ORIGINAL RESEARCH

Variations in the Compressive Strength of a Die Stone with Three Different Sulfates at Eight Different Concentrations: An *In Vitro* Study

Rajesh Vyas[1], Sunil K Vaddamanu[2], Vishwanath Gurumurthy[3], Mohamed S Kuruniyan[4], Syed A Quadri[5], Masroor A Kanji[6]

Abstract

Aim: The present study aimed to evaluate the alteration in the compressive strength (CS) of the die stone with three different sulfate salt additives, each at eight various concentrations.

Materials and methods: The specimens were prepared at specific dimensions (length: 2.5 cm and diameter: 2.5 cm) divided into three test groups based on the type of sulfate additives used [potassium sulfate (K_2SO_4), zinc sulfate ($ZnSO_4 \cdot H_2O$), and manganese sulfate ($MnSO_4 \cdot H_2O$)] and one control group, without any additives. Again, each group was divided into eight subgroups based on concentration of sulfates (ranging from 0.2% to 4%). A total of 375 specimens were tested. CS (in MPa) was evaluated after 72 hours of drying time, using an universal testing machine.

Statistical analysis: A one-way analysis of variance (ANOVA) was used for intergroup comparisons. Individual comparisons were done using the *post hoc* Tukey HSD analysis.

Results: All the three additives at all the concentrations have shown an inferior resistance to compressive forces when compared to the standard specimen. However, the least mean CS was observed at 0.8% of $MnSO_4$ (10.95 MPa) and the highest was at 1% K_2SO_4 (25.28%). A highly significant difference ($p < 0.001$) was observed among the concentrations in all the three groups (K_2SO_4, $MnSO_4$, and $ZnSO_4$ groups) and F values were derived as 69.84, 24.29, and 130.52, respectively. At each concentration, comparisons between the groups have shown a significant difference ($p < 0.05$) at almost all concentrations.

Conclusion: The CS of die stone is shown to be decreased with an increase in all three types of sulfate additives when compared to the control specimen.

Clinical significance: Die stone is an often used gypsum material in the field of dentistry. Compressive strength of the die stone is crucial in prosthetic dentistry; chemical additives such as sulfate salts may increase the CS such that the die stone can withstand clinical and laboratory handling forces.

Keywords: Compressive strength, Die stone, Sulfate.

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Introduction

Gypsum is mainly present in a dihydrate (calcium sulfate dihydrate, $CaSO_4 \cdot 2H_2O$) form and available as gypsum rocks.[1] Owing to a vast variety of applications in medical and dental fields, studies on gypsum products (GPs) have been conducted extensively in the last two centuries by many authors.[2–4] Lavoisier, in 1765, began the research on gypsum products and explained the phenomenon of crystallization of the fire-treated gypsum product when it is rehydrated.[5] With slight modifications, GPs are serving adequately in the dental field, particularly in prosthodontics.[3] Currently, using gypsum products are mostly hemihydrates variations (calcium sulfate hemihydrate, $CaSO_4 \cdot 1/2H_2O$) of calcium sulfate di-hydrate, formed after controlled heating. They are in a powder form and hardens by crystallization when mixed with water.[6]

Compressive strength (CS) or crushing strength GPs, particularly, for dental stone is crucial when used for casts or molds. An inadequate CS may lead to fractures during laboratory and clinical handling.[7,8] Dental stone consists of inherent crystal properties (such as regularly shaped, dense, less porous, and cuboidal crystals), which increase the CS of dental stone. Alteration in mixing time,[9] adding gypsum hardening solutions,[10] dispersing solutions,[11] microcrystalline additives,[11] cyanoacrylates,[12] gum oxides and gum Arabic,[10,11] pulverised plaster,[13] cured resin,[13] and glass fibers;[14] substitution of gauging water with hypochlorite additives[15–17] and microwave-oven-heated hardening[13,18–21] were tried and proposed to increase the CS of the stone. Decreased microporosity of dental stone after setting also increases the CS.[22]

Addition of salts to test the alterations in the CS of dental stone was recorded.[23] Addition of sulfates (for instance, K_2SO_4) forms "syngenite" (a complex compound of $CaSO_4$ and K_2SO_4) in the center of the crystallised nuclei, which is responsible for the formation of further spherulites and maturation of the crystals. Formation of syngenite improves the compressive strength of GPs than the spherulite with

[1–6]Department of Dental Technology, College of Applied Medical Sciences, King Khalid University, Abha, Kingdom of Saudi Arabia

Corresponding Author: Sunil K Vaddamanu, Department of Dental Technology, College of Applied Medical Sciences, King Khalid University, Abha, Kingdom of Saudi Arabia, Phone: +966 5959220377, e-mail: snu@kku.edu.sa

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only $CaSO_4$.[24–26] Both 1-hour compressive strength and 24-hours CSs were increased at almost all concentrations of K_2SO_4.[26] However, the evidence is scarce in estimating the CS type 4 gypsum product (die stone) with different sulfates and at various concentrations.

This study hypothesized that an increase in the CS of diestone with sulfate salts as additives and a further rise in the CS with a rise in the concentrations of the additives. Accordingly, the aim of the present study was to evaluate the variations in the CS of die stone with three different sulfate salt additives at eight various concentrations.

Materials and Methods

Study Design

This is an *in vitro* study conducted at the Rajasthan Dental College, Jaipur, India and it was registered as a PhD thesis in Maharaja Vinayak Global University, India. The study was started after obtaining Institutional review board approval. According to ADA specification no 25, research was carried out in an environment with the temperature and relative humidity, maintained at 25 ± 2°C and 50 ± 10, respectively.[27]

Materials and Equipment

A die stone (KALROCK Kalabhai Pvt Ltd, Art-21112) and three different sulfate additives (Table 1) are available in the Indian market was used. A universal testing machine (W & T Ltd, Brimingham No: E—58601) (Fig. 1) was used to measure the CS. Sandpaper (Numbers 100, John Oakey & Mohan limited, Delhi, India) was used to trim the excess material from the samples.

Preparation of Additives at Various Concentrations

Each of the three additives was diluted at eight different concentrations by mixing 100 mL of distilled water to preweighed additive depending on the concentrations required. Prepared concentrations of additives were 0.2%, 0.4%, 0.6%, 0.8%, 1%, 2%, 3%, and 4%.

Table 1: Type of additives and their information

S. no.	*Additive name*	*Manufacturer's name*	*Batch no.*
1	K_7SO_4 potassium sulfate	Himedia	3-0862
2	$ZnSO_4{\cdot}H_2O$ zinc sulfate	Himedia	3-1715
3	$MnSO_4{\cdot}H_2O$ manganese sulfate	E-Merek	LB963

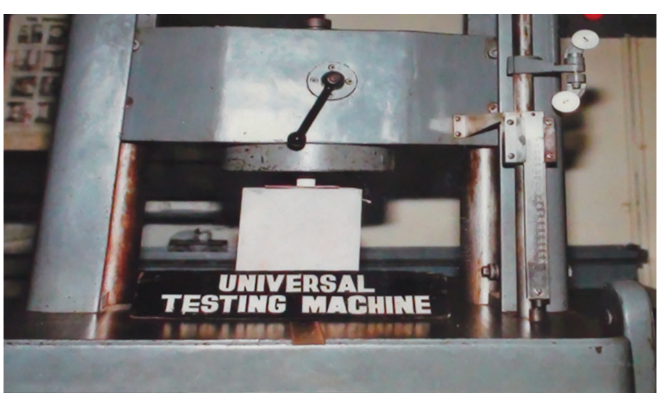

Fig. 1: Universal testing machine used to test the compressive strength

Preparation of the Mold and the Specimens

Cylindrical plastic molds with 4-cm height and 2-cm diameter dimensions were selected to prepare the specimens (Fig. 2). Uniformity of the material was assessed by thorough mixing. A required amount (30 g) of the die stone material was weighed with electronic balance and mixed at a W/P ratio of 0.33 (according to manufacturer specifications) with distilled water which already contains specific concentration of additive. The mixture was then hand stirred till the uniformity is achieved, then poured into a mold under vibration. The material was allowed to set for 24 hours and removed from the mold. Specimens were kept in storage at room temperature for 72 more hours before checking for dry strength. Oversized-specimens were trimmed with the sandpaper. Samples were divided into three test groups and one control group based on the type of additive used: test 1 [potassium sulfate (K_2SO_4)], test 2 [(manganese sulfate ($MnSO_4{\cdot}H_2O$)], test 3 [zinc sulfate ($ZnSO_4$)], and the control group (without any additive). The test groups were again divided into eight subgroups based on the concentrations of the additives prepared (0.2%, 0.4%, 0.6%, 0.8%, 1%, 2%, 3%, and 4%) (Table 1). A total of 375 specimens were tested [15 samples for each concentration in all the three test groups ($15 \times 8 \times 3 = 360$) and 15 samples for the control group]. Standard specimens were prepared without any additives and mean CS of these specimens was taken as reference value.

Measuring Compressive Strength

Compressive strength was evaluated for each specimen by using a universal testing machine. The load was progressively applied on the specimen by the automatic machine till the specimen is fractured. Breaking load for each sample was calculated. Strength was measured in megapascal (MPa).

Statistical Analysis

One-way analysis of variance (ANOVA) was used for intergroup comparisons. Individual comparisons were done using the *post hoc* Tukey HSD analysis. The analysis was done with the help of SPSS (version 20.0) software. $p < 0.05$ was taken as statistically significant.

Fig. 2: Prepared specimen samples

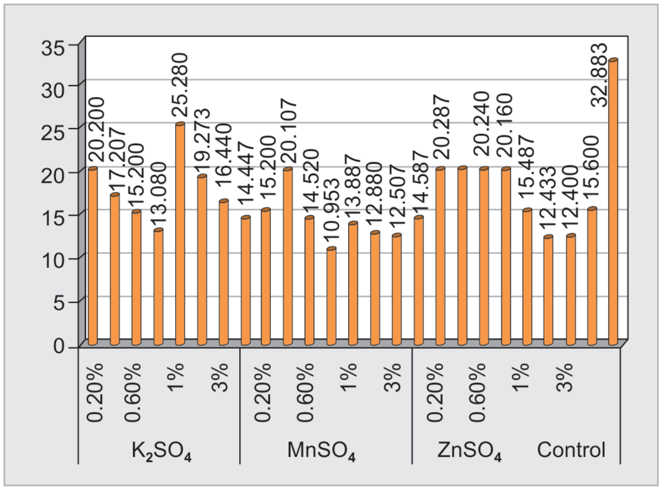

Fig. 3: Comparisons of CS of die stone with various sulfate additives at eight different concentrations

Results

Description of mean CS of the die stone at different concentrations of the three additives is shown in Figure 3. Mean CS of the standard specimens was 32.88 MPa. All the three additives at all the concentrations have shown an inferior resistance to compressive forces when compared to the standard specimen. However, the least mean CS was observed at 0.8% of $MnSO_4$ (10.95 MPa) and the highest was at 1% K_2SO_4 (25.28%). With the one-way ANOVA (analysis of variance), a highly significant difference ($p < 0.001$) was observed among the concentrations in all the three groups (K_2SO_4, $MnSO_4$, and $ZnSO_4$ groups) and F values were derived as 69.84, 24.29, and 130.52 respectively (Table 2). Similarly, One-way ANOVA among the groups at each concentration showed a highly significant difference at all the concentrations (Table 3).

At each concentration, comparisons between the groups using *post hoc* Tukey HSD analysis (Table 2) have shown a significant difference ($p < 0.05$) at almost all concentrations. Some areas—particularly, comparisons between $MnSO_4$ and $ZnSO_4$—have not shown a significant difference in many concentrations. Similarly, comparisons between the concentrations using *post hoc* Tukey HSD have not shown any significant pattern with a concentration change in all the three groups (Table 4).

Discussion

Many studies have been conducted to modify GPs to arrive at desirable physical properties. Specifically, the improvement in CS is proposed to be mainly due to the dense packing of the crystals.[13,14]

Very limited evidence is available on the effects of sulfate additives on CS of die stone. Shen et al.[26] used K_2SO_4 at eight different concentrations and $CaSO_4 \cdot 1/2H_2O$ as additives and

Table 2: One-way ANOVA test showing the comparison among the concentrations in all the three groups

Group	*Concentration (%)*	*n*	*Mean*	*SD*	*p value*
K_2SO_4	0.20	15	20.200	2.0071	$F = 69.837$; $p < 0.001$; highly significant
	0.40	15	17.207	1.4992	
	0.60	15	15.200	2.1320	
	0.80	15	13.080	0.9900	
	1	15	25.280	1.4097	
	2	15	19.273	1.5854	
	3	15	16.440	2.2702	
	4	15	14.447	2.1453	
	Total	120	17.641	4.0555	
$MnSO_4$	0.20	15	15.200	1.4352	$F = 24.291$; $p < 0.001$; highly significant
	0.40	15	20.107	2.6047	
	0.60	15	14.520	1.7957	
	0.80	15	10.953	1.3032	
	1	15	13.887	1.3255	
	2	15	12.880	1.4418	
	3	15	12.507	1.7637	
	4	15	14.587	3.9315	
	Total	120	14.330	3.2735	
$ZnSO_4$	0.20	15	20.287	1.1482	$F = 130.524$; $p < 0.001$; highly significant
	0.40	15	20.240	1.0913	
	0.60	15	20.207	1.3225	
	0.80	15	20.160	1.1356	
	1	15	15.487	1.1673	
	2	15	12.433	1.5586	
	3	15	12.400	1.1212	
	4	15	15.600	0.9628	
	Total	120	17.102	3.5237	
Control		15	32.883	1.9005	

Table 3: One-way ANOVA test among the groups at each concentration

Concentration (%)	*Group*	*n*	*Mean*	*SD*	*p value*
0.02	K_2SO_4	15	20.200	2.0071	$F = 309.953$; $p < 0.001$; highly significant
	$MnSO_4$	15	15.200	1.4352	
	$ZnSO_4$	15	20.287	1.1482	
	Control	15	32.883	1.9005	
0.04	K_2SO_4	15	17.206	1.4992	$F = 211.924$; $p < 0.001$; highly significant
	$MnSO_4$	15	20.106	2.6047	
	$ZnSO_4$	15	20.240	1.0913	
	Control	15	32.882	1.9005	
0.06	K_2SO_4	15	15.200	2.1320	$F = 330.661$; $p < 0.001$; highly significant
	$MnSO_4$	15	14.520	1.7957	
	$ZnSO_4$	15	20.206	1.3225	
	Control	15	32.882	1.9005	
0.08	K_2SO_4	15	13.080	0.9900	$F = 774.585$; $p < 0.001$; highly significant
	$MnSO_4$	15	10.953	1.3032	
	$ZnSO_4$	15	20.160	1.1356	
	Control	15	32.882	1.9005	
1	K_2SO_4	15	25.280	1.4097	$F = 554.528$; $p < 0.001$; highly significant
	$MnSO_4$	15	13.886	1.3255	
	$ZnSO_4$	15	15.486	1.1673	
	Control	15	32.882	1.9005	
2	K_2SO_4	15	19.273	1.5854	$F = 513.152$; $p < 0.001$; highly significant
	$MnSO_4$	15	12.880	1.4418	
	$ZnSO_4$	15	12.443	1.5586	
	Control	15	32.882	1.9005	
3	K_2SO_4	15	16.440	2.2702	$F = 432.811$; $p < 0.001$; highly significant
	$MnSO_4$	15	12.506	1.7637	
	$ZnSO_4$	15	12.400	1.1212	
	Control	15	32.882	1.9005	
4	K_2SO_4	15	14.446	2.1453	$F = 198.323$; $p < 0.001$; highly significant
	$MnSO_4$	15	14.586	3.9315	
	$ZnSO_4$	15	15.600	0.9628	
	Control	15	32.882	1.9005	

Table 4: Comparison between the concentrations using *post hoc* Tukey HSD

Group	*Dependent variable*	*(I) concentration*	*(J) concentration*	*Mean difference (I–J)*	*Std. error*	*Sig.*	*95% confidence interval Lower bound*	*95% confidence interval Upper bound*
I	C strength	1	2	2.9933333	0.6590397	0.000	0.957542	5.029125
			3	5.0000000	0.6590397	0.000	2.964208	7.035792
			4	7.1200000	0.6590397	0.000	5.084208	9.155792
			5	−5.0800000	0.6590397	0.000	−7.115792	−3.044208
			6	0.9266667	0.6590397	0.853	−1.109125	2.962458
			7	3.7600000	0.6590397	0.000	1.724208	5.795792
			8	5.7533333	0.6590397	0.000	3.717542	7.789125
		2	1	−2.9933333	0.6590397	0.000	−5.029125	−0.957542
			3	2.0066667	0.6590397	0.056	−0.029125	4.042458
			4	4.1266667	0.6590397	0.000	2.090875	6.162458
			5	−8.0733333	0.6590397	0.000	−10.109125	−6.037542
			6	−2.0666667	0.6590397	0.044	−4.102458	−0.030875
			7	0.7666667	0.6590397	0.941	−1.269125	2.802458
			8	2.7600000	0.6590397	0.001	0.724208	4.795792

Contd...

Contd...

Group	Dependent variable	(I) concentration	(J) concentration	Mean difference (I–J)	Std. error	Sig.	95% confidence interval Lower bound	Upper bound
		3	1	−5.0000000	0.6590397	0.000	−7.035792	−2.964208
			2	−2.0066667	0.6590397	0.056	−4.042458	0.029125
			4	2.1200000	0.6590397	0.035	0.084208	4.155792
			5	−10.0800000	0.6590397	0.000	−12.115792	−8.044208
			6	−4.0733333	0.6590397	0.000	−6.109125	−2.037542
			7	−1.2400000	0.6590397	0.566	−3.275792	0.795792
			8	0.7533333	0.6590397	0.946	−1.282458	2.789125
		4	1	−7.1200000	0.6590397	0.000	−9.155792	−5.084208
			2	−4.1266667	0.6590397	0.000	−6.162458	−2.090875
			3	−2.1200000	0.6590397	0.035	−4.155792	−0.084208
			5	−12.2000000	0.6590397	0.000	−14.235792	−10.164208
			6	−6.1933333	0.6590397	0.000	−8.229125	−4.157542
			7	−3.3600000	0.6590397	0.000	−5.395792	−1.324208
			8	−1.3666667	0.6590397	0.438	−3.402458	0.669125
		5	1	5.0800000	0.6590397	0.000	3.044208	7.115792
			2	8.0733333	0.6590397	0.000	6.037542	10.109125
			3	10.0800000	0.6590397	0.000	8.044208	12.115792
			4	12.2000000	0.6590397	0.000	10.164208	14.235792
			6	6.0066667	0.6590397	0.000	3.970875	8.042458
			7	8.8400000	0.6590397	0.000	6.804208	10.875792
			8	10.8333333	0.6590397	0.000	8.797542	12.869125
		6	1	−0.9266667	0.6590397	0.853	−2.962458	1.109125
			2	2.0666667	0.6590397	0.044	0.030875	4.102458
			3	4.0733333	0.6590397	0.000	2.037542	6.109125
			4	6.1933333	0.6590397	0.000	4.157542	8.229125
			5	−6.0066667	0.6590397	0.000	−8.042458	−3.970875
			7	2.8333333	0.6590397	0.001	0.797542	4.869125
			8	4.8266667	0.6590397	0.000	2.790875	6.862458
		7	1	−3.7600000	0.6590397	0.000	−5.795792	−1.724208
			2	−0.7666667	0.6590397	0.941	−2.802458	1.269125
			3	1.2400000	0.6590397	0.566	−0.795792	3.275792
			4	3.3600000	0.6590397	0.000	1.324208	5.395792
			5	−8.8400000	0.6590397	0.000	−10.875792	−6.804208
			6	−2.8333333	0.6590397	0.001	−4.869125	−0.797542
			8	1.9933333	0.6590397	0.060	−0.042458	4.029125
		8	1	−5.7533333	0.6590397	0.000	−7.789125	−3.717542
			2	−2.7600000	0.6590397	0.001	−4.795792	−0.724208
			3	−0.7533333	0.6590397	0.946	−2.789125	1.282458
			4	1.3666667	0.6590397	0.438	−0.669125	3.402458
			5	−10.8333333	0.6590397	0.000	−12.869125	−8.797542
			6	−4.8266667	0.6590397	0.000	−6.862458	−2.790875
			7	−1.9933333	0.6590397	0.060	−4.029125	0.042458
II	C strength	1	2	−4.9066667	0.7764377	0.000	−7.305104	−2.508229
			3	0.6800000	0.7764377	0.988	−1.718437	3.078437
			4	4.2466667	0.7764377	0.000	1.848229	6.645104
			5	1.3133333	0.7764377	0.693	−1.085104	3.711771
			6	2.3200000	0.7764377	0.066	−0.078437	4.718437
			7	2.6933333	0.7764377	0.016	0.294896	5.091771
			8	0.6133333	0.7764377	0.993	−1.785104	3.011771
		2	1	4.9066667	0.7764377	0.000	2.508229	7.305104

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Group	Dependent variable	(I) concentration	(J) concentration	Mean difference (I–J)	Std. error	Sig.	95% confidence interval	
							Lower bound	Upper bound
			3	5.5866667	0.7764377	0.000	3.188229	7.985104
			4	9.1533333	0.7764377	0.000	6.754896	11.551771
			5	6.2200000	0.7764377	0.000	3.821563	8.618437
			6	7.2266667	0.7764377	0.000	4.828229	9.625104
			7	7.6000000	0.7764377	0.000	5.201563	9.998437
			8	5.5200000	0.7764377	0.000	3.121563	7.918437
		3	1	−0.6800000	0.7764377	0.988	−3.078437	1.718437
			2	−5.5866667	0.7764377	0.000	−7.985104	−3.188229
			4	3.5666667	0.7764377	0.000	1.168229	5.965104
			5	0.6333333	0.7764377	0.992	−1.765104	3.031771
			6	1.6400000	0.7764377	0.414	−0.758437	4.038437
			7	2.0133333	0.7764377	0.170	−0.385104	4.411771
			8	−0.0666667	0.7764377	1.000	−2.465104	2.331771
		4	1	−4.2466667	0.7764377	0.000	−6.645104	−1.848229
			2	−9.1533333	0.7764377	0.000	−11.551771	−6.754896
			3	−3.5666667	0.7764377	0.000	−5.965104	−1.168229
			5	−2.9333333	0.7764377	0.006	−5.331771	−0.534896
			6	−1.9266667	0.7764377	0.214	−4.325104	0.471771
			7	−1.5533333	0.7764377	0.486	−3.951771	0.845104
			8	−3.6333333	0.7764377	0.000	−6.031771	−1.234896
		5	1	−1.3133333	0.7764377	0.693	−3.711771	1.085104
			2	−6.2200000	0.7764377	0.000	−8.618437	−3.821563
			3	−0.6333333	0.7764377	0.992	−3.031771	1.765104
			4	2.9333333	0.7764377	0.006	0.534896	5.331771
			6	1.0066667	0.7764377	0.898	−1.391771	3.405104
			7	1.3800000	0.7764377	0.637	−1.018437	3.778437
			8	−0.7000000	0.7764377	0.985	−3.098437	1.698437
		6	1	−2.3200000	0.7764377	0.066	−4.718437	0.078437
			2	−7.2266667	0.7764377	0.000	−9.625104	−4.828229
			3	−1.6400000	0.7764377	0.414	−4.038437	0.758437
			4	1.9266667	0.7764377	0.214	−0.471771	4.325104
			5	−1.0066667	0.7764377	0.898	−3.405104	1.391771
			7	0.3733333	0.7764377	1.000	−2.025104	2.771771
			8	−1.7066667	0.7764377	0.361	−4.105104	0.691771
		7	1	−2.6933333	0.7764377	0.016	−5.091771	−0.294896
			2	−7.6000000	0.7764377	0.000	−9.998437	−5.201563
			3	−2.0133333	0.7764377	0.170	−4.411771	0.385104
			4	1.5533333	0.7764377	0.486	−0.845104	3.951771
			5	−1.3800000	0.7764377	0.637	−3.778437	1.018437
			6	−0.3733333	0.7764377	1.000	−2.771771	2.025104
			8	−2.0800000	0.7764377	0.140	−4.478437	0.318437
		8	1	−0.6133333	0.7764377	0.993	−3.011771	1.785104
			2	−5.5200000	0.7764377	0.000	−7.918437	−3.121563
			3	0.0666667	0.7764377	1.000	−2.331771	2.465104
			4	3.6333333	0.7764377	0.000	1.234896	6.031771
			5	0.7000000	0.7764377	0.985	−1.698437	3.098437
			6	1.7066667	0.7764377	0.361	−0.691771	4.105104
			7	2.0800000	0.7764377	0.140	−0.318437	4.478437
III	C strength	1	2	0.0466667	0.4382722	1.000	−1.307168	1.400501
			3	0.0800000	0.4382722	1.000	−1.273835	1.433835

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Group	Dependent variable	(I) concentration	(J) concentration	Mean difference (I–J)	Std. error	Sig.	95% confidence interval Lower bound	Upper bound
			4	0.1266667	0.4382722	1.000	–1.227168	1.480501
			5	4.8000000	0.4382722	0.000	3.446165	6.153835
			6	7.8533333	0.4382722	0.000	6.499499	9.207168
			7	7.8866667	0.4382722	0.000	6.532832	9.240501
			8	4.6866667	0.4382722	0.000	3.332832	6.040501
		2	1	–0.0466667	0.4382722	1.000	–1.400501	1.307168
			3	0.0333333	0.4382722	1.000	–1.320501	1.387168
			4	0.0800000	0.4382722	1.000	–1.273835	1.433835
			5	4.7533333	0.4382722	0.000	3.399499	6.107168
			6	7.8066667	0.4382722	0.000	6.452832	9.160501
			7	7.8400000	0.4382722	0.000	6.486165	9.193835
			8	4.6400000	0.4382722	0.000	3.286165	5.993835
		3	1	–0.0800000	0.4382722	1.000	–1.433835	1.273835
			2	–0.0333333	0.4382722	1.000	–1.387168	1.320501
			4	0.0466667	0.4382722	1.000	–1.307168	1.400501
			5	4.7200000	0.4382722	0.000	3.366165	6.073835
			6	7.7733333	0.4382722	0.000	6.419499	9.127168
			7	7.8066667	0.4382722	0.000	6.452832	9.160501
			8	4.6066667	0.4382722	0.000	3.252832	5.960501
		4	1	–0.1266667	0.4382722	1.000	–1.480501	1.227168
			2	–0.0800000	0.4382722	1.000	–1.433835	1.273835
			3	–0.0466667	0.4382722	1.000	–1.400501	1.307168
			5	4.6733333	0.4382722	0.000	3.319499	6.027168
			6	7.7266667	0.4382722	0.000	6.372832	9.080501
			7	7.7600000	0.4382722	0.000	6.406165	9.113835
			8	4.5600000	0.4382722	0.000	3.206165	5.913835
		5	1	–4.8000000	0.4382722	0.000	–6.153835	–3.446165
			2	–4.7533333	0.4382722	0.000	–6.107168	–3.399499
			3	–4.7200000	0.4382722	0.000	–6.073835	–3.366165
			4	–4.6733333	0.4382722	0.000	–6.027168	–3.319499
			6	3.0533333	0.4382722	0.000	1.699499	4.407168
			7	3.0866667	0.4382722	0.000	1.732832	4.440501
			8	–0.1133333	0.4382722	1.000	–1.467168	1.240501
		6	1	–7.8533333	0.4382722	0.000	–9.207168	–6.499499
			2	–7.8066667	0.4382722	0.000	–9.160501	–6.452832
			3	–7.7733333	0.4382722	0.000	–9.127168	–6.419499
			4	–7.7266667	0.4382722	0.000	–9.080501	–6.372832
			5	–3.0533333	0.4382722	0.000	–4.407168	–1.699499
			7	0.0333333	0.4382722	1.000	–1.320501	1.387168
			8	–3.1666667	0.4382722	0.000	–4.520501	–1.812832
		7	1	–7.8866667	0.4382722	0.000	–9.240501	–6.532832
			2	–7.8400000	0.4382722	0.000	–9.193835	–6.486165
			3	–7.8066667	0.4382722	0.000	–9.160501	–6.452832
			4	–7.7600000	0.4382722	0.000	–9.113835	–6.406165
			5	–3.0866667	0.4382722	0.000	–4.440501	–1.732832
			6	–0.0333333	0.4382722	1.000	–1.387168	1.320501
			8	–3.2000000	0.4382722	0.000	–4.553835	–1.846165
		8	1	–4.6866667	0.4382722	0.000	–6.040501	–3.332832
			2	–4.6400000	0.4382722	0.000	–5.993835	–3.286165
			3	–4.6066667	0.4382722	0.000	–5.960501	–3.252832

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Group	Dependent variable	(I) concentration	(J) concentration	Mean difference (I–J)	Std. error	Sig.	95% confidence interval Lower bound	Upper bound
			4	−4.5600000	0.4382722	0.000	−5.913835	−3.206165
			5	0.1133333	0.4382722	1.000	−1.240501	1.467168
			6	3.1666667	0.4382722	0.000	1.812832	4.520501
			7	3.2000000	0.4382722	0.000	1.846165	4.553835
IV	C strength	1	2	0.0000000	0.6939678	1.000	−2.143685	2.143685
			3	0.0000000	0.6939678	1.000	−2.143685	2.143685
			4	0.0000000	0.6939678	1.000	−2.143685	2.143685
			5	0.0000000	0.6939678	1.000	−2.143685	2.143685
			6	0.0000000	0.6939678	1.000	−2.143685	2.143685
			7	0.0000000	0.6939678	1.000	−2.143685	2.143685
			8	0.0000000	0.6939678	1.000	−2.143685	2.143685
		2	1	0.0000000	0.6939678	1.000	−2.143685	2.143685
			3	0.0000000	0.6939678	1.000	−2.143685	2.143685
			4	0.0000000	0.6939678	1.000	−2.143685	2.143685
			5	0.0000000	0.6939678	1.000	−2.143685	2.143685
			6	0.0000000	0.6939678	1.000	−2.143685	2.143685
			7	0.0000000	0.6939678	1.000	−2.143685	2.143685
			8	0.0000000	0.6939678	1.000	−2.143685	2.143685
		3	1	0.0000000	0.6939678	1.000	−2.143685	2.143685
			2	0.0000000	0.6939678	1.000	−2.143685	2.143685
			4	0.0000000	0.6939678	1.000	−2.143685	2.143685
			5	0.0000000	0.6939678	1.000	−2.143685	2.143685
			6	0.0000000	0.6939678	1.000	−2.143685	2.143685
			7	0.0000000	0.6939678	1.000	−2.143685	2.143685
			8	0.0000000	0.6939678	1.000	−2.143685	2.143685
		4	1	0.0000000	0.6939678	1.000	−2.143685	2.143685
			2	0.0000000	0.6939678	1.000	−2.143685	2.143685
			3	0.0000000	0.6939678	1.000	−2.143685	2.143685
			5	0.0000000	0.6939678	1.000	−2.143685	2.143685
			6	0.0000000	0.6939678	1.000	−2.143685	2.143685
			7	0.0000000	0.6939678	1.000	−2.143685	2.143685
			8	0.0000000	0.6939678	1.000	−2.143685	2.143685
		5	1	0.0000000	0.6939678	1.000	−2.143685	2.143685
			2	0.0000000	0.6939678	1.000	−2.143685	2.143685
			3	0.0000000	0.6939678	1.000	−2.143685	2.143685
			4	0.0000000	0.6939678	1.000	−2.143685	2.143685
			6	0.0000000	0.6939678	1.000	−2.143685	2.143685
			7	0.0000000	0.6939678	1.000	−2.143685	2.143685
			8	0.0000000	0.6939678	1.000	−2.143685	2.143685
		6	1	0.0000000	0.6939678	1.000	−2.143685	2.143685
			2	0.0000000	0.6939678	1.000	−2.143685	2.143685
			3	0.0000000	0.6939678	1.000	−2.143685	2.143685
			4	0.0000000	0.6939678	1.000	−2.143685	2.143685
			5	0.0000000	0.6939678	1.000	−2.143685	2.143685
			7	0.0000000	0.6939678	1.000	−2.143685	2.143685
			8	0.0000000	0.6939678	1.000	−2.143685	2.143685
		7	1	0.0000000	0.6939678	1.000	−2.143685	2.143685
			2	0.0000000	0.6939678	1.000	−2.143685	2.143685
			3	0.0000000	0.6939678	1.000	−2.143685	2.143685
			4	0.0000000	0.6939678	1.000	−2.143685	2.143685

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Group	Dependent variable	(I) concentration	(J) concentration	Mean difference (I–J)	Std. error	Sig.	95% confidence interval	
							Lower bound	Upper bound
			5	0.0000000	0.6939678	1.000	−2.143685	2.143685
			6	0.0000000	0.6939678	1.000	−2.143685	2.143685
			8	0.0000000	0.6939678	1.000	−2.143685	2.143685
		8	1	0.0000000	0.6939678	1.000	−2.143685	2.143685
			2	0.0000000	0.6939678	1.000	−2.143685	2.143685
			3	0.0000000	0.6939678	1.000	−2.143685	2.143685
			4	0.0000000	0.6939678	1.000	−2.143685	2.143685
			5	0.0000000	0.6939678	1.000	−2.143685	2.143685
			6	0.0000000	0.6939678	1.000	−2.143685	2.143685
			7	0.0000000	0.6939678	1.000	−2.143685	2.143685

examined crystal formation in a dental stone under the electron and scanning electron microscope. Authors have opinioned that increased CS might be due to the formation of syngenite, which is a complex compound of CaSO4 and K_2SO_4. Furthermore, almost all concentrations have shown improved immediate and delayed CS. In our study, we have evaluated and compared the efficacy of three sulfate additives (K_2SO_4, $MnSO_4$, and $ZnSO_4$), each at eight different concentrations with the die stone to check variations in CS. In this study, conversely, at all eight concentrations of K_2SO_4 and other two sulfates also have shown a reduced CS compared to the standard specimen (Fig. 3). This may be due to the less crystal structure formation or having a less strength compared to the dental stone crystal structure. This needed further microscopical observations. Compared to the other two sulfate additives, $ZnSO_4$ has shown an improved CS at almost all concentrations. However, maximum CS can be perceived at 1% concentration of K_2SO_4 in the die stone.

Alteration of compressive strength of the die stone with the usage of micro-oven-driven drying was tried[13,18–20] and no alteration in the strength with shortened setting time was observed. Strength is similar to room drying at 24 hours and 7-days post-drying periods and various temperature zones also. Owing to wide variations in the results of the previous studies, in this study, the strength of the material was checked at room temperature. Addition of disinfectants such as sodium hypochlorite and glutaraldehyde to impression materials and alteration in tensile strength of the die-stone was assessed by some authors,[16,17,28] and proposed a negative effect of disinfectants over the strength of the die stone; some authors proposed positive effect[29] and some proposed null effect.[30] De Cesero et al. tried linking of CS with post pouring time. Post pouring 1 hour, 24 hours, and 7 day strength was assessed, concluded, strength increases with post-pouring time.[31] Zakaria et al. in 1988 tried liquid dispersing agents (LDA) and a microcrystalline additive (MCA) and proposed to be increased strength and other physical properties with the additive. The reason behind proposed to be observed improvised crystal packing, by a scanning electron microscopy examination.

Limitations of the Study and Future Directions

CS should be evaluated with an eye on other physical properties of the die stone. Further research is needed to evaluate favorable or unfavorable changes in crystal structure and formation of intermediary products to substantiate the decrease in the CS with various concentrations of sulfate additives.

Conclusion

Within the limitations of the study, the study results show that the CS of die stone may decrease with sulfate salt additives. The dropout of CS is found irrespective of the type of sulfate and concentration used. Furthermore, a decline in the CS is not proportional to the concentration variation of the additives. Amidst of the reduced CS values of all the three additives, $ZnSO_4$ has shown higher CS values compared to the other two.

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