THE EFFECT OF CRUDE AND CALCINED SEPIOLITE ON SOME PHYSICAL AND MECHANICAL PROPERTIES OF GLASS FIBER REINFORCED CONCRETE

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The technical term GRC (glass fiber reinforced concrete) is widely used in the precast industry. This type of concrete, which is obtained by mixing cement, sand, glass fibers and some chemicals, is very durable. Compared to conventional concretes, high compressive, flexural and impact strength is the preferred choice for building facade coatings. In this paper, the usability of sepiolite as a pozzolan in glass fiber reinforced concrete and its effects on mechanical and physical properties were investigated. GRC samples were produced by adding 3% glass fiber by volume to substituted mixtures. Crude and calcined sepiolites were replaced with cement at 5%, 10%, 15% and 20% by weight. Compressive strength, flexural strength, impact strength and abrasion resistance of produced GRC samples were determined. As a result, It was observed that as sepiolite ratio increased, mechanical and physical properties of samples decreased in early and later ages, and crude sepiolite substituted samples had lower mechanical strength than the calcined sepiolite substituted samples.

Keywords: *Glass fiber, GRC, Sepiolite, Calcination*

1. Introduction

As a result of the high demand for concrete in the construction sector, the cement industry is one of the most intensive industries in the world. Due to such intensive production, cement is among industrial productions that harm the environment. In recent years, the need for energy efficiency has led researchers to produce sustainable solutions within the cement sector [1]. The cement industry is faced with more durable and sustainable production by using less energy without sacrificing mechanical properties of the material to be produced. Therefore, the production of doped cement instead of normal cement production has become one of the most common developments [2]. Since additives such as blast furnace slag, fly ash, silica fume and natural pozzolans have economic and technical advantages, they are used in the production of blendend cement [3,4]. Pozzolans reduce the cement participation rate of clinker and improve some properties of cement according to economy and need. For example, when low hydration temperature is targeted, it is very important to have pozzolanic material in the cement. In addition, carbon dioxide gas released into the atmosphere during clinker production in cement plants is indirectly reduced using pozzolan. As a result, pozzolan additive cements provide different properties according to economic and need, as well as making the cement a more environmentally friendly material [5-7]. In this context, sepiolite is a natural clay mineral of magnesium hydrosilicate which belongs to palygorskite group. This mineral fibrous structure, which exhibits pozzolanic properties when calcinated at 830°C, is formed by sequencing the tetrahedral and octahedral oxide layers [8]. It also has channel voids along the fiber [9].

GRC mortar, which has a water/cement ratio of 0.32, is combined with special glass fibers that are resistant to alkalis to form a concrete mixture which is quite high in terms of compressive strength, flexural strength and impact strength compared to normal concrete. Since alkali-resistant fibers in the mixture act as reinforcement, no iron or steel reinforcement is placed in the material. Due to all these features, GRC concretes provide designers endless creativity with 1-1.5 cm thickness and precast production in all forms, and because of its light structure enables fast production, assembly and transportation [10,11].

T. Kavas et al. in their study, 3%, 5%, 10%, 15%, 20% and 30% sepiolite were added to Portland cement clinker and 5% gypsum mixture, respectively, and properties of the cement were tried to improve. Expansion tests, blaine tests, sieve analyzes, setting and end of setting, flexural strength and compressive strength, chemical and chemical tests were applied to mixtures, and proportions of sepiolite added to cement were determined. As a result of experiments, it has been found that addition of 10% sepiolite to concrete improves compressive and flexural strength of the cement despite decrease in the amount of clinker and does not cause any negativity in other properties of the cement [12]. In another study, structural properties and optimum mixing ratios of sepiolite reinforced cement composites were investigated. It has been observed that the addition of 10% sepiolite (natural clay mineral) fiber increases mechanical and physical properties of the mortar. When the mixture

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containing sepiolite was compared with the ordinary portland cement mixture, the compressive strength at 2, 7 and 28 days increased by 3.5%, 6.2% and 7.7%, respectively, while the flexural strength increased by 12.7%, 5.7% and 6.3%. Based on the scanning electron microscope pictures, this improvement was achieved by the formation of a network between sepiolite fibers and cement matrix [13]. Fuente, E et al. showed that corrugated roofing can be produced from sepiolite doped fiber concrete [14,15]. Andrejkovičová S. et al. oily lime with 10%, 20% and 30% metakaolin substitute mortar by adding 5% by weight of fine sepiolite in low humidity environments can be used as a repair mortar and 20% metakaolin and 5% sepiolite substituted lime mortar after 180 days of sepiolite replacement showed higher compressive and flexural strength than the mixture [16]. Martínez-Ramírez, S. et al. investigated the carbonation process and properties of sepiolite doped lime mortar and showed that it slows down the carbonation process in lime mortars because it has no effect on mechanical properties of less than 5% sepiolite-substituted mortar and has water absorption properties [17]. In addition to these studies carried out on cement mortar mixtures, it has been wondered how sepiolite behaves with polymer binders and the effect of addition of polymer, polyvinyl-alcohol, and polyurethane on rheological properties of sepiolite has been investigated. Results showed that polymer molecules bind to the surface of sepiolite particles and stabilize their flow properties at certain concentrations. it has been found that PU polymer covers the sepiolite surface faster than PVA, but PVA coating is smoother [18]. Wu et al. studied on the rheological behavior and mechanical strength of cement paste and mortars prepared with high calcium sepiolite (HCSP). HCSP replaced by 0.0%, 2.5%, 5.0%, 7.5%, 10.0% and 15.0% of cement. The rheological behavior of fresh samples was examined by using Bingham plastic model with approximate plastic viscosity yield. Tests were also conducted to investigate compressive strength, flexural strength and drying shrinkage of hardened samples. Results showed that the addition of HCSP had a negative effect on the rheological behavior of fresh samples. Compressive strength and flexural strength were the highest for samples with HCSP content of 7.5%. Drying shrinkage was the lowest for samples with the highest HCSP content (15.0%) [19].

In this study, in addition to sepiolite researches in the literature, effect of two types of grinded sepiolite (crude and calcinated at 900 °C) obtained from Eskisehir region to properties of concrete with glass fiber were investigated.

2. Materials and Methods

2.1. Material

Aggregate: In the study, AFS 30-35 silica sand obtained from Çeliktaş Industrial Sand Industry and Trade Inc. was used in glass fiber reinforced sepiolite substituted sample production. The grain distribution of sand used in GRC production is given in Table 1.

Cement: CEM I 42.5R cement produced in accordance with TS EN 197-1 standard obtained from Bolu Cement Plant was used in the study. Chemical and physical analysis of cement is given in Table 2

Sepiolite: Sepiolite used in the study was obtained from Eskisehir region and it was used in experimental studies crude and calcinated at 900ºC by replacing to cemented samples with 0-5-10-15-20%. Chemical analysis values of sepiolite used in the study are given in Table 3.

SEM images of the microstructure of samples were taken with FEI brand QuantaFeg 250 model variable pressure device in Düzce University Scientific and Technological Research Application and Research Center. The morphological structure of sepiolite is seen to be in the form of both fibrous blocks and long fiber bundles, and this is supported by other authors [20]. It is clearly seen in Figure 1 that the structure of fibers subjected to calcination process is disrupted and in more oval state.

Glass Fiber: The glass fiber used in the study is cropped as 12 mm long, and 3% by weight was used in all sepiolite substituted GRC samples.

Polymer additives: Bettolatex brand copolymer dispersion based additive material was used to increase water impermeability and adherence in glass fiber reinforced concrete production. Technical properties of polymer additives are given in Table 4.

Table 1

30-35 AFS Silica sand grain distribution

Sieve Size (Micron)	Analysis result (%)	Acceptance Range (%)
+1000	4,0	0-7
710-1000	10,3	2-12
500-710	29,7	20-40
355-500	33,4	15-45
250-355	16,3	2-24
180-250	4,9	1-10
125-180	1,2	0-2
90-125	0,2	0-1
0-90	0,0	0
AFS	32,4 AFS	30-35
Clay	0,20	Max: 0,25

Table 2

Chemical and physical analysis of cement

Components (%)	CEMI 42,5R	TS EN 197-1	Physical Properties			TS EN 197-1
CaO	63.03	50% C + S≥	Setting (Min.)	Start	125	min. 60
SiO_2	29.12			Finish	202	-
Al_2O_3	4.77	-	Density (g / cm ^{3})		3.17	-
Fe_2O_3	4.37	-	Blaine Thickness (cm ^{2}/ g)		4359	-
MgO	2.35	Lim.≤ 5%	Total Volume Expansion (mm)		1.5	max . 10
SO_3	2.99	Lim.≤ 4%	45 µm over sieve%		2.5	-
Na2O	0.29	-				
K2O	0.49	-	Compressive Strength (N / mm ^{2})	2 days	27.5	min. 20
Cl	.0141	Lim.≤ 0.10%		7 days	45.7	-
LOI	1.30	Lim.≤ 5%		28 Days	56.8	min. 42.5 max. 62.5

Table 3

Chemical analysis results of crude sepiolite.

Crude Sepiolite Chemical Content (%)			
MgO	23,06	Fe_2O_3	0.23
Al_2O_3	0.45	Cr_2O_3	0.001
SiO_2	26.34	Na_2O	0.07
SO_3	0.05	Mn_2O_3	0.0023
K_2O	0.20	TiO_2	0.05
CaO	14.59	Other	35.75

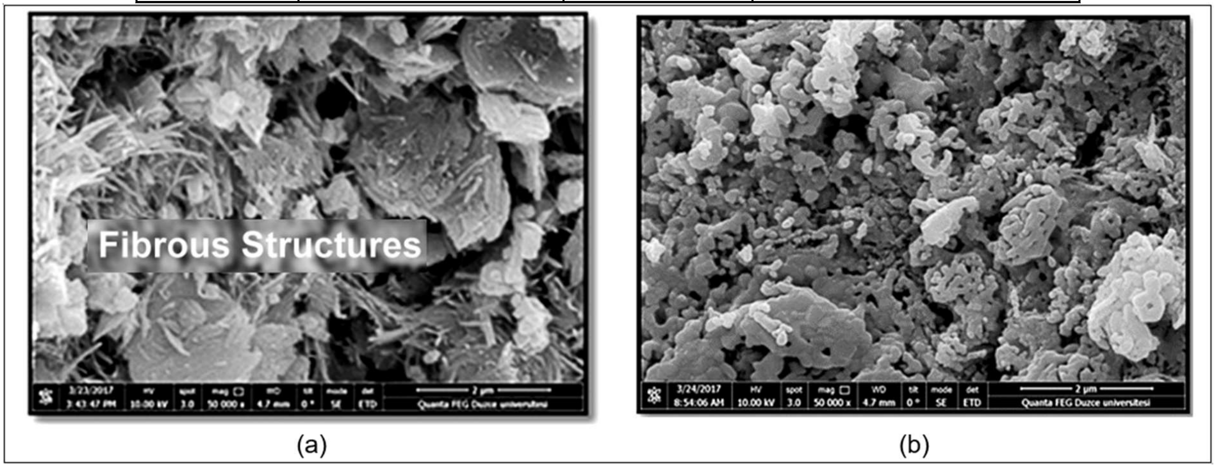

Fig. 1. SEM images: a) Crude sepiolite b) Sepiolite calcinated at 900 ° C.

Table 4

Technical properties of polymer additives.

Structure of Material	Modified Polymer Dispersion
Color	White
Density	1.05 ± 0.05 kg / lt
pH	6,0 ± 1,05
Application Temperature	+ 5 ° C + 35 ° C

Table 5

Physical and chemical properties of plasticizers.

Technical specifications	
Chemical Content	Polycarboxylate Based
Form	Liquid
Color	Light brown
Ph	2.5
Density	1.11 (25 ° C)
Viscosity (Brookfield), cps	500 (25 ° C)

Plasticizer: In the study, polycarboxylate based BUILDENT WR-780 brand super plasticizer additive was used. 1% of binder was added to each batch of experiments. Physical and chemical properties of plasticizer are given in Table 5.

2.2. Methods

2.2.1. Compressive Strength

The compressive strength test was carried out in accordance with TS EN 196-1 " Methods of testing cement - Part 1: Determination of strength" [21].

The reference sample was prepared by volume of 32% cement, 36% silica sand, 3% glass fiber, 25% water, 3% polymer additive and 0.7% super plasticizer. Water ratios of mixtures were determined so that 5-10-15-20% of crude and calcined sepiolite substituted mixtures would have the same spreading diameter as the reference mixture. Total of 9 cubic samples with dimensions of 50x50x50 mm were prepared to be broken at the end of 7 and 28 days of curing time. In the experiment, a single axis cement pressure test device with a loading capacity of 300 kN was used.

2.2.2. Flexural Strength

The flexural strength test was carried out in accordance with TS EN 1170-5 Precast concrete products - test method for glass-fıbre reınforced cement - Part 5: measuring bending strength, "complete bending test" method [22]. GRC mortar was poured into 10x600x600 mm plates for each test series and after 24 hours the sample was removed from the mold and air cured for 7 and 28 days. Before the experiment, produced plates were cut into eight samples with 50±2 mm width, keeping the distance of 50±2 mm from edges as shown in Figure 2, and then subjected to four-point flexural strength test.

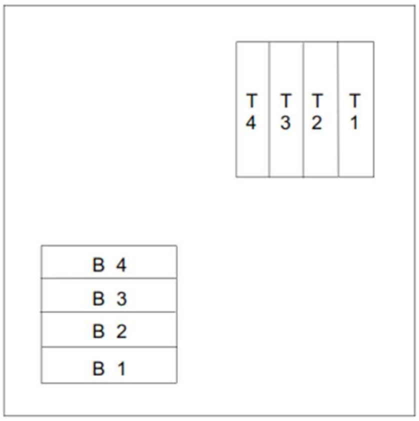

Fig. 2 - Location and marking of test pieces.

For the flexural test, Testomatic Micro 350 with digital control unit was used. Tensile values of the flexural test specimens were calculated according to Equation 1.

$$\sigma = \frac{F \times L}{b \times d^2} \quad (1)$$

Here;
σ: Flexural strength (MPa) b: Sample width (mm)
F: Largest load at break (N) d: Sample height (mm)
L: Distance between bearings (mm)

2.2.3. Impact Strength

For this experiment, for each crude and calcined sepiolite substituted mixtures, 3 pieces of 40x40x160 mm in size, totally 27 samples were produced and a Charpy impact test instrument with a pendulum weight of 8.5 kg and a distance of 120 cm to the sample was used.

2.2.4. Abrasion Resistance

A Bohme test instrument was used for abrasion resistance and GRC samples were cut in accordance with TS 699 [23] and weighed in precision scales. An abrasive force of 294 ± 3 N was applied to each sample. 16 cycles of 22 turns each were implemented. Mass losses in samples were determined in % and evaluated. In this test, abrasive powder with grain size F 80 in accordance with ISO 8684-1 was used as abrasive material [24].

2.2.5. Concrete Mixing Calculation

In the study, cement, silica sand, water, polymer additive, plasticizer and glass fiber were used in the production of GRC reference samples. The reference sample was replaced by crude and calcined sepiolite in 5%, 10%, 15% and 20% by weight of cement.

Silica sand, cement and sepiolite in the mixture were mixed in dry form. Water containing the polymer and the plasticizing additive was then added to the dry mixture and stirred for a further 2 minutes until a homogeneous mixture was obtained, and finally glass fibers were added and mixed. Samples were allowed to air cure for 7 and 28 days at room conditions to complete the setting. The mixture design of reference mortar sample is given in Table 6 and the mixture design of crude and calcined sepiolite substituted samples is given in Table 7.

Table 6

Mixture design of reference mortar sample

Material	Density (g / cm^3)	1 m^3		1 m^3	
		Weight (Kg)	Volume (dm^3)	Weight (%)	Volume (%)
Cement CEM I 42,5	3.00	960.62	320.21	41.98	32.02
Silica Sand AFS No30-35	2.65	960.62	362.50	41.98	36.25
Glass Fiber	2.55	76.85	30.14	3.36	3.01
Water	1.00	249.76	249.76	10.92	24.98
Polymer Additive	1.05	31.7	30.19	1.39	3.02
Plasticizer	1.2	8.65	7.20	0.38	0.72

Table 7

Mixture design of crude and calcined sepiolite substituted samples

Type of Sepiolite	Sepiolite (%)	Sepiolite (Kg)	Cement (Kg)	Silica sand (Kg)	Glass Fiber (Kg)	Water (Kg)	Polymer Additive (Kg)	Plasticizer (Kg)
	0	0	960.62	960.62	76.85	249.76	31.7	8.65
Crude	5	48.03	912.59	960.62	76.85	267.79	31.7	8.65
	10	96.06	864.56	960.62	76.85	288.98	31.7	8.65
	15	144.09	816.53	960.62	76.85	313.33	31.7	8.65
	20	192.12	768.50	960.62	76.85	343.08	31.7	8.65
Calcined	5	48.03	912.59	960.62	76.85	275.91	31.7	8.65
	10	96.06	864.56	960.62	76.85	338.12	31.7	8.65
	15	144.09	816.53	960.62	76.85	418.37	31.7	8.65
	20	192.12	768.50	960.62	76.85	491.41	31.7	8.65

Table 8

Descriptive statistics of GRC compressive strength test results.

Sepiolite Type	Day	Sepiolite (%)	Average Compressive Strength (MPa)	Std. Deflection	Std. Error	95% Confidence Range		Min.	Max.
						Lower Limit	Upper limit		
Crude	7	0	49.050	1.178	0,680	46.123	51.977	47.80	50.14
		5	38.970	1.196	0.690	36.000	41.941	38.24	40.35
		10	30.130	1.005	0.580	27.633	32.628	29.51	31.29
		15	21.333	0.508	0.294	20.070	22.596	21.02	21.92
		20	15.907	0.731	0,422	14.091	17.722	15.07	16.42
Crude	28	0	52.873	1.302	0.752	49.638	56.109	51.77	54.31
		5	45.593	1.356	0.783	42.224	48.963	44.07	46.67
		10	38.527	1.932	1,116	33.727	43.326	36.76	40.59
		15	27.310	3.180	1,836	19.410	35.210	24.03	30.38
		20	19.177	1.058	0.611	16.549	21.804	18.45	20.39
Calcined	7	0	49.050	1,178	0,680	46.123	51.977	47.80	50.14
		5	44.133	0.896	0.518	41.906	46.360	43.11	44.78
		10	41.770	0.927	0.535	39.467	44.073	40.73	42.51
		15	36.007	0.796	0.460	34.029	37.984	35.11	36.63
		20	28.157	0.816	0.471	26.128	30.185	27.53	29.08
	28	0	52.873	1,302	0.752	49.638	56.109	51.77	54.31
		5	55.583	2,819	1.627	48.582	62.585	52.34	57.44
		10	51.423	2,206	1.274	45.944	56.903	49.64	53.89
		15	47.507	1,762	1.018	43.129	51.885	45.48	48.68
		20	38.423	1,895	1.094	33.716	43.131	36.26	39.79

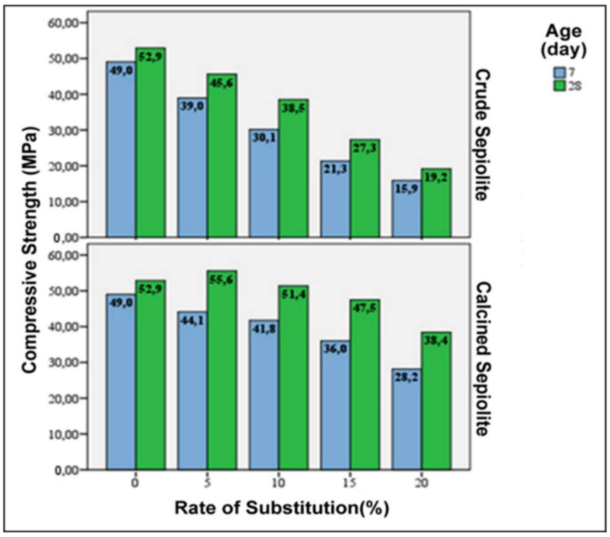

Fig. 3 - Graphical representation of test results for compressive strength of GRC samples.

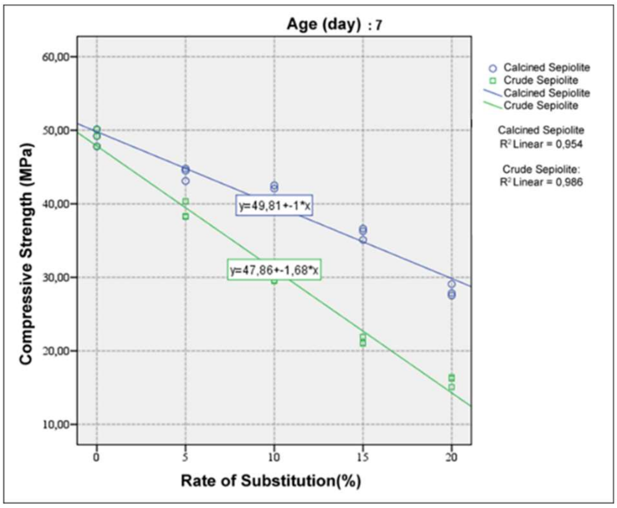

Fig. 4 - Graph showing the relationship between sepiolite substitution amounts and compressive strength values.

3. Results and Discussion

3.1. Compressive Strength

Descriptive statistics of compressive strength test results of GRC samples produced according to TS EN 196-1 [21] are given in Table 8. In addition, graphical representation of the compressive strength test results of 7 and 28 day GRC samples depending on sepiolite substitution ratio is given in Figure 3.

When the average compressive strength data are examined, It is seen that the compressive strength values of calcined sepiolite substituted samples are higher than that of crude sepiolite substituted samples due to calcined sepiolite's lower water absorption level than crude sepiolite. Low water absorption value of calcined sepiolite substituted samples results having less porous structure. Accordingly, compressive strength values are higher. Another reason for this increase is thought to be the pozzolanic activity of sepiolite after calcination [25]. The highest compressive strength value of calcined sepiolite substituted samples on 28th of curing day was observed 55,6 MPa at 5% substitution with approximately 5% strength increase compared to the reference sample [26]. Contrary to other studies in the literature, the strength gradually decreased for all crude sepiolite samples and calcined sepiolite samples after 5% substitution ratio [27,28].

Regression analysis was performed in order to model the relationship between sepiolite substitution amounts and compressive strength values. It is seen that there is a relationship between sepiolite amount and compressive strength values that can be explained by the first order Y = a + bX model equation (Figure 4).

3.2. Flexural Strength

The flexural strength test was carried out in accordance with TS EN 1170-5 [22] and explanatory statistics of test results are given in Table 9. In addition a graphical representation of the flexural strength test results of 7 and 28 day GRC samples depending on sepiolite substitution ratio is given in Figure 5.

When average flexural strength data are examined, it is seen that as amount of calcined sepiolite substitution increases, flexural strength values decrease, and LOP (Elasticity Limit) value of 5% crude sepiolite substituted samples at the age of 7 and 28 days increases compared to 0% reference sample. Moreover, 10% calcined sepiolite substituted MOR (Maximum Strength) value are seen to be increased about 15% compared to reference sample. When compared with calcined sepiolite, it is thought that significant increase in flexural strength of crude sepiolite substituted samples is due to the fibrous structure of crude sepiolite [13]. Consequently, flexural strength values of crude sepiolite substituted samples were higher than calcined sepiolite-substituted samples at all ages.

3.3. Impact Strength

Descriptive statistics of the impact strength data of sepiolite samples obtained as a result of the experiment are given in Table 10. In addition, the graph showing the change in impact strength values due to sepiolite substitution ratios is shown in Figure 6.

When the impact strength data are examined, it is seen that impact strength values decrease with increasing sepiolite substitution amount. Impact strength values of calcined sepiolite substituted samples are slightly higher than those of crude

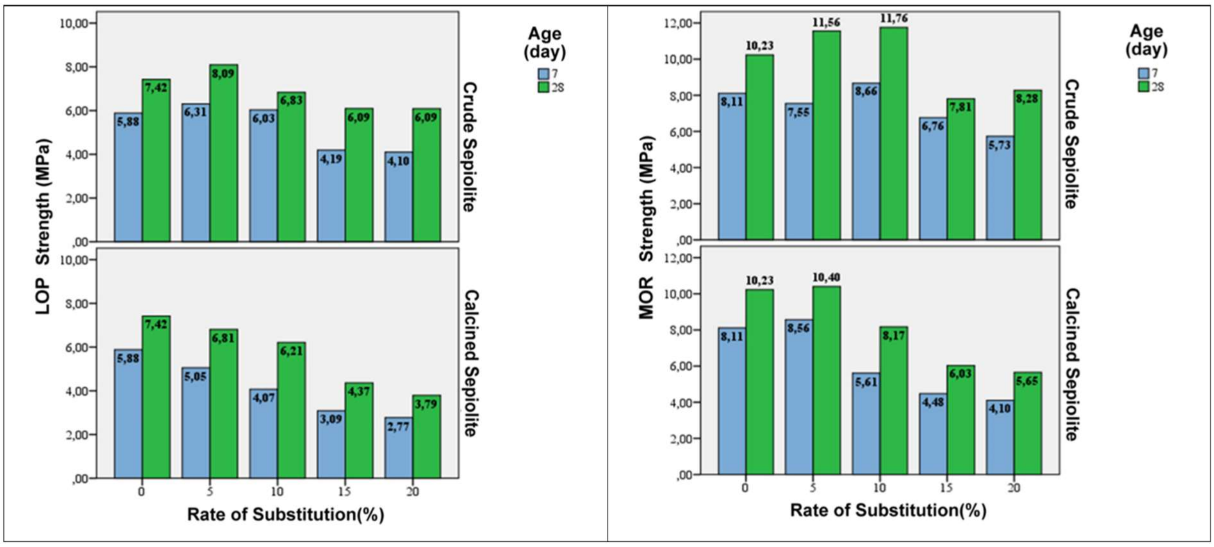

Fig. 5 - Graphical representation of test results for flexural strength of GRC samples.

Table 9

Explanatory statistics of flexural strength test results.

Sepiolite Type	Day	Flexural Strength Type	Sepiolite (%)	Average Flexural Strength (MPa)	Std. Deflection	Std. Error	95% Confidence Range Lower Limit	95% Confidence Range Upper limit	Min.	Max.
Crude	7	LOP Strenght (MPa)	0	5.883	1.543	0.545	4.594	7.173	4.18	8.62
			5	6.310	1.396	0.494	5.142	7.477	4.49	8.04
			10	6.030	1.105	0.391	5.106	6.954	4.51	7.57
			15	4.190	0.965	0.341	3.383	4.997	3.22	6.16
			20	4.097	0.493	0.174	3.685	4.509	3.51	4.65
		MOR Strength (MPa)	0	8.111	1.565	0.553	6.803	9.420	5.32	10.01
			5	7.547	0.812	0.287	6.869	8.226	6.31	8.41
			10	8.665	1.155	0.408	7.700	9.631	6.63	10.64
			15	6.762	0.942	0.333	5.975	7.550	5.74	8.26
			20	5.730	0.621	0.220	5.211	6.250	4.77	6.64
	28	LOP Strenght (MPa)	0	7.421	0.777	0.275	6.772	8.071	6.34	8.46
			5	8.093	0.525	0.186	7.654	8.532	7.58	8.79
			10	6.830	1.101	0.389	5.910	7.751	5.56	8.58
			15	6.094	0.964	0.341	5.287	6.900	4.64	7.50
			20	6.087	0.516	0.182	5.656	6.519	5.23	6.75
		MOR Strength (MPa)	0	10.230	1.276	0.451	9.164	11.297	8.01	11.31
			5	11.557	1.308	0.463	10.463	12.650	9.34	13.20
			10	11.755	1.903	0.673	10.165	13.346	10.10	15.81
			15	7.809	1.165	0.412	6.835	8.783	5.69	9.17
			20	8.277	1.185	0.419	7.286	9.267	6.02	9.40
Calcined	7	LOP Strenght (MPa)	0	5.883	1.543	0.545	4.594	7.173	4.18	8.62
			5	5.051	0.367	0.130	4.744	5.357	4.30	5.52
			10	4.073	0.378	0.134	3.757	4.389	3.42	4.49
			15	3.089	1.147	0.406	2.130	4.048	1.45	5.07
			20	2.771	0.669	0.236	2.212	3.330	1.37	3.35
		MOR Strength (MPa)	0	8.111	1.565	0.553	6.803	9.420	5.32	10.01
			5	8.563	1.945	0.688	6.937	10.189	6.29	12.02
			10	5.608	1.127	0.398	4.666	6.551	3.80	7.03
			15	4.479	0.823	0.291	3.791	5.168	3.16	5.40
			20	4.104	0.737	0.261	3.488	4.720	3.10	5.43
	28	LOP Strenght (MPa)	0	7.421	0.777	0.275	6.772	8.071	6.34	8.46
			5	6.806	0.834	0.295	6.109	7.503	5.60	8.09
			10	6.213	0.458	0.162	5.830	6.595	5.68	7.13
			15	4.367	0.159	0.056	4.234	4.500	4.03	4.52
			20	3.791	0.342	0.121	3.505	4.077	3.32	4.30
		MOR Strength (MPa)	0	10.230	1.276	0.451	9.164	11.297	8.01	11.31
			5	10.400	2.314	0.818	8.466	12.334	8.02	14.37
			10	8.173	0.690	0.244	7.596	8.750	7.03	9.00
			15	6.025	0.882	0.312	5.288	6.763	5.18	7.69
			20	5.653	0.791	0.280	4.992	6.314	4.59	6.77

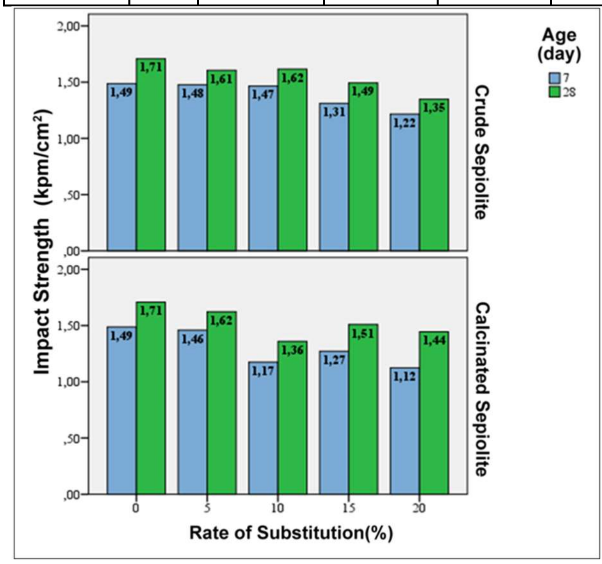

Fig. 6 - Impact strength values of sepiolite-substituted samples.

sepiolite-substituted samples. Furthermore, the maximum impact strength value is in 0% substituted samples, and the lowest impact strength is in 20% sepiolite substituted samples. In order to model the relationship between sepiolite substitution amounts and impact strength values, regression analysis was performed. It is seen that there is a relationship between sepiolite amount and impact strength values which can be explained by the second order model $Y = a + bX + cX^2$ (Figure 7).

3.4. Abrasion Resistance

GRC samples produced in 5 different ratios of 0%, 5%, 10%, 15%, 20% as 3 samples for each. Totally 27 GRC samples with 3% glass fiber were subjected to abrasion test using Bohme tester and results were determined as mass loss in Table 11, graphical representation is given in Figure 8.

Table 10

Descriptive statistics of impact strength data of samples.

Sepiolite Type	Day	Amount of Sepiolite (%)	Impact strength (kpm/cm²)	Std . Deflection	Std . Error	95% Confidence Range		Min.	Max.
						Lower Limit	Upper limit		
Crude	7	0	1.487	0.031	0.018	1.411	1.564	1.46	1.52
		5	1.477	0.016	0.009	1.438	1.516	1.46	1.49
		10	1.465	0.056	0.032	1.326	1.604	1.4	1.51
		15	1.311	0.139	0.080	0.967	1.656	1.16	1.43
		20	1.216	0.064	0.037	1.058	1.374	1.17	1.29
	28	0	1.708	0.067	0.039	1.541	1.875	1.64	1.78
		5	1.606	0.062	0.036	1.451	1.761	1.54	1.66
		10	1.616	0.097	0.056	1.375	1.857	1.53	1.72
		15	1.493	0.057	0.033	1.353	1.634	1.43	1.53
		20	1.348	0.050	0.029	1.224	1.473	1.29	1.39
Calcined	7	0	1.487	0.031	0.018	1.411	1.564	1.46	1.52
		5	1.459	0.000	0.000	1.459	1.459	1.46	1.46
		10	1.175	0.099	0.057	0.930	1.419	1.1	1.29
		15	1.271	0.148	0.085	0.904	1.638	1.12	1.41
		20	1.124	0.094	0.054	0.891	1.357	1.04	1.23
	28	0	1.708	0.067	0.039	1.541	1.875	1.64	1.78
		5	1.622	0.091	0.052	1.397	1.847	1.55	1.72
		10	1.359	0.049	0.028	1.237	1.481	1.31	1.41
		15	1.510	0.095	0.055	1.273	1.746	1.44	1.62
		20	1.444	0.096	0.056	1.205	1.683	1.34	1.52

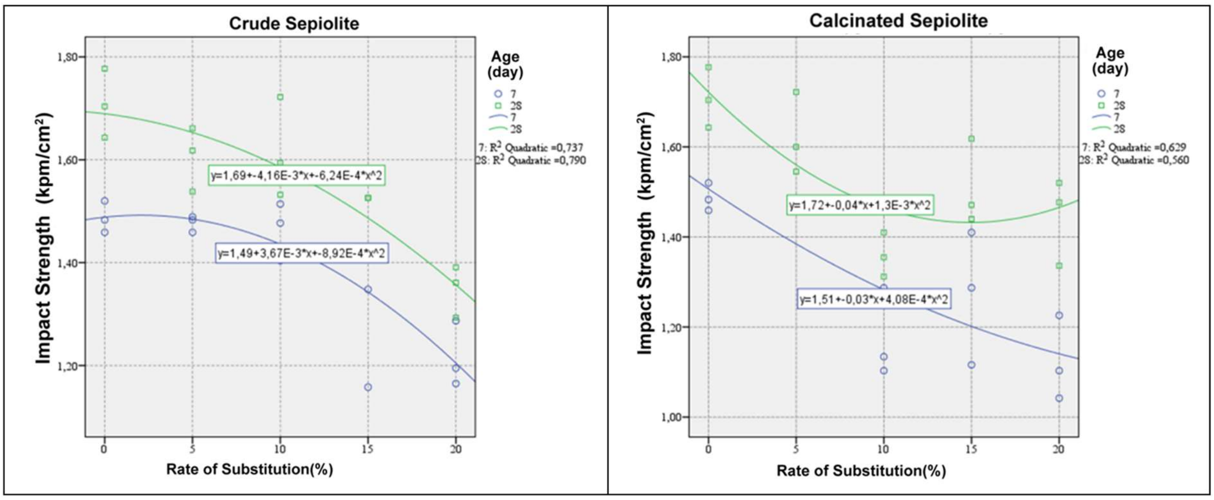

Fig. 7 - Graph showing the relationship between sepiolite substitution amounts and impact strength values

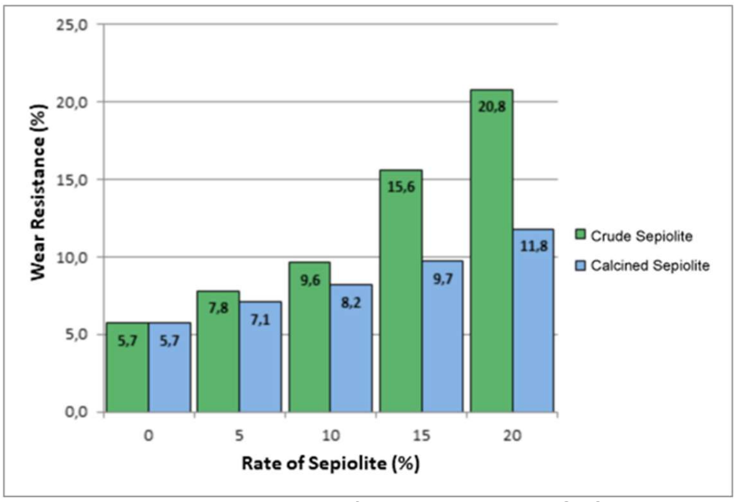

Fig. 8 - Wear resistance results of sepiolite substituted GRC samples.

Table 11

Abrasion resistance results

Sample Name	Amount of Sepiolite (%)	Average Mass Loss (%)
Reference	0	5.7
Crude	5	7.8
	10	9.6
	15	15.6
	20	20.8
Calcined	5	7.1
	10	8.2
	15	9.7
	20	11.8

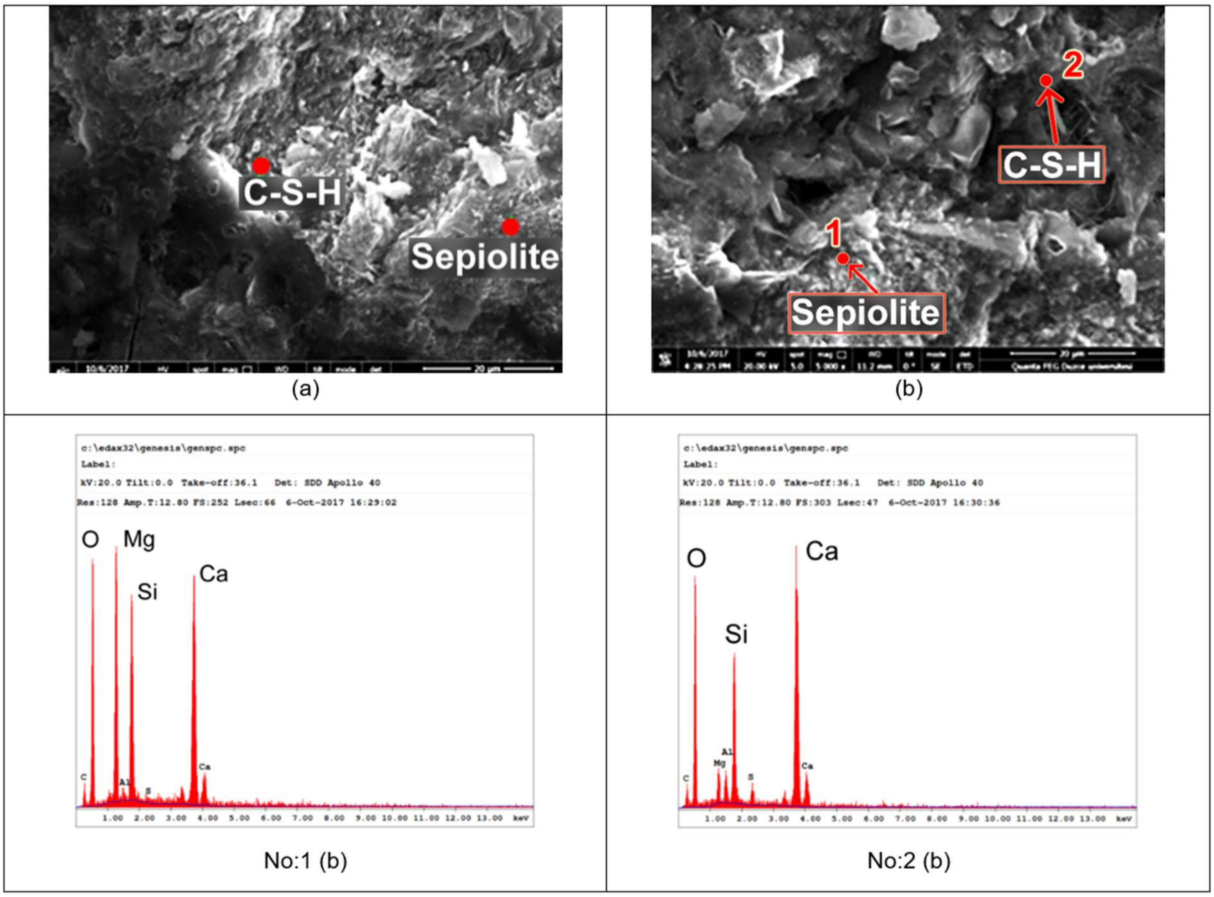

Fig. 9 - SEM image of calcined sepiolite substituted sample (a), SEM and EDS analysis of crude sepiolite substituted sample (b).

When results are examined the abrasion resistance decreases as the amount of sepiolite increases, whereas crude sepiolite substituted samples are less abrasion resistant than calcined sepiolite samples. The highest mass loss was observed as 20,8% by mass at 20% crude sepiolite substituted samples.

When SEM images are examined in Figure 9, it is thought that lower abrasion resistance of crude sepiolite mixtures than calcined sepiolite mixtures is due to higher water absorption value of crude sepiolite compared to calcined sepiolite, and consequently the concrete produced has more porous structure [25,29]. Likewise, lower mechanical properties such as compressive strength and flexural strength can be attributed to this feature of crude sepiolite.

4. Conclusions and recommendations

In this study, compressive strength, flexural strength, impact strength and abrasion resistance tests were performed on sepiolite substituted GRC samples.

As a result of the data obtained from experiments and statistical evaluations, as sepiolite ratio increases, mechanical properties of samples decreases in early and later ages, crude sepiolite substituted samples have lower compressive strength compared to calcined sepiolite substituted samples. While 5-10% crude sepiolite substitution increases impact strength and flexural strength, 5% calcined sepiolite substitution increases the compressive strength of samples compared to the reference sample. Additionally, abrasion resistance decreases with increasing sepiolite content, crude sepiolite substituted samples are less abrasion resistant than calcined sepiolite substituted samples.

It is seen that crude sepiolite substitution up to 10% and calcined sepiolite substitution up to 5% increase the flexural strength of GRC samples as a result of fibrous structure of sepiolite. However excessive sepiolite substitution beyond these ratios results in a reduction in strength. Due to these properties, it is inconvenient to use sepiolite optained from Eskisehir region in structural carrier elements, but it can be used in light coating elements and leveling concretes which are not exposed to high abrasion as filling material due to the density of crude sepiolite which is 22% less than calcined sepiolite. In addition, due to high water content in the structure of sepiolite and its water retaining properties, it is recommended to investigate resistance to high temperatures in substituted composites.

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