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The effect of the main component ratios in the joint filling on the product quality

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Abstract:

When building materials are exposed to environmental and natural factors such as temperature differences, humidity, strong wind and earthquake in the areas where they are applied, irreversible damages such as separation, cracking and level difference occur in structures and building materials. In order to prevent these damages, the joints are left between the building materials and the gaps are filled with filling materials. The composition of the materials filling the joint gaps is also very important. The most important problems encountered in joint fillings are rupture, cracking and therefore permeability. In this study, it is aimed to compare the joint filling materials produced from different proportions of aggregate and white cement against rupture and cracking, and to determine the mixture ratio that exhibits the best performance. Five different recipes were prepared by using calcite powder as aggregate, white Portland cement as binder and water-repellent, volumizing and thickening chemical additives as auxiliary materials. On the prepared test samples; Capillary water absorption, water absorption by weight and volume, unit volume weight, saturated unit volume weight, porosity, compressive strength, bending strength, surface hardness and abrasion resistance tests were carried out. Considering the cost and environmental damage of cement, which is one of the main components in joint filler material, DD2 [Calcite (71.50%)] + White Cement (26.50%) + [Polymer + Cellulose + Plasticizer + Silicone] 2% has been detected as the most appropriate recipe.

Keywords: cement, joint filling, calcite, building materials

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1. Introduction

Throughout the history of humanity, the level of use of industrial raw materials has been an indicator of the level of development and welfare of all societies. As a result of its geological position, Turkey is one of the few countries that can meet most of its industrial raw material needs in terms of diversity and reserves. Turkey ranks 28th in the world in mineral production and 10th in the variety of minerals produced [1]. While 13 of the 90 types of mines traded in the world have not been found in Turkey, it is known that 50 of the remaining mines are quite rich or rich as reserves. Nearly 30 mines have insufficient resources in terms of reserves. Turkey is one of the countries rich in marble, boron, magnesite, pumice, gypsum, perlite and calcite [1].

Calcite is used as an industrial raw material in many fields such as construction, paper, plastic pipes, paint industry, glass, agriculture and medicine. There are three characteristics that define the quality of ground calcium carbonate (GCC), which is used as an industrial mineral, namely grain diameter, colour and chemical purity [2, 3]. The purest whiteness in Turkish calcite deposits was determined in the fields located in the Niğde region. It was also used in this study [4, 5]. A joint is a discontinuity between continuities [6]. In ceramics and similar construction materials, changes in volume (expansion-contraction) may occur in the face of temperature differences, humidity, changing weather conditions and physical effects (earthquake effect-mechanical effects-deformation stresses). Therefore, they should definitely be laid with joints in order not to encounter irreversible or even costly consequences [7, 8]. In addition to leaving joints in ceramic coatings, the material used together with the method of application is also an important factor. Otherwise, if the joint gaps are filled with inflexible white cement and similar hard materials without additives, this will have an effect on the building materials in the coating as if they were laid without joints [9]. In order to obtain positive results, in addition to the cement-based filling materials, performance, workability, resistance to cracking, permanent colour due to the chemicals it contains and smooth surface should be preferred [10]. Joint fillers with anti-bacterial properties should be chosen for wet areas. They offer different characteristics according to the regions for cold and hot climates [11, 12]. The main objective of the study is to determine the most accurate ratio, to contribute calcite, which is abundant in nature, to the economy, and to reduce the use of environmentally undesirable cement.

2. Materials

Calcite, which is one of the main components of the filling material used between the joints of the ceramics, which is the floor covering material used in the buildings, was supplied in ground form from Niğtaş company in Niğde-Turkey to be used within the scope of the study. PÇ 52.5 was preferred as the white Portland cement used as the binder and it was obtained from Çimsa company (Fig. 1). Construction chemicals that provide water repellent, thickener and cause impermeability were supplied by the intermediary firm in Kahramanmaraş city (Fig. 1).

Fig. 1. Materials used in combinations

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3. Methods

3.1. Determining the mixing ratios

In this study, 24%, 26.5%, 29%, 31.5%, 34% of white cement were added to the total mixture in order to determine the most appropriate ratio of calcite used as aggregate and white cement used as binder in the production of ceramic grouting material. DD1, DD2, DD3, DD4, DD5 samples were prepared (Table 1). In addition to white cement and calcite, in order to obtain the appropriate mixture, polymer as water repellent, cellulose volumizer, plasticizer as thickener and silicone (CA-30) for impermeability were added to the mixture in total 2% (Table 1).

Table 1. The combinations for the prepared joint filler samples

Sample No	Ingredients
DD-1	Calcite (74.00%) + White Cement (24.00%) + [Polymer+Cellulose+Plasticizer+Silicone (2%)]
DD-2	Calcite (71.50%) + White Cement (26.50%) + [Polymer+Cellulose+Plasticizer+Silicone (2%)]
DD-3	Calcite (69.00%) + White Cement (29.00%) + [Polymer+Cellulose+Plasticizer+Silicone (2%)]
DD-4	Calcite (66.50%) + White Cement (31.50%) + [Polymer+Cellulose+Plasticizer+Silicone (2%)]
DD-5	Calcite (64.00%) + White Cement (34.00%) + [Polymer+Cellulose+Plasticizer+Silicone (2%)]

3.2. Sample preparation

Within the scope of joint filler production, white cement, calcite (calcite grain size 100 μ and below) polymer, cellulose, plasticizer and silicone were prepared in the proportions as given in Table 1 and mixed with a mixer to make it homogeneous (Fig. 2a). Then, water was added at a constant rate and mixed with white cement acting as a binder and calcite materials used as aggregate until a homogeneous image was obtained (Fig. 2b). In order to obtain a correct mixture into this homogeneous mortar obtained, water-repellent polymer, cellulose as a volumizer, fluid as a thickener and additionally some silicone to prevent lumps were added to the mixture (Fig. 2c÷d).

Fig. 2. Sample preparation: a) mixing calcite and white cement, b) adding water, c) adding chemicals, d) homogenous mixing of ingredients, e) preparation of molds, f) placing the mixture in the mold

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Finally, the joint filler obtained in a homogeneous form was lubricated during the stage of putting the mortar into the mold according to TS EN 12808 Part 3 [13] so that the samples could come out of the mold without any damage (Fig. 2e). In order for the mortar to be completely filled into the mold without any air gaps, the samples were placed with use of the shaking table. The rough surface in the upper part of the mold was removed with the help of a spatula to obtain a flat surface (Fig. 2f). The samples, which were left to dry, were carefully removed from the inserts of the test molds without damaging them after 24 hours.

3.3. Testing Methods

In order to determine some physical and mechanical properties of the joint filler samples obtained at different rates, the samples required for the planned experiments were prepared as required according to TS EN 12808 (2010) (Table 1). All the obtained test samples were subjected to tests after they had been kept in the laboratory environment for 28 days in order to make them usable in the experiments.

3.3.1. Unit volume weight and water absorption

Within the scope of the study, the weight found as a result of drying of the samples obtained for the determination of unit volume weights (UVW) was calculated as W_1. The values obtained by measuring the dimensions of the test samples with a caliper are used in the volume calculation. Unit volume weight and water saturated unit volume weights were calculated according to the equation below.

$$UVW = W_1/V \text{ kg/cm}^3$$

In order to find the amount of water absorption by the samples, that were kept in the laboratory environment for 28 days, were put in an oven at 105° to dry and kept for one day, and then the dried samples were weighed and named as dry weight and W_{dry} was obtained. Then, the samples were left in the curing pool and the samples that were in the water for 24 hours were removed and named as saturated weight, and the W_{sat} was determined. In order to calculate the water absorption by volume, in other words the porosity, the volumes of the samples were calculated with a caliper and expressed as V. Water absorption percentage was calculated by substituting W (%) in the equations below.

$$\text{Water absorption by weight (\%)} = [(W_{sat}-W_{dry}) / W_{sat}] \times 100$$

$$\text{Water absorption by volume (\%)} = [(W_{sat}-W_{dry}) / V] \times 100$$

The samples taken for capillary water absorption test are made in order to determine how much water is absorbed by the sample, which is kept in water for the periods determined according to TS EN 12808 Part 5 [14] (30 min, 240 min). The first weight measurement of the samples was made with use of precision scales and recorded. After the weight measurement, 5 mm and 10 mm markings were made on the clean surface of the samples, which was smoothed with a spatula. Then, the samples were brought into contact with water up to a minimum of 5 mm with the marked surface facing down, and after waiting for 30 minutes, they were removed and the wet surface of the samples was wiped with a cloth and the measurements were taken again with use of precision scales. The sample was put back into the water and kept in water for another 210 minutes to complete 240 minutes, and the experiment was completed by taking the weight values in the same way.

3.3.2. Böhme abrasion test

The wear resistance determination of the joint filler samples, obtained in this study, was carried out according to the standards in the Böhme abrasion test TS 699 [15, 16]. Five samples, representing the mixture for each group, were cut into cubes with a side length of 71 ± 1.5 mm in accordance with mentioned standard and produced with a base area of 50 cm². The Böhme abrasion test is to determine the volume loss that occurs as a result of 16 cycles consisting of a total of 22 cycles by pouring corundum (crystalline Al_2O_3) powder as an abrasive on a rotating steel disc and exposing the sample placed on the rotary table to the pressure of 0.06 N/mm² on the contact surface area.

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As the first step, the weights of the samples to be tested are calculated using precision scales (Fig. 3a). Then, 20 ± 0.5 g of abrasive powder are added evenly in a circle on the friction path of the test device (Fig. 3b). The sample to be tested is placed in its slot on the test device and the device is set to run for 22 cycles. The experiment is started, and when the number of cycles is completed, the rotating disc stops automatically, thus completing the 1st cycle (Fig. 3b). The test samples are rotated to 90 degrees and continued until 4 cycles are completed. The test is completed by making 352 cycles in total. Afterwards, the samples are cleaned with a brush without being damaged and then weighed. The obtained values are calculated according to the following formula [15, 16].

$$\text{Abrasion resistance } (cm^3/50cm^2) = \frac{\text{Weight loss after 352 cycles}}{\text{Unit volume weight}}$$

3.3.3. Bending strength

The bending strength of the obtained joint filler materials was determined on samples with dimensions of 40x40x160 mm according to the standard TS EN 12808 Part 3 [13]. The tests were carried out by applying the 50 N load with the "Zwick/ 2010 Universal Test" device, which can perform bending, tensile and compression tests with a capacity of 20 kN. Bending strength was measured by mid-point loading method, adjusting the support span to be 2.5 times the sample height on average. The tests also consisted of 5 repetitions and the averages were taken (Fig. 3c).

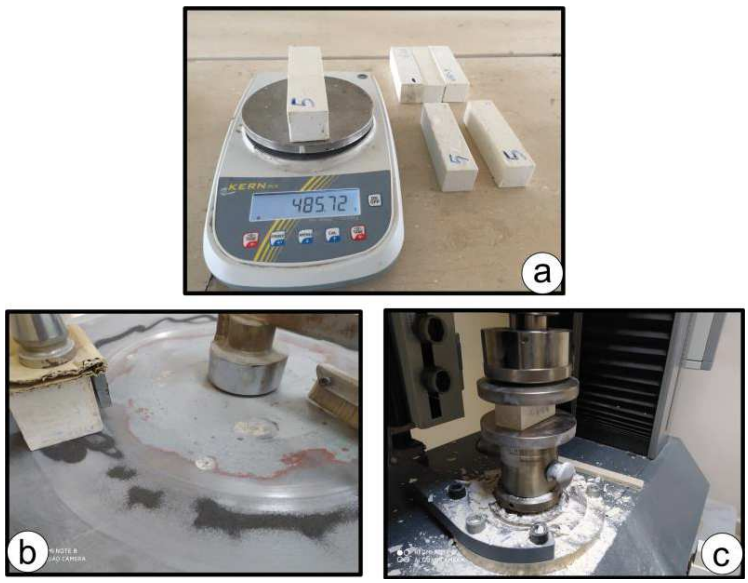

Fig. 3. a) Weighing of samples, b) Böhme abrasion test, c) Bending-compressing strength test

3.3.4. Compressive strength

The samples to be used for the compressive strength test were selected from the pieces that were broken during the bending test, larger than 4×4×4 cm. The loading speed of the samples, placed between the compression jaws, which is the special accessory of the Zwick Roell/2010 Universal Tester, was determined as 2400 N per second. The compressive strength test of the obtained joint fillers was carried out in accordance with TS EN 12808 (2010) Part 3. An analysis was carried out on 5 samples for each combination of the material compiled in accordance with the standard (Fig. 3c).

4. Discussion and results

All of the tests were carried out according to the TS EN 12808 (2010) standard, and the required value ranges according to the aforementioned standard are given in Table 2.

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Table 2. Required value ranges in TS EN 12808 (2010) standard for joint filler tests

Experiments	Standard Values	TSE Standard
Water absorption (30 minutes)	≤ 5 g	EN 12808-5
Water absorption (240 minutes)	≤ 10 g	EN 12808-5
Abrasion resistance	≤ 2000 mm^3	EN 12808-2
Shrinkage	≤ 3 mm/m	EN 12808-4
Surface hardness	≥ 40	EN 12808-3
Bending strength	≥ 2.5 N/mm^2	EN 12808-3
Compressive strength	≥ 15 N/mm^2	EN 12808-3

Unit volume weight (BHA) and saturated unit volume weight (DBHA) values of joint fillers are given in Fig. 4, respectively. The specific gravity tests performed on the blocks, on the other hand, were obtained from the DD5 sample with the highest as 1.51 g/cm^3; the lowest value was measured from the samples 1.43 g/cm^3 from DD1 sample (Table 3, Fig. 4).

Table 3. Unit volume weight and water absorption tests results

	Unit volume weight	Saturated Unit volume weight	Water absorption by weight			Water absorption by volume	Capillary water absorption	
			30 minutes	240 minutes	24 hours	24 hours	30 minutes	240 minutes
Standard	*	*	*	*	*	*	5 g	10 g
DD-1	1.43	1.79	16.97	22.42	26.92	38.57	6.2	10.3
DD-2	1.44	1.82	15.44	21.72	25.72	38.41	5.7	9.7
DD-3	1.46	1.84	15.05	20.83	25.57	38.32	4.9	9.3
DD-4	1.48	1.86	14.37	20.04	25.33	38.21	4.6	9.1
DD-5	1.51	1.88	13.59	19.42	24.18	37.98	4.1	8.8

It was observed that the specific gravity increased with the increase of the white cement ratio, while the unit weight values decreased with the increase of the calcite ratio acting as aggregate. When the water-saturated unit volume weights are examined, parallel values with the unit volume weight were observed (Table 3, Fig. 4).

A decrease was observed in the water absorption values of 30 minutes, 240 minutes and 24 hours, respectively, as regards DD1 to DD5, as the amount of cement increased. The maximum water absorption value at the end of 24 hours was 26.92% in DD1, and the minimum was 24.18% in DD5. The water absorption values by volume were measured as 38.57%, 38.41%, 38.32%, 38.21% and 37.98%, respectively, as regards DD1 to DD5. It was observed that the porosity decreased as the specific gravity values of the materials increased depending on the amount of cement (Table 3, Fig. 5).

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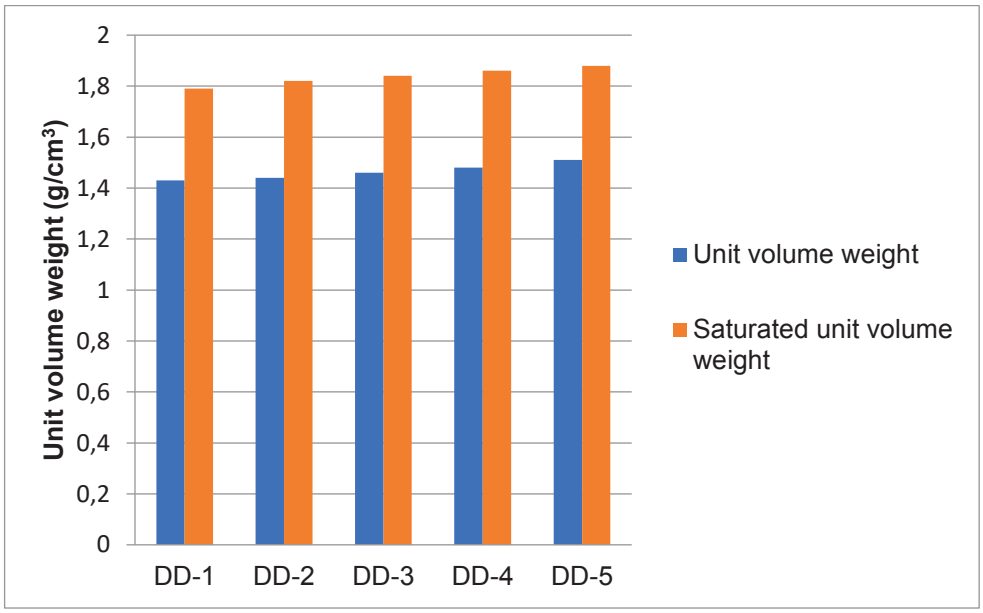

Fig. 4 Unit volume weight of the samples

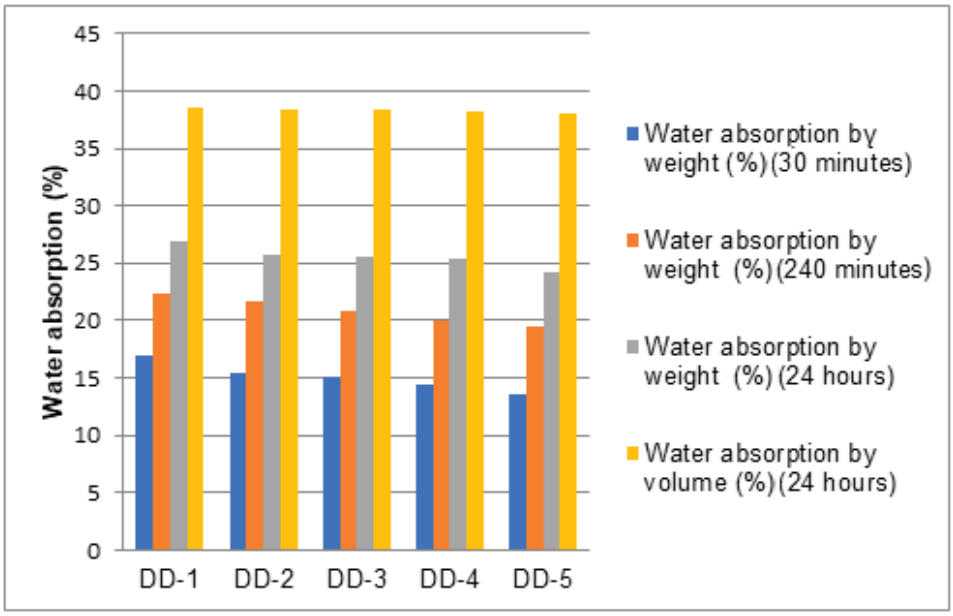

Fig. 5. Water absorption by weight and volume water absorption of the samples

The capillary water absorption rate is a parameter of primary importance in the case of joint filling materials, which is the main subject of this study, and the tests were carried out as specified in TS EN 12808 (2010). It is requested that the capillary water absorption value should not exceed 5 grams within 30 minutes and 10 grams within 240 minutes (Table 2). In Fig. 6, the relationships between DD1 and DD5 water absorption in the joint filling material within 30 minutes and 240 minutes are presented graphically. It was observed that the water absorption amount did not exceed the critical values, except for DD1 and DD2 after 30 minutes, and except for DD1 after 240 minutes. After the obtained joint filling mortars were used in the application area, solidified and hardened, an increase of the cement ratio by reducing the calcite ratio of the total volume significantly increased the capillary water absorption value (Table 3, Fig. 6). By increasing the calcite utilization rate, the water absorption rate of the final product will increase.

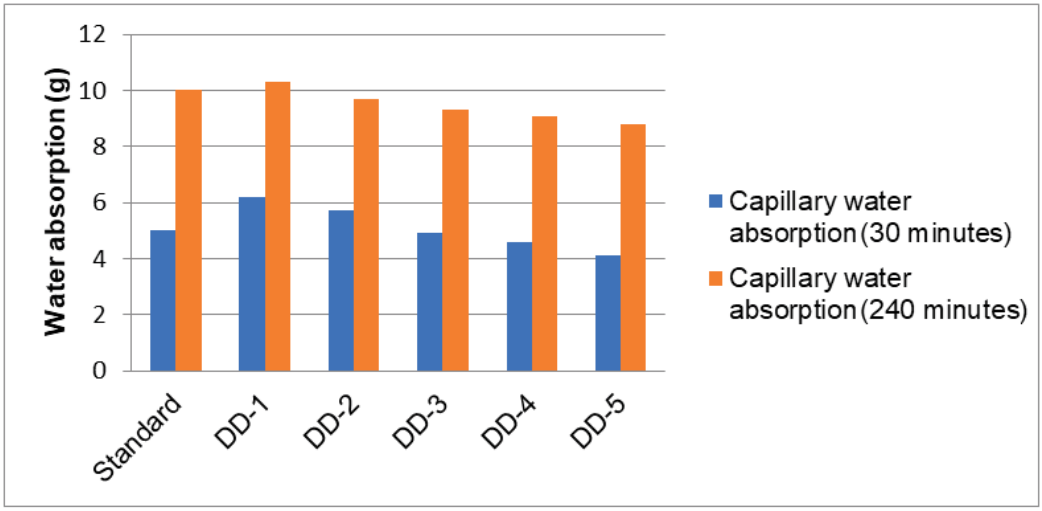

Fig. 6. Capillary water absorption of the samples

Table 4. Abrasion resistance, bending resistance and compressive strength results

	Abrasion resistence		Bending strength			Compressive strength		
	Weight loss (g)	Abrasion resistance ($cm^3/50cm^2$)	3 day	7 day	28 day	3 day	7 day	28 day
Standard	*	*	*	*	2.5	*	*	15.0
DD-1	11.33	31.69	1.88	2.4	3.29	9.31	11.1	15.13
DD-2	7.44	20.64	2.01	2.66	3.78	10.23	12.6	16.61
DD-3	6.84	18.72	2.21	2.87	3.99	12.35	13.9	16.92
DD-4	5.88	15.88	2.29	3.01	4.11	13.13	16.1	18.29
DD-5	4.71	12.44	2.98	3.32	5.12	14.67	17.2	19.91

In Fig. 7, the relationships between the abrasion resistance of the joint filler material and the weight loss are given. While the highest amount of wear was 11.33 g in the DD1 sample, the lowest amount of wear was measured as 4.71 g in the DD5 sample. Abrasion resistances were determined as 7.92, 5.16, 4.68, 3.97, 3.11 in samples DD1, DD2, DD3, DD4 and DD5, respectively. Considering this situation, it is seen that a more durable joint filling material is obtained in terms of abrasion resistance when the calcite ratio in the joint filler material is decreased and the cement ratio is increased (Table 4, Fig. 7).

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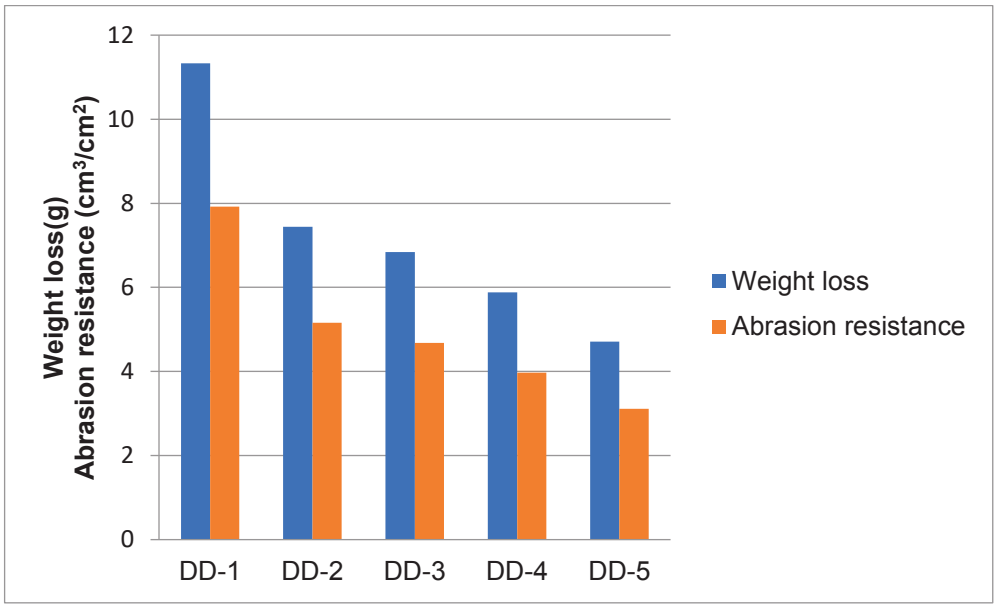

Fig. 7. Abrasion resistance test results of the samples

The results of the bending strength tests are given in Table 4. The tensile strength after 3, 7 and 28 days of bending in the obtained joint filler samples are given in Fig. 8.

According to TS EN 12808 standard, joint filler materials after 28 days are required to have the bending strength of at least 2.5 MPa. According to the results from the 3-day test samples, only DD5 ≥ 2.5 MPa is above the threshold. According to the 7-day test results, all samples except DD1 are within the required range in the standard, and according to the 28-day results, it is observed that all samples are within the required value in the standard. At the end of 28 days, the lowest bending strength was 3.29 MPa in the case of DD1; the highest bending strength value was 5.12 MPa in the case of DD5 (Table 4, Fig. 8).

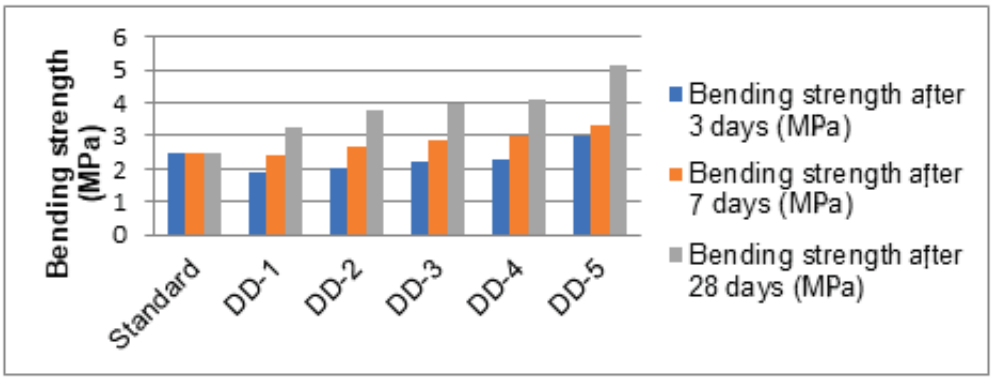

Fig. 8. Bending strength of the samples

As in the case of the bending strength tests, tests on compressive strength were carried out in accordance with Part 3 of TS EN 12808 [13]. Accordingly, the compressive strength of the joint filling material is required to be ≥ 15 MPa or more (Table 2). Compressive strength results after 3 and 7 days for DD1, DD2, DD3, DD4 and DD5 were 9.31÷11.05 MPa, 10.23÷12.62 MPa, 12.35÷13.87 MPa, 13.13÷16.11 MPa and 14.67÷17.24 MPa obtained respectively. For the same samples the 28-day compressive strength values were obtained as 15.13 MPa, 16.61 MPa, 16.92 MPa, 18.29 MPa and 19.91 MPa respectively.

In the case of the 3-day test results, none of the samples are within the required range, while after 7 days DD3 (16.11) and DD4 (17.24) are within the required ranges. According to the 28-day test results,

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all of the samples except DD1 are in the range of values (≥ 15 MPa) required in the standard (Fig. 9, Table 4).

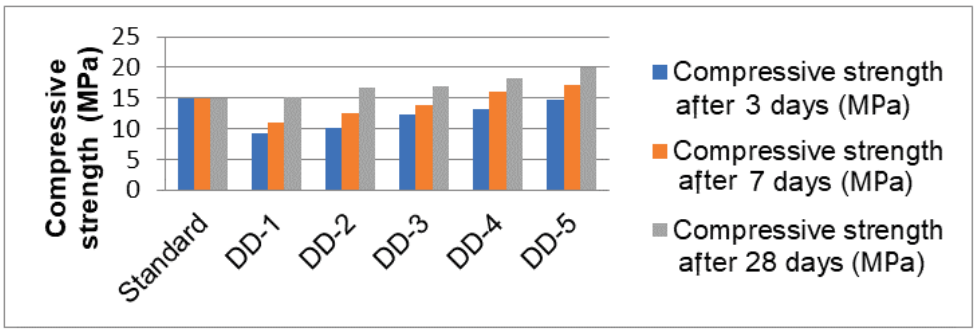

Fig. 9. Compressive strength of the samples

5. Conclusions

As conclusions:

- With the decrease of calcite in the total mixture ratio and the increase of cement, the unit volume weight and saturated unit volume weight values increased, and the water absorption values by weight and volume decreased inversely.
- Considering capillary water absorption, since reducing the use of cement in the joint filling material is among the primary objectives of the study, it can be concluded that the most ideal example was DD3 after 30 minutes and DD2 after 240 minutes; a better joint filling material can be obtained in terms of water absorption.
- An increase of the cement ratio in the mixture increased the wear resistance and it was observed that the sample with the highest wear resistance was DD5.
- According to the 28-day bending test results, it was observed that all the samples were within the required value in the standard, while the 28-day compressive strength was found to be within the required (≥ 15 MPa) values in the standard, except for DD1.
- Even if the sample DD5 gave the best results in compressive strength and bending strength, it would be correct to say that the sample with the most appropriate ratio was DD2, considering the determination of the correct ratios.
- In this study, the use of excess cement was prevented and positive results were obtained both in economic and environmental terms.
- Although it is very important to choose the correct component ratios in the joint filler material, it should be ensured that it contains less water in the mixture by using either direct impermeability additives or water-repellent chemical additives, and thus special joint fillers can be produced.

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