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Effect of Using Recycled Colemanite Waste and Cathode Ray Tube Glass in the Cement Mortar on Physical and Mechanical Properties

Salih Taner YILDIRIM [1], Arif YILMAZOĞLU [2,*]

[1] *Department of Civil Engineering, Kocaeli University, Kocaeli, 41380, Turkey,* ***ORCID:*** *0000-0003-0021-0625*
[2] *Department of Civil Engineering, Kocaeli University, Kocaeli, 41380, Turkey,* ***ORCID:*** *0000-0002-3995-3904*

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Abstract

In this study, the performance of colemanite, which is a valuable boron waste, and recycled cathode ray tube glass (CRT) in the cement mortar was examined by experimentally. Colemanite waste (CW) and CRT were replaced with cement and aggregate and used as mineral additives, and their effect on the physical and mechanical properties (PP and MP) of mortar was investigated. In addition to the reference sample that didn't contain CW or CRT, seven more samples were used. In these samples, cement was used at a rate of 2.5% along with CW, and the aggregate was replaced with CRT at the rates of 10%, 20%, and 30%, and with the combination of CW and CRT. The workability, unit weight, and water absorption, compressive strength (CS), flexural strength (FS), and abrasion resistance properties of the mortars were compared. As a result of this study, it has been observed that the use of waste materials can make positive contributions to some of the PP and MP of the mortar. Thus, the goal of both improving the properties of the mortar and making it affordable by using waste materials were achieved.

1. Introduction

Mortar generally serves as a binder between wall units made of materials such as brick, briquettes, and autoclaved aerated concrete, or as a plastering material to protect the walls against external factors and improve the aesthetic appearance. The mechanical and physical properties expected from a good mortar mixture are resistance to external factors, low permeability, void-free structure and good adhesion to surfaces. In order to provide and develop these desired properties, additives are also occasionally utilized in mortars.

In today's world, where the problem of sustainability has become an increasingly widespread issue with the consumption of natural resources, the needs of the constantly developing construction sector are increasing and varying day by day. It is now an economic need for the construction industry to develop sustainable, eco-friendly mortar and concrete products from non-organic industrial waste products. The number of studies that examine how the using different industrial wastes as alternative materials improve the properties of mortar and concrete, and reduce costs, energy consumption, and environmental pollution with the elimination of these wastes is increasing every day.

Turkey is a boron-rich country, which is an industrial raw material. Thanks to technological developments in recent years, the number of sectors where boron is used has been increasing. Industrial applications for the utilization of boron waste by reusing it in concrete and thus reducing environmental pollution are limited. There are some studies in the literature where the waste of colemanite concentrator, a type of boron mineral, is used as an admixture in cement manufacturing, and PP and MP of that cement, such as the concrete slump test, FS, CS, and shrinkage were investigated. In the study conducted by Sevim [1], the concrete produced by using colemanite waste (CW) at the rates of 3%, 5%, 10%, and 15% was observed in terms of its properties of shrinkage, CS, and splitting tensile strength. As the result, in comparison to the reference sample, the new type of concrete produced by the addition of CW in the

* Corresponding Author: arifyilmazoglu69@gmail.com

mixing ratios of 3% and 5% was observed to have higher 28-day CS and tensile strength, and 37% less drying shrinkage. Mushurov et al. [2] used CW at rates of 5% and 7% and metakaolin at rates of 20% and 30%, it was concluded that the rates of colemanite used in the study significantly reduced the 28-day CS and FS. Gencel et al. [3] used CW in concrete, replacing aggregate with CW at 10%, 20%, 30%, 40%, and 50% aggregated and examined their mechanical and physical properties. It is observed that the best result is provided by 10% colemanite replacement, and which somewhat increases the slump and unit weight value. Conversely, the CS and FS decreased at all respective rates.

Considering the storage, disposal, and transportation costs, as well as the increase in the daily accumulation of waste glass (WG) in recent years, which is the most widespread waste material in the world, an urgent solution to eliminate WG is being sought. In addition to the glasses that can be found in many different colours and textures in different industries, there are many other kinds of glass, such as window glass, bottle glass, LCD screen glass, and cathode ray tube (CRT) glass, etc. [4-10]. While it is necessary in the glass industry to separate and recycle different types of glass and use one kind of glass during production, all kinds of WG can be used in cement-based mortar and concrete without the need to separate [9-10]. There are industrial applications for the utilization of the WG by reusing it in mortar and concrete, thus reducing environmental pollution. Kou and Poon [11] investigated the properties of self-consolidating concrete produced by replacing river sand with10 mm recycled glass aggregate at rates of 5%, 10%, and 15%. Based on the test results, it has been observed that CS, tensile strength, modulus of elasticity, and drying shrinkage decreased with the increase of the WG content in the recycled glass aggregate concrete while the chlorine ion penetration resistance increased. The properties of a new type of concrete produced by replacing fine aggregate with recycled glass at the rates of 10%, 15%, and 20% were investigated through experimental methods by Ismail and Al-Hashmi [12]. After 28 days of experiments in which it was observed that the WG increases the pozzolanic effect, it was concluded that CS value of the samples produced by using 10% and 15% recycled glass aggregate was lower than that of the reference samples, while an increase was seen in the values of FS and CS of the samples produced by using 20% recycled glass aggregate. In the study conducted by Kavas et al. [13], the use of glass wastes that are recycled into fine grains in the manufacturing of cement as an additive was investigated. For this purpose, WG was added to the cement at the rates of 5%, 10%, 15%, 20%, 25%, and 30% in the preparation of mortar. After the experiments, in line with the increasing WG, an average of 9% decrease in the 90-day CS and a 2.4% decrease in FS were observed in all produced cement groups. Despite these results, it has been observed that even though introducing WG additives into cement up to a rate of 30% causes loss of MP; it is possible to use this type of cement in areas like field concrete, in which strength values do not come to the fore.

When the glass contacts concrete, cement, or mortar, the alkalies in these materials affect the silicates in the glass, causing alkali-silica reactions (ASR), and as a result, expansion and internal stresses occur. Since ASR does not occur when there is no moisture in the environment, it is indicated that glass aggregate concrete should not be used in an environment where it may be exposed to water [10]. Although not all kinds of glass cause ASR, it is necessary to check whether the kind of glass being used triggers an ASR reaction in the mortar before use, and if it occurs, the necessary additives should be used for protection [4, 9, 14, 15]. In the studies conducted by Topçu et al. [14], it was stated that ASR causes expansion increases, and internal stresses in direct proportion to the increase in the amount of WG in the concrete. In order to decrease the expansion and keep it under the critical level, fly ash surpassing 20%, and the chemical additive of Li_2CO_3 at the rate of 2% should be utilized. In addition, it has been observed in various studies that whether the glass is colourless, brown, or green has an effect on expansion, and colourless glasses cause the biggest expansion [4, 14, 15]. In their literature review, Saha et al. [16] stated that the replacement of cement with silica fume, blast furnace slag, and fly ash in order to reduce ASR in active glasses has proven to be effective in many studies. In a study conducted by Yildirim [9], in which cement was replaced with CRT glass at the rates of 5%, 10%, 15%, and 20%, new types of concrete samples with good consistency and increased unit weight, and reduced water absorption capacity were obtained. In the new concrete, a slight decrease in the 28 and 90-day CS and FS, a slight increase in the modulus of elasticity, and a slight decrease in abrasion were obtained due to the increase of the glass content in the concrete. Also, ASR expansion values determined with the ASTM C1260-07 [17] were found to be well below the 0.1% limit value for all samples. One of the problems that arises when glass aggregate is used in concrete because of the cracking of the glass and the spreading of these cracks within the concrete [9, 14, 18, 19]. According to Siddiqui et al. [20], the smooth surface of the glass facilitates crack movement, which negatively affects strength. The FS of mortar samples containing glass aggregate can be 10% less. In addition, when the size of the aggregates is increased from 1 mm to 3 mm, it is seen that the strength and resistance to cracks increase. In the study carried out by Batayneh et al. [21] in which WG, plastic, and broken concrete pieces were added at rates of 5%, 10%, 15% and 20% to the concrete being produced, and CS, FS, and the splitting tensile strength of the concrete were tested. The researchers stated that there is an increase in CS value, especially in the splitting and FS values of the glass aggregate concrete.

In this study, the performance of CRT glass and CW a valuable boron waste in the mortar was examined. CW and CRT glass were replaced with cement and aggregate, and used as mineral additives, and their effect on the PP and MP of the mortar was investigated. Together with the reference sample, a total of eight samples were used in which cement was replaced with CW at the rate of 2.5%, and aggregate was replaced with CRT glass at the rates of 10%, 20% and 30%, and with the combination of CW and CRT glass. The workability (flow), unit weight, water absorption, CS, FS, and abrasion resistance properties of the mortars were compared. This experimental study intended to improve certain PP and MP of the mortar with the use of waste materials as well as to provide an affordable alternative and environmental protection with the utilization of these materials.

2. Materials and Method

2.1. Materials

The analyses of cement, CW, and CRT properties are given in Table 1. The cement used in this study was supplied from Nuh Cement Factory and was CEM I/42.5 R cement conforming to TS 197-1 [22]. The CW used in the study was obtained from Kütahya Emet Eti Mines. On the other hand, CRT is milled and recycled by a company called Exitcom operating in Kocaeli. River sand in the range of 0-4 mm was used in the mortar. Figure 1 shows CRT and CW materials. CRT was obtained from the company as ground, with the CW sample, it was obtained from the waste piles in the quarry in its current form. Since it was proven that the CRT sample did not cause any problems in terms of ASR in the study performed by Yildirim (2018), the ASR test was not performed again in this study [9].

As seen in Figure 2, CRT has a fine distribution and sand has a coarser distribution. Here, it is aimed that the curve will approach the more ideal Fuller-Thompson curve since it will pull the curve up a little if CRT is used [23]. For this purpose, CRT10, CRT20, and CRT30 mixtures were made by replacing 10%, 20%, and 30% sand with CRT, and their granulometric compositions were shown. As can be seen, the increase in the CRT ratio brought the curve closer to the Fuller-Thompson curve. The CW material was used here as a mineral cement additive and was added to the mortar at the rate of 2.5% of the cement.

Reference sample, CW (2.5%) sample, three different 10%, 20% and 30% CRT samples, and 3 different CW (2.5%) + 10% CRT, CW (2.5%) + 20% CRT, CW (2.5%) + 30% CRT samples with mix designs seen in Table 2 were used in the study. From the mortars produced from the samples, six samples of 40x40x160 mm in size were used for unit weight, water absorption, FS and CS tests, and three samples of 71x71x71 mm in size for abrasion tests.

2.2. Method

The eight types of samples produced were first subjected to the flow table test according to ASTM C 1437 in the fresh state of the mortar and their spreading diameters were measured as the flow value [24]. Then, six samples of 40x40x160 mm and three pieces of 71x71x71 mm were kept in water until they were 28 days old after they were taken out of the mold. Three 40x40x160 mm samples were dried and weighed after they came out of the water, and their saturated dry surface weights were found. The dry weights were found by weighing the samples

(a) CRT (b) CW

Figure 1. Physical appearance of the CRT and CW.

Table 1. Properties of cement, CW and CRT.

Chemical properties				PP and MP			
Constituent (%)	**Cement**	**CW**	**CRT**	**Properties**	**Cement**	**CW**	**CRT**
SiO_2	20.5	18.77	50.9	Specific gravity (g/cm^3)	3.12	2.42	2.70
Al_2O_3	4.65	5.23	2.62	Blaine (m^2/kg)	360	102	-
Fe_2O_3	3.40	1.98	0.12	Mass stability (mm)	2.00	-	-
CaO	62.7	17.59	1.54	Starting setting time (min)	153	-	-
Free CaO	1.09	-	-	Final setting time (min)	188	-	-
MgO	1.02	6.78	0.64	90 µ sieve (%)	0.20	-	-
SO_3	2.21	0.20	-	45 µ sieve (%)	12.8	-	-
Na_2O	0.18	0.08	3.60	2-day strength (MPa)	30.2	-	-
K_2O	0.41	1.40	4.30	7-day strength (MPa)	51.1	-	-
PbO	-	-	0.29	28-day strength (MPa)	62.2	-	-
BaO	-	-	9.10				
Sb_2O_3	-	-	0.31				
ZrO2	-	-	0.91				
SrO	-	-	5.97				
TiO	-	-	0.39				
CeO_2	-	-	0.25				
B_2O_3	-	28.28	-				
Insoluble residue	0.60	-	-				
Ignition loss	2.15	0.54	-				

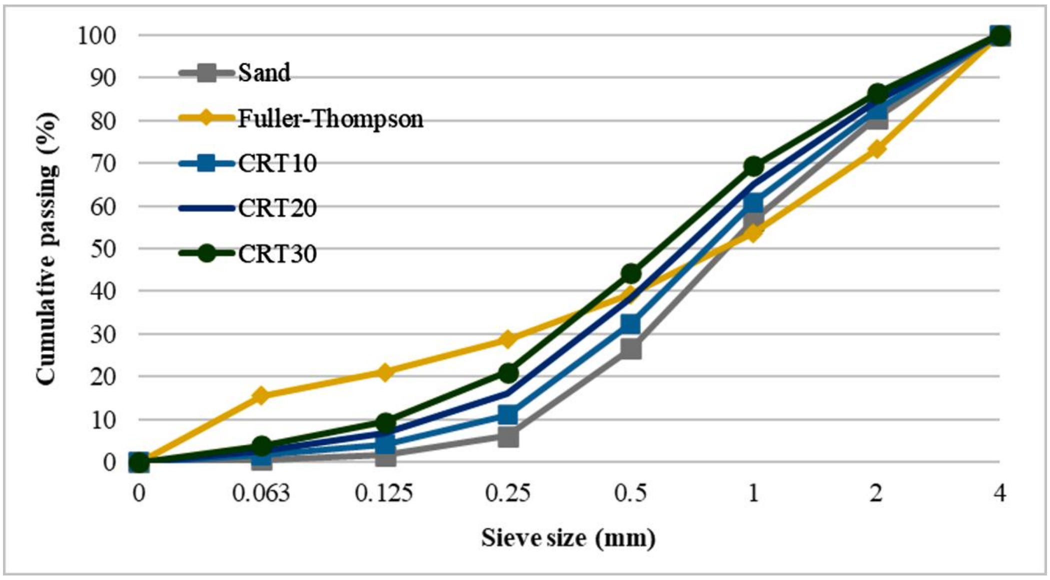

Figure 2. Particle size distributions of sand, CRT10, CRT20 and CRT30.

Table 2. Mortar mix designs.

Materials	**Type of the mortars (kg/m^3)**							
Compound	**R**	**2.5CW**	**CRT10**	**CRT20**	**CRT30**	**2.5CW/CRT10**	**2.5CW/CRT20**	**2.5CW/CRT30**
CEM I 42.5	350	341.3	350	350	350	341.3	341.3	341.3
CW	0	8.75	0	0	0	8.75	8.75	8.75
Sand	1050	1050	945	840	735	945	840	735
CRT	0	0	105	210	315	105	210	315
Water	175	175	175	175	175	175	175	175

to a constant weight for at least 24 hours in the oven. Dry unit weights were calculated by proportioning the sample weights to their volumes, and water absorption rates were calculated from the difference (%) between the two weighings [25]. The other 3 samples of 40x40x160 mm were subjected to a 3-point flexural test according to EN 196-1 and their FS were found. Again according to the same standard, the CS of the samples was found by breaking the 40x40 mm part into a cubic shape [26]. Samples with dimensions of 71x71x71 mm were subjected to the Böhme abrasion test according to EN 13892 [27]. The samples were subjected to abrasive action on the horizontal rotating disk, 16 times each time, and 22 rotations each time. Volumetric material losses from the surface of the samples were determined.

3. Experimental Results

3.1. Workability (Flow)

As it is seen in Figure 3, the flow of all samples containing admixtures is higher than that of the reference sample. The 2.50% replacement of cement with CW provides a 5.33% increase in flow with an increase of 8 mm [3], and an increase of up to 20% has been achieved by providing an increase of approximately 40 mm in the use of CRT [10]. The use of both colemanite and CRT increased slightly, reaching a difference of approximately 50 mm compared to the reference sample. Using the amount of CRT at the level of 30% reduces the flow compared to the levels of 10% and 20%.

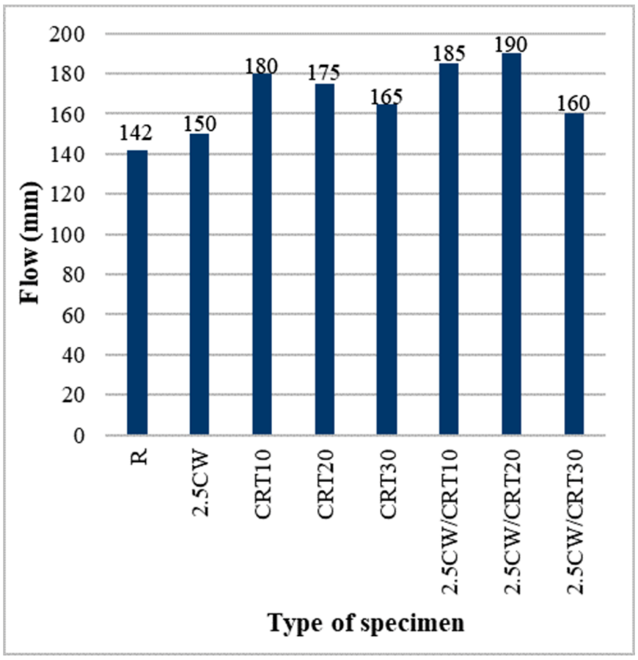

Figure 3. Flow value of the mortar samples.

3.2. Dry Unit Weight and Water Absorption

As can be seen in Figure 4, the addition of CW caused a unit weight increase of about 0.50% while reducing the water absorption by about 3% [3]. While the increase in the amount of CRT, the water absorption increased by about 11% and the unit weights increased by about 0.50%. In addition, water absorption decreased by about 20% compared to the reference sample by making a very serious decrease with the use of both CW and CRT [10]. On the other hand, the unit weight increased by 1.50% on average. Here, using CW and CRT together gave the best results.

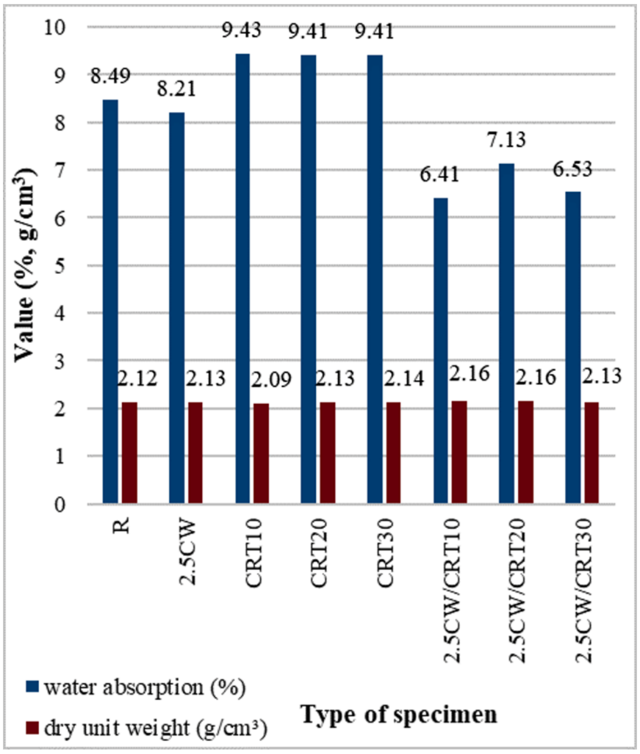

Figure 4. Dry unit weight and water absorption values of the mortar samples.

3.3. Compressive Strength (CS) and Flexural Strength (FS)

In Figure 5, it is seen that the CS and FS of the mortar reduce with the increase in the amount of additive. The addition of CW provided a very small increase in mortar strength compared to the reference sample [1, 3]. However, the use of CW and CRT together in mortar caused reductions of up to 30% in FS and up to 40% in CS [11, 20]. The replacement of up to 20% of sand with CRT resulted in a CS reduction of close to 5 MPa and a FS reduction of 0.17 MPa by remaining in more acceptable ranges [13].

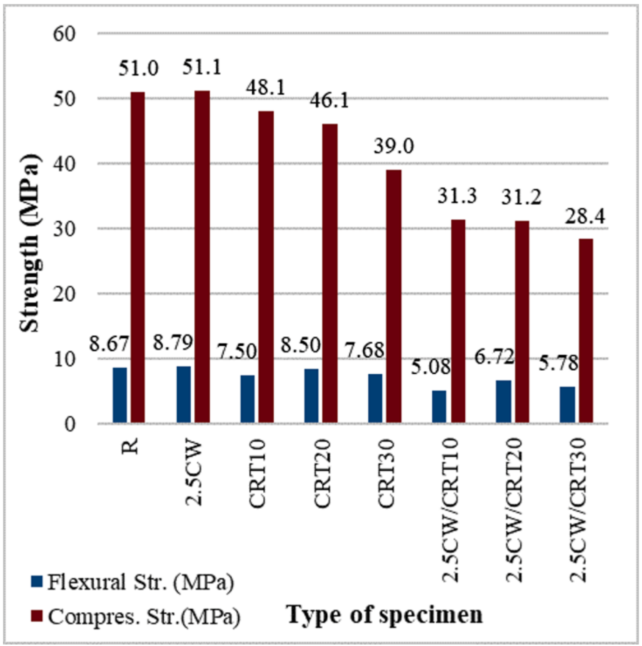

Figure 5. CS and FS of the mortar samples.

3.4. Abrasion Resistance

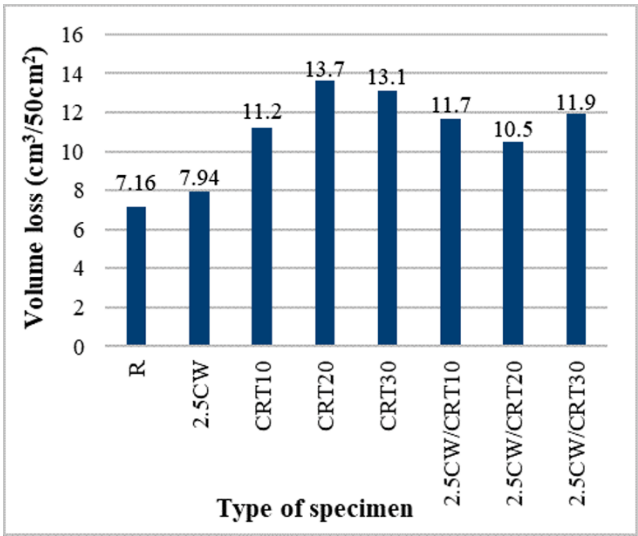

Figure 6. Volume loss in mortar samples as a result of abrasion.

In Figure 6, it is seen that the lowest volume loss as a result of abrasion occurred in the reference sample with 7.16 cm^3. On the other hand, the CRT20 sample showed the highest volume loss value of 13.7 cm^3, with an increase of 47.6%. Yildirim [9] found that the addition of WG reduces the abrasion loss of concrete. According to this; the contribution of the coarse aggregate used to the abrasion resistance can also be taken into consideration. Although the volume loss values of the CRT-added mortars were higher than the reference sample when CRT was used together with CW, it gave approximately 35% higher values on average compared to the reference sample by reducing volume loss slightly. The volume loss of the mortar sample containing only CW showed a closer value to that of the reference sample, with 7.94 cm^3.

4. Discussion

In Table 3, the literature findings of the studies on concrete/mortar produced with WG or CW are shown and compared with the results of this study. Considering the percentage of replacement, type of substitute, and type of waste, the effect of these parameters on the relevant experiment is shown. The expression "+" means that the relevant value has increased, the expression "-" means that the relevant value has decreased, and the expression "No change" means that the relevant value has not changed or has not changed significantly. The abbreviations F.A, C.A, P.C and LCD define fine aggregate, coarse aggregate, Portland cement and liquid crystal display, respectively. The abbreviations "vol. %" and "wt. %" refer to the percent replacement by volume and mass of the waste material, respectively.

As can be seen from Table 3, different types of WG and their use in different proportions had different effects on the workability value of concrete/mortar. In the literature studies, WG was mostly replaced with fine aggregate and used in concrete/mortar. The use of CRT as WG in concrete/mortar generally increased the slump value of the concrete/mortar [28, 29, 38, 41-45]. These findings support the results of this study. It was stated that the low water absorption, high density, and smooth surface of the WG may have increased the slump of concrete [41]. However, in some studies, it has been stated that the use of CRT causes a decrease in the slump of concrete [40]. In some studies [46], the addition of CW to concrete/mortar had a positive influence on workability, while in some studies [3] it had a negative effect. It was also reported that the addition of CW didn't have a remarkable effect on workability [47].

MP such as FS, CS, and splitting tensile strength of concretes containing WG varied according to the type of WG, percentage of replacement, smoothness of WG, and its adherence to cement paste. The addition of WG caused an increase in FS, splitting tensile strength and CS for studies [6, 28, 29, 31, 33-36, 38, 40, 41, 43, 44] but caused a decrease for studies [21, 32, 37, 39, 42, 45]. The 50% and 100% replacement of fine aggregate by volume with CRT caused a 21% and 32% reduction in CS of the concrete, respectively. FS of concrete samples with 50% CRT and 100% CRT decreased by 9% and 14%, respectively, compared to the reference concrete [28]. Ali and Al-Tersawy [34] replaced fine aggregate with WG at 10%, 20%, 30%, 40%, and 50% by volume. For 10%,

Table 3. Literature findings on the PP and MP of concretes/mortars containing WG and CW.

Ref.	Source	Replacement (%)	Type of Sub.	Slump/ Flow	Compressive strength	Tensile strength	Flexural strength	Density	Water absorption	Abrasion resistance
This study	CRT	10, 20 &30 (wt. %)	F.A	+	-		-	No change	+	-
[28]	CRT	50 & 100 (vol. %)	F.A	+	-		-		-	
[29]	CRT	25, 50, 75 & 100 (vol. %)	F.A	+	-		-	+	+	
[30]	Waste glass	20, 50 & 100 (vol. %)	F.A	No change	+/-		+	-	+	
[31]	Soda-lime silicate glass	10, 20, 30, 40 & 50 (wt. %)	F.A	+/-	-		-	-	-	
[21]	Waste glass	5, 10, 15 & 20 (vol. %)	F.A	-	+	No change	+	-		
[6]	LCD	20, 40, 60 & 80 (vol. %)	F.A	-	-	+/-	-			
[32]	Waste glass	25, 50, 75 & 100 (wt. %)	F.A	+	+	No change	No change			
[33]	Waste glass	10, 20 & 30 (vol. %)	C.A	-	-			-		
[34]	Waste glass	10, 20, 30, 40 & 50 (vol. %)	F.A	+	-	-	-			
[35]	Waste glass	15, 30, 45 & 60 (wt. %)	F.A	+	-	-		-	-	
[36]	Green waste glass	30, 50 & 70 (wt. %)	F.A	-	-	-	-			
[37]	Waste E-glass	10, 20, 30, 40 & 50 (wt. %)	F.A	-	+					
[38]	CRT	100 (wt. %)	C.A	+	-	-	-			
[39]	CRT	80 & 100 (wt. %)	F.A		+		+			
[40]	CRT	5, 15 & 25 (vol. %)	F.A	-	-		+/-	+		
[41]	CRT	25, 50 & 75 (vol. %)	F.A	+	-	-				
[42]	CRT	100 (wt. %)	F.A	+	+		+			
[43]	CRT	25, 50, 75 & 100 (vol. %)	F.A	+	-		-	+	-	
[44]	CRT	30, 60 & 100 (vol. %)	F.A	+	-			+	-	
[45]	CRT	25, 50 & 75 (wt. %)	F.A	+	+		+			
[46]	CW	2, 4, 6, 8, 10 & 12 (wt. %)	P.C	+	-			-		
[47]	CW	1, 3 & 5 (wt. %)	P.C	No change	+/-	+/-				
[48]	CW	1, 3, 5 & 7 (wt. %)	P.C	Fix	-				+	
[3]	CW	10, 20, 30, 40 & 50 (vol. %)	F.A and C.A	-	-	-		-		

20%, 30%, 40% and 50% WG replacement percentages, CS of the concretes reduced by 5%, 15%, 18%, 23% and 24% compared to the reference concrete, respectively. For 10%, 20%, 30%, 40%, and 50% WG replacement percentages, 9%, 15%, 16%, 24%, and 28% reductions occurred in splitting tensile strength of concrete, respectively. In addition, 3%, 11%, 12%, 23%, and 24% reductions in FS occurred for 10%, 20%, 30%, 40%, and 50% WG replacement percentages [34]. These literature findings are in agreement with the results of this study. Nevertheless, in some studies [30, 6, 40], the addition of WG caused both an increase and a decrease in MP of concrete. The addition of CW to concrete generally resulted in reductions in FS, CS and splitting tensile strength of concrete [3, 46-48].

The increment in the density of concrete containing WG is attributed to the greater specific gravity of WG than that of natural aggregate (fine aggregate) [29, 40, 43, 44]. On the other hand, if the specific gravity of WG is lower than that of natural aggregate, the density of concrete containing WG decreases [21, 30, 31, 33, 35]. Therefore, the specific gravity of WG on the density of concrete with WG is of great importance. The reason why there was no remarkable change in the density of concrete in this study was because of the closeness of the specific gravity of sand and WG. Because the specific gravity of CW is lower than that of Portland cement, the replacement of Portland cement with CW generally reduced the density of the concrete [3, 46].

Factors such as type of WG and water absorption of WG and the particle size of WG affected the water absorption of the concrete [28-31, 35, 43, 44]. In addition, it was stated that the pore space among the particles influences the water absorption of the concrete [29]. There are very few studies on the water absorption of concrete containing CW.

Literature studies on the abrasion resistance of concrete containing WG and CW are scarce. Therefore, more experimental studies are needed on the abrasion resistance of concrete with WG and CW.

5. Conclusion

The following results were obtained in this study:

1) The use of both CW and CRT increased the flow value of the mortar. The increase in flow value reached approximately 50 mm when CW was used with CRT together.

2) The use of CW and CRT caused very low increases in unit weights. While the use of CW reduced the water absorption rate by increasing the fullness of the mortar, the use of CRT increased the water absorption rate.

3) CS and FS showed a very low increase with the use of CW, it showed serious decreases around 20 MPa with the use of both CW and CRT. The use of CRT up to 20% is a more acceptable rate in terms of strength and this rate caused a reduction in strength up to 5 MPa in comparison to the reference sample.

4) The addition of CW to the mortar increased the amount of abrasion of the mortar. The volume loss of the mortar sample containing 20% CRT is 9.1% higher than that of the reference sample. The combined use of CW and CRT caused a slight decrease in the volume loss compared to CRT.

5) In particular, the use of CW in mortar had a positive effect on FS, CS, workability, unit weight and water absorption while it had a negative effect on abrasion resistance. While the addition of CRT to the mortar caused a negative effect in general, it gave more acceptable values in terms of all properties when used up to 10%.

It is expected that the findings found in this study will benefit scientific studies in the future in terms of environmental protection and economic advantages. There is also a large amount of colemanite waste and WG in Turkey. It is also noteworthy that there is still very little literature research on colemanite. It will be beneficial to both to recycle it and to increase research on this waste. It is also noteworthy that the abrasion resistance of mortars with colemanite and glass aggregates has hardly been studied. Therefore, more work is needed on this subject.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require an ethical committee permission, and legal-special permission.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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