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Statistical analysis of the influences of admixtures and elevated temperatures on mortar properties

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Abstract. Mortar is produced with different degrees of temperature and ratios of admixture materials. In order to produce strength mortar, the degree of temperature and the ratio of admixture materials must be optimized. This paper examines experimental effects by applying certain degrees of temperature and ratios of admixture materials to statistically understand the changes in the strength of mortar. The Taguchi method is used for the above-mentioned optimization problem. Firstly, factorial ANOVA is used to investigate the difference of means between the experiments. Due to the significant differences in obtained means, the regression analysis is applied. On the other hand, the effects of the varying degrees of temperature and admixture ratios are presented via 3D plots. Finally, the statistical results of ANOVA and Taguchi indicate that degree of temperature and the different ratios of admixture materials can affect the behaviour of mortar under the tests.

Keywords: admixture; ANOVA; mortar; taguchi method; temperature

1. Introduction

The use of admixture reduces the amount of water and cement by keeping constant ratio of water/cement to be used in the concrete mixture, and it also provides economic benefits. When the appropriate ratio of admixture is not set, the workability problems arise with the plasticizer concretes. The admixtures of accelerator and retarder make the work easy in cold and hot weather by changing the setting time of fresh concrete. The efficiency of air entraining which is used to strengthen the freeze-thaw durability of concrete, increases depending on repeating more and more (Topcu *et al.* 2006). Especially for these features admixtures are used in producing concrete. The experiment results of concrete under high temperature that is produced using admixtures should be investigated in order to understand how they perform in case of fire. Experiments should be made under high temperatures to understand the performance of concretes produced using additives at the time of the fire. When concrete is exposed to high temperatures, its physical and mechanical features change. Concrete loses %50 of its durance when the temperature rises to 600°C and loses %80 of its durance when the temperature rises to 800°C (Kaya and Yazicioglu 2015a). Structures such as houses, schools, factories, tunnels, bridges, etc. are exposed to high temperatures in the fire; therefore, today's modern structures are built more durably by using admixtures in concrete. It should be considered that how it performs under high temperature while producing high performance concrete is known (Kizilkanat and Yuzer 2008).

Tanyildizi and Sahin (2015), investigated the effect of different degrees of temperatures on compressive strength of concrete. In their experiments, the values of compressive strength were analysed at 20°C, 200°C, 400°C, and 600°C, respectively, and the optimum value was obtained as 200°C and 5% silica fume using the Taguchi method and ANOVA analysis. Bozkurt (2013) used the Taguchi method to investigate concrete performance, concrete strength and ultrasonic pulse velocity by using 5 different ratios of perlite powder (0%, 5%, 10%, 15% and 20%) and 4 different degrees of temperature (20°C, 400°C, 600°C, 900°C). He obtained the highest compressive strength and ultrasonic pulse velocity at 0% and 5% ratios and 20°C temperature. Admixtures of concrete are used in order to strengthen the concrete or to get concrete economically by changing some features of mortar admixture materials. Also, they are used to increase plasticity of concrete, reach early and high durance, provide imperviousness and durance to freeze, change setting time as well (Topcu 1996). Admixtures are defined as water-swellable materials in concrete technology. Admixtures decreasing the mixing water of concrete and admixtures retarding or accelerating the setting time of fresh concrete are substances in the additive group called additives. Admixtures may have negative effects on concrete features unless they are not used in an appropriate ratio. Therefore, laboratory tests should be performed before using admixtures in concrete mixtures (Topcu *et al.* 2006).

Setting time is the time from the moment when a plastic (shapeable) concrete is obtained by completing the mixing process of the materials until the fresh concrete begins to harden. Retarder admixtures make setting time extend and

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accelerator admixtures make setting time shorten (Topcu *et al.* 2006, Kaya and Yazicioglu 2015a, Kizilkanat and Yuzer 2008, Topcu 1996, Kaya *et al.* 2014, Binici *et al.* 2013). Air entraining is the incorporation of additives that ensure very small size (usually not larger than 0.1 mm in diameter) and uniformly dispersed air bubbles within the cement paste in fresh concrete, and make air bubbles that remain permanent after the cement paste hardens (Topcu *et al.* 2006, Kaya and Yazicioglu 2015a, Kizilkanat and Yuzer 2008, Topcu 1996, Binici *et al.* 2013, Subasi *et al.* 2011, Kaya and Yazicioglu 2015b). Sevil *et al.* (2011) used plasticizer as an admixture in order to reinforce mortar so that strong and rigid masonry walls can be built. Canbaz *et al.* (2016) studied on admixtures that are light, self-leveling, easily cured, and applied screeds as a construction material. Schackow *et al.* (2019) investigated three stabilized mortars to masonry walls using air entraining agents and settling retardant plasticizer to compare with a conventional mortar with lime. They produced three different mortars by using retardant plasticizer and air entraining admixtures. The studies showed that mortars with retardant plasticizer have the workability for a longer time. The advantages of mortar are lighter mass density and higher incorporated air content of mortar. Retardant plasticizer in stabilized mortar increases the water retentively compared with the conventional mortar. Chatterjee and Das (2013) investigated the flow response of self-compacting mortars using Taguchi and ANOVA interaction. The analysis results showed that the minimum powder to fine aggregate ratio should be 55% and super-plasticizer dose should be between 1.5% and 2%.

Devi *et al.* (2019) examined Kota stone slurry powder with accelerators to test its workability, strength, resistance, etc. Their experiments show that accelerators reduced the workability because of low plasticity effect. Furthermore, a combination of accelerators and Kota stone slurry powder shows lower strength at all curing ages. Erdal *et al.* (2018) predicted concrete compressive strength with 12 different methods. They got satisfying results with regression which was one of the methods used. Chang *et al.* (2018) modelled compressive strength of mortar by regression and explored Ultrasonic pulse velocity. Saridemir (2017) modelled the flexural strength of mineral admixtured mortars by using regression analysis. Ramezanianpour *et al.* (2014) investigated strength of mortar by the Taguchi method. The results showed that the use of low-reactivity GGBFS can increase the durability of high-strength concrete but decrease the compressive strength. Tang (2014) employed the Taguchi method to optimize the process condition of synthetic LWA using recycled glass cullets and reservoir sediments with minimum number of tests. Tang (2010) investigated the effect of high-volume mineral admixtures via regression analysis. Ou *et al.* (2012) used the Taguchi method to reduce computational cost in their circular reinforced concrete columns study. Peng *et al.* (2012) analysed aggregate distribution of concrete with ANOVA and found that their vertical drilled sample is different from their horizontal drilled sample in terms of compressive strengths. Yeh (2008) explored the effect of superplasticizers on workability of concrete and the results were positive. Teimortashlu (2018) analysed tertiary blended self-compacting mortars to optimize strength via the Taguchi method and ANOVA. Cui *et al.* (2017) explored two new anti-washout grouting materials via ANOVA. Cuenca-Moyano *et al.* (2020) investigated the effects of air entraining and plasticizer admixture on masonry mortar properties via ANOVA.

Previous studies show that temperature and admixture materials are two main components of mortar. The qualities of the above-mentioned components are evaluated by using unit weight, ultrasonic pulse velocity, tensile strength, and compressive strength. Unlike previous studies, in this study, four different admixture materials are investigated respectively: plasticizer, retarder, accelerator, and air entraining. In this study, the optimum degrees of temperature and ratios of admixture are determined by the Taguchi method, the differences between group means are tested by ANOVA, and the qualities are modelled by linear regression and represented by 3D plots.

Table 1 Properties of cement

SiO_2	CaO	Al_2O_2	Fe_2O_3	MgO	Na_2O	K_2O	SO_3	LOI
19.65	62.14	5.34	2.89	1.34	0.35	0.7	3.05	3.75

Spec. Gravity	Blaine, cm^2/g	Compressive Strength, MPa		
3.07	3758	26.2 (2-day)	45 (7-day)	55.7 (28-day)

Table 2 Analysis results of the water (mg/lt)

pH	Na_2O	Ka_2O	CI	SO_4	Zn	Pb	P_2O_3	NO_3	Hardness Fd^0	Turbidity NTU
7.35	52	11	66	80	5.06	0.05	1.5	0.1	30.11	0.25

Table 3 The grain size distribution of CEN standard sand

Sieve interval (mm)	2.0	1.6	1.0	0.5	0.16	0.08
Cumulative sieve remaining amount (%)	0	7 ± 5	33 ± 5	67 ± 5	87 ± 5	99 ± 1

2. Experimental study

2.1 Materials

2.1.1 Cement

The samples are produced by using the CEM I 42.5 type of cement which is produced by Eskişehir cement factory. Properties of cement are shown in Table 1.

2.1.2 Water

The samples are produced by using the tap water of Eskişehir. Analysis results of the tap water are presented in Table 2.

2.1.3 Aggregate

The samples are produced using the CEN type of standard sand. CEN (European Committee for Standardization) type standard sand (ISO standard sand) is a type of natural sand, especially the finest fractions of which are siliceous, clean, and the particles are generally isometric and round in shape. This sand is sieved after drying in a

Table 4 Properties of admixtures

Materials	Appearance	Colour	Odour	pH	Flash point	Vapor pressure	Density	Solubility water solubility	Viscosity, kinematic
Plasticizer	Liquid	Green, brown	Characteristic	ca. 6.75 (23°C)	>100°C	23 hPa	ca. 1.185g/cm^3 (23°C)	Completely soluble	ca. > 20.5 mm^2/s (40°C)
Retarder	Liquid	Yellow	Pleasant	ca. 8.5	Not applicable	23 hPa	ca. 1.15g/cm^3 (23°C)	Soluble	> 7 mm^2/s (40°C)
Accelerator	Liquid	Violet	Characteristic	ca. 9 (23°C)	>100°C	23 hPa	ca. 1.17g/cm^3 (23°C)	Completely soluble	Ca.> 20.5 mm^2/s (40°C)
Air entraining	Liquid	Dark amber	Characteristic	ca. 8.13 (23°C)	>100^{0}C	23 hPa	ca. 1.010g/cm^3 (23°C)	Completely soluble	ca. > 20.5 mm^2/s (40°C)

Table 5 Mixture proportions of admixture materials

Materials	Ratio A	Ratio B	Ratio C	Ratio D
Plasticizer	0%	1%	2%	3%
Retarder	0%	0.5%	1%	2%
Accelerator	0%	1.5%	2%	3%
Air entraining	0%	0.1%	0.5%	1%

Table 6 Degrees of temperature

	Degree A	Degree B	Degree C	Degree D
Temperature	20°C	100°C	300°C	600°C

special workshop. The distribution of grain is presented in Table 3.

2.1.4 Admixtures

The samples are produced using 4 different types of admixtures which are plasticizer, retarder, accelerator, and air entraining in different ratios. The properties of admixture materials are shown in Table 4. Sika Plastiment as a plasticizer, Sika Retarder as a retarder, SikaRapid-1 as an accelerator, and Sika Air as an air-entraining are used as admixtures.

2.2 Design of experiments

In this study, mortars with admixtures under high temperature are examined. Each time, just one type of admixture material is used in order to produce mortar samples in size of 40×40×160 mm. The mortar samples, which are produced according to TS EN 196-1 (TS 2016), are cured within lime saturated water with the temperature of 20±2°C until the 28th day. In addition, the following procedure is the exposure of the samples at different degrees of temperature such as 20°C, 100°C, 300°C, 600°C for an hour. This procedure is applied as follows as in Fig. 1. Just after this procedure, hardened mortar tests are applied to these samples.

Hardened mortar tests are unit weight, ultrasonic pulse velocity, tensile strength, and compressive strength. The results of the application of the tests for each of the samples for six times are analysed statistically. The experiments are shown in Fig. 2.

2.3 Mixture proportions

During the production process, 1350 g sand, 450 g cement, and 225 g water are used as mixture proportion for the specimens. Admixture ratios are changed as shown in Table 5 for different specimens. Admixture materials (i.e., plasticizer, retarder, accelerator, and air entraining) are used separately during the experiments. It is determined the percentage based on cement weight.



(a) (b)

Fig. 1 Exposure of the samples at high degree of temperature



(a) Ultrasonic pulse velocity (b) Tensile strength



(c) Compressive strength

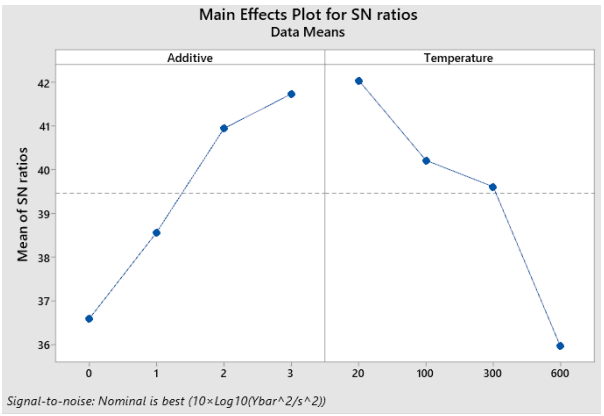
Fig. 2 The experiments of ultrasonic pulse velocity, tensile strength, and compressive strength

2.4 Degree of temperature

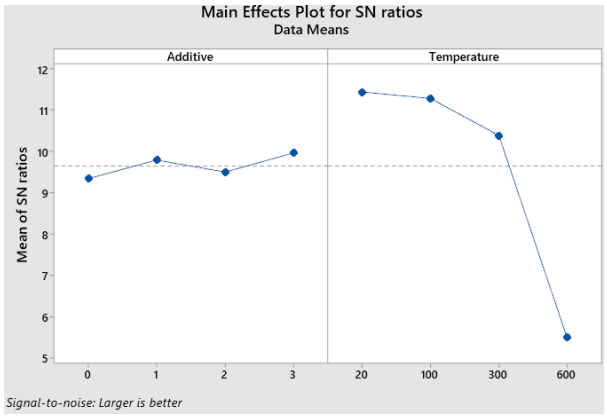
All specimens are exposed to four different degrees of temperature as shown in Table 6.

2.5 Statistical methods

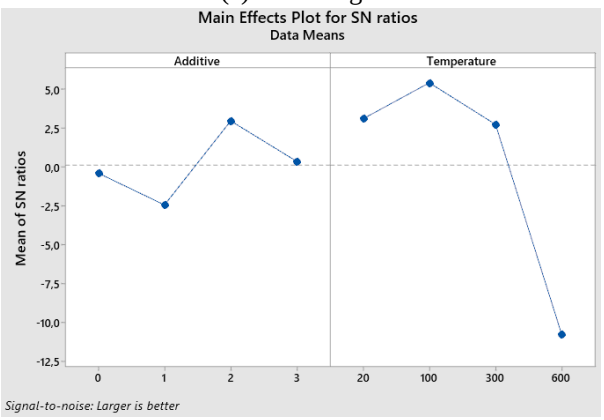
In this study, the Taguchi method is used to obtain



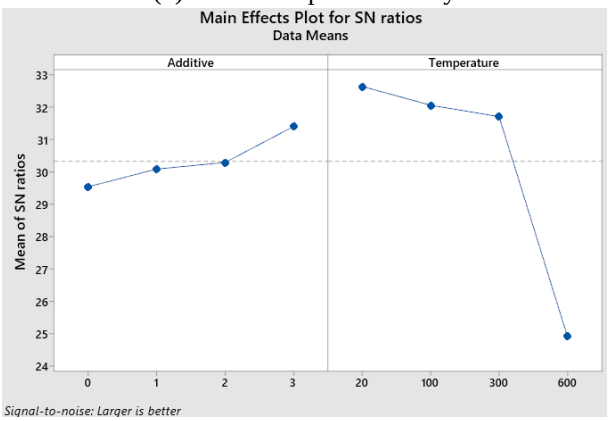
(a) Unit weight



(b) Ultrasonic pulse velocity

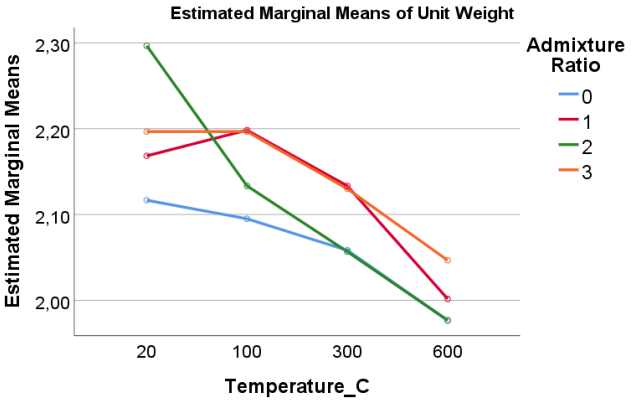


(c) Tensile strength

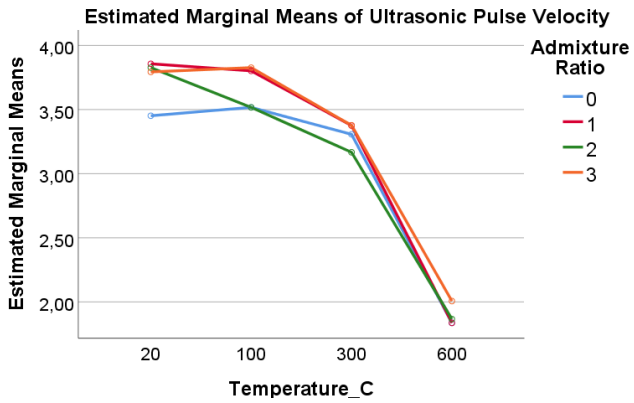


(d) Compressive strength

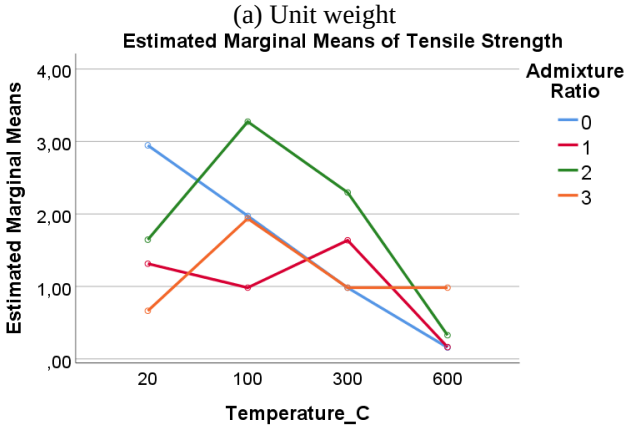
Fig. 3 Taguchi response plots for signal-to-noise ratios for plasticizer



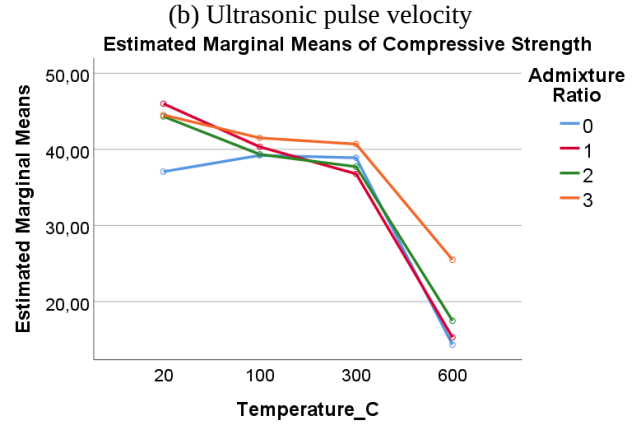
(a) Unit weight



(b) Ultrasonic pulse velocity



(c) Tensile strength



(d) Compressive strength

Fig. 4 Estimated marginal means plots for plasticizer

Table 7 Taguchi response table for signal to noise ratios for plasticizer

	Factor	A	B	C	D	Delta	Rank
Unit weight	Temperature	42.04	40.22	39.61	35.97	6.07	1
	Admixture	36.59	38.57	40.94	41.73	5.14	2
Ultrasonic pulse velocity	Temperature	11.427	11.271	10.380	5.496	5.931	1
	Admixture	9.335	9.786	9.497	9.958	0.623	2
Tensile strength	Temperature	30.951	54.058	27.324	-107.542	161.600	1
	Admixture	-0.3976	-24.354	29.592	0.3528	53.946	2
Compressive strength	Temperature	32.63	32.05	31.70	24.93	7.70	1
	Admixture	29.53	30.08	30.29	31.40	1.86	2

Table 8 ANOVA and regression results of plasticizer

Dependent Parameters	Independent Parameters	ANOVA Results			Regression Results					
					Full Model			Significant Model		
		F	*P* value	Partial η^2	Coefficients	*P* value	R^2_{Adj}	Coefficients	*P* value	R^2_{Adj}
Unit weight	Intercept	521758	<0.001	1.000	2.14952	<0.001	0.7362	2.15978	<0.001	0.7334
	Temperature	209.643	<0.001	.887	-0.00028	<0.001		-0.00034	<0.001	
	Admixture	35.666	<0.001	.572	0.03012	<0.001		0.02329	<0.001	
	Temperature*Admixture	15.456	<0.001	.635	-0.00003	0.162		NA	NA	
Ultrasonic pulse velocity	Intercept	223364	<0.001	1.000	3.85941	<0.001	0.9085	3.65514	<0.001	0.9725
	Temperature	4180.01	<0.001	.994	-0.00311	<0.001		-0.00001	<0.001	
	Admixture	61.477	<0.001	.697	0.07331	0.024		0.05454	<0.001	
	Temperature*Admixture	17.809	<0.001	.667	-0.00007	0.436		NA	NA	
Tensile strength	Intercept	24127	<0.001	.997	2.46863	<0.001	0.4477	2.46863	<0.001	0.4477
	Temperature	1516.84	<0.001	.983	-0.00407	<0.001		-0.00407	<0.001	
	Admixture	474.007	<0.001	.947	-0.29765	0.002		-0.29765	0.002	
	Temperature*Admixture	453.629	<0.001	.981	0.00107	<0.001		0.00107	<0.001	
Compressive strength	Intercept	98618	<0.001	.999	44.25537	<0.001	0.8515	42.95383	<0.001	0.8461
	Temperature	2599.24	<0.001	.990	-0.04664	<0.001		-0.04154	<0.001	
	Admixture	110.641	<0.001	.806	0.84693	0.129		1.71463	<0.001	
	Temperature*Admixture	40.120	<0.001	.819	0.00340	0.040		NA	NA	

optimum results with Minitab software. Factorial ANOVA is used to test the differences between the group means. For the equality of sample sizes, Tukey HSD is used as Post Hoc test to specify significant differences between pairs of means. ANOVA results are obtained with SPSS. Linear regression is used for modelling the relationship between dependent variable of unit weight, ultrasonic pulse velocity, tensile strength, compressive strength, and explanatory variables of temperature and admixtures materials separately. Furthermore, the relationship is investigated by 3D plot, and surface plots are obtained with *plot3D* library in R.

Since degrees of temperature and ratio of admixture materials have 4 factors, 4^2 factorial design is used. Signal-to-noise ratios are set as nominal-is-best for unit weight and larger-is-better for ultrasonic pulse velocity, tensile strength, and compressive strength in Taguchi analyses. The formulas of signal-to-noise S/N ratio by using base 10 log for the nominal-is-best and the larger-is-better are given in Eq. (1) and (2)

$$S/N_{nominal} = 10Log(\bar{Y}^2/s^2) \quad (1)$$

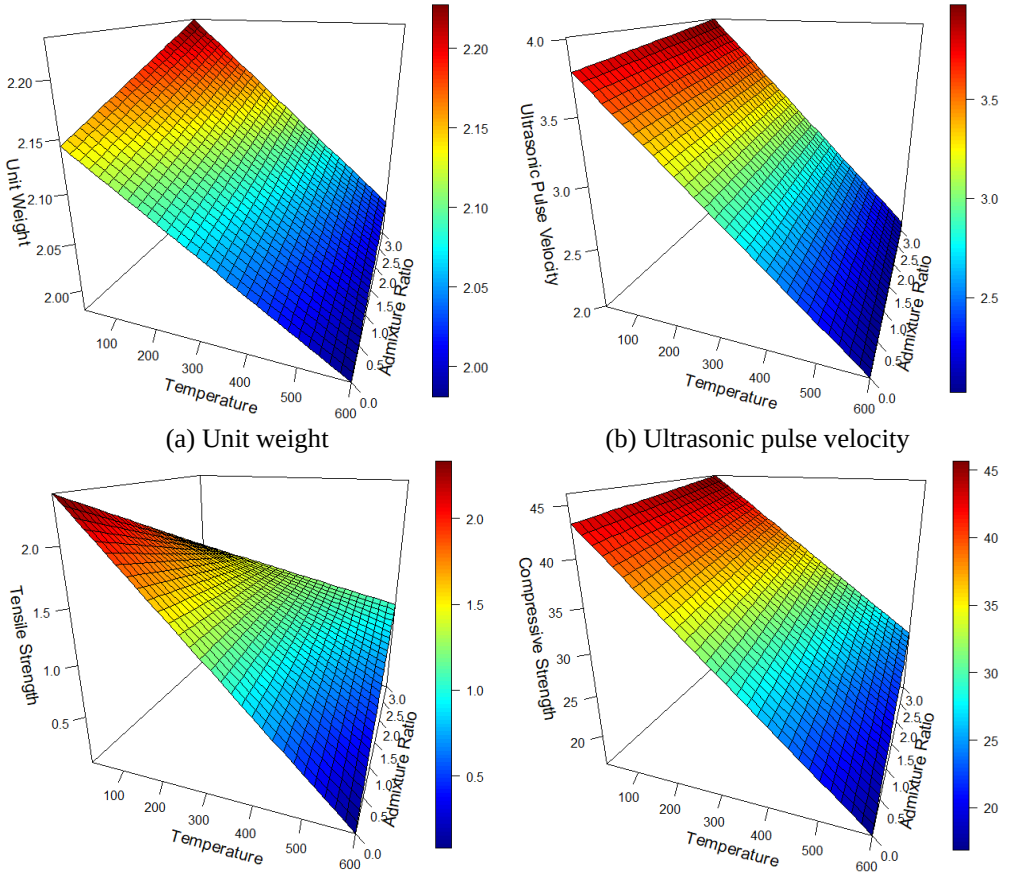
$$S/N_{larger} = -10Log\left(\sum(1/Y^2)/n\right) \quad (2)$$

Factorial ANOVA model is in Eq. (3)

$$y_{ijk} = \mu + \delta_i + \beta_j + \delta\beta_{ij} + \varepsilon_{ijk}$$
$$i = 1,2,3,4,\ j = 1,2,3,4,\ k = 1,2,3,4,5,6 \quad (3)$$

where y_{ijk} is the *kth* observation at the *ith* level of factor temperature and the *jth* level of factor admixture materials, μ is population mean, δ_i is the fixed effect for the *ith* level of factor temperature, β_j is the fixed effect for the *jth* level of factor admixture materials, $\delta\beta_{ij}$ is the interaction effect between factors temperature and admixture materials and ε_{ijk} is the random error effect (Senoglu and Acitas 2011). The null hypotheses are given in Eq. (4) for the model given in Eq. (3)

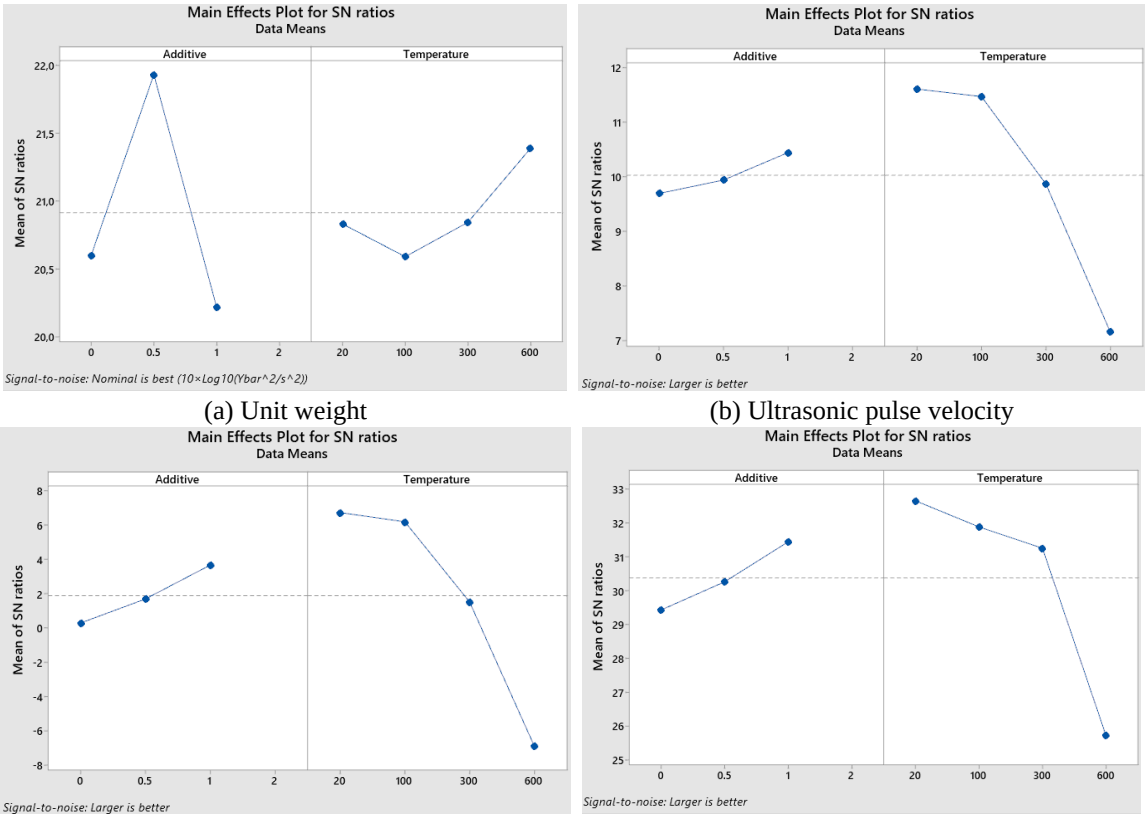
$$H_{01}: \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$$
$$H_{02}: \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$$
$$H_{03}: \beta\delta_1 = \beta\delta_2 = \beta\delta_3 = \beta\delta_4 = 0 \quad (4)$$
$$i = 1,2,3,4,\ j = 1,2,3,4,\ k = 1,2,3,4,5,6$$



(a) Unit weight (b) Ultrasonic pulse velocity

(c) Tensile strength (d) Compressive strength

Fig. 5 Surface 3D plots for plasticizer



(a) Unit weight (b) Ultrasonic pulse velocity

(c) Tensile strength (d) Compressive strength

Fig. 6 Taguchi response plots for signal to noise ratios for retarder

Table 9 Post Hoc results of plasticizer

Parameters		Degree of temperature				Ratio of admixture			
		A (20°C)	B (100°C)	C (300°C)	D (600°C)	A (0%)	B (1%)	C (2%)	D (3%)
Unit weight	A		<0.001	<0.001	<0.001		<0.001	<0.001	<0.001
	B	<0.001		<0.001	<0.001	<0.001		.654	.173
	C	<0.001	<0.001		<0.001	<0.001	.654		.010
	D	<0.001	<0.001	<0.001		<0.001	.173	.010	
Ultrasonic pulse velocity	A		.004	<0.001	<0.001		<0.001	.004	<0.001
	B	.004		<0.001	<0.001	<0.001		<0.001	.296
	C	<0.001	<0.001		<0.001	.004	<0.001		<0.001
	D	<0.001	<0.001	<0.001		<0.001	.296	<0.001	
Tensile strength	A		<0.001	<0.001	<0.001		<0.001	<0.001	<0.001
	B	<0.001		<0.001	<0.001	<0.001		<0.001	<0.001
	C	<0.001	<0.001		<0.001	<0.001	<0.001		<0.001
	D	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	
Compressive strength	A		<0.001	<0.001	<0.001		<0.001	<0.001	<0.001
	B	<0.001		<0.001	<0.001	<0.001		.984	<0.001
	C	<0.001	<0.001		<0.001	<0.001	.984		<0.001
	D	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	

3. Results and discussion

The optimum level of factors is determined by the Taguchi method and degrees of temperature and ratios of admixtures are specified as A, B, C, and D, respectively. Since the normality assumptions are satisfied for all the variables, factorial ANOVA is used for exploring the effects of the factors. Linear regression analysis is used for modelling mortar depending on degrees of temperature and ratios of admixture. The relationship is represented by a 3D plot similar to Kivak's (2014) work.

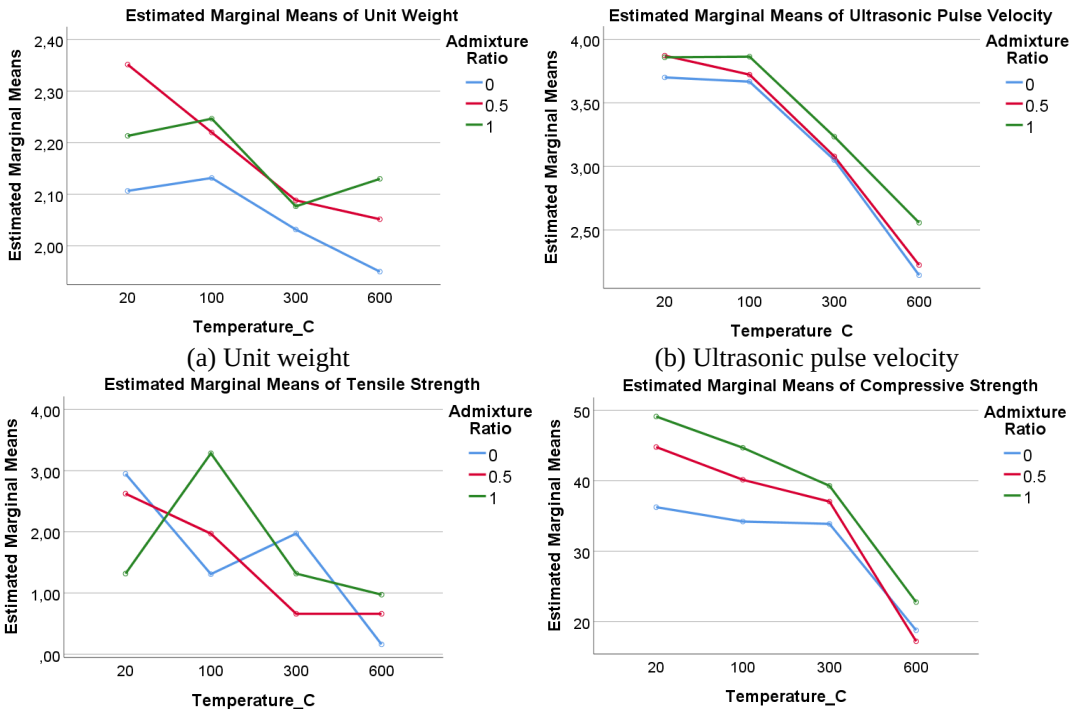
3.1 Plasticizer

The results of plasticizer for Taguchi's signal-to-noise ratios are given in Table 7 and Fig. 3. The results show that degrees of temperature affect mortar more than ratios of admixture materials. The optimum combinations are 20°C degree of temperature and 3% ratio of admixture for unit weight, ultrasonic pulse velocity, compressive strength and 100°C degree of temperature and 2% ratio of admixture for tensile strength. Higher ratios of admixtures and lower temperatures are more effective on the results of unit weight, ultrasonic pulse velocity, and compressive strength. The use of 3% plasticizer reduced the amount of air gap in the mortar samples to the greatest extent. In addition, those mortar samples containing plasticizer are adversely affected by high temperatures. For this reason, the best results are seen in those mortar samples containing 20°C and 3% plasticizer.

As can be seen in Fig. 4, the lines intersect each other and this suggests that there can be differences between the group means. Higher temperatures have a negative effect on unit weight, ultrasonic pulse velocity, tensile strength, and compressive strength. Unit weight decreases after 100°C, tensile strength is not affected at 20°C, 300°C, and 600°C temperatures when admixture ratio is %3. Ultrasonic pulse velocity and compressive strength decrease dramatically after 300°C.

As can be seen in Table 8, there are statistically significant differences between the group means as determined by factorial ANOVA (psig<0.001) as degrees of temperature and ratios of admixture materials affect unit weight, ultrasonic pulse velocity, tensile strength, and compressive strength. Table 9 presents Post Hoc test results. In pairwise comparisons of unit weight, while all subgroups of degrees of temperature are significant for the differences between the means of unit weight, all the subgroups of ratios of admixture materials are significant except for 1%-2% and 1%-3%. In pairwise comparisons of ultrasonic pulse velocity, while all the subgroups of degrees of temperature are significant for the difference between the means of Ultrasonic pulse velocity, all the subgroups of ratio of admixture materials are significant except for 1%-3%. In pairwise comparisons of tensile strength, all the subgroups of degrees of temperature and all the subgroups of ratios of admixture materials are significant for the differences between the means. In pairwise comparisons of compressive strength, while all the subgroups of degrees of temperature are significant for the differences between the means of compressive strength, all the subgroups of ratios of admixture materials are significant except for 1%-2%. Results of Partial Eta Squared show that the effect of temperature is higher than admixture materials.

Regression results are given in Table 8 for mortar with plasticizer, and R^2 values are high for unit weight, ultrasonic pulse velocity, and compressive strength. While the interaction coefficient of temperature and admixture is significant for both tensile and compressive strength, it is not significant for unit weight and ultrasonic pulse velocity. considering the interaction coefficient of temperature and admixture, using optimum combination reduces the negative effect of higher temperatures in tensile and compressive strength. Coefficient of temperature is reduced



(a) Unit weight (b) Ultrasonic pulse velocity

(c) Tensile strength (d) Compressive strength

Fig. 7 Estimated marginal means plots for retarder

Table 10 Taguchi response table for signal to noise ratios for retarder

	Factor	A	B	C	D	Delta	Rank
Unit weight	Temperature	20.83	20.59	20.84	21.39	0.80	2
	Admixture	20.60	21.93	20.22	NA	1.71	1
Ultrasonic pulse velocity	Temperature	11.604	11.466	9.868	7.165	4.439	1
	Admixture	9.694	9.941	10.443	NA	0.748	2
Tensile strength	Temperature	67.053	61.701	15.039	-68.776	135.829	1
	Admixture	0.283	16.838	36.588	NA	33.750	2
Compressive strength	Temperature	32.64	31.88	31.25	25.73	6.91	1
	Admixture	29.43	30.26	31.44	NA	2.01	2

dramatically from full model to significant model for ultrasonic pulse velocity. Adjusted R^2 values are high for unit weight, ultrasonic pulse velocity, and compressive strength, but it is moderate for tensile strength.

Surface plots are given in Fig. 5 respectively for mortar with plasticizer. As can be seen in the figures, degree of temperature affects unit weight, ultrasonic pulse velocity, tensile strength, and compressive strength more than admixture ratio. The results of unit weight, ultrasonic pulse velocity, compressive strength, and tensile strength experiment decrease because of the increase of air void structure by vaporizing caused by elevated temperature. Because of high temperature, changes in the structure of mortar cause a gradual decrease in tensile strength and compressive strength.

3.2 Retarder

In the additives produced by using the retarder, the samples with 2% additives are not set and experiments cannot be performed on them. Taguchi response results for signal-to-noise ratios are given in Table 10 and Fig. 6. The results show that varying degrees of temperature affect mortar more than different ratios of admixture materials, except for unit weight. In addition, elevated temperature has a negative effect on mortar. The optimum combinations are 20°C and %1 for ultrasonic pulse velocity, tensile strength, and compressive strength.

As seen in Fig. 7, since some lines intersect each other, there can be differences between some of the group means. Ultrasonic pulse velocity dramatically decreases after 100°C while the breakdown point is 300°C for compressive strength.

As can be seen in Table 11, there are statistically significant differences between some of the group means as determined by Factorial ANOVA (psig<0.05 and psig<0.1), varying degrees of temperature and ratios of admixture materials affect unit weight, ultrasonic pulse velocity, tensile strength, and compressive strength, except for the interaction effect of both temperature and admixture on unit weight (psig=0.819>0.1). Table 12 presents Post Hoc test results. In pairwise comparisons of unit weight, there is a significant difference between the subgroup means of degrees of temperature just for 20°C-300°C, 20°C-600°C,

Table 11 ANOVA and regression results of retarder

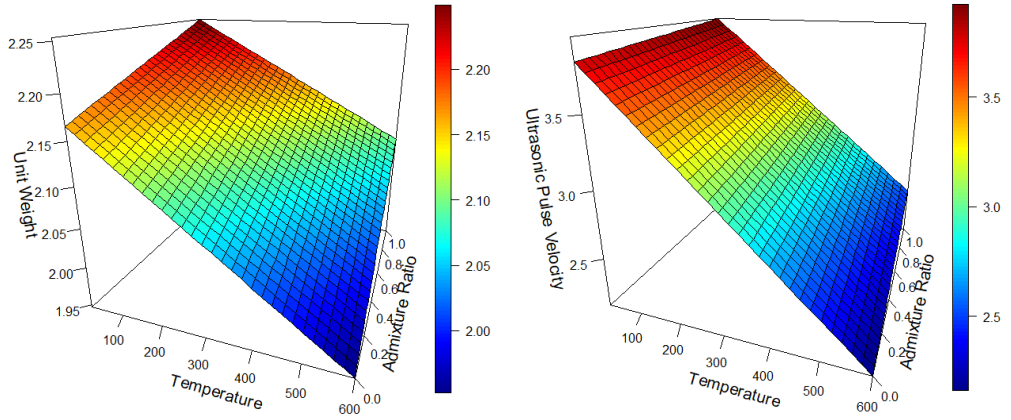
Dependent Parameters	Independent Parameters	ANOVA Results			Regression Results					
					Full Model			Significant Model		
		F	*P* value	Partial η^2	Coefficients	*P* value	R^2_{Adj}	Coefficients	*P* value	R^2_{Adj}
Unit weight	Intercept	8514.67	.064	<0.001	2.17418	<0.001	0.1487	2.16067	<0.001	0.1385
	Temperature	3.924	.013	.164	-0.00038	0.022		-0.00033	0.002	
	Admixture	2.880	.064	.088	0.08463	0.322		0.11167	0.049	
	Temperature*Admixture	.483	.819	.046	0.00011	0.673		NA	NA	
Ultrasonic pulse velocity	Intercept	38710.6	<0.001	.998	3.86877	<0.001	0.9435	3.86877	<0.001	0.9435
	Temperature	449.311	<0.001	.957	-0.00290	<0.001		-0.00290	<0.001	
	Admixture	17.823	<0.001	.373	0.13205	0.049		0.13205	0.049	
	Temperature*Admixture	1.933	.090	.162	0.00042	0.036		0.00042	0.036	
Tensile strength	Intercept	34335.1	<0.001	.998	2.52576	<0.001	0.5452	2.37970	<0.001	0.5292
	Temperature	2140.37	<0.001	.991	-0.00388	<0.001		-0.00306	<0.001	
	Admixture	66.707	<0.001	.690	-0.29213	0.297		NA	NA	
	Temperature*Admixture	855.845	<0.001	.988	0.00164	0.050		NA	NA	
Compressive strength	Intercept	19957.4	<0.001	.997	38.93096	<0.001	0.9019	38.93096	<0.001	0.9019
	Temperature	455.036	<0.001	.958	-0.03205	<0.001		-0.03205	<0.001	
	Admixture	91.691	<0.001	.753	12.02744	<0.001		12.02744	<0.001	
	Temperature*Admixture	8.673	<0.001	.464	-0.01508	<0.001		-0.01508	<0.001	

Table 12 Post Hoc results of retarder

Parameters		Degree of temperature				Ratio of admixture			
		A (20°C)	B (100°C)	C (300°C)	D (600°C)	A (0%)	B (1%)	C (2%)	D (3%)
Unit weight	A		.982	.084	.038		.085	.128	NA
	B	.982		.182	.092	.085		.978	NA
	C	.084	.182		.0987	.128	.978		NA
	D	.038	.092	.987		NA	NA	NA	NA
Ultrasonic pulse velocity	A		.583	<0.001	<0.001		.567	<0.001	NA
	B	.583		<0.001	<0.001	.567		.006	NA
	C	<0.001	<0.001		<0.001	<0.001	.006		NA
	D	<0.001	<0.001	<0.001		NA	NA	NA	NA
Tensile strength	A		<0.001	<0.001	<0.001		<0.001	<0.001	NA
	B	<0.001		<0.001	<0.001	<0.001		<0.001	NA
	C	<0.001	<0.001		<0.001	<0.001	<0.001		NA
	D	<0.001	<0.001	<0.001		NA	NA	NA	NA
Compressive strength	A		<0.001	<0.001	<0.001		<0.001	<0.001	NA
	B	<0.001		<0.001	<0.001	<0.001		<0.001	NA
	C	<0.001	<0.001		<0.001	<0.001	<0.001		NA
	D	<0.001	<0.001	<0.001		NA	NA	NA	NA

100°C-600°C temperatures, and 0%-0.5% ratio. In pairwise comparisons of ultrasonic pulse velocity, while all the subgroups of degrees of temperature are significant for the difference between the means of ultrasonic pulse velocity except for 20°C 100°C, all the subgroups of ratios of admixture materials are significant except for 0%-0.5%.

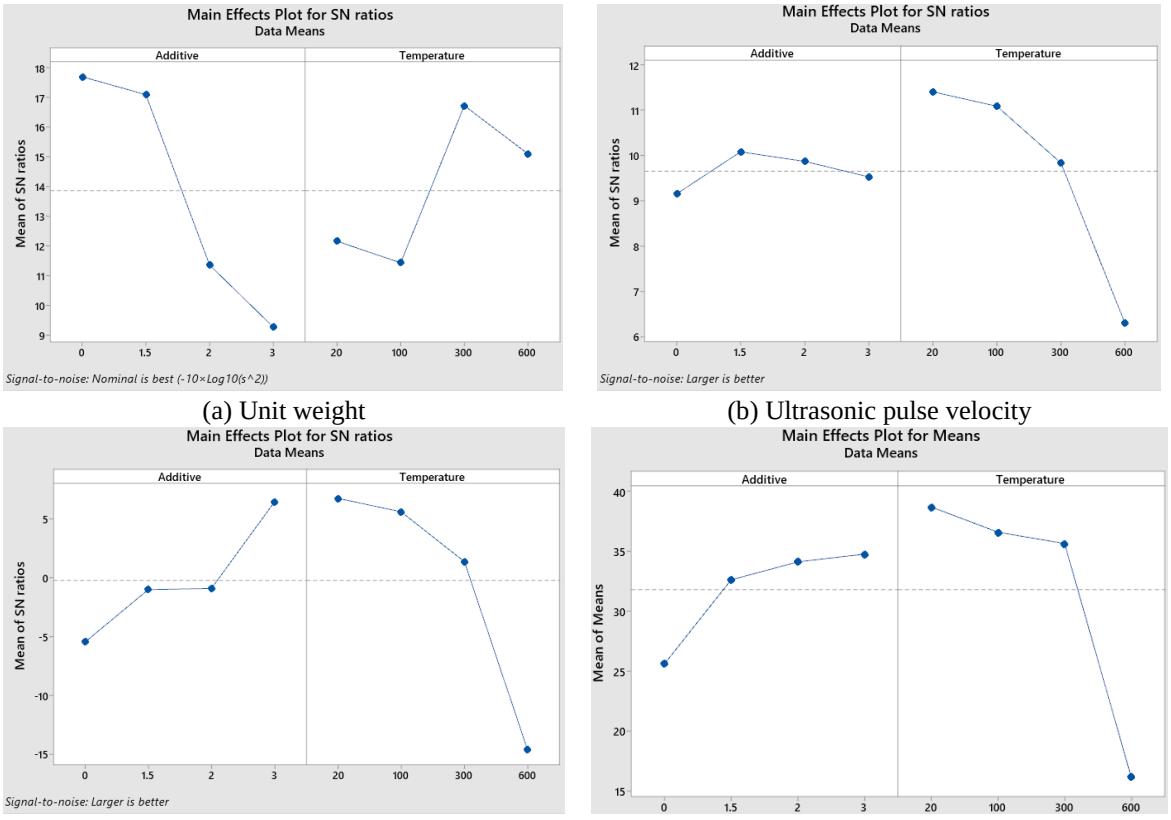
In pairwise comparisons of tensile strength, all the subgroups of degrees of temperature and all the subgroups of ratio of admixture materials are significant for the difference between the means. In pairwise comparisons of compressive strength, while all the subgroups of degrees of temperature are significant for the difference between the means of compressive strength, all the subgroups of ratios of admixture materials are significant. The results above are supported by Fig. 7, where some lines do not intersect each other. Results of Partial Eta Squared show that the effect of temperature is higher than admixture materials. Regression results are given in Table 11 for Retarder. The interaction coefficient is significant for ultrasonic pulse velocity and compressive strength. Furthermore, admixture ratios are not significant for tensile strength. The interaction coefficient has a positive effect on ultrasonic pulse velocity, but it has a negative effect on compressive strength. Adjusted R-squared values are high for ultrasonic pulse velocity and



(a) Unit weight (b) Ultrasonic pulse velocity

(c) Tensile strength (d) Compressive strength

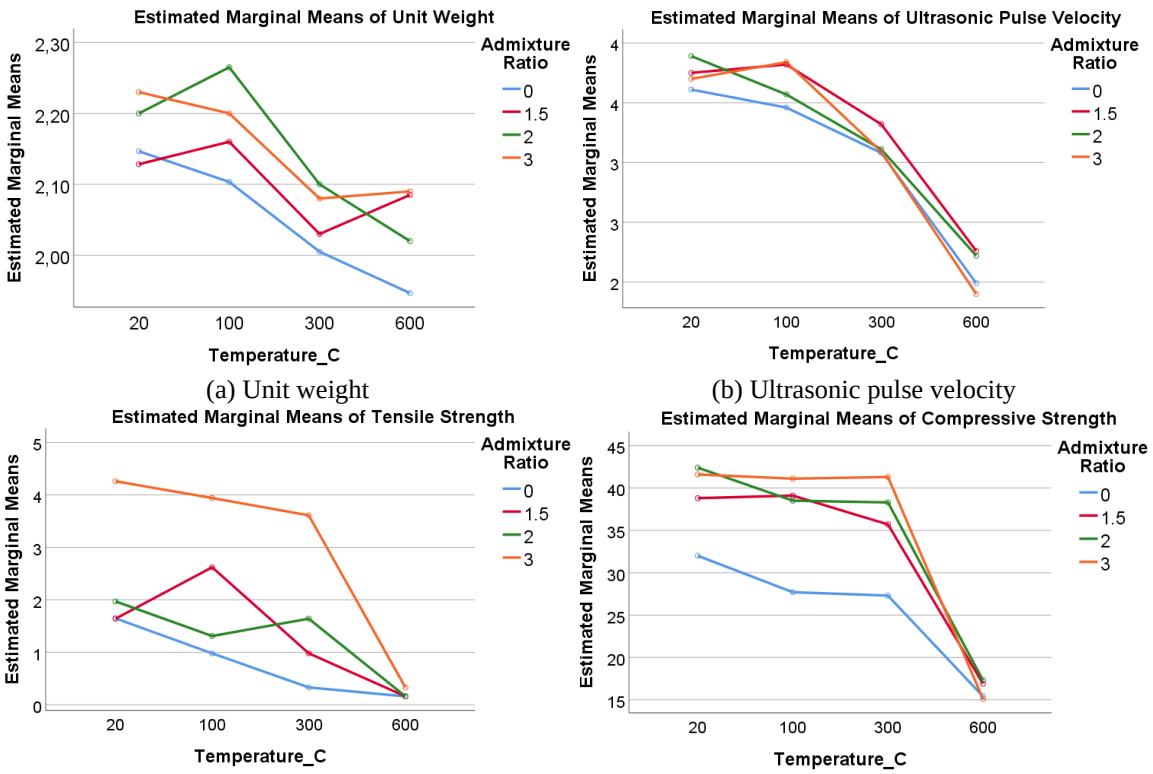
Fig. 8 Surface 3D plots for retarder



(a) Unit weight (b) Ultrasonic pulse velocity

(c) Tensile strength (d) Compressive strength

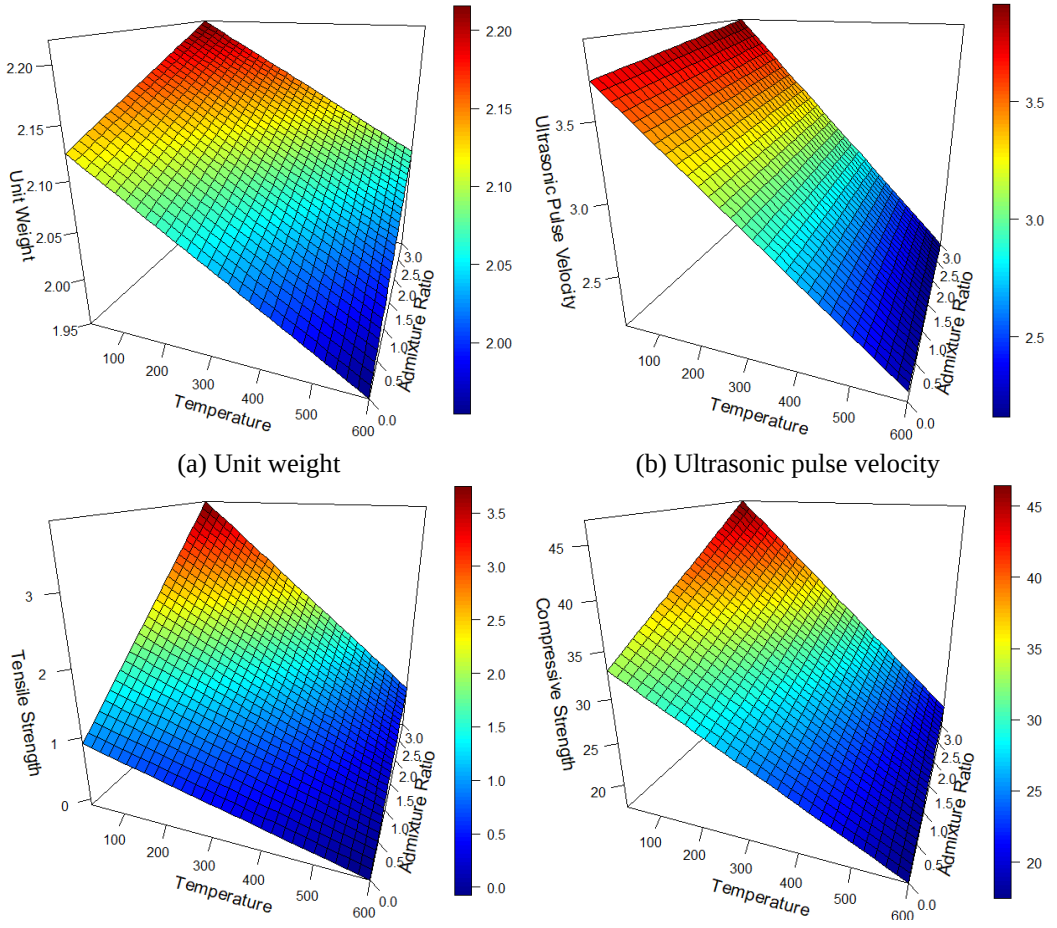
Fig. 9 Taguchi response plots for signal to noise ratios for accelerator



(a) Unit weight (b) Ultrasonic pulse velocity

(c) Tensile strength (d) Compressive strength

Fig. 10 Estimated marginal means plots for accelerator



(a) Unit weight (b) Ultrasonic pulse velocity

(c) Tensile strength (d) Compressive strength

Fig. 11 Surface 3D plots for accelerator

Table 13 Taguchi response table for signal to noise ratios for accelerator

	Factor	A	B	C	D	Delta	Rank
Unit weight	Temperature	12.165	11.438	16.723	15.102	5.285	2
	Admixture	17.696	17.092	11.365	9.276	8.420	1
Ultrasonic pulse velocity	Temperature	11.393	11.077	9.830	6.311	5.082	1
	Admixture	9.149	10.074	9.865	9.523	0.925	2
Tensile strength	Temperature	67.509	56.061	13.796	-145.944	213.453	1
	Admixture	-54.453	-0.9951	-0.8948	64.774	119.226	2
Compressive strength	Temperature	31.60	31.11	30.87	23.79	7.82	1
	Admixture	27.43	29.71	30.11	30.11	2.69	2

Table 14 ANOVA and regression results of accelerator

Dependent Parameters	Independent Parameters	ANOVA Results			Regression Results					
					Full Model			Significant Model		
		F	*P* value	Partial η^2	Coefficients	*P* value	R^2_{Adj}	Coefficients	*P* value	R^2_{Adj}
Unit weight	Intercept	6032.85	<0.001	.987	2.13100	6032.9	0.0497	2.18190	<0.001	0.0470
	Temperature	2.063	.112	.072	-0.00030	2.063		-0.00027	0.019	
	Admixture	.737	.533	.027	0 .03104	.737				
	Temperature*Admixture	.129	.999	.014	0.00002	.129				
Ultrasonic pulse velocity	Intercept	9171.56	<0.001	.991	3.78146	9171.6	0.7891	3.90647	<0.001	0.7879
	Temperature	132.594	<0.001	.833	-0.00265	132.59		-0.00292	<0.001	
	Admixture	2.598	.058	.089	0.07692	2.598				
	Temperature*Admixture	.900	.529	.092	-0.00016	.900				
Tensile strength	Intercept	92367.3	<0.001	.999	0.93478	92367.	0.6609	0.93478	<0.001	0.6609
	Temperature	8736.00	<0.001	.997	-0.00173	8736.0		-0.00173	<0.001	
	Admixture	8639.41	<0.001	.997	1.00877	8639.4		1.00877	<0.001	
	Temperature*Admixture	1167.55	<0.001	.992	-0.00127	1167.6		-0.00127	<0.001	
Compressive strength	Intercept	11356.4	<0.001	.993	33.59286	11356.	0.7939	33.59286	<0.001	0.7939
	Temperature	308.831	<0.001	.921	-0.027407	308.83		-0.027407	<0.001	
	Admixture	50.010	<0.001	.652	4.82589	50.010		4.82589	<0.001	
	Temperature*Admixture	5.859	<0.001	.397	-0.00643	5.859		-0.00643	0.002	

Table 15 Post Hoc results of accelerator

Parameters		Degree of temperature				Ratio of admixture			
		A (20°C)	B (100°C)	C (300°C)	D (600°C)	A (0%)	B (1%)	C (2%)	D (3%)
Unit weight	A		.999	.388	.266		.913	.600	.569
	B	.999		.347	.233	.913		.935	.919
	C	.388	.347		.995	.600	.935		.999
	D	.266	.233	.995		.569	.919	.999	
Ultrasonic pulse velocity	A		.898	<0.001	<0.001		.041	.310	.724
	B	.898		<0.001	<0.001	.041		.771	.352
	C	<0.001	<0.001		<0.001	.310	.771		.898
	D	<0.001	<0.001	<0.001		.724	.352	.898	
Tensile strength	A		<0.001	<0.001	<0.001		<0.001	<0.001	<0.001
	B	<0.001		<0.001	<0.001	<0.001		<0.001	<0.001
	C	<0.001	<0.001		<0.001	<0.001	<0.001		<0.001
	D	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	
Compressive strength	A		.069	.003	<0.001		<0.001	<0.001	<0.001
	B	.069		.675	<0.001	<0.001		.291	.060
	C	.003	.675		<0.001	<0.001	.291		.867
	D	<0.001	<0.001	. <0.001		<0.001	.060	.867	

compressive strength, but it is moderate for tensile strength and it is low for unit weight.

Surface plots are given in Fig. 8 respectively for retarder. As can be seen in the figures, varying degrees of temperature affect dependent variables more than admixture for ultrasonic pulse velocity, tensile strength, compressive strength, but admixture ratio has almost the same effect as temperature for unit weight. Using %1 retarder increases the value of compressive strength in elevated temperatures, but high value of tensile strength is obtained in low temperatures.

3.3 Accelerator

Taguchi response results for signal-to-noise ratios are given in Table 13 and Fig. 9. The results show that varying degrees of temperature affects mortar more than varying ratios of admixture materials except for unit weight. Using the setting accelerator additive in the mortar samples at a rate of 3% has a positive effect on the tensile and compressive strengths at 20°C. Elevated temperature has a negative effect on the mortar samples produced by using accelerator. The optimum degree of temperature is 20°C for ultrasonic pulse velocity, tensile strength, and compressive strength. On the other hand, the optimum ratio of accelerator is 3% for tensile strength and compressive strength.

As can be seen in Fig. 10, almost all the lines intersect each other, so there can be differences between the group means. While ultrasonic pulse velocity has almost approximate values up to 100°C in all admixture rates, compressive strength has approximate values up to 300°C except for 0% of ratio. In tensile strength, maximum change is seen at the 3% admixture ratio.

As can be seen in Table 14, there are statistically significant differences between some of the group means as determined by Factorial ANOVA (psig<0.05 and psig<0.1). Degree of temperature and ratio of admixture materials affect ultrasonic pulse velocity, tensile strength, and compressive strength. However, the interaction effect of temperature and admixture does not affect ultrasonic pulse velocity (psig=0.529>0.1). Unit weight is not significant, as well. Table 15 presents Post Hoc test results. In pairwise comparisons of unit weight, all the subgroup degrees of temperature and all the subgroup ratios of admixture materials are not significant, either. In pairwise comparisons of ultrasonic pulse velocity, all the subgroup degrees of temperature are significant for the difference between the means of ultrasonic pulse velocity, except for 20°C-100°C. In addition, among all the subgroup ratios of admixture materials of only 0%-1.5% is significant. In pairwise comparisons of tensile strength, all the subgroup degrees of temperature and all the subgroup ratios of admixture materials are significant for the difference between the means. In pairwise comparisons of compressive strength, while all the subgroup degrees of temperature are significant for the difference between the means of compressive strength except for 100°C-300°C, all the subgroup ratios of admixture materials are significant except for 1.5%-2% and 2%-3%. Results of Partial Eta Squared show that the effect of temperature is higher than admixture materials.

Regression results are given in Table 14 for accelerator. Admixture and interaction of temperature and admixture are not significant for unit weight and Ultrasonic pulse velocity. While admixture has a positive effect on tensile strength and compressive strength, interaction of temperature and admixture has a negative effect on tensile strength and compressive strength. Adjusted R-squared values are high for ultrasonic pulse velocity and compressive strength, but it is moderate for tensile strength and it is low for unit weight.

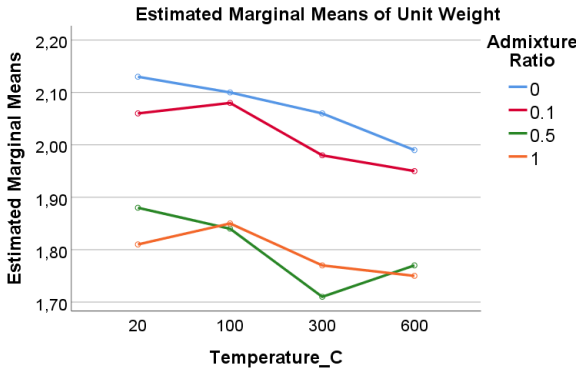
Surface plots are given in Fig. 11 respectively for accelerator mortar. As can be seen in the figures, degree of temperature affects dependent variable more than admixture ratio for ultrasonic pulse velocity. It is observed that using accelerator at high ratios performs best under lower temperatures. Using high ratio admixture gives good results.

3.4 Air entraining

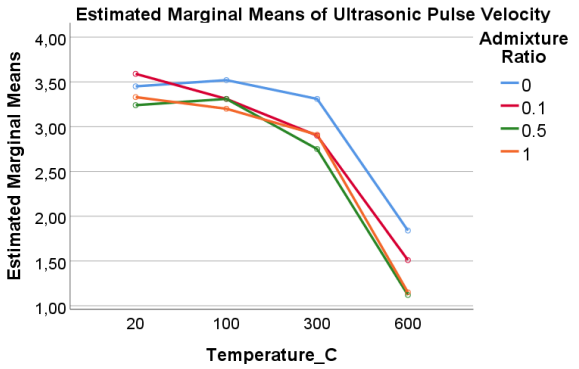
Taguchi response results for signal-to-noise ratios are given in Table 16 and Fig. 12. The results show that degree of temperature affects mortar more than ratio of admixture materials except for unit weight. While higher temperatures and higher ratios of admixture are optimum for unit weight, lower temperatures and minimum ratios of admixture are optimum for ultrasonic pulse velocity, tensile strength, and compressive strength. While lack of air entraining additives in mortar samples provides positive results in tensile and compressive strengths at 100°C, it provides the best values at 20°C in ultrasonic pulse velocity results. However, unit weight reaches maximum values at 100°C and 1% of admixtures.

As shown in Fig. 13, some lines intersect each other so there can be differences between some of the group means. In unit weight, admixtures of 0%-%0.1 and %0.5-1% provide similar results. In tensile strength, the maximum change is observed at 0% of admixture. According to the results of ultrasonic pulse velocity and tensile strength, the breakdown point is 300°C.

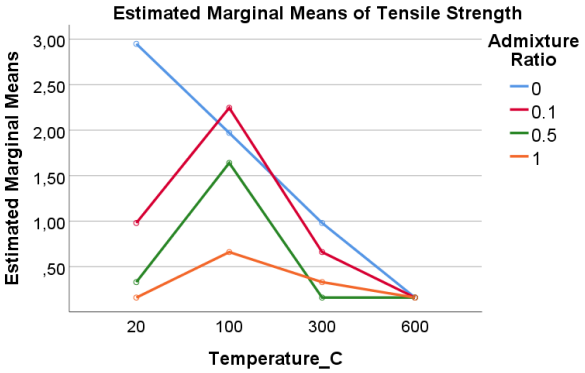
As can be seen in Table 17, there are statistically significant differences between all the group means for ultrasonic pulse velocity, tensile strength, and compressive strength. However, there is only one significant difference mean, which is admixture for unit weight. Table 18 presents Post Hoc test results. In pairwise comparisons of unit weight, there is no significant difference between the means of all the subgroups of degree of temperature. There is a significant difference between 0%-0.5%, 0%-1%, 0.1%-0.5% and 0.1%-1% ratios of admixture materials. In pairwise comparisons of ultrasonic pulse velocity, all the subgroup degrees of temperature are significant for the difference between the means of Ultrasonic pulse velocity except for 20°C-100°C and all the subgroups of ratios of admixture materials are significant except for 0.5%-1%. In pairwise comparisons of tensile strength, all the subgroup degrees of temperature and all the subgroup ratios of admixture materials are significant for the difference



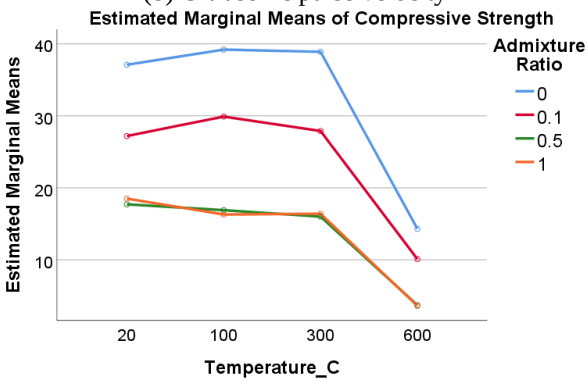
(a) Unit weight



(b) Ultrasonic pulse velocity

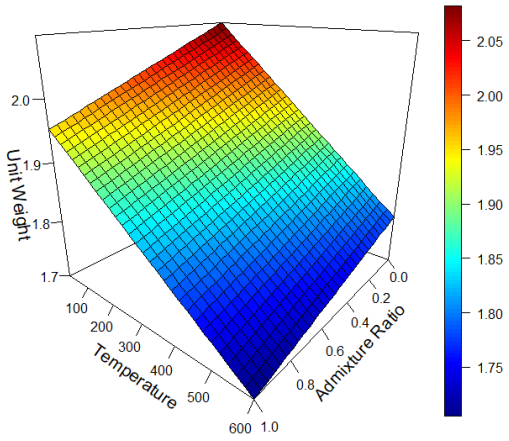


(c) Tensile strength

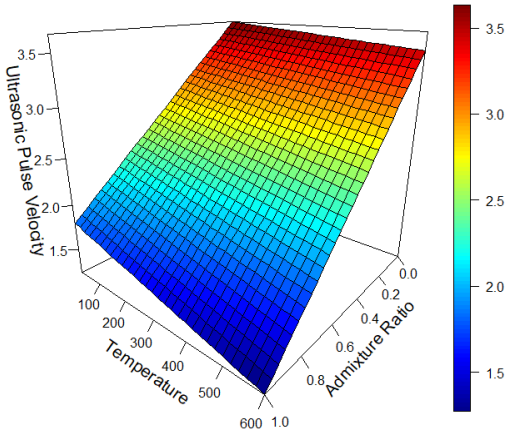


(d) Compressive strength

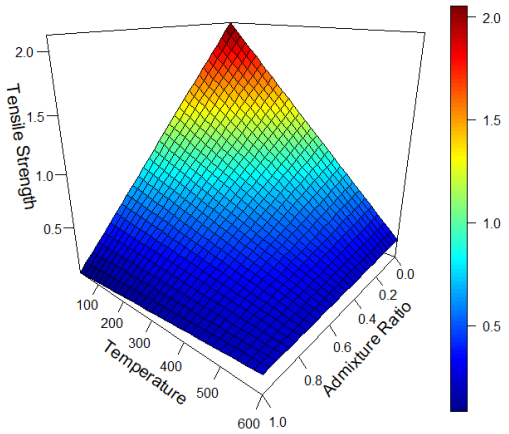
Fig. 13 Estimated marginal means plots for Air entraining



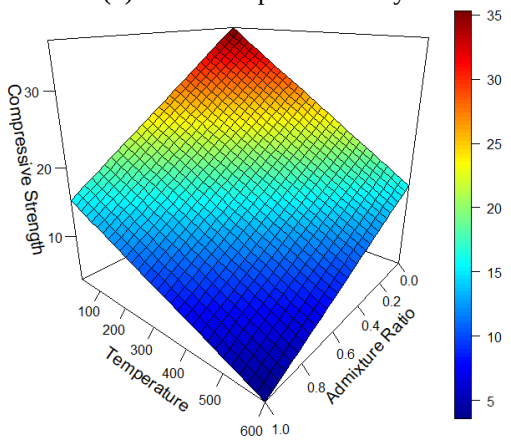
(a) Unit weight



(b) Ultrasonic pulse velocity



(c) Tensile strength



(d) Compressive strength

Fig. 14 Surface 3D plots for air entraining

Table 16 Taguchi response table for signal to noise ratios for air entraining

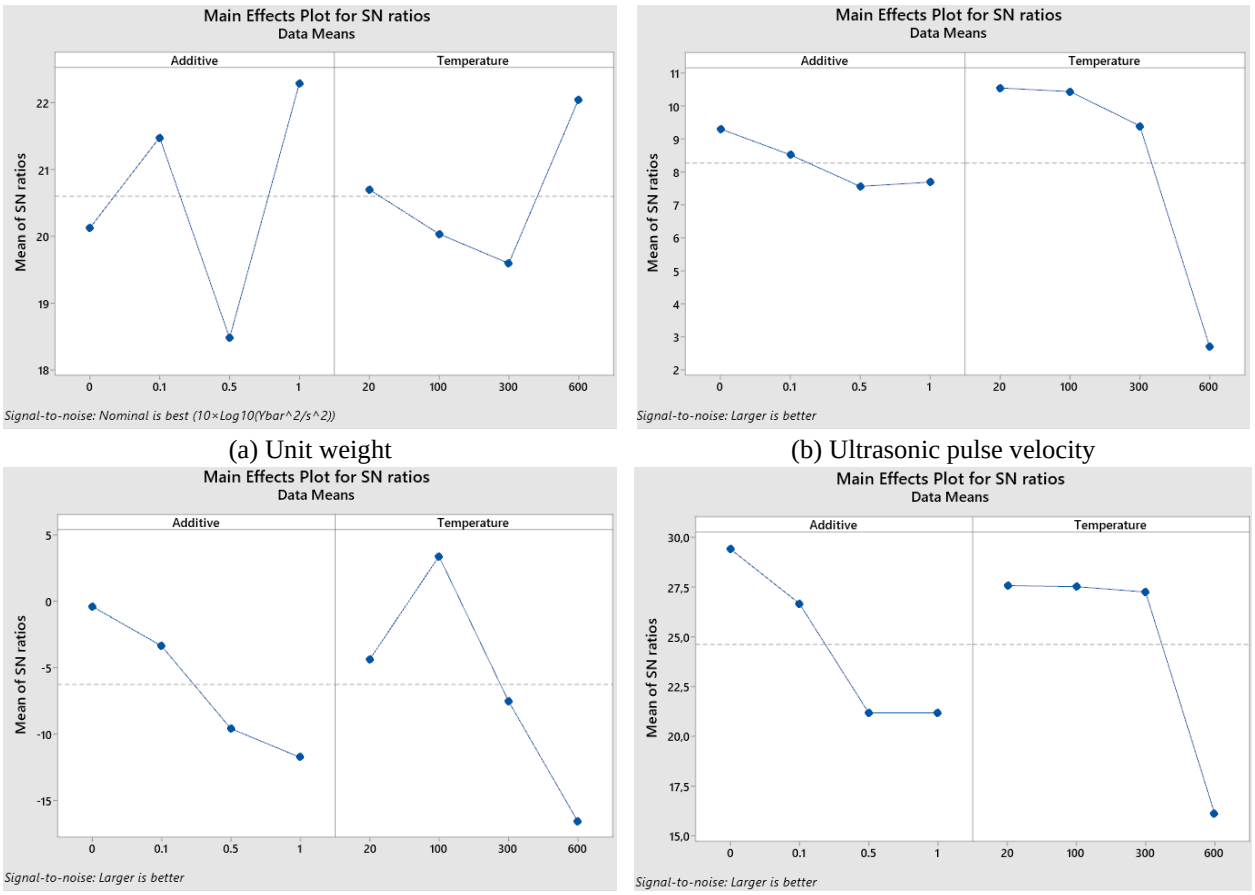
	Factor	A	B	C	D	Delta	Rank
Unit weight	Temperature	20.70	20.04	19.60	22.05	2.45	2
	Admixture	20.12	21.48	18.48	22.30	3.81	1
Ultrasonic pulse velocity	Temperature	10.538	10.428	9.393	2.710	7.827	1
	Admixture	9.303	8.517	7.560	7.689	1.743	2
Tensile strength	Temperature	-4.399	3.386	-7.500	-16.557	19.943	1
	Admixture	-0.385	-3.354	-9.579	-11.743	11.358	2
Compressive strength	Temperature	27.57	57.51	27.24	16.13	11.44	1
	Admixture	29.42	26.67	21.18	21.18	8.23	2

Table 17 ANOVA and regression results of air entraining

Dependent Parameters	Independent Parameters	ANOVA Results			Regression Results					
					Full Model			Significant Model		
		F	*P* value	Partial η^2	Coefficients	*P* value	R^2_{Adj}	Coefficients	*P* value	R^2_{Adj}
Unit weight	Intercept	8757.33	<0.001	.991	2.14700	<0.001	0.2565	2.08510	<0.001	0.2633
	Temperature	1.856	.144	.065	-0.00020	0.072		-0.00020	0.029	
	Admixture	12.272	<0.001	.315	-0.10830	<0.001		-0.28430	<0.001	
	Temperature*Admixture	.133	.999	.015	0.00003	0.701				
Ultrasonic pulse velocity	Intercept	18443.3	<0.001	.996	3.76266	<0.001	0.8603	3.80273	<0.001	0.8565
	Temperature	522.234	<0.001	.951	-0.00297	<0.001		-0.00349	<0.001	
	Admixture	22.495	<0.001	.458	-0.05921	0.198		-0.34073	<0.001	
	Temperature*Admixture	3.156	.003	.262	-0.00032	0.064				
Tensile strength	Intercept	28620.4	<0.001	.997	2.19080	<0.001	0.6753	2.19080	<0.001	0.6753
	Temperature	4057.86	<0.001	.993	-0.00357	<0.001		-0.00357	<0.001	
	Admixture	2658.15	<0.001	.990	-1.95807	<0.001		-1.95807	<0.001	
	Temperature*Admixture	939.725	<0.001	.991	0.00353	<0.001		0.00353	<0.001	
Compressive strength	Intercept	19969.4	<0.001	.996	36.70550	<0.001	0.7316	36.70550	<0.001	0.7316
	Temperature	854.152	<0.001	.970	-0.03558	<0.001		-0.03558	<0.001	
	Admixture	938.746	<0.001	.972	-20.46507	<0.001		-20.46507	<0.001	
	Temperature*Admixture	21.991	<0.001	.712	0.01381	0.042		0.01381	0.042	

Table 18 Post Hoc results of air entraining

Parameters		Degree of temperature				Ratio of admixture			
		A (20°C)	B (100°C)	C (300°C)	D (600°C)	A (0%)	B (1%)	C (2%)	D (3%)
Unit weight	A		.999	.413	.277		.803	<0.001	<0.001
	B	.999		.438	.297	.803		.002	.001
	C	.413	.438		.994	<0.001	.002		.999
	D	.277	.297	.994		<0.001	.001	.999	
Ultrasonic pulse velocity	A		.649	<0.001	<0.001		.004	<0.001	<0.001
	B	.649		<0.001	<0.001	.004		.001	.013
	C	<0.001	<0.001		<0.001	<0.001	.001		.883
	D	<0.001	<0.001	<0.001		<0.001	.013	.883	
Tensile strength	A		<0.001	<0.001	<0.001		<0.001	<0.001	<0.001
	B	<0.001		<0.001	<0.001	<0.001		<0.001	<0.001
	C	<0.001	<0.001		<0.001	<0.001	<0.001		<0.001
	D	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	
Compressive strength	A		.708	.861	<0.001		<0.001	<0.001	<0.001
	B	.708		.255	<0.001	<0.001		<0.001	<0.001
	C	.861	.255		<0.001	<0.001	<0.001		.991
	D	<0.001	<0.001	<0.001		<0.001	<0.001	.991	



(a) Unit weight (b) Ultrasonic pulse velocity

(c) Tensile strength (d) Compressive strength

Fig. 12 Taguchi response plots for signal to noise ratios for air entraining

between the means. In pairwise comparisons of compressive strength, all the subgroups degrees of temperature are significant for the difference between the means of compressive strength except for 20°C-100°C, 20°C-300°C, 100°C-300°C, and all the subgroups ratios of admixture materials are significant except for 0.5%-1%. Results of Partial Eta Squared show that the effect of temperature is higher than admixture materials for ultrasonic pulse velocity and Tensile strength, but the effect of temperature is lower than admixture materials for compressive strength.

Regression results are given in Table 17 for air entraining and R^2 values are high for Ultrasonic pulse velocity, tensile strength, and compressive strength. The interaction coefficient is significant for tensile strength and compressive strength, but it is not for unit weight and Ultrasonic pulse velocity. Admixture increasing with high temperature affects ultrasonic pulse velocity negatively, which shows that air void ratio increases depending on high temperature. Adjusted R-squared values are high for ultrasonic pulse velocity and compressive strength, but it is moderate for tensile strength and it is low for unit weight.

Surface plots are given in Fig. 14 respectively for air entraining. As can be seen in the figure, the best results are observed at lower temperatures and minimum ratios of admixtures. However, using air entraining admixture is essential for obtaining watertight mortar. In addition, using air entraining admixture at high temperatures has a negative effect on the results of all the experiments.

4. Conclusions

Our results suggest that varying degrees of temperature and ratios of admixture have a significant effect on the experiments. In other words, unit weight, ultrasonic pulse velocity, tensile strength, compressive strength values are affected by different degrees of temperature and varying ratios of admixture. In this study, their optimum values are obtained for mortar.

Considering the results of plasticizer, when plasticizer is used, there is an inverse relationship with temperature in unit weight, ultrasonic pulse velocity, and compressive strength while tensile strength is not affected dramatically by temperature. While ultrasonic pulse velocity and compressive strength do not show too much change up to 300°C, they do after 300°C by decreasing seriously. Tensile strength provides approximate values at 20°C and 600°C when 3% admixture is used, while changes are observed when 0% is used. Considering regression coefficient, while the effects of temperature and admixture are negative, their interaction effects are positive. This explains why there is no great difference at 20°C and 600°C depending on increasing temperature at 3% admixture.

According to retarder results, using retarder admixtures over 1% causes so much distortion in experiment that data cannot be analysed. The ultrasonic pulse velocity for all the ratios of admixture provides approximate results between 20°C and 100°C, while compressive strengths yield similar results between 20°C and 300°C. Although the admixture ratio does not have a significant effect on the tensile strength according to the regression results, it has a significant effect on the differences between the group means according to ANOVA. The maximum change in unit weight is seen when 0.5% admixture ratio used.

With regard to results of accelerator, ultrasonic pulse velocity and compressive strength values decrease severely after 300°C. Tensile strength provides optimum value at lower temperatures and higher ratio of admixture. In tensile and compressive strength, admixture has a positive effect while temperature has a negative effect. However, interaction effect of temperature and admixture has a negative effect. This explains why lower temperatures and higher ratios of admixture are optimum for tensile and compressive strength. However, it cannot be observed that admixture has a significant effect on unit weight and ultrasonic pulse velocity.

With respect to results of air entraining, similar values are obtained for between 0%-0.1% and 0.5%-1% ratios of admixtures. Tensile strength does not differ much at 20°C and 600°C temperatures. Compressive strength provides approximate outcomes at 0.5% and 1% ratios of admixtures. Temperature and admixture have a negative effect for all the criteria while their interaction effects have a significant and positive only on tensile and compressive strength. Admixture at all the degrees of temperature negatively affects ultrasonic pulse velocity, tensile strength, and compressive strength.

In summary, these results indicate that ultrasonic pulse velocity, tensile and compressive strength values are optimum at only 20°C and 100°C. Higher ratios of admixtures provide better results for plasticizer, retarder, and accelerator while it provides better results, especially in tensile and compressive strength for air entraining.

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References

Binici, H., Temiz, H., Sevinc, A.H., Eken, M., Kara, M. and Sayir, Z. (2013), "Investigation of aluminium sawdust, pumice concrete and gas concrete powder incorporating concretes under high temperature", *Elect. J. Constr. Tech.*, **9**(1), 1-15. (in Turkish)

Bozkurt, N. (2013), "The effect of high temperature on concrete containing perlite powder", *SDU Int. J. Tech. Sci.*, **5**(1), 87-93.

Canbaz, M., Topçu, I.B. and Atesin, Ö. (2016), "Effect of admixture ratio and aggregate type on self-leveling screed properties", *Constr. Build. Mater.*, **116**, 321-325. https://doi.org/10.1016/j.conbuildmat.2016.04.084.

Chang, S.C., Wang, C.C. and Wang, H.Y. (2018), "Study on the engineering and electricity properties of cement mortar added with waste LCD glass and piezoelectric powders", *Comput. Concrete*, **21**(3), 311-319. https://doi.org/10.12989/cac.2018.21.3.311.

Chatterjee, A. and Das, D. (2013), "Assessing flow response of self-compacting mortar by taguchi method and Anova interaction", *Mater. Res.*, **16**(5), 1084-1091.

Cuenca-Moyano, G.M., Martín-Pascual, J., Martín-Morales, M., Valverde-Palacios, I. and Zamorano, M. (2020), "Effects of water to cement ratio, recycled fine aggregate and air entraining/plasticizer admixture on masonry mortar properties", *Constr. Build. Mater.*, **230**, 1-18. https://doi.org/10.1016/j.conbuildmat.2019.116929.

Cui, W., Huang, J., Song, H. and Xiao, M. (2017), "Development of two new anti-washout grouting materials using multi-way ANOVA in conjunction with grey relational analysis", *Constr. Build. Mater.*, **156**, 184-198. https://doi.org/10.1016/j.conbuildmat.2017.08.126.

Devi, K., Saini, B. and Aggarwal, P. (2019), "Utilization of Kota stone slurry powder and accelerators in concrete", *Comput. Concrete*, **23**(3), 189-201. https://doi.org/10.12989/cac.2019.23.3.189.

Erdal, H., Erdal, M., Simsek, O. and Erdal, H.İ. (2018), "Prediction of concrete compressive strength using non-destructive test results", *Comput. Concrete*, **21**(4), 407-417. https://doi.org/10.12989/cac.2018.21.4.407.

Kaya, T. and Yazicioglu, S. (2015a), "Effect of high temperature on mechanical and physical properties of mortars with calcined bentonite additive", *BEU J. Sci.*, **4**(2), 150-160. (in Turkish)

Kaya, T. and Yazicioglu, S. (2015b), "High Temperature influence on the mechanical properties of concrete which covered with different type plasters", *Bilecik Şeyh Edebali Univ. J. Sci.*, **2**(2), 43-52.

Kaya, T., Karakurt, C. and Dumangoz, M. (2014), "Effect of high temperature on porosity and compressive strength of mineral additive used self-compacting concretes", *Bilecik Şeyh Edebali Univ. J. Sci.*, **1**(1), 39-44. (in Turkish)

Kivak, T. (2014), "Optimization of surface roughness and flank wear using the Taguchi method in milling of Hadfield steel with PVD and CVD coated inserts", *Meas.*, **50**, 19-28. https://doi.org/10.1016/j.measurement.2013.12.017.

Kızılkanat, A.B. and Yüzer, N. (2008), "Compressive strength-color change relationship in mortars subjected to high temperatures", *Tech. J. Turkish Chamber Civil Eng.*, **289**, 4381-4392. (in Turkish)

Ou, Y.C., Kurniawan, R.A., Kurniawan, D.P. and Nguyen, N.D. (2012), "Plastic hinge length of circular reinforced concrete columns", *Comput. Concrete*, **10**(6), 663-681. https://doi.org/10.12989/cac.2012.10.6.663.

Peng, S.S., Wang, E.H., Wang, H.Y. and Chou, Y.T. (2012), "Quality assessment of high performance concrete using digitized image elements", *Comput. Concrete*, **10**(4), 409-417. https://doi.org/10.12989/cac.2012.10.4.409.

Ramezanianpour, A.A., Kazemian, A., Radaei, E., AzariJafari, H. and Moghaddam, M.A. (2014), "Influence of Iranian low-reactivity GGBFS on the properties of mortars and concretes by Taguchi method", *Comput. Concrete*, **13**(4), 423-436. https://doi.org/10.12989/cac.2014.13.4.423.

Saridemir, M. (2017), "Modelling the flexural strength of mortars containing different mineral admixtures via GEP and RA", *Comput. Concrete*, **19**(6), 717-724. https://doi.org/10.12989/cac.2017.19.6.717.

Schackow, A., Ferrari, A.K., Effting, C., Alves, V.O. and Gomes, I.R. (2019), "Stabilized mortar with air incorporator agent and plasticizer set retarder: Performance measurement", *Revista IBRACON de Estruturas e Materiais*, **12**(6), 1248-1259. https://doi.org/10.1590/S1983-41952019000600002.

Senoglu, B. and Acitas, S. (2011), "Statistical experiment design: Fixed effect models", Nobel Publication and Distribution, Ankara, Turkey. (in Turkish)

Sevil, T., Baran, M., Bilir, T. and Canbay, E. (2011), "Use of steel fiber reinforced mortar for seismic strengthening", *Constr. Build. Mater.*, **25**(2), 892-899. https://doi.org/10.1016/j.conbuildmat.2010.06.096.

Subasi, S., Isbilir, B. and Ercan, I. (2011), "Effect of high temperature on mechanical properties of cement samples with fly ash substitution", *J. Polytech.*, **14**(2), 141-148.

Tang, C.W. (2010), "Hydration properties of cement pastes containing high-volume mineral admixtures", *Comput. Concrete*, **7**(1), 17-38. https://doi.org/10.12989/cac.2010.7.1.017.

Tang, C.W. (2014), "Producing synthetic lightweight aggregates by treating waste TFT-LCD glass powder and reservoir sediments", *Comput. Concrete*, **13**(3), 325-342. https://doi.org/10.12989/cac.2014.13.3.325.

Tanyildizi, H. and Sahin, M. (2015), "Application of Taguchi method for optimization of concrete strengthened with polymer after high temperature", *Constr. Build. Mater.*, **79**, 97-103. https://doi.org/10.1016/j.conbuildmat.2015.01.039.

Teimortashlu, E., Dehestani, M. and Jalal, M. (2018), "Application of Taguchi method for compressive strength optimization of tertiary blended self-compacting mortar", *Constr. Build. Mater.*, **190**, 1182-1191. https://doi.org/10.1016/j.conbuildmat.2018.09.165.

Topcu, İ.B. (1996), "Effect of plasticizer and frost resistance admixtures on concrete properties", *Proceedings of National Concrete Congress*, 45-54, İstanbul, Turkey. (in Turkish)

Topcu, I.B., Canbaz, M. and Karakurt, C. (2006), "Utilization of chemical admixtures for concrete production", *J. Polytech.*, **9**(1), 59-63. (in Turkish)

TS 196-1. (2016), "Methods of testing cement-Part 1: Determination of strength", TSE, Ankara, Turkey.

Unverdi, A. (2021), "Statistical modelling of mechanical properties of mortars with chemical admixtures under high temperature and fire effect", Ph.D. Dissertation of Philosophy, Eskisehir Osmangazi University, Eskisehir, Turkey.

Yeh, I.C. (2008), "Modeling slump of concrete with fly ash and superplasticizer", *Comput. Concrete*, **5**(6), 559-572. https://doi.org/10.12989/cac.2008.5.6.559.

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