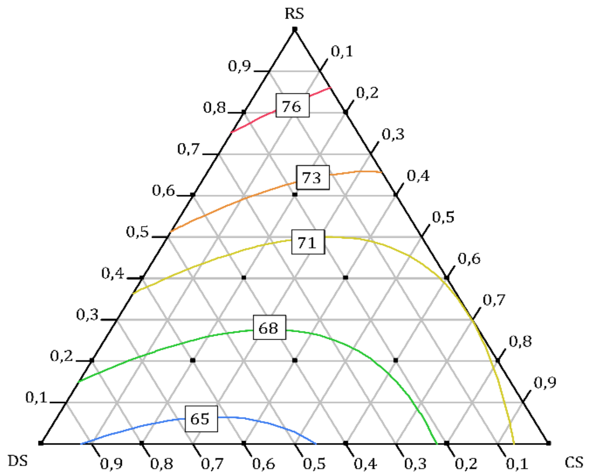

Figure 2 Ternary plot of slump flow (cm) as function of RS, CS and DS proportions

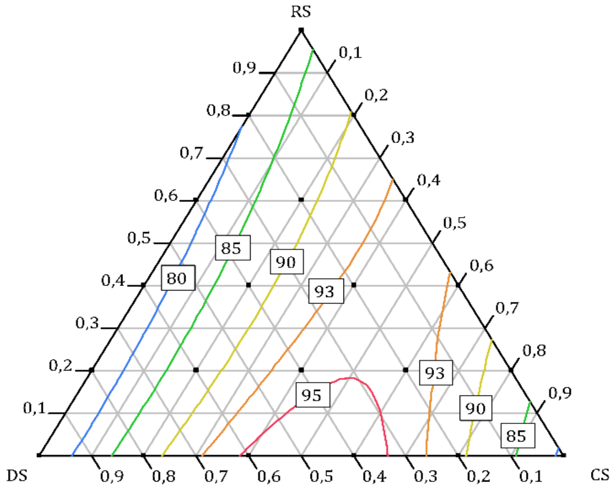

Figure 3 Ternary plot of L-Box ratio (%) as function of RS, CS and DS proportions

Results also indicate that L-Box ratio increases with the increase of CS and DS proportions in RS-CS and CS-DS binary systems respectively, corresponding to proportions of approximately 0.5 of both CS and DS, and then decreased. This can be explained by the larger amount of excess paste due to the filling effect of CS and DS fine grains (Bouziani, 2013).

The effect of different sands proportions on the flow time of V-funnel and sieve segregation test are illustrated in Figure 4 and Figure 5. It is evident that V-funnel time clearly increased with the increase of DS proportion. This can be attributed to the large finesse of DS which requires high water and paste demand (Benabed et al., 2012) (Rmili et al., 2009). It was also observed that the increase in CS content led to a significant increase in static stability due to the angular shape and the important fines content of CS (Zeghichi et al., 2014) (Nécira et al., 2017) (Bouziani, 2013).

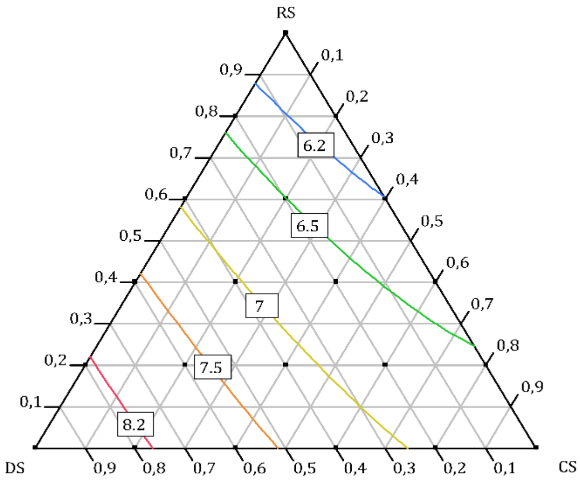

Figure 4 Ternary plot of V-funnel time (s) as function of RS, CS and DS proportions

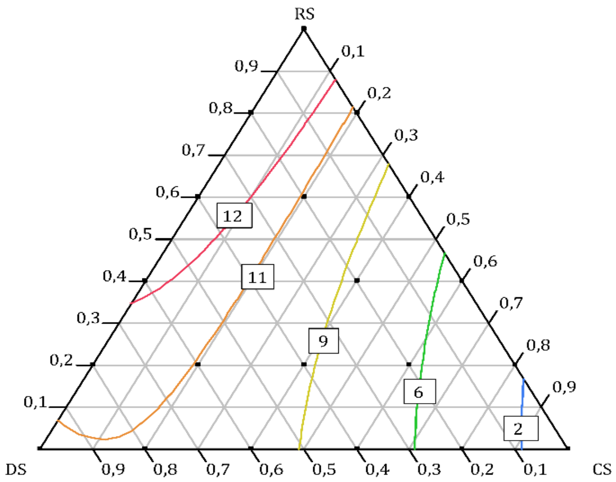

Figure 5 Ternary plot of sieve stability (%) as function of RS, CS and DS proportions

Compressive strength plot at 28 days is shown in Figure 6. It can be seen that the increase of RS gives higher compressive strengths than those with high DS and CS contents. This enhancement of strength can be attributed to the well graded of RS and the calcareous nature and the angular form of CS, while the decrease in strength is attributed to the high intergranular porosity caused by the rounded shape and the large finesse of DS (Zeghichi et al., 2014) (Nécira et al., 2017) (Bouziani, 2013) (Benabed et al., 2012).

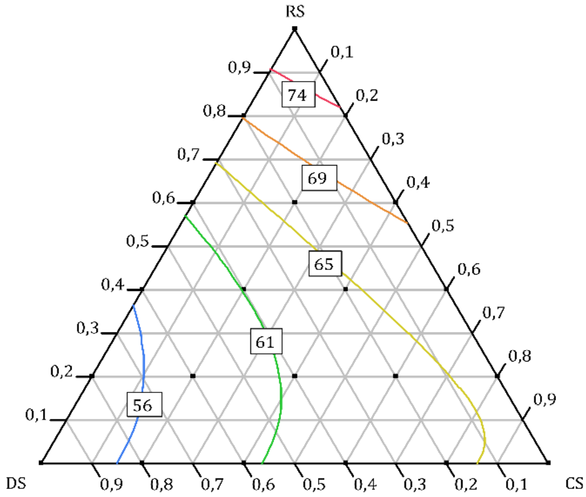

Figure 6 Ternary plot of Rc28 (MPa) as function of RS, CS and DS proportions

The results of slump flow and L-Box test are presented Figure 7 and Figure 8. As clearly shown, the increase of sand content leads to an increase in flowability. On the other hand, slump flow decreases with an increase in gravel content for mixtures made with high contents of G1 (i.e. 2/3G1-1/3G2). An increase in the content of gravel 3/8 leads to a significant increase in the interparticle friction, thus resulting in a reduction in flowability (Aïssoun, Hwang, & Khayat, 2016). In the case of equal proportions of G1 and G2 (i.e. 1/2G1-1/2G2), the increase of gravel content increases slump flow until a maximum value (79 cm) and then decreased.

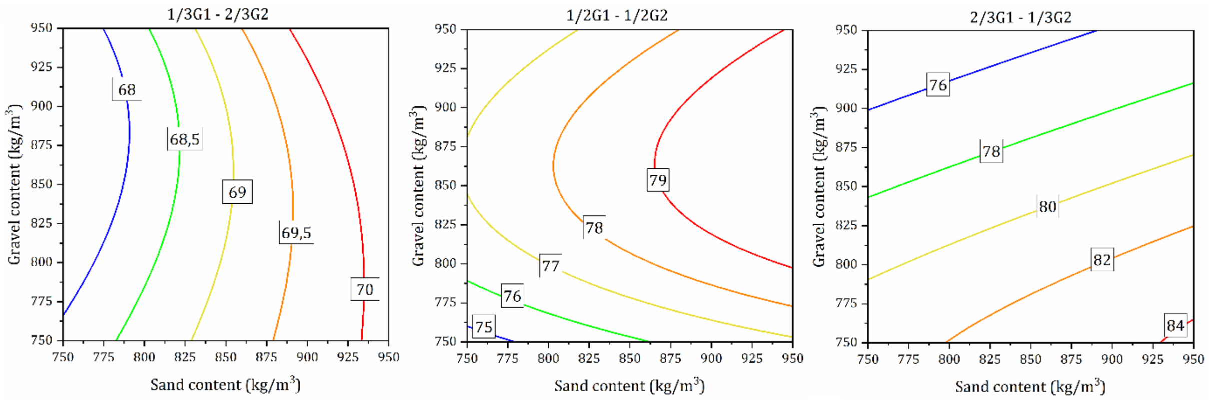

Figure 7 Contour plots of the Slump flow (cm) as function of sand and gravel contents

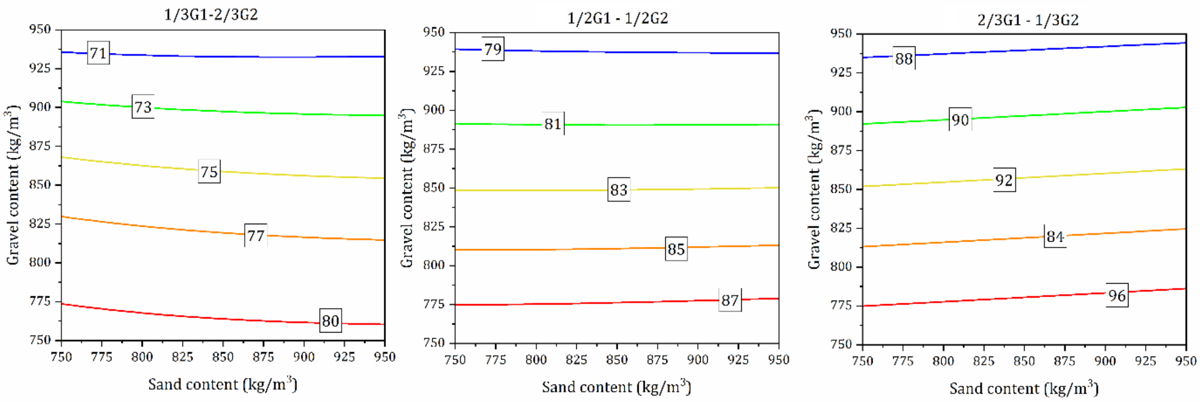

Figure 8 Contour plots of L-Box ratio (%) as function of sand and gravel contents

This phenomenon can be explained by the fact that sand particles filled spaces between the coarser aggregates G1, thereby increasing the compactness of the mixture and hence larger amount of excess paste for lubrication purpose. Once the voids were completely filled, G1 then began to occupy the place of sand particles which results in a large volume of void and consequently the flowability decreases(Bouziani, 2013). It should be noted also that the amount of sand content has no appreciable effect on L-box measurements. On the other hand, we note that an increase in gravel content leads to a decrease in passing ability and this is due to the fact that the granular blocking is related to the probability of presence of coarse aggregate (Roussel, Nguyen, Yazoghli, & Coussot, 2009).

Figure 9 and Figure 10 present contour plots of V-funnel and sieve segregation test as function of sand ang gravel content. Results show that an increase in sand content leads to a decrease in static stability. It was observed also that V-funnel time and static stability increase with an increase in gravel content, which confirm once again that viscosity and static stability enhance with the increase of aggregate size and content (Hu & Wang, 2011) (Sahraoui & Bouziani, 2019a).

The contour plots of compressive strength presented in Figure 11 illustrate the trade-offs between sand and gravel content. In order to better insights the effect of sand and gravel, the preview should be focused on mixtures made with high contents of G1 and G2 where the negative impact of increasing sand content can be clearly shown. On the other hand, an increase of gravel content leads to a significant improvement in mechanical strength. This compressive strength changes can be mainly attributed to the effect of aggregate size on pores characteristics and cement paste thickness (Yu, Sun, Wang, & Hu, 2019).

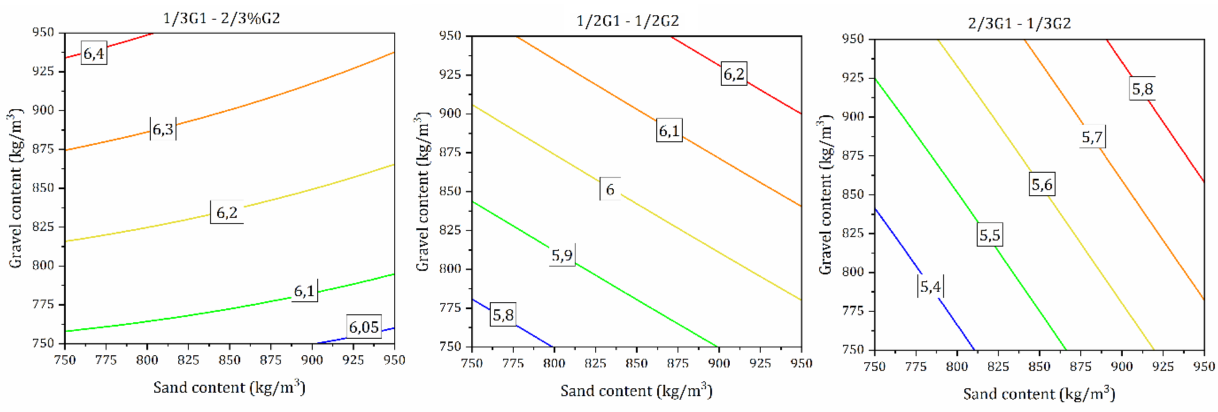

Figure 9 Contour plots of V-funnel time (s) as function of sand and gravel contents

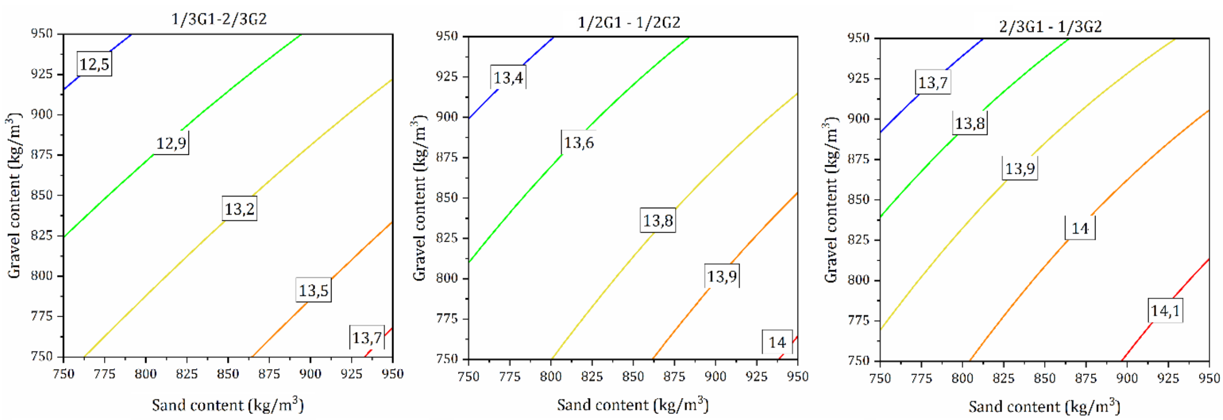

Figure 10 Contour plots of sieve stability (%) as function of sand and gravel contents

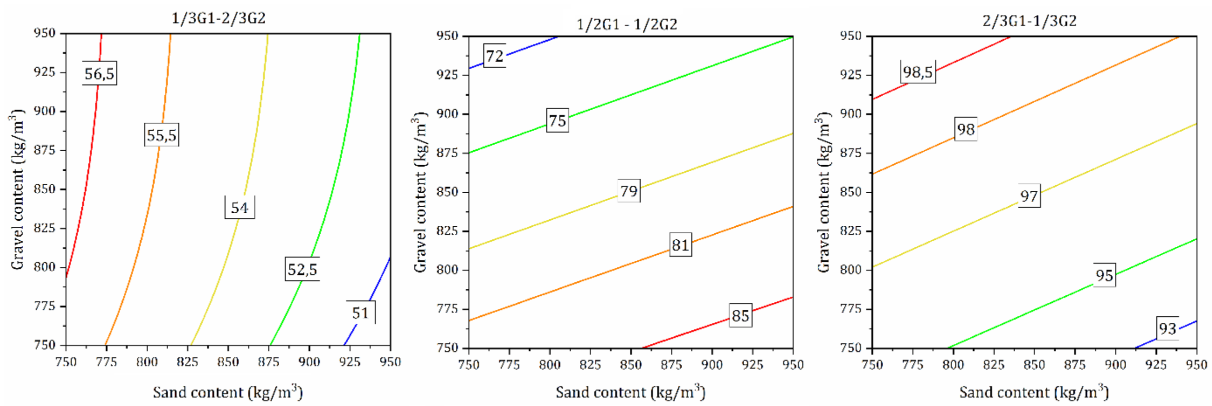

Figure 11 Contour plots of Rc28 (MPa) as function of sand and gravel contents

4. Conclusion

Based on the results of this modelling investigation, the following conclusions were derived:

- The design of experiments is a very useful method that aims to analyze, describe and improve the precision of the developed ANN models.
- Exploiting the experiment results in binary and ternary contours plots could provide more flexibility for analyzing and interpreting the obtained results.
- The increase of RS proportion led to a significant increase in flowability
- The highest passing ability was obtained for sand binary or ternary mixtures composed of 50% of both RS and CS.
- V-funnel time decreased with the increase of DS proportion, while the enhancement of static stability was attributed to the high amount of fine content of CS.
- High DS content leads to a decrease in mechanical compressive strength at 28 days.
- The increase of sand content improves the flowability, while the increase in gravel content leads to a significant decrease in passing ability expressed by L-box test.
- V-funnel time and static stability increased with the increase of gravel content.
- A negative impact of increasing sand content in compressive strength can be clearly shown. Instead, an increase of gravel content leads to a significant improvement in mechanical strength.

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